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Influence of Cross-Sectional Geometry on the Acoustic Performance of Mufflers: A Finite Element Study

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Abstract

In this study, the acoustic performance of two muffler prototypes with elliptical and cylindrical cross-sections is numerically investigated and compared. The primary objective is to quantify the influence of cross-sectional geometry on sound transmission loss (STL) characteristics and to identify the resulting changes in wave propagation behavior. Finite element simulations were conducted in COMSOL Multiphysics®, and STL spectra were obtained over a broad frequency range. The results show that both mufflers exhibit comparable transmission loss at low frequencies; however, distinct differences emerge as frequency increases. The elliptical muffler demonstrates enhanced attenuation across certain mid- and high-frequency bands, attributed to the asymmetric distribution of the acoustic pressure field and the altered propagation paths of incident waves. In contrast, the cylindrical muffler, owing to its geometric symmetry, aligns more closely with analytical predictions and idealized acoustic models at lower frequencies. Detailed analysis of pressure contours and resonance patterns further confirms that the elliptical configuration introduces frequency shifts in pressure peaks and distinct mode shapes. These findings underscore the significant role of geometric design in determining muffler performance and provide valuable guidelines for optimizing cross-sectional profiles to achieve superior noise reduction in automotive and industrial applications.

Keywords: Transmission loss; Acoustics; Muffler; Resonance.

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1. Introduction

Mufflers are vital components of automotive and industrial exhaust systems designed to control noise and reduce acoustic pollution. They are typically categorized as reactive or dissipative devices [1]. Reactive mufflers employ reflection, interference, and internal resonance effects to attenuate low- and mid-frequency noise [1,2], while dissipative types use sound-absorbing materials to suppress high-frequency components [3,4]. Hybrid configurations combining both mechanisms can achieve broadband noise reduction with minimal flow resistance [5].

At low frequencies, the performance of reactive mufflers can be accurately described using plane-wave theory, where transmission loss mainly depends on the chamber volume and expansion ratio [6]. However, beyond the cut-off frequency, higher-order transverse modes arise, causing strong oscillations and unpredictable variations in sound transmission loss (STL) [7]. In this range, the cross-sectional geometry, previously negligible, becomes a key factor influencing resonance and anti-resonance behavior [8].

Operational and environmental factors further affect muffler performance. Variations in exhaust -gas temperature alter the speed of sound and thus shift the STL spectrum [9]. Structural modifications, such as multi-outlet arrangements, may improve flow efficiency but change acoustic boundary conditions and reflection patterns. Consequently, understanding how geometric asymmetry, such as replacing a symmetric cylindrical chamber with an elliptical one, affects acoustic behavior is essential for reliable design optimization [10].

This study numerically investigates and compares the acoustic performance of elliptical and cylindrical reactive mufflers using finite-element simulations in COMSOL Multiphysics®**.** The analysis covers STL behavior from low to high frequencies, examines temperature-dependent performance, and evaluates outlet configuration effects. The findings provide insights into how non-circular geometries can enhance noise attenuation efficiency in practical automotive and industrial applications [11,12].

2. General discussion

In this study, a comparative investigation was conducted on the acoustic performance of two simple reactive muffler configurations (expansion chambers). The primary objective was to precisely evaluate the effects of cross-sectional geometry, as well as the influence of increased outlet number and fluid temperature, on sound transmission loss, particularly in the higher acoustic mode region.

2.1 Simulation Assumptions

Two mufflers with different geometries were designed for acoustic analysis: an elliptical cross-section (200 × 128 mm) and a cylindrical cross-section (80 mm radius), both 400 mm in height. The inlet was a 40 mm diameter, 100 mm long tube for all cases. Two outlet configurations were considered: a single outlet (40 mm) and two outlets (20 mm each) to maintain geometric proportion. Air was used as the working fluid, with temperature-dependent properties. Simulations were conducted at 953 K (hot exhaust) and 300 K (ambient), showing that gas temperature significantly affects wave propagation and sound transmission loss.

