

A Practical CAE Approach to Determine Acoustic Cavity Modes for Vehicle NVH Development

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ABSTRACT

The role of acoustic cavity modes in vehicle NVH (noise, vibration and harshness) development is well established in the automotive industry today. Prior knowledge of these modes can help prevent potential issues later in the development cycle, as well as aid in root cause analysis of vibro-acoustic issues. OEMs utilize them as part of their overall modal alignment strategy and cascade them to major system and sub-system suppliers for robust NVH designs. Today, acoustic cavity modes can be obtained rather easily using CAE (computer aided engineering) methods early in the development cycle. However, unlike acoustic modal testing, the CAE normal mode solution cannot scale the relative amplitudes of the modes. The sheer number of acoustic modal frequencies to be avoided can be a serious deterrent during the early design phase. This paper proposes an alternate approach for acoustic modal analyses using CAE to scale the relative amplitudes of cavity modes. An omni-directional acoustic source is placed at critical interior cavity locations and acoustic frequency responses are generated akin to an acoustic modal test. This approach is successful in scaling the relative importance of the acoustic cavity modes, and has a reasonable correlation with modes found from actual testing. This information holds much more value from a vehicle NVH development perspective because the relative strengths of the modes are known and the number of acoustic modal frequencies to avoid is greatly reduced. From a practical vehicle NVH development perspective, this approach has clear benefits over traditional CAE acoustic normal mode analysis methodology in use today.

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INTRODUCTION

The traditional NVH product development strategies at automotive OEMs have for the most part successfully used frequency based modal alignment strategies to avoid structure borne vibration issues. In recent years, with the emphasis shifting to computer models, acoustic modes of the vehicle interior cavity have been more readily available. Sanderson and Onsay have detailed a CAE interior cavity model validation using acoustic modal testing [1]. There are several technical papers that show the effect of acoustic cavity modes on booming noise and road noise. Wycakert, Auweraer and Hendrixx have identified the correlation between acoustic modes and operational data for road noise [2]. Kavarana, Shaw and Schiller have shown the effect of an acoustic cavity mode on booming noise during acceleration [3]. As modern day vehicle NVH design has gravitated to digital models, it would make sense to apply acoustic cavity mode information early in the design phase. However, acoustic modal testing continues to be used more as trouble shooting tool rather than being integrated in the vehicle modal alignment strategy that

includes vibro-acoustic issues. Two potential reasons that may be driving this situation are both inherent to the CAE normal mode solution:

a. The normal mode solution doesn't provide any amplitude scaling. This makes it difficult to assign relative importance to certain modes that later result in some issue when physical prototypes become available.

b. The sheer numbers of modes predicted by the CAE normal mode solution are not easy to avoid for several systems and sub-systems that form the vehicle NVH domain. It is impractical to cascade such a large number of acoustic cavity mode information to system/sub-system suppliers thereby potentially reducing their usefulness early in the design phase.

The driving force for the activity detailed in this paper was the incidence of booming noise in an SUV [3]. It presented an issue that was recognized during physical vehicle development; the booming noise in the interior during acceleration was judged to be objectionable. Initial root cause investigation attributed the issue to the exhaust system. An

acoustic modal analysis of the interior cavity showed the presence of a strong acoustic cavity mode at the incident frequency. When the exhaust system was modified, the exhaust booming peak was attenuated and the interior booming noise concern was eliminated. If the acoustic cavity mode information were made available and utilized during initial design planning, such issues could be avoided. Furthermore, cascading such information to Tier 1 suppliers can reduce development costs and timing by potentially avoiding re-design when such issues arise. However, doing this using the current CAE normal mode solution is difficult due to the reasons outlined earlier. If CAE methods could somehow scale the modes, the highest amplitude mode(s) could be more easily avoided during major system/sub-system design.

In this paper, a modified CAE method is employed to scale the mode shapes. An omni-directional sound source is employed within a detailed CAE model and acoustic transfer functions akin to test are calculated. CAE results are compared to actual acoustic modal analysis test results. There is reasonable agreement between CAE and test data for acoustic modes. Using modes generated in this manner has much more practical value in NVH development when compared to present scheme mainly because there are fewer and only relevant modes to deal with in the vibro-acoustic modal alignment strategy.

