The Car Audio System Nobody Would Build part 1

ANALYZING AND CHOOSING YOUR AUDIO "ROOM"
BY JON R. WHITLEDGE

For just over three years, I've been working on a system that's been a labor of love, and the outcome thus far seems to validate the effort. After hearing the audio system, numerous noteworthy individuals, including home audio component designers, former IASCA World Champions, audio component reviewers, musicians and recording engineers have been generous in their praise, calling it the finest mobile audio system they've ever heard. The design and fabrication of my system drew heavily upon my experience as a scientist, engineer, craftsman, IASCA competitor and IASCA sound quality judge.[1,2] Whether you are, or intend to be, a serious IASCA competitor or you simply enjoy the beauty of music reproduced accurately, I hope the principles discussed in this series will help you achieve your sonic goals.

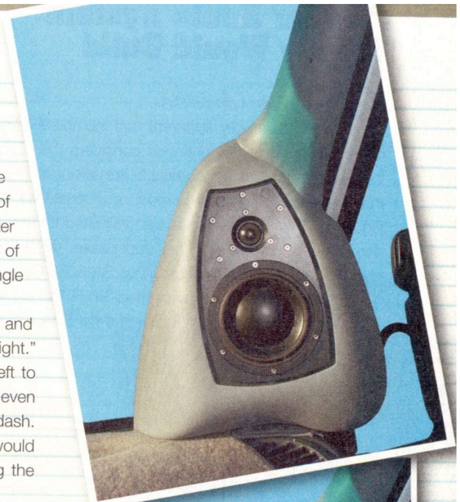
As a system designer, my goal was to design and build an audio system of exceptional caliber, perhaps unprecedented, capable of winning IASCA's Semi-Pro Street class.[3] According to IASCA's rules, sound quality judging is conducted from the driver's seat. Therefore, my first important performance goal was already defined.

When I started this project, I was quite fortunate to be able to select an appropriate vehicle as the audio system's "room" or platform. Although it's common to choose an automobile before considering the audio system, there are considerable sonic benefits to the unorthodox approach of choosing the automobile as a part of the overall audio system design. With home audio systems, the room in which the audio system plays is known to dramatically impact the performance of the audio system. In a likewise manner, an audio system in a car is dramatically impacted by the size and type of car in which the system is installed.

Cockpit Geometry

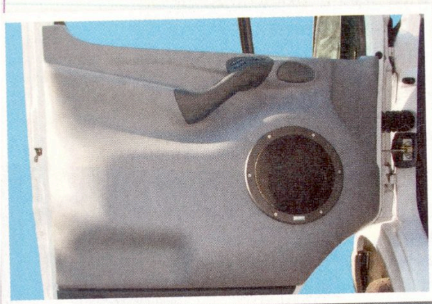
The first of many considerations was cockpit geometry. IASCA awards up to 15 points for a subcategory of Sound Stage called "Listening Position." According to the rules, "The best systems will give the illusion of the stage being well in front of the listeners (even apparently exceeding the front boundary of the vehicle)."[4] My strategy, therefore, was to find a vehicle where the windshield and potential speaker locations could be placed well in front of the listening position, in this case, the driver's seat. Speaking of the windshield, one study done by the engineers at Harmon-Motive suggests that the best windshield angle for imaging is one whose angle is greater than 55 degrees from horizontal.[5]

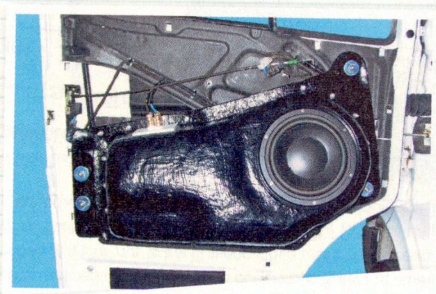
I believed that cockpit geometry would influence the feasibility of certain loudspeaker driver locations, and that in turn, would influence my score in another IASCA subcategory of Sound Stage called "Stage Height." IASCA awards up to 15 points for a stage that "… is at horizon level with no hint of instability from left to right."[6] It was apparent that in order to score maximally in this category, it would be desirable, perhaps even necessary, to have the tweeter and the midrange located as high as possible, preferably above the dash. Consequently, my strategy was to find a vehicle where the geometry of the dash and the A-pillars would accommodate a tweeter and midrange pair on both the left and right without significantly obstructing the driver's vision of the road or the rearview mirrors.