2.2 Simulation

Numerical simulations were conducted in COMSOL Multiphysics® using the *Pressure Acoustics, Frequency Domain* interface. Identical boundary and physical conditions were applied to all cases to ensure fair comparison. Plane-wave boundaries were defined at the inlet and outlet, and all walls were modeled as perfectly rigid. A fine mesh with at least ten elements per wavelength was used to ensure numerical accuracy. The models were analyzed over a wide frequency range to evaluate the effects of geometry, outlet configuration, and temperature on sound transmission loss and resonance behavior.

2.3 Numerical Acoustic Equations

A plane wave with a specified amplitude was applied at the inlet as the incident pressure P_{in} The incident acoustic power W_{in} passing through the inlet cross-section S_{in} is calculated as [2]:

$$W_{in} = \int_0^{S_{in}} \frac{{P_{in}}^2}{2\rho_0 c_0} dS_{in} \quad (1)$$

where ρ_0 and c_0 denote the air density and sound speed, respectively. Similarly, the reflected and transmitted acoustic powers, W_{re} and W_{tr}, are obtained from the pressure amplitudes P_{re} and P_{tr} over the inlet and outlet surfaces S_{in} and S_{tr} [6]:

$$W_{re} = \int_0^{S_{in}} \frac{{P_{re}}^2}{2\rho_0 c_0} dS_{in} \quad (2)$$

$$W_{tr} = \int_0^{S_{tr}} \frac{{P_{tr}}^2}{2\rho_0 c_0} dS_{tr} \quad (3)$$

The Sound Transmission Loss (STL) is then expressed as:

$$STL = 10 \log \frac{W_{in}}{W_{tr}} \quad (4)$$

3. Results and Discussion

In the following, the accuracy and reliability of the obtained sound transmission loss (STL) results are examined first, and then the effects of various parameters on the acoustic performance of the muffler are analyzed.

3.1 Validations

In this study, a benchmark muffler problem from a reference textbook [7] was simulated using COMSOL Multiphysics® to validate the numerical approach. The theoretical and numerical results for both the fundamental frequency and peak Sound Transmission Loss (STL) showed excellent agreement, confirming the validity and accuracy of the proposed model.

Subsequently, two different geometrical configurations were analyzed under identical boundary conditions to investigate the effect of cross-sectional shape on acoustic performance. The numerical results demonstrated close consistency with analytical predictions, further verifying the model's reliability and its applicability to more complex geometries.

The simulations were performed using the Pressure Acoustics, Frequency Domain interface, where both inlet and outlet boundaries were defined as plane wave radiation and the muffler walls were treated as sound-hard boundaries. The input excitation was modeled as a harmonic plane wave, and STL was computed by integrating the acoustic power at the inlet and outlet surfaces across a frequency range.

A physics-controlled mesh was employed, ensuring accurate wave resolution with at least 10 second-order elements per wavelength, exceeding standard requirements to minimize numerical dispersion and capture resonant pressure variations accurately.

The main parameters used for model validation are summarized in Table 1, and the meshing configuration is illustrated in Figure 1. The corresponding STL results are presented in Figure 2 and Table 2, showing strong agreement with the theoretical predictions.

Table 1. Validation model Properties. [7]

Property	Value
Cylinder Diameter Ratio (D/d)	3 and 4
Muffler Length (l)	0.4 m
Diameter of the Exhaust pipe and Tail Pipe (d)	40 mm
Default Shell Diameter (D)	120 and 160 mm
Exhaust Gas Temperature (T)	953 K
Exhaust Gas Density (ρ_0)	0.37 kg/m³
Speed of Sound (c_0)	619 m/s

(a) (b)

Figure 1. Mesh configuration for the cylindrical muffler. (a): $D/d = 3$ and (b): $D/d = 4$.

