20th International Congress on Sound & Vibration

ICSV20
Bangkok,Thailand
7-11 July 2013

NEW SOUND ABSORPTION IMPROVEMENT STRATEGY FOR QRD ELEMENT

Iwan Yahya and Harjana

The iwany Acoustics Research Group (iARG), Physics Dept. Sebelas Maret Unicersity, Solo, Indonesia 57126

e-mail: iwanyy@yahoo.com

The sound absorption performance and the frequency response of quadratic residue diffuser (QRD) element was investigated using a laboratory experiment. An array of constrained length thin tubes was attached to the inner side of perforated panel for shifting the frequency response of the QRD element purposes. This new coupled structure gives two significant advantages. Firstly, it increases the value of oscillating mass inside orifices which is the increasing energy loss due to viscous damping mechanism without any changes on porosity of the perforated panel. Secondly, it also changes the response of QRD element to act as a single cavity Helmholtz resonator with multiple extended necks instead of cavity backed perforated panel. As a results, the proposed strategy gives a significant improvement on the sound absorption coefficient of the QRD element especially on the low and mid frequency range without any changes on its basic shape and dimension.

Keywords: *array of constrained tubes, QRD element, sound absorption*

1. Introduction

Micro Perforated panel (MPP) are a unique sound absorber that have been used and developed for long time especially for dealing with severe circumstance to reduce noise without porous or fibrous materials. Such robust absorber has many advantages compared to other resonant absorber but has limitation especially on its frequency band absorption.

Theoretical development to increase the frequency range absorption is initially contributed by Maa using a double resonator which is arrangement of two similar MPP constructed separetly in a single cavity. A different strategy, for example, is proposed later by Jung et al by means of single and multi layered system. Results from this work shows a close agreement between experimental data from impedance tube and reverberation room test to the lumped and distributed model with Maa's impedance. Another significant improvement is also provided by Maa that allows precise predicting of MPP properties.[1-4]

Acoustical characterization and applications of MPP have been conducted by many other researchers as well. The influence of radius of perforation and perforation rates on its sound absorption were investigated by Jaouen and Becot, where the theoretical analysis based on a porous media model after Atalla et al. The result was compared to laboratory test of two different prototypes MPP with variation on its porosity and resistivity. The acoustical behaviors of their prototypes are estimated accurately in the frequency range [200-4500] Hz which is the main range of building and transportation noise.[5,6] The other work by Sakagami et al investigates the acoustical effect of thickness, the use of elastic support, and attaching honeycomb structure to MPP since those three treatments are important in practical room applications.[7] Similar work also conducted by Hannink by using the concept of tube resonators.[8] The reason for attaching honeycomb and array of tube resonators structure behind the MPP is for increasing the strength purpose without any significant increment on its weight. Even though combination of honeycomb structure and air layer between MPP and the back wall are electrically equivalent to additional impedance in the lumped model, but they find that this treatment does not affect normal absorption.

The use of perforated surface is also found in Wu et al where they report that the diffuser has enhanced absorption when it uses perforated plate in some wells. A perforated plate not only extends the absorption to lower band but also maintaining good performance at mid frequency range. This behavior hence the diffuser become considerably better wide absorber.[9] In this case the diffuser wells work in a same manner with the cavity backed MPP.

Two successive similar investigation by Wang et al and Wang and Huang gives another better understanding on the properties of cavity backed MPP. Based on experimental proves Wang et al found that the shape of the back cavity can significantly alter absorption mechanism and changes the overall performance of the cavity backed MPP. Wang and Huang then continue this work with the use of parallel arrangement or array of three cavities with different depth covered by a MPP. This research shows that the array requires lower an acoustics resistance for good absorption performance and the frequency response shift due to inter resonator interaction.[10,11]

Those mentioned prior works above entirely cover issue for MPP performance enhancement through two different strategies. The first is a surface treatment by means of changes on porosity and resistivity and the second one is cavity variations. No other method has been published yet proposing a different approach.

The following analysis in this paper dealing with such a new approach that has not been reported by previous researchers yet. Concept of a cavity backed array of constrained short thin tubes (ACST) is presented and its acoustic behavior is investigated by a laboratory work where the perforated panel (PP) is utilized instead of MPP as in many previous approaches. The influence of tubes number, its configuration on the changes of impedance and sound absorption coefficient are measured. Changes on acoustic behavior due to the cavity depth and tube length are also investigated; both are done by using impedance tube test method.