Considerations For Midranges

Before I chose the midrange driver, I examined the fundamental frequencies of various instruments and vocalists. From Figure 1, I determined the human voice extends as low as E_2, or 82.4Hz and extends as high as C_6, or 1,046.5Hz. Knowing this helped me determine if I could find a midrange driver that would avoid placing a crossover point within the fundamental range of the human voice. Typical dome midrange drivers can reproduce fundamental frequencies down to about 300-500Hz, while some midrange drivers can reproduce fundamental frequencies as low as 80Hz. Thus, it was decided that a midrange driver capable of going as low in frequency as possible was the preferred choice, provided I had sufficient room for the required enclosure.





Given the probable lower limit in frequency response of the midranges, I was left with the choice of the woofer. Again, referring to Figure 1, I determined that a woofer, mounted somewhere in the front cockpit area to keep the listening position as far forward as possible, would need to reproduce fundamental frequencies down to at least E_1 (41.2Hz). Typical woofers, nominally 10" in diameter, can play as low as 40Hz, provided they are placed in enclosures of sufficient volume. An aperiodic closed-box system was considered an option, provided that I could find a way to vent the enclosure to the outside of the automobile. It seemed impractical at best, and impossible at worst, to believe that a woofer system could be designed to reach as low as 30.87 or 27.5Hz, the lowest notes of an electric bass guitar or grand piano, respectively. Therefore, the lowest fundamental frequencies were relegated to the subwoofer system.

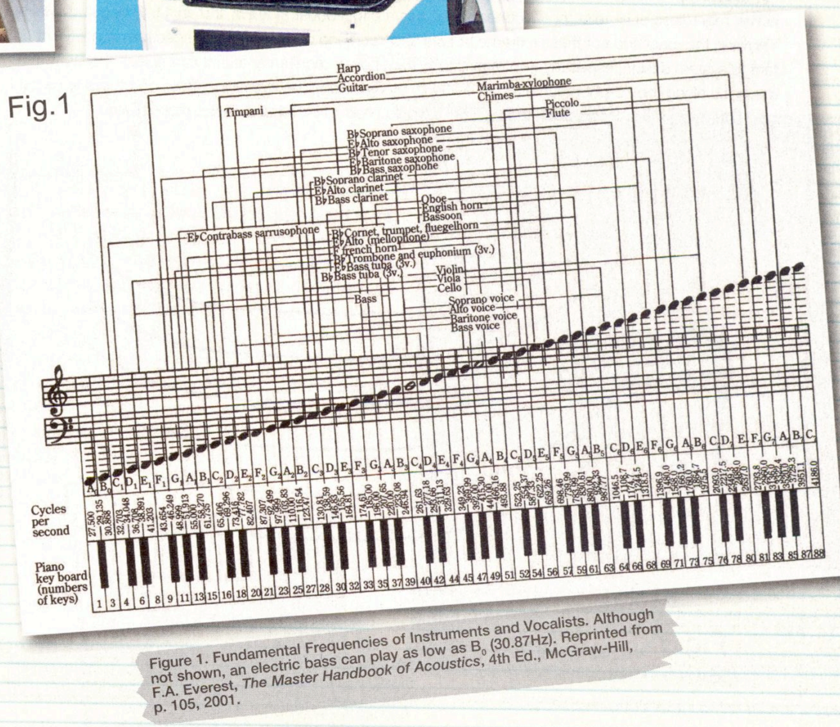
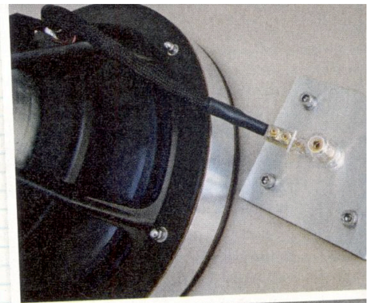


Figure 1. Fundamental Frequencies of Instruments and Vocalists. Although not shown, an electric bass can play as low as B_0 (30.87Hz). Reprinted from F.A. Everest, *The Master Handbook of Acoustics*, 4th Ed., McGraw-Hill, p. 105, 2001.