(a)

(b)

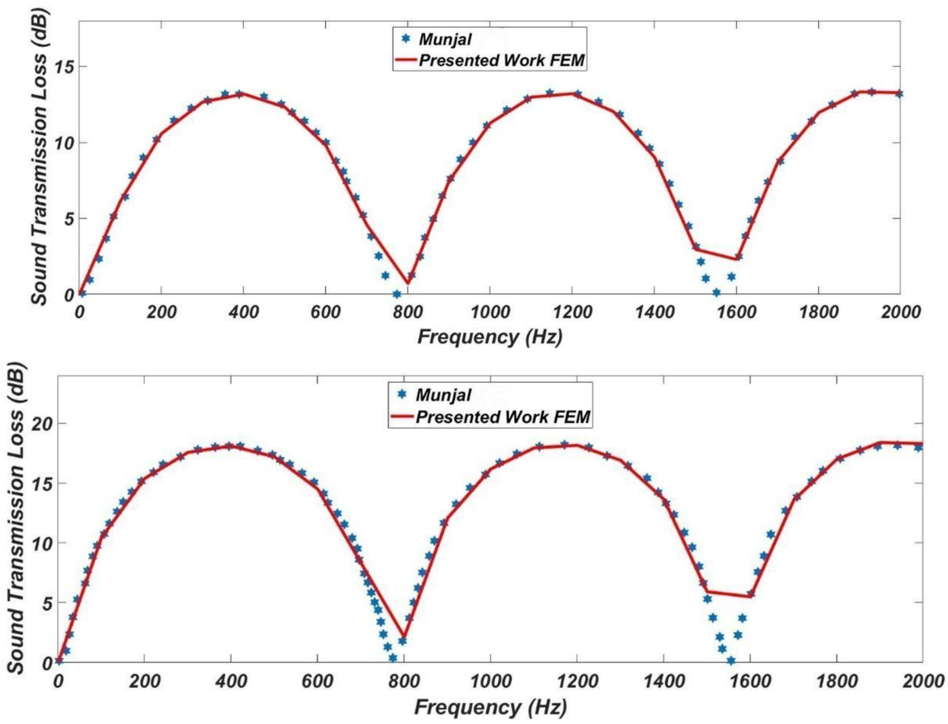

Figure 2. Demonstration of the FEM acoustic response of the present approach against the theoretical [7].

Table 2. Validation Response Properties. (Relative Error (RE)= $\frac{FEM-Theory}{Theory}\%$).

Property	Munjal	FEM	Relative Error
Fundamental Frequency	774 Hz	801 Hz	3.49%
STL_{Peak} (D/d = 3)	13.06 dB	13.16 dB	0.77%
STL_{Peak} (D/d = 4)	18.06 dB	18.08 dB	0.11%

3.2 Sound Transmission Loss

Figure 3, presents a comparison of the sound transmission loss (STL) of cylindrical and elliptical mufflers over the frequency range of 0–3000 Hz. Over this range, both geometries exhibit nearly identical acoustic behavior, as evidenced by the close alignment of resonance peaks and anti-resonance troughs at similar frequencies. This strong agreement indicates that, in the low- to mid-frequency regime, the cross-sectional shape of the muffler plays a negligible role in determining its overall acoustic performance. The underlying reason for this behavior lies in the relatively long acoustic wavelengths associated with these frequencies, which are significantly larger than the characteristic dimensions of the muffler cross section. Under such conditions, the pressure field inside the chamber remains almost spatially uniform in the transverse direction, and the acoustic response is therefore dominated by one-dimensional longitudinal modes rather than higher-order transverse modes. Consequently, geometric differences between cylindrical and elliptical cross sections do not significantly affect the STL response in this frequency range. Both muffler configurations exhibit three dominant resonance frequencies at approximately 750 Hz, 1550 Hz, and 2350 Hz, corresponding to standing wave formation within the expansion chamber, with maximum STL values of approximately 18 dB observed for both geometries.

