NOISE CONTROL OF CONSTRUCTION EQUIPMENT

M.Tech. Thesis

By

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DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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A THESIS

Submitted in partial fulfillment of the requirements for the award of the degree
of
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by
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CANDIDATE'S DECLARATION

I hereby certify that the work being presented in the thesis titled **Noise Control of Construction Equipment** in the partial fulfillments of the requirements for the award of the degree of **M.Tech THESIS** and submitted in the **Department of Mechanical engineering, Indian Institute of Technology Indore** is an authentic record of my own work performed during the time period of April, 2022 to May, 2023 under the supervision of Dr. Anand Parey, Professor, Department of Mechanical Engineering, Indian Institute of Technology Indore.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other institute.

Shubham 01/06/2023

Signature of the student with date

(Shubham Kumar)

This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.

Signature of the Supervisor of M.Tech. thesis (with date)
Prof. Anand Parey 01/06/2023

Shubham Kumar has successfully given his M.Tech. Oral Examination held on **25/05/2023**.

Signature(s) of Supervisor(s) of M.Tech. thesis
Date: 01/06/2023

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Date: 05/06/23

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Date: 04.06.2023

Signature of PSPC Member#2
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Dedicated to my Parents

ABSTRACT

Increased use of heavy machinery and equipment as a result of the construction industry's rapid growth has increased noise levels at construction sites. Excessive noise not only poses a serious risk to the health and wellbeing of employees, but it also has an impact on the ecosystems and communities in the area. As a result, there is an urgent need to address the problem of noise pollution in construction equipment. In this thesis, the effectiveness of sound-dampening mats as a noise-control measure for construction equipment is examined.

The study starts out by examining the current level of noise pollution in the construction industry and highlighting its negative effects on both human health and the environment. It looks at the sources of noise made by construction equipment and the legislative measures in place to control noise. The study then specifically examines sound-dampening mats' potential as a passive noise-control method.

In this thesis, the construction equipment used was "Tractor Loader Backhoe (TLB)" and noise level was measured inside the cabin of the same and then Sound Pressure Level v/s Frequency spectrum was obtained.

The noise level within the cabin was measured both with and without sound dampening material after the model was constructed in COMSOL Multiphysics and put through a simulation.

Following an examination of the literature, "Polyurethane Foam" was chosen as the material for noise reduction since it is quite popular in the automotive industry and offers both noise reduction and good insulation.

Ultimately, the adoption of sound dampening mats as an integral part of noise control strategies in construction equipment promotes sustainable construction practices, contributing to a healthier and quieter environment for workers and surrounding communities.

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ABBREVIATIONS

PU	**Polyurethane**
SPL	**Sound Pressure Level**
SLM	**Sound Level Meter**
TLB	**Tractor Loader Backhoe**
NVH	**Noise, Vibration, and Harshness**
EU	**European Union**
SDMats	**Sound Dampening Mats**
SEA	**Statistical Energy Analysis**
LRT	**Light Rail System**
dB	**Decibels**
Hz	**Hertz**
NAH	**Nearfield Acoustical Holography**
PML	**Perfectly Matched Layer**

CHAPTER-1

1. Introduction

1.1 What are Sound and Noise?

Sound is what we hear. Noise is unwanted sound. The difference between sound and noise depends upon the listener and the circumstances. Rock music can be pleasurable sound to one person and an annoying noise to another. In either case, it can be hazardous to a person's hearing if the sound is loud and if they are exposed long and often enough.

Sound is produced by vibrating objects and reaches the listener's ears as waves in the air or other media. When an object vibrates, it causes slight changes in air pressure. These air pressure changes travel as waves through the air and produce sound. To illustrate, imagine striking a drum surface with a stick. The drum surface vibrates back and forth. As it moves forward, it pushes the air in contact with the surface. This creates a positive (higher) pressure by compressing the air. When the surface moves in the opposite direction, it creates a negative (lower) pressure by decompressing the air. Thus, as the drum surface vibrates, it creates alternating regions of higher and lower air pressure. These pressure variations travel through the air as sound waves (Fig 1.1) [1].

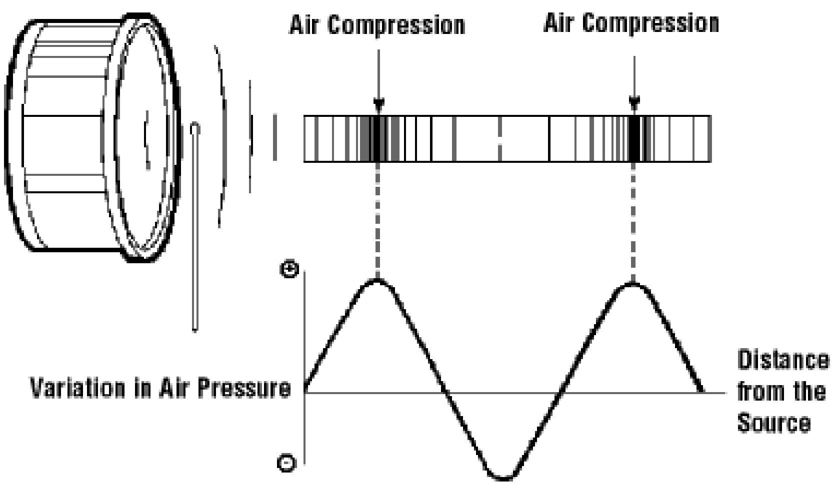

Fig. 1.1 Generation of sound waves [1]

1.1.1 Acoustics

The study of mechanical waves in gases, liquids, and solids, including topics like vibration, sound, ultrasound, and infrasound, is the focus of the physics subfield of acoustics. An acoustician is a scientist who specializes in acoustics, and an acoustical engineer is a person who specializes in acoustics technology. The audio and noise control industries are the most prominent examples of how acoustics is used in contemporary society.

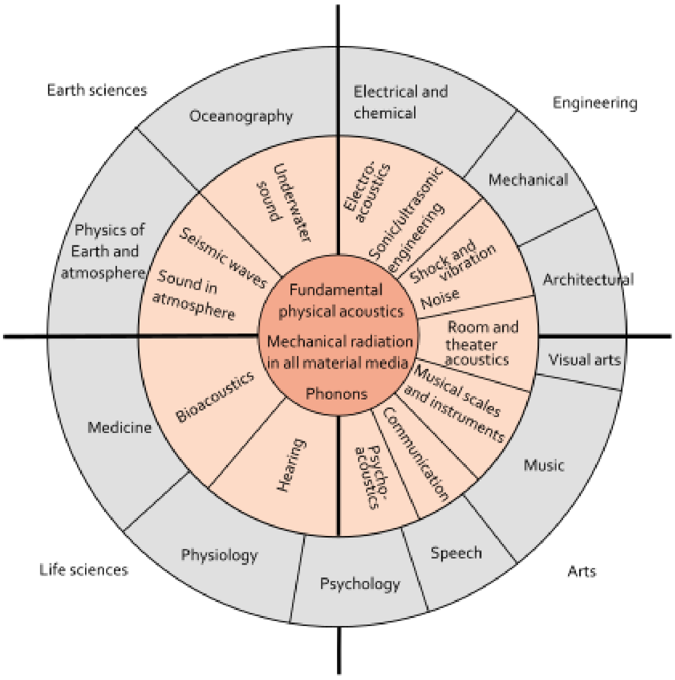

Fig.1.2 Lindsay's Wheel of Acoustics, which shows fields within acoustics [2]

Speaking is one of the most defining aspects of human development and culture, and hearing is one of the most essential survival skills in the animal kingdom. As a result, the science of acoustics is applied in many areas of human society, including music, architecture, medicine, industrial production, and warfare. The use of sound and hearing is common among animal species, too, including songbirds and frogs, in territorial marking and mating rituals. As in many other fields of knowledge, art, craft, science, and technology have stimulated one another to advance the whole. The "Wheel of Acoustics" by Robert Bruce Lindsay is a widely used summary of the various acoustic disciplines [2].

1.1.2 Wave Propagation: Pressure Levels

Sound waves move through fluids like air and water as changes in the atmospheric pressure. Even though this disturbance is typically slight, it is still audible to human ears. The threshold of hearing, which refers to the smallest sound that a person can detect, is nine orders of magnitude smaller than the surrounding pressure. The sound pressure level (SPL), which is expressed on a logarithmic scale in decibels, is a measure of how loud these disturbances are [2].

1.1.3 Wave Propagation: Frequency

Physicists and acoustic engineers tend to discuss sound pressure levels in terms of frequencies, partly because this is how our ears interpret sound. What we perceive as "higher pitched" or "lower pitched" noises are pressure vibrations with more or fewer cycles per second, respectively. Acoustic signals are sampled in time in a standard method of measuring sound, and the results are then displayed in more informative ways such octave bands or time frequency plots. Both of these widely utilized techniques are employed to analyze sound and comprehend the acoustic phenomenon.

The three categories of audio, ultrasonic, and infrasonic can be used to categorize the complete spectrum. The audio frequency range is 20 Hz to 20,000 Hz. This range is significant because the human ear can pick up on its frequencies. Applications for this range include verbal communication and music. The extremely high frequencies, 20,000 Hz and above, are referred to as the ultrasonic range. Shorter wavelengths in this region provide higher resolution in imaging systems. The ultrasonic frequency range is essential for medical applications including elastography and ultrasonography. The lowest frequencies on the other end of the spectrum are referred to as the infrasonic range. It is possible to examine geological processes like earthquakes using these frequencies.

Acoustic signals and their qualities may be seen and measured more easily with the use of analytical tools like the spectrum analyzer. Such an instrument generates a spectrogram, which is a visual representation of the pressure level and frequency profiles that change over time and define a particular acoustic signal [2].

1.2 Noise from Construction Equipment

The construction industry plays a vital role in the development and expansion of infrastructure, contributing to economic growth and societal progress. However, the operation of construction equipment often generates excessive noise levels, posing significant challenges to the health and well-being of workers, as well as causing disturbances to nearby communities. Consequently, the implementation of effective noise control measures in construction equipment has become a pressing concern in order to mitigate the adverse effects of noise pollution [3]

Excavators, cranes, bulldozers, loaders, concrete mixers, and other tools and vehicles used in construction projects are all included in the category of "construction equipment." For carrying out various tasks like excavation, material handling, and concrete placement, these powerful machines are crucial. However, the high levels of noise that are released as a result of the mechanical processes used in these operations can be harmful to the operators as well as the surrounding area.

