ENC-2020-0083

AN OPTIMAL NUMERICAL-ANALYTICAL METHODOLOGY FOR MULTIPLE PERFORATED DISCS IN DUCTS

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***Abstract.** Many researchers address different models for perforated discs. However, no content in the literature helps design engineers to correctly apply the models considering a set of perforated discs in series in the elaboration of an industrial noise control project, as well as how to calculate certain flow parameters, such as the local Mach number in a given hole in the disc. Therefore, the proposed work suggests an optimal methodology for applying a set of perforated discs in series inside ducts. The developed analysis presents a unique and optimal numerical-analytical methodology for the application of the perforated disc aiming at the attenuation of industrial noise in high-speed flows. Through the application of the Transfer Matrix Method (TMM) coupled with the Finite Element Method (FEM) and the finite volume method (FVM), an optimum procedure is presented for the placement and dimensioning of perforated discs in ducts with high speed flows. The applied methodology is validated through a case study presented and confirms the validity of its use for calculating the speed inside the holes of a perforated disc and the best set of those inside a duct. Additionally, it shows the understanding of the flow downstream of a reduction valve that causes the noise phenomenon, as well as the attenuation influence of fluidic parameters under the action of a passive reactive device.*

***Keywords:** Transfer Matrix Method, Aeroacoustics, Perforated discs, FEM, CFD*

1. INTRODUCTION

Currently, in the piping system that contains pressure reducing valves, many researchers focus mainly on the valve structure to reduce noise, pressure loss, and cavitation (Qian, 2014). Chern et al. (2015) researched globe valves to increase their control capacity, while Rao et al. (2015) and Song et al. (2010) focus their work on the optimization of butterfly valves for noise perfomance. On the other hand, other researchers focused on valves flow study, considerably developing knowledge about the phenomenon of sound propagation using both, experimental and numerical approaches, which is the case for Amirante et al. with three articles published in 2014. Several authors such as Liu et al. (2014), Wu D. et al. (2015), Song XG. et al. (2010) Song X. et al. (2014) Yuan X. and Guo K. (2015) and Valdés (2014 and 2015) present works demonstrating the importance of pipeline analysis using the computational fluidynamic method. As quoted by Qian et al. (2015), many authors followed the path of transmission loss (TL) analysis, developing widely known concepts, such as Guo F. et al. (2013), Zeng L. et al. (2015), Sekhar et al. (2015), among others. Further specifying the theme and meeting the proposed work, authors made numerous analysis of this parameter using computational and analytical approaches to perforated discs, which is the case for Phong et al. (2013), Mendez S. and Eldredge JD. (2013), Antebas AG. et al. (2013), Mimani A. and Munjal ML. (2011), Rao and Munjal (1998), Mimani A., Munjal ML. (2012), Phong and Papamoschou (2015), Betts (2000), Lee D.H. (2004) Iljae Lee (2005), and Phong (2012).

The application of perforated discs in noise control is highly convenient and economical compared to other alternatives that depend on the shape change of the ducts or physical changes in the properties of used fluids.

The analysis of perforated discs in ducts is relevant for the most diverse applications of noise control, such as automotive exhaust mufflers, liners in aeronautical engines, and pneumatic exhaust valves, as highlighted by

Papamouschou (2015). Such applications have already been proven effective and used for more than three decades (Betts, 2000), especially the study regarding the bias flow is performed to optimize the construction of such important components as performed by Yuanyuan et al. (2019).

To perform acoustic analysis, many analytical and computational methods are employed. Numerical methods such as finite elements method (FEM), computational fluid dynamics (CFD), and boundary elements method (BEM) are the main and most comprehensive to be used for acoustic analysis. From the analytical point of view, mathematical models such as electroacoustic analogies, concentrated elements, vibroacoustic analogies and the Transfer Matrix Method (TMM) represent the main and most comprehensive means of analysing the phenomenon of acoustic propagation for sundry cases. Thus, authors such as Oriol Guasch (2017), Jae-Deok Jung et al. (2017), Noé Jiménez (2020), and Mohamed Elmalki (2017), use and show the Transfer Matrix Method (TMM) as being extremely accurate and versatile for the study of sound propagation.

1. Theoretical Basis

The internal noise in a duct can be considered as a result of Reynolds stresses, as well as pressure and flow fluctuations as addressed by Reethof (1978). He states that, qualitatively, pressure and speed fluctuations result in the development of noise sources, having directivity and intensity characteristics of their environmental acoustic nature and singularities, of the environment in which it propagates. The following work aimsto mitigate the noise generated inside pipelines through the application of perforated discs.

The study of non-linear acoustic phenomena is the key to understand and model perforated discs. Initially, numerous experiments at different frequencies and varying the Reynolds number of the flow, inside the holes, were performed by Sivian (1935), resulting in an empirical formula for the acoustic impedance of small holes. Later, in 1950, Ingard and Labate (1950) experimentally demonstrated that the nonlinear behavior of the impedance in the orifice is due to the interaction between the sound field and the circulatory effects of the flow. Continuing that research, Ingard and Ising (1967) conducted experiments in orifices in which the particle velocity was directly measured using hot-wire anemometry. To describe the behavior of an orifice's acoustic impedance, Ronneberger (1972) tried to determine the orifice impedance in a disc inside a drained duct (impedance due to grazing flow). He observed that the orifice resistance in high values of U_0 / r_0 is independent of the frequency and increases linearly with the flow velocity, U_0, along the radius duct, r_0. He attributed this behavior to the appearance of a thin shear layer adjacent to the hole.