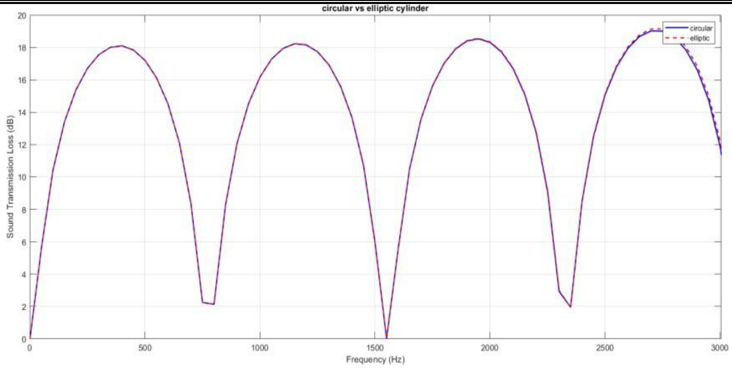

Figure 3. STL Comparison of Elliptical and Cylindrical Mufflers.

Figure 4, extends the frequency range of the analysis up to 10,000 Hz. At higher frequencies (above 3000 Hz), noticeable differences emerge between the circular and elliptical muffler configurations. In the elliptical muffler, geometric asymmetry along the principal axes causes a splitting of transverse resonance frequencies, which results in multiple closely spaced resonance peaks and more pronounced oscillations in the STL response. By contrast, the circular muffler preserves full axial symmetry, leading to a smoother, more regular, and predictable STL behavior across the same frequency range. The maximum STL attained by the elliptical muffler reaches values of up to approximately 45 dB, whereas the corresponding peak values for the circular muffler remain below 25 dB. Furthermore, beyond roughly 5000 Hz, the STL response of the elliptical muffler becomes increasingly irregular and highly fluctuating, while the circular muffler continues to exhibit a stable and repeatable response pattern.

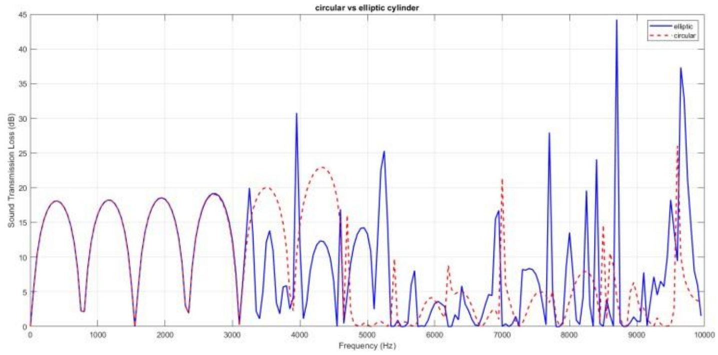

Figure 4. Sound transmission loss of the two mufflers up to 10,000 Hz.

Figure 5, shows the STL comparison between a single-outlet and a dual-outlet circular muffler up to 3,000 Hz. The dual-outlet muffler consistently achieves 2–3 dB higher STL across the frequency range, particularly at resonance peaks. This improvement is due to better energy distribution and reduced reflections, as the parallel outlets increase effective acoustic impedance and enhance sound attenuation.

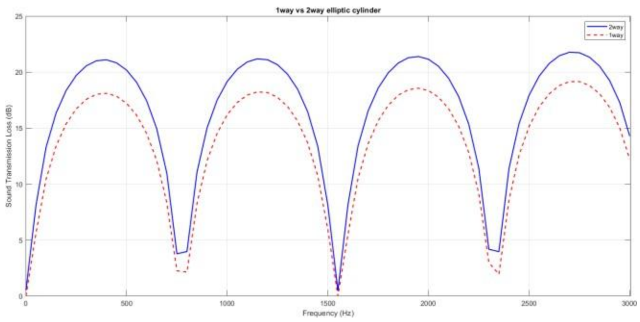

Figure 5. Sound transmission loss (STL) curves of the elliptical muffler with one and two outlets.

