**Proceedings of the Institute of Acoustics**

# Noise Control Modelling in Non-Diffuse Enclosed Spaces using an Image Source Model

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## 1. INTRODUCTION.

Noise control methods are used to reduce the noise exposure of workers in an industrial environment. Until now only ray-tracing models, such as the RAYCUB model by Ondet and Barbry[1], were capable of geometrically modelling noise control methods such as acoustic barriers and addition of absorptive material to room surfaces (absorptive patches). However, ray-tracing models have long run-times and may not be of practical use when a comparison of several alternative noise control methods is required.

It has been shown that image-source based models can accurately predict sound distribution in factories[2,3], but due to their limited geometric representation of the space the effect on the sound distribution of noise control methods cannot be predicted. The current image-source factory noise prediction model developed by Lindqvist[4], rewritten by Ondet[5] and extended by Dance[6] used a geometric representation of a parallelepiped shaped space with each of the six surfaces having an associated absorption coefficient. The model did not incorporate any method of representing barriers or absorptive patches.

Barriers have been represented in the image-source model NOISMAP developed by Sergeyev[7] and in NOISE developed by Shield[8] as arbitrarily positioned and totally sound absorbing of the direct sound path only. Kurze[9] developed this further by reradiating the direct sound from the barrier uninterrupted to the receiver positions. Kotarbuiska[10] developed an image-source barrier reflection-diffraction model specifically for flat rooms, that is reflections from walls were ignored. Stehel and Braune[11] briefly detailed an image-source model capable of modelling barriers which could reflect sound from any room surface or barrier in a parallelepiped enclosed space.

The representation of absorptive patches using an image-source model was developed by Gibbs and Jones[12]. Their model was capable of modelling up to one centrally located patch per surface, all patches having the same absorption coefficient, but with varying surface absorption coefficients.

This paper presents a development of the image-source model, CISM, which is capable of modelling the effects on sound distribution of noise control methods. The CISM predictions are compared to those obtained from RAYCUB and its derivatives in two hypothetical cases where absorptive patches are installed, and in a real barrier case.

## 2. THE CISM MODEL

The CISM model[13] has been previously described in detail, so only an brief description will be given here. CISM was developed to be a practical sound distribution prediction tool based on the analysis of the prediction accuracy and representational methods of RAYCUB in both empty and fitted industrial and laboratory spaces[14]. CISM models sound sources as point sources with associated sound power and directivity. The room surfaces each have an associated absorption coefficient. Groups of fittings are modelled as zones near the floor and ceiling or on either side of a gangway, each zone having an average absorption coefficient. The densities of the groups of fittings are represented using the Kuttruff scattering frequency parameter which is dependant on the surface area of the fittings and the volume containing the fittings. Air attenuation is also modelled.

### 2.1 Modelling Absorptive Patches.

CISM has been developed, based on the Gibbs and Jones model, to represent any number of arbitrarily positioned and sized absorptive patches on any room surface. To calculate the effect of an absorptive patch on a single sound path, travelling from a sound source to a receiver, it is necessary to calculate the positions of the image patches which the sound path might cross. This includes the real absorptive patch and all combinations of image patches after a number of reflections in each direction of interest. If the sound path crosses any of the image patches then the reflection coefficient of the patch instead of the reflection coefficient of the surface has to be used in the overall calculation of room surface attenuation.

### 2.2 Modelling Totally Absorptive Barriers

An extension to the patches model allows any number of totally absorptive barriers to be represented, provided each barrier is parallel to a room surface. The additional requirement is a procedure which checks whether the initial image barrier or the real barrier is crossed by the sound path.

## 3. COMPARISON OF THE CISM AND RAYCUB PREDICTIONS.

An investigation using a hypothetical space and a validation using real data were carried out so that the predictions of RAYCUB and CISM could be compared, and the accuracy of the models established. The investigation concerned the modelling of absorptive patches in two configurations of the hypothetical space. The validation of the barrier model consisted of predicting the insertion loss (IL) due to a single barrier in a non-diffuse enclosed space with a sound source in two positions.

### 3.1 Absorptive Patch Predictions

The hypothetical space was 30m long by 8m wide by 3.85m high. The walls were assumed to have an absorption coefficient of 0.1, the floor 0.05 and the ceiling 0.15. The source was assumed to be omni-directional and located 0.85m above the floor in one corner of the room. The receivers were all located at a height of 1.5m along the centre line of the space, 3m apart. The number of reflections was determined using an energy discontinuity percentage of 99%, that is the percentage of energy which should be attenuated before the ray or sound path is terminated.

**Configuration 1.** Each surface had an absorptive patch, centrally positioned, covering one-quarter of its area. Each patch was assumed to have an absorption coefficient equal to the reflection coefficient of the surface on which it was mounted.

