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## On Muffler Design for Transmitted Noise Reduction

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**ABSTRACT:** This paper is the results of an undergraduate final term project. The aim of project was to investigate the passive noise reduction methods in mufflers. Also, another aim of this study is to examine and design mufflers with various geometries. This is learning the effect of geometry on noise transmission loss maximization performance of mufflers. Four-pole method is used to determine the noise transmission loss. Two different cross-sectional geometries are considered for the mufflers, i.e. rectangular and circular. These mufflers are produced and tested. A noise transmission test bench is used for the measurement of noise transmission loss of these mufflers. The analytical results from simulation are compared with the experimental results. The effect of geometry of mufflers on the maximization of the transmitted noise loss are investigated and reported. The results of this study can help students to learn the basics of muffler design for noise reduction applications. Furthermore, it shows the effect of geometry on the acoustic performance of mufflers.

**Keywords:** Muffler, Noise Reduction Loss Maximization, Design, Production

## 1. Introduction

There are many unwanted sounds that are coming from vehicles, machines and industrial applications. The unwanted noise level can lead to very dangerous diseases and permanent hearing loss on the person's body. Therefore, there is a need to use from some devices to reduce the level of unwanted emitted noise from structures. Mufflers are devices which reduce the radiated noise from some structures like engines by attenuating of sound. They can be categorized as reactive and absorptive. In this study, we consider the reactive mufflers which dissipate the noise energy by their specific geometries. The reactive mufflers contains air as a fluid medium in their inside areas. There can be perforated tubes and external raises and bumps on the internal surface area (Gerges et al. 2005). Ranjbar et al. investigated various methods for noise reduction of various structures (Ranjbar et al. 2006- Ranjbar et al. 2017).

This paper is the results of an undergraduate final term project. The aim of project was to investigate the passive noise reduction methods. Also, another aim of this study is to examine and design mufflers with various geometries. Furthermore, the geometrical effect of muffler on their noise transmission loss maximization performance is studied. In the next sections, the theory of modeling, simulation and testing procedure are presented.

## 2. Material and Methods

Munjal et al. described the noise attenuation in reactive mufflers by using transfer matrix method (Munjal et al. 1973). By using transfer matrix method with four poles we can determine the noise transmission loss (TL). The parameters that used for the TL measurement are internal and external pressures and velocities of a straight duct with a length of L, i.e.  $p_i, v_i$  and  $p_o, v_o$ .

$$p_i = Ap_o + Bv_o \tag{1}$$

$$v_i = Cp_o + Dv_o \tag{2}$$

The A, B, C, D values are four pole parameters. For the no viscous fluid medium if Mach Number is less than 0.2, then four pole parameters can be written as;

$$A = e^{-jMK_c L} \cdot \cos(K_c L) \tag{3}$$

$$B = j \left( \frac{\rho c}{S} \right) e^{-jMK_c L} \cdot \sin(K_c L) \tag{4}$$

$$C = j \left( \frac{S}{\rho c} \right) e^{-jMK_c L} \cdot \sin(K_c L) \tag{5}$$

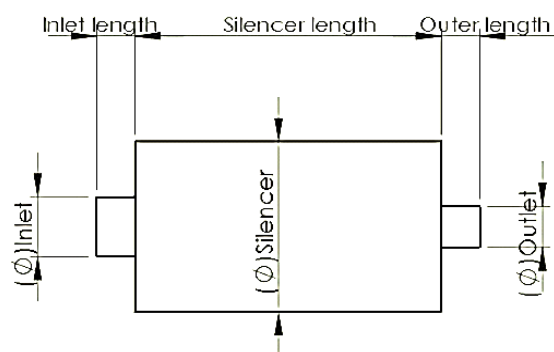
$$D = e^{-jMK_c L} \cdot \cos(K_c L) \tag{6}$$

M is mean flow Mach number, c is speed of sound,  $K_c$  is convective wave number, K is acoustic wave number and  $\rho$  is fluid density. According to four pole parameters, if we define a matrix as  $T_j$ :