The exposure to excessive noise in construction equipment can lead to hearing impairment and other auditory disorders among workers. Prolonged exposure to high noise levels without adequate hearing protection can cause irreversible damage to the delicate structures of the inner ear. Moreover, the constant presence of loud noise can negatively impact communication, concentration, and job performance, increasing the risk of accidents and errors on construction sites.

1.3 Noise, Vibration and Harshness

Noise Transmission Paths:

- Structure-borne: Through connection points and structural interfaces, the vehicle subsystems directly transmit dynamic forces to the vehicle body. This causes the structure and the body panels of the Equipment to vibrate. The operator is surrounded by air inside the equipment as a result of the structural vibrations, which results in noise. For instance, the engine suspension transfers engine vibrations to the chassis, which in turn vibrates the equipment's body panels like the firewall and floor. This causes changes in the equipment's internal acoustic pressure, which results in noise.
- Air-borne: Pressure waves inside the vehicle are created by the pressure waves that travel outside the vehicle and are caused by vibrations in the equipment body panels. For instance, the vibration of the engine block and covers causes pressure changes in the engine compartment; the noise caused by the vibration is transmitted to the interior of the vehicle through the panels that surround the engine. In contrast, in some instances the presence of holes or direct air connections between an enclosure and another allow a direct transmission line through the air. This example shows an airborne path that also includes a structural element. The low attenuation that is frequently observed in this latter scenario recommends that this type of transmission path should be minimized from the beginning of the design process [3].

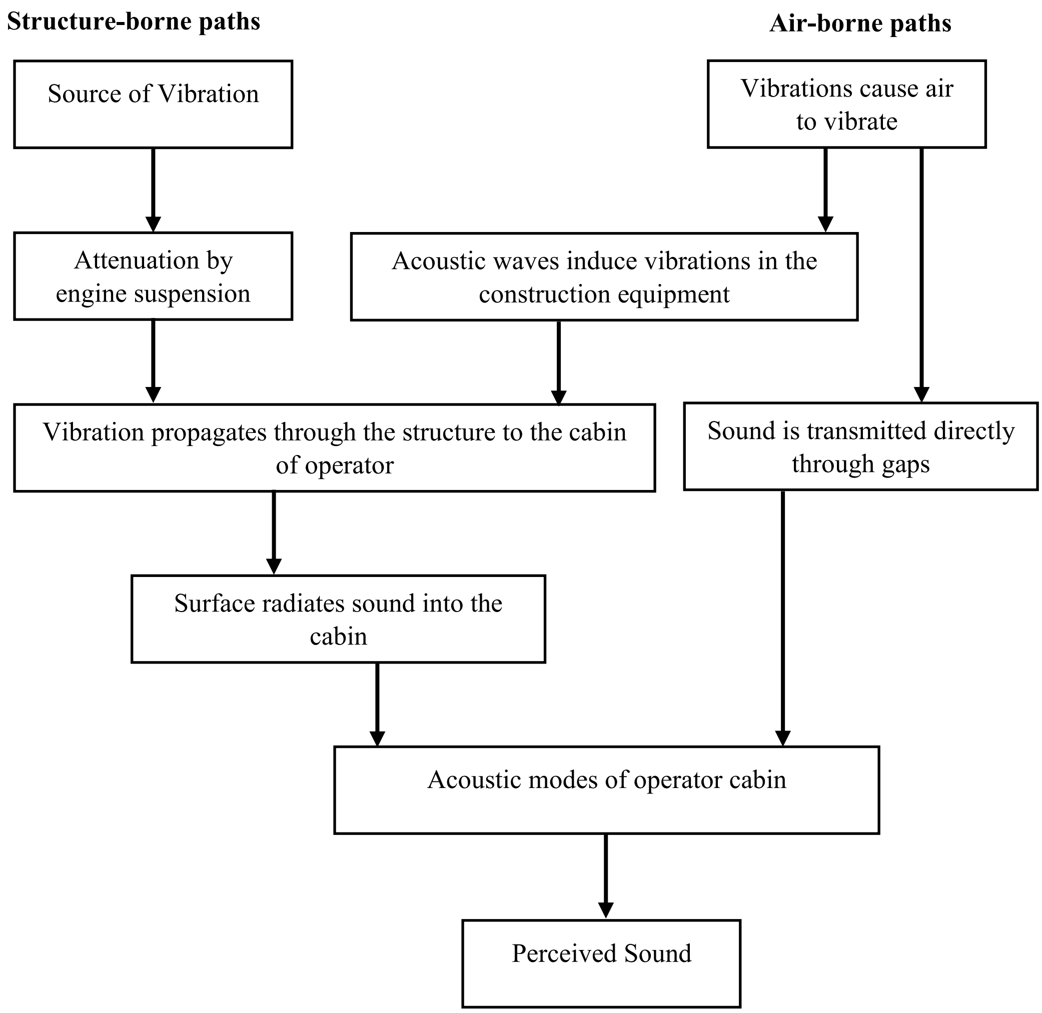

Fig. 1.3 Structure-borne and air-borne paths of sound transmission

1.4 Why There is a Need of Controlling Noise?

The simple and basic reason for controlling noise is in its meaning that it is unwanted and it can produce noise pollution in our environment to a greater extent.

The detrimental effects of noise exposure on physical and mental health are numerous and significant. Prolonged or excessive exposure to noise can lead to various adverse health impacts that can have far-reaching consequences.

One of the primary health concerns associated with noise exposure is hearing loss. Continuous exposure to high noise levels can damage the delicate structures of the inner ear, leading to permanent hearing impairment. This can result in difficulties in communication, reduced quality of life, and social isolation.

Furthermore, research has shown that noise pollution is linked to an increased risk of ischemic strokes, hypertension, and cardiovascular disease. The constant exposure to loud noise can disrupt the cardiovascular system, leading to elevated blood pressure levels and stress responses. Over time, this can contribute to the development of cardiovascular conditions, including heart attacks and other associated risks such as myocardial infarction.

In addition to physical health issues, noise pollution can have profound emotional and psychological impacts. The continuous presence of excessive noise can cause chronic stress, anxiety, and irritability, leading to a decline in overall mental well-being. It can also affect cognitive function and impair learning abilities, resulting in reduced working performance and productivity.

For pregnant individuals, noise exposure poses particular risks. Studies have indicated that exposure to high noise levels during pregnancy can increase the risk of complications, including preterm birth and low birth weight. It is crucial to create environments with reduced noise levels to protect the health and well-being of both the pregnant individuals and their unborn children.

The growing concerns regarding the health effects of noise pollution have prompted increased attention from policymakers. The European Union (EU), for instance, recognizes the severity of noise-related concerns and has placed importance on addressing them. In fact, noise-related concerns have been given a similar rating as those associated with global warming, highlighting the urgency of addressing noise pollution and implementing measures to mitigate its adverse effects.

In conclusion, noise exposure is associated with a range of physical and mental health problems. These include hearing loss, increased risk of strokes, hypertension, cardiovascular disease, emotional and psychological impacts, pregnancy complications, restlessness, headaches, inadequate sleep, annoyance, learning impairment, and reduced working performance. The recognition of these health effects by organizations such as the EU emphasizes the need for concerted efforts to reduce noise pollution and prioritize the health and well-being of individuals and communities [4].

1.5 The Use of PU Foam as a Sound Absorbing Material

In the context of noise mitigation, two effective methods commonly used are sound insulation and sound absorption. Sound insulation aims to block or reduce the transmission of sound waves, while sound absorption focuses on reducing the reflection and reverberation of sound within a space.

One of the simplest and widely employed methods for noise absorption is the use of acoustically absorbing materials. In the automotive industry, materials such as fiber composites and polyurethane foam have been traditionally used for this purpose.

When it comes to fibrous materials, such as fiber composites, sound absorption occurs due to the numerous boundaries present in the material. As sound waves travel through the fibrous structure, they encounter these boundaries, leading to multiple interactions and collisions. These collisions cause the sound waves to lose energy, resulting in a reduction of the sound's intensity.

Polyurethane foam, on the other hand, possesses a porous structure that enhances sound absorption. The foam's structure allows for multiple collisions between the sound waves and the internal walls of the foam. This leads to the conversion of acoustic energy into vibrations within the foam's walls, generating heat in the process. A significant portion of this heat is then released into the surroundings, further contributing to the dissipation of the sound energy [5].

Fig 1.4 Sound absorbing PU foam

Polyurethane (PU) foam is extensively used in today's vehicles for its exceptional sound absorption properties. Here are some specific applications where PU foam is utilized for sound absorption in vehicles:

- Interior panels: PU foam is integrated into interior panels such as door panels, dashboard components, and headliners to minimize noise transmission. The foam's porous structure allows it to trap and absorb sound waves, reducing the level of noise that reaches the vehicle's interior.
- Floor and carpet underlay: PU foam is employed as an underlay for vehicle floors and carpets to dampen noise and vibrations. It acts as a barrier, absorbing impact and reducing the transfer of noise from the road and engine into the cabin.
- Engine compartments: PU foam is utilized in engine compartments to mitigate the transmission of engine noise and vibrations into the cabin. By applying foam insulation in specific areas, such as the firewall or engine cover, the foam absorbs the noise generated by the engine, contributing to a quieter cabin environment.
- Wheel arch liners: PU foam is used in wheel arch liners to dampen road noise and minimize the transfer of tire noise into the cabin. The foam acts as a barrier, absorbing the sound waves generated by the interaction between the tires and the road surface.
- Acoustic insulation pads: PU foam is incorporated as acoustic insulation pads in various areas of the vehicle, such as behind interior trim panels or in the pillars. These pads absorb and dissipate sound energy, reducing noise levels within the cabin.

- Air ducts and ventilation systems: PU foam can be applied within air ducts and ventilation systems to attenuate noise generated by airflow and fans. The foam helps to absorb sound waves and minimize the transmission of noise throughout the vehicle.

Fig. 1.5 (a)

Fig. 1.5 (b)

Fig. 1.5 (c)

Fig. 1.5 (d)

Fig 1.5 a, b, c, and d. PU foam sheets applied on various locations inside a vehicle [6].

The use of PU foam for sound absorption in vehicles provides a quieter and more comfortable driving experience by reducing the impact of external noise sources and vibrations. It enhances the overall acoustic performance of the vehicle's interior, contributing to a more enjoyable journey for the occupants.