**Configuration 2.** The three room surfaces closest to the source were one-quarter covered with absorptive material, the absorption coefficients of the patches being chosen as in Configuration 1.

### Configuration 1 Predictions

Three representations of Configuration 1 were modelled by both CISM and RAYCUB to demonstrate the necessity of absorptive patch modelling, as well as facilitating direct comparison of the models.

| | |
|---|---|
| Representation 1- | used the averaged absorption coefficient of all the surface areas and all the patches, applied to all of the room surfaces. |
| Representation 2- | used the averaged absorption coefficient for each surface |
| Representation 3- | modelled each surface exactly, with two absorption coefficients for the patch and the surface.. |

Three sound propagation (SP) graphs are shown, the CISM predictions for all three representations in Figure 1 and the RAYCUB predictions for all three representations in Figure 2.

As can be seen from Figure 1 the predictions by CISM using Representation 1 and 2 gave very similar sound levels for all of the receiver positions. With Representation 3 the predicted sound level near the sound source was higher than for the other representations, but the levels decreased rapidly in the centre of the space due to the effect of the patches on the side walls, floor and ceiling. The RAYCUB predictions for all three representations gave very similar SP curves to those of CISM, see Figure 2.

A comparison of the predictions by Representation 3 with those of Representations 1 and 2 shows that it is necessary to precisely model both the position and absorption of each patch, in order to predict the effect of the patches on sound propagation.

### Configuration 2 Predictions

As the necessity of modelling patches individually has been established, using Configuration 1, Configuration 2 was intended to demonstrate that it is possible to predict the effectiveness of a typical noise control technique.

Figure 3 shows the SP predicted using both CISM and RAYCUB with Representation 3. As can been seen there was a 3dB drop in the predicted sound level by both models compared to the Configuration 1 predictions for the nearest receiver point to the sound source. The SP curves diverged with increasing distance from the sound source until at the furthest receiver point there was a 4dB difference, the RAYCUB model producing the more attenuated curve. At this stage it is unclear as to which model was producing the most realistic SP curve.

### 3.2 Barrier Predictions

An empty factory space containing a barrier was used to compare the predictions of three models: CISM, RAYCUB-DIR and REDIR.

RAYCUB-DIR is an enhanced version of RAYCUB[14] which includes a source directivity model and run-time and representation optimisations. REDIR[16] is an extension to RAYCUB-DIR which includes a barrier diffraction model based on a simplified implementation of the geometric theory of diffraction. The models predicted the insertion loss (IL) due to the barrier at increasing distance from the sound source. The predicted IL was compared to the measured value at each position.

### The Test Space and Measurements

Sound measurements were taken in a enclosed empty factory space by Jones[15]. The space was 56m long, 36m wide and 8.6m high rising to a central apex of 10.6m. The walls were constructed of brick, the ceiling was cladded and the floor was made of concrete. A free-standing barrier of dimensions 0.1m x 2.7m x 2.4m (high) was positioned away from the walls in the space. The measured absorption coefficients of the barrier were 0.4 at 125Hz, approximately 0.95 between 250Hz and 1kHz, and 0.8 at 2kHz and above.

Sound measurements, in the form of SP curves, both with and without the barrier present were made for the octave bands 125Hz to 4kHz. The sound 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 beyond the barrier.

### The Barrier Model Validation

Table 1 shows the logarithmically averaged IL prediction differences (dB), (predicted minus measured IL), for each octave band 125Hz to 4kHz. Figures 4-6 show the measured and predicted IL curves for the 125Hz, 1kHz and 4kHz octave bands, respectively.

TABLE 1

*The averaged IL prediction differences for the Barrier Validation.*

| 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 |
| CISM | 1.84 | 3.28 | 2.85 | 4.04 | 2.51 | 0.90 |

CISM over-estimates the IL directly behind the barrier, for the octave bands up to 1kHz, but as the distance from the sound source increases the accuracy of the prediction improves. The former effect was caused by the barrier being modelled as totally sound absorbing. Also diffraction effects around the edge of the free standing barrier which would increase the sound levels on the far side of the barrier were not included in the model. The effect of the barrier on insertion loss reduces with increasing distance from the barrier, as the sound reflected from room surfaces dominates the sound field in this region, which the model has previously been shown to accurately predict.

For the higher frequencies the shape of the predicted IL curve and IL values were much closer for all the receiver points, see Figure 6, due to the diffraction effects lessening at these frequencies.

Although CISM is less representative than RAYCUB-DIR it produced more accurate predictions. This seems to indicate that a basic image-source method of modelling is considerably more accurate than that of ray-tracing when diffraction effects are ignored. However, the ray-tracing model REDIR which included a diffraction approximation and was geometrically representative produced the most accurate predictions. The data preparation and the prediction times for the CISM model were approximately one-tenth of the times required for either of the other models.

