DETERMINATION OF ACOUSTIC CHARACTERISTICS OF MELAMINE FOAM WITH EXPERIMENTAL VALIDATION

Behzad Ahmed Zai*[1], Saad Sami†[1], Majid Shahzad‡[1], Rashid Ali♦[2]
[1]Space and upper atmosphere research commission, Pakistan
[2]Materials and chemical engineering, Ghulam Ishaq Khan institute of engineering sciences and technology, Pakistan

Résumé

Les lanceurs spatiaux subissent des charges dynamiques sévères tout au long du vol. Les charges acoustiques sont l'une de ces charges qui sont très critiques pour le lanceur au moment de l'allumage et du décollage. Les amplitudes des charges acoustiques sont généralement très élevées et doivent être diminuées pour économiser les composants électroniques. En règle générale, l'un des matériaux isolants les plus courants et les plus efficaces est la mousse de mélamine (MF). Dans cet article, les panneaux MF de réduction du bruit acoustique et environnemental d'épaisseurs variables (25, 50 et 75 mm) sont analysés. Un logiciel commercial FEA est utilisé pour estimer les paramètres acoustiques qui sont validés expérimentalement à l'aide d'un tube d'impédance, basé sur la méthode des matrices de transfert. Le tube d'impédance peut mesurer le coefficient d'absorption acoustique incident normal et la perte de transmission pour la gamme de fréquences de 64 Hz à 6,2 kHz. Un tube d'impédance classique à deux microphones est connecté à un porte-échantillon en aval de la première paire de microphones et à une section en aval du porte-échantillon qui accueille une seconde paire de microphones. Deux agencements séparés de tube d'impédance sont utilisés pour mesurer le coefficient d'absorption et la perte de transmission. La FEA et les résultats expérimentaux sont comparés et trouvés dans de bons accords. De plus, l'épaisseur de mousse d'isolation optimisée est obtenue en fonction des paramètres acoustiques requis.

Mots clefs : Mousse de mélamine, coefficient d'absorption, perte de transmission, niveau de pression acoustique, tube d'impédance

Abstract

Space launch vehicles experience severe dynamic loadings throughout the flight. Acoustic loads are one such load which are very critical to the launch vehicle at the time of ignition and take off. The amplitudes of acoustic loadings are generally very high and required to be diminished to save electronic components. Typically, one of the most common and efficient insulating material is Melamine Foam (MF). In this paper, the acoustic and environmental noise reduction MF panels of variable thicknesses (25, 50 and 75mm) are analyzed. Commercial FEA software is used to estimate the acoustic parameters which are experimentally validated using impedance tube based on transfer matrix method. The impedance tube can measure the normal incident sound absorption coefficient and transmission loss for frequency range of 64 Hz to 6.2 kHz. A conventional, two-microphone impedance tube, is connected to a sample holder downstream of the first microphone pair and a section downstream of the sample holder that accommodates a second pair of microphones. Two separate arrangements of impedance tube are used to measure the absorption coefficient and transmission loss. The FEA and experimental results are compared and found in good agreements Furthermore, the optimized insulation foam thickness is obtained based on required acoustic parameters.

Keywords: Melamine foam, absorption coefficient, transmission loss, sound pressure level, impedance tube

1 Introduction

In space missions, satellite launch system encounters a wide range of broadband noise loads. Therefore, acoustic emission and transmission must be studied during critical instants of a launch system including maximum dynamic pressure condition, transonic flight condition and lift off.

The upper stages of launch system are subjected to extreme broad band and random acoustic excitation. The high velocity jet noise emitted from the rocket boosters is reflected back to payload from the launching platform at the time of lift-off, consequently compromising the entire mission. Sound pressure level (SPL) inside a fairing cavity could reach to 120–140 dB which can cause significant damage to sensitive elements (e.g. solar panel and power supply). For the determination of SPL inside fairing, a vibro-acoustic environmental analysis must be carried out. Numerical prediction of vibro-acoustic response of satellite launch vehicle is a prerequisite so that the noise control engineer could effectively optimize the vehicle system [1-3]. Therefore, it is a standard operating procedure to qualify payloads under launch environment response conditions before flight [4].

While designing for acoustic noise attenuation, the upper parts of the launchers such as payload fairing and bays have

* behzad_zai@pnec.nust.edu.pk
† saadme79@gmail.com
‡ dr_majid@engineer.com
♦ rashidali@giki.edu.pk

the prime importance. Passive techniques with acoustic blankets were used by Glaese and Anderson [5], they presented structural-acoustic modeling for a full-scale composite launch vehicle payload fairing. The purpose of these analyses and experimental efforts was to provide data and valid models that will be used for active acoustic control for payload fairing. Furthermore, they implemented a closed-loop acoustic transmission reduction that was measured on a full-scale composite payload fairing. There are two approaches which are adopted to reduce SPL in fairing. The first is by increasing the transmission loss along the fairing's wall, this approach will increase the design cost and reduce mass ratio of optimized design. Thus, the second approach is more commonly used to absorb the acoustic load. It is achieved with the help of an acoustic blanket of optimized thickness. For this purpose, the most commonly used porous material is MF.

Among commonly used porous materials, MF was characterized by its light weight, high flexibility and high sound absorption coefficient within a mid-high frequency noise range [6, 7]. Moreover, MF was experimentally demonstrated by National Aeronautics and Space Administration (NASA) to have superior noise attenuation performance as traditional acoustic blankets [8-10]. Li et al [11] paid great efforts to investigate noise reduction in a cylindrical cavity with MF lining within the low-medium frequency range (100–400 Hz). They derived natural frequencies of the cylindrical cavity with presence of locally and non-locally reacting liners from theories of the cylindrical cavity lining. They demonstrated that MF lining could achieve noise reduction by up to 4–8 dB within the low and medium-frequency range. Furthermore, different porous material was used by many other researchers as noise attenuation blankets to attenuate sound energy by trapping and dissipating it in the form of heat [12-18].

The acoustical performance of blanket materials can be characterized in many ways, since knowledge of different parameters, such as Biot´s parameters, are significant when acoustic noise control treatment designs are specified. Biot´s parameters include physical properties such as porosity, density, resistivity, tortuosity, thermal characteristic lengths and viscosity of the material being used. These parameters are necessary in the computation of absorption and transmission loss of the acoustic foam and are usually provided by the material manufacturer, if not can be measured experimentally as presented by Lauriks [19].

