International Conference KNOWLEDGE-BASED ORGANIZATION
Vol. XXV No 3 2019

NUMERICAL MODELS FOR THE ANALYSIS OF THE ACOUSTIC WAVE PROPAGATION

Vasile NĂSTĂSESCU*, Ghiță BÂRSAN, Silvia MARZAVAN***

*** "Ferdinand I" Military Technical Academy, Bucharest, Romania**
****"Nicolae Bălcescu" Land Forces Academy, Sibiu, Romania**
nastasescuv@gmail.com

Abstract: *This paper presents some authors' results regarding numerical modelling of the acoustic wave propagation, using the Ansys program. The acoustic wave propagation is studied under conditions of existence of acoustic absorbing panels. Different materials are taken into account (aluminium, foam, oak, polystyrene) for considered acoustic absorbing panels. Also, different dimensions and different cases for fixing the panels were considered. The acoustic wave propagation was studied in stationary conditions and in dynamic conditions at different values of sound frequencies. A comparative analysis is performed regarding the influence of different conditions upon acoustic wave propagation. Our studies presented in this paper are referring to the acoustic propagation in an open space, like on airports or around the acoustic sources placed in open space. The aim of this paper is to offer our experience in this field for a numerical analysis of the ways for sound level reduction. Also the facilities of the Ansys program for the solving of such problems are presented in a practical manner of use.*

Keywords: acoustic wave, acoustic pressure, absorption, acoustic fluid, finite element

1. Introduction

The numerical analysis by finite element method offers new and efficient possibilities for different parameters calculus of acoustics phenomena. Such a calculus allows us to know the acoustic pressure level around an acoustic source, but allows us to study how we can obtain a low level of sounds, for better working and living conditions. The Ansys program has in its finite element library dedicated elements for plane and spatial problems and other specific facilities about which more information will be presented in this paper.

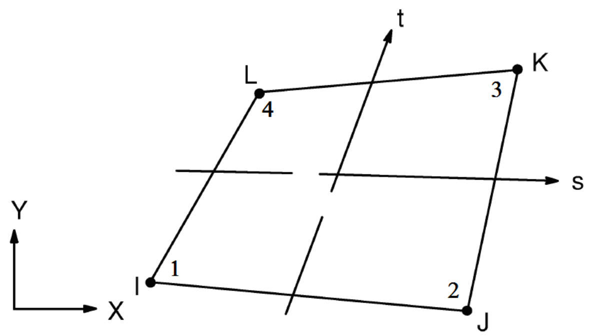
2. Acoustic Finite Elements

The modeling of the acoustic pressure field has some peculiarities depending on the acoustic domain, which can be a closed one or an open one. Depending on the problem, the numerical model can be a 2D or 3D one; the 2D model can be a planar (plane stress, plane strain) or axisymmetric model. There are some dedicated finite elements, in the Ansys program, for solving problems regarding the acoustic wave propagation and their interaction with a structure.

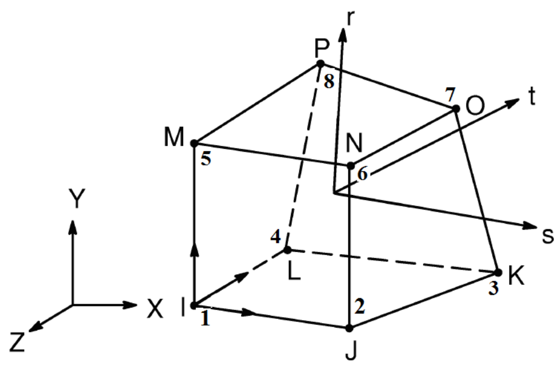
The most used acoustic finite elements are named FLUID29 for 2D modeling and FLUID30 respectively for 3D modeling, in the Ansys finite element library. Next to these finite elements, other kinds of finite elements were designed for infinitely modeling of the acoustic domain; practically, such finite elements are placed on the acoustic domain boundary and they work like a damping at the boundary by simulating the energy dissipation.

