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Noise emission reduction of a jet engine by double cylindrical perforated liners in a combustion chamber

Mahadi Hassan[1]
[1]Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chattogram-4349, Bangladesh

Md. Jubair Uddin Zidan[2]
[2]Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chattogram-4349, Bangladesh

Md. Kotuvuddin Islam Monna[3]
[3]Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chattogram-4349, Bangladesh

Sheikh Ittehad Uddin[4]
[4]Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chattogram-4349, Bangladesh

E-mail: jubairzidan99@gmail.com, u1603117@student.cuet.ac.bd, kotubuddinislammonna180@gmail.com, sheikhittehaduddinrafsan@gmail.com

Abstract

The major goal of this study is to look into the noise emission characteristics of a gas turbine in jet engine and see how well double cylindrical perforated liners performed in comparison to typical liner designs in reducing noise. All of the terminology involved in gas turbine noise generation have been carefully investigated, and the procedures for measuring the noise created by gas turbines have been researched through published literature in order to achieve the goal. Two of the most prevalent methods for measuring and studying an object's acoustic qualities are the reverberation room method and plane wave decomposition method. A double cylindrical perforated model is developed in SOLIDWORKS using actual dimensions, and the model is then imported into ANSYS Fluent for the wind tunnel testing. All of the parameters and data were gathered and fed into the model as input. The wind tunnel simulation is used to investigate the model geometry's acoustic power level. Simulations reveal a significant attenuation of noise, where the maximum acoustic power level at the source is 138db, diminishing to 38.98db at the endpoint of the liner. This considerable reduction showcases the efficacy of the perforated sections and muffler in dampening the acoustic output. The contour maps from the acoustic profile vividly illustrate how the liner's unique configuration distributes and mitigates noise throughout its geometry. These results underscore the practical benefits of integrating perforation and specialized muffler designs in reducing noise emissions in gas turbine systems, offering a substantial improvement in environmental noise management and system design.

Keywords: *Double cylindrical perforated liner, acoustic qualities, noise reduction.*

1. Introduction

Gas turbine noise primarily stems from vibrations and turbulent flow, with combustion regarded as a key contributor. The interaction between hot exhaust gases and cooler air via perforated liners helps reduce temperatures but it also generates acoustic emissions. These thermo-acoustic instabilities, caused by the interaction of combustor acoustics with fluctuating heat release [1], increase noise and vibration levels, potentially leading to hardware damage, reduced turbine efficiency, and shorter rotor blade lifespan.[2]

To mitigate these effects, perforated liners have been developed to dampen sound pressure by converting acoustic energy into flow energy and canceling noise at resonance frequencies. At the resonance frequency, the liner

provides a noise damping effect by shifting the phase of the incident noise wave by 180° and wave cancellation is done [1]. Even without airflow, these liners can absorb sound through vortex shedding at the apertures. Given the increasing use of gas turbines in various industries and the growing concern over noise pollution, especially near airports, this research highlights the urgent need for effective noise reduction strategies. The use of a double cylindrical perforated liner is innovative, particularly in how it distributes and attenuates sound. This design could offer new ways to manage sound propagation and absorption within the engine, significantly enhancing noise reduction capabilities. The reported reduction from 138 dB to 38.98 dB at the endpoint of the liner is substantial. This demonstrates the effectiveness of the double cylindrical setup combined with the muffler geometry in reducing noise emissions, a significant improvement over traditional designs. Excessive noise not only impacts the environment but also poses significant risks to turbine components, causing stress-induced cracks and damage. Reducing noise emissions is essential to improving turbine performance, enhancing workplace conditions, and addressing environmental concerns.

This study aims to identify the primary noise sources in gas turbines and evaluate the effectiveness of cylindrical perforated liners in reducing noise emissions. Using ansys fluent for acoustic modeling and simulation.

2. Methodology

Assumptions

Before conducting the experiments in this project, several key assumptions were made to simplify the complex analyses and make the study more manageable. These assumptions include the following:

- The perforated liner geometry is considered equivalent to the combustor shell.
- Simplified geometry is assumed to yield comparable results.
- The flow across the surface of the body is uniform.
- All parameters and data were collected and applied as inputs for the model.
- Minor sound anomalies detected during microphone tests are disregarded.