Equal Loudness

It may not be readily apparent that incredible levels of power may be required for an audio system dedicated to sound quality until one considers the concept of equal loudness. The concept of equal loudness involves the human ear's variable sensitivity to the loudness of various frequencies. Research has shown that the B-weighting filter is most appropriate for common loudness levels associated with music (refer to Figure 2). This observation is also validated by the practices of *Stereophile* magazine's John Atkinson, who uses B-weighting for all of his loudspeaker measurements.[7] For those of you in the car audio industry, it is important to note that the ubiquitous SA-3055 Competition Autosound Analyzer/SPL Meter, manufactured by AudioControl, measures unweighted SPL.[8] This explains why some installers have observed that when a car's audio system is equalized to create a flat RTA measured response, the degree of musical realism achieved by their system is dismal.

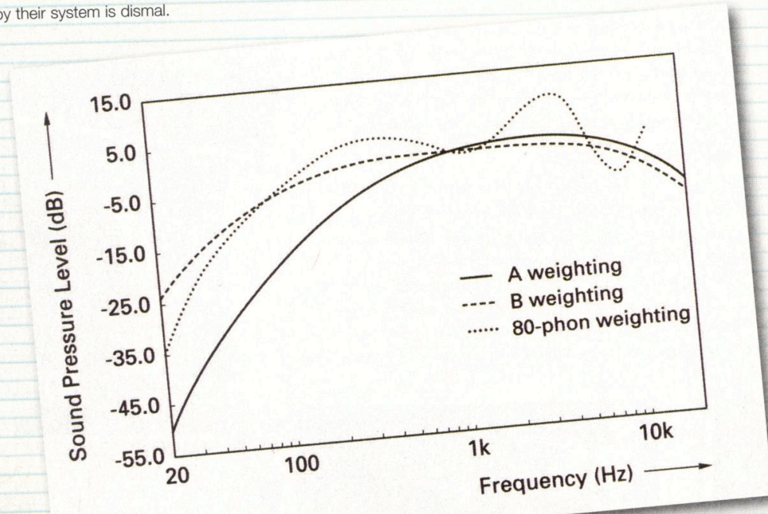


Fig.2

Figure 2. A-, B- and 80-phon weighting curves. Reprinted from R. M. Aarts, "A Comparison of Some Loudness Measures for Loudspeaker Listening Tests," *J. Audio Eng. Soc.*, Vol. 40, No. 3, p. 143, Mar. 1992.

Figure 3 shows a family of unweighted SPL curves as a function of frequency that incorporate B-weighted compensation. The curves are plotted in 10dB intervals from 50 to 100dB referenced to 1kHz. Each curve, regardless of its reference loudness level, has a 24dB boost at 20Hz and an 11dB boost at 20kHz. Knowing the magnitude of these extreme boosts and each end of the frequency spectrum is vitally important to system design, especially with regard to system power requirements. For example, if a system were designed along the 70-phon curve (70dB at 1kHz, by definition), the overall loudness of the system would be 97dB and the loudness at 20Hz and 20kHz would need to be 94 and 81dB, respectively.

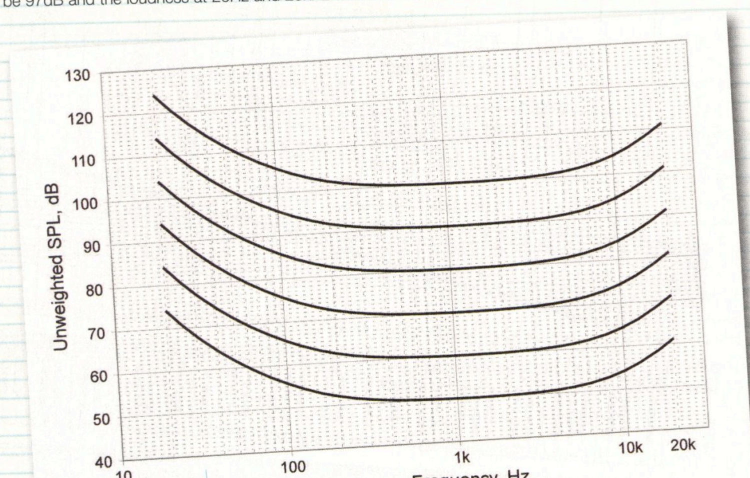
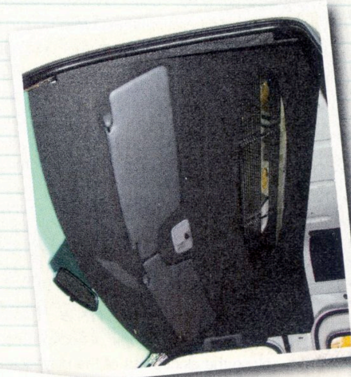


Fig.3

Figure 3. Family of unweighted SPL curves incorporating the B-weighted filter. Courtesy J. R. Whitledge.

