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Structural and acoustic noise radiated by CD drives

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ABSTRACT

Optical drives inside PCs operate at high speed, which may result in significant noise. These drives function both as airborne and structural vibration sources. Three main paths can be distinguished through which noise is emitted to the surroundings: (1) the vibrations of the front of the drive emit noise directly into the far field, (2) the sound waves induced by the vibrations of the faces of the drive inside the enclosure excite the PC enclosure and (3) the structural vibrations of the drive excite the PC enclosure at its mounting points causing the enclosure to radiate sound. The techniques used to determine the contribution of each path are described and preliminary results of an experimental setup are presented in this paper. The contribution of the structural path is determined by comparing the results of a normal setup with the result of a setup for which the structural path is eliminated by mounting the CD-drive on a support that is structurally uncoupled from the PC. Direct measurements of the pressure with a scanning microphone were made. Also, a reconstruction of the pressure field using the Boundary Element Method based on the measured surface velocities of the main radiating surfaces was performed.

1. INTRODUCTION

The increase in performance of PCs has lead to an increase in operational speed of the internal optical drives that can be found in a typical PC configuration. As a consequence of the high revolutionary speed, these devices have become a significant source of noise and structural vibrations.

The structural vibrations are the result of small mass unbalances in the rotational system, exciting the entire structure of the drive at the rotational frequency through the connections points. These vibrations cause the surfaces of the drive to vibrate, thus emitting noise. In addition they also excite the structure of the PC that houses the drive through its connection points. Due to the mechanism driving the vibrations, the emitted noise and structural vibrations at the connections points of the drive are tonal in nature. Furthermore, the spinning disk introduces a turbulent air layer around its surface. The pressure disturbances present in this air layer are responsible for additional (airborne) noise that excites the optical drive's enclosure. This airborne noise mechanism is broadband in nature.

In the present study the physical mechanisms *causing* the initial vibrations are not investigated. The focus is on the transfer paths between source and receiver. The optical drive is modeled as a black box that acts both as a noise source and as a source of structural vibrations

that excites the PC at the connections points of the drive. The sources are considered to be composed of broadband noise and tonal noise.

Three transfer paths can be distinguished for a PC. The distinction between the components is made based on the path the vibrations have traveled from the CD-ROM drive to the observer. The three paths are defined as:

- Direct acoustic path (1): The noise that is emitted by the front panel of the optical drive into the far field
- Indirect acoustic path (2): The noise emitted by the surfaces of the drive inside the PC enclosure excites the PC enclosure and causes the PC enclosure to radiate noise into the far field
- Structural path (3): The noise radiated by the surfaces of the PC enclosure as a result of the structural vibrations at the connection points of the drive.

A schematic representation of the three paths is found in Figure 1.

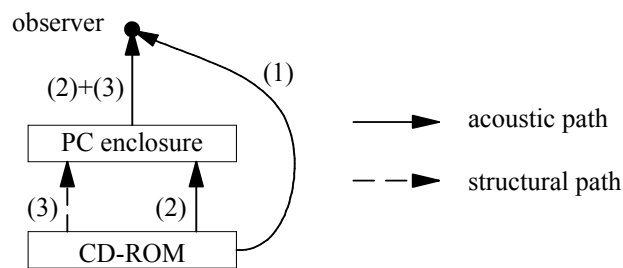


Figure 1: Schematic representation of the three paths contributing to the noise observed in the far field; the direct acoustic path (1) the indirect acoustic path (2) the structural path (3)

In order to find an effective solution for the noise problem at hand, the contribution of the three aforementioned paths to the noise spectrum found in the far field has to be determined. An example of the far field noise spectrum of a typical PC/CD-ROM setup measured in an anechoic room is given in Figure 2. During this measurement the CD-ROM drive is operated at a constant angular speed and it is controlled from an external PC that is acoustically separated from the measurement setup. In this way the PC that houses the CD-ROM drive remains switched off, thus preventing it from contributing additional noise to the sound field.