DOI: 10.2478/kbo-2019-0129

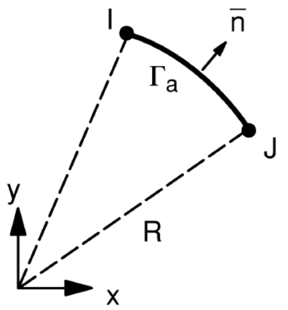
So, no reflection wave occurs. FLUID 129 and respectively FLUID130 finite elements are used for endless boundary modeling in the wave propagation direction. In the case of the interaction between the acoustic waves with a structure, like in the case of the present acoustic absorbing panel, other proper structure finite elements can be used. A detailed description of all these finite elements can be found in Ansys theoretical manual and in the main literature about finite element modeling [1], [6], [10] and [11]. Those two finite element types are presented in Figure 1.



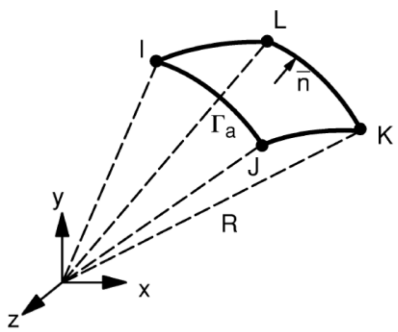
a) FLUID29



b) FLUID30



c) FLUID129



d) FLUID130

Figure 1. Acoustic finite elements

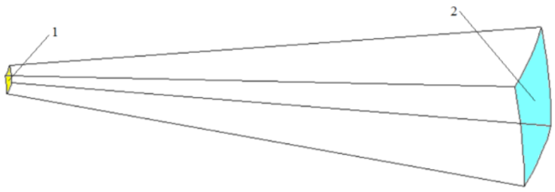
The finite elements FLUID129 and FLUID130 are used for the modelling of an infinite domain. The common approach consists in the introduction of a virtual boundary Γ_a for absorbing the waves and so an infinite domain is truncated, becoming a finite domain.

Next to these finite elements, the Ansys finite element library has other elements dedicated to acoustic fluid modelling. So, FLUID220 is a 3D finite element (brick) having 20 nodes; FLUID221 is also a 3D finite element (tetrahedral) having 10 nodes.

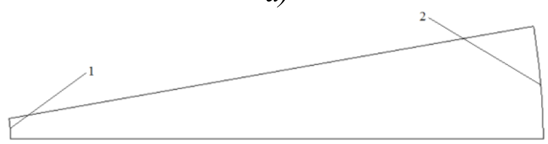
As far as the mechanical structure is concerned, its modelling can be performed using appropriate finite elements. A very important aspect in numerical modelling of acoustic wave propagation, in the presence or absence of a structure is the choice of the model type. For a 3D model no special problems appear, but when it is a 2D model we have to use the appropriate options. So, for using axisymmetric finite elements, all the problem issues must have this future of axisymmetrical aspect: the acoustic source, propagation domain, boundary conditions and so on. Then, it must be known that in the case of an acoustic source, supposed to be a point, the acoustic waves starting from that point are spherical. Also, it must be known that, in a solid elastic environment, the sound propagation occurs by longitudinal and transversal waves. In liquid and gaseous environments (including the atmosphere), the sound propagation occurs only by longitudinal waves.

3. Finite Element Models

No matter the model type, 2D or 3D, the acoustic source can be considered a point-shaped one, a partial or total spherical surface around that point.



a)



b)

Figure 2. Model types

In the Figure 2, those two model types are presented: a 3D partial model and a 2D model. The acoustic source is simulated by applying the acoustic pressure on the spherical surface 1, having a radius (generally much smaller than the size of the domain) towards the point-shaped source.

The surface 2 (Figure 2) is that surface where finite elements FLUID130 or Fluid129, respectively, are applied. The 2D model (Figure 2-b), geometrically, is the same for those two options: axisymmetric or planar. For a given problem, the models 3D and 2D with axisymmmetric option practically lead to the same results.

In the Figure 3, the acoustic pressure field is presented when a 3D model is used.

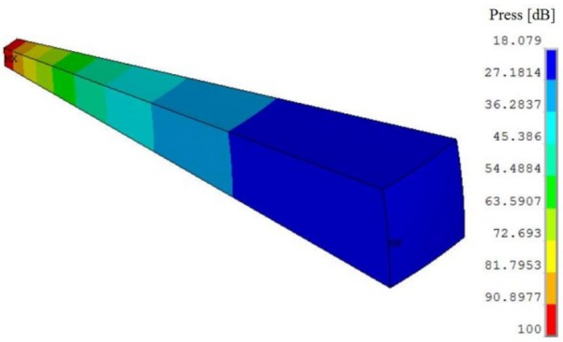


Figure 3. The 3D acoustic pressure field

In the Figure 4, the acoustic pressure field is presented when a 2D axisymmetric model is used.