Perforated element mufflers had their functionality and acoustic efficiency attested by such authors against simple tubular mufflers. However, the study of aeroacoustics systematically perforated elements began only in the late 1935s, when Sivian (1935) introduced a model based on an empirical experiment.

Those authors presented different models that meet specific cases that each one highlighted. There are four cases: without flow, with the flow, with bias flow, and in the presence of grazing flow (exemplified through Fig. 1).
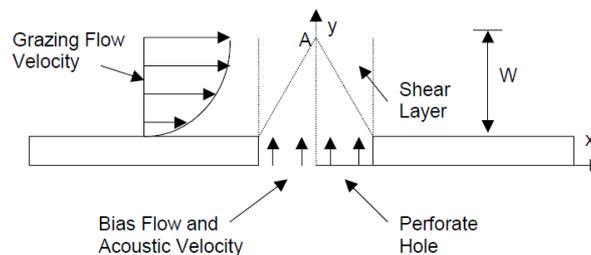

Figure 1 - Grazing flow and bias flow in a perforated disc (Betts, 2000).

In the analysis of perforated discs, certain parameters are spotlighted, such as i) the impedance of a perforated disc, ξ; ii) the local Mach number of the flow (M); iii) the disc thickness, t_w; iv) the hole diameter, d_h; v) the noise frequency, f; vi) porosity, σ (it represents the ratio of open area and intrinsically takes geometric parameters such as the hole diameter and the distance between the center of holes).

Based on the experimental results of Sivian (1935), Jayaraman conducted an analytical and empirical study regarding perforated discs in 1980, isolating each constructive parameter, and presenting their influence on the transmission loss. Therefore, the referred author presented a formula that expresses the influence of the geometric parameters of perforated discs, given as:

$$(\psi l)^2 = \left(\frac{4\sigma}{d_h \Delta}\right)\left(\frac{l^2}{1-r^2}\right) \tag{1}$$

where, *(ψl)²* represents the dimensionless parameter that groups all constructive characteristics of a perforated disc, *r* denotes the diameter of the pipe, *l* denotes the length of the duct, and Δ denotes the length of the oscillating gas column in the perforations. Thus, Jayaraman (1980), through Eq.1 and some experiments, came to the following conclusions:

- As the duct diameter increases, the natural frequency peaks will change to lower frequencies, so long as ($1 / (1-r^2)$) does not change significantly.
- Increased porosity causes the peaks to move to higher frequencies.
- With an increase of the hole diameter, Δ will increase, leading to a decrease in the natural frequency peaks.
- The higher the number of holes, the less the parameters influence the impedance, since the non-linear part becomes more significant.

2. Theoretical Modeling of Impedance Applied To Perforated Discs

Sullivan and Crocker (1978), using the two-microphone method, measured the impedance of a perforated element in the presence of bias flow, however, it was also performed for a fully developed flow.

Later, Sullivan (1979) reviewed all existing perforated literature at the time and selected the model that best described the behavior of a perforated disc (for the case without flow) and a muffler (for the case with bias flow).

For the grazing flow case, however, the impedance in the stationary medium was simplified, assuming that the mean flow had no contact with the cavity. Thus, there is a need for an empirical understanding of the formula for a grazing flow in concentric tube resonators.

Identifying such a gap in the literature, Iljae Lee (2005) made a Ph.D thesis to experimentally obtain the impedance of different perforated discs, denominating the following generic formula through her experiments:

$$\xi = \frac{R + ik_0(t_w + \alpha d_h)}{\sigma} \tag{2}$$

where, k_0 denotes the wave number, R is the resistance, and α the correction coefficient of the output for reactance, which is associated with the interaction between holes (see Iljae Lee, 2005).

The Eq. 2 is used at the calculation of Transmission Loss in the Transfer Matrix Method.

3. Transfer Matrix Method Applied To Perforated Discs

For the current work, the analytical method called the Transfer Matrix Method (TMM) was chosen, the choice was based on the fact that, for performing acoustic analysis of more than one perforated disc, this method is computationally cheaper to use, meets the requirements of the problem. Also, it is validated by several literatures, and it is capable of analyzing an entire assembly along with an acoustic system and it can be easily modified for adding or subtracting elements in the analysis, facilitating the development of an optimal and flexible methodology for the most diverse projects.

The transfer matrix of an acoustical element is a function of geometry, medium state variables, average flow velocity, and duct properties (Beranek, 2006).

In this methodology, each component of the circuit relates the acoustic pressure to the volume speed at the ends of the circuit with the input data (Ataide de S., 2018). See Fig.2.
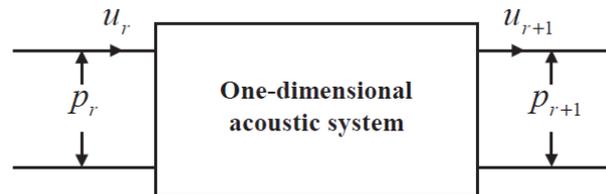

Figure2 - Representation of a four-pole acoustic element (Lee, 2002).