In recent years, the advancement in the utilization of MF along with other material is being carried out by different researchers. Ji et. al [20] investigated a porous labyrinthine type of acoustic metamaterials (LAMs), a sort of acoustic meta surface, analytically, numerically, and in laboratory tests. The LAMs are composed of a series of porous elements, where stainless steel plates with various lengths are inserted into the MF. Moreover, Yang et al. [21] explored the physical properties and corresponding mechanism of MF which was modified by phenolic resin. They found out that this phenomenon had a significant effect on the pore size of MF. There was a remarkable improvement in sound transmission loss (STL) compared to that without phenolic resin. However, STLs did not increase monotonically.

The acoustic properties of a porous material are first estimated analytically. Therefore, Finite Element Techniques are extensively useful in resolving problems arising in different industrial sector. COMSOL is one such software being used for solving complex acoustic problems which basically revolve around pressure waves in a fluid. The acoustics mode provides two types of analysis; Time-Harmonic and Eigen-Value [22]. Zheng et al. [23] utilized COMSOL to develop acoustic models for high frequency resonators of a Turbo charged internal combustion engine. Using the software, the realistic flow patterns of the possible 3D effects were observed for losses incurred during combustion. Another experimental work was presented using two-source location technique to obtain two-port matrices and transmission losses of four sample resonator with varying the mean flow speeds. Tomasz [24], presented a numerical method for the calculation of frequency dependent sound transmission loss within a reflective pipe with outlet to acoustic-free space using COMSOL.

For experimental validation of results obtained using Finite Element Analysis (FEA), the impedance tube method is commonly used to measure the normal incident sound absorption coefficient and transmission loss for different materials [25]. Bolton et al. [26] described a method for measuring the normal incidence transmission loss and related acoustical properties of a sample placed in a four-microphone standing wave tube. The similar work was presented by Hua and Herrin [27], they used the two-load method to determine the transmission loss of a muffler or silencer. Several practical measurement considerations were examined. The use of the impedance tube is not only limited to measure the acoustic parameter of porous material but also used in variety of applications such as fluid and soil transmission loss measurements [28-30].

Berardi considered natural fibers as a valid raw material for producing sound absorbing panels at a reduced cost. Moreover, these fibers often have good thermal insulation properties [31]. Similar research on natural fiber and nano fiber is presented by Iannace et al. [32, 33]. They characterized natural materials as an alternative to traditional synthetic materials in the fields of acoustic treatments and energy saving. Furthermore, researcher used artificial intelligence for acoustic characterization of different material [34]. These researchers performed very useful research in the field of acoustic and presented different alternatives which can be used as an effective acoustic material.

In this paper, the theory underlying the transfer matrix approach is described first, then followed by a description of the experimental setup using impedance tube. Various results, including the normal incidence transmission loss and absorption coefficients are then presented for an acoustic insulation of variable thickness MF both numerically and experimentally. The working frequency range is described with the placement of small and large diameter tubes. The resonance features are obtained due to sample constraint around its edges for both absorption coefficient and transmission loss. The acoustic characteristics at different thicknesses of

MF are presented for estimation of required insulation blanket within payload fairing to protect satellite and other electronic components from harmful noise effect.

2 Analytical relation

The material absorption coefficient is an important parameter which is characterized by its normal or random incidence characteristics. The ISO standard 10534-2-(1998) illustrates the well-known process to determine the absorption and impedance characteristics of noise insulating materials through "two microphones" or "transfer-function" method for as shown in Figure 1.

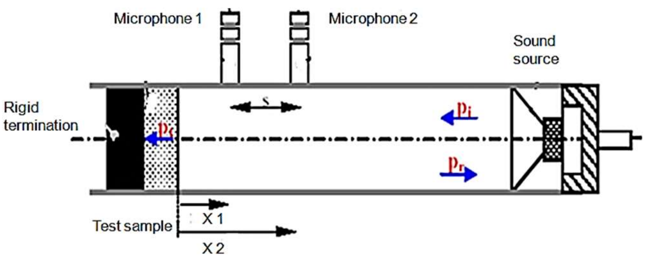

Figure 1: Two microphone impedance tube for the measurement of absorption coefficient

The transfer function method mainly relied upon the ratio of the sound pressures of the reflected and the incident wave at termination (at x = 0), given by Eq. (1) [35]. The absorption coefficient relation for materials is given in Eq. (2).

$$R = [(H_{12} - e^{-jks})/(e^{jks} - H_{12})](e^{j2ki}) \quad (1)$$

$$\alpha = 1 - |R^2| \quad (2)$$

Absorption coefficient for random incidence can also be measured in a reverberant room, where the acoustic diffuse fields can be simulated with approximation. The transmission loss computation of noise absorbent materials is essential in building acoustic and environmental noise reduction studies. Internationally, impedance tube method is widely adopted for determining the sound absorption coefficient, [36]. However, there is no international standard procedure of measuring sound transmission loss when used in conjunction with the impedance tubes. Bolton et al. [37] modified a sound absorption measurement impedance tube so that it could be used in measuring the sound transmission loss of automotive sealant materials. Ho et al. [38] measured the sound transmission of perforated panels with an impedance tube somewhat similar to Bolton's measurement system, the differences among two is the type of sample holder and a monotonic wave. More recently, a commercial sound transmission measuring system, proposed by Ryu (2000), has become available i.e., the B&K 4206T transmission loss tube kit. Generally sound transmission loss measurement tubes comprise of three parts: the upstream tube, the sample holder and the downstream tube. They implemented enclosed boundary conditions in the downstream tube with a semi-anechoic termination whereas Ryu [39] tested with both open and closed boundary conditions during his work.

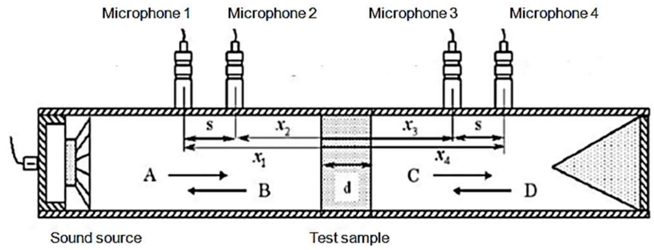

Figure 2: Four microphone impedance tube for the measurement of transmission loss

The impedance tube used for computation of transmission loss is shown in Figure 2. A set of two microphones (MP1 & MP2) are mounted in the up-stream tube, similarly two microphones (MP3 & MP4) are mounted in the downstream tube to measure both incident and reflected waves. The reference position (x = 0) is given as the front surface of a sample: x_1, x_2, x_3, x_4 denote each microphone's position. If a one-dimensional plane wave in the tube is assumed to be $pe^{j(wt-kx)}$ then the Fourier components of the sound pressure at micro-phone placed at positions 1, 2, 3 and 4, after eliminating the time-dependent term, can be expressed by the following equations [40].