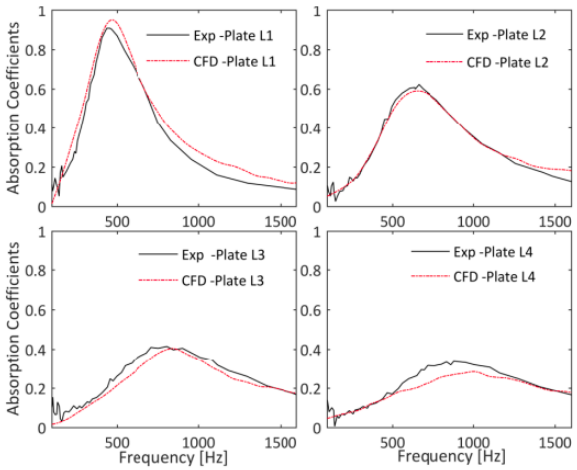


Fig. 1. CFD and experimental comparison of absorption coefficients for single layer plate absorbers from the experiments of Lee and Kwon

Physical Velocity Porous Media Model (PVPM Model)

The physical velocity porous media (PVPM) model[3] is designed to simulate fluid flow over perforated surfaces without accounting for the intricate geometry of individual perforations, which would be computationally intensive and costly to resolve. By representing the perforated plate as a homogenous material layer, the model reduces computational demands. Acoustic impedance, defined as the resistance to acoustic flow due to applied pressure, is evaluated through parameters of inertial and viscous resistance, as well as flow velocity. The PVPM model, incorporated in ansys fluent (ansys fluent, 2021), is employed to simulate the acoustic absorption properties of perforated liners. The primary aim is to calculate the absorption coefficient, with model validation based on the experimental work of lee and kwon [4] , who investigated the acoustic behavior of perforated plate absorbers.

Experimental procedure

In this experimental setup, airflow is initiated through a wind tunnel, where air is drawn into the system by a fan, passing through the intake system. To mitigate intake noise, perforated liners are installed within the intake segment. The test section, positioned sufficiently downstream, ensures the generation of a plane wave. A full-scale double-perforated cylinder sample, equipped with microphones, is placed in the test section. White noise is generated to propagate with the airflow through the open air intake duct. As axial airflow passes through the test section, the microphones record pressure data from within the double-perforated liners. The airflow velocity is incrementally increased from 10 m/s to 30 m/s in 5 m/s intervals. This experiment aims to assess the actual performance and damping characteristics of various full-scale double-perforated cylinders. The entire procedure will be conducted virtually using Ansys Fluent (Ansys Fluent, 2021).

Modelling

The double cylindrical perforated liner was modeled using SOLIDWORKS, with dimensions chosen based on actual physical measurements. After establishing the external geometry of the muffler, a hollow space was created inside the model to represent the internal structure. The final design, as shown in the figure, displays all key features of the liner, including the perforated section, which is enclosed by an outer cylindrical structure functioning as the muffler. In preparation for simulation, the model will be meshed to ensure accurate representation. Following this, an acoustic wind tunnel analysis will be conducted using ANSYS software to evaluate the acoustic and aerodynamic performance of the design.

