Numerical Modelling of Helmholtz Resonator

1. Objective:

Explore how changes in the geometrical parameters of the Helmholtz resonator, such as cavity volume, neck length, and neck diameter, affect its resonant frequency and overall acoustic behaviour. This allows for a deeper understanding of the resonator's characteristics and the underlying physics involved.

Determine the resonant frequency of the Helmholtz resonator by simulating its acoustic response using numerical methods. This involves studying the relationship between the dimensions of the resonator and its resonance frequency.

2. Introduction:

The Helmholtz resonator consists of a cavity with a small neck or opening and is capable of resonating at a specific frequency when exposed to sound waves.

The unique characteristic of the Helmholtz resonator lies in its ability to absorb or amplify sound at its resonant frequency. This property has found applications in diverse areas, ranging from musical instruments and architectural acoustics to automotive engineering and noise control.

In recent years, numerical modelling techniques have become an invaluable tool for studying and understanding the behaviour of complex systems. Numerical simulations allow researchers to investigate the intricate details of the Helmholtz resonator's acoustic response, making it possible to analyse its performance under various conditions and explore design optimization.

Through this experiment, we aim to enhance our understanding of the fundamental principles governing the Helmholtz resonator, refine numerical modelling techniques, and potentially discover novel insights that can be applied to practical applications. This research has implications in fields such as noise control, musical instrument design, architectural

acoustics, and engineering, where optimising the behaviour of acoustic devices is crucial.

3. Theory:

The Helmholtz resonator is a simple acoustic device that operates based on the principles of resonance. Resonance occurs when a system vibrates at its natural frequency or a harmonic multiple of it, resulting in a build up of energy and amplification of the system's response. In the case of the Helmholtz resonator, this resonance phenomenon is utilised to either absorb or amplify sound at a specific frequency.

The Helmholtz resonator consists of three main components: a cavity, a neck or opening, and a volume of air enclosed within the cavity. The cavity is typically a hollow container, such as a bottle or tube, while the neck is a narrow passage connecting the cavity to the surrounding environment. The size and shape of these components determine the resonant frequency of the device.

The behaviour of the Helmholtz resonator can be explained using the concept of acoustic mass and compliance. The mass of air inside the cavity, together with the volume and length of the neck, contribute to the device's acoustic mass. The compliance, or springiness, of the system is determined by the compressibility of the air in the cavity and neck.

When a sound wave of a specific frequency encounters a Helmholtz resonator, it causes the air within the cavity to vibrate. The vibration creates oscillating pressure variations, resulting in air movement in and out of the cavity through the neck. This movement of air establishes a resonance condition when the oscillating pressure and airflow are in phase, leading to a peak response at the resonant frequency.

Resonance Frequency:

$$f_H = \frac{v}{2\pi} \sqrt{\frac{A}{V_0 L_{eq}}}$$

- V is static volume of cavity
- A is cross sectional area of neck
- L is equivalent length of neck with end correction
- v is speed of sound in gas

The length of the neck appears in the denominator because the inertia of the air in the neck is proportional to the length. The volume of the cavity appears in the denominator because the spring constant of the air in the cavity is inversely proportional to its volume. The area of the neck matters for two reasons. Increasing the area of the neck increases the inertia of the air proportionately, but also decreases the velocity at which the air rushes in and out.

Transmission Loss : The measurement of transmission loss requires the acoustic powers of the incident and transmitted waves. The incident wave on the upstream side is measured in the frequency domain by wave decomposition utilising two microphones.The measurement of the transmitted wave on the downstream side relies on a signal separation in time domain by introducing a transient input (burst random or burst sine in the present study) travelling through the long tube. While burst random used in the absence of flow facilitates a rapid measurement, it has relatively low power compared to burst sine which concentrates the input power on a single frequency.