$$p_1 = Ae^{-jkx_1} + Be^{jkx_1} \quad (3)$$

$$p_2 = Ae^{-jkx_2} + Be^{jkx_2} \quad (4)$$

$$p_3 = Ae^{-jkx_3} + Be^{jkx_3} \quad (5)$$

$$p_4 = Ae^{-jkx_4} + Be^{jkx_4} \quad (6)$$

Eq. (3) - (6) can be rearranged to solve for the coefficients A to D as shown in Eq. (7) - (10)

$$A = [j(p_1 e^{jkx_2} - p_2 e^{-jkx_2})/2\sin k(x_1 - x_2)] \quad (7)$$

$$B = [j(p_1 e^{jkx_2} - p_2 e^{-jkx_2})/2\sin k(x_1 - x_2)] \quad (8)$$

$$C = [j(p_1 e^{jkx_2} - p_2 e^{-jkx_2})/2\sin k(x_1 - x_2)] \quad (9)$$

$$D = [j(p_1 e^{jkx_2} - p_2 e^{-jkx_2})/2\sin k(x_1 - x_2)] \quad (10)$$

In order to simplify the equation, the two microphones were placed at an equal distance. The transmission coefficient (*T*) is defined by the ratio *C/A* and the transmission loss (*TL*) equals$-20\log|H_t|$:

$$TL = 20\log|(e^{jks} - H_{12})/(e^{jks} - H_{34})| - 20\log|H_t| \quad (11)$$

Where, $s = |x_1 - x_2| = |x_3 - x_4|$, $H_{12} = p_2/p_1$ is the transfer function, which is the ratio of the Fourier-transform component between the sound pressures at positions 1 and 2 and $H_{34} = p_4/p_3$ is the transfer function, which is the ratio of the Fourier-transform component between the sound pressures at positions 3 and 4. $H_t = \sqrt{|S_d/S_u|}$. White noise was generated by the spectrum analyzer and the noise signal was simultaneously measured using all 4 microphones.

3 Acoustic analysis

3.1 Absorption coefficient

Absorption properties of open cell and acoustic proofing foam is computed using pressure acoustic model of analytical software. In porous materials, acoustic wave travels through a complex arrangement of small interconnected pores. Since the pores are small, losses usually arise due to heat conduction and friction. Porous foams are not only used in the sound proofing of rooms and ducts but also to mitigate reverberation problems in closed spaces. The aim of this model is to distinguish the absorption properties more specifically, the surface impedance and the absorption coefficient of a layer of acoustic foam in terms of frequency. A 2D model is employed to simulate the absorption behavior of the porous material over a wide range of frequency band.

Figure 3 depicts the schematic and simulation results for the measurement of absorption coefficient. It is shown that an incident sound wave strikes the surface of the porous MF at an angle of 90 degrees. Only a small portion of domain width is modeled and the periodic Floquet conditions are applied on the left and right boundary to extend the domain to infinity. A plane wave radiation condition is applied at the top of the domain. MF is modeled as a rigid porous elastic material and the material parameters used in the simulation model are listed in Table 1. A rigid surface is used at the bottom to eliminate further transmission of the incident wave. The surrounding fluid domain consists of air. Sound wave are travelling from top to bottom and subsequent acoustic energy suppressions are encountered in MF.

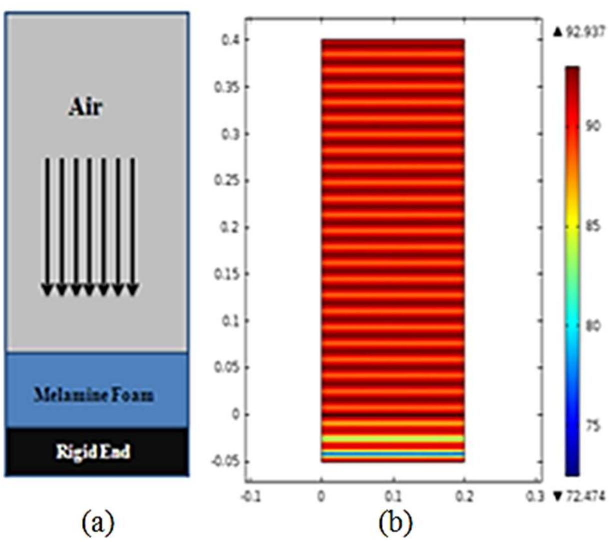

Figure 3: (a) Schematics for absorption coefficient, (b) numerical simulation results for absorption coefficient

Table 1: Melamine material parameters for absorption coefficient Computation

Quantity	Unit	Value
Porosity	-	0.995
Flow resistivity	$Pa \cdot s/m^2$	10,500
Viscous characteristic length parameter	-	0.49
Thermal characteristic length	µm	470
Viscous characteristic length	µm	240
Tortuosity factor	-	1.0059

3.2 Transmission loss

The Poro-elastic waves interface method is utilized to compute the transmission losses. The Poro-elastic wave model describes as the small deformation elastic waves propagating in a porous material coupled to waves in a fluid. The model accounts for the coupled displacement of the fluid/structure making it a fluid-structure interaction problem. The 2D axisymmetric geometry is shown in Figure 5. The central portion contains MF, acting as acoustic insulation material and air in the rest of the system. The porous material is assumed to be isotropic with parameters as listed in Table 2. The acoustic pressure level throughout the domain is also shown in Figure 4. Sound wave travelling from bottom to top and subsequent acoustic energy suppression is encountered in MF.

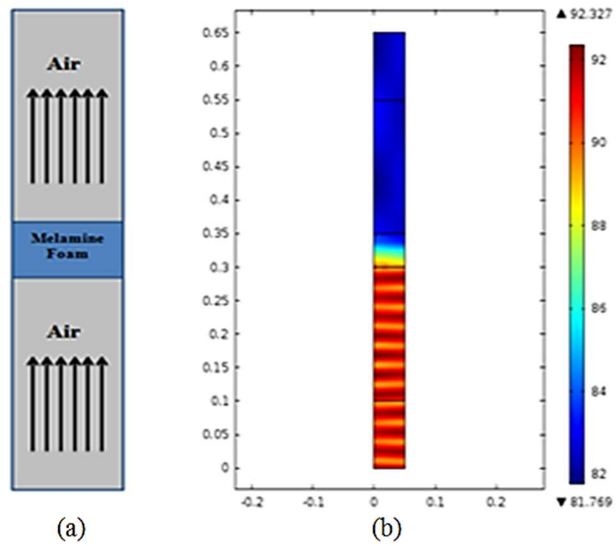

Figure 4: (a) Schematics for transmission loss, (b) numerical simulation results for transmission loss