1.6 Motivation for This Thesis

The thesis "Noise Control in Construction Equipment" is motivated by the need to address the adverse effects of noise pollution on the operators of construction equipment. Excessive noise in construction sites can lead to various health issues for workers, including hearing loss, stress, and reduced cognitive performance. The thesis aims to investigate the potential of Polyurethane (PU) foam as a noise reduction solution in construction equipment through simulation-based studies. By utilizing simulation techniques, the thesis seeks to evaluate the effectiveness of PU foam in reducing noise emissions from construction machinery. The objective is to provide insights and recommendations for the implementation of PU foam as a practical noise control measure in the construction industry, ultimately improving the working conditions and overall well-being of equipment operators.

1.7 Research Objective

The research objectives of the thesis are as follows:

- To measure the actual noise levels entering the cabin of the Tractor Loader Backhoe (TLB) through practical measurements. This objective aims to obtain accurate data on the noise levels experienced by operators inside the TLB cabin during various operational conditions.
- To explore and evaluate the effectiveness of PU foam as a sound-absorbing material in reducing and controlling the noise levels inside the TLB cabin. This objective involves utilizing simulation techniques to analyse the impact of PU foam on noise reduction. By simulating the behaviour of PU foam, the objective is to assess its potential in mitigating noise and improving the acoustic environment within the TLB cabin.

CHAPTER-2

2.1 LITERATURE REVIEW

2.1.1 Mir et. al (2022) proposed that construction noise poses occupational hazards in the construction industry. This review aims to provide a holistic understanding of construction noise management by proposing a new framework and analyzing previous studies. The framework consists of four steps: noise assessment, prediction, control, and monitoring. The review highlights research themes, achievements, limitations, and research gaps. It offers insights into effective noise assessment methods, predictive models, control strategies, and monitoring techniques. The review encourages the development of innovative approaches and technologies to address construction noise challenges. Overall, it promotes proactive measures for a safer working environment in construction [7].

2.1.2 Saleh et. al (2016) studied the effectiveness and practicality of using commercially purchased sound dampening mats (SDMats) as sound barriers in heavy-equipment engine compartments to reduce noise exposures to operating engineers in construction. The study measured sound pressure levels (SPLs) before and after installing SDMats during idle and full-throttle settings. The results showed a significant reduction in SPLs inside the operator cabs, with a 5.6-7.6 dBA decrease during full-throttle settings. The installation of SDMats was found to be a simple, affordable, and highly effective engineering control intervention, potentially reducing the reliance on hearing-protection devices for construction workers. Further research is needed to explore their application in different construction scenarios and long-term effectiveness [8].

2.1.3 Gupta and Parey (2022) examined the analytical and experimental approaches used to predict and validate sound transmission loss in hemispherical shells. The Statistical Energy Analysis (SEA) technique is employed to develop an analytical model capable of calculating sound transmission loss across a wide frequency range. The proposed SEA formulation is validated through experimental measurements using the sound intensity method. The study reveals a strong agreement between the analytical predictions and measured transmission loss. Furthermore, the review explores the impact of design parameters, including absorption coefficient, thickness, radius, and material variations, on the transmission loss based on the proposed SEA model. These findings provide valuable insights into optimizing the acoustic performance of hemispherical shells, aiding in their effective design and implementation across industries [9].

2.1.4 Xie et. al (2022) studied the light rail transit (LRT) which is an urban rail system with higher capacity than trams, operating on exclusive tracks. This review focuses on the cabin noise analysis of four light rail lines in Taipei and Singapore. Using a smartphone app calibrated against a sound level meter, the study found that all lines had relatively quiet cabins with overall equivalent noise levels below 75 dBA. However, there was a significant presence of low-frequency noise, indicating the need for further research to improve aural comfort. The difference between the overall equivalent dBA and dBC indicated a more than 10 dB gap, highlighting the prominence of low-frequency noise in the light rail systems Strategies to reduce low-frequency noise in LRT systems should be explored to enhance the passenger experience [10].

2.1.5 Caillet et. al (2012) focused on improving acoustical comfort in helicopter cabins as part of the "Comfortable Helicopter" research program. Eurocopter has implemented a comprehensive approach that involves diagnosing and modeling noise sources and developing innovative sound-proofing concepts. Their methodology includes Nearfield Acoustical Holography measurements and geometrical acoustics simulations. The developed solutions, such as optimized panels, windows, and Main Gear Box suspension devices, have been flight tested and shown significant improvements in cabin noise levels. Euro copter remains committed to further reducing noise and enhancing comfort in helicopter cabins [11].

2.1.6 Vitkauskaite and Grubliauskas (2018) focused on sound absorption within enclosed buildings as a means to create safer environments in public buildings, workplaces, shopping centers, and similar structures where high noise levels are prevalent. In recent decades, the rise of urbanization and increased vehicle activity has contributed to a significant increase in urban noise pollution, negatively impacting both quality of life and public health. In this study, Perforated panels have gained popularity for sound control in such environments due to their sound absorption properties. This literature review explores the acoustic properties of perforated panels and includes an examination of the Zorba modeling program, which enables the determination of acoustic impedance and absorption coefficient of these panels. The review specifically evaluates the use of perforated panels with circular holes, slats, and slots [12].

2.1.7 Ang et. al (2016) focused on the automotive, maritime, aerospace, and defense sectors, with an emphasis on cars and armored vehicles. This study intends to provide an overview of current industry practices for cabin noise management in diverse industries. It emphasises how certain structural and acoustic modes can couple together in automobile cabins, which are typically made of thin structural panels, to produce booming noise that is uncomfortable for passengers. Decoupling structural and acoustic modes through acoustical treatments or structural changes is a common strategy used to reduce vibroacoustic problems. Excessive modifications, however, can result in weight restrictions and have a negative impact on things like fuel economy and vehicle performance. Furthermore, low-frequency noise control is limited by current solutions. As an alternative strategy to reduce cabin noise, there is growing interest in researching the viability of acoustic metamaterials [13].

2.1.8 Carletti (2013) focused on the methods used to counteract the negative impacts of excessive noise levels on operators' health and job performance in construction machinery. Despite the fact that present methods largely concentrate on lowering sound pressure levels to meet legal standards, they are insufficient to improve the subjective human response to noise. A change in perspective is required to include various noise control criteria that address psychophysical characteristics associated to subjective acoustical discomfort in order to ensure safe and comfortable working conditions for employees. The objective of this study was to adapt a technique based on Sound Quality for the noise control of construction machinery, and the results of that investigation are presented in this paper. The goal is to establish new standards for hearing-related criteria that not only lower noise levels at the operator's location but also lessen perceived discomfort [14].

2.1.9 Kim et. al (2012) focused mainly on the interior noise analysis of construction equipment cabins. In the study, a four-step analytical process is suggested that can be used when doing early design work. Modelling, vibration analysis, acoustic analysis, and overall interior noise analysis are all covered in the process. The approach provides for the prediction and evaluation of cabin interior noise levels by utilizing numerical analysis and observed data. Comparisons with measured data from various construction equipment cabins serve to verify the procedure's efficacy. Overall, this analytical technique offers designers and engineers insightful information that can be used to optimize cabin design and guarantee operator safety and comfort [15].

CHAPTER-3

3 METHODOLOGY (Setup)

This chapter includes the procedure of the project which consists of both experimental setup and simulation.

3.1 Experimental Setup

3.1.1 Experimental Equipment

The experimental equipment includes the following which was used in the experiment.

- **Sound Level Meter:**
  - A Sound Level Meter (SLM) is an instrument (commonly hand-held) that is designed to measure sound levels in a standardized way.
  - It responds to sound in approximately the same way as the human ear and gives objective, reproducible measurements of sound pressure levels. [16]

  Features:
  - Dynamic range in excess of 123 dB(A) – 0.5 Hz – 20 kHz broadband linear range.
  - Simultaneous noise and weather data acquisition – 24- or 16-bit recording during all or parts of measurement [17].

Fig. 3.1 Sound Level Meter Type 2250

- **Microphone Used: Prepolarized Free Field ½” Microphone Type 4189**

  For the purpose of capturing and measuring the sound levels within the TLB cabin, a specific type of microphone was utilized in the experiment. The chosen microphone was the Prepolarized Free Field ½” Microphone, specifically the Type 4189 model. This particular microphone is designed to accurately capture sound in free field conditions, making it suitable for the experimental setup.

  The open-circuit sensitivity of the Type 4189 microphone was determined to be -26.2 dB re 1V/Pa. This sensitivity value provides an indication of how the microphone converts acoustic energy into electrical signals. It signifies the magnitude of the electrical output generated by the microphone in response to a sound pressure level of 1 Pascal (Pa). To put it in perspective, this sensitivity is equivalent to 49.2 millivolts per Pascal (mV/Pa), which represents the voltage produced by the microphone per unit of sound pressure.

  In order to account for uncertainties and ensure accurate measurements, the experiment considered a 95% confidence level with an associated uncertainty of 0.2 dB. This uncertainty value reflects the potential variability or deviation of ±0.2 dB in the measured sound pressure levels captured by the microphone.

  To maintain consistency and validity throughout the experiment, specific conditions were adhered to during the measurements. The microphone's sensitivity and specifications were valid at a temperature of 23°C, an ambient static pressure of 101.3 KPa, a relative humidity of 50%, and a frequency of 251.2 Hz. Additionally, an external polarization voltage of 0 volts was applied to the microphone during the experiment.

  By providing these elaborate details regarding the microphone type, its open-circuit sensitivity, the equivalent voltage value, the associated uncertainty, and the specific conditions under which the measurements were performed, the experiment aimed to ensure accurate and reliable sound level measurements within the TLB cabin. This meticulous approach to microphone selection and measurement conditions contributes to the overall validity and credibility of the experimental results.

Fig. 3.2 Prepolarized Free Field 1/2” Microphone Type 4189

- **Construction Equipment Chosen**

  In the context of my project, the carefully selected construction equipment was the Tractor Loader Backhoe (TLB). This particular machine, known as a TLB, holds great significance in the construction, farming, and various other industries due to its versatility and robust capabilities. The TLB is a unique piece of heavy-duty equipment that combines the functions of a tractor, front loader, and backhoe, making it an indispensable asset for a wide range of applications.

