On the acoustic effect of screens and perforated facings

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ABSTRACT

This paper presents a discussion on the acoustical effects on absorptive treatments located behind visual screens and perforated facings. All facings will have some acoustic effect. It is desirable to know what effect a facing may have. It may not be significant at the frequencies of interest, that is, acoustically transparent, or it may not be insignificant. This paper discusses some prediction methodologies for both visual screens and perforated facings and compares outcomes with reported measurements. It concludes with some questions which at present (to this author) remain unanswered.

1 INTRODUCTION

When there is a screen or perforated facing in front of acoustic treatment, there will be some change to the effective absorption coefficients of the acoustic fibre or treatment which is located behind the facing. There is a very large amount of theoretical information and measured data available for acoustic treatment with perforated and other partially acoustically open facings. Most of the information available relates to facings which have relatively small open areas and generally less than 25% open. It is often stated that perforated or slotted facings which are more that 20%-25% open have negligible effect on the absorptive ability of the acoustic treatment located behind facing. What if a space, such as that shown in Figure 1, has large areas of acoustic treatments which are faced with relatively open screens comprising relatively wide linear elements? Are there any significant changes to the absorption values affecting the prediction of reverberation times in the space? This paper considers a methodology to predict the effect on the acoustic treatment located behind facings or screens which may have open areas much greater than 25%. It also considers what limits there should be placed on the methodology.

Source: (Woodhead International, 2004. Private communication)
Figure 1: Shandong Convention Centre

2 OVERVIEW

When a sound wave is incident on a screen comprised of solid elements and openings between solid elements, some energy will be reflected or scattered, and some will pass through. Because of the wave nature of sound, the amount of energy transmitted is frequency dependent. Very broadly, wavelengths that are long compared with the dimension of the solid elements of the screen, wrap around the elements and continue through with almost no reflection and the screen is considered to be acoustically open. With very very small wavelengths compared with the dimensions of the solid elements, most of the energy that impinges on the facing is reflected and the absorption coefficient of the treatment is significantly reduced, approaching the open area of the facing.

For example, consider 1m x1m area of acoustically absorbent material. A facing comprising 2mm wide 1000m long solid strips spaced 2mm apart across the full face is 50% open and we probably assume that there would be little change to the absorption coefficients. However if there was one central strip 500 mm wide 1000 mm high, it is 50% open but there would be significant reduction (up to 50%) in the absorptive treatment affecting the room acoustic. Where the dimensions of the screen elements are such that the wavelengths at the frequencies of interest are between these extremes, some analysis is required to determine how much of the energy flows past the screen or facing to reach the absorptive material.

3 ACCESS FACTOR

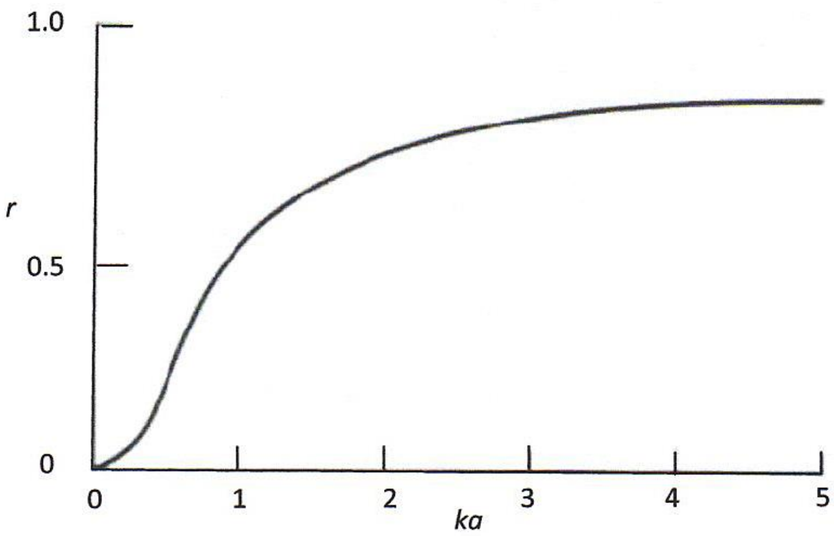
Schultz (Schultz:1986) introduced the concept of an access factor (AF) in relation to perforated metals. This approach is based on measured attenuation of various perforated metals at high frequency and resultant published charts of attenuation vs frequency and AF vs frequency for particular combinations of perforation patterns. The AF is the proportion of acoustic power impinging on the total area of the screen or facing being considered that continues past the facing. The higher the access factor, the lower the degradation of the acoustic absorption of the treated area compared with the situation where no screen is present. While this approach is not directly relevant to the discussion in this paper, AF has been used as a relevant parameter.

