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Analysis of Noise Level with Convergent and Divergent Shape of Muffler and its Impact on Noise Pollution

Ravi Jatola[1*] and Amit Kumar Gupta[2]

[1]Department of Mechanical Engineering, SGSITS, Indore, M.P., India; [2]Department of Mechanical Engineering, IET-DAVV, Indore, M.P., India

E-mail/Orcid Id:

RJ, ravijatola@yahoo.com, https://orcid.org/0000-0003-3089-2356; *AKG,* akgupta@ietdavv.edu.in, https://orcid.org/0009-0008-7894-9693

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Abstract: Noise pollution is one of the key hazards that decreases people's quality of life globally. Due to the rapid development of technology, industrialization, urbanization, and transportation networks, noise pollution has reached serious levels in recent years. Sound transmission loss, the attenuation of sound as it passes through diverse objects and environments, is crucial in lowering noise pollution and preserving the acoustic integrity of ecosystems. Due to de-throttling tactics implemented to optimize cylinder fill, the intake system of internal combustion engines is the primary noise source while the vehicle is at low speeds and high loads. Therefore, achieving high acoustic performance of intake systems constitutes a critical issue in complying with the increasingly stringent European regulations for overall noise emission. The Transmission Loss computation is typically the most used technique for describing a system's acoustic performances. This work provided an overview of sound transmission loss and discussed its substantial environmental effects. It investigates the fundamentals of sound transmission, the factors that influence it, and the environmental impacts of sound attenuation. This paper proposed a comparison of three designs like straight duct (muffler), convergent and divergent design of muffler. The main aim is to observe sound transmission loss and compare the noise level with three muffler configurations with the same gas volume. High transmission loss indicates more noise reduction in muffler design, which will help reduce environmental noise pollution.

Introduction

In order to stop negative health impacts, including high blood pressure, insomnia, nausea, heart attacks, depression, dizziness, and hearing loss, this level of noise pollution needs to be examined and regulated (Mir et al., 2023; Goel et al., 2023; Haloi et al., 2023). The regulation of traffic noise limits, physical inspections of cars, timing truck operations during the evening or night, and the implementation of fines for noise pollution are only a few of the solutions that various countries have implemented to address this problem by suitable design of muffler (Yuvaraj et al., 2022). Sound transmission loss has a significant negative impact on the environment. First, Noise pollution damages animals and ecosystems (Münzel et al., 2014). It can obstruct animal movement and obstruct mating, communication, and navigation, which could endanger species. Every part of our existence is infused with the power of sound, which is usually commended for its ability to convey concepts, feelings, and beauty (Chivate et al., 2022). It is essential to our basic form of communication, our life's music, and an essential component of the natural world (Lu et al., 2019). Our aural environment is changing as a result of current technology advancements and growing urbanisation, sometimes not in a good way (Li et al., 2008). This acoustic modification causes noise pollution, which puts human health at risk, disturbs ecosystems, and throws off the environment's delicate balance. Sound transmission loss is the cornerstone for comprehending and addressing noise pollution (Mohammad et al., 2020). developed in their technical article using three side-branch orifice designs on an adaptive quarter-wave tube to assess which was least harmed by the high-speed exhaust gas crossing the side-branch (Fu et al., 2021).

*Corresponding Author: ravijatola@yahoo.com

Their technical paper described the results of combining an active noise control system with a reactive muffler to eliminate sound in a cylindrical duct. A Grey prediction based on Grey theory was also used for this hybrid system and the experimentation that explored the integrated noise reduction system. The experiment used a mixed adaptive algorithm for this system (Shaaban et al., 2022). The scattering matrix results of Herschel–Quincke resonators fitted in conjunction with an acoustic liner were published in their technical paper. This method seeks to increase liner efficiency by reducing both broadband and tone noise. It makes use of Herschel–Quincke tube circumferential arrays on a primary duct in serial conjunction with a locally responding liner with a specified impedance (Das et al., 2022). Clarifying the intricate relationship between environmental conditions and sound transmission loss is the aim of this effort. It is vital to comprehend the fundamental ideas underlying sound attenuation to investigate the muffler, reduce the sound transmission loss, and diminish its effects on the environment (Zhao et al., 2024). In this research work, work has been done about noise pollution and the inlet and outlet cylindrical design of the muffler has been changed to convergent and divergent design and it has been told which shop will get more sound transmission loss.

