COMPUTER PREDICTION OF INSERTION LOSS DUE TO A SINGLE BARRIER IN A NON-DIFFUSE EMPTY SPACE.

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1. INTRODUCTION.

One approach to reducing the noise exposure of workers in an industrial environment is to use acoustic barriers around specific machinery. Therefore computer prediction models of sound distribution should be capable of accurately modelling the acoustic performance of such barriers. Presented here is a preliminary investigation into the prediction of insertion loss (IL) due to a single barrier in an enclosed non-diffuse space.

The Ondet and Barbry model, RAYCUB [1], for the prediction of sound distribution in factory spaces, has been independently validated and found to produce accurate predictions in enclosed spaces [2],[3]. The model is also geometrically correct for empty spaces, that is all of the space's surfaces can be accurately physically represented and the sound propagation can be traced. The model is therefore suitable for the inclusion of a barrier model.

This paper describes the modelling of barriers using an extension to RAYCUB, a validation in a test space, and discusses the results obtained.

2. THE TEST SPACE.

Sound measurements were taken in a enclosed test space by Jones [4]. The test space was a shallow empty factory of length 56m, width 36m and a height of 8.6m rising to a central pitch of 10.6m. The walls were constructed of brick, the ceiling was cladded and the floor was made of concrete. The factory was not fitted with machinery, but did contain steel skips, set away from the measurement area. Sound measurements taken in the space demonstrated the existence of a non-diffuse sound field. A barrier of dimensions 0.1m x 2.7m x 2.4m (high) was positioned centrally in the space, see Figure 1a.

3. THE MEASUREMENTS.

Two sets of measurements both with and without the barrier present were made in the test space. The sound source used during the measurements was a Bruel and Kjaer Type 4224, which showed a significant directivity pattern, with a directivity factor of 3 directly in front

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of the loudspeaker when measured under free-field conditions. Sound propagation (SP) measurements in the test space were made for each of the octave bands 125Hz to 4kHz.

Case 1. For the first set of measurements the source was positioned at a distance of 1m directly in front of the barrier, at a height of 0.2m. SP measurements were taken at six points one metre apart in the vicinity of the barrier, see Figure 1b.

Case 2. For the second set of measurements the source was located 5m directly in front of the barrier. SP measurements were taken on both sides of the barrier, as shown in Figure 1c.

When the barrier was not present it would seem from the measurements that interference effects were occurring as the sound level increased significantly with increasing distance from the source. This was particular apparent for the 500Hz and 2kHz octave bands when the source was positioned as in Case 2.

This effect is not reproduced by any of the models discussed here, as they are based on geometric acoustics. It has been shown in a previous paper [5] that it is possible to reproduce these interference effects using computer modelling based on wave theory. In industrial spaces this effect would be negated by the fittings in the space and the large number of sound sources which are likely to be non-coherent.

4. THE BARRIER MODELS DEVELOPED.

For the modelling of insertion loss due to a barrier it must be assumed that the model predicts the sound levels very accurately in the empty spaces without the barrier present. The RAYCUB-DIR model, an extension of RAYCUB, has been shown to give accurate predictions [3], within 1dB of the measured sound levels on average, and so was considered suitable for the inclusion of a barrier model.

The most precise representation of RAYCUB-DIR was merged with the most appropriate barrier theory using the simplest possible implementation. The barrier model was based on the geometric theory of diffraction [6], using an extended version of the Benedetto and Spagnolo idea of a diffraction area around a barrier [7]. Three different versions of the barrier model were developed using this essential approach.

Redirection Diffraction Model - REDIR.

For this model an imaginary plane follows the perimeter of the barrier at a distance λ (where λ is the wavelength of the mid-frequency of the octave band of interest). If a sound ray strikes this "diffraction area" it is randomly redirected propagating along its new path with no additional attenuation, see Figure 2.

The Redistribution Diffraction Model - REDIS.

This model also represented the barrier including a diffraction area, but if a ray strikes the diffraction area a secondary source is created at the incident point. The energy of the ray is reattributed to the secondary source, with no attenuation loss. The secondary source is assumed to be omni-directional, see Figure 3. The rays from the secondary source are followed, but are not allowed to create tertiary sources.