4. Methodology:

- Define the geometry.
- Open Ansys workbench which is a simulation and 3D design software.
- Choose the Analysis system. In this experiment we selected 'Harmonic Acoustic'.
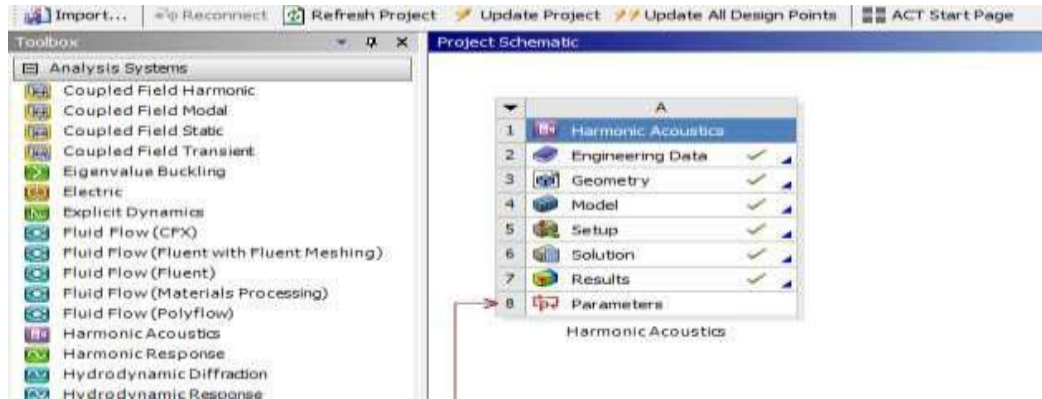
- Now make geometry in design modular.
- Assign appropriate material to the model. The properties include density, speed of sound and viscosity of the medium in which the resonator is operating. Here air is used as a medium.
- Generate a mesh for the model to discretize the geometry. The mesh density should be chosen carefully to ensure accurate representation of the resonator's features.
- Then go to settings and then select each boundary and select its condition which is already there in boundary conditions and insert some numerical values manually.
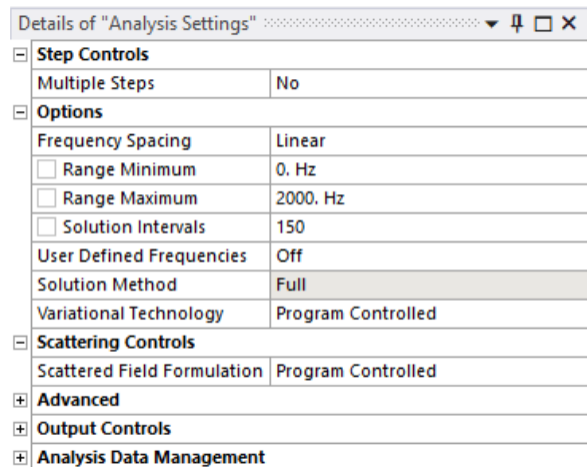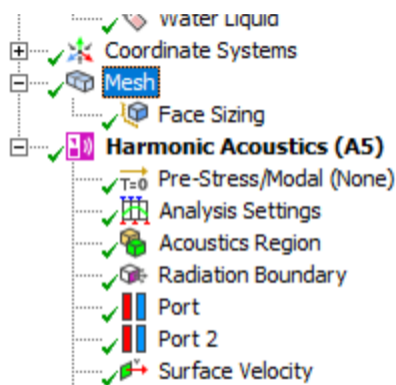