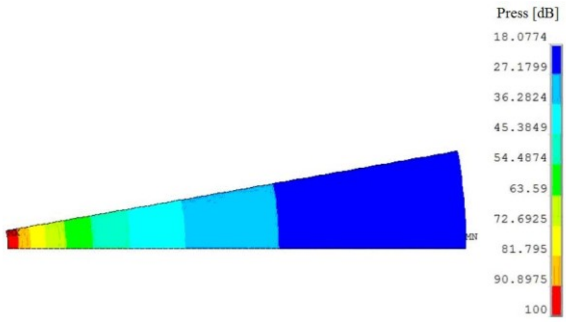


Figure 4. The 2D axisymmetric acoustic pressure field

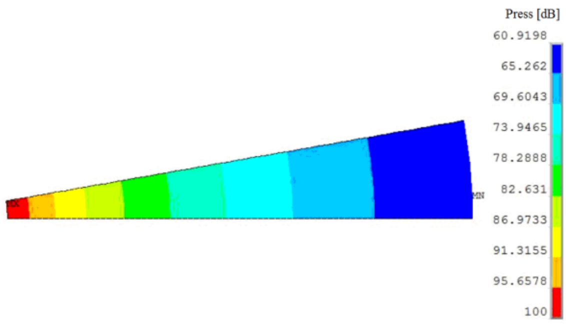


Figure 5. The 2D planar acoustic pressure field

When a 2D planar model is used for the same input data, the results are certainly very different. This aspect is shown by the analysis of the data presented in the Figures 4 and 5.

4. Numerical Model for the Study of Soundproofing Panels

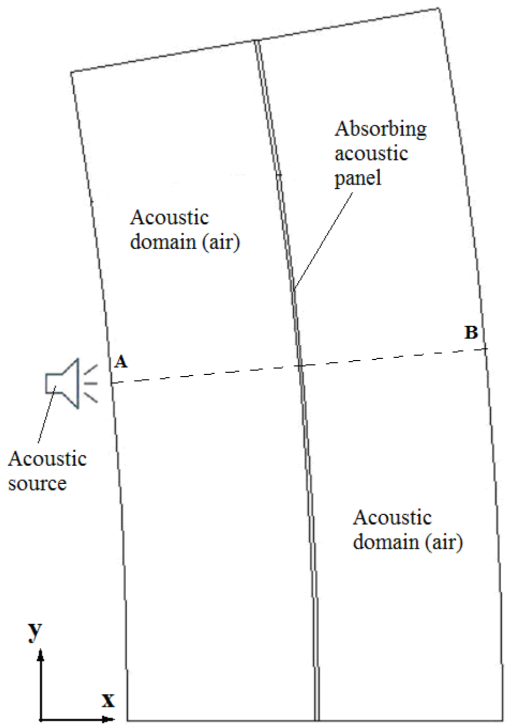


Figure 6. Problem formulation

The effects of the soundproofing (acoustic absorbing) panels can be studied by the finite element method. So, different issues can be studied, such as the panel material influence, the way of the panel support (fixing), the reduction rate of acoustic pressure level, etc.

The models which are to be presented can be used in the problems consisting in the acoustic absorbing evaluation of different panels. Such a model is presented in the Figure 6. In this figure, we can see the point-shaped acoustic source from which the acoustic waves start, the acoustic domain (air) with and without the absorbing panel.

The model presented in the Figure 6 is a 2D model (easier than a 3D model and more efficient in terms of computer time) with the option of planar acoustic waves, because the source (loudspeaker) emits one way, and the propagation occurs in the air, only by longitudinal waves. For panel modelling, appropriate structural finite elements can be used. In this case, we used the finite element PLANE42.

For a comparative analysis of the results, the input data presented in the Table 1 were used. In the model presented in the Figure 6, the geometrical characteristics are: the x-size of the domain is 1 m; the radius defining the domain curvatures is 10.0, respectively 11.0 m. The thickness of the panel is 20 mm and it is placed just in the middle.