APPROACH

A cargo van (panel van) trimmed body structure was chosen for this project. This structure was chosen for multiple reasons:

- a. Simple geometrical shape (approximating a rectangular box)
- b. Few seats (only two front ones)
- c. Minimum amount of trim (only forward of B-Pillar)
- d. Already available detailed CAE trimmed body model

On the physical side, a standard acoustic modal analysis was performed. On the digital side, a conventional normal mode solution for acoustic modes was first obtained using CAE. Subsequently, CAE analysis (hereafter referred to as the Modified CAE Approach) attempted to use an omni-directional sound source to duplicate the test scenario and scale the acoustic modes using the acoustic transfer functions from the measured locations. For consistency and valid comparisons, the measured locations were kept the same between test and simulation. The acoustic transfer functions for the test and CAE simulations were then compared for frequency and amplitude. Two different CAE models that are detailed later in the paper were also investigated for this modified CAE approach. The first one treats the entire acoustic cavity as one continuous medium, whereas the second one treats the air gaps between trim and sheet metal (hereafter referred to as the trim-air gap system) as separate cavities.

CAE NORMAL MODES

The passenger cabin acoustic cavity is defined by volume elements. For the Nastran model used in this paper, tetra elements were used. The acoustic cavity created, as seen in [Figure 1](#), was defined using the interior geometry of the vehicle and given ambient air properties. Two seat volumes were defined using "heavy air" properties to account for foam absorptive properties that are different from ambient air. An instrument panel (IP) volume was defined using "light air" properties to account for the absorptive properties of everything inside the IP. Center console and side wall volumes were also defined but they retained ambient air properties. The entire acoustic cavity resulted in approximately 40,000 nodes with element lengths ranging from 20-70 mm and averaging 40 mm.

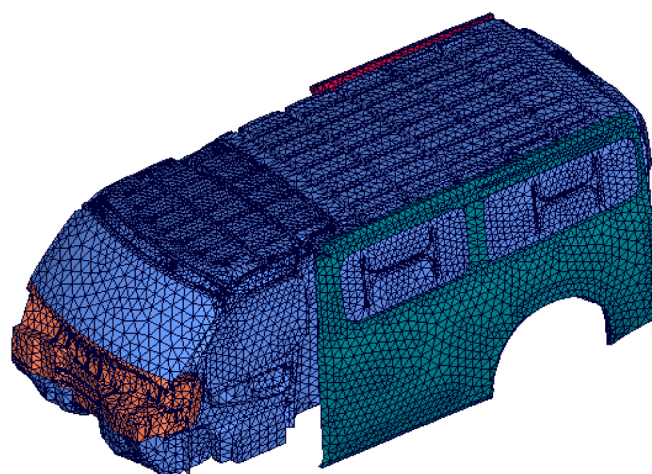


Figure 1. Acoustic cavity volume of passenger cabin

The current simulation practice for determining passenger cabin acoustic modal frequencies is to solve the normal modes of a rigid walled acoustic cavity without damping. The rigid walled solution would be similar to physically testing a concrete enclosed volume.

Therefore, there are no effects from the surrounding structure. The normal mode solution produces no amplitude information. Mode scaling of some sort can be obtained by using damping from test data for example, but the main purpose of this effort is to obtain mode amplitude scaling from the digital model prior to physical prototype build.

PHYSICAL TESTING

A traditional acoustic modal analysis was performed on the trimmed body of the structure. The trimmed body structure was supported to simulate near free-free boundary condition using four soft airbags. The cavity was excited using an omni-directional volume velocity sound source and the acoustic transfer functions (P/Q) were measured at 144 locations using microphone grids. Burst-random excitation was employed as source signal and source was placed in the rear corner of the cavity. The acquired transfer functions were

curve fitted using the LMS Polymax curve-fitter (modified least squares complex frequency domain estimation) to determine the mode shapes. The sum block of all the microphones was used to quantify the relative strength of modes in the acoustic cavity. The sum block response, often used in modal analysis, is the averaged response of all frequency response functions (FRFs) recorded at all measured locations and is generally a good indicator of all modes present in the system.

MODIFIED CAE APPROACH

An acoustic modal analysis in a physical test consists of a realistic automotive structure and does not contain rigid walls used in the CAE normal mode solution. The sound field in the interior cavity is significantly affected by the acoustic modal characteristics of the cavity, the dynamic response of the surrounding structure and by the type of coupling between these dynamic systems. The physical acoustic modal test involves using an acoustic source, such as a volume velocity source, to excite the passenger cabin and uses a finite number of microphones to measure the pressure in the air cavity. The surrounding structure might include flexible panels as well as air between the trim and outer panels that may behave as a separate cavity. These parameters must be accounted for if the CAE solution is to accurately estimate the physical test results.

