MODELLING OF SOUND FIELDS IN ENCLOSED SPACES WITH ABSORBENT ROOM SURFACES. PART IV: ANECHOIC CHAMBER

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1 INTRODUCTION

The prediction of internal to external sound fields has not been extensively investigated [1,2]. Here the results of three computer models are compared in an idealised environment, a reverberation chamber adjacent to an anechoic chamber connected by a large aperture. The sound field in an anechoic chamber approximates to the free field at all but the lowest frequencies. As it has been shown that rooms with highly absorbent surfaces are more accurately modelled using Millington absorption coefficients [3], it was necessary to determine the room absorption coefficient for the anechoic chamber. Hence two sets of predictions were obtained for the three mathematical models.

2 MEASUREMENTS

Four sets of measurements were taken in order to assess the accuracy of the computer predictions. The four measurements were as follows: to determine the absorption coefficient of the anechoic chamber (non-empty), to determine the absorption coefficient of the reverberation chamber, to calculate the source sound power, and finally sound level and reverberation time measurements in the anechoic chamber.

2.1 Anechoic Chamber Absorption Coefficient Measurements

Early decay time measurements were taken in the anechoic chamber, using the MLSSA measurement system in combination with an omni-directional loudspeaker, at various positions in the room. The average early decay time was calculated from which the absorption coefficient across six octave bands, 125 Hz to 4 kHz, see Table 1, were determined. Millington absorption coefficients were derived from a conversion graph, see Figure 1.

Table 1: Sabine/Millington absorption coefficients for anechoic and reverberation chambers

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Sabine α	1.00	1.00	1.00	1.00	1.00	1.00
Millington α	0.65	0.65	0.65	0.65	0.65	0.65
Reverb α	0.065	0.062	0.064	0.058	0.05	0.052

2.2 Reverberation Chamber Absorption Coefficient Measurements

Reverberation time measurements were taken in the reverberation chamber (doors to the anechoic room shut), using the MLSSA measurement system in combination with an omni-directional loudspeaker, at various positions in the room. The average reverberation time was calculated, and applied to the Sabine formula to determine the absorption coefficient across eight octave bands, 125 Hz to 4 kHz. As Millington absorption coefficients are only appropriate for highly absorbent materials it was unnecessary to convert the reverberation chamber absorption coefficient to the Millington equivalents.

2.3 Reverberation Chamber Source Sound Power Measurements

The source sound power was determined from the sound levels measured at various positions in the reverberation chamber, using a sound analyser excited by an omni-directional loudspeaker. The average sound levels were calculated, for each of the six octave bands, and diffuse field theory was used to calculate the necessary sound power levels to obtain the measured sound levels.

2.4 Coupled Room: Sound Level and Reverberation Time Measurements

The anechoic chamber was 6.8 m by 7.1 m by 4.2 m connected by an aperture, 2.6 m by 1.9 m, through a 1 m corridor into the reverberation chamber, 6.6 m by 7.1 m by 4.2 m. MLSSA measurements (RT15) were taken at six receiver positions in the anechoic chamber; simultaneously a sound analyser measured the sound pressure level, whilst the aperture was open, see Figure 2.

3 PREDICTIONS

All computer models used precisely the same representation for the two rooms. However, due to the size of the rooms, the lowest frequency could not be predicted accurately due to the limitations of geometric acoustics, which requires that the wavelength of interest be shorter than the room dimensions by a factor of at least two. Hence, it would be incorrect to predict the 125 Hz octave band, although these results are presented for completeness and are included in the analysis. Two sets of predictions were made, the first using standard absorption coefficients, and the second based on Millington absorption coefficients for the anechoic chamber.

Each model used the same input parameters, 70 reflections or a tracing time equal to that given by the Sabine reverberation time formula for the reverberation chamber. Finally, RAMSETE and RAYNOISE used a diffraction approximation based on the work of Maekawa [4], where as FAME did not use a diffraction approximation in the following cases.

3.1 Sound Level Predictions using Sabine Absorption Coefficients

Table 2 shows the average absolute prediction difference (predicted minus measured sound level) for the three computer models in the anechoic chamber.

