

SCALE-MODEL EVALUATION OF THE PERFORMANCE OF SUSPENDED BAFFLE ARRAYS IN TYPICAL FACTORY SOUND FIELDS

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1. Introduction

Sound fields in industrial buildings are often controlled by the installation of arrays of baffles (rectangular pieces of sound-absorptive material) suspended from the building roof. Several researchers have measured the performance, in particular the absorption coefficient, of baffle arrays in reverberation rooms - that is, in a diffuse sound field. Unfortunately, the sound fields in most industrial buildings are non-diffuse for reasons related to the room shape, surface absorption and the presence of fittings (machines, stockpiles and other obstacles in the room). The performance of absorptive materials in a non-diffuse sound field may be very different from that in a diffuse sound field. In order to determine the performance of baffles in non-diffuse fields such as those found in typical factories, reverberation times and steady-state sound pressure levels were measured in a 1:8 scale model with variable dimensions, and containing various arrays of baffles. The experimental results were then predicted using a ray-tracing model, with the input parameters describing the baffle array varied in order to obtain a best fit. In this report, the results for the preliminary series of tests are described and summarized, with emphasis on the experimental work.

2. Scale model

The 1:8 scale model of an idealized typical industrial workroom was built. In its various factory configurations it had a length of 30 mFS (FS = full-scale equivalent value), a width of 15 mFS and variable height (5, 10, 15 mFS). A second configuration, with dimensions of 15 mFS cube was also tested to simulate reverberation-room tests with a diffuse sound field. The floor of the model was made of painted concrete. Its walls were made of varnished 12 mm plywood. Its roofs were of varnished 3 mm plywood. The average absorption coefficient of these surfaces was about 0.06 at all test frequencies, values typical of real factories at all but the lowest frequencies. In its factory configurations two roofs were used; one was flat, the other singly pitched with a 1:3 slope and the roof apex parallel to the long dimension of the model. The model was tested when both empty and fitted with 12 2mFS-cube varnished wood boxes located randomly over the floor area. In its reverberation-room configuration the model always contained 6 of these boxes located on the floor to promote sound-field diffuseness.

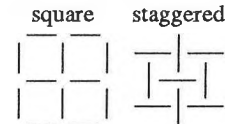
3. Measurements made

Measurements were made of sound decay / reverberation time and of sound propagation (the variation with distance of the difference between the sound pressure level and the source sound power level) in third-octave bands from 800-20000 Hz (100-2500 HzFS). The sound source was a 75 mm diameter tweeter loudspeaker. For sound propagation testing a rigid cone narrowing from 75 mm to 3 mm was attached to the tweeter. This resulted in a compact source which was omnidirectional even at the highest test frequencies. Its constant output sound power was measured in an anechoic chamber. A B+K 4135 1/4" microphone was used as the receiver. In each test, sound decays were measured at 4 source/receiver positions and the results averaged. For sound propagation testing the source was located 5 mFS from one end wall, at half width and at a height of 1 mFS. The receiver was at half width and at a height of 1.5 mFS; sound pressure levels were measured at source/receiver distances of 1, 2, 5, 10, 15, 20, 25 mFS. Octave-band sound propagation values were derived from the third-octave

results. Measurements were made using a Nortronics 830 real-time analyser. The temperature and relative humidity were measured for each test in order to determine the applicable air absorption.

4. Baffles and baffle arrays

Scale-model baffles were made from 6 mm (48 mmFS) thick Armstrong AF530 mineral wool. The absorption coefficient of this material was measured in a full-scale reverberation room to increase monotonically from 0.27 to 0.76 over the test frequency range. This is reasonably close to the absorption of typical unfaced full-scale baffles. The baffles had dimensions of either 1.2 x 1.2 mFS or 1.2 x 0.6 mFS. Arrays of baffles were assembled, by stringing the baffles on wires, using two baffle patterns, referred to as 'square' and 'staggered' as illustrated below:



Four densities of baffles were tested; these are referred to as 1/4, 1/2, 1/1 and 2/1. For example, 1/2 indicates that the array contained 1 mFS² of baffle material per 2 mFS² of roof area. In both the flat and pitched-roof cases, the top surface of the baffle array was in the same horizontal plane as the tops of the side walls.