Some researchers explained how enhanced stainless steel qualities in automotive exhaust systems are growing in response to the need for lighter vehicles and more stringent exhaust gas laws (Kalita and Singh, 2023; Oh and Lee, 2023). However, depending on the portions for which the materials are intended to be utilised, the qualities of the steel used in vehicle exhaust systems vary (Barbieri and Barbieri, 2006). In light of the situation, Kawasaki Steel created sophisticated stainless steels appropriate for every item by utilising all of the most recent production equipment in Chiba Works (Fan and Ji, 2019), outlined how the cathodic protection offered by the aluminized coating was used to boost the pitting corrosion resistance of automobile exhaust system components, thereby enabling the creation of aluminized stainless sheet steel (He et al., 2024). Stainless steel was first utilised in cars to satisfy societal demands for clean exhaust emissions and lighter cars that get greater fuel efficiency, as they explained in their scientific paper (Sagar and Munjal, 2017). Their technical article discussed how an expansion chamber's end correction is affected by the thickness of the duct's inlet and outlet walls. It was looked into both numerically and practically utilising 3-D FEM programme for stationary medium. According to the scientific article by Kawasaki (Wang et al., 2022), the issue of environmental pollution has resulted in increased requirements for car exhaust systems. When perforated mufflers were modelled using the finite element approach, the central route was swapped out for a transfer matrix that connected the acoustic velocity through the perforations to the pressure differential between the two sides of the perforated surface (Chiu, 2013). It is intended for use at temperatures of 800°C or lower. According to Lee and Wang (2006), sound-absorbing materials are highly effective at controlling noise because they absorb the majority of the sound energy that strikes them. They are employed in various settings, including pathways, near sources of noise, and occasionally near receivers (Mishra et al., 2021; Liu et al., 2022). Although all materials absorb some incident sound, the term "acoustical material" has historically been used to refer to materials that have been created with the express intention of offering high absorption values. In the scientific study, Chhibber et al. (2018) explained that an automobile engine's performance depends not only on its main components but also on the efficiency of its auxiliary systems, such as the fuel, engine cooling, exhaust, and intake systems. An essential component of every automobile vehicle, the exhaust system helps improve the vehicle's ride quality and fuel efficiency (Liu et al., 2016; Reddy, 2017). In order to guarantee that the engine emits the necessary exhaust gas while also reducing noise, an efficient exhaust system design is essential. In their scientific publication, Deryabin (2022) discussed the benefits of using an active noise control system in conjunction with a reactive muffler to eliminate sound in a cylindrical duct. A Grey prediction based on Grey theory was also used for this hybrid system in addition to the experimentation that explored the integrated noise reduction system. The experiment used a mixed adaptive algorithm for this system (Saha et al., 2023). In their technical report, a novel method for simulating concentric partly perforated invading tube mufflers was introduced by Chaitanya and Munjal (2011). A closed form solution of the transmission loss of the partly perforated invading tube muffler was derived for acoustic impedance in the linear domain. In their technical publication, Otaru et al. (2022) provided a numerical method for resolving the Helmholtz equation-governed three-dimensional interior acoustic problem. The ability to eliminate the singularity analytically was the primary characteristic of this formulation (Shi et al., 2022). In their technical article, Denia and Selamet (2008) described how reactive silencers with extended inlet and output ducts can be optimised for shape and parametric factors. To determine

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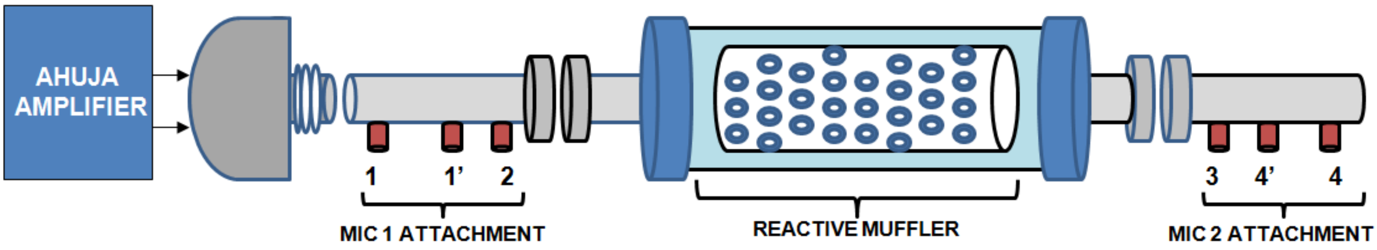