Table 2: Average Errors (dB) for 3 computer models in the coupled room (Sabine α).

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
FAME	7.7	6.5	6.8	4.5	4.7	4.2
RAMSETE	1.5	2.0	1.6	3.0	3.2	3.4
RAYNOISE	4.0	3.2	3.9	3.6	4.1	5.8

In terms of sound levels the RAMSETE model was the most accurate, 2.5 dB logarithmically average error for the six central octave bands, followed by RAYNOISE 4.2 dB and FAME, which gave a 5.9 dB average error. Hence, it would appear that the double diffraction modelling of RAMSETE gave a significant improvement in prediction accuracy, RAYNOISE can only model single diffraction and FAME had no diffraction model, hence their respective results. This is confirmed by the individual octave band analysis of the FAME predictions, no diffraction modelled, which show improving prediction accuracy with increasing frequency.

3.2 Reverberation Time Predictions using Sabine Absorption Coefficients

Table 3 shows the average reverberation time calculated from the reverberation times at six receiver positions, for the three computer models in the coupled room.

Table 3: Average measured and predicted reverberation times (Sabine α).

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Measured	1.81	1.93	1.84	2.16	2.04	1.74
FAME	2.39	2.31	2.20	2.25	2.20	2.05
RAMSETE	1.87	1.79	2.03	2.10	2.18	2.07
RAYNOISE	1.70	1.77	1.73	1.82	1.90	1.67

Table 4 is an analysis of table 3 with the prediction accuracy in term of percentages over the six receiver positions in the coupled room, see Figure 3.

Table 4: Average RT percentage error in the coupled room (Sabine α)

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
FAME	49.3	33.3	24.5	21.2	24.3	21.2
RAMSETE	15.4	9.2	13.3	4.6	6.4	19.1
RAYNOISE	10.1	15.0	18.5	24.4	22.0	22.6

The same trend as was found for the steady state levels, Table 2, was found in the temporal results, Table 4. The RAMSETE model were the most accurate, 11.3% average reverberation time error, followed by RAYNOISE with an 18.8% error and FAME, a 29.0% error. The accuracy of the predictions also converged with increasing frequency, confirming that it was diffraction which significantly improved the prediction accuracy of RAYNOISE and RAMSETE above that of the purely geometrical FAME.

3.3 Sound Level Predictions using Millington Absorption Coefficients

The computer models remodelled the rooms using Millington absorption coefficients, see Table 1, rather than Sabine absorption coefficients for absorbent in the anechoic chamber. All other parameters were otherwise unchanged. Table 5 shows the average errors for the three computer models in the coupled room.

Table 5: Average Errors (dB) for 3 computer models in the coupled room (Millington α)

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
FAME	3.0	1.1	1.4	1.5	1.6	3.5
RAMSETE	1.5	2.3	2.0	3.5	3.5	3.2
RAYNOISE	2.1	1.2	1.0	1.6	1.6	2.1

Using Millington rather than Sabine absorption coefficient improved the prediction accuracy of FAME and RAYNOISE by 3.8 dB and 2.6 dB on average across the six central octave bands, an average absolute error of 2.1 dB and 1.6 dB, respectively. For RAMSETE the overall prediction accuracy was similar, better at low and high frequencies, but worse in the mid-frequencies and consequently 0.2 dB worse than the standard absorption coefficient predictions, an absolute average error of 2.7 dB.

3.4 Reverberation Time Predictions using Millington Absorption Coefficients

Table 6 shows the average reverberation time calculated from the reverberation times at six receiver positions, for the three computer models in the coupled room, see Figure 4.

Table 6: Average measured and predicted reverberation times (Millington α)

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Measured	1.81	1.93	1.84	2.16	2.04	1.74
FAME	2.18	2.18	2.09	2.17	2.11	1.74
RAMSETE	2.07	2.10	1.96	2.03	2.12	2.01
RAYNOISE	1.58	1.58	1.53	1.58	1.62	1.45

Table 7 is an analysis of table 6 with the prediction accuracy in term of percentages over the six receiver positions in the coupled room.