Table 1: Extrude parameters of the given model

Feature	From	Direction	Length	Draft
Extrude	Sketch Plane	Mid Plane	2.20m	None

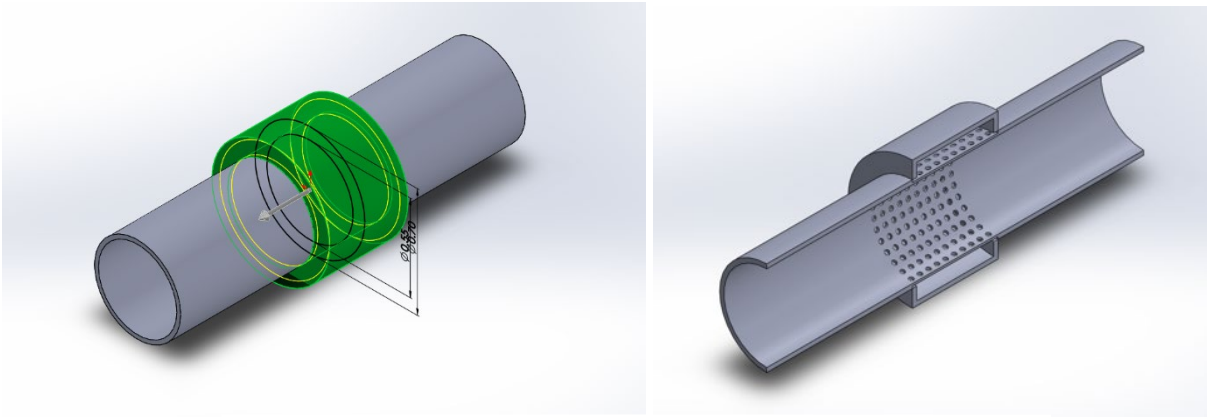


Fig. 2. Design of double cylindrical perforated liner with muffler
geometry with Liner model sectional view

3. Result

Meshing and boundary conditions

The acoustic simulation described in this section was conducted using ANSYS Workbench. The mesh comprised 1,659,536 cells with a nodal count of 313,208, ensuring a comprehensive representation of the flow field. The maximum element size was meticulously constrained to 0.16 meters to optimize spatial resolution. Further refinement of the mesh was achieved through the incorporation of up to five inflation layers, with a growth rate of 1.2, enhancing near-wall resolution while maintaining computational efficiency. Mesh skewness was rigorously controlled, with values maintained below 0.8 to ensure the quality and accuracy of the numerical simulations. This meticulous attention to mesh detail underpinned the robustness of the subsequent flow simulations and the reliability of the results obtained Fluent Flow (Fluid) analysis was utilized to create the mesh and run the simulation. The geometry, initially created in SOLIDWORKS, was exported as a STEP file and then imported into ANSYS. Upon importing the geometry, the mesh was created using default mesh characteristics. Air was introduced at an inlet pressure of 900 kPa. This setup provided a solid foundation for the detailed acoustic assessments that followed.

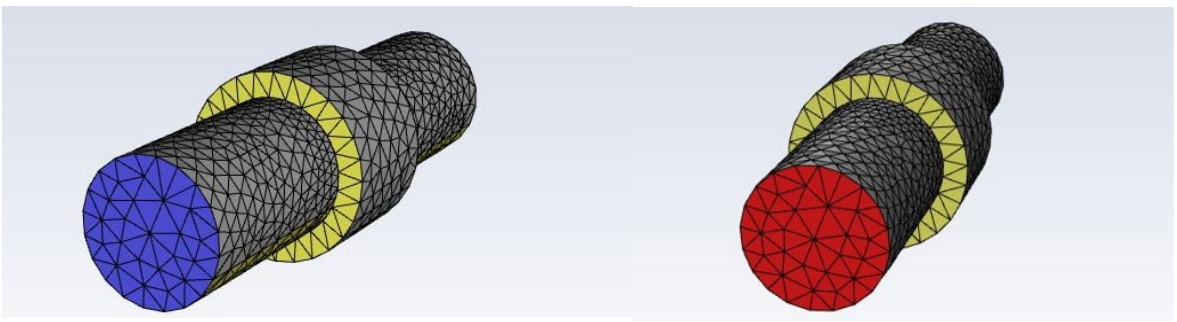


Fig. 3. Inlet and outlet of the model

Simulation

Figure 3.15 shows the acoustic profile of the model in terms of acoustic power level in dB. The maximum acoustic power level here in the sample is measured at 1.38e+02 dB (138 dB). The acoustic profile shows the maximum acoustic noise is generated at the end point of the perforated section. The muffler over the perforated section shows no noise.

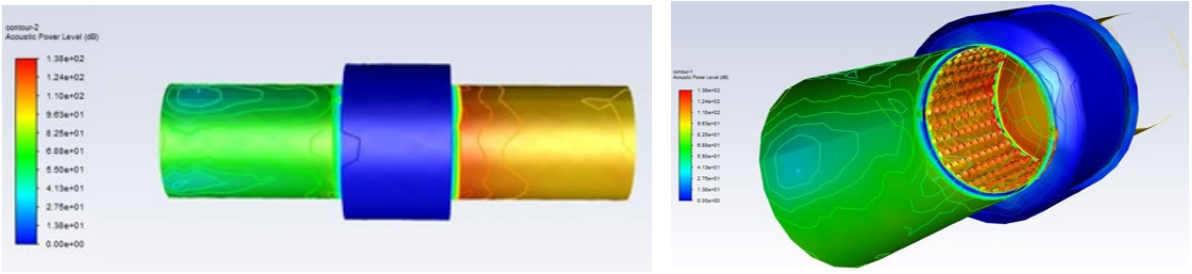


Fig. 4. Acoustic simulation profile on double cylindrical perforated liner geometry

Figure 5 shows the acoustic profile of the model in terms of acoustic power level in dB. The maximum acoustic power level here in the sample is measured at 1.38e+02 dB (138 dB). The acoustic profile shows the maximum acoustic noise is generated. In Figure 6, it can be seen that the middle zone is exposed to much more noise which might harm the inner parts of the turbine engine.