Figure 1. Schematic layout for noise level measurement

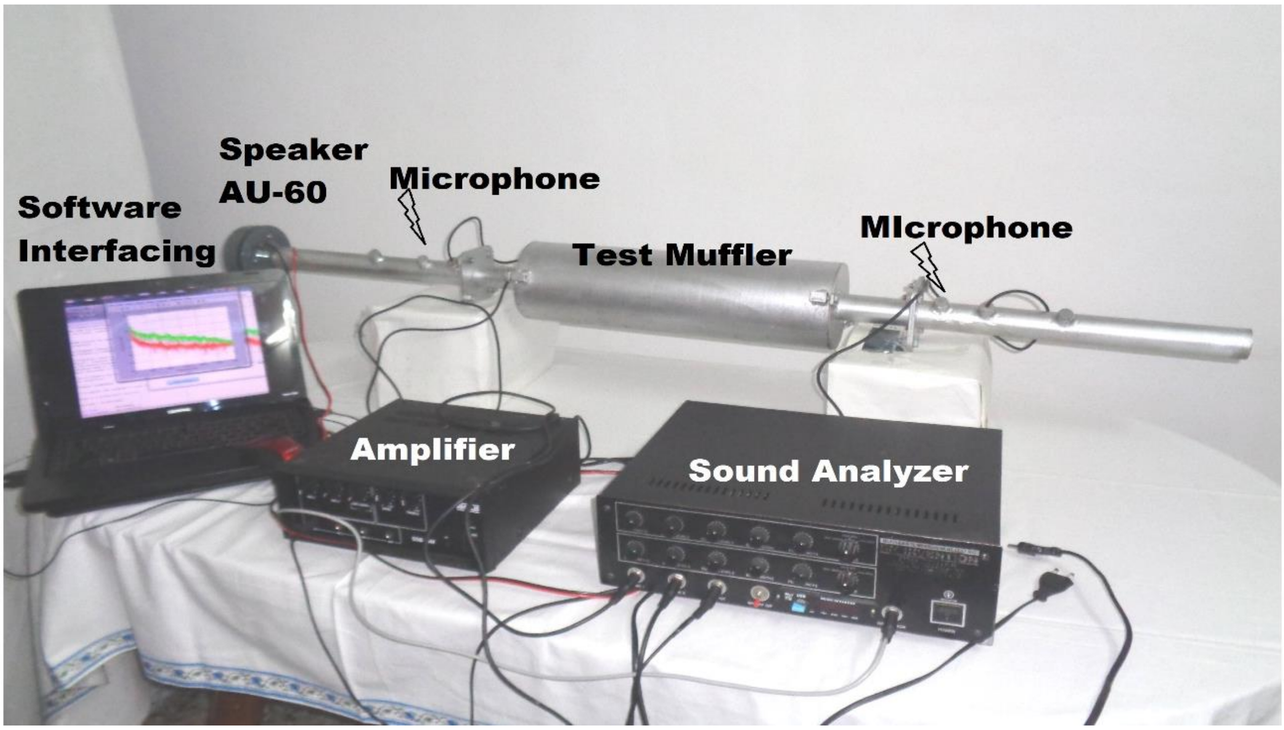

Figure 2. Experimental set-up prepared in the laboratory for noise measurement of the empty muffler.