Thus, the element r relates the state variables (p, v) to the input with elements r + 1 of the output (Munjal, 1987). This circuit can be represented by a four-pole element. In the matrix form it is known as the transfer matrix (Munjal, 1987), (Instprocess & Beranek, 2006). Therefore, we obtain:

$$\begin{bmatrix} p_n \\ v_n \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p_{n+1} \\ v_{n+1} \end{bmatrix} \tag{3}$$

And, for a complete set of perforated discs, for example, the transfer matrix of a system composed of n elements can be obtained by successively applying Equation 3 (Thieme, 2000), (Munjal, 1987), (Candido, 2016), (Inst.ván & Beranek, 2006).

$$T_{system} == T^{(1)}T^{(2)} \dots T^{(r)} \dots T^{(n)} \tag{4}$$

It is possible to develop transfer matrices for the most diverse elements in a system. For the following work, two necessary matrices to solve the proposed problem will be analyzed: 1) Transfer matrix for a uniform duct, 2) Transfer matrix for a perforated disk.

For the uniform duct:

$$T_{duct,without\,flow} = \begin{bmatrix} cos(kl) & jY_r\,sin(kl) \\ \dfrac{j}{Y_r}sin(kl) & cos(kl) \end{bmatrix} \tag{5}$$

or, for the flow case:

$$T_{duct,with\,flow} = e^{-jMkl}\begin{bmatrix} cos(kl) & jY_r\,sin(kl) \\ \dfrac{j}{Y_r}sin(kl) & cos(kl) \end{bmatrix} \tag{6}$$

where k denotes wave number, l the length of the duct, M the number of Mach, and Yr denotes the specific acoustic impedance of the medium (ρc).

In the case of perforated discs such as the four-pole transfer matrix, it can be expressed by (Lee, 2002):

$$T_{Perforated\,discs} = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix} = \begin{bmatrix} 1 & \rho_0 c_0 \xi \\ 0 & 1 \end{bmatrix} \tag{7}$$

where ξ represents the normalized acoustic impedance of the panel.

The expression developed above is based on the premise that the thickness of the panel is so thin compared to the acoustic wavelength, that it is possible to neglect the phase difference of the particle speed between the two faces of the attenuator.

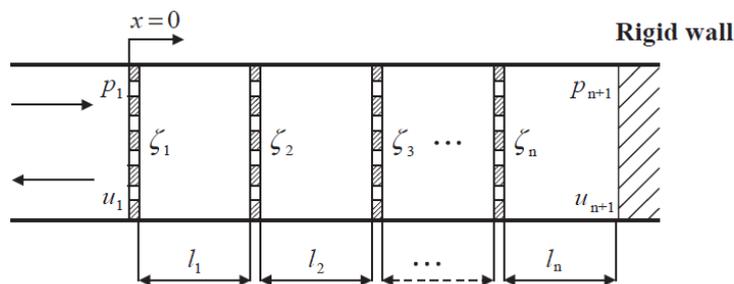More than a single perforated disc can be used, as shown in Fig. 3.

Figure 3 - Multiple perforated discs (Lee, 2002).

In the case of applying multiple perforated discs separated by a certain length of duct, as seen in Fig. 3, the total transfer matrix still obeys the rule:

$$[T] = [T_{PP}]_1[T_{te}]_1 \cdots [T_{PP}]_n[T_{te}]_n \tag{8}$$

where [T$_{PP}$]$_1$ is referenced to the transfer matrix of the perforated disc with index one and [T$_{te}$]$_1$ indicates the transfer matrix of the uniform tube with flow index one until index n.

To calculate the efficiency of the system, it has opted for the use of transmission loss, PT, which is defined as the difference between the sound power level between the incident wave, i, in the muffler and the transmitted wave, t, for the case of an anechoic termination (Munjal, 1987), (Inst.ván & Beranek, 2006).It can be expressed by the following equation:

$$PT = 20log\left(\left|\frac{T_{11}+\left(\frac{S}{c}\right)T_{12}+\left(\frac{c}{S}\right)T_{21}+T_{22}}{2}\right|\right) \qquad (9)$$

where c denotes the speed of sound at the desired temperature and S is the cross-sectional area of the duct.

Among the performance criteria, *PT* is the easiest to predict, as the source impedance is not taken into account and the output is modeled as anechoic. Thus, this performance parameter is the most used in the design stage of the mufflers, (Instván & Beranek, 2006).

4. Steps to apply the project methodology

This methodology is being developed to apply a set of perforated discs inside ducts through the following steps:
- Step 1: Analysis of separate perforated discs through analytical modeling by Papamoschou D., 2012;
- Step 2: Definition of the optimal location of the first perforated disc through FEM;
- Step 3: Definition of the optimal location of the subsequent perforated discs through FEM;
- Step 4: Analysis of the fluidic phenomenon and the physical parameters obtainment for the application of analytical modeling through CFD;
- Step 5: Use of the TMM model for the final calculation of transmission loss.