## 4. CONCLUSIONS.

An image-source model which has been shown previously to accurately predict sound distribution in empty and fitted laboratory and industrial spaces has been extended, enabling the effectiveness of noise control methods to be evaluated. The noise control methods investigated here were additional absorption on room surfaces, and absorbent acoustic barriers.

An investigation of a hypothetical case using the RAYCUB model showed that representing patches using an averaged absorption coefficient either for the entire room or for each surface produced almost identical predictions. These were significantly different from the predictons using a model where each patch was accurately represented. The CISM model predictions using three different representations showed almost identical results to those of RAYCUB. However, when modelling strategically positioned absorptive patches the predicted sound propagation curves of RAYCUB and CISM diverged with increasing distance from the sound source. Further investigation is required to established which model, if either, is correct.

A barrier validation of CISM in an empty factory space showed insertion loss propagation predictions in the octave bands 125Hz to 4kHz, to be slightly more accurate on average than those of RAYCUB-DIR. This was unexpected because the space in itself was of a complex nature and hence other approximations were involved. However, REDIR was more accurate because it could attempt to model diffraction whereas CISM could not.

CISM has been shown to be an accurate model capable of modelling complex factory spaces which have been treated using noise control methods. The barrier noise control predictions were more accurate and produced in a fraction of the time of those produced by the basic ray-tracing model.

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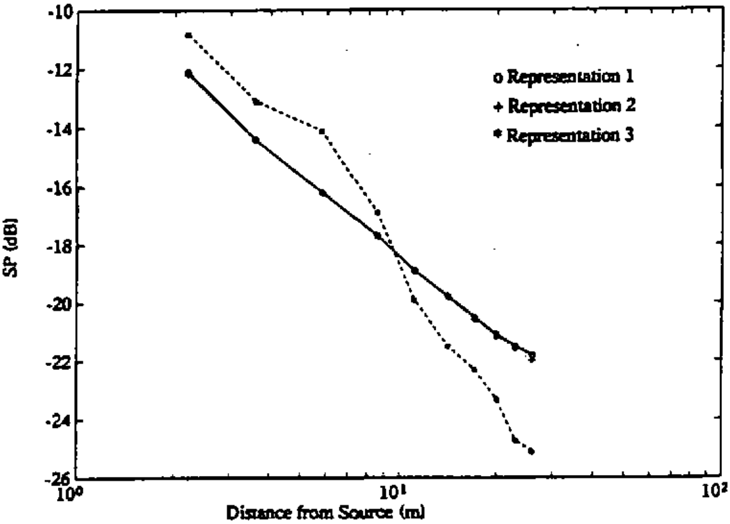

Figure 1. CISM Predicted Sound Propagation for Configuration 1

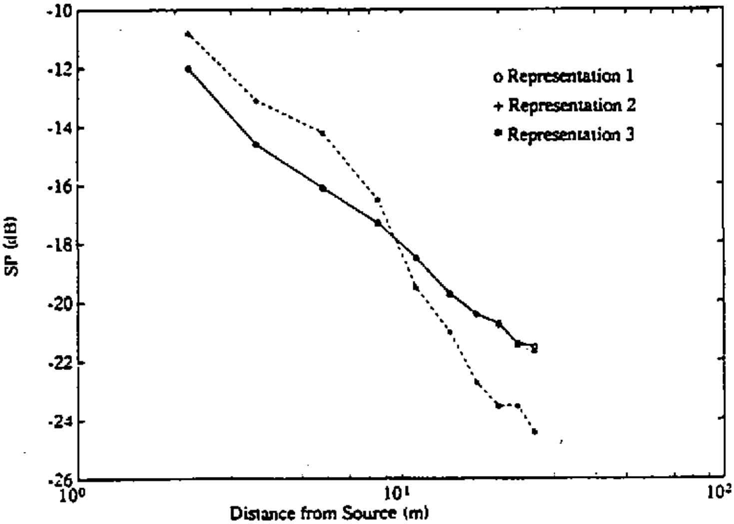

Figure 2. RAYCUB Predicted Sound Propagation for Configuration 1

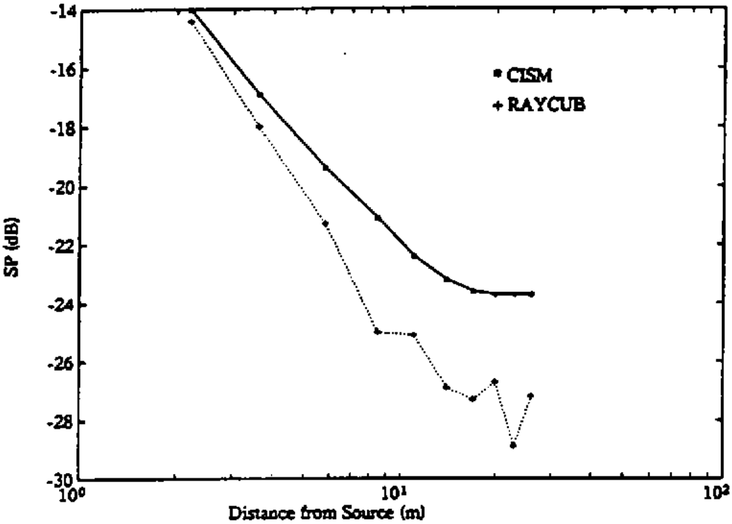

Figure 3. Predicted Sound Propagation for Configuration 2, using Representation 3