2. From MPP to Array of Constrained Short Tubes

The basic design of the proposed ACST and its comparison with the classic MPP are depicted in Figure (1a) and Figure (1b). An ACST is simply a PP coupled by an open ended short thin tube on each of its perforation to form an array of extended orifices. Combination of this coupled structure with the back cavity then becomes a multiple extended necks Helmholtz resonator with a mutual cavity. Transformation from classic cavity backed MPP to ACST has major advantages since it gives flexibility on tuning the impedance and frequency response of the absorber both by controlling the tubes dimension to change the mass and variation on its cavity depth. This feature hence ACST a unique design to have three accumulatively different possible working mechanisms, i.e. as a classic cavity backed PP, extended neck Helmholtz resonator, and half wave resonator in a single structure.

Acoustic behavior of ACST then could be analysed in many ways. It is possible to conduct domain decomposition and applying the transfer matrix after Selamet and Lee for predicting its frequency response and transmission loss.[12] On the other way one could also applying similar technique after Jung et al and Liu et al by using lumped model for prediction purpose and get a better understanding of ACST properties.[2,13] No such results presented in this paper yet since the analysis focused on the results from laboratory works.

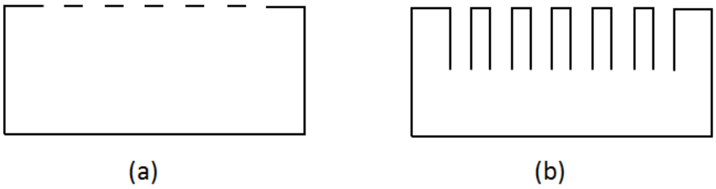


Figure 1. Cavity backed structures: (a). MPP and (b). ACST

To understand the behavior due to the transformation from MPP to ACST, one could consider a single cavity backed perforated absorber as depicted in Fig. (1a). Maa proposed formula for calculating the absorption coefficient and relative impedance $r + j\omega m$ of the MPP absorber at normal incident respectively given by[3],

$$\alpha = \frac{4r}{(1+r)^2 + \left[\omega m - \cot(\frac{\omega D}{c})\right]^2} \tag{1}$$

and

$$r = \frac{32\eta}{\sigma\rho c}\frac{1}{a^2}\left[\left(1+\frac{k^2}{32}\right)^{1/2} + \frac{\sqrt{2}}{32}\frac{ka}{t}\right] \tag{2}$$

where relative impedance is ratio of specific acoustic impedance per unit area divided by the characteristic impedance ρc in air. ρ being density and c is the velocity of sound in the air while t, a, σ and D are the panel thickness, orifice diameter, panel porosity and the cavity depth respectively. $k = 10d\sqrt{f}$. η is coefficient of viscosity in air and f is frequency.

As the tubes are attached to the entire PP orifice, the ACST is then could be modelled as Helmholtz resonator with an array of extended neck in an individual cavity. Predicting model after Mechel for array of Helmholtz resonators with circular necks could be adopted with modification. A correction should be implemented to the impedance relation due to the changes of surface porosity, spring reactance of resonator volume and also oscillating masses in the front and back orifice. Since the orifice and the tubes has an equal diameter, the surface porosity of ACST is then given by

$$\sigma = n\pi a^2/B \tag{3}$$

where n is the number of orifice, a and B are orifice radius and ACST cross section respectively. The tube neck length of ACST is now taken into account for determine of neck impedance instead of orifice thickness as in classic Mechel model. See Mechel pages 435 to 437 for details.[14]

3. Devices and Experimental Procedures

The experimental set up is based on ASTM E1050-98 as schematized and is shown in Fig. (2), which is a standard method for measuring sound absorption and reflection coefficient based on transfer function analysis. The experiment has been conducted by using B&K 4206 impedance tube that connected to B&K Pulse 3160 Analyzer. The large tube with 100 mm diameter was utilized since the analysis to be focused in low and mid frequency range up to 1.6 kHz. The whole data acquisition and processing are controlled by computer with a dedicated B&K material testing software.

