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Bradley, J. S.

Publisher’s version / Version de l'éditeur:

Proceedings of Inter-Noise '81: Practice of Noise Control Engineering: 06 October 1981, Amsterdam, The Netherlands, 1, pp. 221-224, 1981

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NRCC-36886

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October 1981

A version of this document is published in / Une version de ce document se trouve dans:
Proceedings of Inter-Noise '81 : Practice of Noise Control Engineering
Amsterdam, The Netherlands, October 6-8, 1981, pp. 221-224

inter·noise 81

SOUND DECAYS IN RECTANGULAR ROOMS

J.S. Bradley

Division of Building Research
National Research Council of Canada
Ottawa, Canada, K1A 0R6

Measured reverberant sound decays are frequently used in noise control calculations that are based on the assumption of diffuse field conditions. Diffuse field theory suggests that decays plotted in terms of decibels versus time should be linear and related to the absorbing properties of the room.[1] It is known that in many real situations measured decays deviate from these simple expectations. The present work is concerned with the effect of two conditions for which ideal diffusion would not be expected in rectangular rooms: the effect of an absorbing surface, and the effect of varying room ratios. Initially, decays were computed using a computer model based on an image sources approach. A simpler composite decay curve technique was then devised that agreed well with the computed decays. Finally, measured decays were obtained to demonstrate the validity of the computed results.

IMAGE SOURCES COMPUTER MODEL

For rectangular rooms it is quite simple to calculate the magnitude and arrival time of individual reflections using the method of image sources.[2] Each image source in a cell of the lattice of image rooms represents a particular reflection. Although the technique is well known, it is necessary to compute an extremely large number of reflections in considering a complete 60 dB decay in a typical reverberation chamber (85 million reflections were needed for one 4 s decay). The computer program accommodated the large number of reflections by adding the energy of each reflection into one of 20 sums representing 20 time intervals in the decay. Thus it was only necessary to store 20 numbers representing a decay and not the details of each reflection. The computer program could also be interrupted and restarted without loss of data whenever computer time was available. The image sources technique assumes specular reflections; where more diffuse reflections occur it would not be appropriate.

Decays were first computed for a room corresponding to the large NRC reverberation chamber (7.98 m x 6.48 m x 4.88 m) with varying amounts of absorption on one surface. Curved decays were produced that differed increasingly from an Eyring-type prediction as more absorption was added. Fig. 1 shows an example in which $\alpha = 0.25$ for the absorbing surface and $\alpha = 0.025$ for the other surfaces. Even for no added absorption the computed decay was not perfectly linear and indicated a longer reverberation time than would the associated Eyring reverberation time (Fig. 2).

Initial experiments with room ratios were made by varying only one dimension. As one dimension of the room was made longer than the others, the decays became increasingly more curved and the associated reverberation times increasingly greater than those obtained from the Eyring formula. Fig. 3 gives an example for a room 14.69 m x 6.48 m x 4.88 m. From a large number of computed decays it appeared that the particular decay shape was unique to the particular conditions for which it was derived.

COMPOSITE DECAY CURVE TECHNIQUE

As up to two or more weeks of computer time were required to compute decays using the image sources computer model, it was clearly not a practical means of estimating the expected decay curves. A composite decay curve model was therefore derived that was computationally simpler and produced decays in close agreement with the image source computer model results. The composite decay model assumed a transition from a three-dimensional to a two-dimensional and, finally, to a one-dimensional decay process. The least rapidly decaying process was assumed to predominate at a given point in the decay. One can calculate a decay envelope of the sound intensity I as a function of time as:

$$I(t) = dN/dt \cdot \bar{I}(t)$$

where dN/dt is the rate of arrival of reflections and $\bar{I}(t)$ is the mean intensity of a reflection at time t. As shown by Bolt et al.,[2] in a rectangular room

$$I(t) = (4\pi c/V)\ (1 - \bar{\alpha})^{ctS/4V} \tag{1}$$

where c = speed of sound, V = room volume, S = room surface area. It may similarly be shown for two-dimensional and one-dimensional enclosures respectively that

$$I(t) = (2\pi/(At))\ \ (1 - \bar{\alpha})^{ctp/\pi A} \tag{2}$$

where A = area of the enclosure, p = perimeter.

$$I(t) = (2/(c\ \ell\ t^2))\ (1 - \bar{\alpha})^{ct/\ell} \tag{3}$$

where ℓ is the length of the enclosure. The decay can be described initially as a three-dimensional process, as given by Eq. 1, and then as a two-dimensional, and ultimately as a one-dimensional process. The over-all composite decay curve is formed by selecting the least rapidly decaying process at each point.