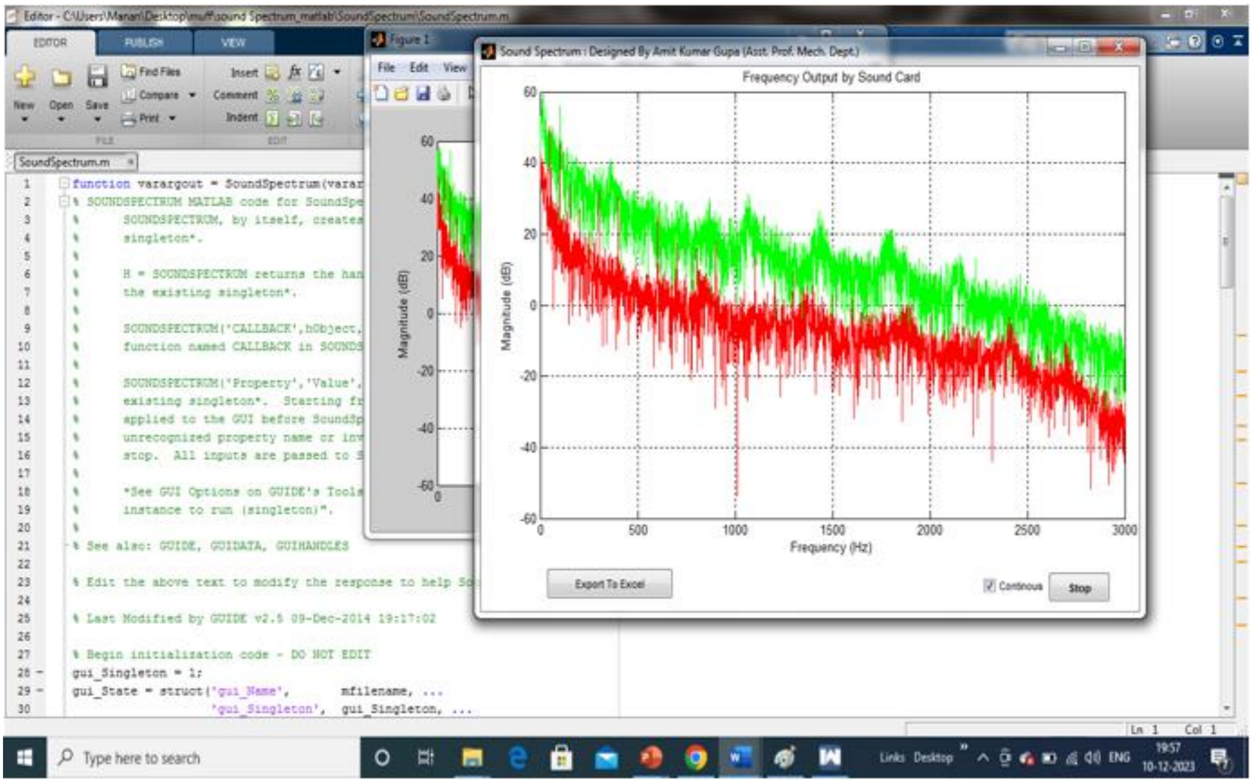

Figure 3. Time domain signal achieved by the sound analyser.

the proper size for the inlet and exit ducts, parametric optimisation was used. Shape optimisation was used to determine the ideal duct profile, which improved the mufflers' acoustic characteristics within a certain frequency range. Shao et al. (2020) detailed the quality of the Particle Swarm Optimisation solutions for a few linear acoustic issues in their technical paper. The report detailed the step-by-step implementation of this technique and examined two problems: parametric optimisation of mufflers and shape optimisation of acoustic horns. A closed form equation for the transmission loss of the twin expansion chamber silencer of uneven length and area was proposed by Elsayed et al. (2017) in their technical report. It is also demonstrated that chambers with various sizes yield considerable tuning benefits.

Methodologies

Validation of Experimental and FEA Result of Empty Circular Cylindrical Muffler

The Sound Analyzer is made up of two assemblies, one for the computer's upstream input signal (shown in green) and another for the downstream output signal (shown in red). Differences in their FFT analysis are examined using sound spectrum analysis tools built on Matlab.

The gearbox loss, which represents changes in sound pressure levels, is evaluated in this. Our circuit's adaptability and usefulness are increased by its customizable sensitivity, frequency selection, and range customization. Measurement of the Noise Level of an Empty Muffler by Experimental and FEA.

To fully cover the frequency range of 1 to 3000 Hz, the experiment needs two measurement slots at locations 1-1' and 4-4', as indicated in the image. Pressure readings between 400 and 3000 Hz are taken at positions 1-2-3-4, while those between 10 and 400 Hz are taken at locations 1'-2-3-4'. In order to calculate the transfer function between the sound pressure levels at the two sites, the measuring set-up needs to use two microphones. To prevent sound leakage, all areas—aside from those that house the microphones—are carefully sealed with rubber caps. The analysis makes use of the Wave 1-D tool, a one-dimensional gas dynamics code that simulates engine cycle performance using the finite volume method. The precision with which this instrument measures transmission loss (TL), a crucial factor in evaluating sound transmission characteristics, is widely recognised.