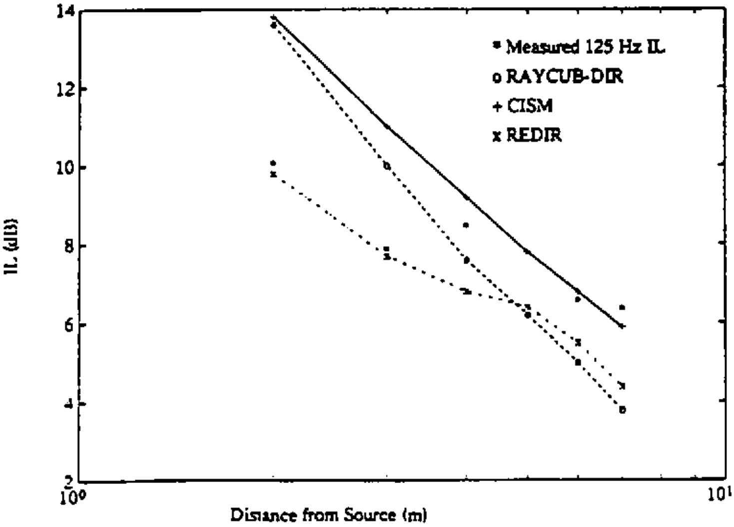

Figure 4. Measured and Predicted IL curves for the Barrier Validation, 125 Hz

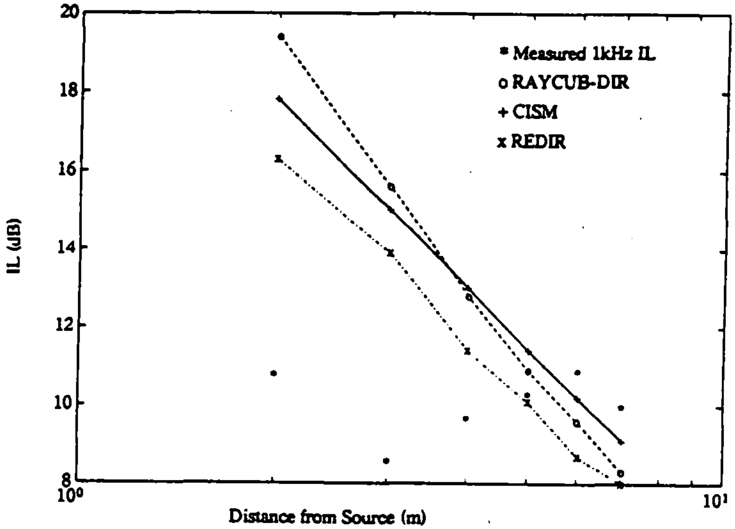

Figure 5. Measured and Predicted IL curves for the Barrier Validation, 1kHz

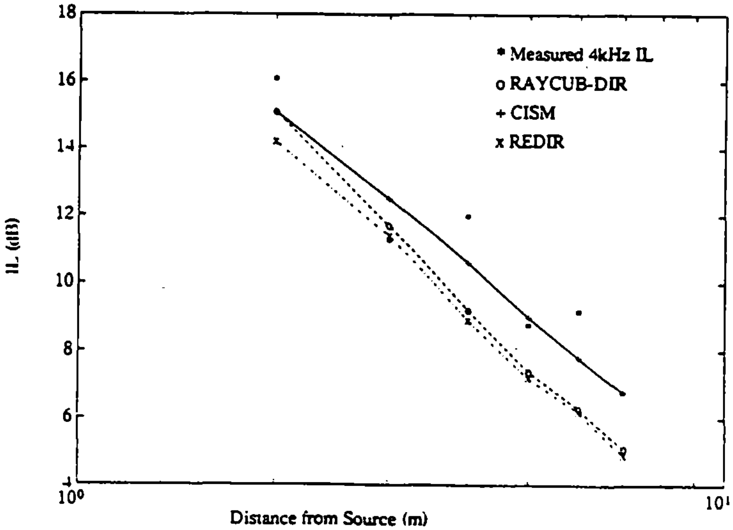

Figure 6. Measured and Predicted IL curves for the Barrier Validation, 4 kHz