Consider an element of a screen which is L long by d wide. If we can determine the proportion of energy incident on that element that is reflected and/or scattered back into the room, and repeat this assessment for all the different solid elements comprising the screen, then we can assess the total power flowing past the screen compared with that incident on the total screen area, giving the AF.

4 SCATTERING FROM A SOLID ELEMENT

The prediction of total sound power scattered from a rigid cylinder with radius a per unit length is presented in section 8.1 (Morse and Ingard:1968). The results of this analysis have been used in this paper to predict the reflected energy from screen elements that have a face dimension $d = 2a$. In the analysis, the authors considered an incident beam which is twice as wide as the cylinder, that is extending a or $d/2$ each side of the cylinder.

Although the equations presented in the text are not easily manipulated, the resultant graph of total power scattered per unit length as a proportion of the total power incident on the rod per unit length is plotted against the parameter ka where k is the wavenumber of the wave being considered. The curve shown in Figure 1 (Morse and Ingard:1968;402) is relatively smooth and can be used to graphically determine the reflected power back from the cylinder from which the AF for a particular screen can be determined. The term r has been used for the value of the ordinate, that is, the ratio of reflected power versus incident power per unit length of solid element d wide.



Source (Morse and Ingard,1968:402)
Figure 2: The back scattering of sound waves *r* from a rigid cylinder radius *a*

In order to use spreadsheet predictions rather than graphical methods, the curve has been split into three segments and polynomial curve fitting was applied to each segment. This allows spreadsheet calculations of *r* for any particular value of *ka* excluding very high values of *ka* where *r* asymptotes to 1.0

The resulting equations are

$$r = -6.0414(ka)^5 + 4.2997(ka)^4 + 0.9242(ka)^3 - 0.2594(ka)^2 + 0.1368(ka) \text{ for } ka < 0.66 \quad (1)$$

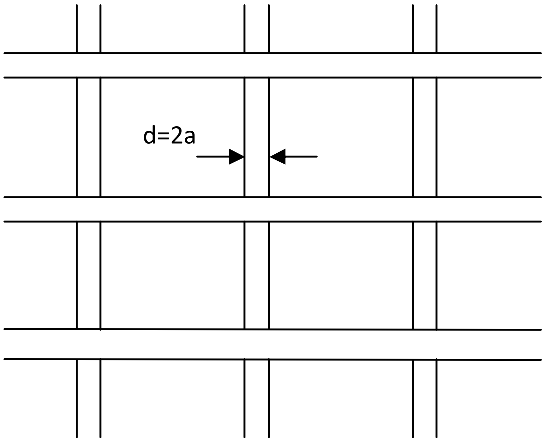
$$r = 0.001(ka)^5 - 0.0199(ka)^4 + 0.1567(ka)^3 - 0.6176(ka)^2 + 1.2576(ka) - 0.2829; \text{ for } 0.65 < ka < 6.1 \quad (2)$$

$$r = 2E\text{-}10(ka)^5 - 6E\text{-}08(ka)^4 + 7E\text{-}06(ka)3 - 0.00041(ka)^2 + 0.0131(ka) + 0.7757 \text{ for } ka > 6.0 \quad (3)$$

$$\square\square = \frac{\square\square\square}{\square} \quad (4)$$

5 METHODOLGY

Consider the screen in Figure 3 comprised of the same size elements. If the entire energy incident on the particular elements is reflected (*r*=1) then the AF for the screen would simply equal the open area. In the general case where r<1, the reflected energy from all the solid elements is ñrò multiplied by the proportion of solid material relative to the total screen area to give the total energy (R) reflected from the total area of the screen, compared with the incident energy. Hence (1-R) is the ratio of power flowing through the screen compared with that incident on the total screen area, that is, the AF.



Source: (Author, 2018)
Figure 3: Screen with solid elements in a two way pattern

By way of example, consider a screen with d = 40 mm wide timber elements on 300 mm centres in a two way pattern. The open area is 75% and 2a = 40 mm. *k* is the wavenumber.