Table 1. Model input data

	Density	Sound velocity
	kg/m^3	m/s
Air	1.225	340
Aluminium	2700	5092
Foam	100.0	2236
Polystyrene	1045	1481
Oak	720	4000

The acoustic domain has an angular dimension of 10 degrees. On the right hand curve of the acoustic domain, finite elements FLUID129 were used.

The source acoustic pressure is 100 dB and it is applied in a node belonging to the half of the curve length. Three finite element dimensions were used: 10, 20 and 30 mm. The Table 2 contains the results for these three finite element sizes.

Table 2. Comparative analysis of mesh sizes

F.E. size	Nodes	Elements	Max. value	Min. value	Differences
1 cm	16,261	16,160	88, 4586	87, 0160	1, 4426
2 cm	4,131	4, 080	89, 4436	88, 1241	1, 3195
3 cm	2,835	2, 800	89,7507	88, 4696	1, 2811
		Average values:	***89, 2176***	***87, 8699***	***1, 3477***
Errors (%) compared to the average values, respectively:					
1 cm			***-0.85***	***-0.97***	***7.04***
2 cm			***0.25***	***0.29***	***-2.09***
3 cm			***0.60***	***0.68***	***-4.94***

5. Results and Discussions

Using the numerical model presented in the Figure 6 and choosing a mesh with the finite element size of 20 mm (this size is the best as the Table 2 results show), the following results were obtained.

In the Figure 7, the acoustic pressure field, without any panel, is presented. Along the A-B direction (Figure 6), the pressure attenuation, without any panel, is presented in the Figure 8.

In the Figures 9 and 10, the influence of the absorbing panel presence can be seen, comparatively with the same issues presented in the Figures 7 and 8. As far as the panel is concerned, (its UX-displacements and equivalent stress von Mises state, presented in the Figure 11), this is under a very small loading (practically negligible). The results, graphically presented in the Figures 9…11, are referring to an acoustic absorbing panel of aluminium, where its lower end is clamped and the upper end is free. Such results were achieved for those four materials: aluminium, foam, polystyrene and oak.

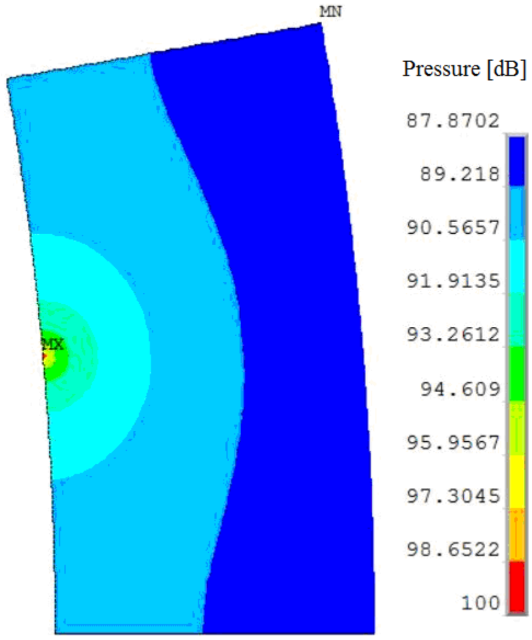


Figure 7. Acoustic pressure field, no panel

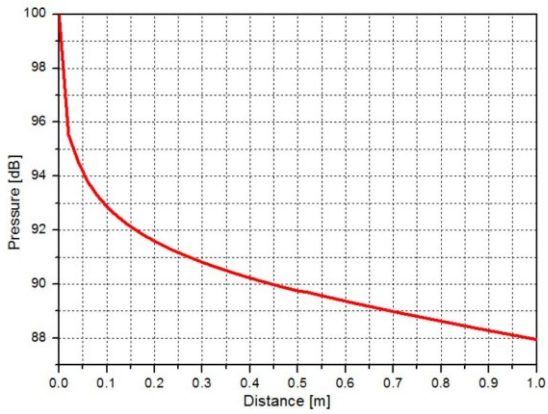


Figure 8. Pressure attenuation, no panel

As the Figure 12 shows, in the considered cases, where only the materials are different, the attenuation rates are practically slightly influenced by the panel materials.

The height of the panel and the blocking of both ends lead to significantly different results.