Table 7: Average RT percentage error in the coupled room (Millington α)

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
FAME	27.8	18.2	13.3	12.9	11.9	7.7
RAMSETE	14.1	7.1	6.5	6.7	5.6	15.9
RAYNOISE	12.4	17.8	16.7	26.7	20.9	16.8

Comparing the Millington based predictions, Table 7 with those using Sabine absorption coefficients, Table 4, it can be seen that on average FAME improved from a 29.0% average RT error to a 15.3% average error. Similarly, RAMSETE improved to a 9.3% from an 11.3% using Sabine absorption coefficients. RAYNOISE was only marginally affected with an average improvement of 0.2% from 18.8% average error. This indicates that the purely geometrical model was significantly affected by including Millington absorption coefficients but the models with a diffraction approximation were only marginally affected.

3.5 Discussion

Predicting internal to external sound fields has been found to be possible, but none of the models were capable of accurately simultaneously predicting the sound level and reverberation time to within 2dB and 14%, respectively. This numbers were chosen to represent what could be considered to be engineering accuracy. RAMSETE could predict reverberation time, but not the sound level, where as RAYNOISE could predict the sound level but not the reverberation time. Both these models were improved when Millington absorption coefficients were used to represent the absorbent material.

As FAME did not include a diffraction model and this was show to be a significant factor in predicting the external sound field, the model was further developed to see if the external sound field could be accurately predicted in terms of steady state and temporal acoustic parameters.

4. DEVELOPMENT OF AN INTERNAL DIFFRACTION MODEL

A similar approach was taken to the development of an internal diffraction model as previously used to develop a barrier diffraction model, based on the geometric theory of diffraction [5,6].

4.1 Internal Diffraction Model

The barrier diffraction model used in FAME is based on a transparent diffraction area around perimeter of the barrier, which randomly scatters any ray striking the area. The size of the diffraction area is the wavelength of interest.

An entrapping diffraction area covering the aperture plus one wavelength around the perimeter was used, offset from the wall by a distance of 1m, will allow any ray through only once from then it will reflect sound specularly without any acoustic losses. The internal edge has an associated diffraction area, 1 wavelength wide, which when struck randomly radiates the ray either through the aperture or on to the entrapping surface, and thus creates a "hole" for the sound to fall into.

4.2 Results using Millington Absorption Coefficients

Table 8 presents the prediction accuracy of the FAME models with and without diffraction when Millington absorption coefficients were assumed.

Table 8: Average Errors (dB) for FAME models in the coupled room (Millington α)

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
FAME λ=0	3.0	1.1	1.4	1.5	1.6	3.5
FAME λ=1	1.2	0.9	1.1	1.8	2.3	3.5

Overall including diffraction improved the average prediction difference by 0.2 from 2.1 dB for the six central octave bands to 1.9. However, both model still predicted to bands outside the 2 dB accuracy limit, see Table 8.

Table 9 shows the average absolute percentage difference between the measured and predicted reverberation time at each of the six receiver positions for the FAME model with and without diffraction, again assuming Millington absorption coefficients.

Table 9: Average RT percentage errors for the FAME models in the coupled room (Millington α)

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
FAME λ=0	27.8	18.2	13.3	12.9	11.9	7.7
FAME λ=1	35.9	19.7	6.5	6.5	0.6	1.1

Predicting reverberation time proved to be more difficult than predicting steady-state levels. The 125 Hz prediction can be considered marginal, as the reproducibility of this measurement would be poor, hence FAME with diffraction was the most consistently accurate model, 11.7% error compared to 15.3% error without diffraction. However, both models did predict two octave bands outside the 14% limit.

5 CONCLUSIONS

Three computer models have been compared in an internal to external sound field scenario represented by a reverberation chamber and an anechoic chamber. It was found that none of the models could simultaneously accurately predict the steady state and temporal sound field. However, it was determined that diffraction was a significant contributor to accurate predictions for both steady state and temporal acoustic parameters.

When the rooms were repredicted using Millington absorption coefficients for the absorbent material the prediction accuracy significantly improved for two of the three models, the third was only marginally affected.

As diffraction was found to be of significant effect the FAME model was extended to include an internal diffraction approximation based on its barrier diffraction model. FAME λ=1 gave a 1.8 dB average sound level error and 11.7% reverberation time error across the six central octave bands using Millington absorption coefficients and hence meet the engineering accuracy criteria.