Table 1: Access Factor vs Frequency for screen in Fig 3

Factor	63	125	250	500	1000	2000	4000
ka	0.023	0.046	0.092	0.183	0.366	0.732	1.465
r	0.01	0.015	0.02	0.035	0.1	0.46	0.64
R = 0.25*r*	0	0	0	.008	0.025	0.115	0.16
AF = (1-R)	1	1	1	0.99	0.98	0.89	0.84

The above method can be used where all the solid elements have the same cross dimension.

A similar approach can be used to estimate the AF for a more complicated screen comprising different size elements. The reflective effects R of each of the similar size elements can be assessed individually and then summed to find the total AF = 1-R for the screen.

Consider a 4800 mm wide by 4600 mm high screen, where there are

A; 3 horizontal strips 4800 mm long 145 mm wide giving 2.088 m^2 or 9.46% of the total screen area
B: 4 horizontal strips 4800 mm long 250 mm wide giving 4.8 m^2 or 21.74% of the total screen area
C: 7 vertical segments 90 mm wide 3165 mm long giving 1.994 m^2 or 9.03% of the total screen area
Total ñreflectingò area is 8.882 m^2 and the screen is 60% open.

Table 2 below shows the prediction process to arrive at the AF for the screen.

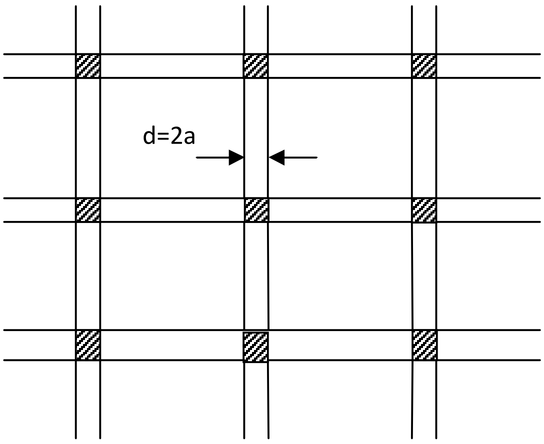
Table 2: Access Factor vs Frequency for 4.8 x 4.6 m described above

	Frequency		125	250	500	1000	2000	4000
A								
145	dimension-mm	ka	0.17	0.33	0.66	1.33	2.66	5.31
14400	long	r	0.022	0.079	0.322	0.607	0.778	0.843
9.46	% closed of total area	R	0.002108	0.007426	0.030451	0.057426	0.073609	0.079724

	Frequency		125	250	500	1000	2000	4000
B								
250	dimension-mm	ka	0.29	0.57	1.14	2.29	4.58	9.16
19200	long	r	0.057	0.257	0.550	0.756	0.835	0.868
21.74	% closed of total area	R	0.012354	0.055874	0.119634	0.164295	0.181609	0.188643
C								
90	dimension-mm	ka	0.10	0.21	0.41	0.82	1.65	3.30
22155	net length	r	0.013	0.031	0.129	0.413	0.679	0.804
9.03	% closed of total area	R	0.001153	0.002779	0.011672	0.037303	0.061329	0.072617
	Total for panel	R	0.015615	0.066079	0.161757	0.259023	0.316547	0.340984
	Panel	AF	0.984385	0.933921	0.838243	0.740977	0.683453	0.659016
for an assumed α with no screen			0.23	0.5	0.7	0.85	0.95	1
predicted resultant α with screen			0.23	0.47	0.59	0.63	0.65	0.66

It can be seen from the predicted results that there would be quite measurable effects on the sound absorption in the room where these 60% open screens are used over significant areas of the wall.

The methodology described above ignores the fact that at the crossing points of the two way system, (Figure 4) the effective width of the horizontal element is much greater than the width of the horizontal element given the presence of the vertical element. For very open screens, this is a small effect but as screen open areas reduce, a greater portion of (in this case) each horizontal element length will be significantly greater than *d* wide.



Source: (Author, 2018)
Figure 4: Crossover areas for screen with solid elements in a two way pattern

6 PREDICTION MEASUREMENT AND DISCUSSION

Laboratory testing on the screens discussed in Section 5 or other two way open screens have not been undertaken. To determine if the hypothesis seemed reasonable, the prediction method was used to predict absorption coefficients for products incorporating acoustically open facings where published absorption coefficient data was available.