- Now insert transmission loss from the solution and pressure level from the solution option and set the required parameters. After clicking on the solution option, we will get the pressure level plot and transmission loss plot.
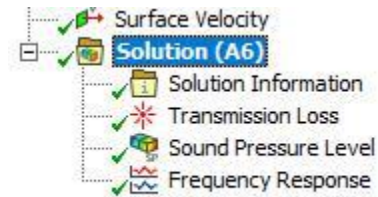
- Finally, the transmission loss of the system is plotted. The graph can be compared to measurements performed on the same system by varying the volume and shape of the system.
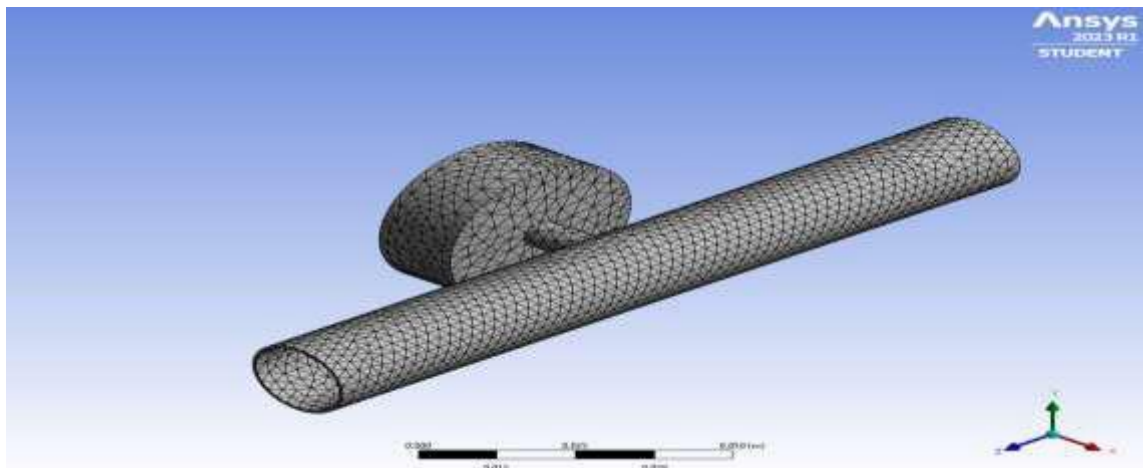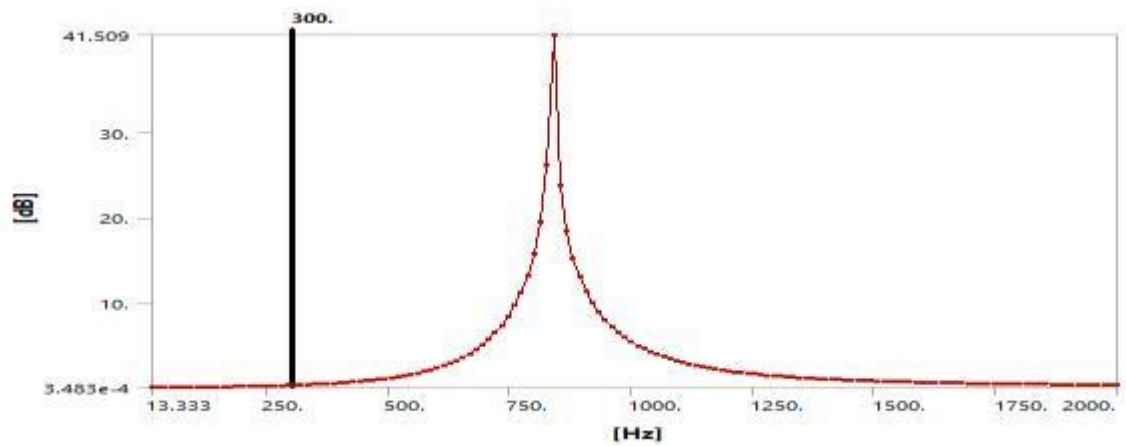
Model 1
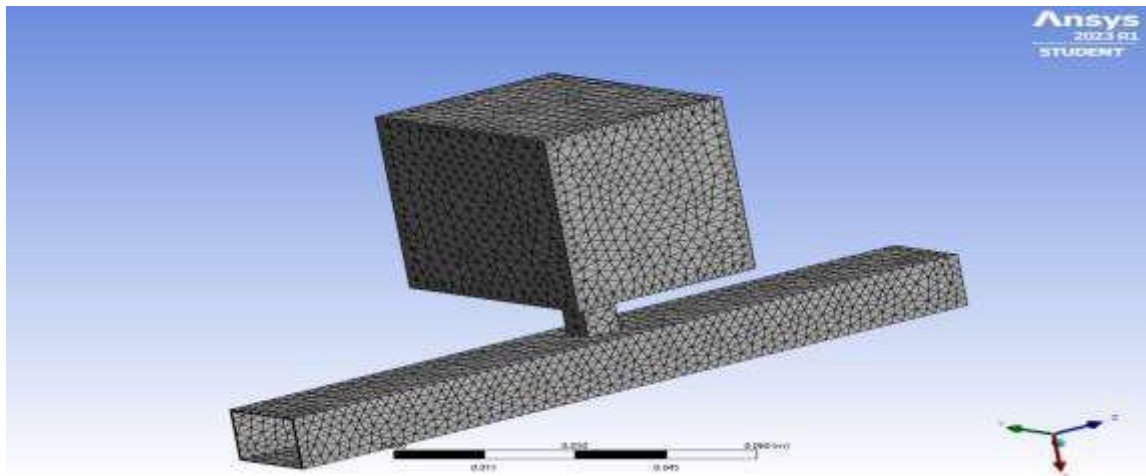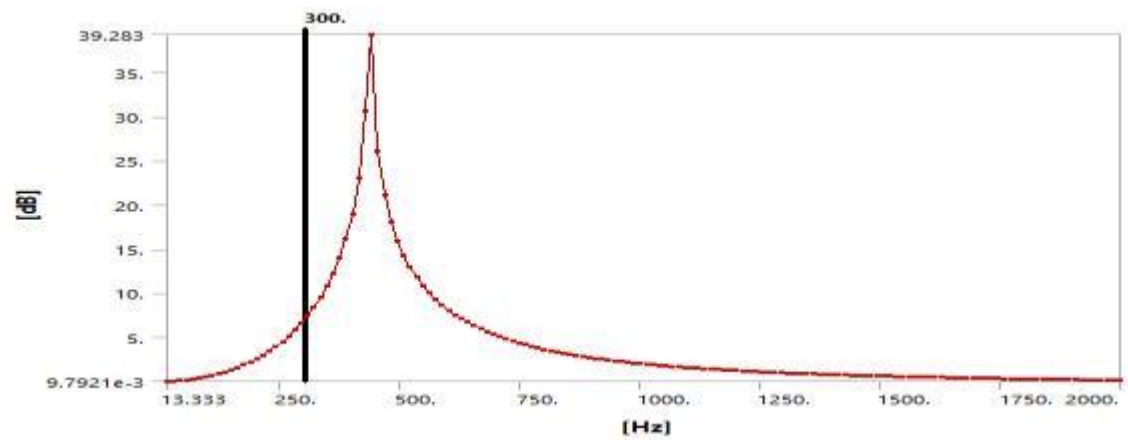
Geometry:
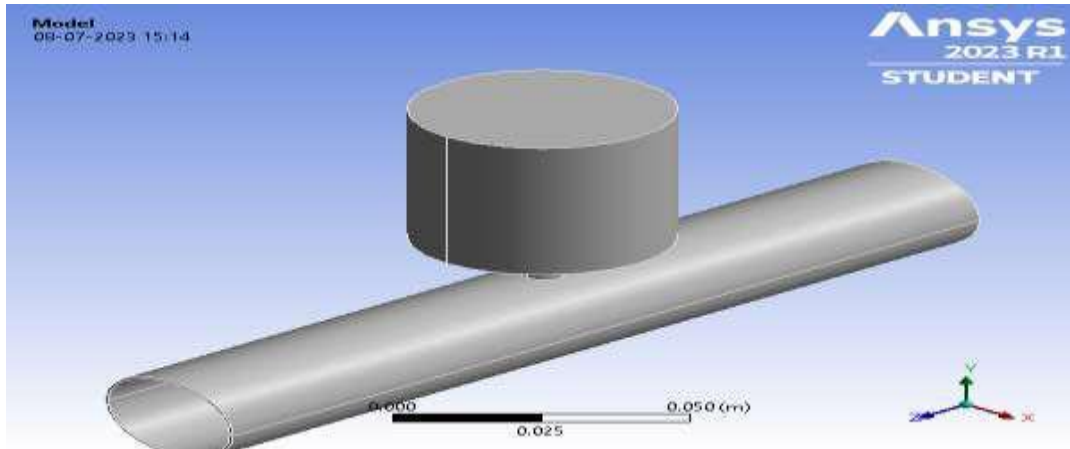
Meshing:
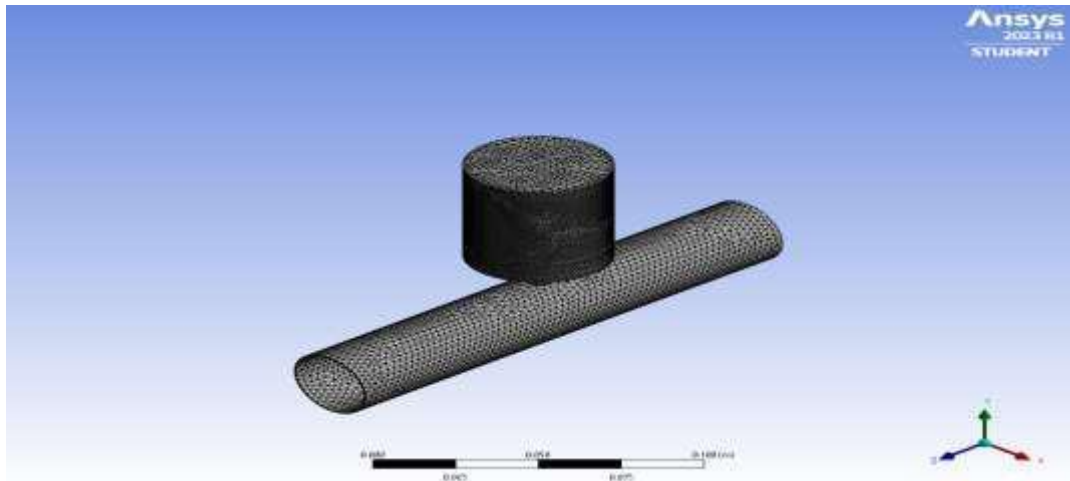
Transmission Loss Plot :
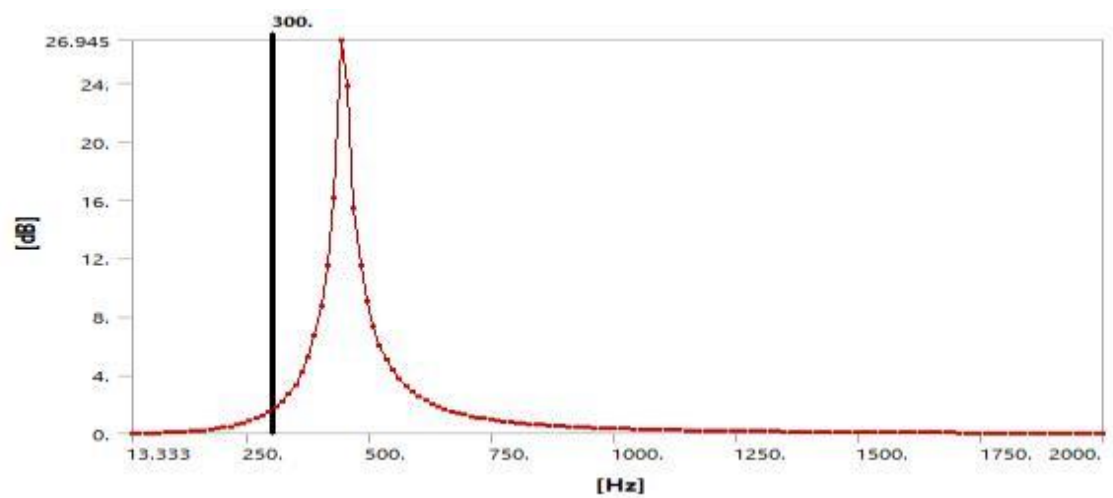
Model 2