The Enlarged Barrier Model - ENLARGE.

In this model the dimensions of the barrier are increased to that of the original barrier plus the diffraction area, see Figure 4.

5. THE BARRIER MODEL VALIDATION.

The original RAYCUB-DIR model was also used to model barrier performance, using a single plane with an associated absorption coefficient to represent the barrier.

SP predictions were produced, for each octave band 125Hz to 4kHz, with and without the barrier present, allowing the calculation of insertion loss (IL). A representative sample of predicted IL curves are presented in Figures 5 and 6. In the discussion below the average insertion loss prediction difference for each of the four models RAYCUB-DIR, REDIR, REDIS and ENLARGE are compared.

Case 1.

TABLE 1 shows the logarithmically averaged IL prediction differences (dB), (predicted minus measured IL), for case 1 at each octave band 125Hz to 4kHz. Figure 5 shows the IL graphs for the 125Hz, 1kHz and 4kHz octave bands for this case.

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TABLE 1

The averaged IL prediction differences for case 1.

Frequency (Hz)	125	250	500	1k	2k	4k
RAYCUB-DIR	1.91	3.71	4.14	4.86	2.84	1.68
REDIR	0.98	1.63	2.29	3.26	1.69	1.88
REDIS	1.60	3.44	4.16	4.62	2.73	1.7
ENLARGE	2.41	4.2	4.15	4.86	2.98	1.77

RAYCUB-DIR. At 125Hz the predictions were accurate, slightly high at the receiver point closest to the barrier and low at the receiver point furthest from the barrier. The over-predictions were due to ignoring the diffraction effect and thus less sound reached into the barrier shadow. For the 4kHz octave band, where the diffraction effect would have the smallest effect the predictions became significantly more accurate, as seen in Figure 5.3.

REDIR. All the predicted ILs were accurate except for the 1kHz octave band where they were significantly too high, see Figure 5.2, but the prediction differences were less than for RAYCUB-DIR, indicating that the model was not representative of the diffraction that was actually occurring.

REDIS. The predictions were all very similar to those of RAYCUB-DIR, indicating that in a large space an averaging effect takes place, the rays radiated from the secondary sources approaching what would have been a single ray in RAYCUB-DIR.

ENLARGE. The predicted ILs were very similar to those of REDIS and RAYCUB-DIR. This indicates that when the source is close to a barrier increasing the size of the barrier has little effect on the prediction accuracy using models based on the given assumptions.

Overall, the predictions converged to the measured IL at the furthest points from the barrier, as the barrier's effect becomes negligible in the reverberant sound field. As the frequency increased the different modelling methods produced similar results, as would be expected. At all of the octave bands investigated the REDIR model predicted the IL at the first receiver point after the barrier, where diffraction has the most effect on IL, more accurately than the other barrier models.

The measured insertion loss propagation at 1kHz, see Figure 5.2, shows a distinct increase with increasing distance from the barrier. This can be attributed to interference effects when the barrier was not present.

Case 2.

TABLE 2 shows the logarithmically averaged IL prediction differences (dB), (predicted minus measured IL), for case 2 at each octave band 125Hz to 4kHz. Figure 6 shows the IL graphs for the 125Hz, 1kHz and 4kHz octave bands for this case.

TABLE 2.

The averaged IL prediction differences for case 2.

Frequency-Hz	125	250	500	1k	2k	4k
RAYCUB-DIR	2.34	1.88	0.65	0.77	2.21	1.41
REDIR	2.3	1.43	1.8	0.96	1.84	1.48
REDIS	2.25	1.84	0.67	0.64	2.21	1.61
ENLARGE	3.32	2.48	0.61	0.72	2.25	1.63

RAYCUB-DIR. As can be seen in Figures 6.1 to 6.3, the IL curves generally followed the measured IL reasonably closely and hence gave good prediction accuracy, see TABLE 2. The predictions were more accurate than in the previous case because the source was further from the barrier and the diffraction effect was reduced. For the 125Hz octave band, Figure 6.1, the shape of the predicted IL curve was incorrect, as the diffraction effect was not modelled.

