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Effect of intrinsic parameters on sound absorption and transmission loss-A parametric study

Paresh Shravage[a)]
Sachin Jain[b)]
Nagesh Karanth[c)]
Noise, Vibration and Harshness Lab
Automotive Research Association of India
P.O. Box 832
Pune-411004 INDIA

Sound absorbing materials are indispensable nowadays for noise control treatments in transport industry. The acoustical behavior of these acoustic materials is governed by five physical (e.g., porosity, flow resistivity, tortuosity, viscous characteristic length, and thermal characteristic length) as well as three mechanical parameters (e.g., Young's modulus, Poisson ratio, and loss factor). The characterization of these porous materials is very crucial as it plays an important role in design and development stage itself for predicting acoustic behavior of multilayer porous materials for higher sound absorption and transmission loss. This prediction depends on measurement accuracy of macroscopic physical parameters which are very difficult to measure except porosity and flow resistivity, which is the only standardized test until today; also availability of such rigs is also a problem for manufactures as they are available only at specialized test laboratories. This paper presents effect of all these parameters on sound absorption coefficient and transmission loss of the porous materials using rigid (Johnson–Champoux–Allard), limp and elastic (Biot) model for poroelastic materials. It also discusses results of simulation with effect of each parameter on acoustic behavior of the sound absorbing materials.

1 INTRODUCTION

Acoustic porous material models are formulated in terms of macroscopically measurable physical properties of the frame and fluid. The most important macroscopic physical parameters as discussed in literature are flow resistivity, porosity, tortuosity and characteristics lengths[1,2]. The advantage of such theoretical formulation is that it enables the investigation of the influence of the various directly measurable physical macroscopic parameters of the porous material so that a particular set of physical parameters can be identified that will result in porous material having specified performance. In addition, it is easy to use simplified models that are derived by neglecting the elastic parameters that are judged to be least significant in a particular situation (e.g., the bulk elastic properties in the case of a nearly rigid porous material exposed to airborne incident sound) may be used in preliminary analyses. It should be noted, of course, that there is a direct link between

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[a)] Email address: Shravage.nvh@araiindia.com
[b)] Email address: Jain.nvh@araiindia.com
[c)] Email address: Karanth.nvh@araiindia.com

the microscopic structure of a porous material (e.g., fiber radius, fiber orientation, fiber material density, number of fibers per unit material volume, etc.) and its macroscopic properties. To-date, however, there is little information available linking the microscopic properties of a porous material to its macroscopic properties. This paper presents effect of intrinsic physical parameters on normal incidence sound absorption as well sound transmission loss.

2 EFFECT OF PHYSICAL PARAMETERS ON ABSORPTION AND TRANSMISSION LOSS

Rigid porous model (Johnson-Champoux-Allard) model is used to check the effect of physical parameters on normal incidence sound absorption coefficient while limp model is used to simulate effect of physical parameters on sound transmission loss. Rigid porous model requires five physical parameters to simulate acoustic behavior of porous materials while limp model require five physical parameter and density. Biot model is based upon five physical as well three elastic parameters.

2.1 Effect of Flow Resistivity

The material simulated in this section is melamine foam of 30 mm thickness Flow resistivity of the material is varied in linear steps while other parameters are kept constant. The values of other parameters used in the simulation are given in Table 1.

From Fig. 1(a), it is clear that with increase in flow resistivity up to a certain value, there is significant increase in sound absorption coefficient in the mid frequency range. After that absorption decreases slightly and remains constant, it is because of the impedance mismatch between the air and the absorbent which causes the reflection of sound from the front face reducing the absorption of porous material[3]. Materials like cellular rubber or polyimide foam show similar behaviour as they have very high flow resistivity values. In Fig. 1(b), influence of flow resistivity on sound transmission loss is depicted and sharp increase in sound transmission loss with increase is observed.

2.2 Effect of Porosity

30 mm Melamine foam is simulated to check the influence of porosity variation on normal incidence sound absorption and transmission loss. The materials parameters used for this simulation are given in Table 2. Porosity is varied from 0.5 to 1 keeping other parameters constant. Porous materials generally have porosity near to 1 resulting into high absorption values. In Fig. 2(a) influence of porosity on normal incidence sound absorption coefficient shown. From this figure it is observed that porosity also has more influence on sound absorption at mid to high frequencies. Sound absorption increases with increase in porosity. Similar trend is observed for sound transmission loss of the material.