Step 1 is performed by defining the transmission loss of the perforated discs separately to know which frequency bands it is sized on. Steps 2 and 3 are performed using Finite Element Method (FEM) software (Hypermesh), to perform the modal fluid analysis inside the duct and then making the modal superposition until the duct cutoff frequency aiming to identify the region under the highest pressure. Then, in step 4, computational fluid dynamics software (CFD) is used to obtain the necessary parameters to fill the transfer matrix of the perforated disc, aiming for the transmission loss in step 5.

5. Case of Study

The following chapter presents one proposed problem of a case study provided by the UFMG School of Engineering. It is a research work by FAPEMIG, in association with ISOBRASIL, entitled "Development and Evaluation of the Performance of Noise perforated discs for Electro-Control Valves electronic", whose process number is EDT-101864/05.

The proposed case study is based on an experimental test bench consisting of a butterfly valve and subsequently modules for pressure reduction. It consists of perforated discs arranged in a unit or a set, as shown in Fig. 4.
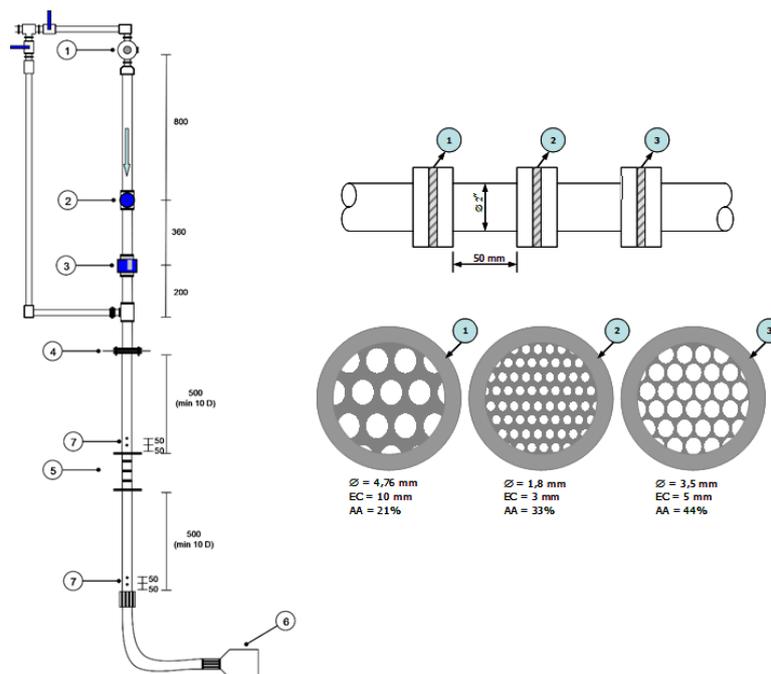

Figure 4 – Attenuation bench and perforated discs.

As we can see in Fig. 4, the number 4 represents the butterfly valve, 7 is the measurement sensors, and 5 the location of perforated discs.

Such discs illustrated by Fig.4, have different geometric parameters and were used in the duct in different positions aiming the optimal use for the reduction of the sound pressure level. As a result, an optimal distance of 50 mm between the perforated discs was obtained.

6.   Results and discussions

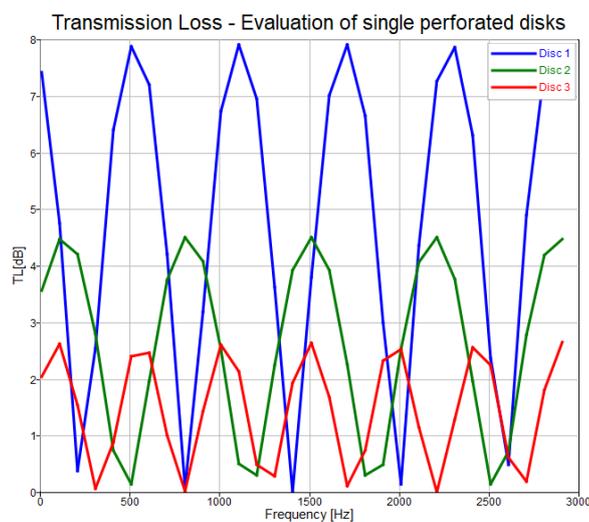Applying step one for each of the disks exemplified by Fig. 5, we obtained:

Figure 5 – Evaluation of single perforated disks

In this chart, it is possible to identify the peak attenuation of each disk separately as a function of frequency.

Then, the position of the first perforated disc in the duct is defined by applying step 2. The modal superposition performed for the first disc is shown in Fig. 6.
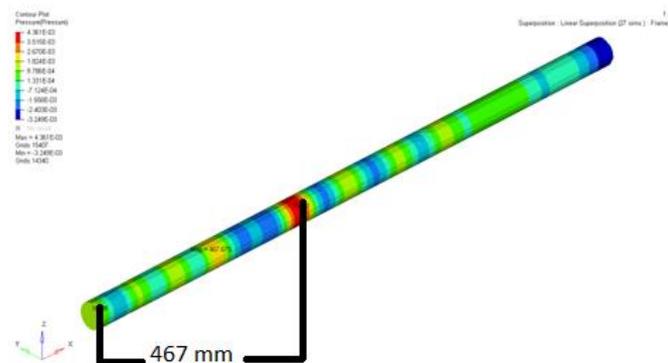

Figure 6 – Modal Superposition for the first perforated disc.