Geometry:
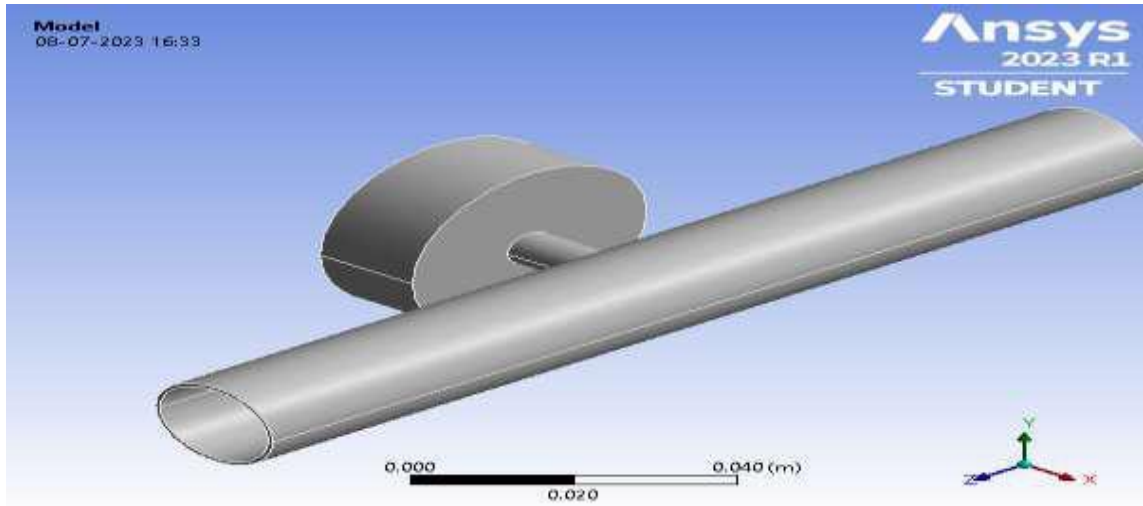
Meshing:

Transmission Loss Plot :