2.3 Effect of Tortuosity

Melamine foam is simulated to check the influence of tortuosity variation on normal incidence sound absorption and transmission loss. The materials parameters used for this simulation are given in Table 3. Tortuosity is varied from 1 to 10 keeping other parameters constant. Porous materials generally have tortuosity close to 1. In Fig. 3(a) influence of tortuosity on normal incidence sound absorption coefficient shown. From this figure it is observed that absorption is higher near to the peaks, while more riffle is observed at high frequencies as it is responsible for the difference between the speed of sound in air and the speed of sound through a porous material[4]. When tortuosity is higher, it will affect sound speed inside the material. This feature will have vital influence on absorption of the porous material mounted on rigid surface as they will exhibit absorption maxima and minima at the acoustic resonance and antiresonance frequencies as seen in Fig. 3(a). Figure 3(b) shows effect of tortuosity on normal incidence sound transmission loss of the porous material. The effect of tortuosity on sound transmission loss is similar to absorption.

2.4 Effect of characteristics Lengths (VCL & TCL)

Characteristics lengths are related to viscous and thermal effects in poroelastic materials. There are two types of characteristics lengths as described in literature. Viscous characteristic length is related to viscous effects at mid to high frequencies while Thermal characteristic length is related to thermal effects at high frequencies in porous materials. In foams, TCL is generally higher than VCL. The simulation parameters are shown in Table 4.

In fibrous materials, VCL is approximately similar to TCL as they are made up of fibres of equal diameters. In this section influence of VCL over sound absorption coefficient is analysed. The variation in VCL was chosen from 1μm to 500 μm. Figure 4(a) shows influence of VCL on sound absorption coefficient. As VCL is related to diameter of the channel interconnecting to other pores, it provides path for sound propagation[5]. As seen in above figure when VCL is low, its influence at sound absorption coefficient is higher at mid and high frequency band and sound absorption is lower in that frequency band. Lower VCL will result in low fluid content inside the porous sample decreasing its porosity and increase in tortuosity as solid content of the material will increase and can be verified by seeing Fig. 4(b) which shows effect of VCL on sound transmission loss of porous material. Low value of VCL results in higher transmission loss at mid and high frequencies. At higher value of VCL, sound transmission loss decreases as pores become open increasing fluid content inside the material. In next section, effect of TCL on sound absorption coefficient and sound transmission loss is discussed. TCL is varied from 1μm to 700 μm keeping other physical parameters constant. The simulation parameters are given in Table 5 below. From Fig. 5(a), it is observed that there is no significant effect of TCL on sound absorption coefficient in the entire frequency band of interest.

Figure 5(b) shows effect of TCL on sound transmission loss of the porous material except at very low value of TCL, where increase in sound transmission loss of the material is found, this is due to low cross-sectional area of the pores inside the porous material which results into high flow resistivity and tortuosity of the porous material. When the optimized value of TCL is attained around 250 μm which is the measured TCL for this material, sound transmission loss decreases and remains constant over the frequency range.

3 EFFECT OF MECHANICAL PARAMETERS OF SOUND ABSORPTION AND SOUND TRANSMISSION LOSS

In Biot theory, the open cell porous materials are also characterized by three macroscopic elastic properties with five macroscopic physical parameters. These elastic properties are Young’s modulus, Poisson ratio and loss factor. These properties are always complex valued and frequency dependent due to viscosity of the frame of the porous material[6]. In elastic porous materials strong coupling exists between frame and fluid resulting into one airborne wave, which propagates into only fluid and frame borne wave which propagates into both frame and fluid. The mechanical parameters in poroelastic materials are related to the elastic nature of the porous material. This section presents a parametric study of elastic parameters with influence on normal incidence sound absorption of the porous materials. Biot model is used to study effect of these parameters on acoustic behaviour of the porous material and it is simulated in COMSOL®.

The physical parameters used for the parametric study are given in Table 6. The density of the material was 8.8 Kg/m^3.