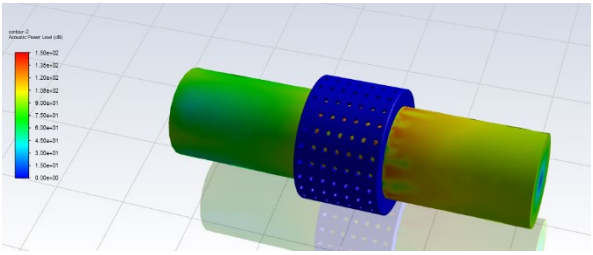


Fig. 5. Sample of acoustic profile (with perforation on the muffler) measured at acoustic power level (dB)

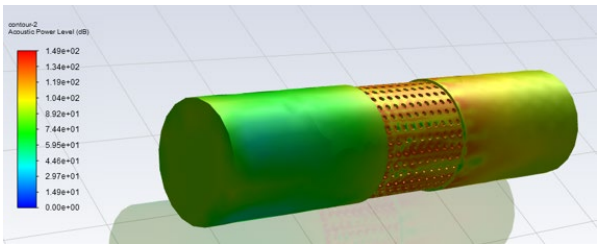


Fig. 6. Acoustic simulation on double cylindrical perforated liner geometry without muffler

Results and discussions

Upon completing the simulation, the maximum acoustic power level in the model showed a result of 138dB. The contour of the acoustic profile showed that the maximum acoustic power level was generated in the perforated section and the muffler dampened the acoustic noise from reaching the outside environment whereas at the end point of the liner, the acoustic power level is 38.98dB which indicates a good amount of noise dampening has been achieved throughout the liner geometry.

The noise profile in the interior geometry is a clear indication of how the noise generated in the liner gets distributed throughout the liner geometry because of the double cylindrical perforated setup. The difference in maximum acoustic noise level values is an indication of how adding perforation and a muffler geometry can reduce noise emission in gas turbines.

Due to the pioneering and contemporary nature of this work, recent established data from the literature were not available, posing significant challenges in validating the computational findings through established benchmarks. Consequently, the sole method to ascertain the accuracy of the data involved experimental verification in a physical setup. However, limitations in the current laboratory testing facilities precluded such experimental validation. Thus, the expansion of experimental validation capabilities represents a critical future scope of this research.