Since the muffler was assumed to be filled with air, variations in temperature lead to changes in the speed of sound and air density according to the ideal gas law, as summarized in Table 3. No specific material was assigned to the muffler structure; instead, the surrounding walls were modeled as rigid bodies. Therefore, the present study focuses solely on the acoustic behavior of air within the muffler, and the observed resonance points correspond to the air rather than the structure itself. As the temperature increases, the speed of sound rises, and since the acoustic frequency is directly proportional to the speed of sound, this results in a shift of the transmission loss curve toward higher frequencies, as illustrated in Figure 6 and 7.

Table 3. Key properties of air.

Temperature (K)	Speed of Sound (m/s)	Air Density (kg/m³)
953	619	0.37
300	347	1.18

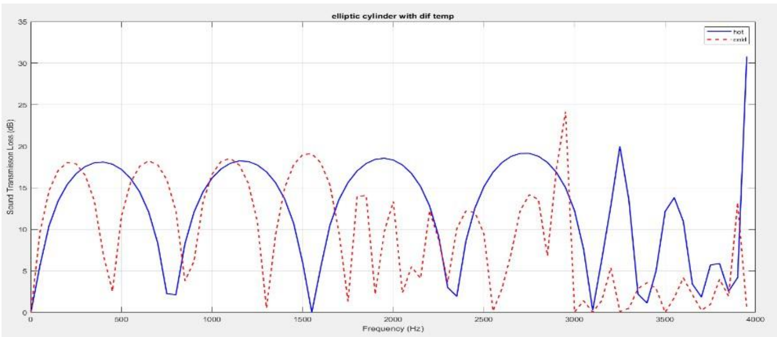

Figure 6. Sound transmission loss of the elliptical muffler at 300 K and 953 K.

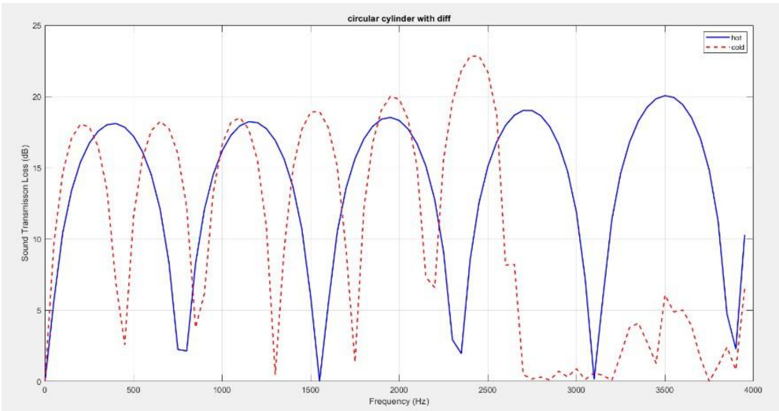

Figure 7. Sound transmission loss of the cylindrical muffler at 300 K and 953 K.

Future Outlook

Acoustic metamaterials offer new opportunities to enhance sound attenuation beyond conventional mufflers. Studies [12–14] show that integrating metamaterial-inspired structures can create tunable bandgaps, strong localized resonances, and improved transmission loss, highlighting a promising direction for high-performance, compact muffler designs.

Conclusion

This study compared the acoustic performance of elliptical and cylindrical mufflers. At low and mid frequencies, both geometries behave similarly, while at high frequencies, the elliptical muffler shows higher but more fluctuating transmission loss due to geometric asymmetry. Increasing outlets slightly improves performance, and higher temperatures shift STL to higher frequencies. The results highlight the importance of geometry, outlet design, and temperature in optimizing muffler noise reduction.