6.1 50% open parallel elements

In an article published in the Chinese Journal of Acoustics, the author presented results for measured absorption coefficients for absorbent material behind a 50% open screen, and with no screen present to determine the effect on absorption of such a screen. Unfortunately, both the paper and the reference have been lost and the reference has not been found using on-line searches. The screen comprised 20 mm wide parallel solid square elements spaced 20 mm apart, that is 50% open. Using the approach outlined above, the predicted AF and the ratio of measured absorption coefficients are shown in table 3 below.

Table 3: Predicted and measured AF for 50% open screen comprising 20 mm wide parallel elements

Frequency		3150	4000	5000
Measured ratio of Ŭ with and without the screen in place	(AF)	0.9	0.85	0.74
Predicted	AF	0.87	0.82	0.77

The results show that even with 50% open screens comprising relatively small width elements, there are measurable effects at the upper frequencies. They also show that there was moderately good agreement between predicted and measured.

6.2 Luxalon parallel strip ceilings

Data sheets published by Hunter Douglas Luxalon provide measured absorption data for various products. (Luxalon: 2003). The product range includes 80 mm, 130 mm and 180 mm wide parallel elements, all with 20 mm gaps between the elements. In addition to the solid strips, the manufacturer offers perforated metal strips. In the following tables, the reference absorption coefficients used for the ñno screenò case are those measured for the 130 mm wide system where the strip metal was 26% open 1 mm diameter perforated metal, approximating an acoustically open facing. The following table shows predicted and measured results for 80B (20% open) and 180B (10% open) ceilings with a 160 mm plenum depth.

Table 4: Predicted and measured absorption coefficients for 80B and 180B Luxalon Ceilings

	Frequency		125	250	500	1000	2000	4000
80 B	20 mm gap 100 mm module							
80	dimension-mm	ka	0.09	0.18	0.37	0.73	1.47	2.93
20	% open area	r	0.011	0.026	0.098	0.363	0.642	0.791
80	% area closed	R	0.00906	0.02051	0.0787	0.29050	0.51349	0.63261
	this 1-way grid	AF	0.991	0.979	0.921	0.710	0.487	0.367
	fully perforated Ŭ		0.21	0.6	0.9	0.78	0.96	0.97
	predicted reduced Ŭ		0.21	0.59	0.83	0.55	0.47	0.36
	measured Ŭ		0.24	0.68	0.67	0.66	0.39	0.32
180B	20 mm gap 200 mm module							
180	dimension-mm	ka	0.21	0.41	0.82	1.65	3.30	6.59
10	% open area	r	0.031	0.129	0.413	0.679	0.804	0.848
90	% area closed	R	0.02770	0.11633	0.37176	0.61122	0.72371	0.7629
	this 1-way grid	AF	0.972	0.884	0.628	0.389	0.276	0.237
	fully perforated Ŭ		0.21	0.6	0.9	0.78	0.96	0.97
	predicted reduced Ŭ		0.20	0.53	0.57	0.30	0.27	0.23
	measured Ŭ		0.29	0.71	0.47	0.34	0.27	0.21

There is some general agreement in the upper frequencies. Low to mid frequency results would be affected by resonance effects which will occur and which are not addressed by the proposed assessment method. This is not likely to be a problem for relatively open screens for which the approach was developed. Both results over predict the $\breve{U}$ at 500 Hz, that is, under predict the AF. The relatively close spacing between the solid elements, may also be a factor limiting the range of application given the primary model assessed the acoustic scattering from a single element, with the incident beam width onto the solid element being *d* plus d/2 each side. As the adjacent elements are well within d/2 of each other, we expect that this is likely to affect the limits of application.

6.3 Screens with two way elements

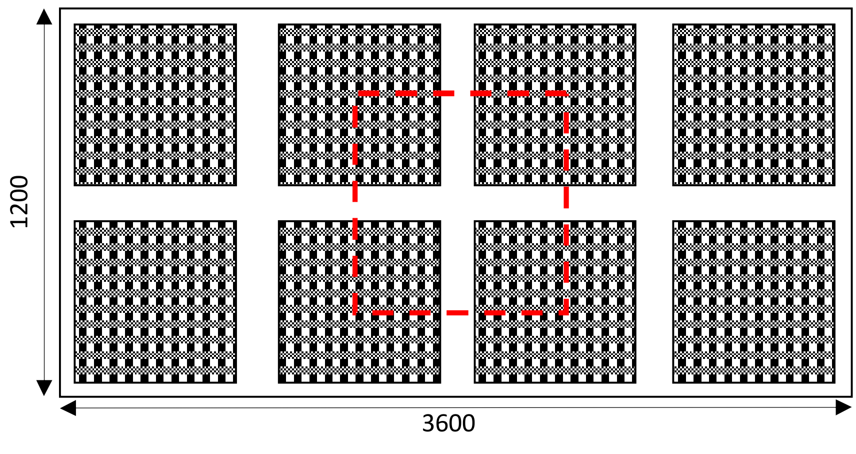
Published data for open screens or facings incorporating two way elements do not appear to be available.