Acoustic behaviour of porous materials can be completely described by five physical and three elastic parameters. These elastic parameters are only related to structure borne vibrations of the frame as they do no take part in sound absorption or transmission mechanism. The elastic parameters used for simulation are depicted in Table 7 below

Figure 6(a) shows influence of Young's modulus on sound absorption coefficient of porous material. There is no influence of Young's modulus on the sound absorption coefficient except shift in the resonance frequency of the frame of porous material. For a porous material, Allard[7] has calculated the resonance frequency of the frame of porous material and it is given as

$$f = \left(\frac{1}{4d}\right)\left(\frac{E}{\rho}\right)^{1/2} \qquad (1)$$

In this equation d is thickness, E is Young's modulus and ρ is the density of the material. As seen in Fig. 6(a), shift in resonance frequency is observed with increase in Young's modulus. The poroelastic material is also characterized by Poisson ratio of the material. The parameters used for this parametric study are given in Table 8. The effect of Poisson ratio is also similar to effect of Young's modulus on sound absorption as shown in Fig. 6(b) as long as shear modulus G of the material is constant. The shear modulus of the material is given by

$$G = \frac{E}{2(1+\nu)} \qquad (2)$$

Earlier the effect of single parameter shear modulus was studied by Bolton and his group and it is proved that shear modulus with bulk density of the material controls the dynamic behavior of the porous material[8]. Similar effect of Young's modulus and Poisson ratio is found on sound transmission loss as shown in Figs. 7(a) and 7(b) respectively.

4 CONCLUSIONS

The paper presents the effect of physical parameters on sound absorption coefficient as well as sound transmission loss of the porous materials. From this parametric study, it is clear that flow resistivity is one of the most governing parameter of acoustic behavior of the porous material along with porosity and tortuosity while elastic parameters does not contribute to the acoustic behavior of the poroelastic materials

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Table 1 - Macroscopic Physical Parameters.

Physical Parameters	ϕ	σ	α_∞	Λ	Λ'
Values	0.995	1000-120000	1.03	99	142

Table 2 - Macroscopic Physical Parameters.

Physical Parameters	ϕ	σ	α_∞	Λ	Λ'
Values	0.5-1.0	10186	1.03	99	142

Table 3 - Macroscopic Physical Parameters.

Physical Parameters	ϕ	σ	α_∞	Λ	Λ'
Values	0.995	10186	1-10	99	142

Table 4 - Macroscopic Physical Parameters.

Physical Parameters	ϕ	σ	α_∞	Λ	Λ'
Values	0.995	10186	1.03	1-200	142

Table 5 - Macroscopic Physical Parameters.

Physical Parameters	ϕ	σ	α_∞	Λ	Λ'
Values	0.995	10186	1.03	99	1-700

Table 6 - Macroscopic Physical Parameters.

Physical Parameters	Values
Flow Resistivity [Ns/m^4]	10186
Porosity [-]	0.995
Tortuosity [-]	1.03
VCL [µm]	99
TCL[µm]	142

Table 7 - Mechanical Parameters.

Mechanical Parameters	Values
Young’s Modulus [N/m^2]	10000-300000
Poisson Ratio [-]	0.38
Loss Factor	0.009

Table 8 - Mechanical Parameters.

Mechanical Parameters	Values
Young’s Modulus [N/m^2]	80000
Poisson Ratio [-]	0-0.48
Loss Factor	0.009

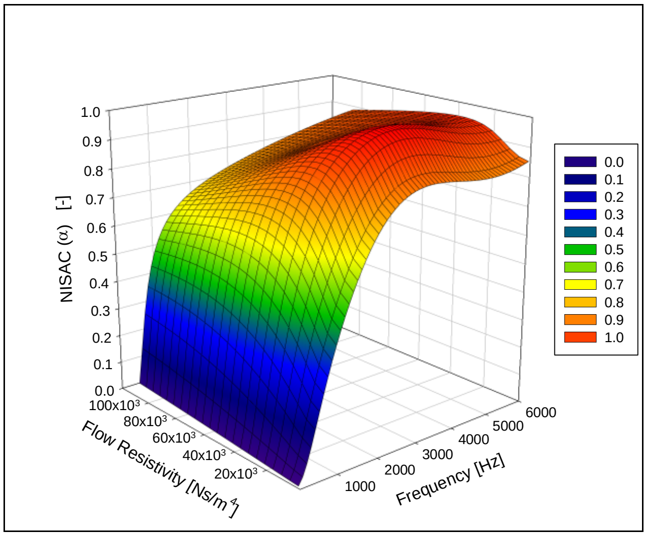

Fig. 1(a) - Effect of Flow resistivity on Normal Incidence Sound Absorption Coefficient (NISAC).