Validation of Experimental Set-Up

The test configuration is created considering the requirements listed in Figure 1. For both upstream and downstream impedance tubes, the microphone spacing is 50 mm. Calculations are made for upper and lower frequencies in order to prevent non-plane wave mode propagation within the tube. This 76 mm inner diameter experiment tube has frequencies that are roughly 3000 Hz at its highest and 50 Hz at its lowest, respectively.

The implant Figure 3 shows the geometry of the central inlet and outlet muffler. For all these configurations the experimental results show good agreement with the numerical results.

Comparison of Wave 1-D and Experimental Results

Attenuation curves show a considerable agreement between experimental data (using the two-load method) and results from Finite Element Analysis (FEA) software like Ricardo Wave 1-D. Mesh parameters are to blame for any minor differences found in the FEA findings. This flexibility allows different muffler shapes to be modelled for TL predictions, as shown in Figure 4. Practical evaluations frequently become unreasonably expensive and complicated because of the growing complexity of silencer geometry. Therefore, in such cases, FEA tools become the best method for producing precise gearbox loss estimations, guaranteeing that desired results are realized for silencer performance assessment.

Comparison of straight, convergent and divergent cylindrical muffler

In order to study wave propagation phenomena, expansion chamber dimensions are carefully taken into account. In order to guarantee that one-dimensional computations are accurate over a wide frequency range, the length-to-diameter ratio was chosen. The frequency response of a particular muffler is represented by transmission loss, which is chosen as an appropriate metric. The duct capacity remains constant, including cylindrical central intake and exit, Convergent duct and Divergent duct. The configuration is shown in Figure 5, where "amb1" stands for the duct's input point (Acoustic Piston) and "amb2" for the outflow point (Anechoic Termination). This thorough design technique makes a comprehensive investigation of wave behaviour and transmission loss in expansion chambers possible.

Results and discussion

Three configurations are taken with the same gas volumes are used to evaluate transmission loss, namely divergent and convergent ducts and a cylindrical duct. In contrast to the other two cases, the Convergent Cylindrical Duct case exhibits the highest Transmission Loss (20.2 dB) shown in Figure 6. The attenuation curve demonstrates how well taper mufflers lower noise levels in the medium to high-frequency range. All three examples, however, behave similarly in the low- to mid-

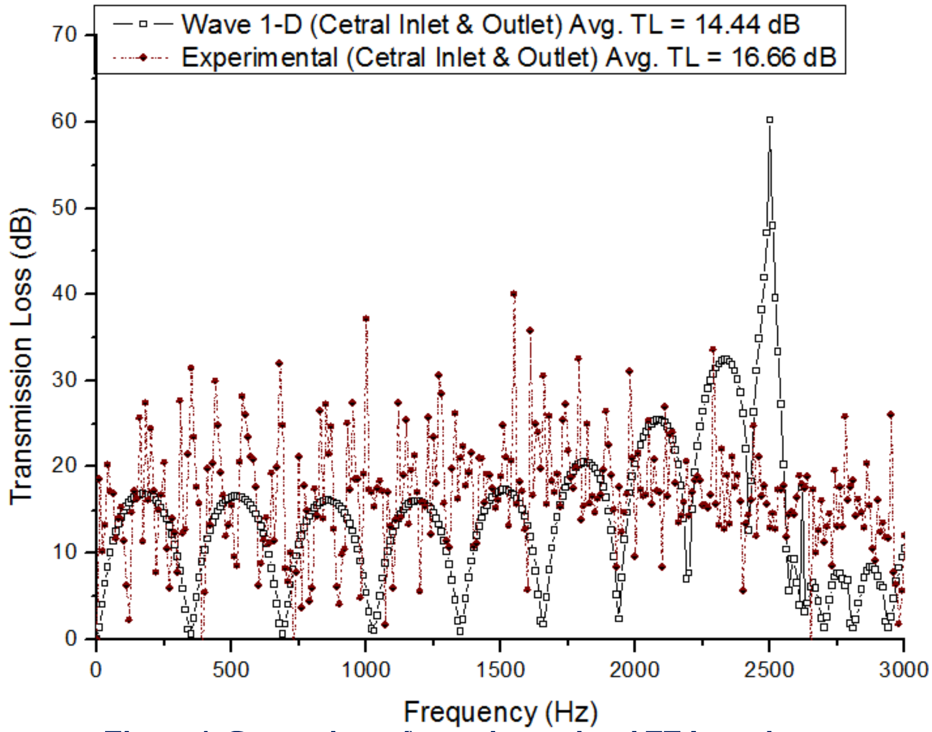

Figure 4. Comparison of experimental and FEA results.

