INTERIM REPORT

Design Improvements of Acoustic Responses of an Automotive Air Intake System

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Abbreviations

AIS – Air Intake System

BEM – Boundary Element Analysis

CAE – Computer Aided Engineering

FEA – Finite Element Analysis

GIT – Grid Independence Test

NVH – Noise, Vibration and Harshness

SPL – Sound Pressure Levels

1 Introduction

Noise pollution has been shown to have adverse effects the health of human beings [1]. The noises humans are exposed to everyday especially in the city can lead to a wide range of health effects such as sleep disturbance, tinnitus, cognitive impairment in children and annoyance. It is important that we reduce noise pollution in everyday lives to improve the health of humans. Regulations are set by the government [2] to ensure that noise levels in cities can be controlled. There are many sources of environmental noise that can lead to adverse health effects. One the sources is from the transportation sector. Current motor vehicles are powered by combustion engines. Combustions engines produce noise from various parts such as the engine, exhaust system, and the air intake system (AIS). An AIS generates noise through the resonance produced by the engine during operation.

The AIS is responsible for drawing ambient air and directing it into the engine, allowing for smooth and consistent airflow that can be used to crate power through the combustion of an internal-combustion engine (ICE). An AIS consists of a snorkel, intake tube, air filter and airbox as seen in Figure 1.

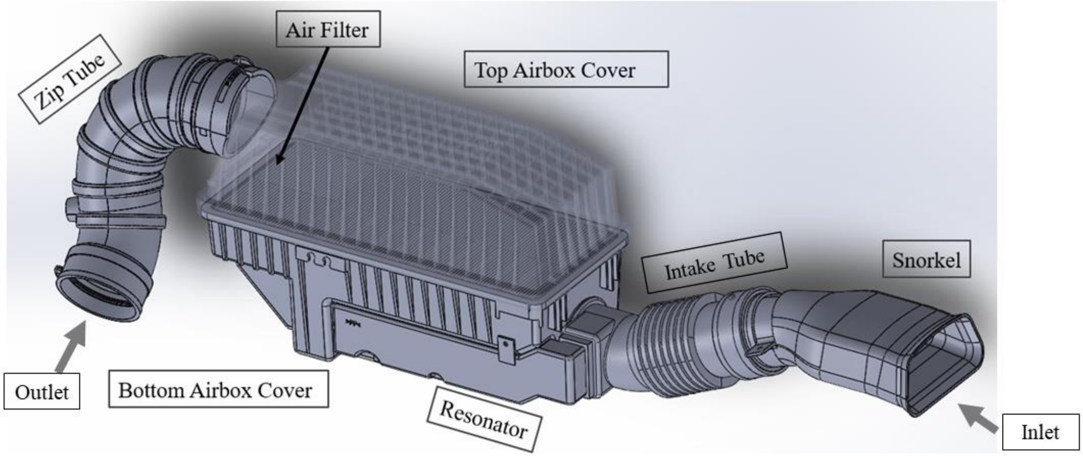


Figure 1: Model of Air Intake System of the Proton Iriz 1.3 [3]

Reduction of noise in motor vehicles have been increasing in research as noise pollution has been studied to affect humans [4]. The noise of an air intake system is usually measured by the sound pressure level (SPL) inside the AIS. Reducing the SPL levels in an AIS can help reduce the noise generated in the operation of a motor vehicle, improving he comfort of the driver and passengers inside the car. There are multiple ways in improving acoustic response of an AIS. One of the methods is the introduction of resonators into AIS.

Resonators have been used widely by the industry as one of the ways to reduce the noise generated from the AIS. This can be seen in Figure 2, where a resonator can be seen in the AIS for Toyota Corolla and BMW.

(a) (b)

Figure 2: Resonators found in (a) Toyota Corolla and (b) BMW

There are two types of resonators used to improve acoustic performance of an air intake, there quarter lambda resonators and there are also resonators that branch of from the main air intake flow which are mostly called Helmholtz resonators that are shown in Figure 3. Both resonators have different characteristics combating acoustic performance.