Through the modal superposition, 467 mm from the butterfly valve is the best position for applying the disc aiming to increase the local impedance (in the experiment it was placed at 500 mm).

As the assembly has three perforated discs, for the application of the other two perforated discs (Fig. 7 and Fig. 8), step 2 is applied again, respecting the choice of perforated discs through the performed experiment and, for their location, they are placed following the theory of modal superposition.
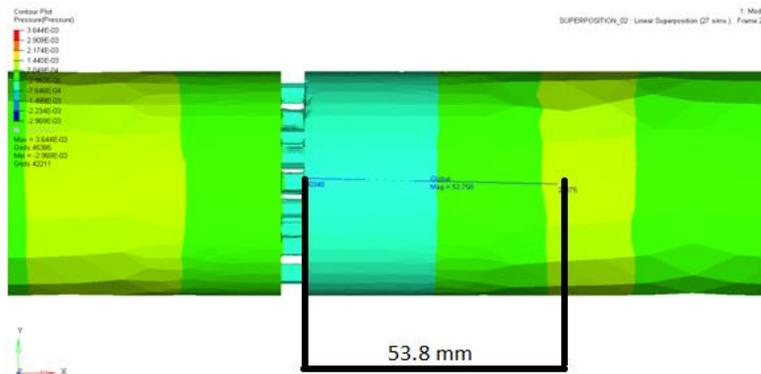
Figure 7 – Modal superposition for the second perforated disc.

Then, the optimum distance of 53.8 mm from the first disc is obtained for the second disc and it is applied again for the third disc.
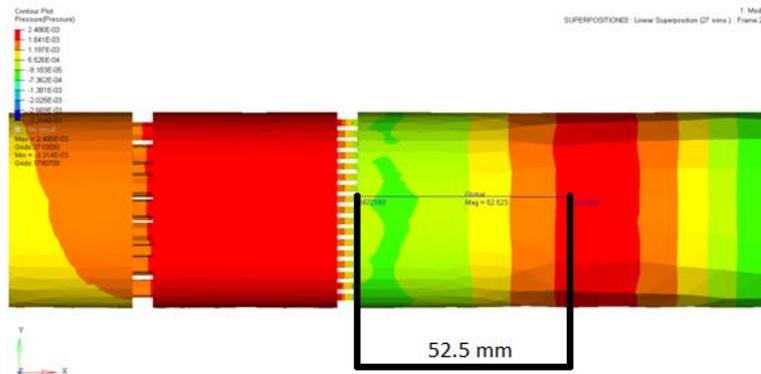

Figure 8 – Modal superposition for the third perforated disc.

Using the method employed, the last disc applied has an optimal distance of 52.5 mm from the second disc. This ends the calculation for the best location of the perforated discs in the analysis.

Continuing the application of the methodology, step 4 aims to perform a fluid dynamic simulation.

The CFD simulation is extremely important for data acquisition to feed the analytical resolution program and for the understanding of the fluidic phenomenon involved. Thus, representing recirculation areas of high speed and pressure behavior in the duct, as illustrated by Fig.9.
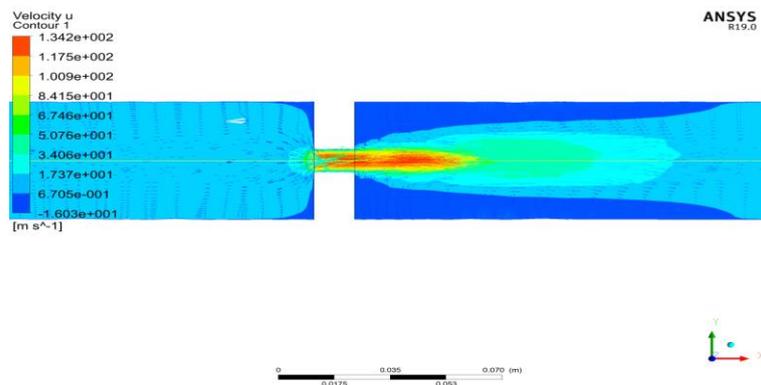

Figure 9 – Velocity contour at the butterfly valve.

In Figure 9, it is possible to identify areas of recirculation at the extremities after the throat, in which the velocity is extremely low and, logically, the central region of the flow with the highest velocity to a certain distance.

For achieving the flow velocity and pressure data, the graph in Fig.10 was used. Extracting the data from a concentric line to the duct, it is possible to identify the absolute value of the velocity easily, both in the throat and in the perforated disc.
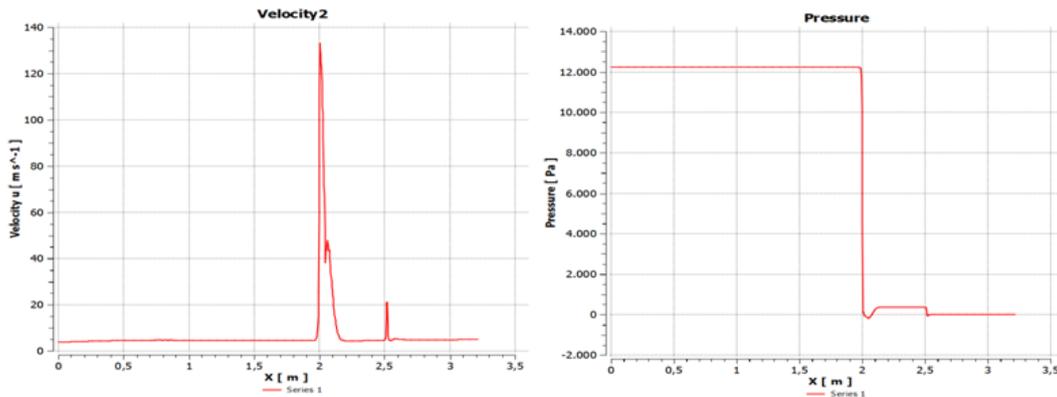

Figure 10 – Velocity and pressure at the centerline.

