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A SIMPLE COMPUTER MODEL OF THE ACOUSTIC TRANSIENT RESPONSE OF A RECTANGULAR ENCLOSURE

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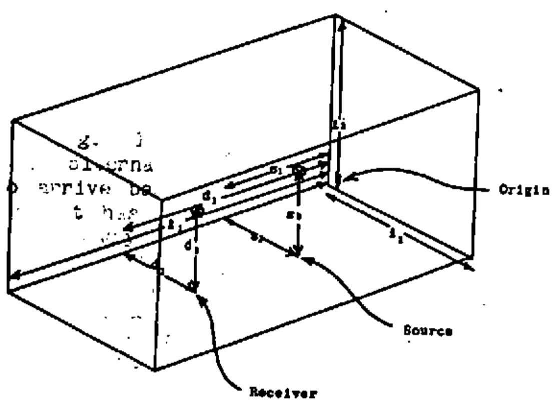
INTRODUCTION

To a first approximation, the linear dimensions of the walls of most halls are considerably greater than the wavelength of the sound in the middle to upper frequency range where the transient response of the hall is most critical. It is therefore valid to consider reflection in terms of an image source as the wall approximates to an infinite reflecting plane. Moreover, because the total distance travelled by such reflections between source and receiver is many times the wavelength, such image sources may be regarded as incoherent. For simplicity of analysis, a gaussian pulse is assumed to emanate from a point, monopole source and all effects of air absorption have been neglected.

THE ADDITION OF MULTIPLE IMPULSE REFLECTIONS

Figure 1 depicts a source and receiver in a rectangular enclosure with co-ordinates defined as shown. The (ijk) reflection is then defined as that which arises from i,j,k reflections from walls perpendicular to l_1, l_2, l_3 having absorption coefficients α_1, α_2, α_3 respectively. Such a reflection can then be regarded as being due to an image source distant x_{ijk} from the receiver.

Figure 1



It has already been shown [1] that

$x^2_{ijk} = F_1^2(i) + F_2^2(j) + F_3^2(k)$ where

$F_1(i) = (i - 1)l_1 + s_1 + d_1$ (i odd)

$= il_1 + d_1 - s_1$ (i even)

and similarly for

$F_2(j), F_3(k)$ (1)

The delay caused by travel over this distance will be x_{ijk}/c and the magnitude of the peak intensity will be reduced by a factor of x^2_{ijk} for a point source and also by each reflection from an imperfect reflector according to the factor

$$(1 - \alpha_1)^{|i|} (1 - \alpha_2)^{|j|} (1 - \alpha_3)^{|k|}$$

The gaussian pulse, at distance x from the source is described by

$$I(x,t) = \frac{I_o}{x^2} \exp\left(-\frac{(t - t)^2}{2\sigma^2}\right) \qquad (2)$$

where I_o is the peak pulse intensity at unit distance from the source and t is the time at which the pulse reaches its maximum intensity. By setting t = 0 when x = 0,

$$t_{ijk} = \frac{x_{ijk}}{c}$$

Thus the intensity of the ijkth reflection varies with time according to the expression

$$I_{ijk}(t) = \frac{I_o}{x^2_{ijk}} (1 - \alpha_1)^{|i|} (1 - \alpha_2)^{|j|} (1 - \alpha_3)^{|k|} \exp\left\{\frac{-(t - x_{ijk}/c)^2}{2\sigma^2}\right\} \qquad (3)$$

and the total effect of all image sources is given by

$$I_T(t) = \sum_{\substack{i=0 \\ j=0 \\ k=0}}^{\infty} I_{ijk}(t) \qquad (4)$$

For convenience $I_T(t)$ is expressed as a level on a relative dB scale, L_{dB}, using the expression

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$$L_{dB} = 10 \log_{10} (10^6 I_T(t)/I_D) \tag{5}$$

where I_D is the peak intensity of sound travelling directly from source to receiver.

In this way, $L_{dB} = 0$ corresponds approximately to t = reverberation time of the enclosure.

The parameter σ may be used to scale the length of the pulse.

COMPUTATIONAL RESULTS

The summation (equation 4) can only be achieved over a finite number of terms and in this case values of i,j,k from -5 to 5 are used, resulting in 1330 image sources.

Of particular interest in the design of a hall is the variation in transient response as a function of receiver, or audience, position within the hall. For an enclosure of dimensions 30 m long x 20 m wide x 20 m high, the response to a pulse having $\sigma = 5 \times 10^{-4}$ s where both source and receiver are located on the long centre line of the floor, the effects of increasing source- receiver separation are shown in Figures 2 - 4 for an absorption coefficient of 0.2. Figure 5 shows the effect of changes in absorption coefficient upon the response to a longer pulse of $\sigma = 2 \times 10^{-3}$ s in the same enclosure. It is clear that increasing the absorption of the walls can lead to a more irregular decay profile.

This approach to transient response is capable of elaboration in that differing absorption coefficients on each wall or parts of a wall could be accommodated. Departures from rectangular symmetry, whilst possible in principle, would greatly complicate the location of image sources.