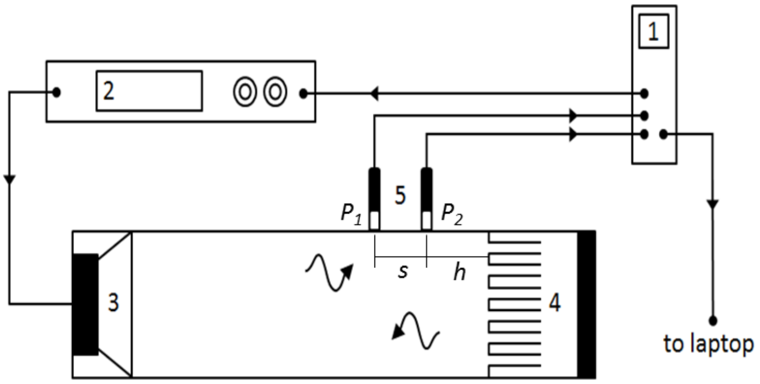


Figure 2. Schematic set-up of the experiment. The device consists of (1). B&K 3160, (2). B&K power amplifier, (3). Impedance tube, (4). Test sample and (5). A pair of B&K 4187 microphones. The entire process controlled by computer equipped with dedicated B&K software for material testing.

The B&K 4206 impedance tube is equipped with an internal fixed loudspeaker at the one end and two B&K 4187 microphones in a certain fixed position from the test sample surface which is placed in the opposite position to the loudspeaker. As the internal function generator of B&K Pulse 3160 being activated, random noise generated from the loudspeaker and propagates inside the tube as a plane waves. Since the far end of the tube are closed tightly there are no portion of incident waves were transmitted and the transfer function calculated based on the captured signal from the two microphones. The microphones capturing both upstream and downstream signals to be decomposed for separating incident and reflected waves component. Such procedures are included in the B&K dedicated material testing software.

The 7.5 mm thickness acrylic based PP and ACST model are shown in Fig. (3). The orifice diameter and tubes length are 5 mm and 50 mm respectively and the entire model have been use in the laboratory test with cavity depth variation 100 mm and 150 mm.

Figure 3. The test samples, from left to right the MPP, MPP attached with eighteen tubes, and the fully attached tubes MPP.

According Fig. (2) the transfer function between two microphones are given by following equation,

$$H_{12} = \frac{P_2}{P_1} = \frac{e^{jkh} + Re^{-jkh}}{e^{jk(h+s)} + e^{-jk(h+s)}} \tag{4}$$

P_1 and P_2 are sound pressure level captured by microphone number one and number two respectively while h and s are the distance of microphones from sample surface. Reflection coefficient (R) and absorption coefficient (α) are given by,

$$R = \frac{H_{12} - e^{jks}}{e^{jks} - H_{12}} e^{j2k(h+s)} \tag{5}$$

and

$$\alpha = 1 - |R|^2 \tag{6}$$

4. Results and Discussion

The influence of tubes attachment on the sound absorption coefficient, alpha, of the PP and ACST depicted in Fig. (4). PP reach its best alpha of 0.186 at the frequency range [522 – 700] Hz while attachment of 18 tubes increase sound absorption performance varying from 0.248 to 0.286 in same frequency range. Significant improvement occur when the entire perforation is fitted with the short tubes to form ACST where alpha is higher than 0.3 at the frequency range [236 – 728] Hz with the best performance 0.6 occur in the range [292 – 416] Hz.