Table 2: Melamine material parameters for transmission loss computation

Quantity	Unit	Value
Density	kg/m^3	9
Young's modulus	kPa	180
Poisson's ratio	-	0.46
Biot-Willis coefficient	-	1
Porosity	-	0.995
Permeability of porous matrix	m^2	1.5e-9

4 Experimental setup

4.1 Introduction

VA-Lab2 IMP is the software code used for the computation of absorption coefficient and transmission loss. The hardware comprises of impedance tube setup and data acquisition system. The Transfer function method uses a set of two microphones to acquire pressure level by a sound generating source near the sample. VA-Lab IMP can accurately separate the incident wave from reflecting wave to measure absorption coefficient. An extended frequency range can be obtained from the combination of measurement results gained from the tubes of different diameters. VA-Lab2 IMP supports the 2-channel hardware to measure absorption coefficient and VA-Lab4

IMP supports four microphones transfer function method to measure transmission loss [41].

4.2 Sample Type

MF is selected porous material for this study of sound attenuation. It is an open cell foam made from melamine resin which is a thermoset polymer. This foam comprises of three-dimensional network structures consisting of slender and easily shaped filaments. Key characteristics of this foam are:

- Low density and high acoustic absorption capacity
- Good heat insulation properties
- Can withstand temperature up to 240^o C

Foam samples of two different diameters (100mm & 30mm) are used to measure transmission losses and absorption coefficients for two different sizes of impedance tube. Test samples are shown in Figure 5

Figure 5: Testing samples of melamine foam (100 mm & 30 mm diameters)

4.3 Testing Setup

Setup of absorption coefficient testing system is shown in Figure 6. To measure the absorption coefficient of material, Source tube and Sample holder are necessary. The sound will be generated via loudspeaker located at the extreme left side and sample holder is located at extreme right of the tube. Two microphones are used to capture the sound energy level before and after absorption. Data acquisition board & a Lab VIEW system are used to gather and process the data. Microphones are positioned in such a way that all the frequency range of interest (64 Hz to 6.3 kHz) should easily be captured.

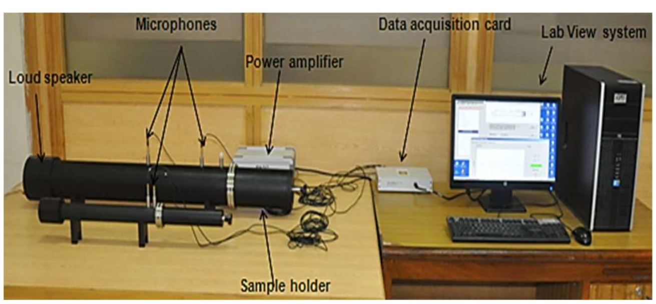

Figure 6: Complete experimental setup for the measurement of absorption coefficient**.**

Setup for measurement of transmission loss is shown in Figure 7. To measure transmission loss, sample holder is replaced by extension tube. The sound will be generated via loudspeaker from the extreme left position; extension tube is attached with the source tube at extreme right, and sample is placed between source tube and extension tube. Two microphones are positioned on the upstream and two are placed on the downstream region. Four microphones are used to measure the sound energy level before and after transmission. Data acquisition system processes these energy levels and provides the transmission loss. Microphones are positioned to capture desired range of frequency from 64 Hz to 6.3 kHz.

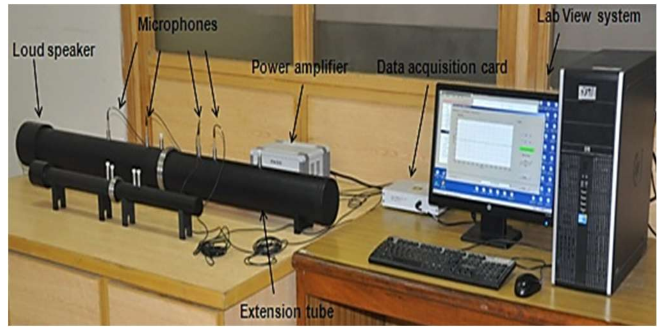

Figure 7: Complete experimental setup for the measurement of transmission loss

For both absorption coefficient and transmission loss, the parameters including tube diameter, distance between two microphones and the distance from the sample to the nearest microphone decide the working frequency range. The data out of this pre-defined range of frequency will be inaccurate. The environmental conditions such as atmospheric pressure, temperature, humidity, velocity and characteristic impedance should be accurately defined.

As per testing standard, the loudspeaker should work at least 10 minutes before testing. The different positions of microphones work in different effectual frequency range, curves out of the range will be random. For both type of testing, the test sample shall fit snugly in the holder. However, it shall not be compressed unduly nor fitted so tightly that it bulges. It is recommended to fill in the interspaces by using Vaseline or Plasticine between the sample and the tube. The test sample can be held firmly, if necessary, by adhesive tape or grease. For example, samples such as carpet material should be firmly attached to the back plate using double-sided adhesive tape to avoid vibration and unwanted air gaps. Most of the specimen, even the uniform one, should be tested repeatedly. Absorption coefficient of the same sample in different diameter tubes will be dissimilar mostly because of the dimension of the specimens and the situation of specimens' edge. Uncertainties to the determined acoustic material properties would come from material samples and placement, bias errors and reference plane definition.

5 Result and Discussion

5.1 Absorption coefficient

The absorption coefficients of the three samples (25mm, 50mm and 75mm) is measured using both the small and large tubes as shown in Figure 8 to Figure 12 for working frequency range of 64 Hz to 6.3 kHz. This range is achieved with three arrangements. First is from 63 Hz to 500 Hz with wide spacing of microphones. Second is from 400 Hz to 1600 Hz with normal spacing. The third arrangement is from 1600 Hz to 6.3 kHz with small diameter tube and normal spacing of microphones. The flow resistance of the material under test is relatively low, and because the sample is effectively anechoically-terminated, most of the incident energy is either transmitted through the sample or is dissipated within it. As a result, the magnitude of the reflection is relatively low consequently having higher absorption coefficient except at the lower frequencies where the sample is stiffened by the effect of the edge constraint. It may be seen, as expected, that the absorption coefficients are nearly unity, except at the lower frequencies.