REFERENCES

1. Haghighi, M.; Mirzaei, R.; Putra, A.; Taban, E. A Comprehensive Review of Advances and Techniques in Muffler Acoustics and Design. *International Journal of Environmental Science and Technology* **2024**, *21*, 8695–8716, doi:10.1007/S13762-024-05686-6/METRICS.
2. Shinde, P. V; P.M., G.; R.A, B.; Y.B, M.; P.B, S. A Review on Muffler Design for Exhaust Noise Attenuation. *International Journal of Engineering and Technology* **2017**, *9*, 428–431, doi:10.21817/IJET/2017/V9I3/170903S066.
3. Cui, F.; Wang, Y.; Richard, ;; Cai, C. Improving Muffler Performance Using Simulation-Based Design.
4. Absorption Materials Used In Muffler: A Review, Ujjal Kalita, Abhijeet Pratap, Sushil Kumar, International Journal of Mechanical and Industrial Technology, ISSN 2348-7593 (Online), Research Publish Journals Available online: https://www.researchpublish.com/papers/absorption-materials-used-in-muffler-a-review (accessed on 9 October 2025).
5. Gupta, A.K.; Tiwari, Dr.A. Performance of Transmission Loss on Hybrid Muffler by Using Rock Wool and Glass Fiber as a Absorbing Materials. *International Journal of Advances in Materials Science and Engineering* **2015**, *4*, 49–57, doi:10.14810/IJAMSE.2015.4406.
6. Chivate, S.; Hujare, P.; Askhedkar, R.; Hujare, D.; Chinchanikar, S. A Review on Acoustic Performance Analysis of Reactive Muffler. *Mater Today Proc* **2022**, *63*, 613–622, doi:10.1016/J.MATPR.2022.04.262.
7. M L Munjal Acoustics of Ducts and Mufflers. 2014.
8. Kalita, U.; Singh, M. Acoustic Performance Analysis of Muffler by Varying Sound Absorption Materials. *Mater Today Proc* **2023**, doi:10.1016/J.MATPR.2023.02.272.
9. Mosa, A.I.; Putra, A.; Mahmood, H.A. EVALUATING THE IMPACT OF STRUCTURE PARAMETERS ON THE ACOUSTIC PERFORMANCE OF AN EXHAUST MUFFLER WITH SHELLS. *Eastern-European Journal of Enterprise Technologies* **2023**, *6*, 43–49, doi:10.15587/1729-4061.2023.289250.
10. Denia, F.D.; Albelda, J.; Fuenmayor, F.J.; Torregrosa, A.J. ACOUSTIC BEHAVIOUR OF ELLIPTICAL CHAMBER MUFFLERS. *J Sound Vib* **2001**, *241*, 401–421, doi:10.1006/JSVI.2000.3289.
11. Fu, J.; Xu, M.; Zhang, Z.; Kang, W.; He, Y. Muffler Structure Improvement Based on Acoustic Finite Element Analysis. *Journal of Low Frequency Noise, Vibration and Active Control* **2019**, *38*, 415–426, doi:10.1177/1461348418825200.
12. Abdoli, E., Zarastvand, M. R., & Talebitooti, R. (2025). Wave propagation numerical simulation approach based on a novel TPMS-based lattice metamaterial for improved vibration transmission of doubly curved sandwich systems. *Engineering with Computers*, 1-18.
13. Zarastvand, M. R., Abdoli, E., & Talebitooti, R. (2025). A lattice metamaterial-based sandwich cylindrical system for numerical simulation approach of vibroacoustic transmission considering triply periodic minimal surface. *Applied Mathematics and Mechanics*, *46*(11), 2035-2054.
14. Abdoli, E., Goodarzvand Chegini, S., & Talebitooti, R. Numerical and Experimental Design of TPMS-Enhanced Dual-Conical Mufflers for Sound Transmission Loss Improvement. *Available at SSRN 5476329*.