  Within the market, one can find a diverse array of TLBs, each catering to specific requirements and differing in terms of load carrying capacity. Noteworthy companies such as JCB India, Mahindra Construction Equipment, Escorts Construction Equipment, ACE (Action Construction Equipment) Limited, CASE India, Tata Hitachi Construction Machinery, Caterpillar India, and Volvo Construction Equipment India, among others, offer a variety of TLB models to suit different operational needs.

In the case of my project, the chosen construction equipment was the "JCB 3DX" TLB model. The JCB 3DX possesses a well-established reputation in the industry, known for its reliability, efficiency, and performance. This specific TLB model was deemed most suitable for the experimental procedures outlined in the subsequent section of this project.

By selecting the JCB 3DX TLB, which is recognized for its robust design and advanced features, the experiment aimed to leverage the machine's capabilities to accurately assess the noise levels experienced within the cabin. The subsequent section will delve into the details of the experimental procedure, shedding light on how the chosen TLB was utilized to conduct the necessary measurements and gather valuable insights regarding noise levels in the working environment.

Fig. 3.3 JCB 3DX

3.1.2 Experimental Procedure

In order to obtain precise and detailed information about the noise levels present within the cabin of the Tractor-Loader-Backhoe (TLB), a series of carefully designed experimental procedures were implemented. The primary objective was to comprehensively assess the impact of different factors on the noise levels experienced by the operator within the TLB cabin. To achieve this, a sound level meter, a reliable and accurate measuring instrument, was utilized to quantify the intensity of sound within the cabin environment.

The experimental process was divided into two main conditions: the closed cabin and the open cabin. Each condition was examined under various circumstances to capture the diverse range of scenarios encountered during TLB operation. These circumstances included measurements taken when the engine was both idle and running, as well as during the active working phase of the TLB, specifically when it was engaged in the digging process and depositing materials into a truck. By examining noise levels across these distinct stages, the experiment aimed to provide a comprehensive understanding of the variations in noise intensity throughout TLB operation.

To ensure a thorough assessment of noise distribution, measurements were conducted from four different directions: the front, left, rear, and right side in the TLB cabin. This approach aimed to identify the primary source or direction from which the highest level of noise was originating. Furthermore, the experiment sought to evaluate the efficacy of closing the doors and windows of the cabin in reducing the noise levels experienced by the operator.

By conducting measurements under six different conditions, encompassing various stages of TLB operation and different directions, the experimental procedure aimed to generate a comprehensive dataset. This dataset would facilitate a deeper understanding of the factors influencing noise levels within the TLB cabin. Furthermore, it would provide valuable insights into potential noise reduction strategies, such as the effectiveness of closing doors and windows, which could significantly contribute to mitigating noise exposure for TLB operators and improving their overall working conditions.

Fig. 3.4 (a) Front side view in cabin

Fig. 3.4 (b) Left side view in cabin

Fig 3.4 (c) Rear side view in cabin

Fig 3.4 (d) Right side view in cabin

Fig. 3.4. a, b, c, and d show front, left, rear, and right-side view of the cabin

3.2 Simulation Through COMSOL

3.2.1 Building a Model of TLB Cabin

In this phase of the research, a model specifically focusing on the cabin of the Tractor Loader Backhoe (TLB) was developed using the COMSOL Multiphysics software. The primary objective was to simulate and analyze the acoustic behavior of the TLB cabin.

For the construction of the TLB cabin in the model, structural steel material was utilized. The dimensions of the cabin in the model were defined as follows:

Length: 1000mm
Width: 1000mm
Height: 1000mm

To replicate the real-world conditions, the thickness of the cabin walls, including the windshield and windows, was set to 5mm. The windshield and rear windows were inclined at an angle of 15º with respect to the vertical axis.

By creating a dedicated model for the TLB cabin, the research focused specifically on studying the acoustic properties and noise control measures within the cabin environment. The model served as a platform for conducting simulations and further analyses related to noise reduction and the application of sound-absorbing materials, such as PU foam, to enhance the acoustic performance of the TLB cabin.

The air enclosure was created around the TLB cabin to simulate the surrounding environment. It behaved as an open space, allowing the propagation of sound waves without reflecting them back into the TLB cabin. This representation provided a more realistic assessment of the acoustic conditions within and around the TLB.

Also, the air enclosure served the purpose of providing a medium for sound waves to travel up to the TLB surface and penetrate into the cabin. It created an environment where the sound waves could propagate freely, mimicking the conditions in a real-world scenario. Additionally, air was provided inside the TLB cabin in the software model, allowing for accurate simulation of the internal acoustic behavior. It can be seen in the figure number 3.3.

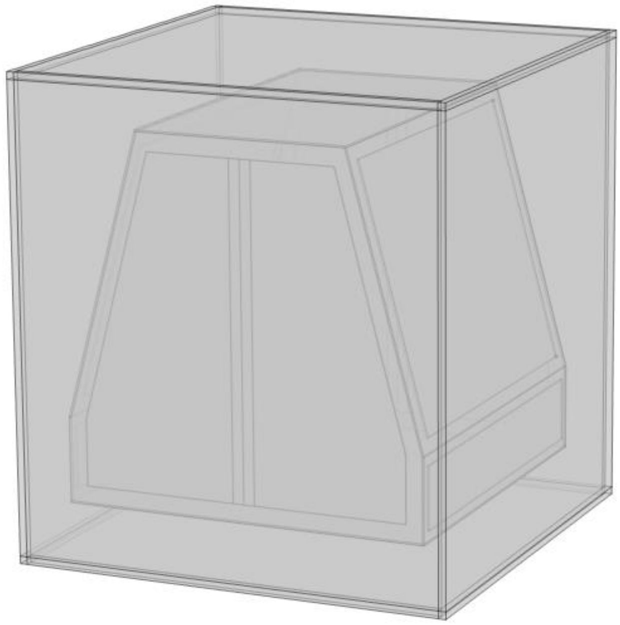

Fig. 3.5 TLB Cabin made in COMSOL Multiphysics

3.2.2 Meshing of TLB Cabin in COMSOL Multiphysics

In the process of creating the model in COMSOL Multiphysics software, meshing was generated to discretize the geometry of the TLB cabin, the air inside the cabin, and the air enclosure. Meshing involves dividing the geometric domain into smaller elements to facilitate numerical calculations and simulations.

In this case, the meshing was performed with a minimum element size of 5mm and a maximum element size of 50mm. This range of element sizes ensured that the mesh adequately captured the details and features of the TLB cabin and the surrounding air enclosure.

The type of meshing employed in this model was free tetrahedral meshing. Tetrahedral elements are four-sided polyhedrons that are well-suited for complex geometries with irregular shapes. This type of meshing allowed for a more accurate representation of the TLB cabin, the air inside the cabin, and the air enclosure.

By using the free tetrahedral meshing technique, the model achieved a fine level of discretization, enabling precise calculations and simulations of the acoustic behavior within the TLB cabin and its surrounding environment. This meshing approach ensured that the analysis captured the intricate details of the geometry while maintaining computational efficiency for the simulations. The meshing is shown in figure number 3.4.

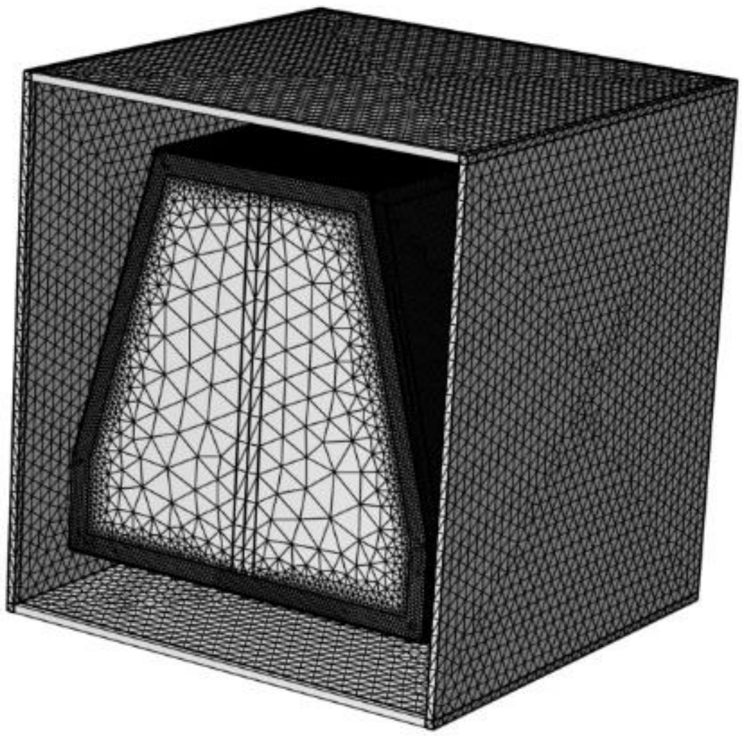

Fig. 3.6 Meshing of TLB cabin

The meshing between air enclosure and the surface of TLB cabin is not shown in the figure 3.4 to get a clear view of meshing of the model.

3.2.3 Applying PU Foam Inside the Cabin

To enhance the noise control within the TLB cabin, a layer of PU foam was applied to specific areas. The PU foam had a thickness of 13mm and was strategically placed on the roof, floor, and B-pillars of the cabin as shown in the fig 3.5 a, b, and c. The application of PU foam aimed to reduce the transmission of noise from the external environment into the cabin, providing a quieter and more comfortable working environment for the operators.

When implementing the PU foam in the simulation model, the properties of the foam were assigned to accurately represent its behavior. The properties provided to the software were as follows:

- Density: The density of the PU foam was set to 80 Kg/m^3. Density determines the mass of the material per unit volume and influences its ability to absorb and dampen sound waves.
- Young's Modulus: The Young's Modulus of the PU foam was defined as 3.5×10^9 Pa. This property describes the foam's stiffness or resistance to deformation under applied stress.
- Poisson's Ratio: The Poisson's Ratio of the PU foam was specified as 0.3. This value represents the material's transverse contraction or expansion in response to axial deformation.
- Speed of Sound: The speed of sound through the PU foam was determined as 337 m/s. This property indicates how quickly sound waves travel through the material.