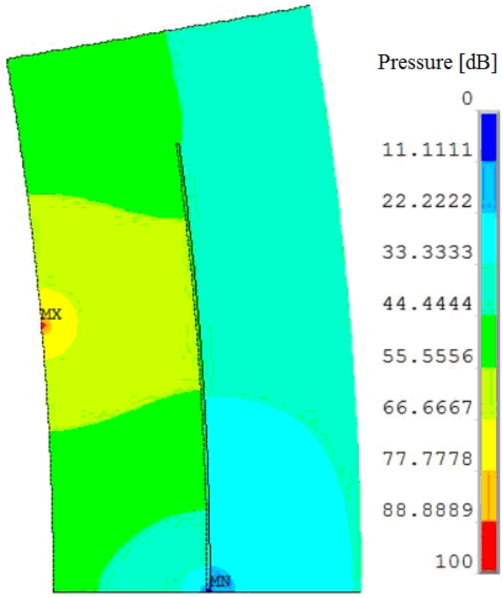


Figure 9. Acoustic pressure field

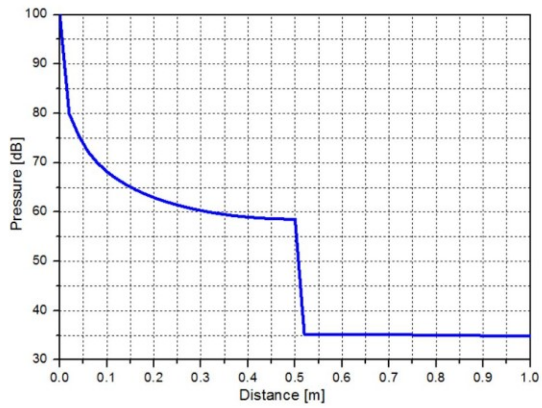


Figure 10. Pressure attenuation curve

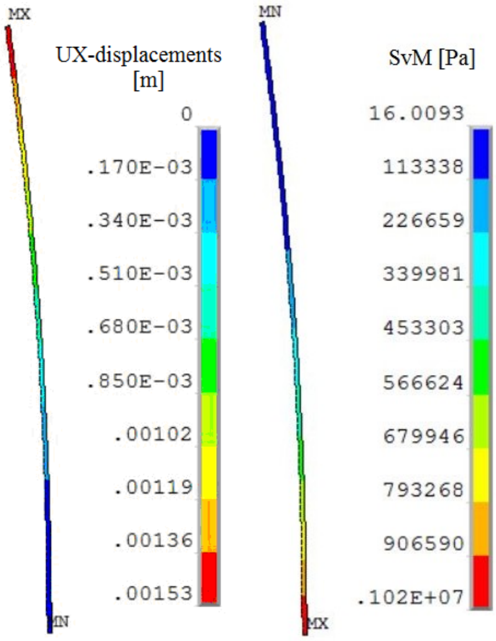


Figure 11. Panel states

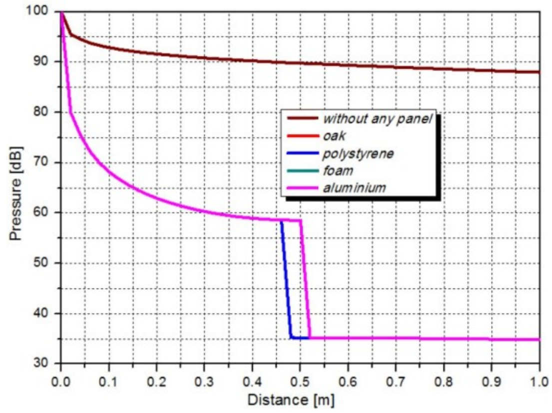


Figure 12. Pressure attenuation curves

So, in the Figure 13, the acoustic pressure field is presented, when the panel is a high one (the same height as the acoustic domain). In this case, the pressure attenuation curve is that presented in the Figure 14. The comparative analysis of the results presented in the Figures 9 and 13, also in the Figures 10 and 14, shows a great difference – a high panel is much more efficient. In this case the pressure in front of the panel is greater, but the pressure behind the panel is much smaller going to zero.