If the distances between the parallel elements are reduced in both directions, the facing approaches a perforated facing with square openings. There are extensive data published for perforated panels. One is considered as described below.

Consider CSR Gyptone 12 mm square perforated plasterboard (Figure 5). The solid cross pieces are 113 mm wide and the perimeter 56.5 mm wide. Each of the perforation groupings comprise 400 (20 x 20) 12 mm square perforations on 25 mm centres. The red dashed segment represents the pattern which is repeated over the ceiling for which the AF and resultant predicted and measured $\breve{U}$ are presented.

The red dashed portion is 600 mm long by 600 mm wide and the various elements are

A;	1 vertical strip 600 mm long 113 mm wide
B:	1 horizontal strip (600-113) mm long 113 mm wide
C:	4 perforated segments totalling an area 487 mm x 487 mm. The perforated area is 16% open



Source (CSR Gyprock: 2018)
Figure 5: Gyptone 12mm Square perforated plasterboard panel

Table 5 below shows the prediction process to arrive at the AF for the ceiling tile. The measured data was for the plasterboard panel with 50 mm 14 kg/m^3 glass fibre in a 200 mm ceiling space cavity. The published sound absorption coefficients include estimated values, however those used in the Table 5 are those which were measured at Auckland University acoustic laboratory. As there are no measurements for the fibre without a facing, the Sabine absorption coefficients for the glass fibre with 150 mm airspace behind was estimated using published measured data for 24 kg/m^3 fibreglass batts with 400 mm airspace behind. These values were then adjusted by predicting $\breve{U}_{stat}$ for 24 kg/m^3 fibreglass batts with 400 mm airspace behind, and for 14 kg/m^3 fibreglass batts with 150 mm airspace using published equations for predicting $\breve{U}_{stat}$ using specific normal impedances for porous liners (Bies and Hansen, 2003: 624-625). The ratios of the two $\breve{U}_{stat}$ values were applied to the published $\breve{U}_{sabine}$ to provide estimates of $\breve{U}_{sabine}$ of the 50 mm 14 kg/m^3 glass fibre in a 200 mm ceiling space cavity.

Table 5: Predicted and measured absorption coefficients for CSR Gyptone 12 mm square plasterboard

	Frequency		125	250	500	1000	2000	4000
A								
113	dimension-mm	ka	0.13	0.26	0.52	1.03	2.07	4.14
600	long	r	0.016	0.046	0.214	0.509	0.736	0.828
18.83	% closed of total area	R	0.003078	0.008721	0.040219	0.095901	0.138707	0.155847
B								
113	dimension-mm	ka	0.13	0.26	0.52	1.03	2.07	4.14
487	long	r	0.016	0.046	0.214	0.509	0.736	0.828
15.29	% closed of total area	R	0.002498	0.007078	0.032644	0.07784	0.112584	0.126496
C								
13	dimension-mm	ka	0.01	0.03	0.06	0.12	0.24	0.48
		r	0.002	0.004	0.007	0.015	0.040	0.179
55.34	% closed of total area	R	0.001097	0.002142	0.004134	0.008241	0.021886	0.099251
	Total of panel	R	0.006673	0.017941	0.076997	0.181982	0.273178	0.381594
	Panel	AF	0.993327	0.982059	0.923003	0.818018	0.726822	0.618406
α	No facing	Sabine α estimated	0.38	0.86	1.2	0.98	1	1.21
α	predicted with panel facing		0.38	0.84	1.11	0.80	0.73	0.75
α	measured PKA		0.65	0.7	0.7	0.65	0.65	0.6

The predictions are not good although they are surprisingly close in the upper frequencies. Good agreement was not expected given that Helmholtz resonator effects are not addressed, but more importantly, there is a significant length of 13 mm wide element, at the crossing points within the perforated sections where the two way system is such that the 13 mm wide dimension assumed for all of the length of the perforated sections in one direction is not appropriate. The effective width at each crossing point is much greater. This would reduce the AF and hence reduce the predicted absorption further. Given that there is much existing information on prediction of the performance of perforated facings, there seemed to be little benefit in pursuing this further.

