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Reflector Responses: A Comparison between ODEON's Modified Ray Tracing Algorithm and a Filtered Boundary Element Method Model

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The biggest challenge for geometrical room acoustic computer models is to capture complex wave phenomena while maintaining the low computational load of the ray tracing algorithm. Special corrections must be added to the ray tracing algorithm to account for wave phenomena such as edge diffraction, which are ignored by classical geometrical acoustics. ODEON, a well-known geometrical computer model, is in the process of upgrading its ray tracing and scattering algorithm. The new algorithm allows users to specify transmission through reflector panel arrays. To aid in the development of ODEON's new algorithm, its predictions are compared with predictions from a boundary element method (BEM) model. The computationally intense BEM model is shown to be very accurate in predicting the response from single- and multi-panel reflector arrays. Comparisons will be shown for several reflector arrays of varied size and density. The BEM results have been filtered into octave bands for ease of comparison.

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Introduction

Reflector panel arrays are commonly employed by concert hall designers to reinforce onstage sound sources. There are three parties that benefit from reflector arrays: the audience, which receives an additional early reflection; ensemble members, who benefit from improved onstage support; and finally the individual performer who can better monitor his own performance in the presence of a nearby reflecting surface. The design of reflector arrays is usually governed by geometrical acoustics, which is a good approximation at high frequencies. At low frequencies, however, the response is increasingly dominated by wave phenomena such as edge diffraction, and the response predicted by geometrical acoustics is less valid. This paper presents a comparison of low frequency reflector array responses predicted in two simulations: the first simulation is a highly accurate and computationally intensive boundary element method (BEM) prediction. The second simulation is ODEON, a computationally non-intense, commercially available geometric (ray tracing) room acoustic model, whose algorithm has been modified to include diffraction effects.

BEM Model

A BEM simulation is conducted using Sysnoise Rev. 5.6 with an omnidirectional sound source and a reflector array. The scattered sound pressure level (SPL) is recorded across a receiver plane (15 m x 15 m, sampled with at least 6 nodes per wavelength) representing an audience (Figure 1). Scattered responses from two reflector panel arrays of varied density are investigated. R5 (Figure 1) is an array of five rectangular panels (10.5 m x 1.2 m), and S35 (Figure 2) is an array of 35 square panels (1.2 m x 1.2 m). In order to compare BEM predictions with the octave band geometric predictions, the BEM predictions are filtered into octave bands according to the following equation (1)

$$p_{band} = \sqrt{\frac{1}{n} \sum_{f \in [f_1, f_2]} |p|^2(f)} \qquad \text{[Pa]} \qquad (1)$$

where f_1 is the lowest narrow band frequency and f_2 is the highest narrow band frequency in the octave band, and n is the number of narrow band frequencies averaged. It was found for these two reflector panels at the frequency bands of interest that n = 8 sufficiently characterizes the response within a frequency band.

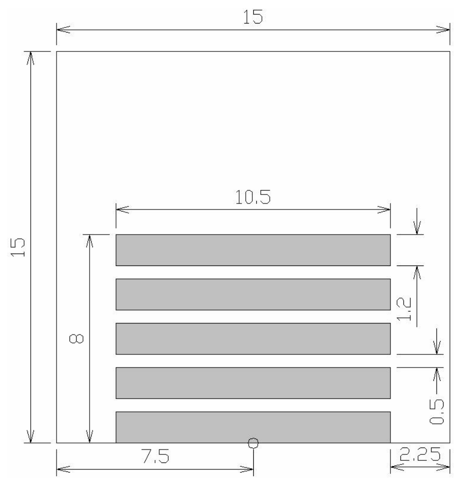

Figure 1: Geometry for array R5. The receiver plane and the source lie in the same plane 5 meters below the reflector array. All quantities are in meters.

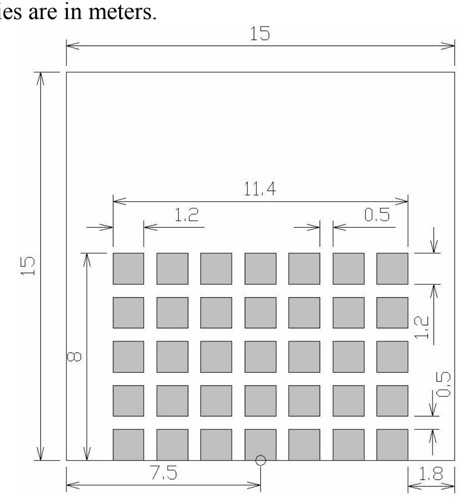

Figure 2: Geometry for array S35. The receiver plane and the source lie in the same plane 5 meters below the reflector array. All quantities are in meters.