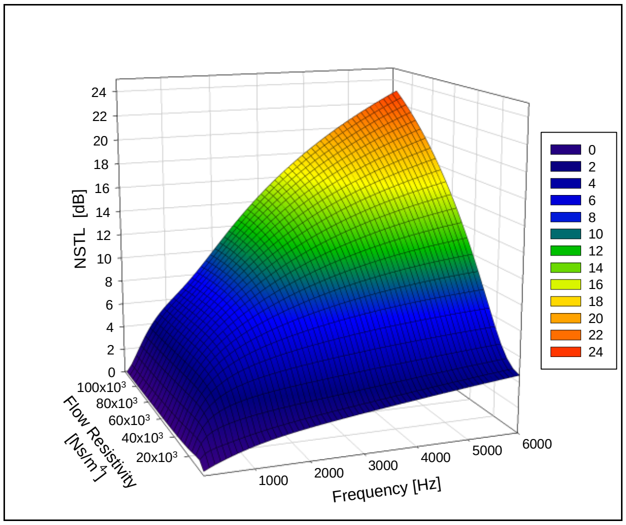

Fig. 1(b) - Effect of Flow resistivity on Normal Incidence Sound Transmission Loss (NISTL).

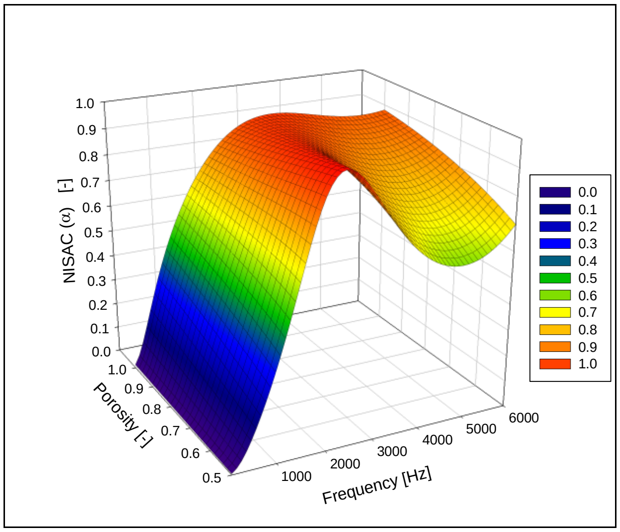

Fig. 2(a) - Effect of Porosity on Normal Incidence Sound Absorption Coefficient (NISAC).

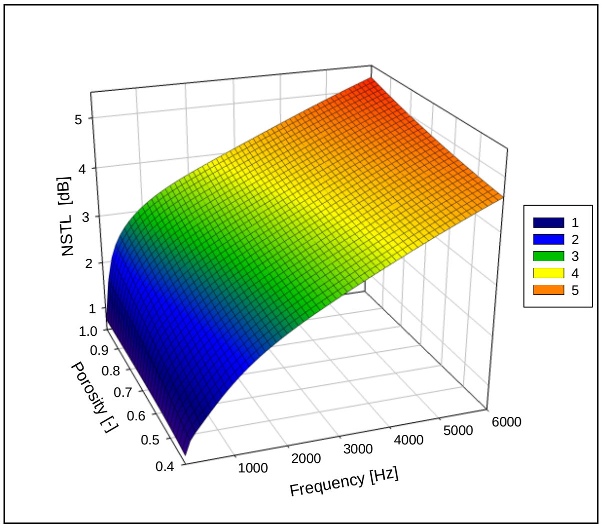

Fig. 2(b) - Effect of Porosity on Normal Incidence Sound Transmission Loss (NISTL).