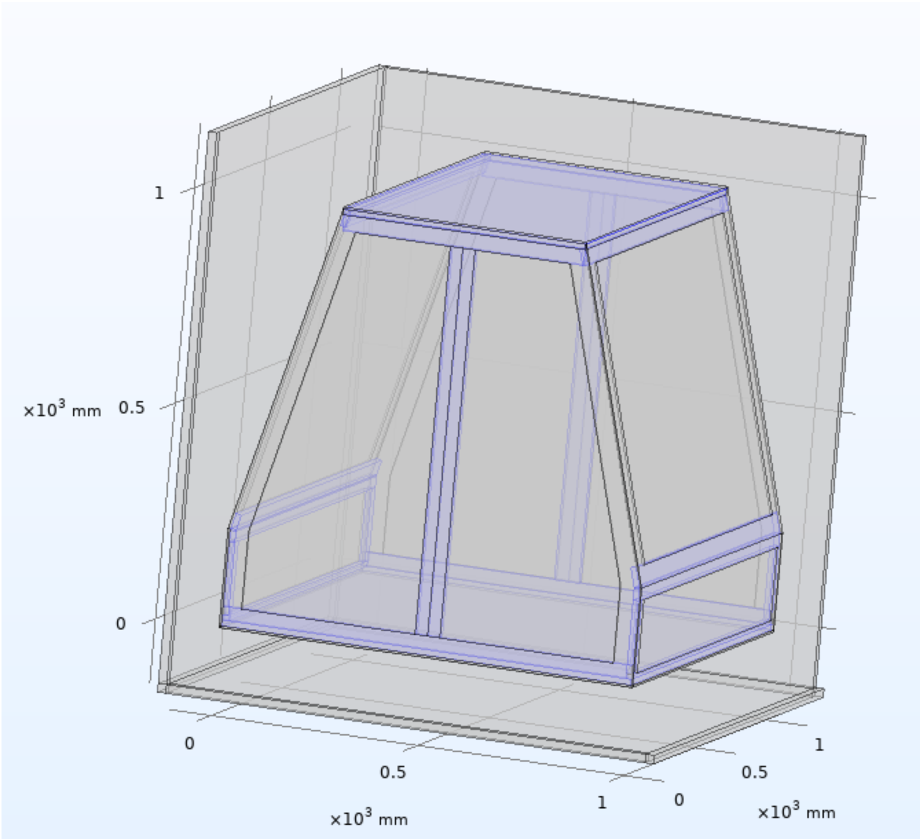

Fig. 3.7 (a)

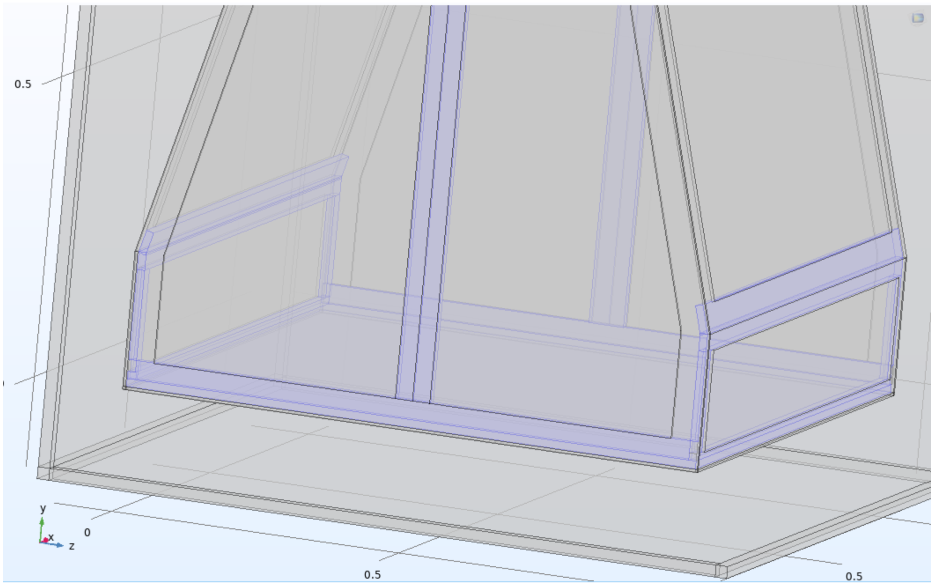

Fig 3.7 (b)

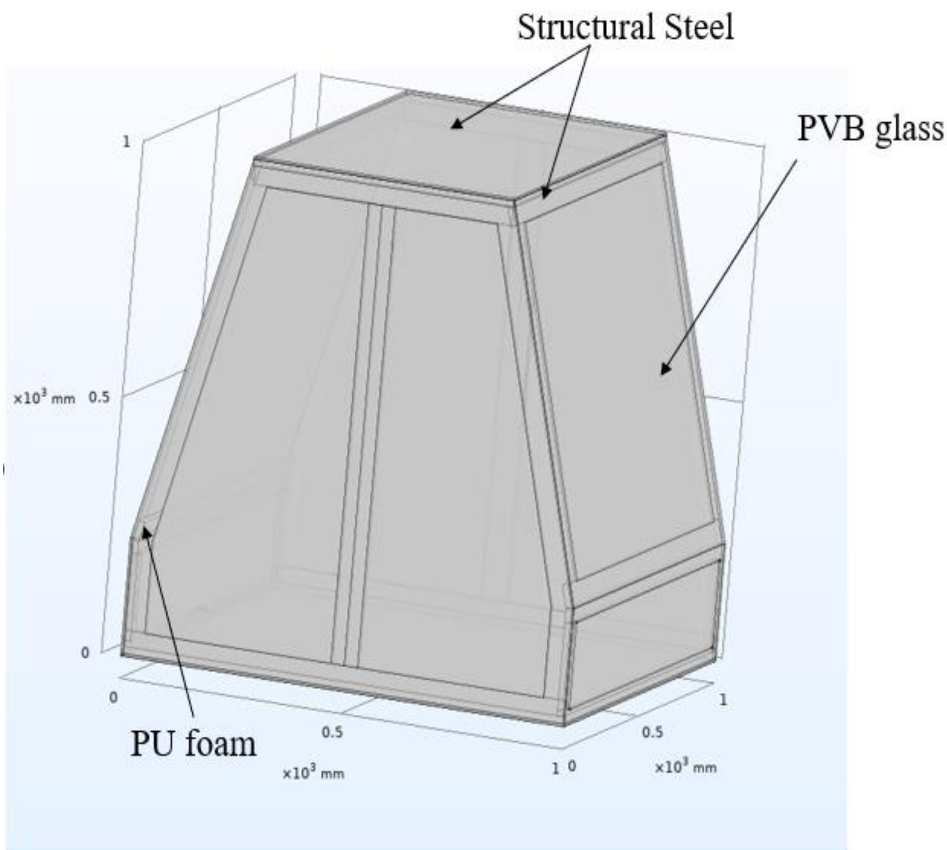

Fig. 3.7 (c)

Fig 3.7 a, b, and c. Model in COMSOL Multiphysics with PU foam

3.2.4 Procedure of Simulation in COMSOL Multiphysics

The simulation procedure involved several key steps to accurately simulate the acoustic behavior of the TLB cabin and its surrounding air enclosure. The following is a more detailed explanation of each step:

- Initial pressure assignment: An initial pressure of 1 Pa was applied to the air surrounding the TLB cabin in the x, y, and z directions. This initial pressure set the starting conditions for the simulation and represents the acoustic field in the vicinity of the TLB cabin.
- Boundary condition: The base of the cabin was given a fixed support boundary condition, ensuring that it remains stationary during the simulation. This boundary condition represents the physical constraint of the TLB cabin being firmly grounded.

- Perfectly Matched Layer (PML) creation: To minimize reflections of sound waves at the boundaries of the air enclosure, a Perfectly Matched Layer (PML) was implemented on the walls. The PML acts as an absorbing layer, preventing sound waves from reflecting back into the simulated domain, and helps simulate an open environment surrounding the TLB cabin.
- Mesh generation: A free tetrahedral meshing technique was used to generate a mesh for the TLB cabin, the air inside the cabin, and the air outside the cabin (the enclosure). This meshing method divides the computational domain into small tetrahedral elements, ensuring a precise representation of the geometry and allowing for accurate calculations of the acoustic properties.
- Point selection and data acquisition: A specific point of interest was selected inside the TLB cabin. The simulation software recorded the frequency versus Sound Pressure Level (SPL) readings at this point. This data acquisition step provided information on the sound pressure levels at different frequencies within the TLB cabin.
- 1D plot creation: Using the recorded frequency versus SPL data from the selected point, a point graph was created in the "1D plot" section of COMSOL Multiphysics. This graph visualized the relationship between frequency and sound pressure levels, allowing for a detailed analysis of the acoustic characteristics at the specific point inside the TLB cabin.
- Results computation: Based on the simulation inputs, including the initial pressure, boundary conditions, and meshing, the simulation software computed the final results. These results included the sound pressure levels, frequency characteristics, and other relevant acoustic parameters at the selected point within the TLB cabin.

Chapter-4

4 RESULTS AND DISCUSSIONS

4.1 Experimental Results

The following results were carried out in the four directions inside the cabin i.e., front, left, rear, and right side in both open as well as closed cabin conditions.