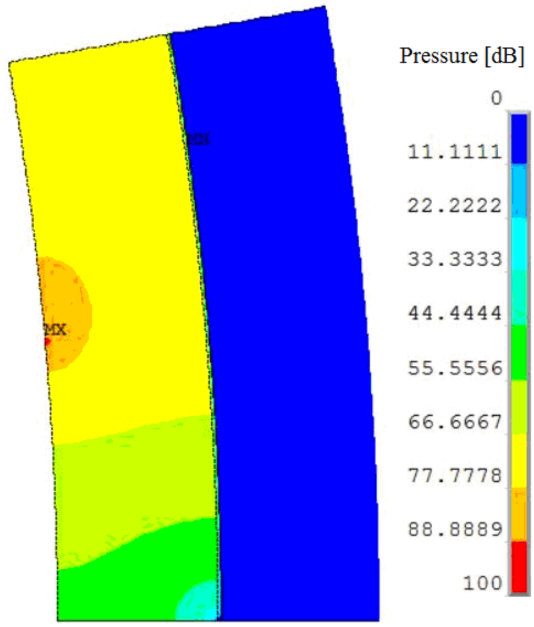


Figure 13. Pressure field, high panel

In this case of a high panel, the state of the ends has a great influence, as the Figure 15 shows. All the results presented in this paper are obtained for the case of an acoustic source working in a stationary mode.

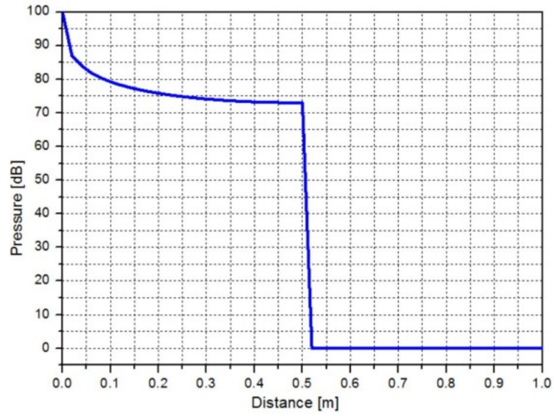


Figure 14. Pressure attenuation curve, high panel

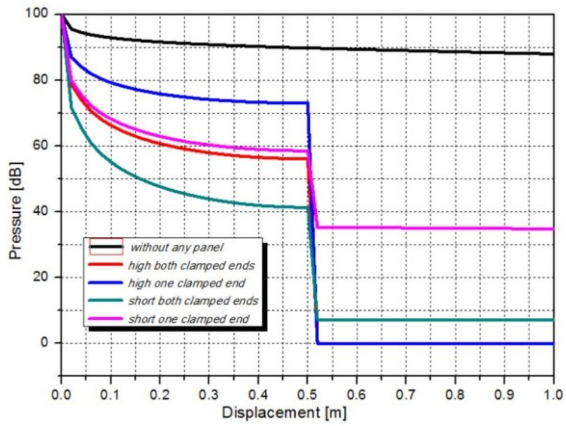


Figure 15. Pressure attenuation curves

In the cases of acoustic sources which work in a transient mode, including the sound frequency, the same above-presented models can be used. So, in the Figures 16 and 17, the acoustic pressure field is presented, by taking into account the frequency of the sound source.
Two frequencies, 200 Hz and 300 Hz, were considered, for the model with a high panel having the lower end clamped. The results, presented in the Figure 16 and 17, show a strong disruption of the acoustic pressure field produced by the wave interference. So, just in front of the panel, there are some zones where the pressure is lower than in the back of the pane. The pressure attenuation curve is also significantly modified as it is presented in the Figure 18; here it can be noticed that the pressure jump is one indicating growth. By post-processing the results, the acoustic pressure dependency with the frequency was performed.