5. Test configurations

Measurements were made for configurations corresponding to various combinations of the variable model, baffle and array parameters. The configurations corresponded to variations of at most one parameter from a reference configuration. The test-parameter values were as follows, with those constituting the reference configuration in bold characters: Roof shape: flat, pitched; Roof height: 5, 10, 15 mFS; Baffle dimensions: **1.2 mFS high x 1.2 mFS wide**, 1.2 mFS high x 0.6 mFS wide, 0.6 mFS high x 1.2 mFS wide; Baffle pattern: square, staggered; Baffle density: 1/4, 1/2, 1/1, 2/1. In each case the model was tested when both empty and fitted.

First, reverberation times were measured in the model without baffle arrays, and with each test baffle array, in its reverberation-room configuration. These results were used to determine the 'approximate-diffuse-field' absorption coefficients of the varnished-wood model surfaces and of each baffle array. Secondly, reverberation times and sound propagation levels were measured in each test configuration in order to determine how these variables varied with each of the above model and baffle parameters, and how this differed in the empty and fitted cases.

6. Results

The experimental results reveal many complicated phenomena. Following are the main preliminary conclusions suggested by these results. Space limitations prohibit more than one result from being illustrated.

General comments - It was generally found that trends were easier to discern at middle and high frequencies, and in the fitted cases. At low frequencies wave effects result in complicated trends. Fittings have the effect of diffusing the sound field, resulting in more regular trends. It was clear that the effect of the introduction

of baffles on the sound field is generally different in the empty and fitted room, different in a diffuse field and in a non-diffuse field and strongly dependent on frequency. Of considerable interest is the fact that its effect was generally different for reverberation time and for sound propagation.

Baffle density - Fig. 1 shows the variation of measured reverberation times with baffle density in the fitted 5 mFS-high flat-roof model with 1.2 x 1.2 mFS baffles in a square pattern. Figure 2 shows the corresponding sound propagation result for the 1000 HzFS octave band. Introduction of the lowest density of baffles into the empty or fitted model significantly reduced the reverberation time. Doubling the density had a similar effect. However, subsequent density increases either were ineffective or, in the empty model at mid frequencies, increased reverberation times. Increasing the baffle density generally resulted in lower sound propagation levels at all frequencies and source/receiver distances.

Room height - As expected, increasing the height of the roof and its suspended baffle array resulted in higher reverberation times, whether the room is empty or fitted. Regarding sound propagation, levels tend to decrease, as expected, by up to a total of 3 dB. However, in most cases levels increase at large source/receiver distances. This suggests that the baffle arrays are acting not only to increase the absorption of the ceiling, but also as a fitted layer.

Roof shape - Roof shape had little effect on the reverberation time and sound propagation levels.

Baffle pattern - Baffle pattern had little effect on the reverberation time and sound propagation levels.

Baffle dimension - Baffle dimension had a small effect on the results. 1.2 mFS square baffles generally resulted the lowest reverberation times and sound propagation levels. 1.2 mFS high x 0.6 mFS wide baffles generally resulted in the highest values.