REDIR. This model produces reasonable prediction accuracy across all octave bands, with an average prediction difference of between 1 and 2.3dB, as does RAYCUB-DIR. However, REDIR was able to accurately predict the shape of the 125Hz IL curve, see Figure 6.1 which demonstrated the diffractional effects. For the central and higher frequencies the maximum IL, which occurred directly after the barrier, were all marginally under-predicted.

REDIS. The same pattern occurs as was seen in barrier case 1 with all the predicted IL curves being very similar to those of the RAYCUB-DIR model, see Figures 6.1 to 6.3. The lowest octave band IL curve was incorrectly predicted, but the other octave bands were accurately predicted. The differences between RAYCUB-DIR and REDIS are reduced due to the increased distance between source and barrier.

ENLARGE. As shown by Figures 6.1 to 6.3, the shape of the IL curves predicted by this model were very similar, but less accurate than those predicted by RAYCUB-DIR, the inaccuracy reducing with increasing frequency. This can be seen from the average prediction differences in TABLE 2, where the differences, above 250Hz, closely resemble those of RAYCUB-DIR. At the higher frequencies the predicted IL curves become identical to those of RAYCUB-DIR, see Figures 6.2 and 6.3.

All the models in this case failed to predict the negative IL at the first receiver point in front of the barrier. However, the predictions of all the models converged to the measured IL at the furthest points, as the barrier effect becomes negligible in the reverberant sound field. All versions model this case more accurately than barrier case 1, as the source was further from the barrier and hence the diffraction effects contributed less to the predicted sound levels.

REDIR produced consistently accurate ILs for all octave bands investigated and predicted the IL accurately directly behind the barrier. All of the models gave improved or better predictions at the higher frequencies, as would be expected as the diffractional effects become less important with increased frequency.

6. CONCLUSIONS.

It has been show that it is possible to model the diffraction effect of a barrier in an enclosed space, using an extended version of the RAYCUB model, based on the geometric theory of diffraction.

Preliminary validation of the models found that the model which introduces a "diffraction area" with randomly redirected rays was the most accurate, the predicted IL curves closely following the measured curves, especially at low frequencies.

As would be expected the models all demonstrated convergence with the measured IL at the furthest receiver point from the source, but none of the models predicted the negative IL in case 2 on the source side of the barrier.

7. ACKNOWLEDGEMENTS

I would like to thank Madame Ondet for providing the original RAYCUB model and Dr Jones for allowing the use of her barrier data. This research was funded by SERC.

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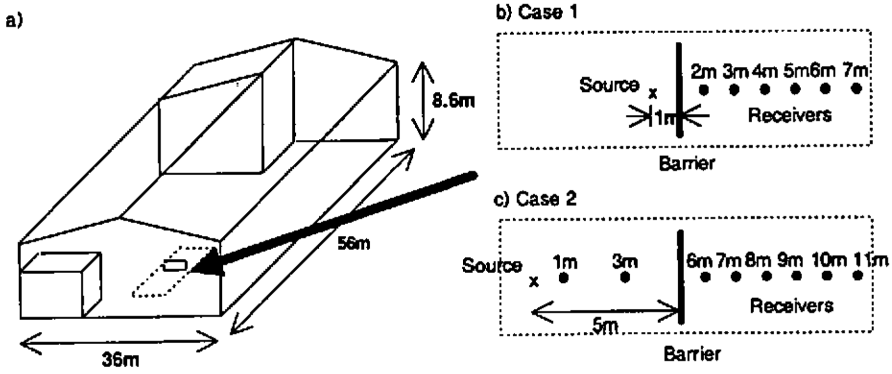

Figure 1. Position of source, receivers and barrier in the two barrier cases modelled.