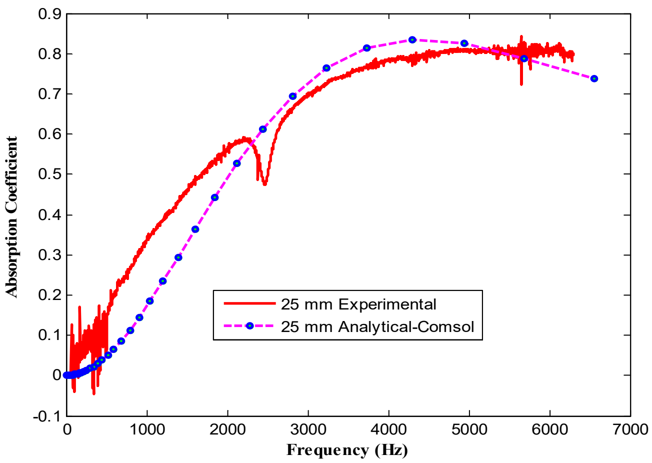

Figure 8: Absorption coefficient for 25 mm thick melamine foam

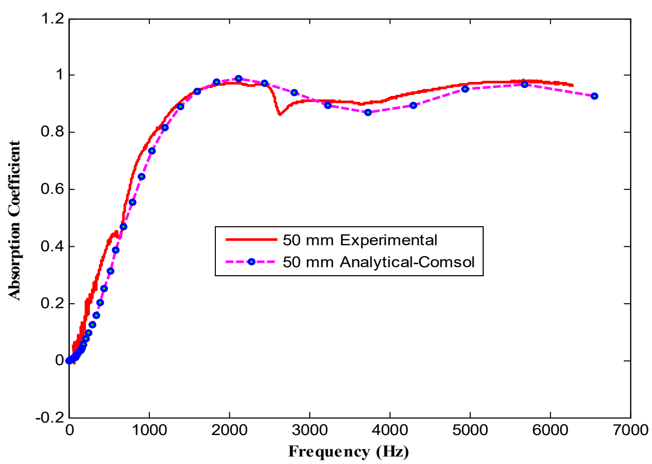

Figure 9: Absorption coefficient for 50 mm thick melamine foam

Note also that there are resonance features at two different locations of all three samples. This behaviour is typical of the effect of sample edge constraint on the normal incidence absorption loss of an elastic porous material [42]. The two features represent the effects of the first two diaphragm-like modes of the samples in which the sample experiences a pure shearing motion. The frequencies at which these features occur are inversely proportional to the sample diameter and are directly proportional to the square root of the ratio of the shear modulus and density of the sample. Thus, the first resonance in the large tube case occurs at approximately one-quarter of the resonance frequency observed in the small tube. The similar relation exists in the difference of diameter of the impedance tube (100 mm & 30 mm). These features are not visible in FEA results because the acoustic analysis is performed on infinite plate sheet where the sample edge constraint effect does not exist.

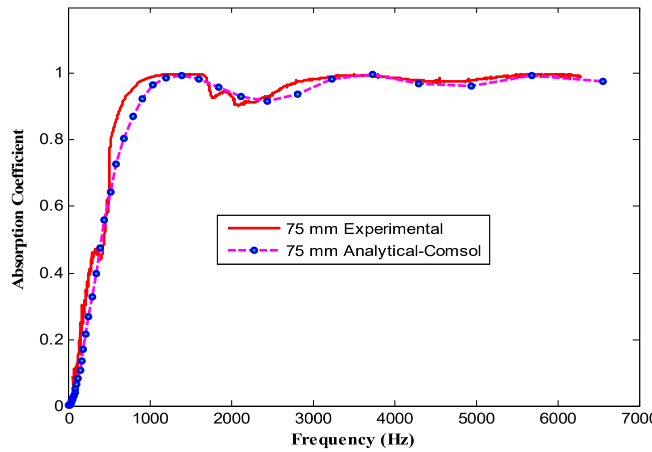

Figure 10: Absorption coefficient for 75 mm thick melamine foam

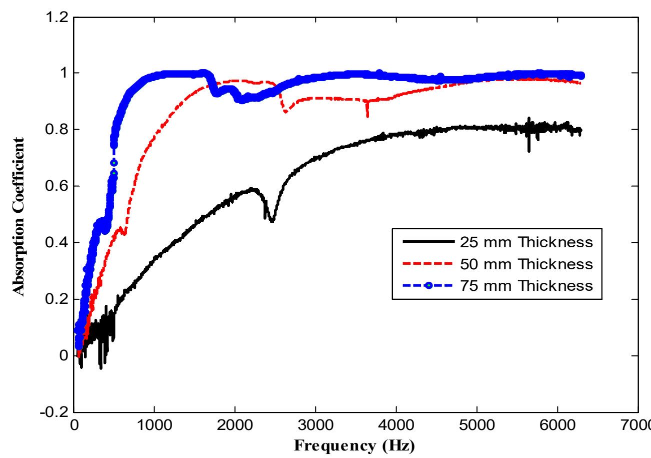

Figure 11: Combined absorption coefficient plot for three thicknesses (Experimental)

Figure 8 – Figure 10, show that the numerical and experimental results are in good agreement. The saturation in absorption coefficient is achieved at lower frequencies as the thickness of the sample is increased. For 25mm thickness sample, total absorption is achieved in between 4,000-5,000 Hz, for 50 mm sample around 2,000 Hz and for 75mm thickness around 1,000 Hz. Combined absorption coefficient plot for three different thickness samples is shown in Figure 11. It can be observed that the absorption coefficient is increasing with the frequency and maximum value of 0.8 is achieved at 4,200Hz for 25mm thickness. Saturation in absorption coefficient is achieved much earlier for higher thickness samples.

These results are compared with other published research as shown in Figure 12. Doutres et al. (2010) used the similar setup and found out acoustic properties of a porous material. The trend and magnitude of absorption coefficient are similar to present research. The saturation of absorption coefficient at the value of 1.0 is achieved at almost same frequency resulting that the properties of the material are almost similar to the MF. However, the slight variation could be because of variation in thickness and change of material properties of test samples. Furthermore, in published research the resonance features are not evident which are highlighted in present research. The prior information of these features can be extremely useful for design and to avoid any possible failure at these critical frequencies.