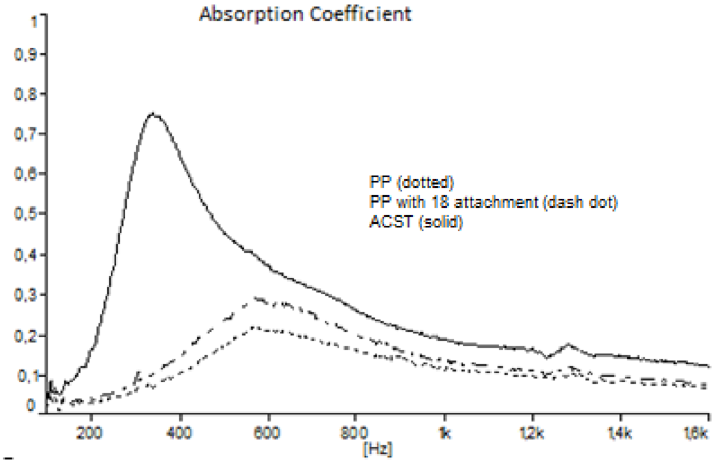
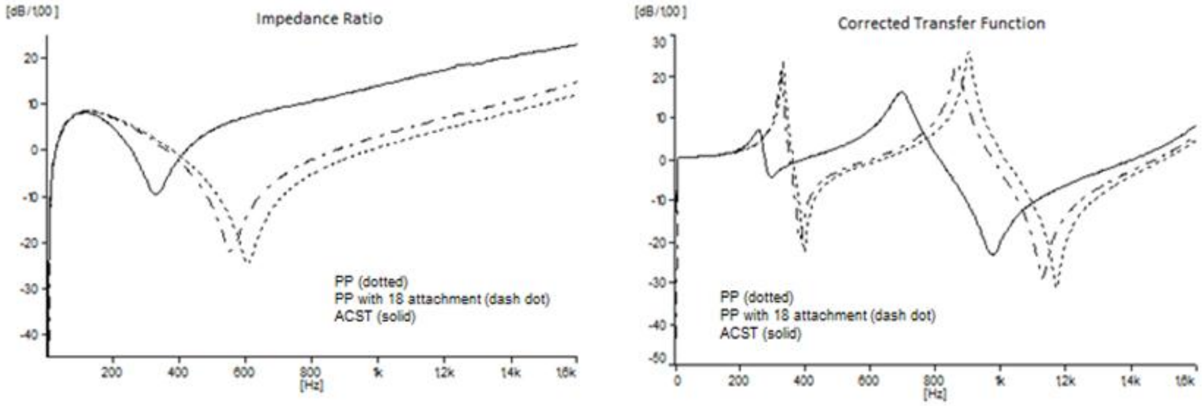


Figure 4. The sound absorption coefficient of PP, PP attached with eighteen tubes, and the ACST.

Related impedance ratio and corrected transfer function are shown in Fig. (5a) and Fig. (5b) respictively. It is clear from Fig. (5a) that increasing number of short tubes attachment to the MPP leads to the increment of impedance ratio which is related to the changes on the value of oscillating mass inside the tubes. As the entire extended orifices is attached the maximum amount of osillating mass is reached and the maximum alpha is occured.

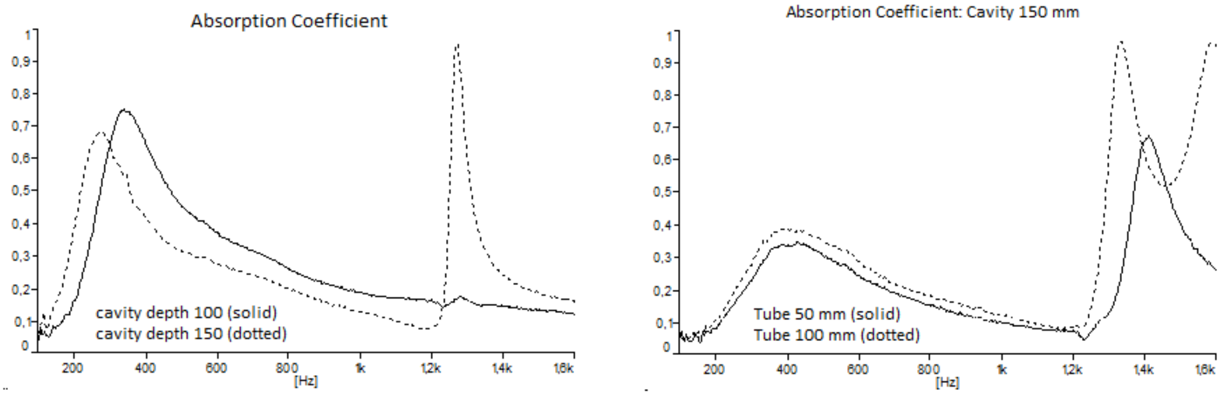
According to electrical analogy of a Helmholtz resonator, extension of orifices length leads to the changes of necks reactance of the Helmholtz resonator. As the commulative reactance increased it shifts the effective sound absorption to the lower frequency band. This evidence shown in Fig. (5b) where the response changes from 330 Hz in the perforated layer to 322 Hz and 254 Hz in the eighteen and full neck attachment respectively. As one could see the value of corrected transfer function is decreased with increment of tubes number. In the other words the ratio of reflected waves to the incident waves also getting smaller which is means that the energy of the sound waves being absorbed effectively when ACST is fully attached.