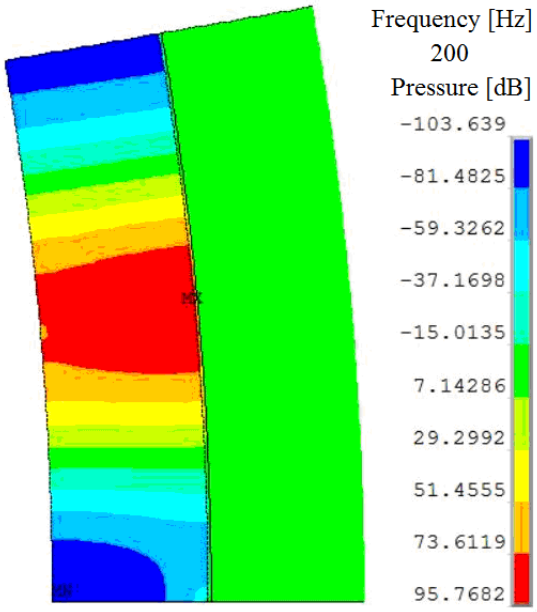


Figure 16. 200 Hz frequency influence

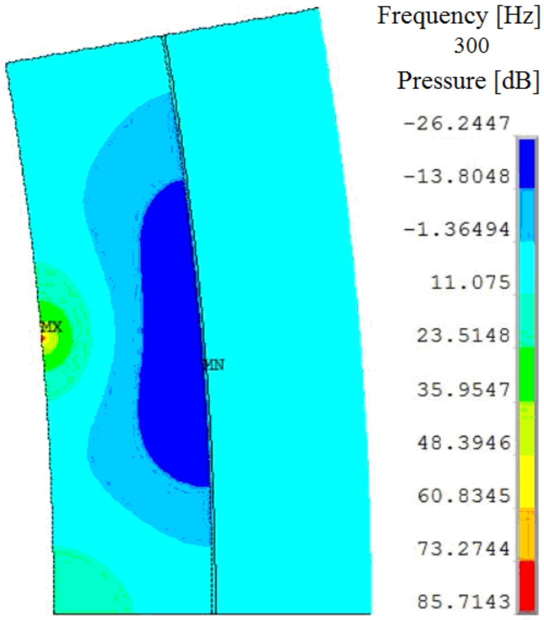


Figure 17. 300 Hz Frequency influence

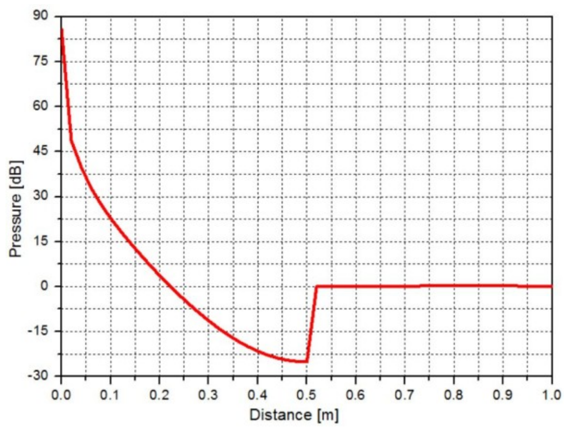


Figure 18. 300 Hz Pressure attenuation curve

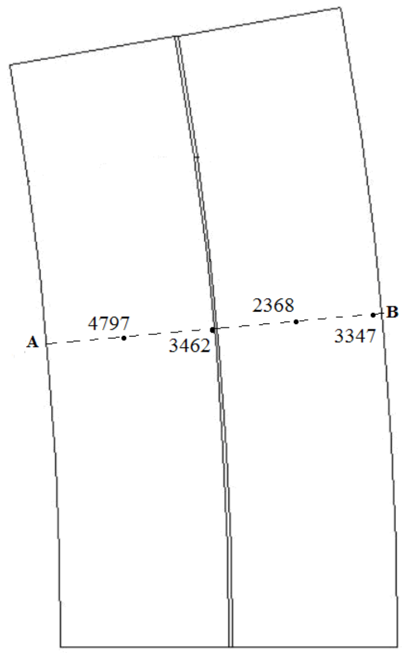


Figure 19. Nodes taken into account

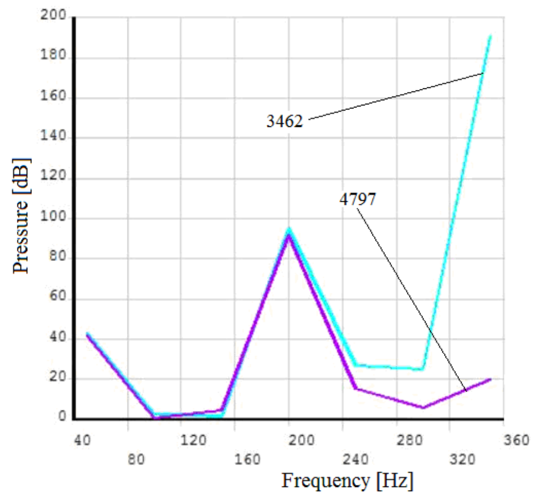


Figure 20. Nodal pressure in front of the panel

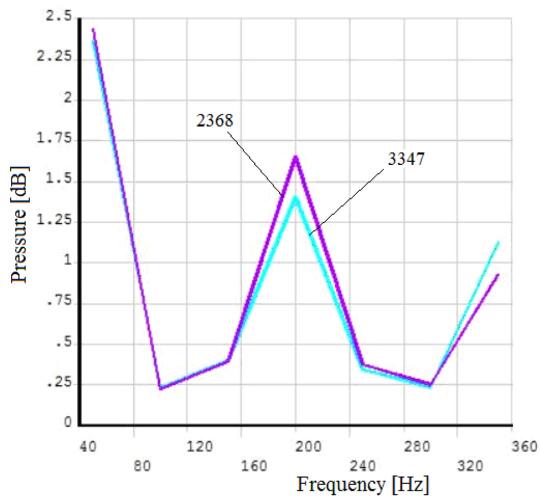


Figure 21. Nodal pressure behind the panel

An acoustic source having the maximum pressure level of 100 dB and a frequency range between 50…350 Hz was considered. For those four nodes, presented in the Figure 19, the nodal acoustic pressure versus frequencies was represented in the Figures 20 and 21.

Of course, a wider range of frequencies can be considered. More node number can also be used in the analysis, other panel materials can be invoked and so on.

6. Conclusions

The complex problem of the acoustic waves propagation and how the acoustic pressure level can be lowered is a problem which can be solved by the finite element method. So, the Ansys program is a very powerful one, having dedicated finite elements for all analysis types and for all models (2D with two options and 3D).

The numerical analysis by the finite element method allows us to study the absorbing rate for different panel materials and for different panel geometric types.

The panel state under acoustic pressure can also be studied. Different panel types are under researching. So, the absorbing acoustic panels can be made from different materials in different combinations, including all composite material types.

In any such problems, the numerical models presented in this paper can be used or can be easily adapted.

References