Such values identified in Fig. 10 can validate the performed simulation, in which experimental data attested a value of approximately 136 m/s in the valve's throat (representing a difference of 0.26% in comparison to the simulation) and 12500 Pa of pressure difference (2.08% difference compared to the simulation - 12240 Pa).

Finally, step 5 is feasible to be performed using such simulations and it is shown below in Fig. 11.

As the modeling provided by Iljae Lee in 2005 (Equation 4) is based on the discs built by him, it was decided to use the data of the discs that most resembled the present work, those named A4 and B4 (see the dissertation "Acoustic Characteristics of Perforated Dissipative and Hybrid Silencers").
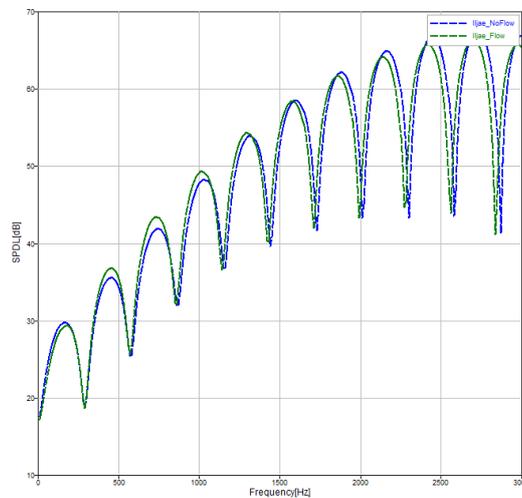

Figure 11 - Response of the TMM model using the Iljae impedance for 20 m/s and without flow.

In agreement with the CFD simulation, Fig. 11 illustrates that the speed inside the hole in the drilled disk is extremely low. Therefore, it does not produce significant effects on the acoustic response.

Despite the low speed on the disc, the study was also performed considering the speed was higher, thus resulting in Fig.12.
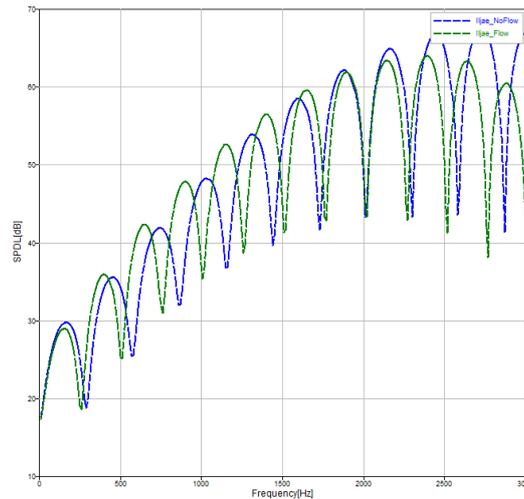
Figure 12 - Response of the TMM model using the Iljae (2005) impedance for Mach 0.5 and without flow.

By investigating Fig.12, it is possible to confirm the importance of taking into account the high speed in a compressible flow for the analysis of transmission loss in perforated discs. It is possible to perceive a displacement of the transmission loss peaks in comparison to the frequency (x-axis), as well as a change in their amplitude. Such effects are relevant for the design of perforated discs.

7. Conclusions

The test-bench was performed repeatedly until the optimum section of the perforated discs was found, as well as the speed of the fluid in the throat in the butterfly valve and the pressure difference between the inlet and outlet of the duct was measured.

Through the performed methodology, it was possible to reach the same conclusion as the optimum places for perforated discs, as well as the CFD simulation were validated through experimental data, thus attesting the effectiveness of the proposed method.

The optimal methodology applied is extremely useful, since it can assist engineers to design and apply perforated discs inside ducts for sound attenuation. Besides, an extremely cheaper and faster methodology was developed compared to the previous need to perform experimental tests and purchase of sensors and actuators capable of performing the procedure.

Finally, the developed methodology makes possible the correct use of the most diverse impedance formulas present in the literature, since it can determine the speed and pressure inside the holes of a perforated disc without the need for experimental tests and laser sensors that are extremely expensive to determine the flow speed inside these passive reactive attenuators.

8.   REFERENCES

Amirante, R., et al. "Evaluation of the flow forces on a direct (single stage) proportional valve by means of a computational fluid dynamic analysis". *Energy Conversion Manage*, v. 48, issue 3, p. 942–953, 2007.

Amirante, R., et al. "Experimental and numerical analysis of cavitation in hydraulic proportional directional valves". *Energy Conversion Manage*, v. 87, p. 208-219, 2014.