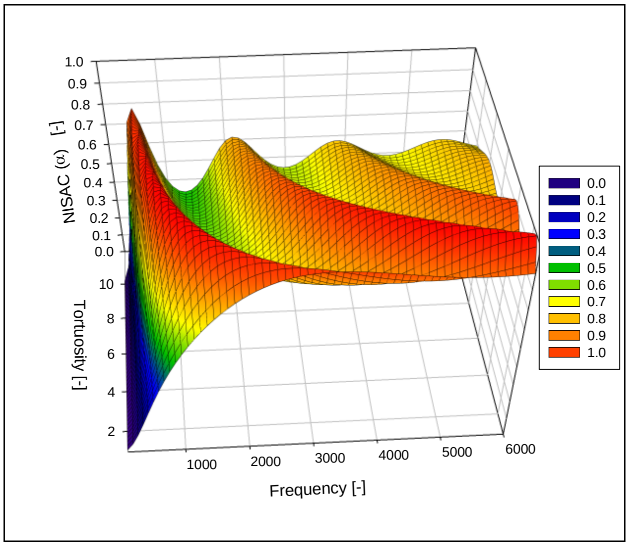

Fig. 3(a) - Effect of Tortuosity on Normal Incidence Sound Absorption Coefficient (NISAC).

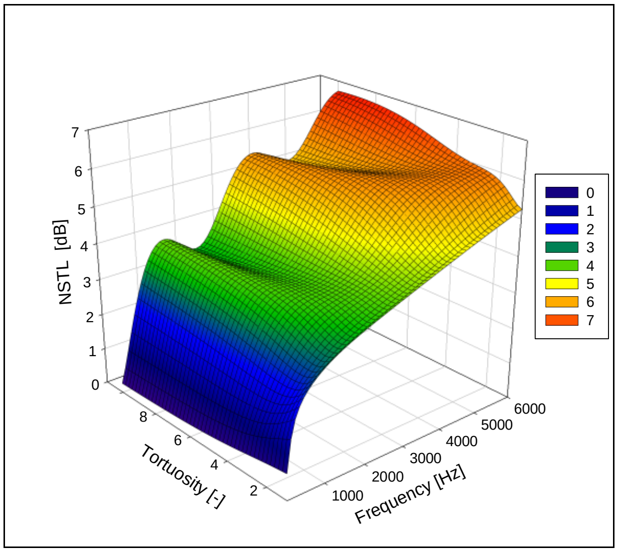

Fig. 3(b) - Effect of Tortuosity on Normal Incidence Sound Transmission Loss (NISTL).

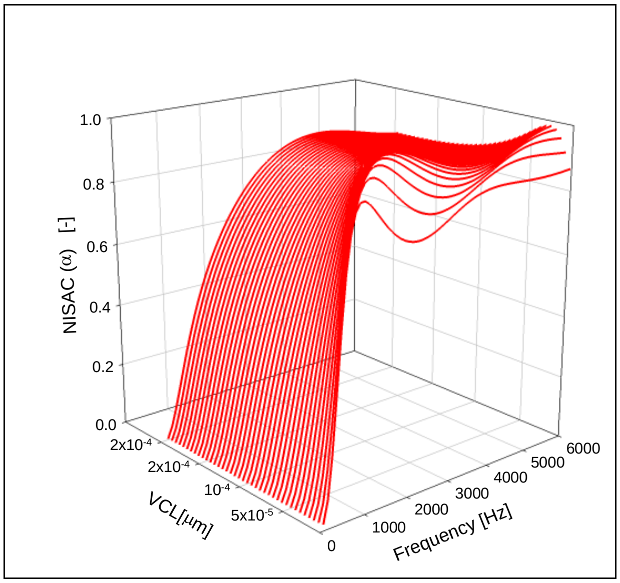

Fig. 4(a) - Effect of VCL on Normal Incidence Sound Absorption Coefficient (NISAC).

