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SIMULTANEOUS PREDICTION OF INTERNAL AND EXTERNAL SOUND FIELDS

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ABSTRACT

The purpose of the project was too develop a mathematical model, which was both accurate and quick to execute, for the simultaneous prediction of steady state and temporal sound fields both in the interior of a room and out to the environment. The sound being modeled would propagate solely through apertures. Hence, it was necessary to model diffraction. A barrier diffraction theory based on the geometric theory of diffraction, as implemented in FAME, was extended to represent diffraction around the perimeter of a building. Measurements around a physical scale model of a building were found to be in good agreement with those of FAME. However, more traditional models based on the Maekawa formula, both single and double diffraction, were found to produce poor predictions in the same space. The speed advantage previously held by the FAME model was lost with the increased complexity of the problem.

1 - INTRODUCTION

The prediction of the sound field in the free-field from an aperture has previously achieved solely using the Maekawa formula [1] to calculate the diffractional effects. This paper presents an extension of a previously published barrier diffraction model [2] to that of a simulated free-field, as well as presenting the results of a current computer model which includes diffraction modeling. The simulated free-field data was taken from a Danish Acoustical Laboratory Report [3] as referenced by the BSI prEN 12354-4:1999 final draft standard concerning the transmission of indoor sound to the outside. This would enable a computer model to accurately simultaneous predict the internal and external sound field of a building for all appropriate acoustical parameters at suitable frequencies.

2 - THE COMPUTER PREDICTION MODELS

Two commercial computer predictions models were used to calculate the sound field in the anechoic chamber, FAME [4] and RAMSETE [5]. A third model, RAYNOISE 3.0 [6], was used in the prediction stage of the research undertaken, but was found to be incapable of predicting the sound field in the space provided.

3 - THE ANECHOIC CHAMBER

The Danish Anechoic Chamber was used to simulate a free-field with a specially designed sound insulated box with varying apertures. A single sound source was used to emit white noise and the sound level was measured around the circumference of a circle with a radius of 2 m at 15 degree intervals, centered on the aperture, at the same height as the sound source, 0.62 m. The sound source was positioned in one corner of the room, see Figure 1, 0.15 m from the sides of the box. The dimensions of the box were 1.21 m by 0.96 m by 0.64 m inside the anechoic chamber of size 12.10 m by 9.70 m by 8.50 m. Sound level measurements were taken at the following frequencies: 1 kHz, 4 kHz and 16 kHz. The aperture was 0.52m by 0.40m. It was assumed that the surfaces of the box were had a consistent absorption coefficient of 0.05, and that the absorption coefficient of the anechoic chamber was 1.0, 0.99 and 0.95, respectively; due to the high frequencies involved, the anechoic chamber created only an approximate free-field.

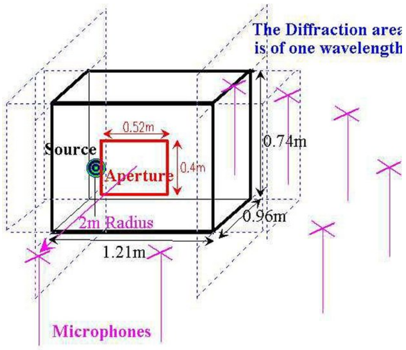

Figure 1: The room showing the source and receiver positions and the FAME diffraction areas.

4 - THE PREDICTIONS

The FAME and RAMSETE models predicted the chamber using identical input parameters. The number of reflections was a consistent 19 and the number of rays traced was set at 65536, which is equal to ten times the volume of the space. RAMSETE could automatically model double diffraction based on a special cut-out feature of the software. However, for FAME each individual diffraction plane had to be defined, see Figure 1. The predictions are presented as a radar graph for a complete circle, composed of the predicted sound levels and their mirror image, see Figures 2, 3 and 4, as the space was symmetrical. The average prediction difference between the predicted and measured sound levels is given as the magnitude of the differences summed and arithmetically averaged, see Table 1.

	1 kHz	4 kHz	16 kHz
FAME	3.0	4.4	3.1
RAMSETE	21.6	12.6	6.2

Table 1: Average prediction differences for the FAME and RAMSETE models.

1 kHz Predictions. From the shape of the measured closure it can be seen that at 1 kHz there was a 30 dB drop in sound level from directly in front of the aperture to directly behind the aperture. The sound level was reduced by 4 dB from 0 to 75 degree then there was a reduction of approximately 4 dB every 15 degrees. Although usually there would be three separate regions of interest: in front of the aperture, to the side and behind the aperture. The RAMSETE model predicted the sound levels accurately from 0 to 45 degrees, as this can be considered a geometrical acoustic problem. However beyond this point there was a massive additional attenuation predicted of approximately 12 dB between 45 and 105 degrees due to a lack of accurate diffraction approximation. At this point the sound level flattened at approximately 26 dB between 105 and 150 degrees caused by the double diffraction effect, after which the predicted sound level was zero as there was no residue sound reflecting from the anechoic surfaces and no triple diffraction model. Hence, the average prediction error of 21.6 dB, see Table 1. The FAME model predicted sound levels accurately for all receiver positions, directly in front of the aperture, to the side of the aperture and behind the aperture. Hence, the average prediction difference was 3.1 dB. It should also be noted that the model executed in one half of the time of the RAMSETE model.