7. Prediction work

The prediction phase of the work involved modelling each test configuration using ray-tracing techniques and predicting the octave-band reverberation times and sound propagation levels. Baffle arrays were modelled by increasing the absorption coefficient of the ceiling. The known prediction parameters (dimensions, source and receiver positions, non-baffle-surface absorption coefficients, fitting density and absorption coefficients, air absorption exponents) were input. The unknown ceiling/baffle absorption coefficients were varied until a best fit with the experimental results was obtained. This established the effective absorption coefficient of the array for that configuration. In general measured sound propagation levels were thus predicted to within ± 2 dB, reverberation times very closely. As an example, Table 1 shows the best-fit coefficients for the empty and fitted flat-roof model with 1.2 mFS-square baffles with 1/2 density in a square pattern, for the three test roof heights - 5, 10 and 15 mFS. Also shown are the best-fit 'approximate-diffuse-field' coefficients determined from reverberation time measurements in the cubic model using the Eyring theory. The non-diffuse coefficients may be significantly lower or higher than the diffuse values. In general, and ignoring many interesting effects, the coefficients are higher for reverberation time than for sound propagation. They also tend to be higher in the fitted model. They tend to decrease with increasing roof height.

Table 1 - Best-fit baffle-array absorption coefficients (see text for details)

Case	Roof height	Reverberation time					Sound propagation				
		125	250	500	1000	2000	125	250	500	1000	2000
Eyring		0.28	0.28	0.20	0.51	0.61	0.28	0.28	0.20	0.51	0.61
Empty	5	0.37	0.42	0.34	0.67	0.82	0.39	0.28	0.27	0.39	0.38
	10	0.23	0.14	0.17	0.34	0.37	0.16	0.09	0.17	0.50	0.15
	15	0.18	0.13	0.18	0.33	0.15	0.18	0.13	0.18	0.33	0.15
Fitted	5	0.37	0.42	0.49	0.67	0.82	0.38	0.31	0.30	0.42	0.44
	10	0.33	0.34	0.42	0.55	0.58	0.34	0.25	0.31	0.30	0.17
	15	0.28	0.33	0.44	0.58	0.62	0.29	0.20	0.21	0.37	0.16

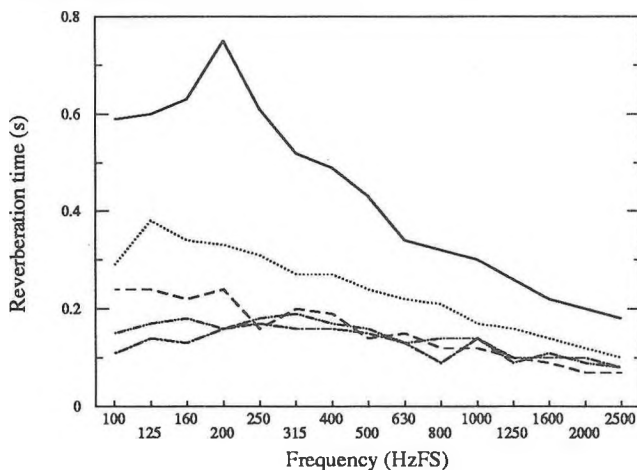


Fig. 1

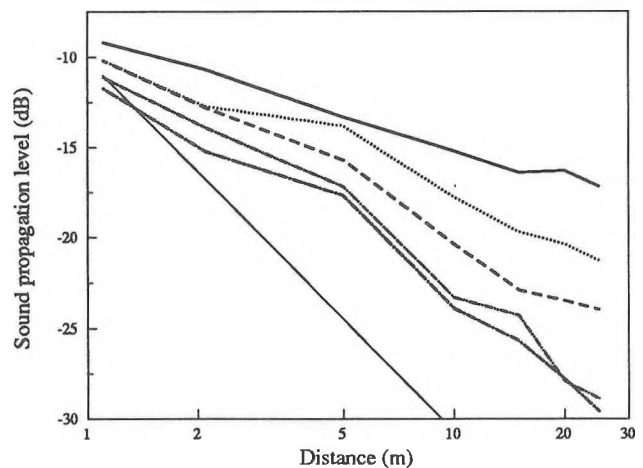


Fig. 2

Variation of measured reverberation time (Fig. 1) and 1000 HzFS octave-band sound propagation (Fig. 2) with baffle density (see text for details): (—) free field; (.....) no baffles; (.....) 1/4; (---) 1/2; (-.-.-) 1/1; (---) 2/1.