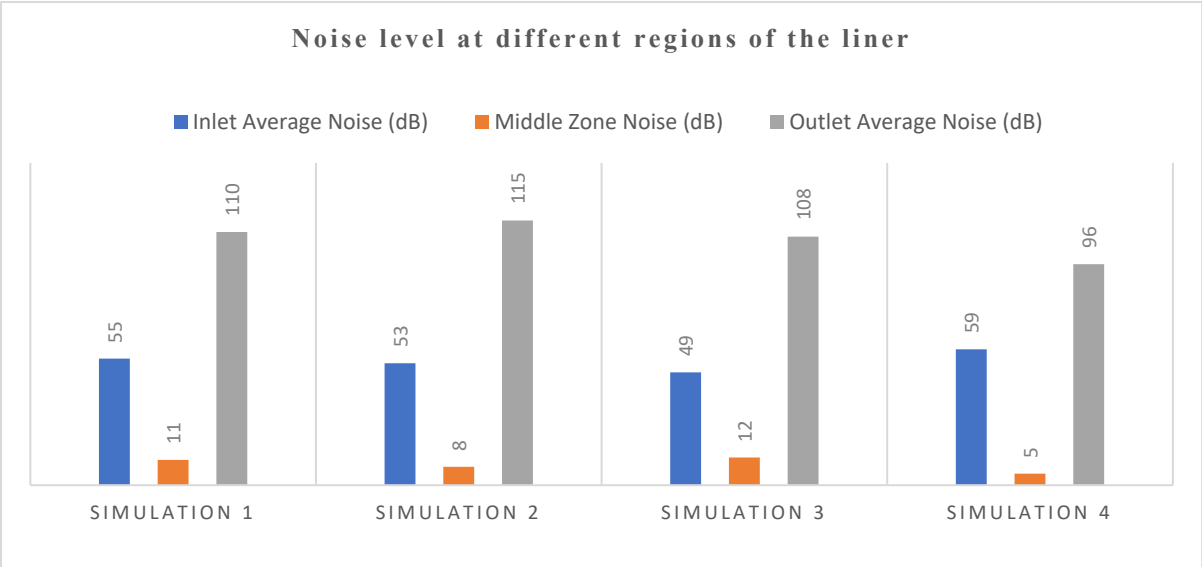


Fig. 7. Average Noise Level at Different Regions of the Liner

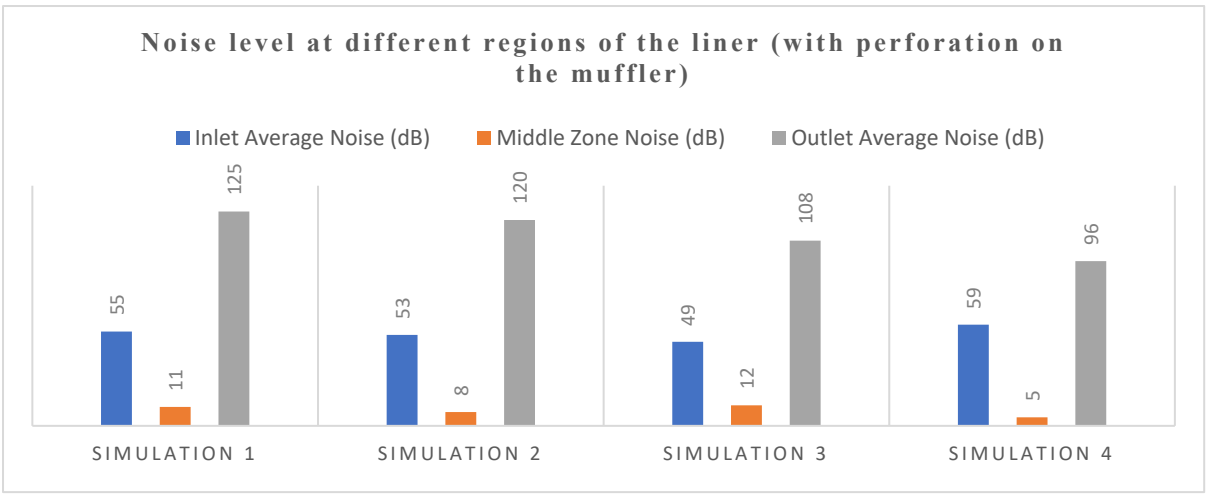


Fig. 8. Average Noise Level at Different Regions of the Liner (with perforation on the muffler)

5. Conclusion

This research presents a groundbreaking approach to reducing noise emissions in jet engines, specifically through the innovative application of double cylindrical perforated liners within the combustion chamber. The study meticulously engineered and simulated these liners using ANSYS Workbench, achieving a notable reduction in noise levels—from 138 dB at the source to 38.98 dB at the liner's endpoint—demonstrating substantial noise attenuation capabilities. The unique design of the double cylindrical perforated liners, combined with the strategic use of a muffler, effectively distributed and mitigated noise across the engine's structure. The acoustic simulation and subsequent profiling provided clear visual evidence of how the noise was absorbed and dispersed through the liner configuration, underscoring the liner's effectiveness in enhancing environmental noise management and system design. Despite the promising results, the study faced challenges in experimental validation due to the absence of established data in the literature, owing to the novelty of the approach, and limitations within current laboratory testing facilities. This gap highlights the necessity for future research to focus on expanding experimental capabilities to validate computational models and theoretical predictions fully.

Ultimately, this research contributes significantly to our understanding of acoustic management in jet engines and offers a viable solution that could be pivotal for industries where noise reduction is crucial. The implications of these findings extend beyond theoretical advancements, proposing practical applications that could revolutionize noise management strategies in aerospace engineering and potentially other fields requiring noise mitigation solutions.

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