7 A NOTE ON PERFORATED FACINGS

7.1 Use of existing prediction methods

The prediction methods for estimating the statistical absorption coefficient $\breve{U}_{stat}$ set out in Appendix C (Bies and Hansen, 2003), include equations for calculating the specific normal impedances for different options including porous liner faced with a perforated facing, equation C,43, from which the $\breve{U}_{stat}$ can be predicted. This methodology predicts $\breve{U}_{stat}$ across the frequency range and also accounts for resonant effects.

The hypothesis using AF was introduced to assess the effect for widely spaced elements of a screen and looked at possible limits as the open area was reduced. An alternate approach is to consider existing methodology for perforated faced porous liners, which also account for resonant effects, and investigate the prediction accuracy as the perforations increase in size to investigate if it is appropriate for facings with much larger open areas.

The relevant equations, C.32, C33, C37 and C43 were used in a spreadsheet and the results compared with measured data. The measured data presents Ŭ$_{sabine}$ whereas the predictions are for Ŭ$_{stat}$. The proposal to investigate upper limits of the approach has not proceeded as comparison of existing measured data with that predicted show significant divergence at some frequencies.

7.2 Comparison of predicted and measured absorption coefficients

The following graphs, Figures 6 ï 9, present some comparisons between the predicted and laboratory measured absorption coefficients against third octave band frequency for different perforated facings over porous liners. There has been no attempt in this presentation to convert Ŭ$_{stat}$ to Ŭ$_{sabine}$, however we would expect the trends to be similar.

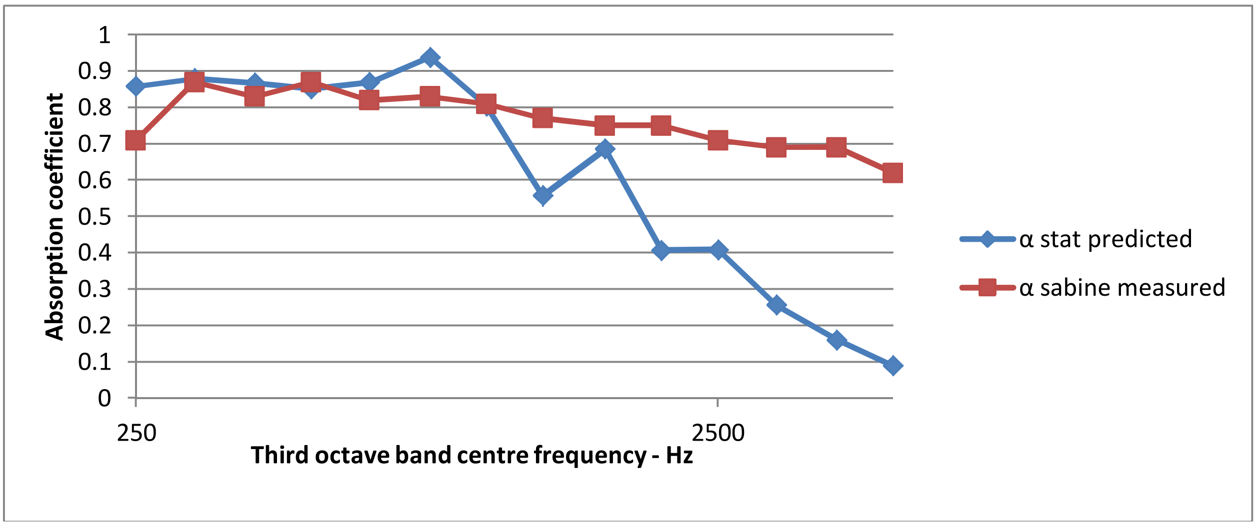


Figure 6: Perforated facing: 2 mm diameter holes, 12.9% open, facing thickness 0.8 mm, 100 mm thick fibre with 100 mm airgap behind the fibre. Sample tested at Acoustic Laboratories Australia Perth Report ALA 10-085