4.1.1 When Engine is OFF

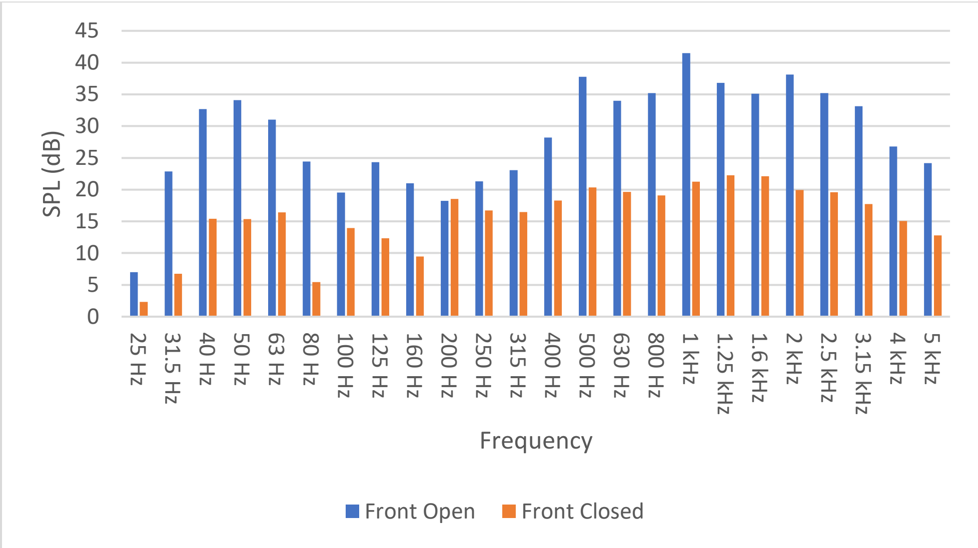

Fig 4.1 Frequency v/s SPL spectrum in 1/3 octave band in FRONT direction (OFF)

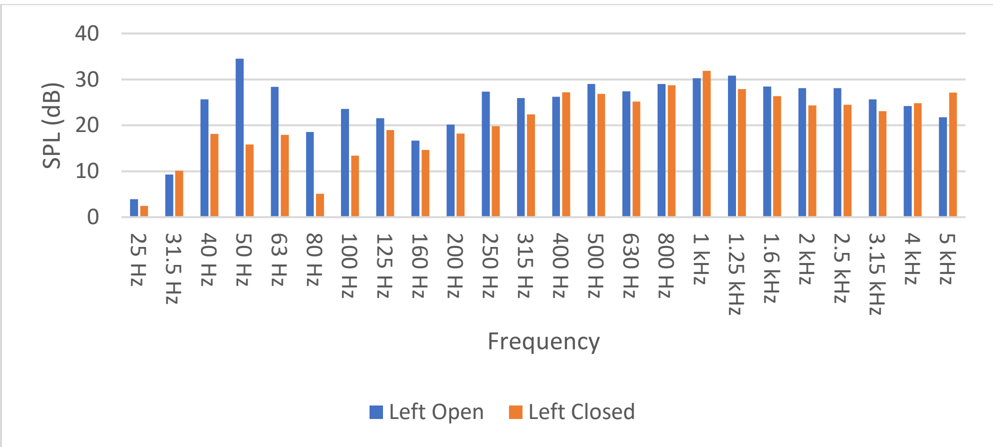

Fig. 4.2 Frequency v/s SPL spectrum in 1/3 octave band in LEFT direction (OFF)

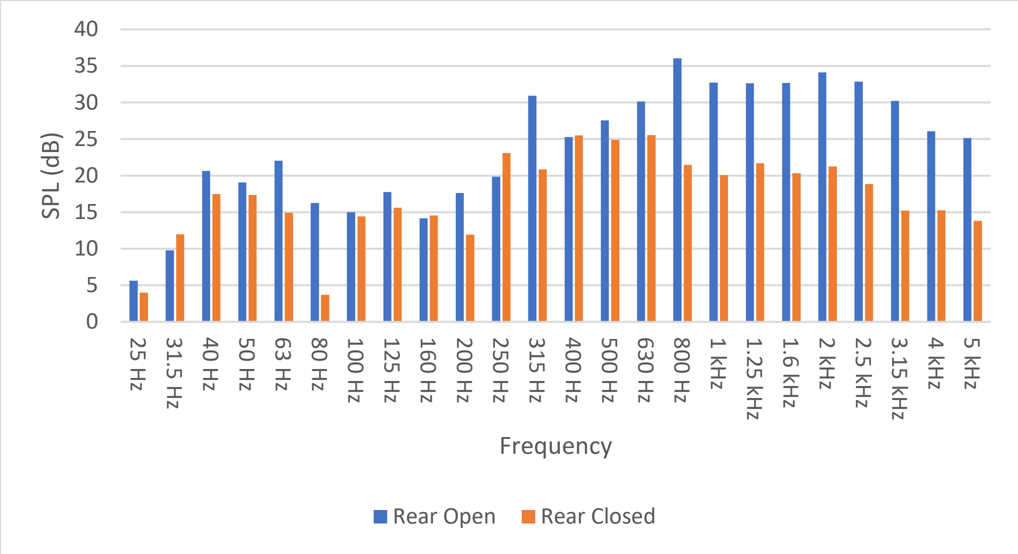

Fig. 4.3 Frequency v/s SPL spectrum in 1/3 octave band in Rear direction (OFF)

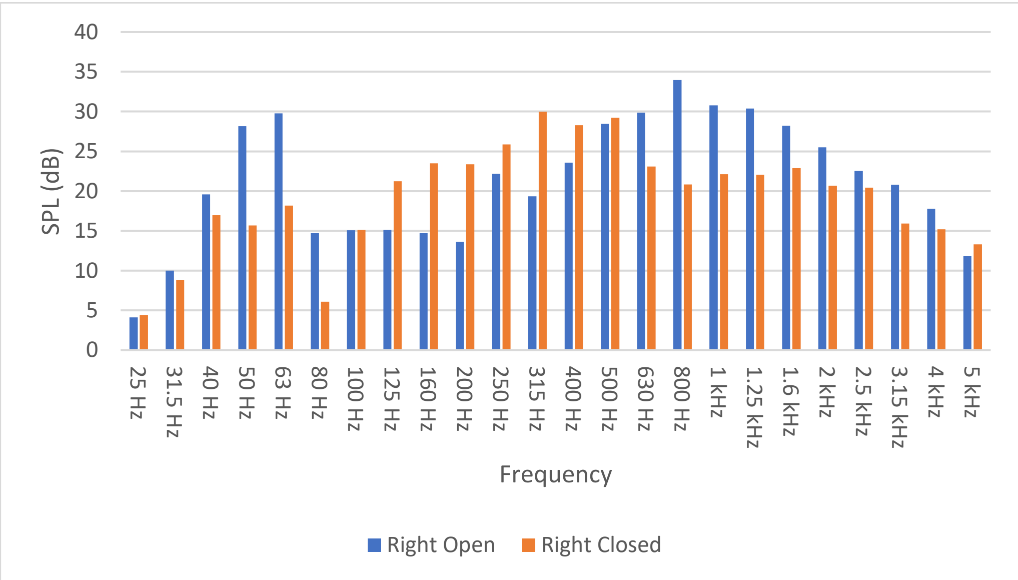

Fig. 4.4 Frequency v/s SPL spectrum in 1/3 octave band in RIGHT direction (OFF)

4.1.2 When Engine is ON

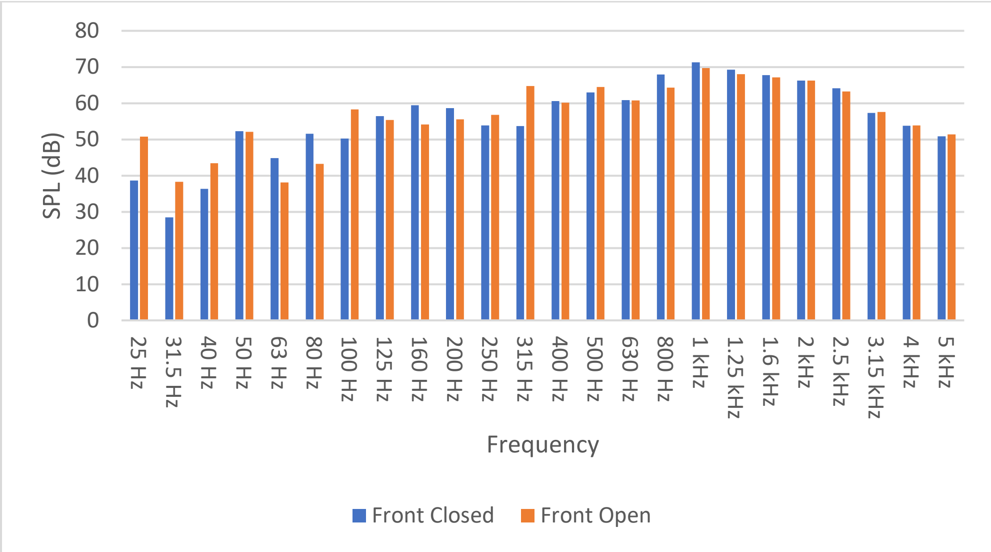

Fig. 4.5 Frequency v/s SPL spectrum in 1/3 octave band in FRONT direction (ON)

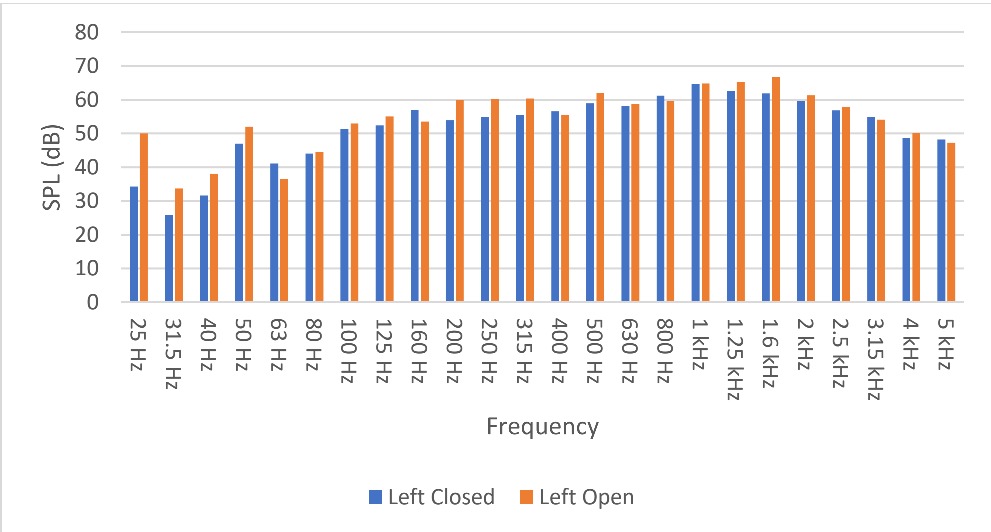

Fig. 4.6 Frequency v/s SPL spectrum in 1/3 octave band in LEFT direction (ON)