[1] Bathe, K-J., *Finite Element Procedures*, Prentice-Hall, Inc., 1996.

[2] Coyewe, J., P., Vanderborck, G., Steichew, W., *A coupling procedure for modeling acoustic problems using finite elements and boundary elements,* Journal de Physique IV, Colloque C5, supplement au Journal de Physique III, Volume 4, May 1994.

[3] Hristev Anatolie, *Mecanica si Acustica,* Editura Didactica si Pedagogica, Bucharest, 1984.

[4] Langdon, S., Chandler-Wilde, S., N., *Finite element methods for acoustic scattering,* Lecture notes, Department of Mathematics, University of Reading, Berkshire, UK, July 18, 2007.

[5] Kinsler E. Lawrence, Austin R. Frey, Alan B. Coppens, James V. Sanders, *Fundamentals of Acoustics,* Fourth Edition, John Wiley & Sons, Inc., 2000.

[6] Kallivokas, L. F., Bielak J. and MacCamy, R. C., *Symmetric Local Absorbing Boundaries in Time and Space,* Journal of Engineering Mechanics, Vol. 117(9), pp. 2027-2048 (1991).

[7] Năstăsescu V., Stefan A., Lupoiu C., *Analiza neliniară a structurilor mecanice prin metoda elementelor finite,* Military Technical Academy Publishing House, Bucharest, 2002.

[8] Năstăsescu V., Bârsan Gh., *Metoda particulelor libere în analiza numerică a mediilor continue,* AGIR Publishing House, Bucharest, 2015.

[9] Năstăsescu V., Bârsan Gh., *Metoda elementelor libere Galerkin în analiza structurilor,* Romanian Academy Publishing House, Bucharest, 2018.

[10] Sandeep T Varghese, Nirmal Chandran, *Acoustic Structure Interaction with Damping Interface,* International Journal of Engineering Research & Technology (IJERT), Vol. 4 Issue 11, November-2015.

[11] Zienkiewicz, O. C., Taylor, R. L., Zhu, J. Z., *The Finite Element Method its Basis and Fundamentals,* 6ed, Elsevier, 2005.

[12] * * * *Ansys, Inc. Theory*, Release 5.7, Twelfth Edition, 2001.