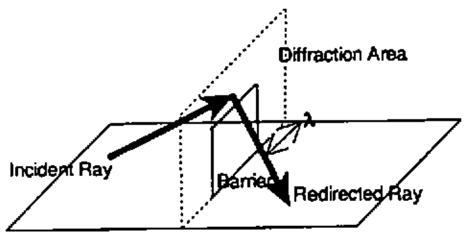

Figure 2. The REDIR model.

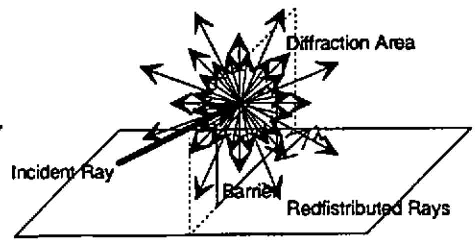

Figure 3. The REDIS model.

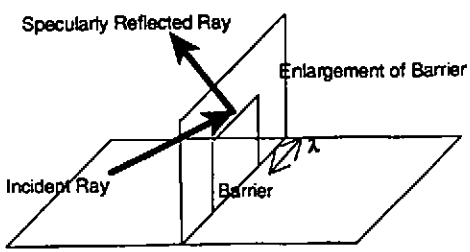

Figure 4. The ENLARGE model.