4 kHz Predictions. From the shape of the measured closure it can be seen that at 4 kHz there was a 38 dB drop in sound level from directly in front of the aperture to directly behind the aperture. The sound level was reduced by 3 dB from 0 to 75 degree then for the 90 and 105 degree receiver positions the sound level was further reduced by 8 dB and hence these prediction angles were considered to be critical. Beyond this point there was an approximate 4 dB reduction in sound level every 15 degrees. As before, the RAMSETE model predicted the sound levels accurately from 0 to 45 degrees, again purely due to geometric consideration. However beyond this point there was a massive additional attenuation predicted of approximately 8 dB for the 60 and 75 degree receiver positions caused by over estimating the effect of first order diffraction. Beyond these receivers the sound level flattened, for angles up to 150 degrees, as the effect of second order diffraction was negligible and the residue intensity became dominate due to the room absorption coefficient of 0.99. For the 165 and 180 degree predictions only residue intensity contributed and hence the sound level was predicted to be only 8 dB, giving an overall prediction accuracy of 12.6 dB. The FAME model predicted sound levels accurately for all receiver positions, directly in front of the aperture and to the side of the aperture, up to 120 degrees. However there was an over prediction of the sound levels at 135 and 150 degrees of approximately 5 dB, although

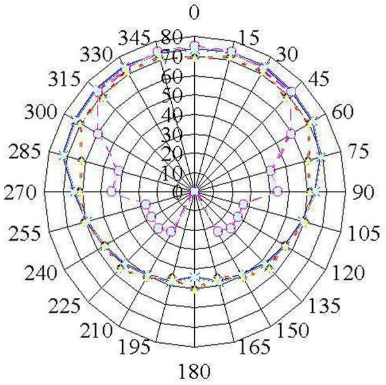

Figure 2: Measured and predicted 1kHz results.

for the receiver positions directly behind the aperture the sound levels were accurately predicted. Hence, the average prediction error was 4.4 dB. It should be noted that the higher the frequency the faster the FAME model executes, as there is less diffraction to approximate, but it should be remembered that FAME requires each frequency to be predicted separately. Thus the overall run-time of RAMSETE and FAME were similar.

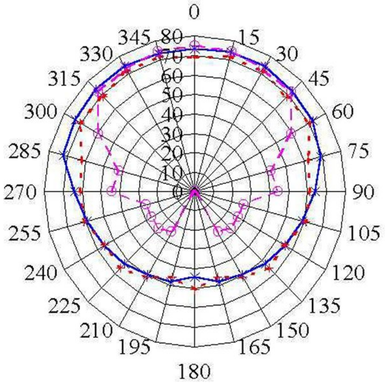

Figure 3: Measured and predicted 4 kHz results.

16 kHz Predictions. From the shape of the measured closure it can be seen that at 16 kHz there was a 50 dB drop in sound level from in front of the aperture to directly behind the aperture. The sound level was not reduced for any of the receivers between 0 to 75 degrees due to the directional nature of the sound source. At 90 degrees there was a 10 dB reduction in sound level and a further 13 dB at 105 degrees and hence as before these were the critical receiver positions to predict. Beyond 105 degrees there was a 4 dB reduction in sound level per 15 degree interval. As before, the RAMSETE model predicted the sound levels accurately from 0 to 45 degrees, again purely due to geometric consideration. However beyond this point: 60, 75 and 90 degrees the sound level was under-predicted by 15 dB, 25 dB and 15 dB, respectively. This was a similar result as found for the 4 kHz prediction with the model under-estimating the diffractional effects. However, beyond 90 degrees RAMSETE was accurate as this region was only affected by residual intensity from the anechoic surfaces, which were assumed to have an absorption coefficient of 0.95. Hence, overall prediction accuracy was considerably improved to 6.1 dB on average. The FAME model predicted sound levels accurately for all receiver positions, directly in front of the aperture, to the side of the aperture and behind the aperture. Hence, confirming that the assumed absorption coefficient for the anechoic chamber were accurate and giving an average prediction difference of 3.1 dB.

5 - SUMMARY AND CONCLUSIONS

The prediction of diffractional effects both through an aperture and around the edges of a box set in an anechoic chamber has been investigated using two computer models. The first model, RAMSETE, was based on the Maekawa formula, while the second was based on a simplification of the geometric theory of diffraction extended to multiple consider diffractions, FAME. It was found that the RAMSETE predicted

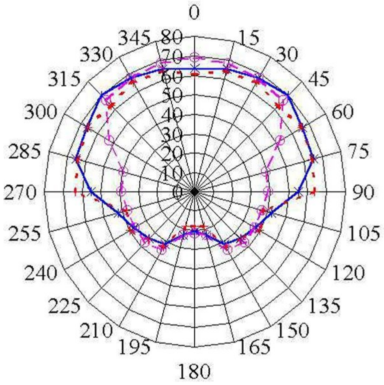

Figure 4: Measured and predicted 16 kHz results.

poorly at all frequencies, especially at the lowest frequency investigated, as this was where the anechoic chamber was effective. As the frequency increased it was thought that the model would become increasing inaccurate, but this was compensated for by higher residue intensity due to reflections from the anechoic chamber and hence the average error actually improved from approximately 22 dB to 6 dB, for both the spaces investigated. The FAME model was shown to accurately predict the sound level at all receiver positions, except one critical region at one frequency, which occurred for both the boxes, and hence the average prediction error increased to more than 4 dB from approximately 3 dB on average. It was shown that the model was at least as fast to execute as the RAMSETE model and significantly more accurate.

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