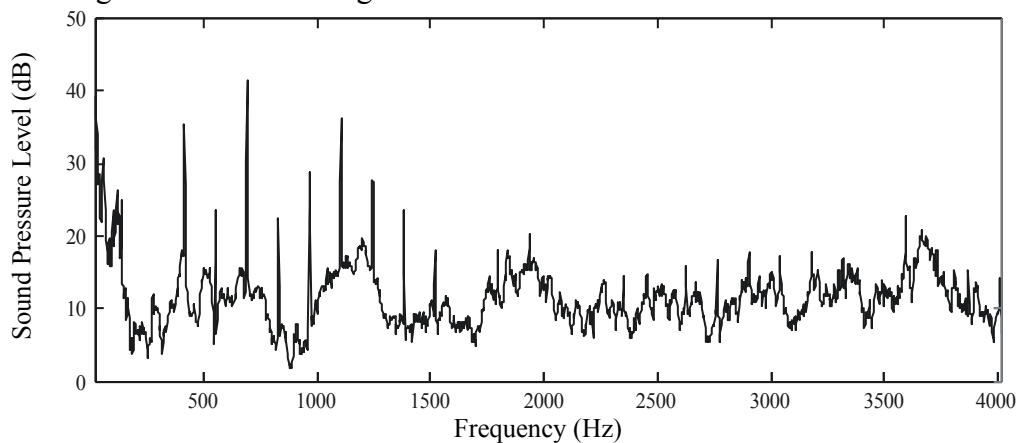


Figure 2: Sound pressure spectrum at 0.6 m from a PC

From the plot in Figure 2 it is clear that the produced sound can be characterized as being mainly tonal in nature. The sound level of the peaks in the spectrum that correspond with the rotational speed of the drive and its higher harmonics are substantially higher than the level of the

broadband noise. Obviously, the locations of the peaks changes with rotational speed of the drive. However, the overall difference in level between broadband and tonal noise remains the same. Therefore, the focus is on the frequencies related to the rotational speed of the disk and its higher harmonics when determining the contribution of the different paths. Furthermore, it is determined that the frequency range of interest lies between 0-2000 Hz. For higher frequencies, the peaks related to rotational frequency sink into the broadband noise which has relatively constant level above 2000 Hz.

2. EXPERIMENTAL SETUPS AND MEASUREMENT TECHNIQUES

In order to determine the contribution of the different paths to the total sound field, two different experimental setups are built and two different measurement techniques are employed. In the present study a commercially available internal CD-ROM drive with a maximum speed of 56x is used. (The maximum rotational operation speed for both CD and DVD drives commercially available is 25,000 rpm.). The drive is operated at a fixed rotational speed of 8350 rpm (140Hz) during all measurements.

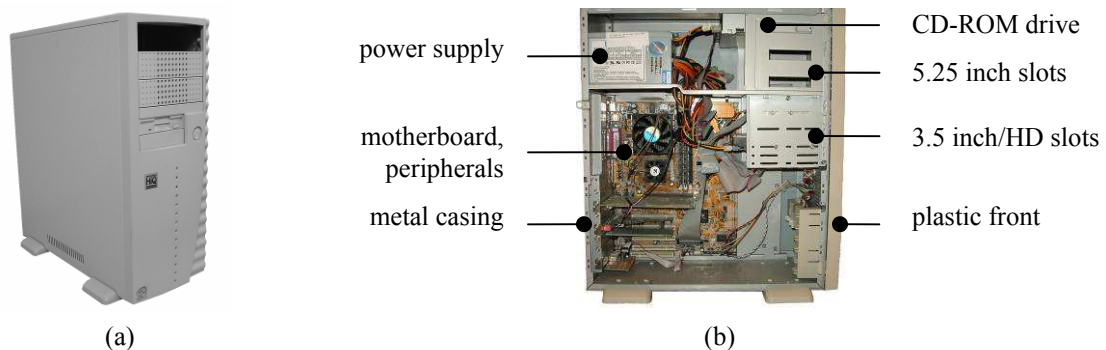


Figure 3: (a) Typical metal PC enclosure with plastic front. (b) PC/CD-ROM configuration that is used as reference setup

A. Measurement setups

The setup that provides the reference spectrum consists of an unaltered typical PC/CD-ROM configuration. The CD-ROM drive is mounted inside one of the 5.25 inch slots of a standard rectangular shaped metal PC casing equipped with motherboard, hard drive and other standard peripherals (see Figure 3). A second setup was designed in order to measure the sound field when the structural path is eliminated. In this setup, the CD-ROM is not directly mounted inside the 5.25 inch slot by means of conventional metal mounting strips, but mounted in a support that is structurally uncoupled from the PC enclosure (see Figure 4). In this way the CD-ROM drive is positioned as if it was normally mounted in the PC enclosure while structural vibrations are not passed on to the PC enclosure. Based on the measurement results of this setup and the results from the reference setup, the relative contribution of the structural path can be determined.