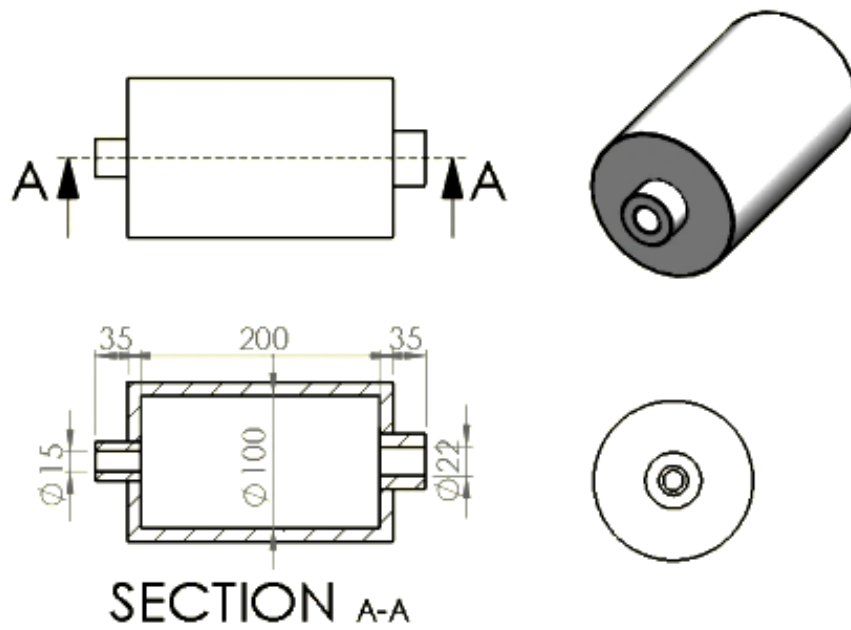
$$T_1 = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \tag{7}$$

This matrix can be described as for one geometry in muffler. So the  $T_2, T_3, \dots, T_n$  can be calculated as well. Total TL value depends on complexity and orientation of muffler. For each orientation, the T matrix must be calculated. According to Figures 1 to 3, the total value of TL for a simple muffler which contains inlet ( $T_1$ ), silencer ( $T_2$ ) and outlet parts ( $T_3$ ) can be defined as:

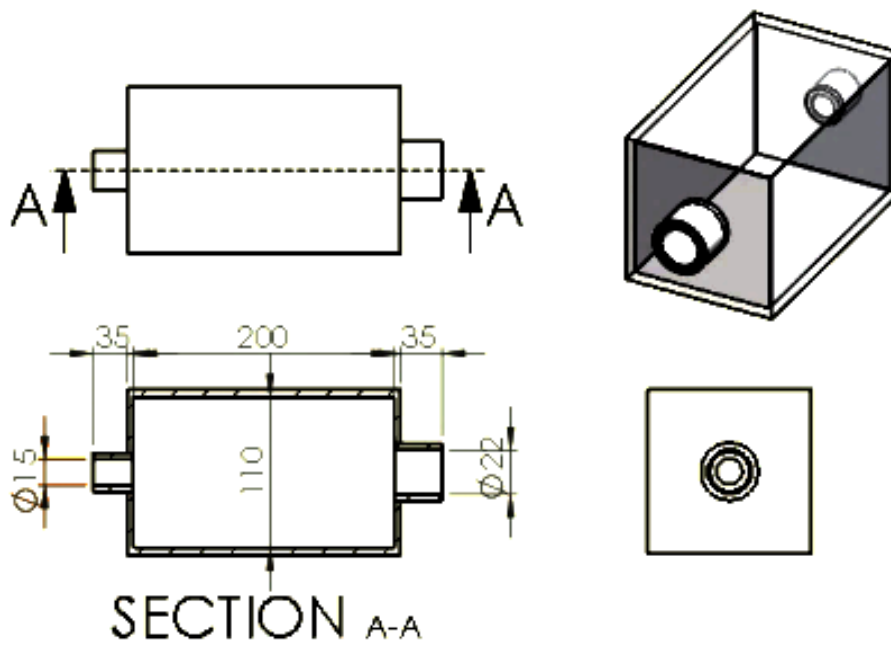
$$T_{total} = T_1 * T_2 * T_3 \tag{8}$$



**Figure 1.** Schematic Representation of Simple Muffler



**Figure 2.** Dimension of Circular Muffler



**Figure 3.** Dimension of Rectangular Muffler

These geometries will be used for the investigation of TL by simulation and experimental testing.