The modified approach attempted in this paper simulates the physical acoustic modal test and account for the realistic boundary conditions of the cavity. A Nastran structure was created, as seen in [Figure 2](#), and coupled to the acoustic cavity. Akusmod was used to create the coupling between the structure and the acoustic cavity. To simulate the volume velocity source, a Nastran acoustic source (ACSRCE) was placed inside the cabin at the same location as the physical test. The acoustic source is omni-directional and is able to excite the entire cabin. The pressure response is measured at several locations in the cabin, similar to the locations of the microphones in the physical test as shown in [Figure 3](#). Therefore, simulation is able to provide acoustic frequency response curves like a physical test. A physical acoustic modal would also include damping in the vehicle; therefore, damping is included in both the structural and the cavity model.

Since the acoustic cavity and the vehicle structure are coupled together in the simulation, the acoustic source is therefore also able to excite the structure and create panel responses. These panel responses can in turn influence the acoustic response. In areas where the acoustic cavity modes are close to panel resonant frequencies, the frequency spectra as well as mode shapes can be significantly affected. This behavior has been reported in literature by Lee, et. al. [4] and Kruntcheva [5].

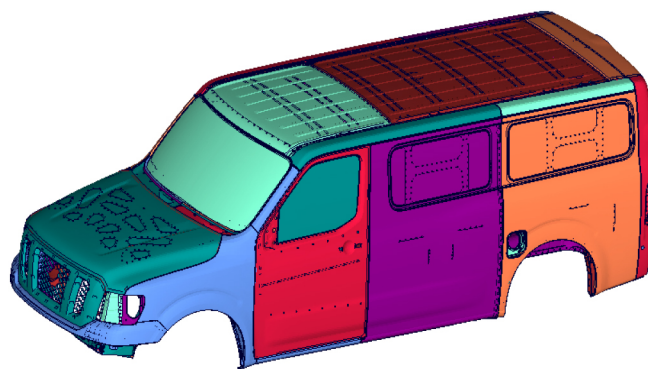


Figure 2. Vehicle structure surrounding passenger cabin

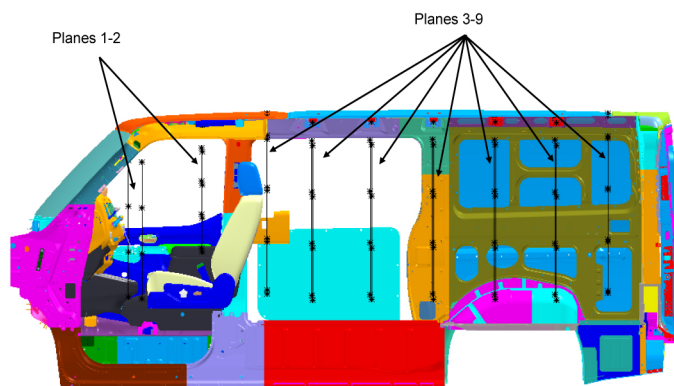


Figure 3. Response locations (same as actual test)

A well-designed trim-air gap system, capturing all air cavities between trim and outer metal, can play an important role in improving the acoustic response characteristics of the cavity [6]. The acoustic cavity was modeled in two different ways for this project. In the first approach, one continuous air cavity was used for the entire volume. In this model, the instrument panel, front console and side air are node matched to the rest of the cavity air, not to the inner metal/plastic structure. This model will be referred to as the “continuous cavity” model in this paper. In the second more detailed model, the instrument panel, front console and side panel air were modeled as separate air cavities and node matching to the cavity air is only done where applicable in those areas. This way the separate air cavities can be coupled to the inner metal/plastic structure. This model will be referred to as the “separated cavities” model in this paper.

RESULTS

CAE NORMAL MODES

As mentioned earlier, the CAE normal mode solution will typically assume rigid walls for the cavity boundary. The typical output is a table of mode frequencies and mode shapes of the acoustic cavity. [Table 1](#) below shows the acoustic modes and [Figure 4](#) shows the first fore-aft cavity mode