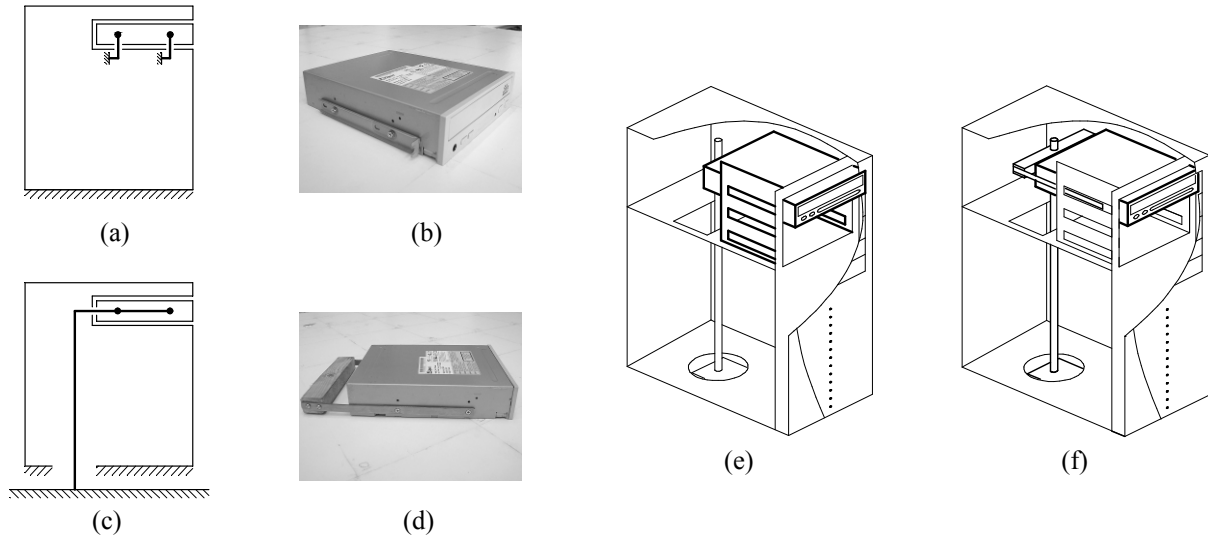


Figure 4: Separation of the structural path; Schematic overview of the PC/CD-ROM setup with the structural path (a) and without the structural path (c). Close up of the CD-ROM drive attached to the conventional metal clips (b) and the non-standard support (d). 3D representation of the setup with (e) and without (f) the structural path

B. Measurement techniques

Two different measurement techniques are used to determine the sound spectrum produced by both setups described above. The first technique consists of a straightforward sound pressure level measurement at four points in the far field (see Figure 5).