6 REFERENCES

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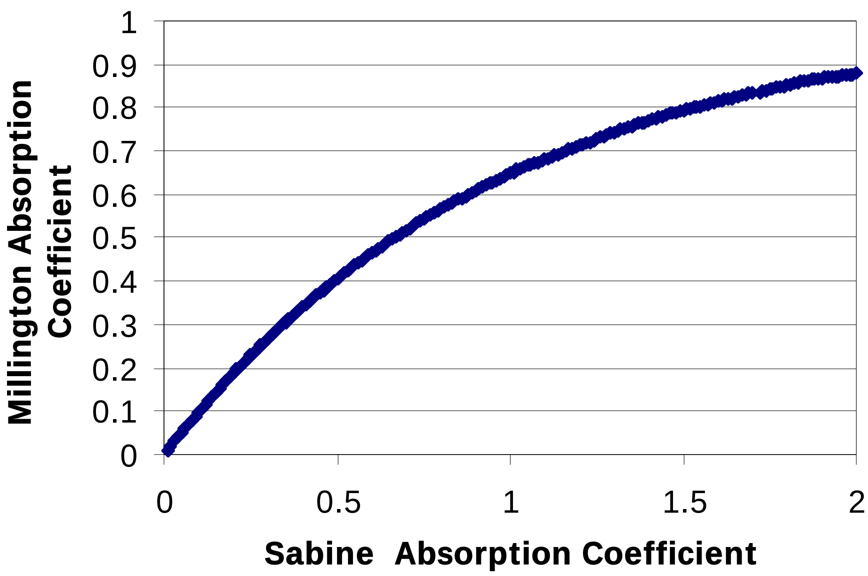
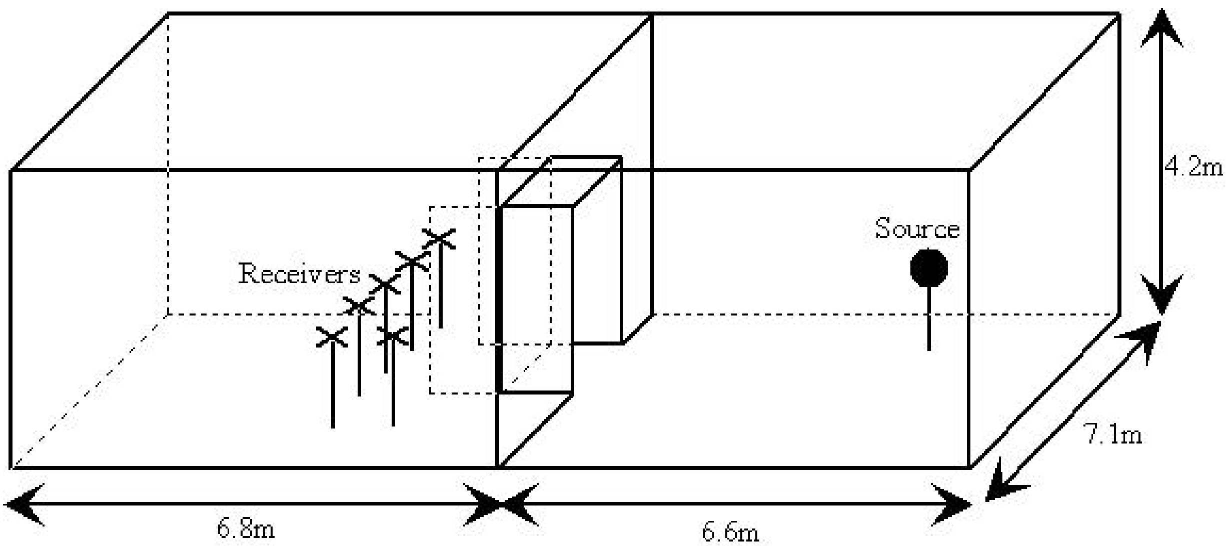


Figure 1. The Sabine to Millington absorption coefficient conversion graph

Figure 2. The anechoic and reverberation chamber including source and receiver positions