**Figure 4.** Manufactured Circular Muffler

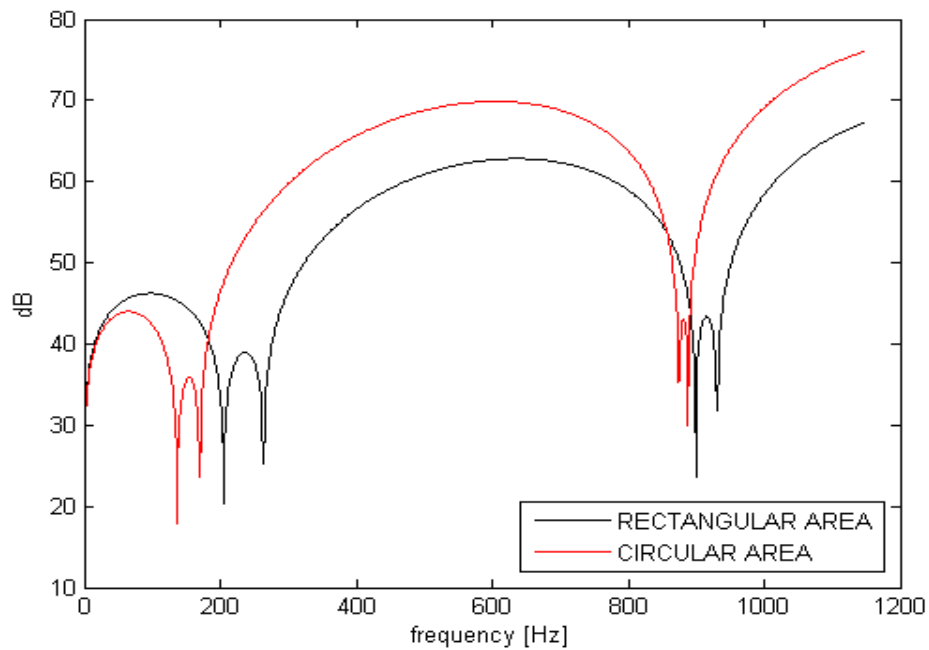


**Figure 5.** Manufactured Rectangular Muffler

In Figures 4 and 5, the models of circular and rectangular cross-sectional mufflers have shown. In next section, the results of simulation and experimental testing will be presented.

### 3. Results and Discussion

For the sake of simulation, the ambient temperature is considered as 20 °C, the speed of sound is 343 m/s and density of air is 1.204 kg/m<sup>3</sup>. These conditions can change the parameters that which affect the four pole constants.



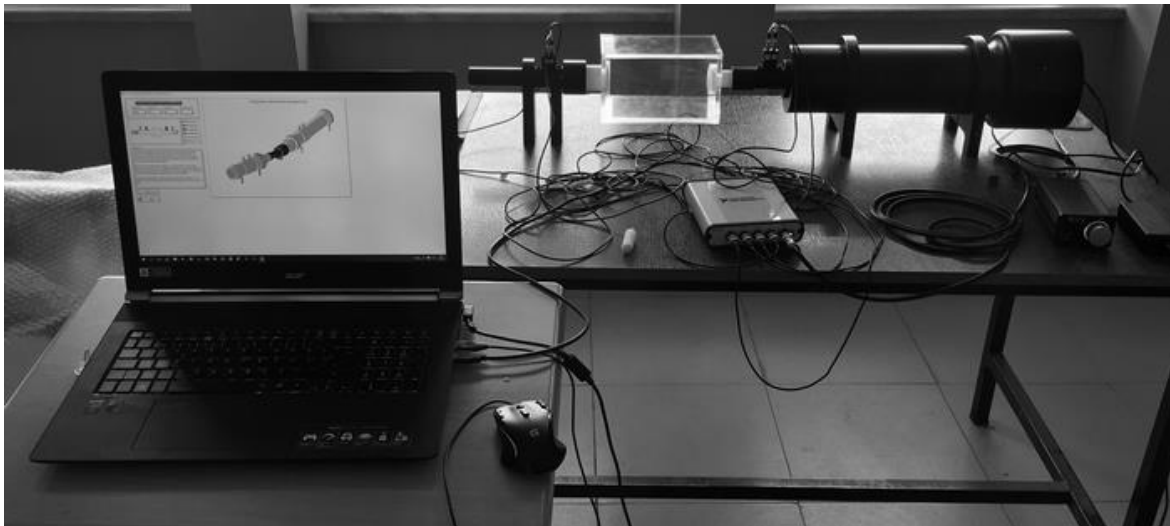
**Figure 6.** Noise Transmission Loss (TL) of Different Geometries