When a loudspeaker is placed in an enclosed environment, substantial reinforcement in the lower frequencies can result. The amount of reinforcement is inversely proportional to the volume of the room. For example, the typical home listening room with a volume of 1,200-1,500ft^3 will boost the loudness of the audio system at 20Hz by 3-5dB.[9] In a small car with an internal volume of 110ft^3, the boost at 20Hz could be as great as 20dB![10] Given the phenomenal level of room gain provided by the enclosed environment of the automobile, and its impact on reducing amplifier power requirements, it behooves a system designer to thoroughly research and experimentally determine room gain for the automobile of interest. In the next article, I'll explain the process of how I determined the room gain for the vehicle I chose.



Resonant Modes

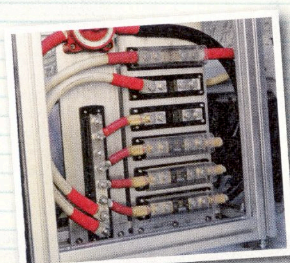
From the previous discussion, it would seem advantageous to select an automobile whose internal volume is relatively small. However, there are at least a couple more considerations when selecting an automobile, including resonant modes and reverberation time. First, let's discuss resonant modes. When air inside a room, or an automobile interior in this case, is excited by the loudspeakers, the air molecules will resonate at particular frequencies dictated by the room's interior dimensions. These resonant frequencies dramatically alter the sound that reaches the listener, usually not for the better. Although room resonance modes are unavoidable, one can choose a room with favorable dimensions to minimize their sonic effects. A large room, with favorable dimensional ratios will have more modes than a small room, but they will be more evenly distributed. Evenly distributed modes will color the sound to a lesser extent. In the next article, I'll explain the process of how I determined the room resonance modes for the vehicle I chose. In the meantime, please refer to two excellent resources on this topic.[11,12]

Reverberation Time

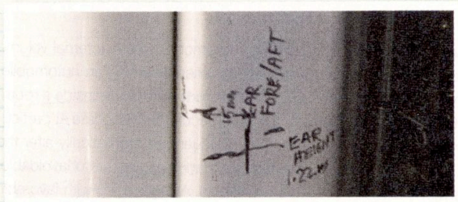
Let's turn our focus to the topic of reverberation time. Reverberation time is the time required for a sound to decay 60dB (one-millionth of its original intensity). Reverberation time is influenced by the size of the room and the absorptivity of its surfaces by the equation:

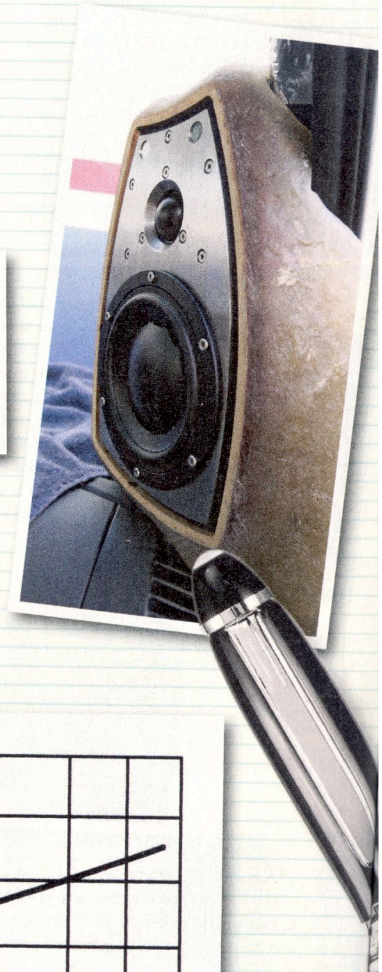
$$RT_{60} = \frac{0.049\,V}{Sa}$$

where *RT60* is the reverberation time in seconds, *V* is the volume of the room in cubic feet, *S* is the total surface area of the room in square feet, and *a* is the average Sabine absorption coefficient.[13] If we consider the interior of an automobile to be similar to a small recording studio, for lack of a better model, the suggested reverberation times for music and speech are shown in Figure 4 (on the next page). The typical reverberation time for passenger cars has been determined to be about 0.04 seconds.[14] This is most likely due to the small internal volume and relatively high absorption coefficients of upholstered and carpeted surfaces. The carpeted and upholstered surfaces would absorb most of the treble and reflect most of the bass, causing ridiculously short reverberation times at high frequencies and longer reverberation times at the lower frequencies. Thus, the interior of most automobiles would impart a thick, congested sound to the bass and a dry, non-spacious sound to the treble. One way to combat this phenomenon is to increase the volume of the room or decrease the overall average absorption coefficient, according to EQ-1.



From Figure 4, I knew that the reverberation time needed to increase by an order of magnitude, or so. To accomplish this, I investigated the effects of simultaneously increasing the volume of the room and reducing the overall average absorption coefficient. First, I guessed that the internal volume of an automobile could be as much as 600ft^3. The results of my calculations showed that by changing the absorption coefficient of the room's surfaces, I could achieve reverberation times between 0.10 and 3.35 seconds, thereby proving that optimal reverberation times could be achieved. I believed this would yield substantial improvements in sound quality over that of conventional automobiles and potentially lead to higher scores in IASCA competitions. For example, IASCA awards up to 20 points for "Spectral Balance," a subcategory of Tonal Balance and up to 10 points for "Ambience," a subcategory of Sound Stage.[15,16]





Common Sense Considerations

Returning to the topic of cockpit geometry, I preferred to avoid the common pitfalls of passenger cars, which place the electronics of the playback system in the trunk. This arrangement necessitates long interconnects and speaker cables. For my system, I desired the shortest possible interconnects and speaker cables. The preferred way to accomplish this, I thought, was by locating the electronics up front in the cockpit, potentially overhead. This would allow the speaker cables to be routed down the A-pillars to the tweeter and midrange drivers on the dash and to the woofers located somewhere in the front of the cockpit. This arrangement would also allow the interconnects, routed from the head unit to the amplifiers or digital signal processor, to be as short as possible.

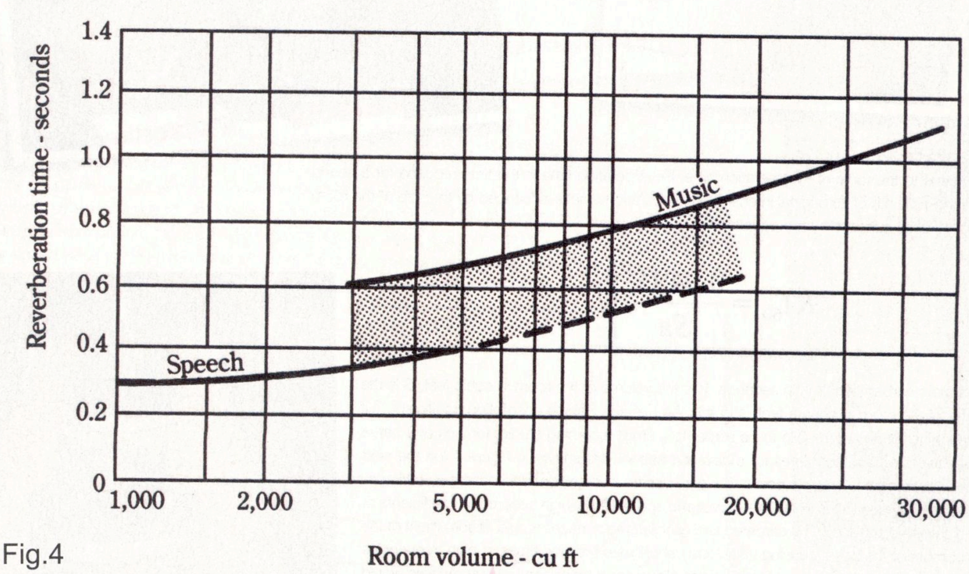


Fig.4

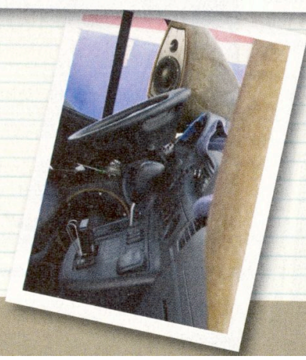


Figure 4. Suggested reverberation times for recording studios. Reprinted from F. A. Everest, *The Master Handbook of Acoustics*, 4th Ed., McGraw-Hill, p. 423, 2001.