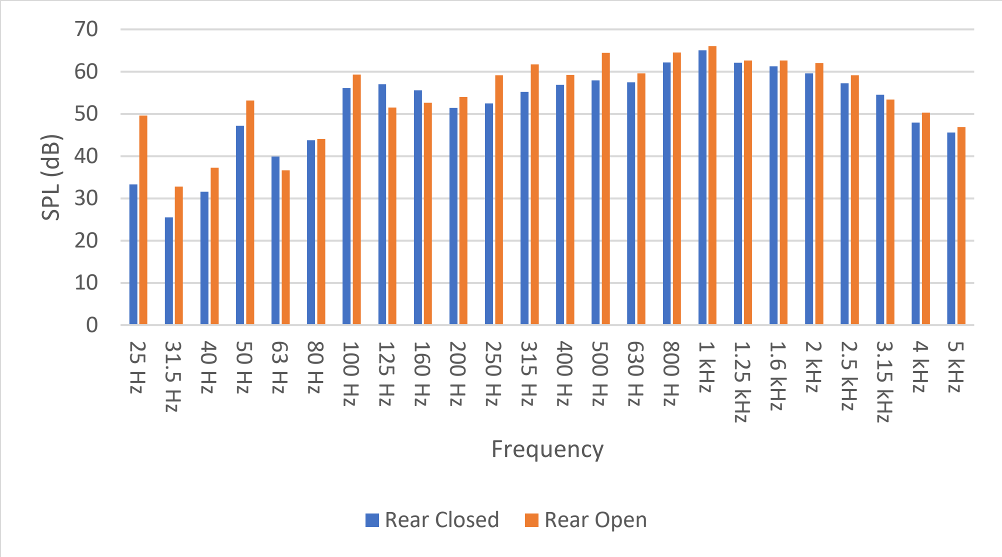

Fig. 4.7 Frequency v/s SPL spectrum in 1/3 octave band in REAR direction (ON)

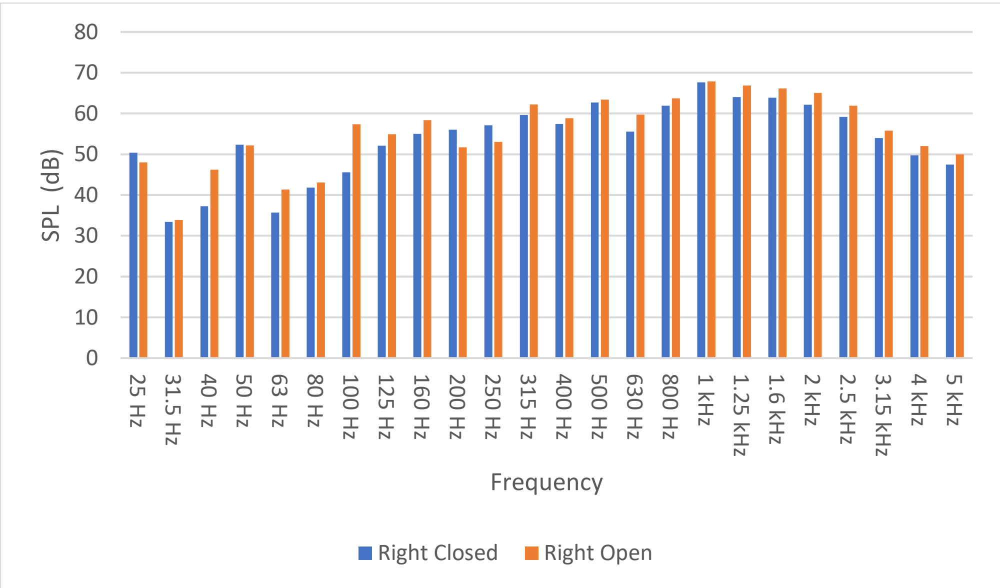

Fig. 4.8 Frequency v/s SPL spectrum in 1/3 octave band in RIGHT direction (ON)

4.1.3 When the TLB is in Working Condition

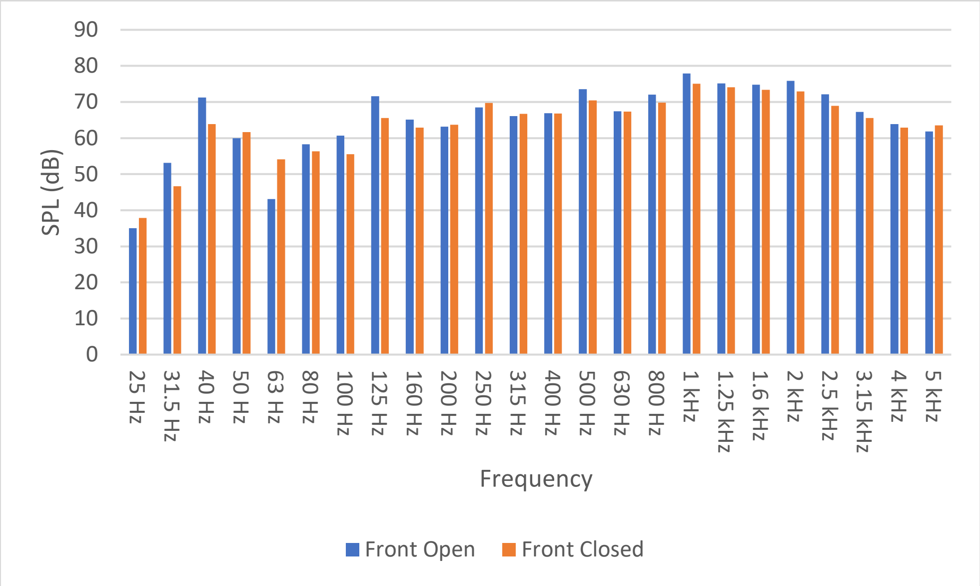

Fig. 4.9 Frequency v/s SPL spectrum in 1/3 octave band in FRONT direction (Working)

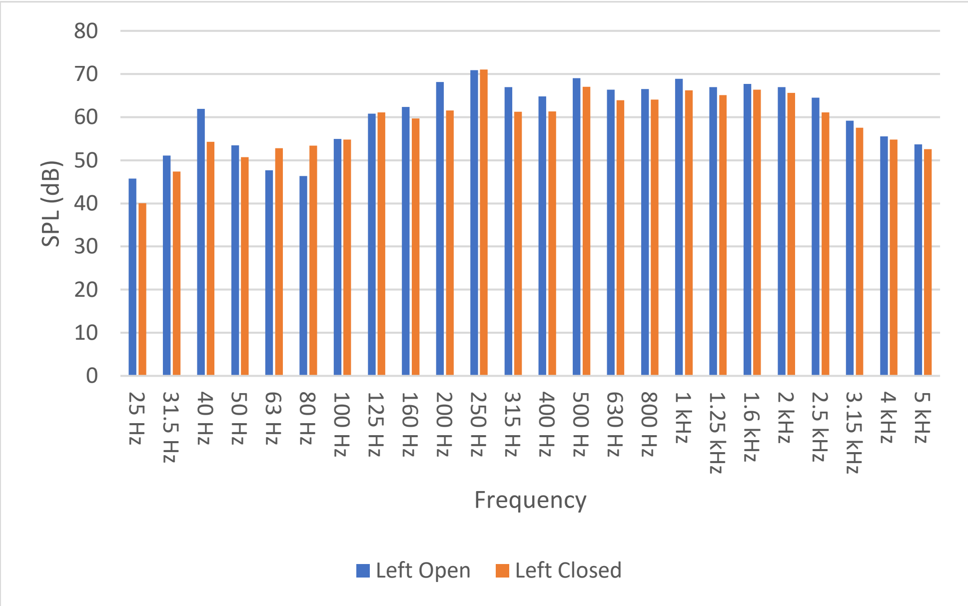

Fig. 4.10 Frequency v/s SPL spectrum in 1/3 octave band in LEFT direction (Working)

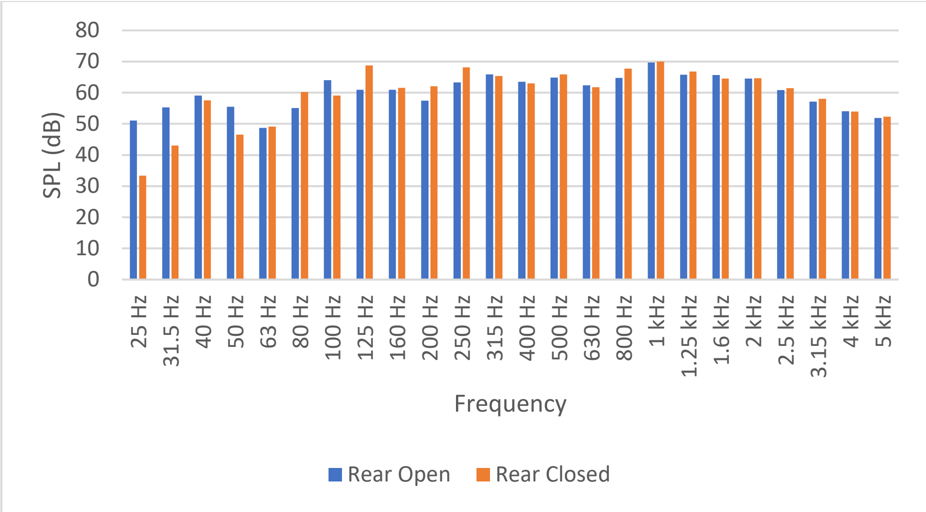

Fig. 4.11 Frequency v/s SPL spectrum in 1/3 octave band in REAR direction (Working)

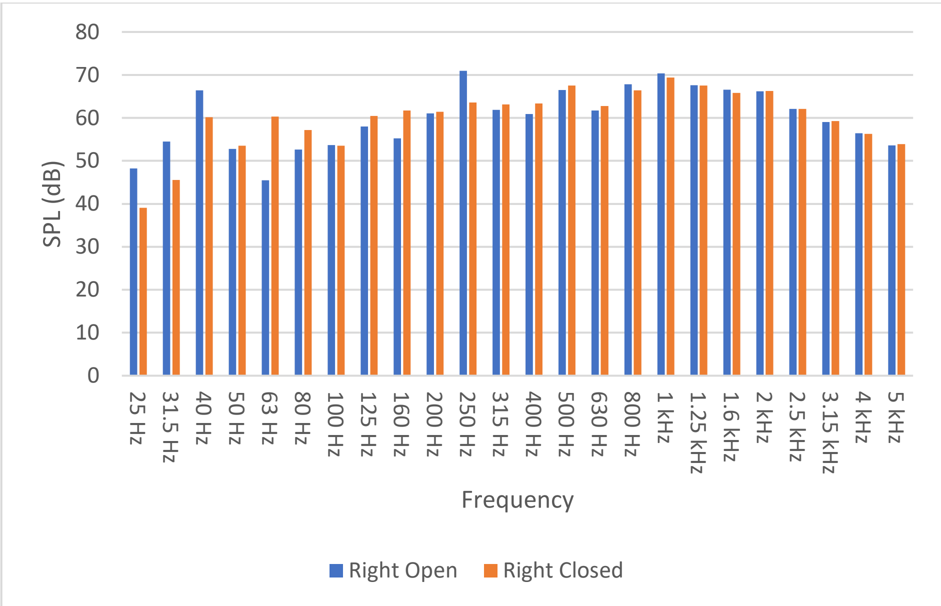

Fig. 4.12 Frequency v/s SPL spectrum in 1/3 octave band in RIGHT direction (Working)

4.3 Simulation Results

The decision to conduct these simulation results specifically for a closed TLB cabin was based on the understanding that the effectiveness of using PU foam as a sound-absorbing material is maximized when the cabin is fully closed. When the cabin is closed, it creates a sealed environment where the sound waves generated by the equipment's operation are contained within the cabin itself.