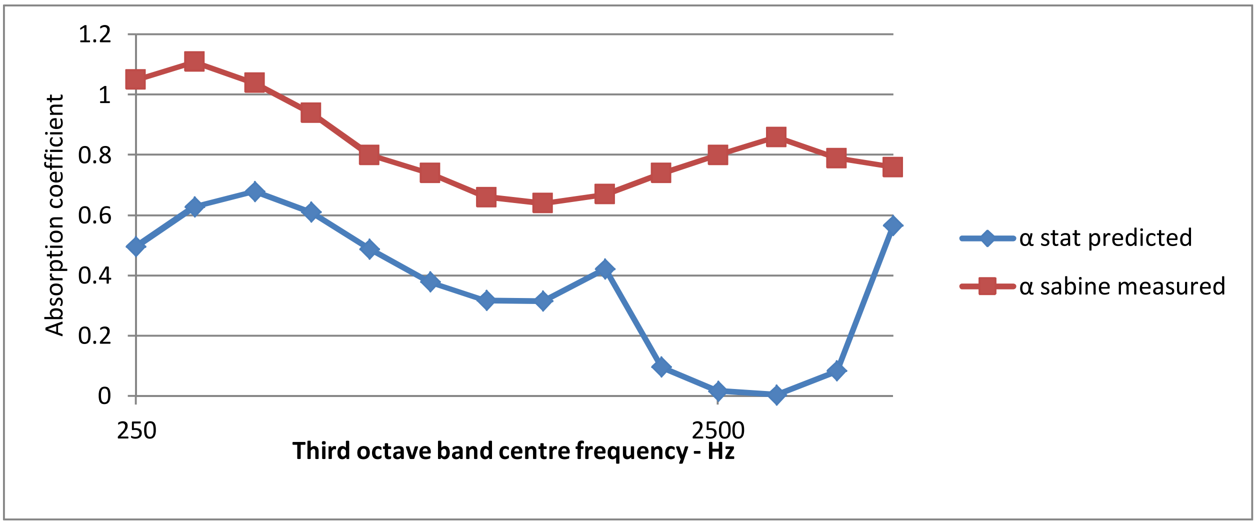


Figure 7: Perforated facing: 9 mm diameter holes, 20.4% open, facing thickness 19 mm, 50 mm thick fibre with 50 mm airgap behind the fibre. Sample tested at RMIT Melbourne. Test 11-105

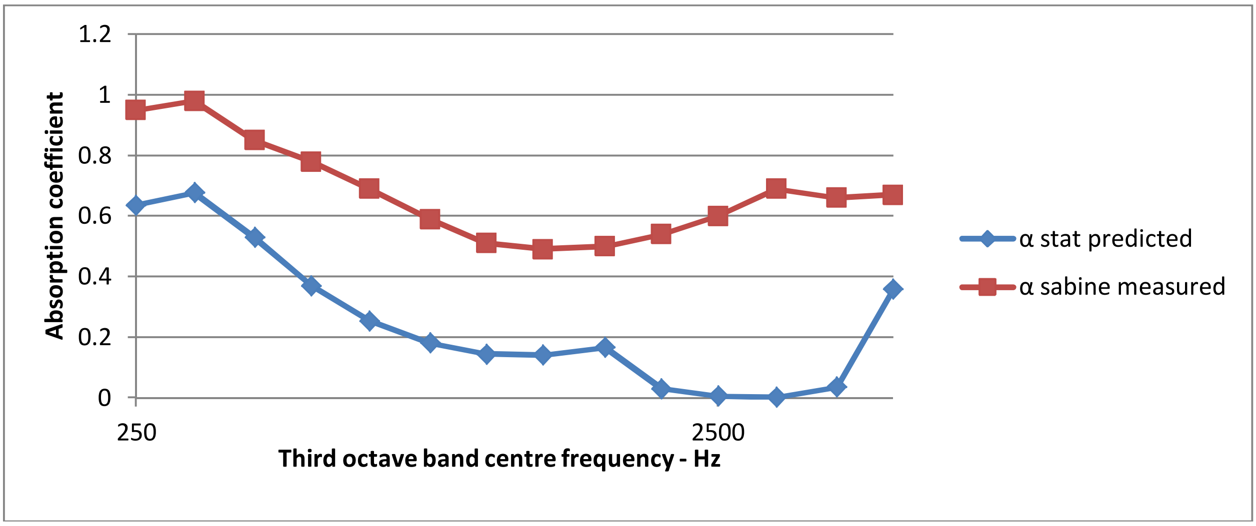


Figure 8: Perforated facing: 9 mm diameter holes, 10.2% open, facing thickness 19 mm, 50 mm thick fibre with 50 mm airgap behind the fibre. Sample tested at RMIT Melbourne. Test 11-107