If an infinite reflector were present and only attenuation due to spherical spreading from the source of sound power level 94 dB (re 10^{-12} W) were considered, the range of scattered SPL across the receiver plane would be 69 to 74 dB (re 20 μPa). However, panel diffraction and edge diffraction interferences lead to scattered SPL lower than 69 dB, and a scattered SPL range much greater than 5 dB. The scattered SPL levels across the receiver plane are summarized with box plots in figures 3 and 4. The top and bottom hash marks represent the maximum and minimum scattered SPL values, while the three horizontal lines correspond to the 25% percentile, median, and 75% percentile of scattered SPL values. As shown in Figures 3 and 4, the predicted scattered SPL from R5 or S35 never reaches 69 dB, and the range of scattered SPL across the receiver plane is always greater than 5 dB.

It has been stated that small panels do not support low frequency reflections [2]. In the 63 Hz octave band, the scattered SPL of S35, which consists of small panels, is well below the scattered SPL of R5, which consists of much larger panels. The respective median values differ by 8 dB, and the respective interquartile ranges do not overlap. Therefore, these results support the conclusion that an array of small panels is less capable of reflecting low frequencies.

ODEON Model

The same reflector panels are simulated in ODEON 8.0, a geometric room acoustical model. Although ODEON employs an energy based model, which does not reproduce wave phenomena such as diffraction, the algorithm has been modified to include the effects of diffraction [3]. Simulating the response of a reflector array, which in the physical world is dominated by diffraction at low frequencies, is a stringent test of how well ODEON's modified algorithm accounts for diffraction. These results are intended to aid in the development of ODEON 9.0, which is scheduled for release in late spring, 2007.

The scattered SPL in ODEON is isolated by constructing an anechoic room model (absorption of all room boundaries is 1) and placing a completely absorbing barrier in the plane between the source and the receiver plane to block direct energy. The transition order is set to 0 so the model is fundamentally particle based (ray tracing) as opposed to image source based. Scattered SPL in ODEON is sampled every 0.25 meters and is found to vary little among the three octave bands shown here. For reflector R5 in Figure 3, the range of scattered SPL values is approximately 50 to 62 dB for each of the three octave bands shown, with a median of 58 dB. For reflector S35 in Figure 4, the range of scattered SPL values is approximately 49 to 61 dB, with a median of 56 dB. In ODEON, therefore, the extra gaps that distinguish S35 from R5 have minimal effect on the scattered response (1 – 2 dB).

At the 125 Hz and 250 Hz octave bands, ODEON's predictions match satisfactorily with the BEM predictions. For R5, the median values at 125 Hz and 250 Hz differ only by 1 dB.

Conclusion

In this paper, the coverage of reflector panels is expressed in terms of the range of scattered SPL values across a receiver plane. ODEON's predictions vary little across frequency. ODEON's predictions match reasonably well with the BEM predictions for the 125 Hz and 250 Hz octave bands for both reflector panel arrays. In the 63 Hz octave band, ODEON overpredicts the BEM simulation, particularly for the case of array S35. Ongoing work on additional reflector arrays will investigate not only the range of scattered SPL values but also how well ODEON predicts the spatial distribution of the scattered SPL.

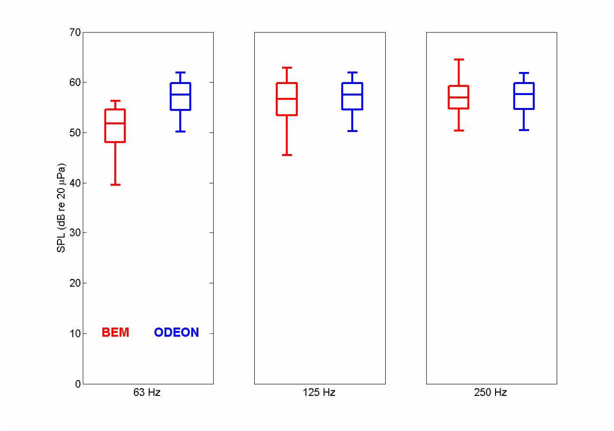

Figure 3: Scattered SPL for R5. For each box plot, the top and bottom hash marks represent the maximum and minimum scattered SPL values, while the three horizontal lines correspond to the 25% percentile, median, and 75% percentile of scattered SPL values.

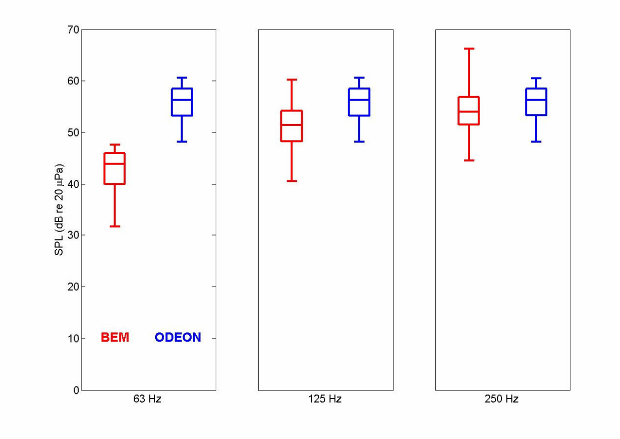

Figure 4: Scattered SPL for S35. For each box plot, the top and bottom hash marks represent the maximum and minimum scattered SPL values, while the three horizontal lines correspond to the 25% percentile, median, and 75% percentile of scattered SPL values.

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