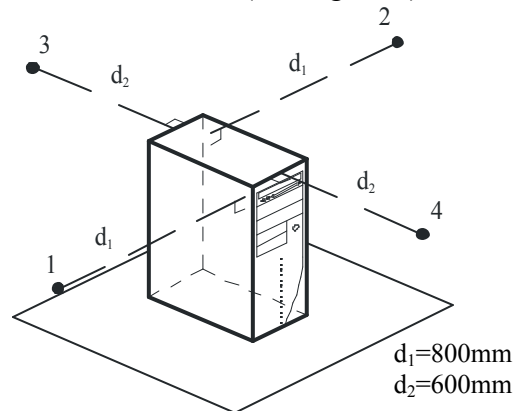


Figure 5: Microphone locations for direct sound pressure level measurements

The second technique to obtain the sound pressure levels is based on the so called boundary element method (BEM). This technique uses an integral of the (harmonic) surface velocities over the closed boundary surface of a body to compute the sound pressure resulting from the vibrating body in an arbitrary point of the sound field [1]. The surface velocities of the different sides of the enclosures are used as input to calculate the sound pressure levels at the four microphone positions in Figure 5. By excluding the surface velocities of the front of the CD-ROM drive, i.e. by setting these surface velocities to zero, the calculated sound pressure at the microphone positions will not include the contribution of the direct acoustic path from the drive. Comparing the contribution of the results obtained with BEM and the results obtained with direct measurements of the sound pressure level will yield the contribution of the direct acoustic path. Notice that this is true for both the case in which the structural path is present and for the case in which the structural path is eliminated. The calculated contribution of the direct acoustic path

should be identical for both cases. This knowledge can be used to give an indication of the accuracy of the proposed method to determine the contribution of the direct acoustic path.

Furthermore, the contribution of the structural path can also be calculated based on BEM results from the case in which the structural path is present and the case in which it is eliminated. The contribution calculated in this fashion should correspond with calculation of the contribution based on direct measurements. This is a second way of validating the accuracy of the BEM results. The contribution of the indirect acoustical path (2) can be directly derived from the BEM results in case the structural path is eliminated, since only the contribution of the indirect acoustical path (2) will be reflected in the BEM results.

An overview of the different experimental setups and the measurement techniques that are used in relation to the contribution of the different paths is given in Figure 6.