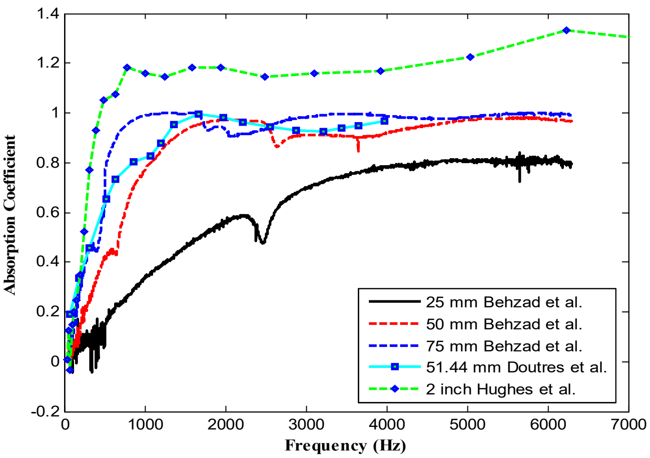

Figure 12: Result comparison for absorption coefficient with published research

Another researcher Hughes et al. (2014) from NASA carried out similar research on variety of test samples including 2 in MF for absorption coefficient only. However, the boundary conditions were different. They used a flat panel rather a cylindrical tube type boundary conditions. They used a higher quality of MF, thus, having better material properties. The active frequency range is same which suggest that both material have a tendency to attenuate the sound wave for a wide frequency range.

5.2 Transmission loss

Transmission loss of all three samples (25mm, 50mm and 75mm) is estimated first through FEA and later validated with both large and small diameter impedance tube as shown in Figure 13 to Figure 16. It is shown that the transmission loss increases monotonically with increasing frequency as expected for a porous layer. The working frequency range is from 64 Hz to 6.3 kHz. Note also that there are resonance features at approximately 450 Hz and 1800 Hz appears in the large and small tube results respectively. This behaviour is typical of the effect of sample edge constraint on the normal incidence transmission loss of an elastic porous material. The similar features are observed in the measured absorption coefficient. Thus, the first resonance in the large tube case occurs at approximately one-quarter of the resonance frequency observed in the small tube. The similar relation exists in the difference of impedance tube diameters (100 mm & 30 mm). These features are not visible in FEA results because the acoustic analysis is performed on infinite plate sheet where the sample edge constraint effect does not exist.

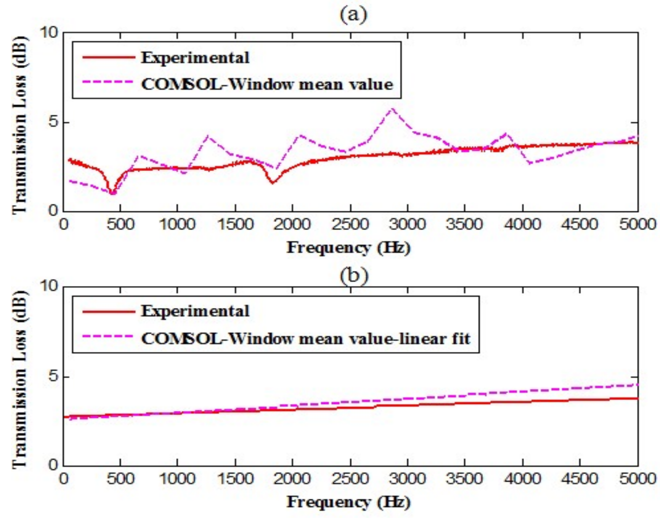

Figure 13: Transmission loss for 25 mm thick melamine foam

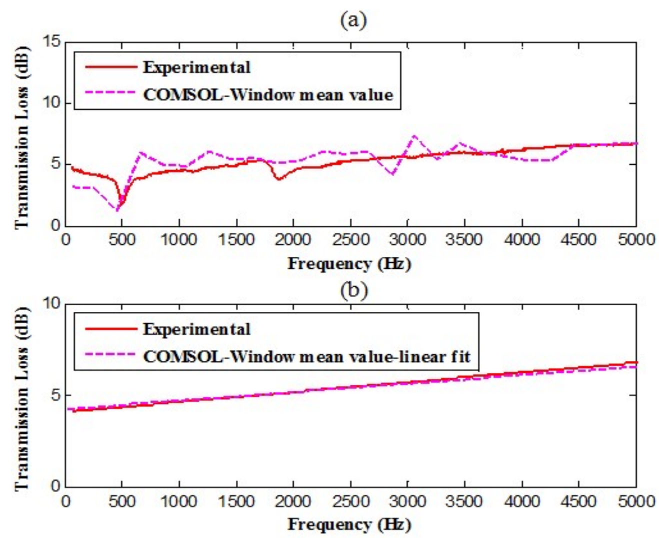

Figure 14: Transmission loss for 50 mm thick melamine foam

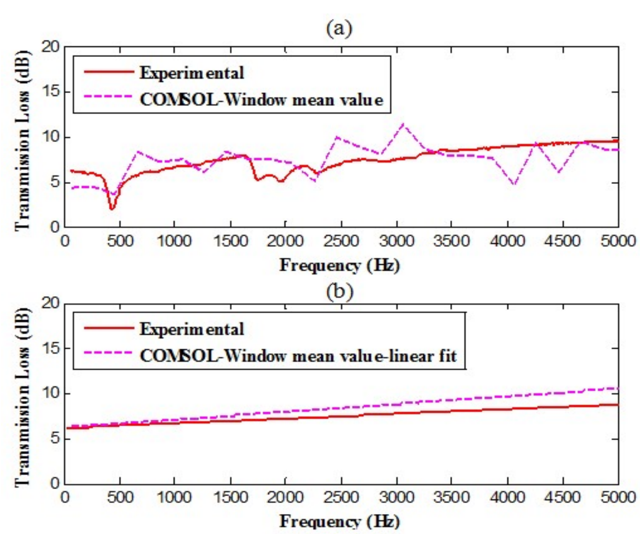

Figure 15: Transmission loss for 75 mm thick melamine foam

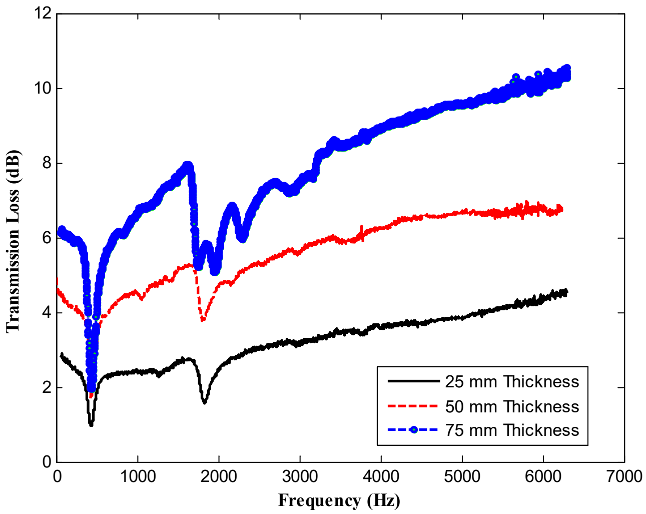

Figure 16: Combined transmission loss plot for three thicknesses (Experimental)

Nonetheless, a close examination of the data shows that the transmission loss does increase with decreasing frequency below the first resonance in both the large and small tube results. Thus, at low frequencies the sample edge constraint causes the normal incidence transmission loss of a porous sample measured in a tube to differ from that of a laterally infinite plane sheet of the same material as depicts in FEA results. This effect becomes more significant as the flow resistivity of the samples increases (therein increasing the strength of the coupling between the solid and fluid phases of the material) and the shear stiffness of the sample increases in proportion to its bulk density (increasing the frequency of the diaphragm-like resonances).