Figure 6 shows the calculated TL for different geometries by numerical simulation. It depicts that in the frequency range less than 200 Hz, the circular shows a better performance. But for the frequencies more than 200 Hz, the rectangular muffler performs better. To examine the results from simulation, an experimental study setup is arranged for the measurement of TL of both mufflers.

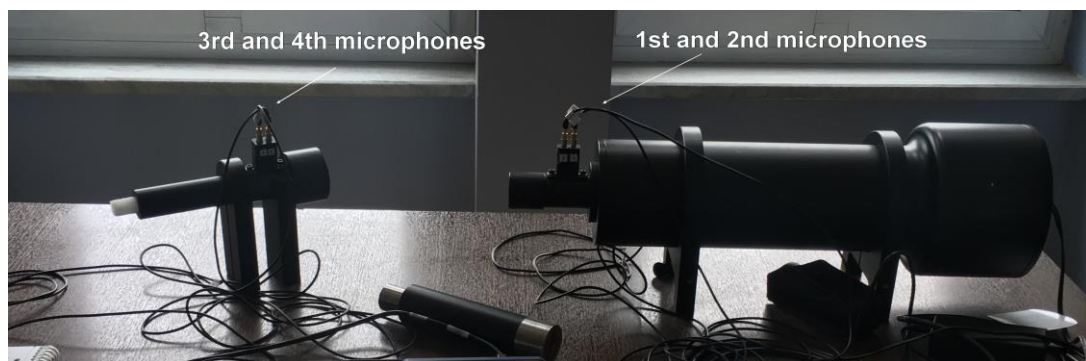
### 3.1. Experimental setup

The main component of a test rig for the measurements of noise analysis called as “Impedance tube”. For this experiment, impedance tube is used for acoustical analysis of noise transmission loss. Impedance tubes can accurately measure the sound properties for manufactured muffler or another silencer according to standards.

The impedance tube is fixed to the ground by three different supports, see Fig. 7. In Figure 8, the general view of impedance tube is shown.



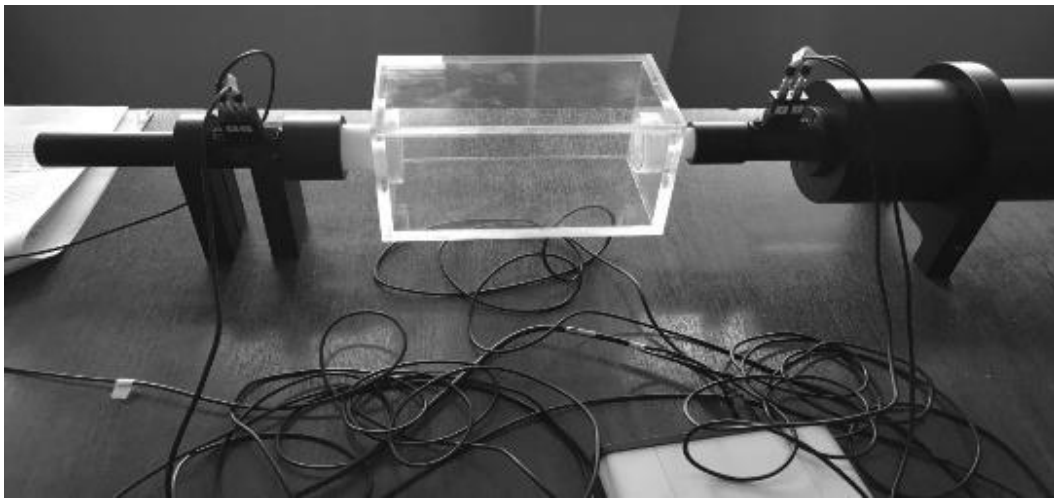
**Figure 7.** The View of Impedance Tube with Its Components while Testing