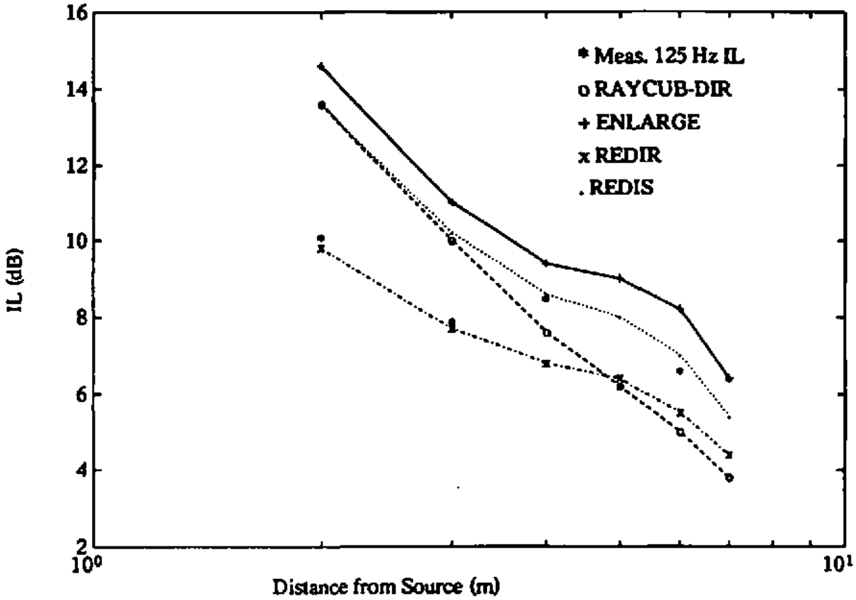

Figure 5.1. Case 1: Measured and Predicted IL curves for the 125Hz Octave Band

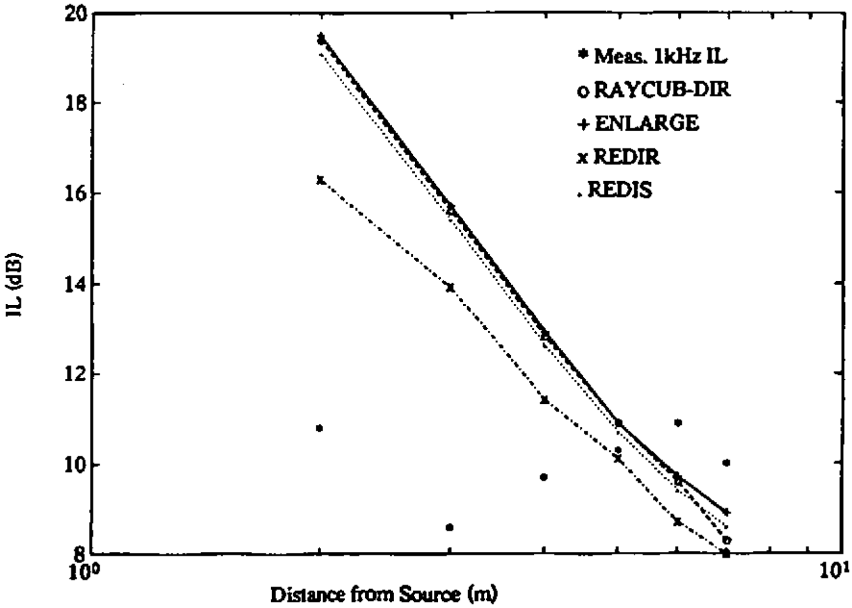

Figure 5.2. Case 1: Measured and Predicted IL curves for the 1kHz Octave Band

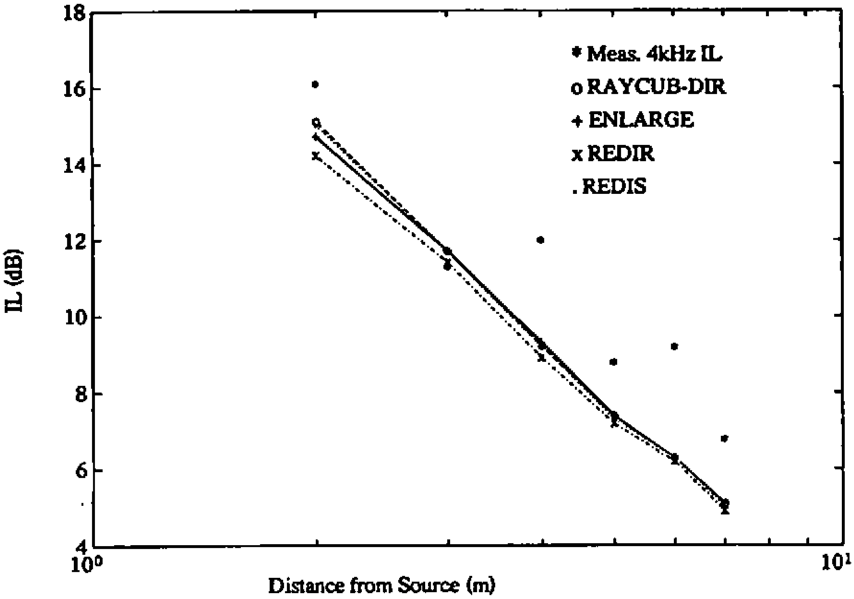

Figure 5.3. Case 1: Measured and Predicted IL curves for the 4kHz Octave Band