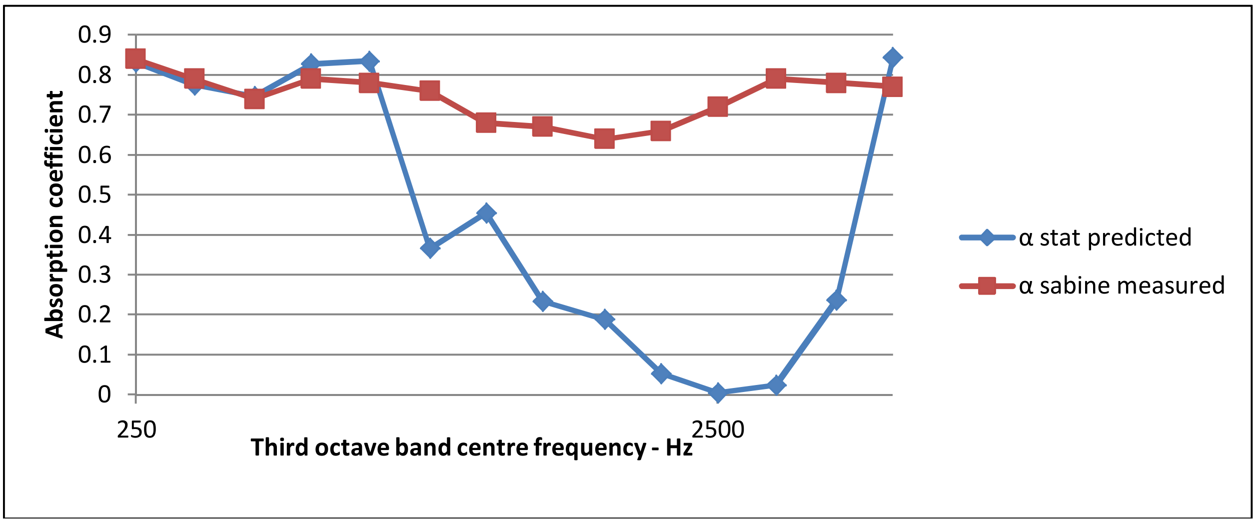


Figure 9: Perforated facing: 12 mm diameter holes, 18.1% open, facing thickness 19 mm, 100 mm thick fibre with 200 mm airgap behind the fibre. Sample tested at RMIT Melbourne. Test 11-106

7.3 Comment

The prediction methodology generally predicts absorption coefficients which approach zero absorption over a relatively broad frequency range somewhere in the frequency spectrum. This dip does not seem to relate to any trends in the results from the laboratory testing. For some facings, the dip occurs outside the usual frequency range of interest, but it generally appears to occur somewhere. Given these discrepancies, the idea of using the prediction methodology to investigate the effect on absorption with increasingly percentage open facings was not pursued.

The equations which predict the specific normal impedance of a perforated plate over a porous liner are based on early works (Morse and Bolt: 1944) and (Bolt: 1947), that is, they have been around for over 70 years. It appears that there have not been publications regarding differences in prediction and measurement or that there is a general understanding that these discrepancies exist.

8 FINAL REMARKS

It appears that using an analysis process based on sound scattered from a solid cylinder is applicable for estimating the reduction in effective absorption of treatment located behind screens where the open area of the screen is greater than 50% open. Laboratory testing of various screens, especially with those comprising two way elements, would be useful in confirming the methodology.

The method may be useful for screens with lower percentage open area, however, for screens incorporating two way elements, the increasing areas of solid material at the crossover points decreases the relevance between the original model concept and the real screen.

The approach does not consider the effect of the screen elements for sound energy propagating back towards the rear of the screen from the porous fibre, effectively increasing the resulting absorption, reducing the net reduction of the absorption effect of the porous liner with no facing present. This would be of minor importance for open screens and would be increasingly more important as the open area decreases. It would be relatively simple to incorporate this additional assessment into the predictive process.

Regarding the comments on prediction of Ǖ$_{stat}$ for a porous liner covered with a perforated facing, it is not clear to me what physical processes are occurring with respect to the sound waves in the region where the theory is predicting almost no energy absorption. It is possible that there is an error in the development of my spreadsheets, but assuming that there is not, it seems that there is an opportunity for further research to investigate the discrepancies between the predicted and measured outcomes.

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