Model 3
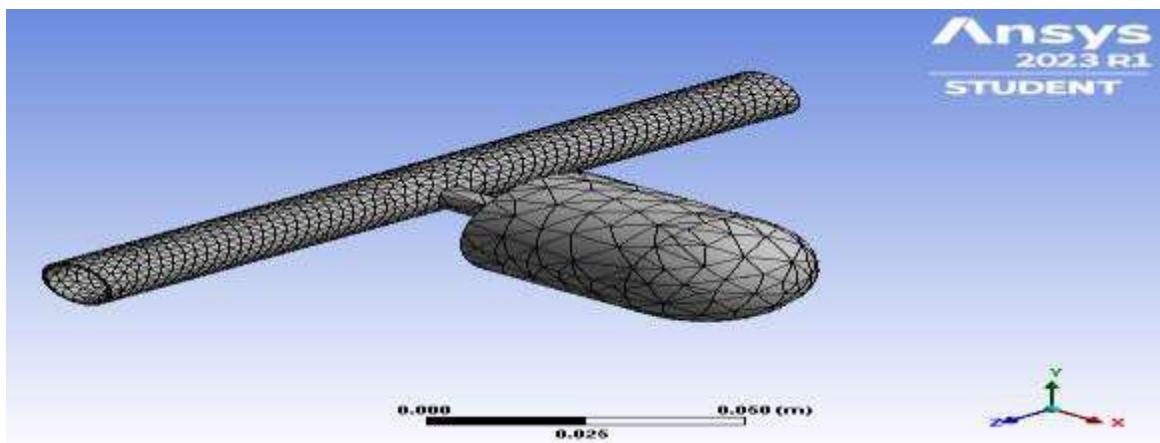
Geometry:
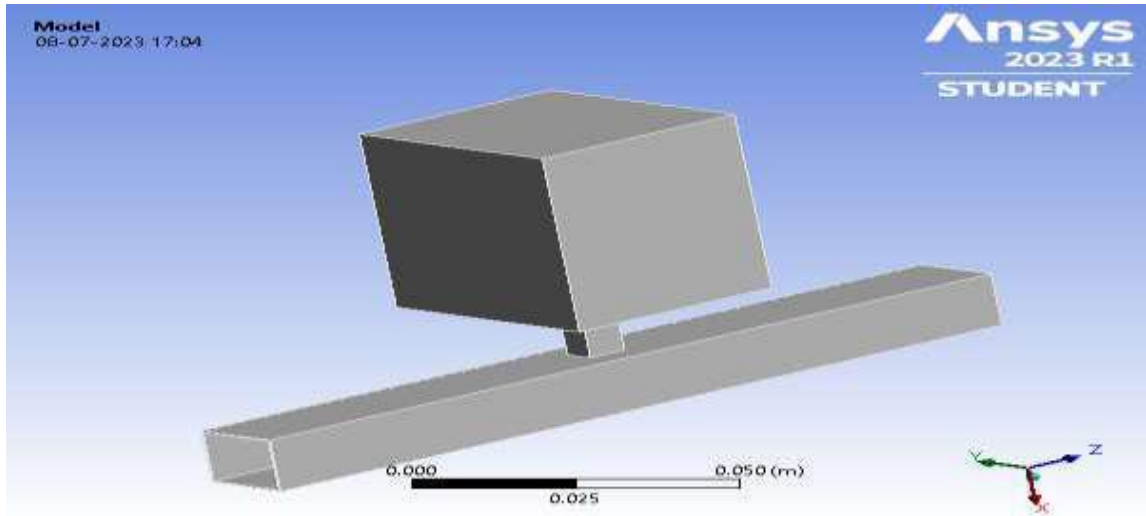
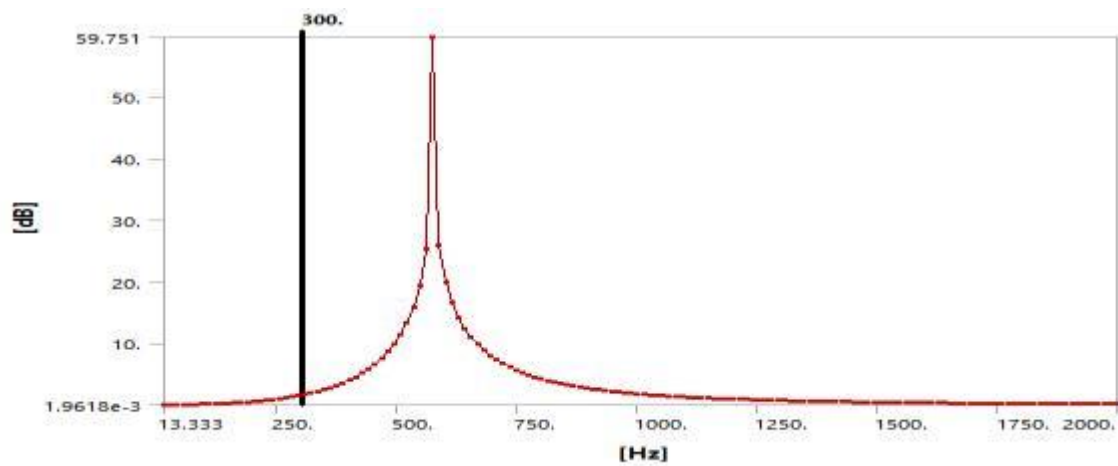Meshing:

Transmission Loss Plot :
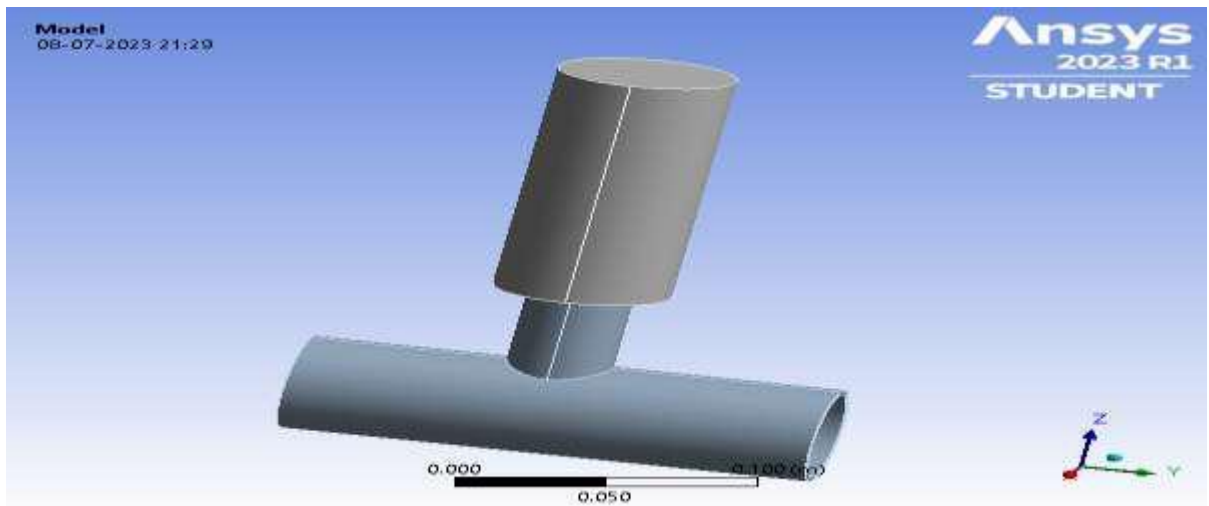
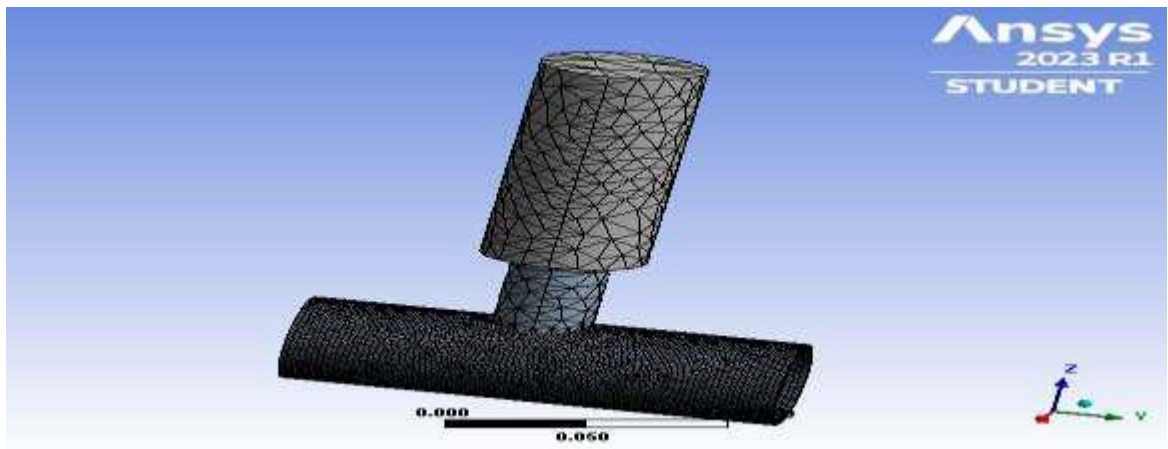## Model 4

Geometry:
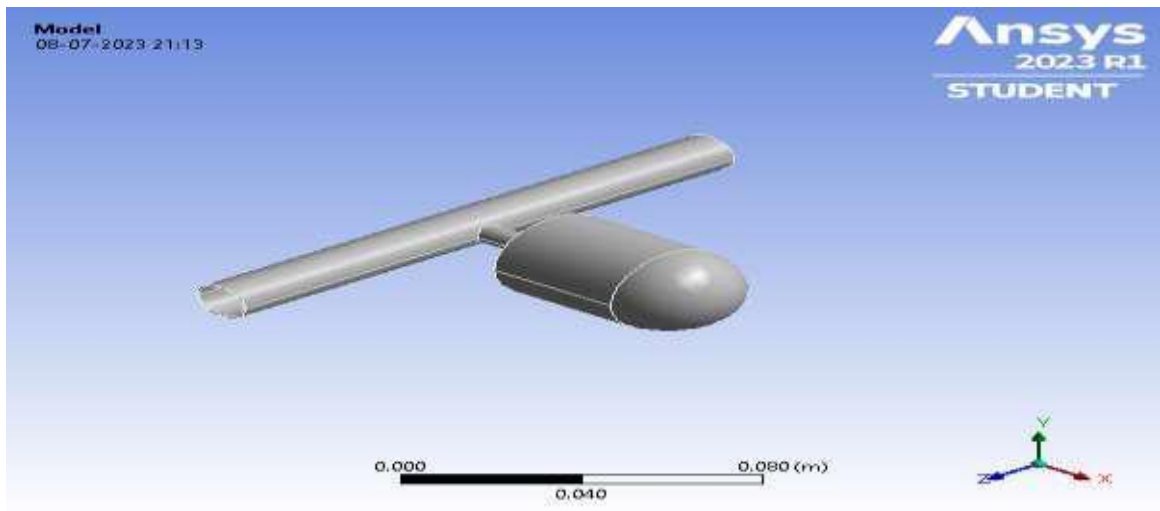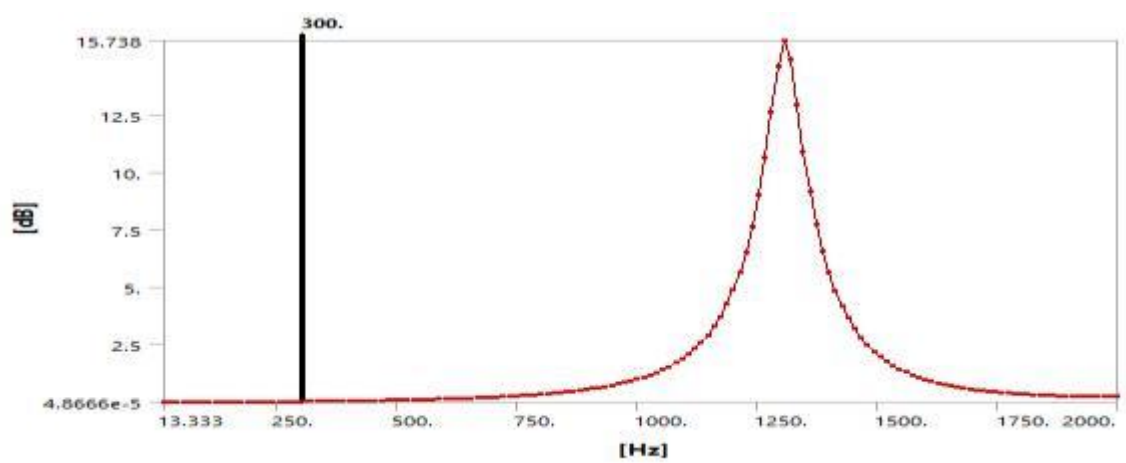