(a) (b)

Figure 5. Comparisson of the impedance ratio and its related transfer function

Influence of back cavity depth and the tubes length are shown in Fig. (6a) and Fig. (6b). As the back cavity depth increased, the cavity reactance of the Helmholtz resonator is also increased and shifting the sound absorption the lower frequency. Another resonance occured on the frequency above of 1.2 kHz for the deeper back cavity. Despite it caused by different mechanism the sound absorption pattern in Fig. (6a) look very similar to Wang and Huang result on the use of parrallel arrangement of multiple MPP absorber with different cavity depths. In this case the experiment was conducted with 50 mm length tube ACST. In the other words, the commulative effect of cavity reactance increment together with the unique response of the short tubes as array of half wavelength resonators brings an important advantage to ACST on controlling the noise using a single structure instead of parrallel arrangement after Wang and Huang.



(a) (b)

Figure 6. Influence of back cavity depth and the tubes length

The other advantage is shown in Fig. (6b). The dotted line is sound absorption coefficient of perforated panel with thirty 100 mm length tubes attached on is perforation. It is clear that increasing of tubes length in a deeper cavity giving possibility for controlling the high frequency noise.

Another comparisson of ACST performance to the existing parrallel arrangement after Wang and Huang also conducted by using two cavity model. In this case as seen in Fig. (7a) the parrallel arrangement model after Wang and Huang model consists of two cavity with different depth d_1 and d_2 while the ACST model has two equal cavity depth d_1 with all tubes length d_2.

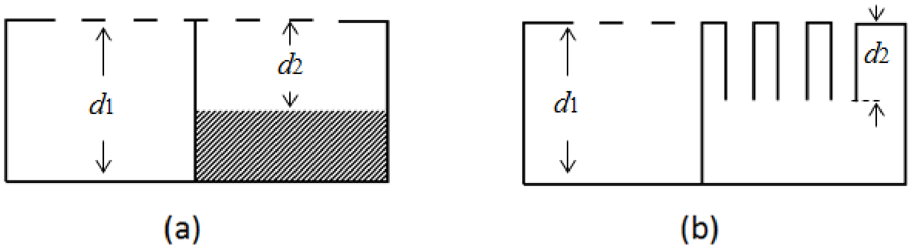


Figure 7. Comparission between (a) after Wang and Huang model and (b) ACST

As seen from Fig. (8), the unique combination of viscous damping mechanism due to the increasing of oscillating mass value and the resonance mechanism related to changes of necks length and cavity reactance of resonator, it gives ACST a much powerful ability to absorp the noise in the lower frequency band.

It is clear here that ACST has two major advantages compare to its competitor model. First, as explained above the extension of orifice dimension with the attachment of tubes array gives a commulative effect since sound absorption mechanism occured on various way such as combination of viscous damping with resonance mechanism instead purely cavity backed MPP resonance mechanism of its competitor. This also provides solution for the problem that not yet solve by Hannink since it is proven that ACST structure affect normal absorption signifcantly which is could not be done by using existing combination of honeycomb structure and air layer between the MPP and its back wall.

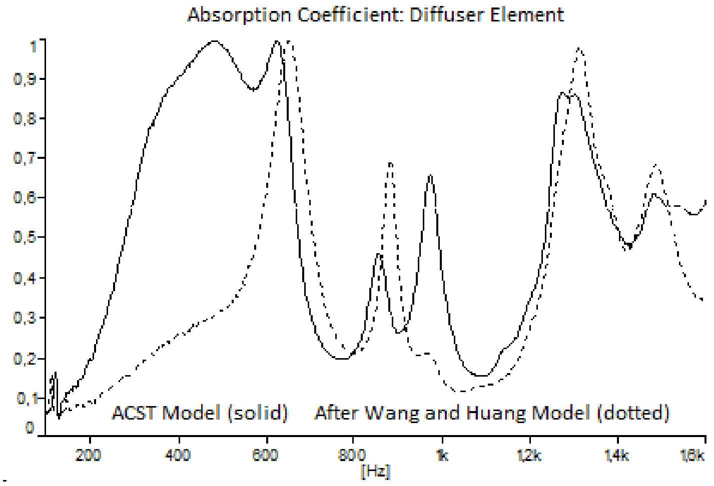


Figure 8. Performance comparission between the after Wang and Huang model and ACST

Secondly, it is very common in QRD optimization purposes to do surface modification by using MPP and extended well depth to controll the low frequency noise[15]. This procedures found a great success on improving the sound absorption but on the other side it changes the scattering pattern of QRD. This evidence would not happened for the ACST since the surface modification strategy does not change the QRD well depth. It would brings a better performance on controlling the low frequency noise without any significant influence on the QRD scattering pattern.