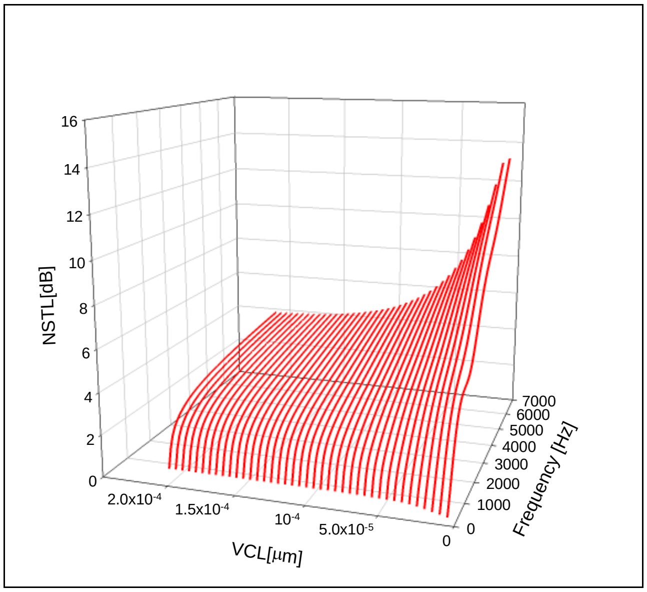

Fig. 4(b) - Effect of VCL on Normal Incidence Sound Transmission Loss (NISTL).

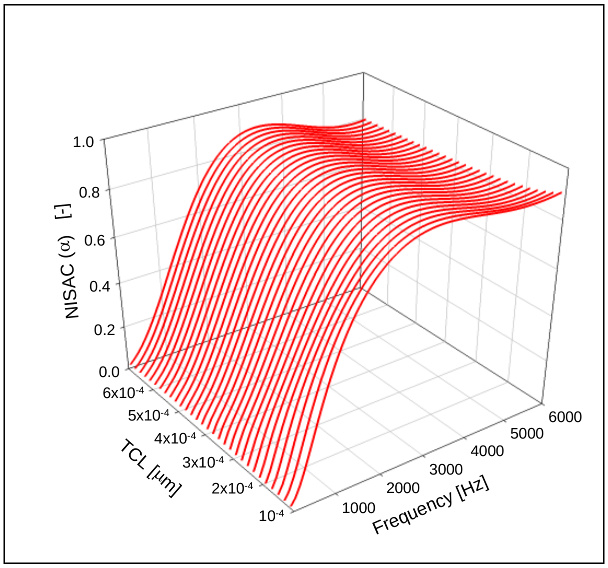

Fig. 5(a) - Effect of TCL on Normal Incidence Sound Absorption Coefficient (NISAC).

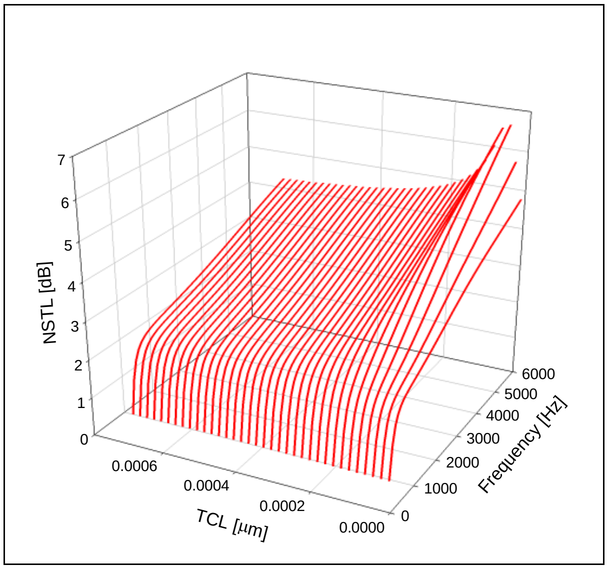

Fig. 5(b) - Effect of TCL on Normal Incidence Sound Transmission Loss (NISTL).