Meshing:

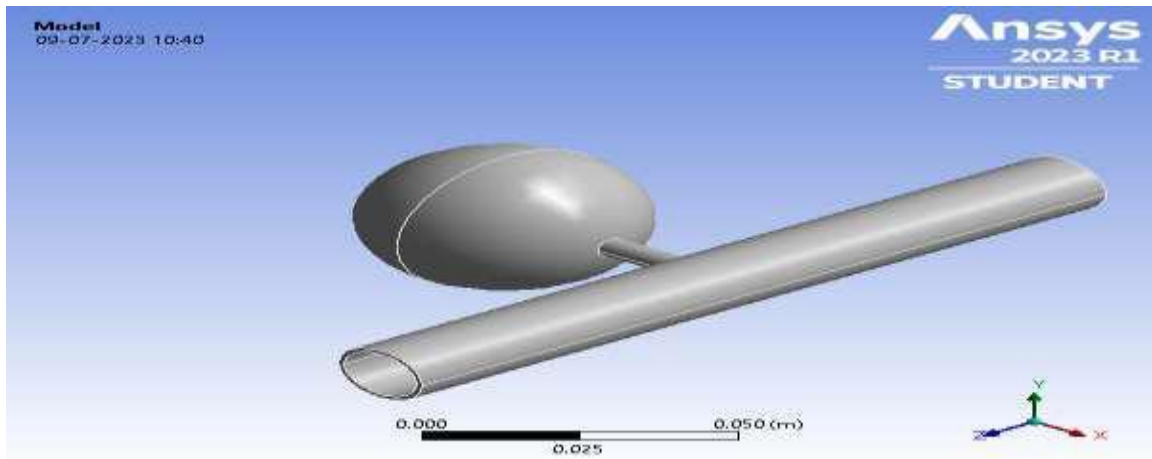Transmission Loss Plot :

Model 5
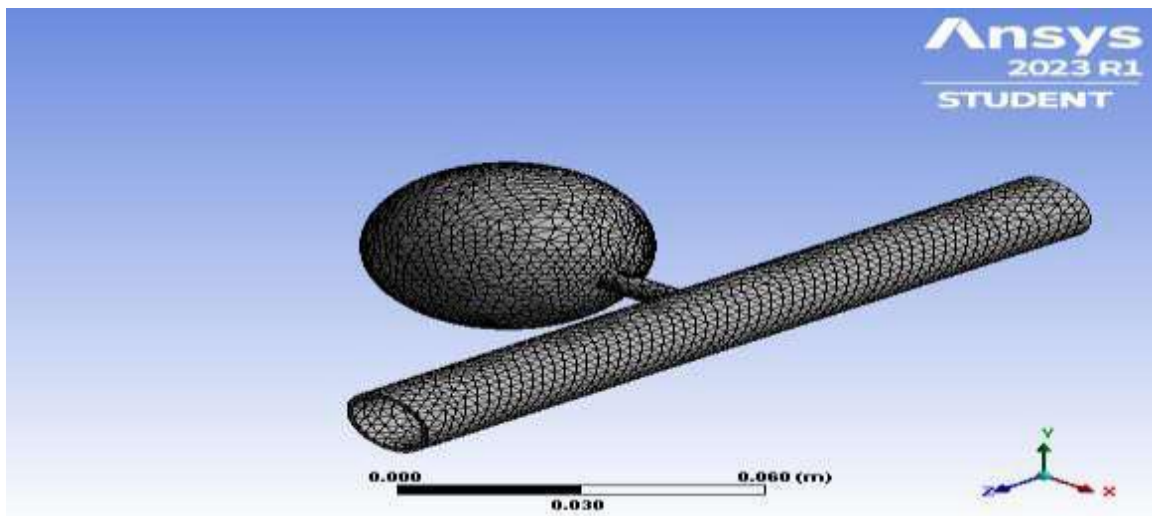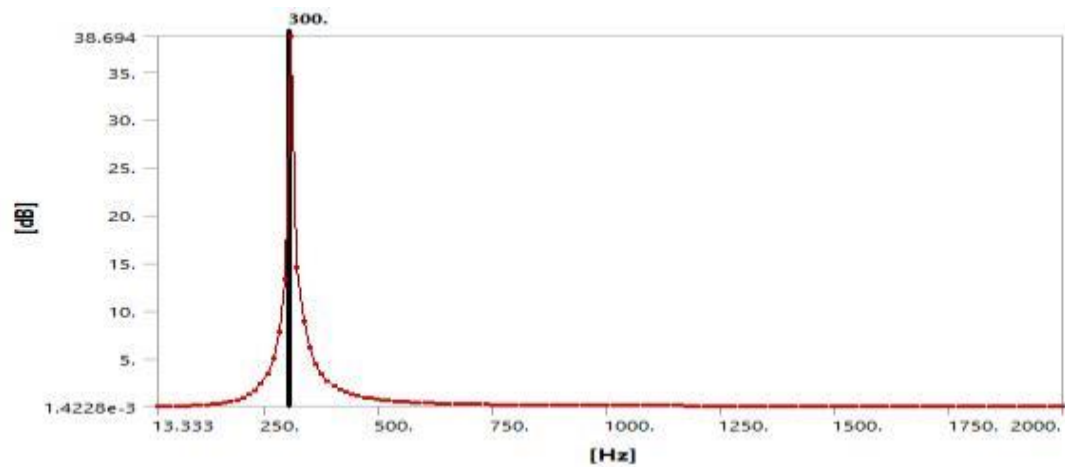
Geometry:

Meshing:

Transmission Loss Plot :

Model 6

Geometry:

Meshing:

Transmission Loss Plot:

5. Result :

Geometries	Peak of Transmission loss (in Hertz)	Result of TL Plot
MODEL 1	440	**Results** ☐ Minimum — 0. dB ☐ Maximum — 26.945 dB
MODEL 2	840	**Results** ☐ Minimum — 3.483e-004 dB ☐ Maximum — 41.509 dB
MODEL 3	440	**Results** ☐ Minimum — 9.7921e-003 dB ☐ Maximum — 39.283 dB
MODEL 4	573.33	**Results** ☐ Minimum — 1.9618e-003 dB ☐ Maximum — 59.751 dB
MODEL 5	1306.7	**Results** ☐ Minimum — 4.8666e-005 dB ☐ Maximum — 15.738 dB
MODEL 6	306.67	**Results** ☐ Minimum — 1.4228e-003 dB ☐ Maximum — 38.694 dB

6. Conclusion:

The experiment on the numerical modelling of the Helmholtz resonator has provided valuable insights into the behaviour and characteristics of this simple yet powerful acoustic device. By employing numerical simulation techniques, we have deepened our understanding of the resonator's response to sound waves and explored the effects of various geometrical parameters on its performance.

Through the experiment, we successfully achieved our objectives, which included analysing the resonant frequency, investigating parameter effects,

validating the numerical model, and exploring design optimization. The resonant frequency of the Helmholtz resonator was determined by simulating its acoustic response and studying the relationship between its dimensions and the resonant frequency. This knowledge is crucial for designing resonators with desired acoustic properties in practical applications.

We have also investigated the effects of different parameters, such as cavity volume, neck length, and neck diameter, on the resonant frequency and overall behaviour of the Helmholtz resonator. This exploration has enhanced our understanding of how changes in these parameters influence the resonator's performance, allowing for informed design choices in various applications.

7. Innovative Aspects:

o Noise Control: Helmholtz resonators are widely employed in noise control applications. They can be used to absorb or attenuate specific frequencies of noise, helping to reduce unwanted sound and improve acoustic comfort. For example, they are utilized in the design of mufflers and exhaust systems in vehicles to minimize engine noise and improve overall sound quality.

o Musical Instruments: Helmholtz resonators play a crucial role in the design of musical instruments. They are incorporated into instruments such as woodwinds, brass instruments, and stringed instruments to enhance specific frequencies, modify the tone quality, and improve the overall sound projection. The resonators contribute to the unique timbre and character of various musical instruments.

o Architectural Acoustics: In architectural acoustics, Helmholtz resonators are utilized to control and shape the sound environment in buildings and performance spaces. They can be strategically

placed to absorb or amplify certain frequencies, optimising the acoustics for speech intelligibility, music performance, or reducing reverberation in large spaces.

o **Industrial Engineering:** Helmholtz resonators find applications in industrial engineering for managing and controlling noise in machinery and equipment. By incorporating resonators into the design, specific frequencies generated by machines can be attenuated, reducing noise pollution and creating a safer and more comfortable working environment.

o **Environmental Noise Reduction:** Helmholtz resonators can be employed in various settings to reduce environmental noise. They can be used in the design of noise barriers and enclosures to mitigate noise from highways, railways, or industrial facilities. Helmholtz resonators offer an effective means of reducing specific frequencies of noise, enhancing overall noise control measures.

o **Wind Instruments:** Many wind instruments, such as flutes and organ pipes, utilize Helmholtz resonators as part of their design. The resonators enhance specific frequencies and contribute to the characteristic sound produced by these instruments.

o **Engineering Design:** Helmholtz resonators are utilised in engineering design for applications that require precise control of sound or vibration. They can be integrated into systems to suppress or amplify specific frequencies, allowing for efficient management of acoustic energy in a wide range of engineering applications.

8. References:

https://www.comsol.com/model/download/737381/models.aco.helmholtz_resonator_with_flow.pdf

https://en.wikipedia.org/wiki/Helmholtz_resonance

Youtube.com

Ansys.com