Composite decay curves calculated in this way were found to agree well with the decays computed using the image sources model (Fig. 1, 2 and 3). Families of calculated composite decay curves were readily derived to demonstrate the effects of room ratios and the addition of an absorbing surface.

MEASURED DECAYS

Measurements were made in a model reverberation chamber with dimensions exactly 40% of those of the large chamber mentioned earlier. Each measured decay presented here is the average of 10 decays, each at five different microphone positions. For situations where the model behaved as a perfectly rectangular room in which sound reflected specularly, good agreement was obtained with the calculated composite decay curves. Fig. 4 illustrates the measured and calculated decays for the model room with one absorbing wall. Similar agreement was achieved when room ratios in the model chamber were varied. The bare room had a measured absorption coefficient of 0.05, and the 1.96 m x 2.59 m absorption covered surface had a measured absorption coefficient of 0.39 at 2500 Hz. Where the walls were not perfectly flat and parallel or where more diffuse reflections occurred, agreement between measured decays and composite decay curves broke down and measured decays tended to be in closer agreement with Eyring-type predictions.

APPLICATIONS

When decay curves are not linear but curved, it is often confusing to consider only a reverberation time based on a linear fit to a particular portion of the decay. The composite decay curve procedure provides a relatively simple method of predicting the complete decay curve. Measured decays will probably only follow the composite decay curve when there is very little diffusion in the decay process. One should probably regard the Eyring decay and the composite decay curves as the bounds between which real decays will occur, with the measured decays more closely agreeing with the Eyring decay when more diffuse reflections exist.

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(1) C.W. Eyring, "Reverberation Time in 'Dead' Rooms," J. Acoust. Soc. Am, 1, 217-234 (1930).

(2) R.H. Bolt, P.E. Doak, and P.J. Westervelt, "Pulse Statistics Analysis of Room Accoustics," J. Acoust. Soc. Am., 22, 328-340 (1950).

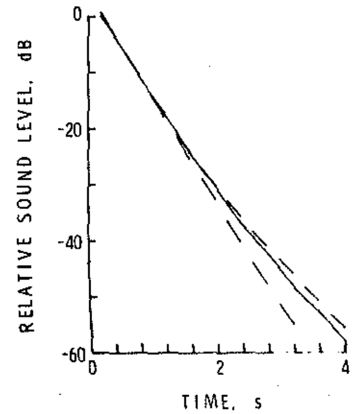

Figure 1 Comparison of image sources (solid line) composite decay curve (upper dashed line), and Eyring decay with one absorbing wall

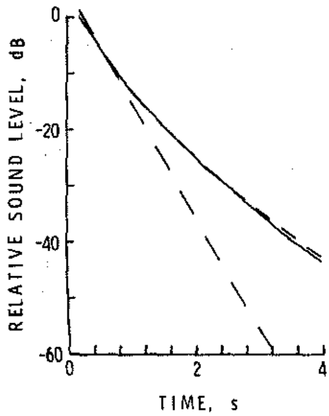

Figure 2 Comparison of image sources (solid line), composite decay curve (upper dashed line), and Eyring decay, for a bare reverberant room (2 = 0.05)

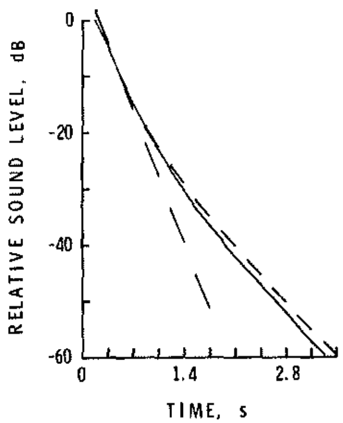

Figure 3 Comparison of image sources (solid line), composite decay curve (upper dashed line), and Eyring decay with increased room ratios

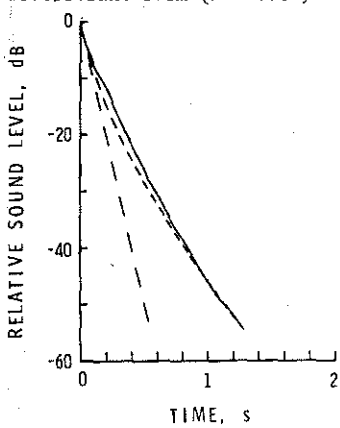

Figure 4 Comparison of measured decay (solid line), composite decay curve (upper dashed line) and Eyring decay for case of one absorbing wall

This paper is a contribution from the Division of Building Research, National Research Council of Canada and is published with the approval of the Director of the Division.