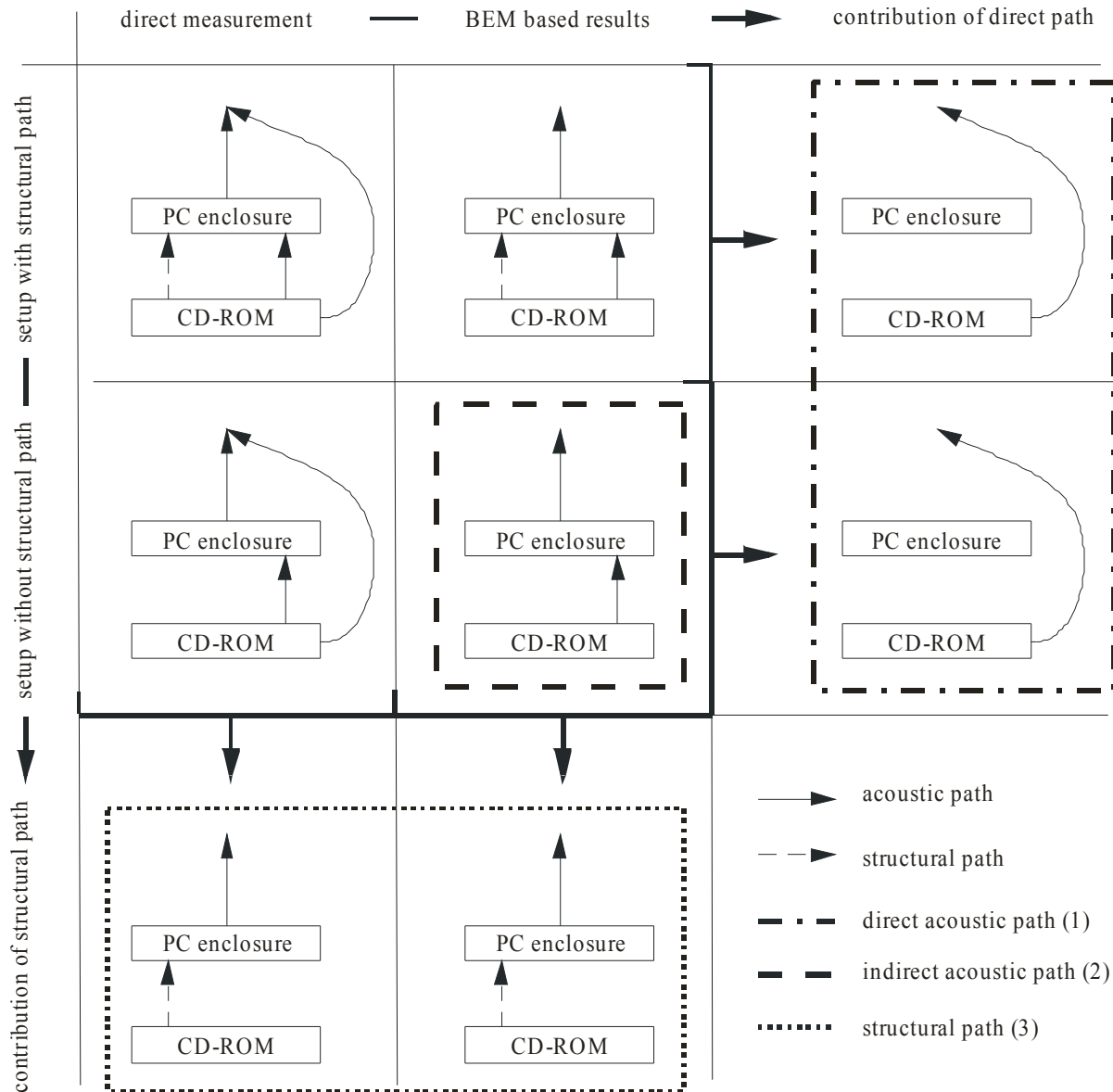


Figure 6: Overview of setups, measurement techniques and transfer path identification methods

The measurements of the surface velocities on the enclosure panels are carried out with a laser-vibro-meter that is mounted on a xz-table which is moving the laser along a scan grid.

Unlike the side panels of the enclosure, the front and back panel can not be measured with the laser-vibro-meter due to their complex geometry and the numerous holes. Instead, a limited number of accelerometers is used to form a scan grid. The surface velocities of the front and back panel are calculated from these measurements. The top panel was also measured using this technique because use of accessibility with the laser-vibro-setup.

3. PRELIMINARY RESULTS

Preliminary results obtained with the different setup and measurement techniques are presented in this section. The focus of the first part is to determine how reliable the produced BEM results based on the measured surface velocities and accelerations are. In the second part, the effects of eliminating the structural path are investigated.

A. Accuracy of the BEM results

The scan grid of the front, back and top plate is relatively coarse, but should be sufficient to represent the first and second eigenmodes of the corresponding plates. The front and back of the PC enclosure are modeled as flat plates, which is an approximation. Holes in these plates are not accounted for in the model. The contribution of these two plates to the total sound field is expected to be relatively small, considering their shape and size compared to the side panels. In order to investigate to what extent the different panels contribute to the total sound field, the results of a BEM model that includes the back and front plates and the results of a BEM model in which the surface velocities are assumed to be zero at these surfaces are plotted in Figure 7.

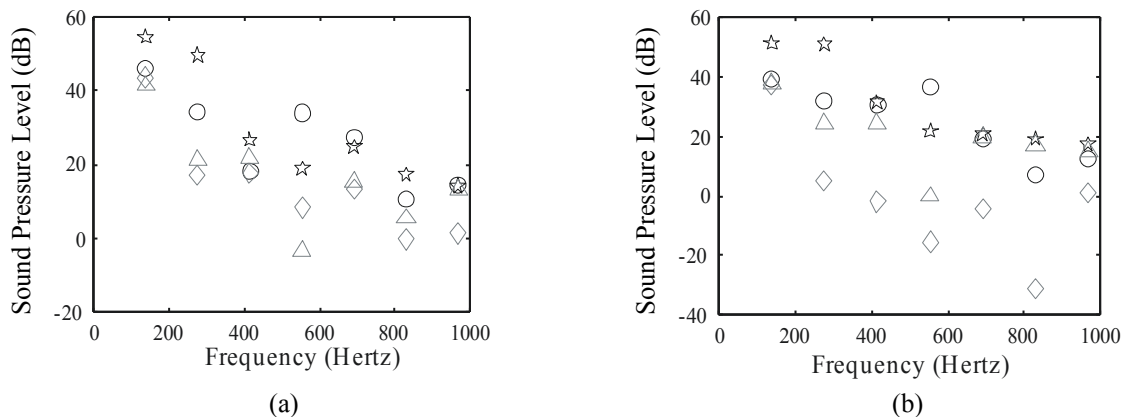


Figure 7: (a) Calculated Sound Pressure Levels (BEM results) at the front (4) microphone position and (b) the left (1) microphone position. BEM calculation including front, top and back panel; * with structural path, o without structural path. BEM calculations excluding front, top, and back panel; Δ with structural path, ◇ without structural path.