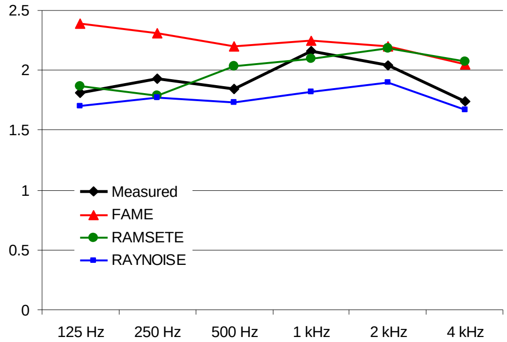


Figure 3. Predicted RTs using Sabine α

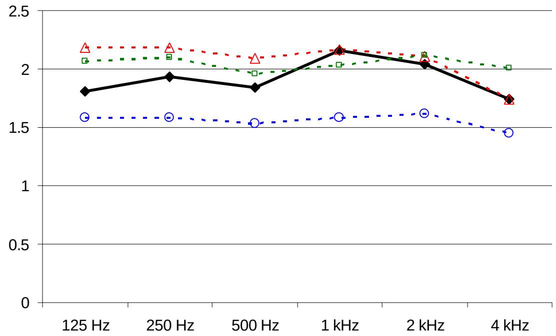


Figure 4. Predicted RTs using Millington α

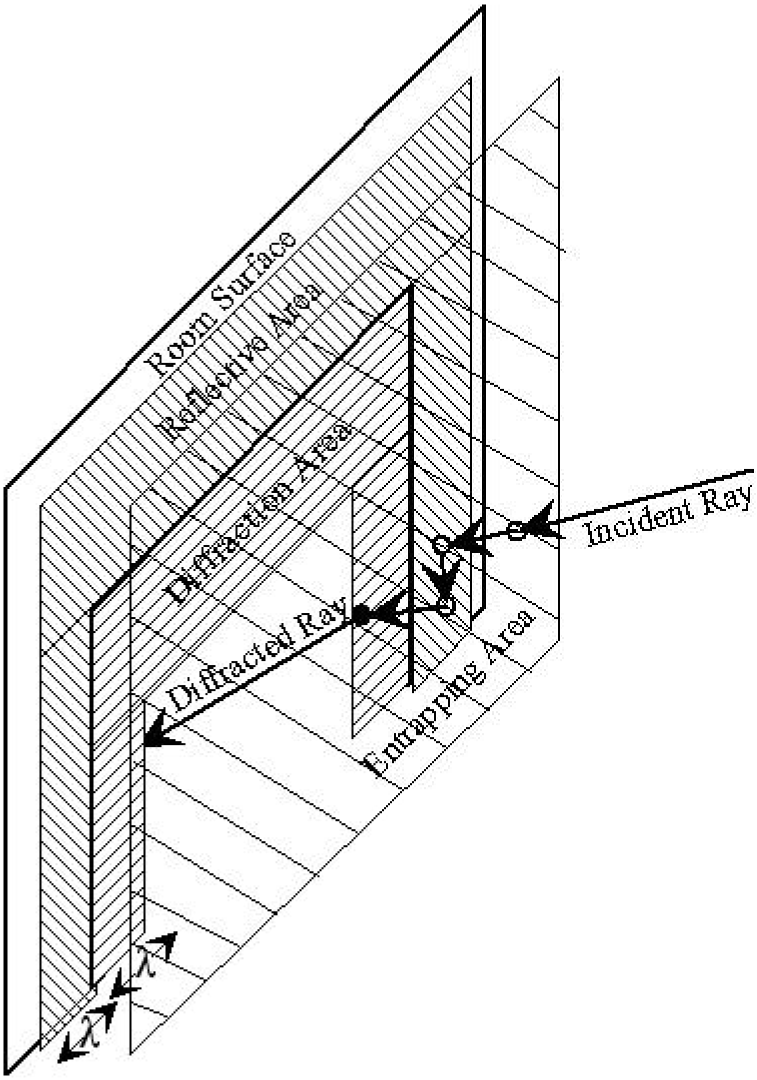


Figure 5. The internal diffraction model with entrapment area 1m from wall surface