Amirante, R., et al. "The importance of a full 3D fluid dynamic analysis to evaluate the flow forces in a hydraulic directional proportional valve". *Eng. Comput.,* v. 31, issue 5, p. 898–922, 2014.

Antebas, AG., et al. "A finite element approach for the acoustic modeling of perforated dissipative mufflers with non-homogeneous properties". *Math Comput. Model*, v. 57, issue 7, p.1970–1978, 2013.

Ataide De S. O., J. *Sobre o uso da técnica da matriz de transferência no estudo da propagaçãoacústicaemtubulações do sistema de ar-condicionadoautomotivo*. Dissertação apresentada ao Programa de Pós-graduação em Engenharia Mecânica da Universidade Federal de Minas Gerais (UFMG), 2018.

Beranek, L.L., Vér, I.L. *Noise and vibration control engineering: Principles and applications*. Canada: John Wiley & Sons, Inc. 1992.

Beranek, Leo L. *Acoustics*. Academic Press. 2nd ed., 1960.

Beranek, Leo L., Mellow, Tim J. *Acoustics: Sound Fields and Transducers*. Academic Press. 1st ed., 2012.

Betts, J. F. *Experiments and impedance modeling of liners including the effect of bias flow*. PhD Thesis, Faculty of Virginia Polytechnic Institute and State University, Hampton, Virginia, 2000.

Candido, G. C. *Estudo Analítico e Numérico do Desempenho Acústico de Silenciadores Reativos na Presença de Escoamento Médio Incompressível*. Dissertação de Mestrado, Brasília, 2016.

Chern, MJ., et al. "Design of cages in globe valve. Proc. Inst. Mech. Eng, Part C".*J. Mech. Eng. Sci.,* v. 229, issue: 3, p. 476-484, 2015.

Guasch, O. et al. "Transfer matrices to characterize linear and quadratic acoustic black holes in duct terminations". *Journal of Sound and Vibration,*v. 395, p.65-79, May. 2017.

Guo, F., et al. "Absence of magnetic state dependent low frequency noise in spin-valve systems". *Phys. Rev. B,* v. 88, issue: 1, 2013.

Ingard, U. and Ising, H. "Acoustic Nonlinearity of an Orifice". *Journal of Acoustical Society of America*, v. 42, issue 1, p. 6–17, 1967.

Ingard, U. and LABATE, S. "Acoustic Circulation Effects and the Nonlinear Impedance of Orifices". *Journal of the Acoustical Society of America*, v.22, p. 211-218, mar. 1950.

Ingård, U. "On the theory and Design of acoustic resonators".*Journal Acoustical Society of America*, v.25, issue: 6, p.1037-1061, 1953.

Jae-Deok, J., et al. "Acoustic insulation performance of a honeycomb panel using a transfer matrix method". *Journal of Engineering for the Maritime Environment*,v.232, Issue: 4, 2018.

Jayaraman, K. and Yam, K. "Decoupling approach to modeling perforated tube muffler components". *Journal Acoustic Society Am.*, v. 69, issue 2, feb. 1980.

Lee, D.H., Kwon, Y.P. "Estimation of the absorption performance of multiple layer perforated panel systems by transfer Matrix method". *Journal of Sound and Vibration,* v.278,p. 847–860, 2004.

Lee, Iljae. M.S. Acoustic *Characteristics of Perforated Dissipative and Hybrid Silencers*. PhD Thesis.The Ohio State University, Ohio, 2005.

Liu, Q., et al. "Design and analysis of operation performance of parameters of the integrated valve under the high temperature condition". *Ann. Nucl. Energy,* v. 71, p. 237–244, 2014.

Liu, Q., et al. "Design and analysis of operation performance of parameters of the integrated valve under the high temperature condition". *Ann. Nucl. Energy*, v. 71 p.237–244, 2014.

Liu, Q., et al. "Three-dimensional computations of water–air flow in a bottom spillway during gate opening". Eng. Appl. Comput. *Fluid Mech.,* v. 8, issue 1,p. 104–115, 2014.

Liu, X. et al. "Modified theory of a microperforated panel with roughened perforations". *EPL (Europhysics Letters)*, v.125, issue: 3, p. 340-344.DOI:10.1209/0295-5075/125/34004, 2014.

Mendez, S., Eldredge, JD. "Acoustic modeling of perforated discs with bias flow for large-eddy simulations". *J. Comput. Phys.,* v. 228, issue:13,p. 4757–4772, 2013.

Mimani, A., Munjal, ML. "3D acoustic analysis of spherical chamber having single inlet and multiple outlet: an impedance matrix approach". *Int. J. Appl. Mech.,* v. 3, issue: 4, p.685–710, 2011.

Mimani, A., Munjal, ML. "Acoustical behavior of single inlet and multiple outlet elliptical cylindrical chamber muffler". *Noise Control Eng. J.,* v. 60, issue:5, p.605–626, 2012.

Mohammed, El M. "Analytical study by transfer matrix and Green's method of a periodic lattice formed by dual Helmholtz resonators (DHR)". *International Conference on Electrical and Information Technologies, (ICEIT),* 2017.

Munjal, M. L. "Analysis and design of mufflers – an overview of research at theIndian institute of science".*Journal of Sound and Vibration*, v. 211, n. 3, p. 425-433, 1998.