REFERENCES

1. D M Allen-Booth and G J McNulty, 1983. Mathematics and Computers in Simulation XXV 229-231. Computer Simulation of Acoustic Intensity in a Rectangular Enclosure.

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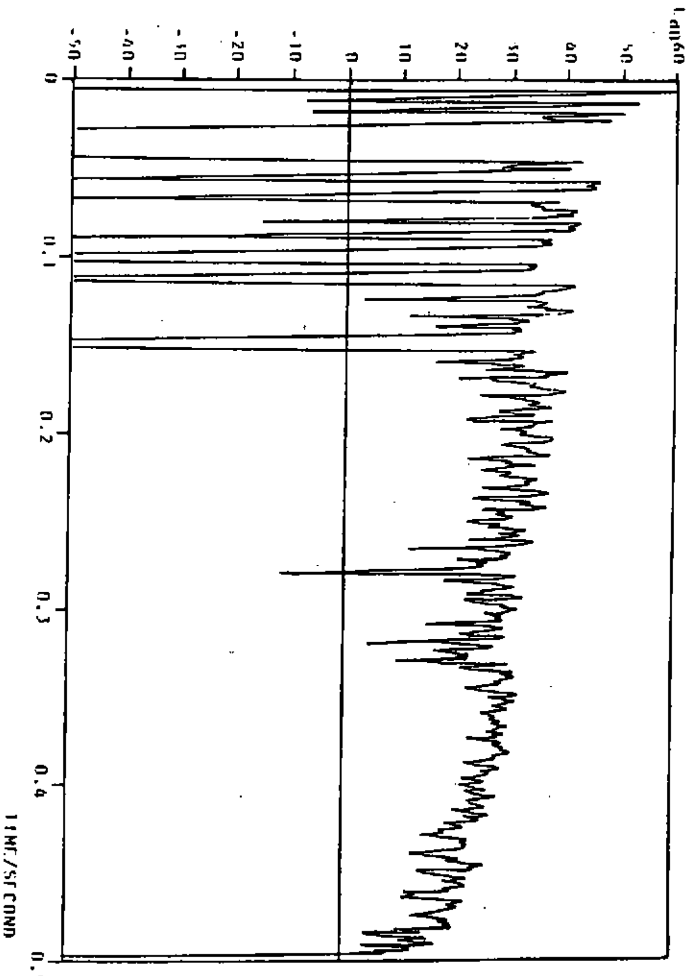


FIGURE 2

IMPULSE TRANSIENT RESPONSE FOR A SOURCE-RECEIVER SEPARATION = 3 m

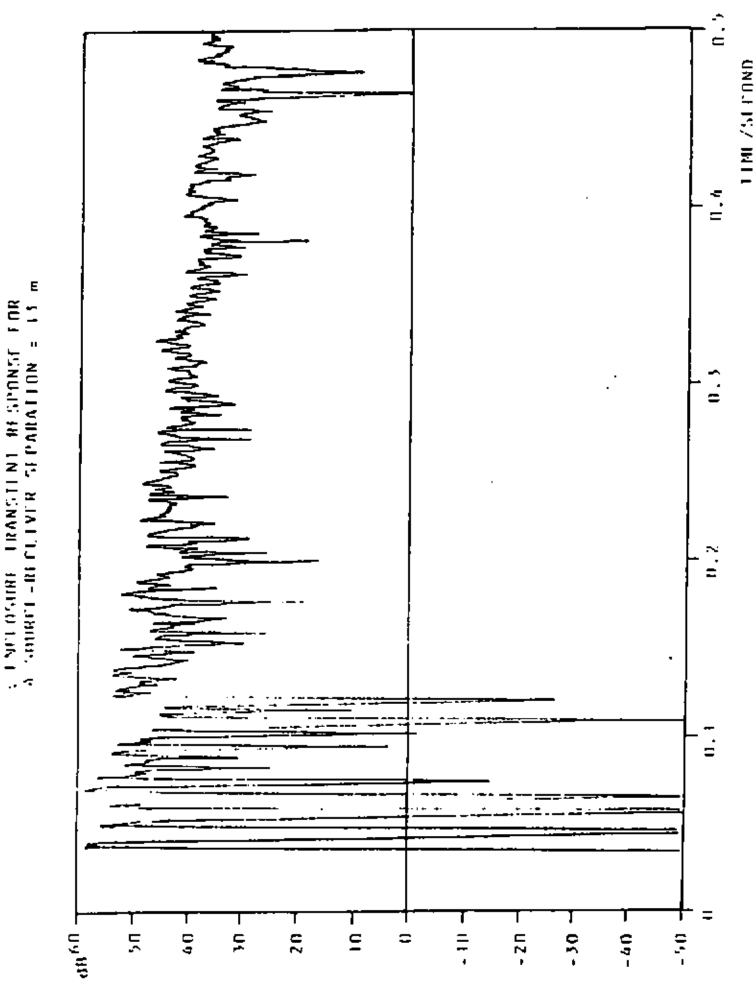
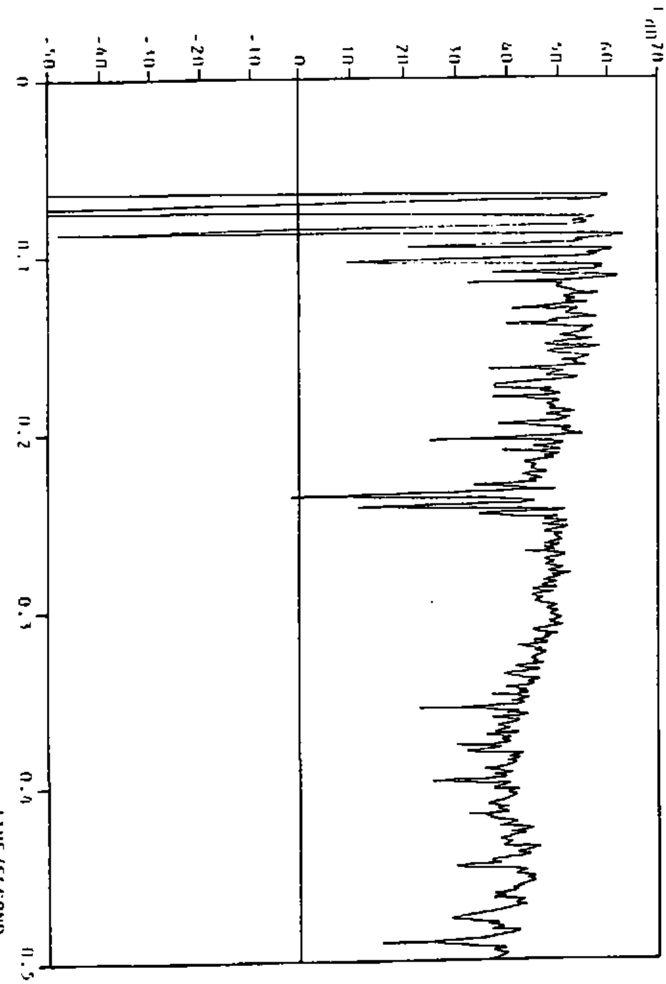