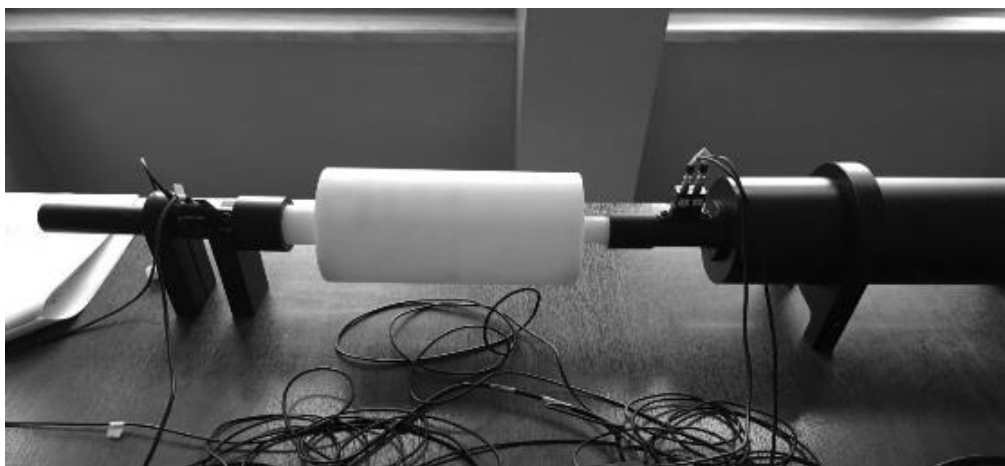
**Figure 8.** Microphones on Impedance Tube

Microphones can be separable from their positions for the calibrating operation. Hence, the screw threads appears in socket of where microphones to be placed. The microphones must be carefully placed after the calibrating operation finished, because this is important for accurate measurements.

While doing a measurement by software, it calculates automatically the frequency response function (FRF) graphs for both tube types. Then, it calculates the TL graphic according to that information.