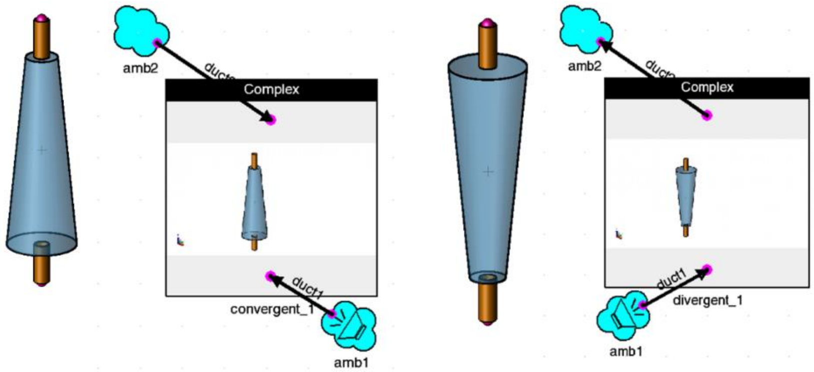

Figure 5. Convergent and Divergent type muffler analysis.

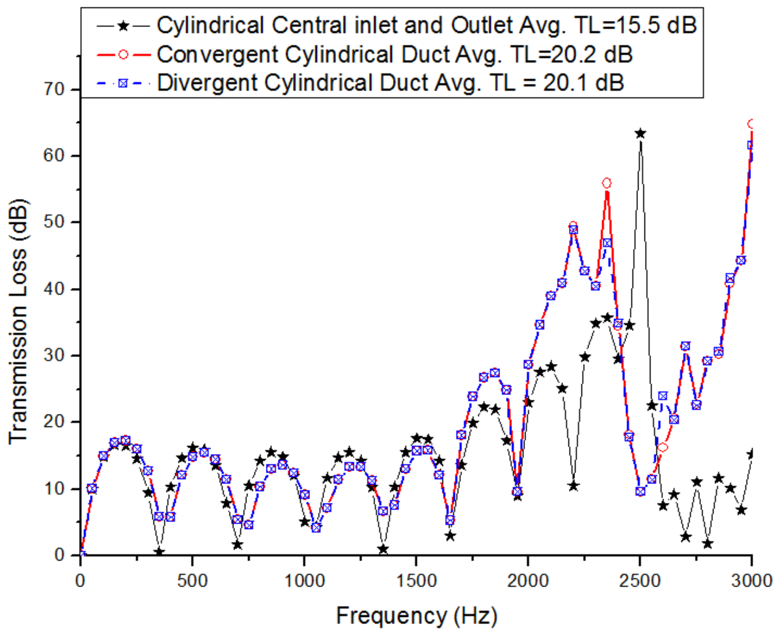

Figure 6. Comparison of TL with Convergent and Divergent Shape of Muffler.

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frequency range, highlighting the taper muffler's limits in those frequency ranges.

Table 1. Noise level for circular, convergent and divergent mufflers.

Sl. No.	Muffler Design	Noise Level
1	Cylindrical Duct	15.5 dB
2	Convergent Cylindrical Duct	20.2 dB
3	Divergent Cylindrical Duct	20.1 dB

Conclusion

In conclusion, sound transmission loss is crucial for the preservation of the environment and the welfare of humans. In order to reduce the negative impacts of noise pollution on the environment, wildlife, and human populations, it is important to comprehend sound attenuation concepts and put them into practice. It has been seen in this work, shown in figure 6, that the sound transmission loss received by the cylindrical shape muffler is 15.5 dB and if its design is altered, then it increases to 20.2 dB, this will reduce the outgoing sound. Creating sustainable solutions safeguarding our acoustic environment and promoting peaceful cohabitation between people and nature calls for interdisciplinary efforts from scientists, engineers, urban planners, and legislators. The development of long-term solutions that safeguard our acoustic environment and promote peaceful cohabitation between people and nature depends on this common effort. Our general well-being and the health of ecosystems are inextricably tied to the harmony of our sonic environments. Therefore, while we proceed, let us keep in mind that a quieter world is a gift to ourselves as well as a legacy of peace we owe to future generations.

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Conflict of Interest

The authors declare no conflict of interest.

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