FIGURE 5



ENCLOSURE TRANSIENT RESPONSE FOR A SOURCE-RECEIVER SEPARATION = 23 m

FIGURE 6

EFFECT OF ABSORPTION COEFFICIENT UPON THE TRANSIENT RESPONSE OF AN ENCLOSURE

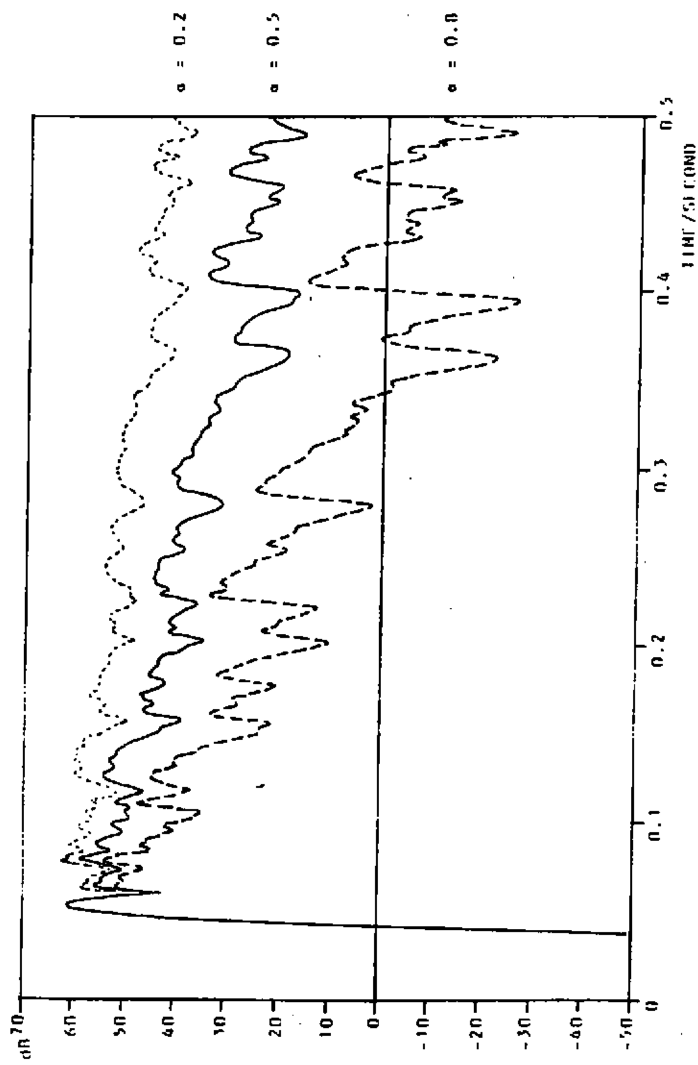


FIGURE 4

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