Figure 13 (a) - Figure 15 (a), show that the analytical results obtained via commercial FEA software and experimental results are in good agreement. It is observed that the trend of both approaches are same, however there is larger variation in analytical results around the experimental value. Therefore, a mean window operation is applied to the data. In this approach the mean of five consecutive values are computed and plotted against the mean frequency. An additional processing in the analytical data is performed with the assumption that the data acquired from experimental setup is being processed. Figure 13 (b) – Figure 15 (b) show the linear fit plot for both analytical and experimental results, these plots follow each other and are in good agreement.

Combined transmission loss plot for three different thickness samples is shown in Figure 16. It is observed that the transmission losses are increasing with the frequency except for ~ 450Hz & ~1,800 Hz, where a resonance effect is evident. Furthermore, an appreciable increase in transmission losses is observed with the increasing foam thickness. Similar to absorption coefficient, the results of transmission loss are compared with other published research (b) as shown in Figure 17. Doutres et al. (2010) used the similar setup and found out acoustic properties of a porous material. The trend and magnitude of transmission loss are similar to present research. Like the absorption coefficient, the magnitude of transmission loss is higher compared to 50 mm MF because of higher thickness and better physical properties. In published research, the resonance features are evident similar to present research at displaced frequencies. Another researcher Hughes et al. (2014) from NASA carried out similar research on variety of test samples for transmission loss. However, the sample configuration was different from the present research.

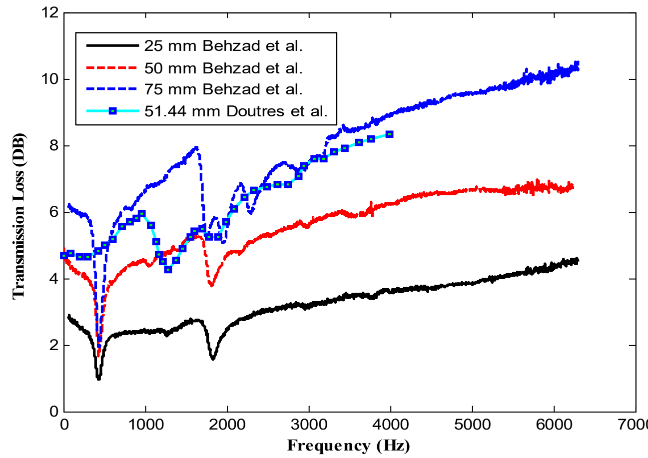

Figure 17: Result comparison for transmission loss with other published research

6 Conclusion

The acoustic parameters including transmission loss and absorption coefficient are investigated both numerically and experimentally with working frequency range of 64 Hz to 6.2 kHz using melamine foam (MF). Three different sample thicknesses are employed to have better correlation of the acoustic parameters with respect to frequency and thickness. The resonance features are identified in both absorption coefficient and transmission loss measurements. The saturation level for absorption coefficients is achieved earlier for higher thickness compared to lower thickness of MF lining. The transmission loss of 2-4 dB (25mm), 4-6 dB (50mm) and 6-8 dB (75mm) is achieved for variable thickness samples. Numerically computed parameters are validated using impedance tube setup and are found in good agreement. These results are very useful to estimate the acoustic characteristics for designing insulation blanket of different structure which are vulnerable against acoustic loading.

References

[1] T. Do. 1999. "Vibroacoustic Modeling Study of the Delta II 10-Foot Composite Fairing." *Journal of the IEST* 42 (6): 26-33.

[2] H. Defosse and M.A. Hamdi. 2000. "Vibro-acoustic study of Ariane V launcher during lift-off." *The 29th International exhibition on noise control engineering, France.*

[3] D. Bianco, P. Francesco, M. Barbarin, P. Vitiello, D. Bartoccini, L. Federico and Citarella Roberto. 2018. "Integrated Aero–Vibroacoustic: The Design Verification Process of Vega-C Launcher." *Applied Sciences* 8(88).

[4] J.M. Scott, B.G. Jay and C.B. Robert. 1996. "General Environmental specification for STS and ELV – Payloads, Subsystems and Components. GEVS-SE." Rev. June, NASA Goddard Space Flight Center, Greenbelt, Maryland, 20771.

[5] R.M. Glaese, E.H. Anderson. 2003. "Initial Structural-Acoustic Modeling and Control Results for a Full-Scale Composite Payload Fairing for Acoustic Launch Load Alleviation." CSA Engineering,2565 Leghorn Street, Mountain View, CA,94043.

[6] G.H. Yuan, X.C. Wang, P.Z. Hou and C.L. Li. 2007. "Absorbing Property of Open-Cell Melamine Foam." *Material Mechanical Engineering* 31(9): 55–57.

[7] J.P. Arenas and M.J Crocker. 2010. "Recent Trends in Porous Sound Absorbing Materials." *Sound and Vibration* 44 (7): 12–17.

[8] A.M. McNelis, W.O. Hughes and M.E. McNelis. 2014. "NASA Engineering and Safety Center (NESC) Enhanced Melamine (ML) Foam Acoustic Test (NEMFAT)." Hampton, VA, USA: National Aeronautics and Space Administration, Langley Research Center.

[9] M. McNelis and W.O. Hughes. 2015. "Effect of Coversheet Materials on the Acoustic Performance of Melamine Foam." NASA Glenn Research Center at Lewis Field.

[10] W.O. Hughes, A.M. McNelis and M. Emcnelis M. 2014. "Acoustic Test Characterization of Melamine Foam for Usage in NASA's Payload Fairing Acoustic Attenuation Systems." Cleveland, OH, USA: Glenn Research Center.

[11] Bin Li, Xiangyu Chen, Wenjie Yan, Shilin Yan and Xu He. 2019. "Theoretical and Experimental Study On Effect of Melamine Foam Lining on Acoustic Characteristics of a Cylindrical Cavity." *Results in Physics* 13.

[12] J.S. Bolton. 2005. "Porous Materials for Sound Absorption and Transmission Control." *Proceedings of Congress and Exposition on Noise Control Engineering*, Brazil.