When the cabin is fully closed, the PU foam can effectively absorb and reduce the transmission of sound waves, resulting in a significant reduction in the noise levels experienced by the operator inside the cabin. The closed cabin acts as a barrier, preventing the escape of sound waves to the surrounding environment and enabling the PU foam to effectively absorb the sound energy.

4.3.1 Results Without PU foam

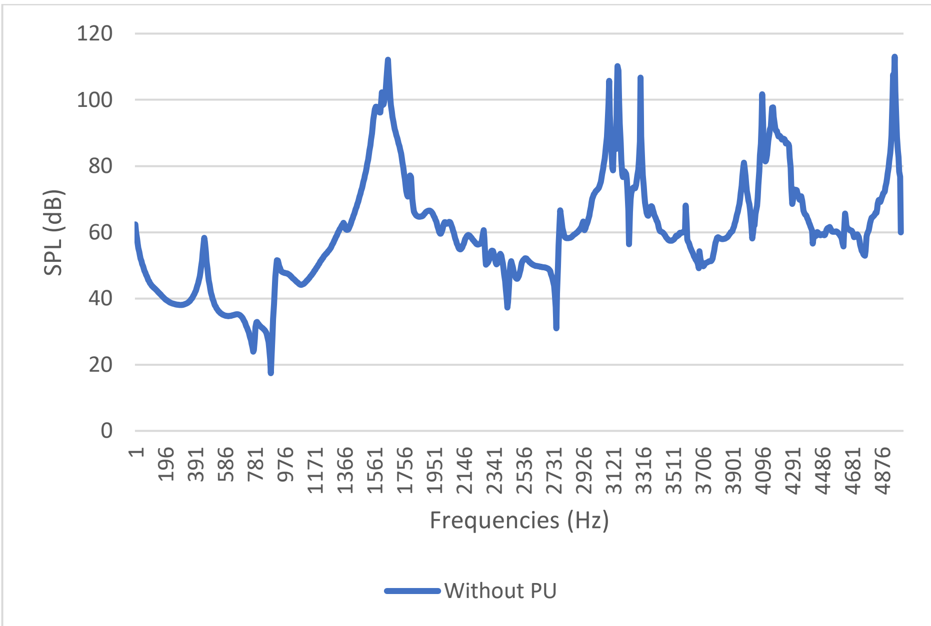

Fig. 4.13 Without PU foam

4.3.2 Results With PU Foam

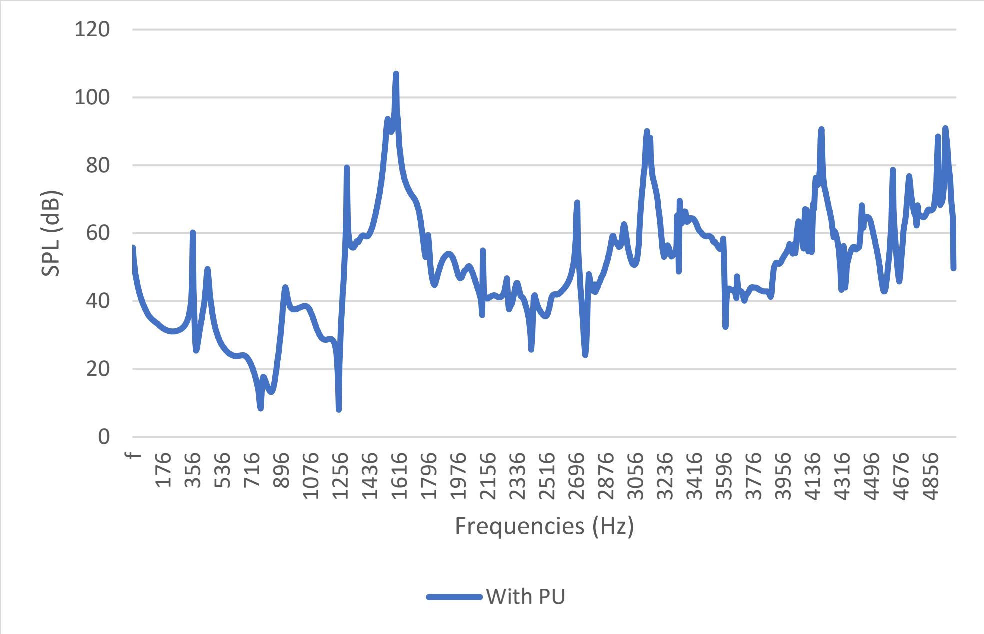

Fig 4.14 With PU foam

4.3.3 With and Without PU Foam Comparison

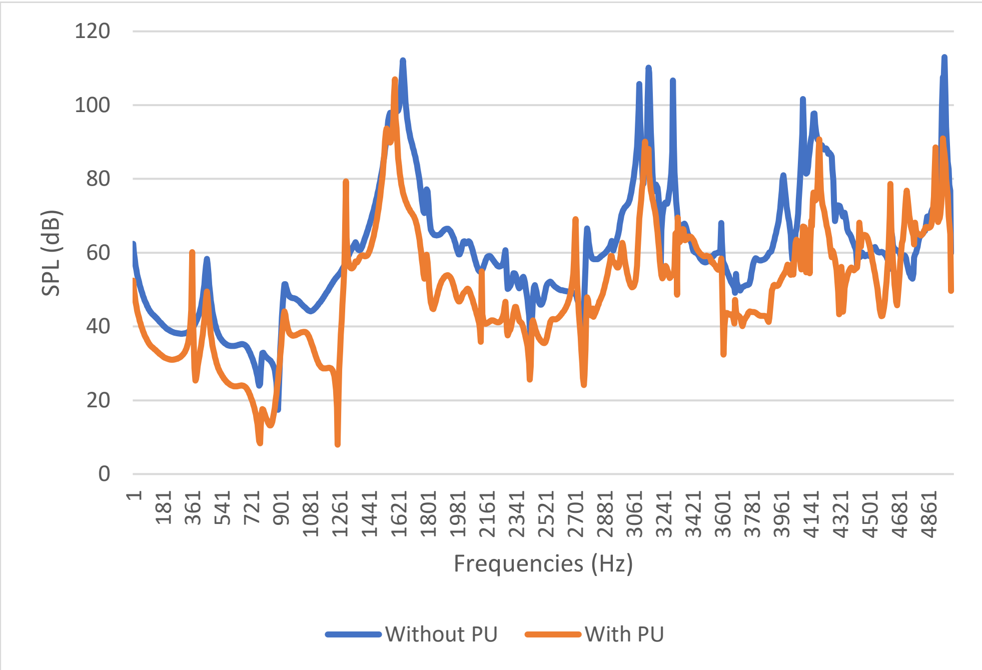

Fig. 4.15 Comparison of 'with and without PU foam'

4.5 Results

From the above frequency v/s SPL spectra we can observe the following results:

- In Experimental data:
  - ♦ The noise level is the highest in Open cabin in the working condition of TLB specifically in the front direction with 77.91 dB.
- In simulation data:
  - ♦ The average SPL without PU foam in the simulation is 120.99 dB.
  - ♦ The average SPL with PU foam in the simulation is 110.30 dB.
  - ♦ Difference in the average values of SPL is 10.69 dB.

CHAPTER 5

5 CONCLUSIONS

5.1 Conclusions by Experiment

In conclusion through experiment, the analysis of the provided data reveals that the maximum noise from the front direction was observed when the machine was in an open condition during operation. This finding emphasizes the significance of addressing noise control measures, particularly from the front direction, to mitigate the adverse effects of noise exposure in such working environments.

5.2 Conclusions by Simulation

In conclusion through simulation, the results obtained from the provided data shed light on the significant impact of PU foam on sound pressure levels (SPLs) in the context of an operator sitting in a TLB (tractor-loader-backhoe). The average SPL without the presence of PU foam was measured at 120.99 dB, representing the baseline noise exposure level experienced by the TLB operator. However, upon the installation of PU foam, the average SPL decreased to 110.30 dB, indicating the effectiveness of PU foam in reducing noise levels experienced by the operator.

The observed difference of 10.69 dB in the average SPL values between the scenarios with and without PU foam highlights the substantial noise reduction achieved by the implementation of PU foam in the TLB. This reduction in noise exposure is crucial for the operator's well-being and can potentially minimize the risk of noise-induced hearing damage or other related health issues.

By significantly decreasing the SPL, PU foam proves to be a practical and technically effective engineering control intervention for mitigating engine noise reaching the TLB operator. This finding is of utmost importance, as it provides evidence for the feasibility and practicality of utilizing PU foam as a sound-dampening material in heavy equipment cabins, enhancing the working conditions and overall safety of operators.

It is important to acknowledge that further studies and evaluations are necessary to validate these findings across different TLB models, operational conditions, and noise sources. Additionally, considering the specific needs and requirements of TLB operators, the long-term durability and performance of PU foam should be examined to ensure its effectiveness over time.

In conclusion, the results strongly support the implementation of PU foam as a valuable noise control measure in TLB cabins. By reducing the average SPL by 10.69 dB, PU foam has the potential to reduce the reliance on hearing-protection devices and provide a practical solution for minimizing noise exposures and safeguarding the hearing health of TLB operators.

5.3 Future Scope

The future scope of this thesis involves conducting experiments on the JCB 3DX model and other construction equipment using PU foam and other various types of sound absorbing materials available. This will allow to validate the simulation approach used in this thesis and assess its applicability across the NVH industry.

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