Munjal, M. L., Doige, A. G. "The two-microphone method incorporating theeffects of mean flow and acoustic damping".*Journal of Sound and Vibration*,v. 137, n. 1, p. 135-138, 1990.

Noé, J. et al. "Iridescent Perfect Absorption in Critically-Coupled Acoustic Metamaterials Using the Transfer Matrix Method". *Applied Sciences, MDPI*, v. 7, issue6, p.618, 2017.

Phong, V., Papamoschou, D. "High frequency acoustic transmission loss of perforated discs at normal incidence". J. *Acoust. Soc. Am.,* v. 134, issue2, p.1090–1101, 2013.

Phong, V., Papamoschou, D. "Acoustic Transmission Loss of Perforated Discs". 18th AIAA/CEAS Aeroacoustics Conference (33rd AIAA Aeroacoustics Conference), Colorado Springs, CO, June. 2012.

Phong, V., Papamoschou, D. "Acoustic Transmission Loss of Perforated Discs". *18th AIAA/CEAS Aeroacoustics Conference (33rd AIAA Aeroacoustics Conference)*, Colorado Springs, CO, Jan. 2012.

Phong, V., Papamoschou, D. "Normal Incidence Acoustic Transmission Loss of Perforated Discs with Bias Flow". *53rdAIAA Aerospace Sciences Meeting*, Florida, AIAA 2015-0742, jan. 2015.

Qian, J., et al. "CFD analysis on the dynamic flow characteristics of the pilot-control globe valve". *Energy Convers.,*v. 87, p. 220–226, 2014.

Qian, J., Wei, L., Jin, Z., et al. "CFD analysis on the dynamic flow characteristics of the pilot-control globe valve". *Energy Convers Manage 2014*, v. 87, p. 220–226, 2014.

Rao, S. *Vibrações Mecânicas*. 4 ed. p. 424, São Paulo: Pearson Prentice Hall, 2008.

Rao, Y.,et al. "Developmentof a butterfly check valve model under natural circulation conditions". *Ann. Nucl. Energy*, v. 76, p.166–71, 2015.

Reethof, G."Turbulence-generated noise in pipe flow". *Ann. Rev. Fluid Mech.,* v. 10, p. 333-367, 1978.

Ronneberger, D. "The acoustical impedance of holes in the wall of flow ducts".*Journal of Sound and Vibration,*v.24, issue 1, p. 133-150, Sep. 1972.

Sekhar, MC.,et al. "Enhanced stability against spin torque noise in current perpendicular to the plane self-biased differential dual spin valves". *J. Magn. Mater*, v. 374, p.740–743, 2015.

Sivian, L. J. "Acoustic impedance of small orifices".*Journal Acoustical Society of America,* v.7, p. 94-101, 1935.

Song, X.,et al. "A CFD analysis of the dynamics of a direct-operated safety relief valve mounted on a pressure vessel". *Energy Convers. Manage.,*v. 81, p.407–419, 2014.

Song, XG. et al. "Transient analysis of a spring-loaded pressure safety valve using computational fluid dynamics (CFD)". *J. Pressure Vessel Technol.,*v. 132, issue: 5, p. 545-561, 2010.

Sullivan, J. W. and CROCKER, M. J. "Analysis of concentric-tube resonators having unpartitioned cavities". *J. Acoustic Soc. Am.,* v. 64, issue 1, jul. 1978.

Sullivan, W. "A Method of Modeling Perforated Muffler Components II. Applications". *J .Acoust. Soc. Am.,* v. 66, p. 779-788, 1979.

Thieme, F. A. *Atenuação de Ruído em Silenciadores Automotivos: Análise Numérica pelo Método das Matrizes de Transferência e Verificação Experimental*.Dissertação de mestrado, Florianópolis, 2000.

Valdés, JR., et al. "A methodology for the parametric modelling of the flow coefficients and flow rate in hydraulic valves". *Energy Convers. Manage,* v. 88, p.598–611, 2014.

Valdés, JR.,et al. "Numerical simulation and experimental validation of the cavitating flow through a ball check valve". *Energy Convers. Manage,* v. 78, p. 776–786, 2014.

Wu, D., et. al. "CFD simulation of flow-pressure characteristics of a pressure control valve for automotive fuel supply system". *Energy Convers. Manage,* v.101, p.658–665, 2015.

Xu, Y.,et al. "Structural optimization of downhole float valve via computational fluid dynamics".*Eng Fail Anal., .*v. 44, p. 85–94, 2014.

Yuan, X., Guo K. "Modelling and analysis for a pilot relief valve using CFD method and deformation theory of thin discs". *Sci. China Technol,* p.1–20, 2015.

Ye, Y.,et al. "Effects of groove shape of notch on the flow characteristics of spool valve". *Energy Conversion Manage,* v. 86, p.1091–1101, 2014.

Yuanyuan, D.,et al. "Comparison of three numerical methods for acoustic propagation in a lined duct with flow". *25th AIAA/CEAS Aeroacoustics Conference,* Delft, The Netherlands, May. 2019.

Zeng, L.,et al. "Flow-induced vibration and noise in control valve". Proc. Inst. Mech. Eng., Part C: J. *Mech. Eng. Sc.,* 2015.

9. RESPONSIBILITY NOTICE