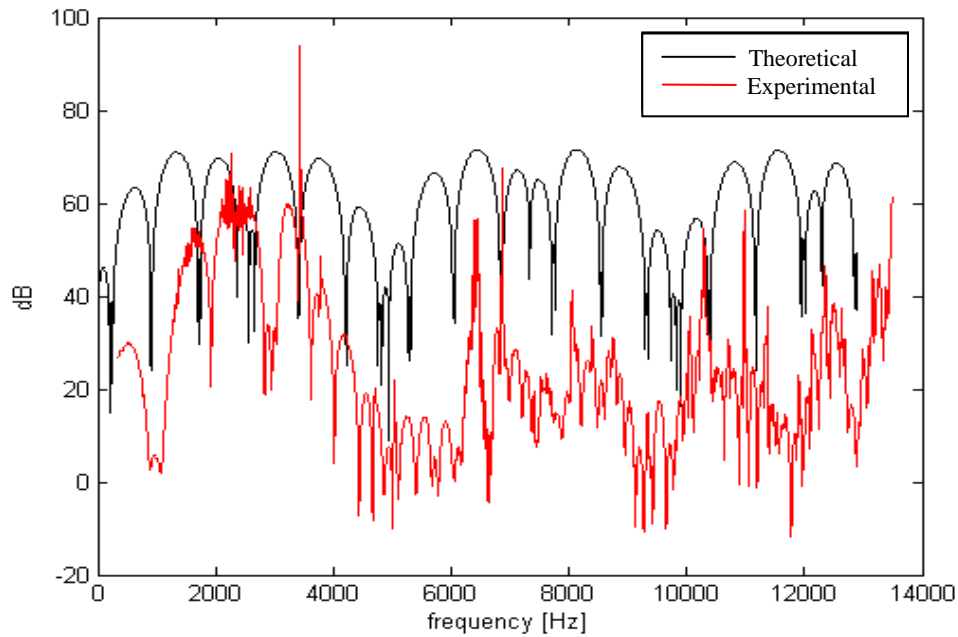


**Figure 9.** Our Rectangular Muffler on Test Bench in Testing Section

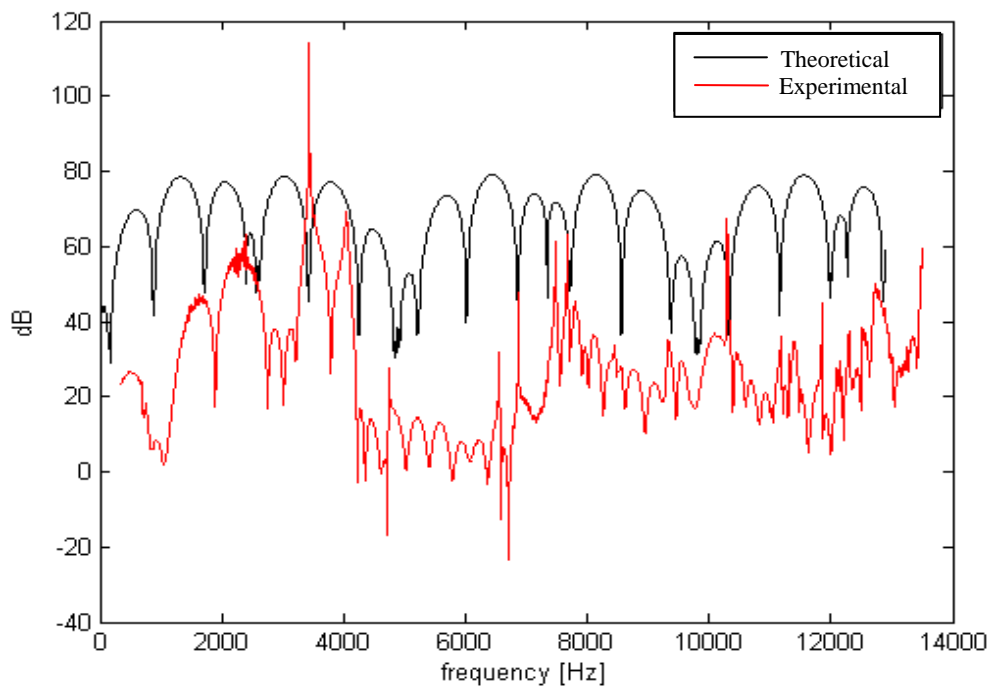


**Figure 10.** Our Circular Muffler on Test Bench in Testing Section

The simulation and experimental results for rectangular muffler are shown in Fig. 11. As we expected, the theoretical solution has greater TL (except some values between 2000 Hz-4000 Hz) than the experimental. The reason of that in Matlab simulation, we can just consider the numerical approach for the calculating the TL. However, in experimental way the solution contains so many different parameters with comparing than the theoretical way. The waves look similar for both cases but the experimental lines are more fluctuated and smaller.



**Figure 11.** Comparison of TL Measurement for Rectangular Muffler in Theoretical and Experimental Way



**Figure 12.** Comparison of TL Measurement for Circular Muffler in Theoretical and Experimental Way

Fig. 12 shows the comparison of simulation and experimental results for circular muffler. The simulation (theoretical way) has averagely greater TL values for frequency ranges. About a specific frequency value which greater than 4000 Hz, the transmission loss value exceeds almost like 118 dB. Also in some points, the theoretical and experimental results are coincident with each other. Like for the rectangular muffler, the randomly increases and decreases or fluctuated waves are reason of external effects which the theoretical way does not include. Furthermore, the cut-off frequency should be considered in all measurements. As, beyond the first cut-off frequency, the simulation theory using one-dimensional wave theory is not valid.

## 4. Conclusion

Undergraduate students could learn the basic of acoustics, muffler design, manufacturing and measurement during performing of this project. They learned the concept of measuring transmission loss, by means of software and experimental setup. They learned the operation of circular and rectangular ducts for different samples and materials. Furthermore, the mufflers with rectangular cross-section show a better performance for maximization of TL. The result of this study can be helpful for those who are new to this field to learn the basics of muffler acoustics simulation and experimentation.

Next groups of undergraduate students will continue this project by examining of different geometries and internal structure of muffler. Some techniques like usage of Helmholtz resonators and internal sound barriers can increase the performance of mufflers. These can be also studied by the new students as well.

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