As expected, the average sound pressure levels are higher when the front, top and back plates are included. The difference in the calculated level is not constant and can be of considerable magnitude depending on the frequency and microphone position. This indicates the three additional panels have to be taken into account when the sound pressure is calculated using a BEM model. The influence of the deviating geometry and the holes in the panels on the BEM results is a subject for further investigation.

B. Contribution of the direct path

The contribution of the direct path can be examined by analyzing the results of the direct measurement of the sound pressure level of the different setups. The results for the left microphone are plotted in Figure 8. It can be seen that in general, eliminating the structural path

leads to a very significant decrease in the average sound pressure level in the far field. However, for peaks 3,4,5 and 13, the level of sound pressure is hardly affected by eliminating the structural path. For peaks 4 and 13 the average sound pressure level increased slightly by eliminating the structural path. These increases in are though to be within measurement accuracy and reproducibility. A possible explanation for this phenomenon is noise cancellation of the contribution of the direct path and the indirect path. Further investigation of the cause of this phenomenon is required. The reductions in the first peak harmonics are significant and clearly indicate the importance of the structural vibration path to the sound radiation.

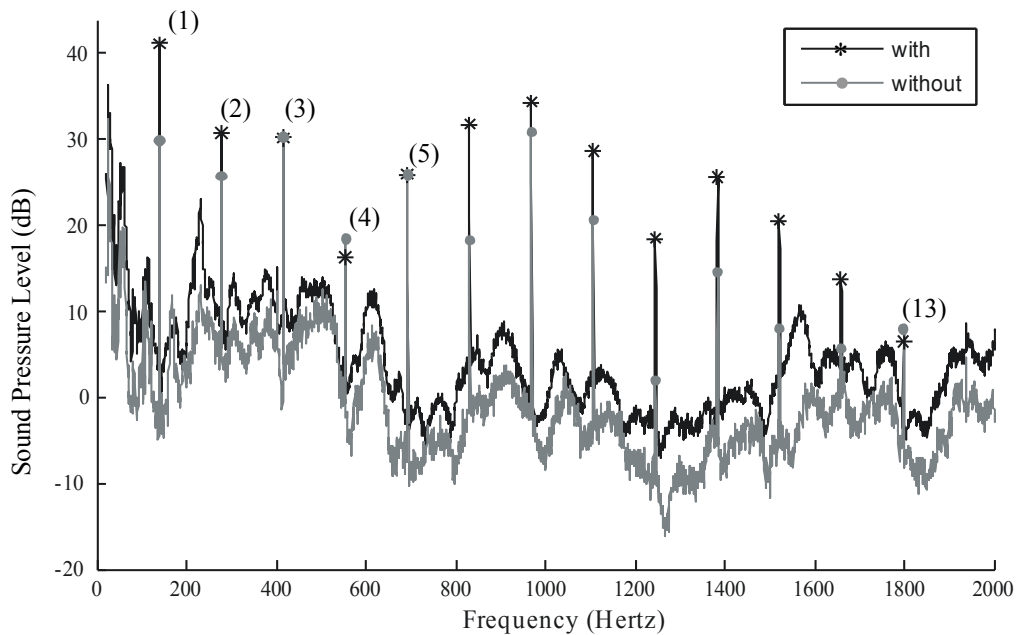


Figure 8: Measured sound pressure level at the left (1) microphone position with and without the structural path

4. CONCLUSIONS

A method to determine the contributions of different transfer paths to the sound field of systems with a combined structural and acoustic source was described. The method uses a combination of multiple experimental setups, measurement techniques and computational techniques to estimate the contributions of the different paths to the total sound field. Calculations of the sound pressure levels based on BEM models with and without the front, top and back plate suggest that these panels can not be neglected in the BEM model. Preliminary results show that the reduction in sound pressure levels due to elimination of the structural path is frequency dependent and that the reduction for the lower frequency harmonics is considerable.

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REFERENCES

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