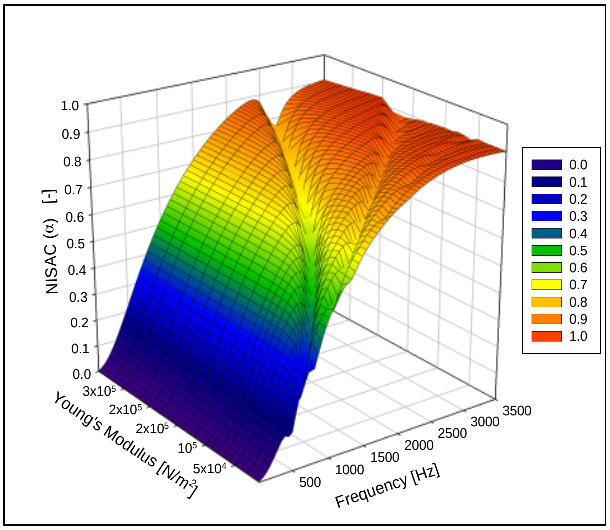

Fig. 6(a) - Effect of Young's modulus on Sound absorption (NISAC).

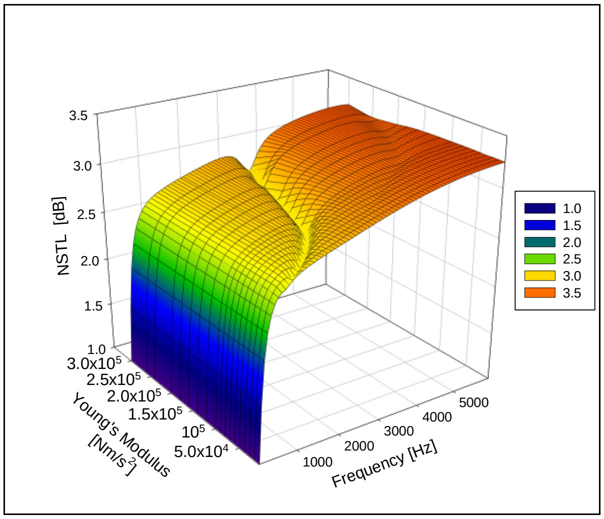

Fig. 6(b) - Effect of Poisson Ratio on Sound absorption (NISAC).

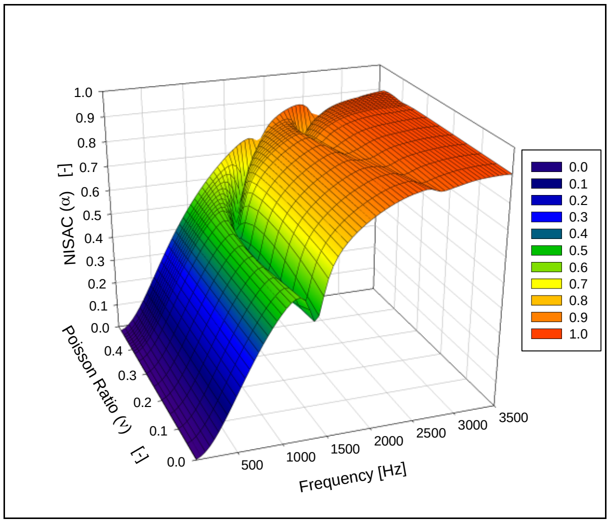

Fig. 7(a) - Effect of Young's modulus on Sound Transmission Loss (NISTL).

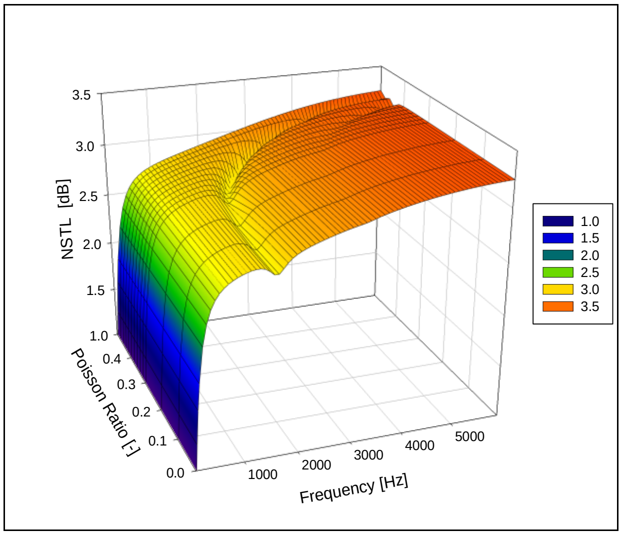

Fig. 7(b) - Effect of Poisson Ratio on Sound Transmission Loss (NISTL).