[13] Olivier Doutres, Yacoubou Salissou, Noureddine Atalla and Raymond Panneton. 2010. "Evaluation of The Acoustic and Non-Acoustic Properties of Sound Absorbing Materials Using a Three-Microphone Impedance Tube." *Applied Acoustics* 71 (6): 506-509.

[14] R. Wijntjes, F. Simon, T. Haase, O. Unruh and E. Tijs. 2016. "Benchmark for Experimentation of Acoustic Transmission Loss Applied to Helicopter Trim Panels." *ERF 2016 42nd European Rotocraft Forum, France*.

[15] Marius Deaconu and Laurentiu Cristea, 2016. "Sound Transmission Loss in Porous and Isotropic Materials. Comparative Analysis Between Impedance Tube and FEM Results." *Proceedings of the Annual Symposium of the Institute of Solid Mechanics and Session of the Commission of Acoustics, SISOM 2016 Bucharest 12-13 May*.

[16] Yacoubou Salissou and Raymond Panneton. 2009. "A General Wave Decomposition Formula for The Measurement of Normal Incidence Sound Transmission Loss in Impedance Tube." *The Journal of the Acoustical Society of America* 125(4): 2083.

[17] Abhishek Kundu and Alain Berry. 2011. "Active Sound Control with Smart Foams Using Piezoelectric Sensoriactuator." *Journal of Intelligent Material Systems and Structures* 22 (16): 1771-1787.

[18] Olivier Doutres and Noureddine Atalla. 2011. "Experimental Estimation of the Transmission Loss Contributions of a Sound Package Placed in a Double Wall Structure." *Applied Acoustics* 22(6): 372-379.

[19] W. Lauriks. 2005. "Characterization of Porous Acoustic Materials. Symposium on the Acoustics of Poro-Elastic Materials." France.

[20] Guosheng Ji, Yi Fang, Jie Zhou and Xun Huang. 2019. "Porous Labyrinthine Acoustic Metamaterials with High Transmission Loss Property." *Journal of Applied Physics* 125(21).

[21] Yong Yang, Zhou Chen, Tengzhou Xu, Ruonan Han and Desire Emefa Awuye. 2019. "Sound Insulation and Hydrophobic Properties of Phenolic Resin Modified Melamine Foam: Role of Micro-Morphology, Materials Research Express."

[22] COMSOL Multiphysics modeling Guide.

[23] W. Zheng. 2011. "Development of Acoustic Models for High Frequency Resonators for Turbocharged IC-Engines." MS thesis in Sound & Vibration Stockholm, Sweden.

[24] S. Tomasz. 2010. "Finite Element Modeling of Sound Transmission Loss in Reflective Pipe." Poznan University of Technology Institute of Applied Mechanics, Poland.

[25] Hiroshi Nakagawa and Kunikazu Hirosawa. 2018. "Development of A Narrow Impedance Tube to Measure Normal Absorption Coefficient and Transmission Loss at High Frequencies Around 10 kHz." Acoustic Science & Technology 39 (6).

[26] J. Stuart Bolton, Taewook Yoo and Oliviero Olivieri. 2007. "Measurement of Normal Incidence Transmission Loss and Other Acoustical Properties of Materials Placed in a Standing Wave Tube." *Technical Review, Brüel& Kjær Sound & Vibration Measurement A/S.*

[27] X. Hua and D. Herrin. 2013. "Practical Considerations when using the Two-Load Method to Determine the Transmission Loss of Mufflers and Silencers." *SAE International Journal of Passenger Cars – Mechanical System* 6(2).

[28] Miša Oblak, Miha Pirnat and Miha Boltežar. 2018. "An Impedance Tube Submerged in A Liquid for The Low-Frequency Transmission-Loss Measurement of a Porous Material." *Applied Acoustics* 139: 203-212.

[29] Behrooz Yousefzadeh. 2008. "An Experimental Study of Sound Transmission Loss (STL) Measurement Techniques using an Impedance Tube." *The Journal of the Acoustical Society of America* 123.

[30] Martin Wolkesson. 2012. "Evaluation of Impedance Tube Methods a Two Microphone In-Situ Method for Road Surfaces and The Three Microphone Transfer Function Method for Porous Materials." MS Thesis, Department of Civil and Environmental Engineering Division of Applied Acoustics, Chalmers University of Technology, Sweden.

[31] U. Berardi, G. Iannace. 2015. "Acoustic characterization of natural fibers for sound absorption applications. " Building and Environment 94(2): 840-852.

[32] G. Iannace.. 2014. "Acoustic Properties of Nanofibers." Noise & Vibration Worldwide https://doi.org/10.1260/0957-4565.45.10.29

[33] G. Iannace.. 2017. "The acoustic characterization of green materials." Noise & Vibration Worldwide https://doi.org/10.1177/1351010X17704624

[34] G. Ciaburro, G. Iannace. 2021. "Acoustic Characterization of Rooms Using Reverberation Time Estimation Based on Supervised Learning Algorithm." *Appl. Sci. 11*(4), 1661; https://doi.org/10.3390/app11041661

[35] A.F. Seybert and D.F. Ross. 1997. "Experimental Determination of Acoustic Properties Using a Two-Microphone Random-Excitation Technique." *The Journal of the Acoustical Society of America* 61(5): 1362-1370.

[36] ISO 10534-2. 1998. "Acoustics – determination of sound absorption coefficient and impedance in impedance tubes – part 2: transfer-function method", ISO 10534-2.

[37] J.S. Bolton, N.M. Shiau and Y.J. Kang. 1996. "Sound Transmission Through Multi-Panel Structures Lined with Elastic Porous Materials." *Journal of Sound and Vibration* (191): 317–347.

[38] K.N. Ho, Z. Yang, X.X. Zhang and P. Sheng. 2005. "Measurements of Sound Transmission Through Panels of Locally Resonant Materials Between Impedance Tubes." *Applied Acoustics* 66: 751–765.

[39] Y. Ryu. 2000. "The acoustic impedance measurement system using two microphones, Bruel & Kjaer sound & vibration measurement a/s, Denmark."

[40] S.S. Jung, Y.T. Kim, Y.B. Lee. 2008. "Measurement of Sound Transmission Loss by Using Impedance Tubes." *Journal of the Korean Physical Society* 53 (2): 596-600.

[41] User's Manual "Impedance Tube Test System" No: BSWA-III-C021-03-0027-IMP Ver.: V1.03 Release Data: Mar./09/2010 BSWA TECH.

[42] L.L. Beranek. 1947. "Some notes on the measurement of acoustic impedance*." Journal of Acoustic Soc. Am.* 19: 420-427.