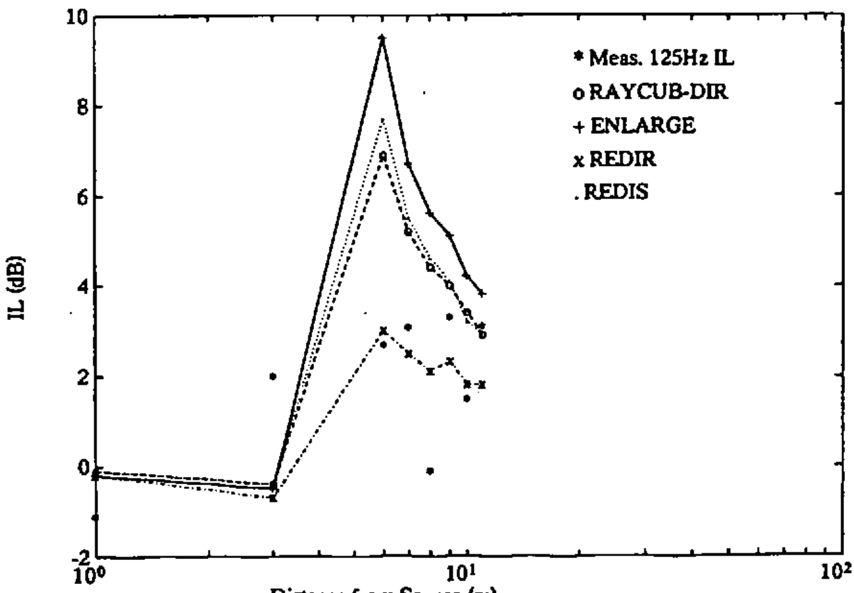

Figure 6.1. Case 2: Measured and Predicted IL curves for the 125Hz Octave Band

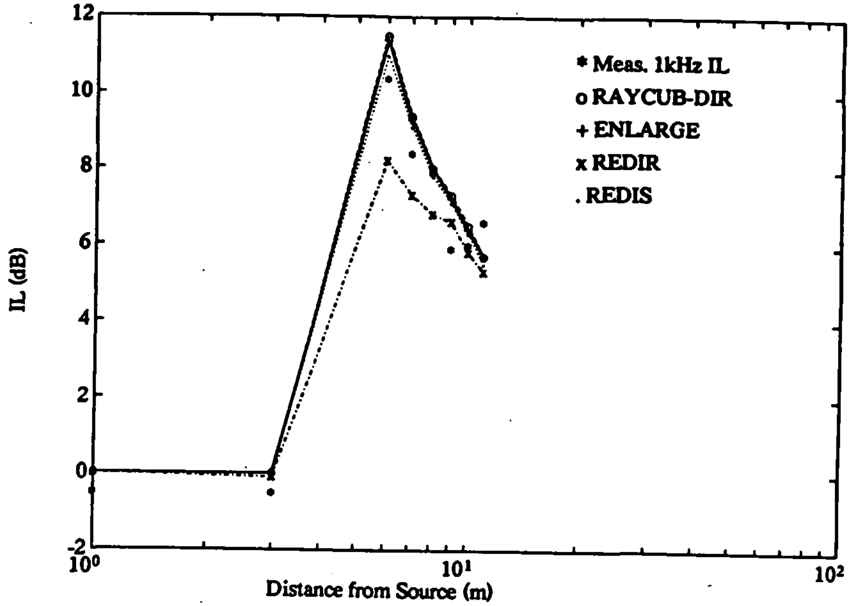

Figure 6.2. Case 2: Measured and Predicted IL curves for the 1kHz Octave Band

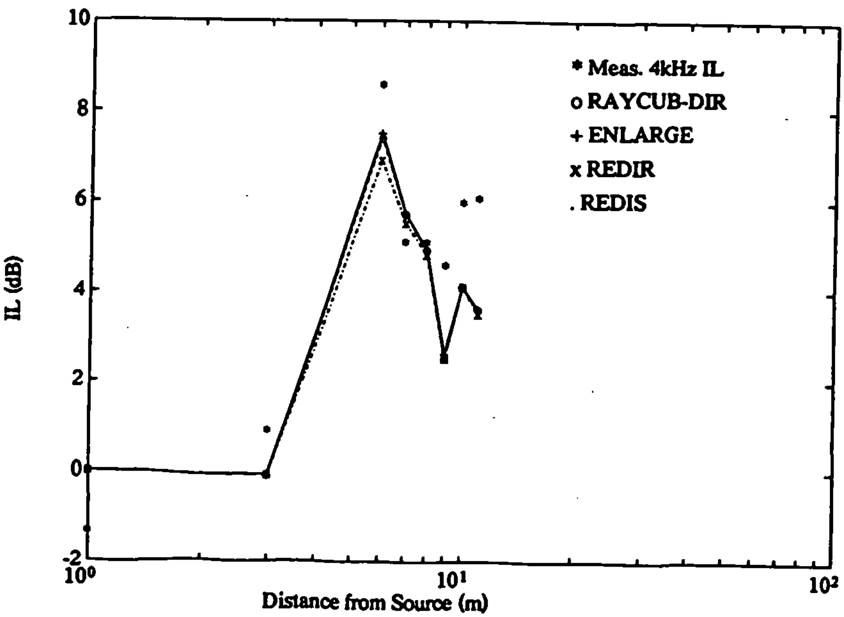

Figure 6.3. Case 2: Measured and Predicted IL curves for the 4kHz Octave Band