Weight and Space

Based on the SPL requirements for sound quality at 20Hz, I knew the subwoofer would need to be massive, potentially consisting of a plurality of large drivers, each 12" or greater in diameter. A subwoofer design such as this would typically require a sealed enclosure approximately 1-3ft^3 in volume, per driver, to achieve the least amount of roll-off at low frequencies. The enclosure for such a system would, by necessity, be extremely large and heavy, and would require hundreds, if not thousands, of watts to achieve the desired SPLs. I also needed a high-performance alternator capable of delivering as much as 200 amps, in addition to a large auxiliary battery dedicated solely to the audio system.

The Final Choice

In accordance with the aforementioned vehicle selection criteria, I chose a '05 Dodge (Mercedes-built) Sprinter 3500 SHC as my competition vehicle platform. The "3500" and "SHC" designate a 1-ton cargo capacity and a high roof, respectively. This extreme cargo capacity permitted the use of a large and heavy subwoofer system, and the high roof permitted the electronics to be mounted up front and overhead in the cockpit area. The windshield, sloped very closely to the ideal 55 degrees, was about 1.15m (45.3") in front of the listening position. The headliner in the cockpit area sloped steeply upward, thereby distributing resonant modes more evenly. Furthermore, the cockpit geometry allowed for a tweeter and midrange enclosure on each corner of the dash. In order to deliver sufficient power to the audio system, the vehicle was equipped with a 200-amp Bosch alternator as a factory option. In essence, I believed this unorthodox vehicle was the ideal platform for a competition vehicle, and one I haven't seen used. This unusual choice of vehicle, combined with innovative design and meticulous craftsmanship, purely to serve sound quality, is why this article is called "The Car Audio System Nobody Would Build." Please stay tuned for Part 2 and beyond to see why.

Resources

1. M.S. Polymer Science, B.S. Mechanical Engineering Technology, both from the Univ. of Akron, Akron, OH. 19 years of industrial experience as a Polymer Scientist and Mechanical Engineer. Visit www.whitledgedesigns.com.

2. J. Whitledge's former EuroVan was the topic of a magazine article, R. McPherson, "Weird Science," Car Audio and Electronics, Jan 2004, Vol. 17, No. 1, pp. 10, 58-62, 64. Visit www.caraudiomag.com/v_features/0401cae_2001_volkswagen_eurovan/index.html.

3. 2004-2007 IASCA competition class designation. 2008 designation is "Pro Class." Visit www.iasca.com.

4. Section-04-2008 Sound Rules, pp. SQ-13&14, visit www.iasca.com.

5. R. E. Shively and W. N. House, Harman-Motive, Inc., "Perceived Boundary Effects in an Automotive Vehicle Interior," 100th AES Convention, May 1996, AES preprint no. 4245.

6. Section-04-2008 Sound Rules, pp. SQ-16&17, visit www.iasca.com.

7. J. Atkinson, "Measuring Loudspeakers, Part One," Stereophile, refer to www.stereophile.com/features/99/.

8. "SA-3055 Competition Autosound Analyzer/SPL Meter Operation Manual," AudioControl P/N 9021100, p. 3-7, 1998.

9. V. Dickason, The Loudspeaker Design Cookbook, 6th Ed., Audio Amateur Press, p. 197, 2000.

10. V. Dickason, The Loudspeaker Design Cookbook, 6th Ed., Audio Amateur Press, p. 199, 2000.

11. R. Harley, The Complete Guide to High-end Audio, 1st Ed., Acapella Publishing, pp. 93-100, 1994.

12. F. A. Everest, The Master Handbook of Acoustics, 4th Ed., McGraw-Hill, pp. 275-288 & 317-351, 2001.

13. R. Harley, The Complete Guide to High-End Audio, 1st Ed., Acapella Publishing, p. 103, 1994.

14. S. -K. Lee and D. -J. Yu, "Measurement of reverberation time of a passenger car utilizing the wavelet filter bank," Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, Vol. 219, No. 3, pp. 329-336, 2005.

15. Section-04-2008 Sound Rules, pp. SQ-11&12, visit www.iasca.com.

16. Section-04-2008 Sound Rules, pp. SQ-19, visit www.iasca.com.