5. Conclussion

The perforated panel based ACST gives major advantages compared to previous surface modification techniques such as cavity backed MPP and is extended well depth as implemented by many previous researchers. The unique design of ACST with its inner cavity modification is more effective for controlling lower frequency noise compared to the existing parrallel arrangement of multiple MPP backed with different cavity depth. It also brings possibility for absorbing high frequency noise using single structure with longer tubes backed by a deeper cavity. The proposed ACST also has a unique feature to keep scattering characteristics of a QRD.

Acknowledgement

The authors would like to thanks the Directorate Generale of Higher Education (DGHE) Republic of Indonesia and the Research Institute (LPPM) of Sebelas Maret University for supporting the research through the University Excellent Research Grant contract number 2342/UN27.16/PN/2012. To their entire colleagues at the Physics Department for the very nice academic atmosphere and sharing, their family for patience and understanding, and all students at iARG for the spirit and nice discussions.

REFERENCES

[1] Maa, D. Y., Theory and design of microperforated panel sound-absorbing. *Construction, Scienta Sinica* **XVIII**, 55-71, (1957)

[2] Jung, S. S., Kim, Y. T., Lee, D. H., Kim, H. C., Cho, S. I., and Lee, J. K., Sound absorption of microperforated panel. *Journal of the Korean Physical Society*, Vol **50** (4), 1044-1051 (2007)

[3] Maa, D. Y., Potential of microperforated panel absorbers. *J. Acoust. Soc. Am.*, **104** (5), 2861-2866 (1998)

[4] Maa, D. Y., Practical single MPP absorber. *International Journal of Acoustics and Vibration*, Vol **12**, No. 1, 3-6 (2007)

[5] Joauen, L., and Becot, F. X., Acoustical characterization of perforated facings. *J. Acoust. Soc. Am.*, **129** (3), 1400-1406 (2011)

[6] Atalla, N., Sgard, F., and Amedin, C.K., On the modeling of sound radiation from poroelastics materials. *J. Acoust. Soc. Am.*, **120**(4), 1990-1995 (2006)

[7] Sakagami, K., Morimoto, M., and Yairi, M., Application of microperforated panel absorbers to room interior surfaces. *International Journal of Acoustics and Vibration*, Vol **13**, No. 3, 120-124 (2008)

[8] Hannink, M., *Acoustic resonator for the reduction of sound radiation and transmission*. PhD Thesis, University of Twente, Enschede, The Netherlands, May 2007

[9] Wu, T., Cox, T. J., and Lam, Y. L., A profiled structure with improved low frequency absorption. *J. Acoust. Soc. Am.*, **110** (6), 3064-3070 (2001)

[10] Wang, C., Cheng, L., Pan, J., and Yu, G., Sound absorption of a micro-perforated panel backed by an irregular-shaped cavity. *J. Acoust. Soc. Am.*, **127** (1), 238-246 (2010)

[11] Wang, C., and Huang, L., On the acoustic properties of parallel arrangement of multiple microperforated panel absorbers with different cavity depths. *J. Acoust. Soc. Am.*, **130**(1), 208-218 (2011)

[12] Selamet, A., and Lee, I., Helmholtz resonator with extended neck. *J. Acoust. Soc. Am.*, **113**(4) 1975-1985 (2003)

[13] Liu, F., Horowitz, S., Nishida, T., Cattafesta, L., and Sheplak, M., A multiple degree of freedom electromechanical Helmholtz resonator. *J. Acoust. Soc. Am.*, **122**(1) 291-301 (2007)

[14] Mechel, F. P., *Formulas of Acoustics*, 2nd Edition. Springer-Verlag, Berlin (2008)

[15] Cox, T. J., and D'Antonio, P., *Acoustic Absorbers and Diffusers. Theory, Design and Application*. Spon Press, London (2004)