(a) (b)

Figure 3: Images of (a) quarter lambda resonator and (b) Helmholtz Resonator

The main focus of this project is to improve the acoustic performance of AIS in the Proton Iriz 1.3. This can be achieved by reducing the resonance inside the air intake at specific points.

Resonators besides affecting the acoustic performance of the AIS, also affect the volumetric efficiency of the AIS [5]. A reduce in volumetric efficiency may affect the output of the powertrain, forcing the driver to the vehicle to put more load into the powertrain, raising the noise of the powertrain. It is possible to minimize the efficiency loss of the AIS through various configurations of the resonators.

1.1 Research Questions

The questions that are aimed to be solved in this research are:

1. How to locate the areas along an Air Intake System that experiences high noise levels.
2. How to improve the noise levels of current Air Intake System?

1.2 Research Objectives

The objectives of this research are:

1. To develop a validated acoustic simulation model of an Air Intake System to identify the location of the highest noise along an Air Intake System
2. To modify the current Air Intake System by adding resonators at the identified areas.

1.3 Hypothesis

Areas with high noise levels can be located along the Air Intake System through the use of simulations and noise can be reduced by adding resonators at identified locations.

1.4 Scope

The scope of the research is to run simulation so the AIS to determine the location along the AIS that produce peak noise. This research will be completely done in simulation using ANSYS 2020r1. The scope of the analysis for this research is to improve the acoustic performance of the AIS. The impact of AIS performance with the addition of resonators are not analyzed. No prototype will be produced in this research and thus there will be no budget for the research.

2 Literature Review

2.1 Noise pollution and the effects on health

The World Health Organization (WHO) states that air pollution and traffic noise are the two biggest environmental pollutants that are affecting human health. Base on the studies in [1][4], it is believed that there is a increase association between exposure to road traffic and aircraft noise to various health issues.

An estimate of 61000 years of loss life from Hypertension and various heart diseases, 45000 years for cognitive impairment of children, 903000 years for sleep disturbance, 22000 years for tinnitus and 587000 years for annoyance is due to the exposure of environmental noises such as road traffic and aircraft noises in Western Europe alone.

The calculations seen above come from the calculation of disease ability adjusted life-years (DALY). The equation for DALY can be seen in the Eq. (1).

$$DALY = YLL + YLD \tag{1}$$

Where YLL is the number of "years of life loss" while YLD is the number of "years lived with disability". The numbers in this research show that it is important to reduce environmental noise to improve human health.

2.2 Methods of analyzing NVH levels

Noise generated from a vehicle come from different sources. As a vehicle consists of various moving parts, it is important that research and testing is done extensively to ensure that the NVH levels of a vehicle is reduced. One of the areas that is always looked into to reduce NVH levels is the powertrain of the vehicle. There are a lot of moving parts in a powertrain. Engine combustion, transmission, differential and drivetrain axles have a lot of moving parts and all produce noise during operation [6]. It is important to reduce the noises in these systems to allow for a quite and efficient operation.

There are different ways the automotive industry has used to analyze the NVH levels of the powertrain. 3D FEA and BEM are commonly used to analyze the structure of models while analyzing the vibrations and natural frequency of models as shown in Figure 4. A model is usually built in a CAE Modeling software as detailed as possible. This includes the components and subsystems of the powertrain to ensure that structural paths are also taken into account during structural analysis of the powertrain. SPL levels and accurate structural paths contributing to vibrations can be obtained through this method of analysis.

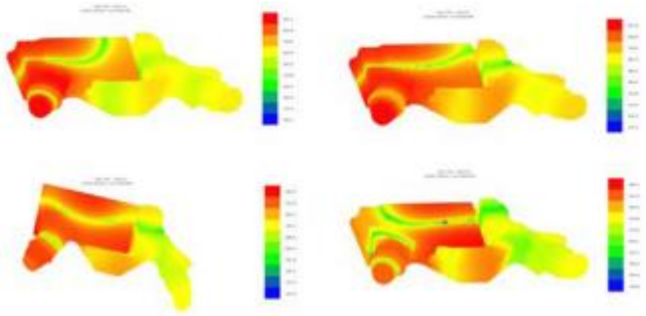


Figure 4: 3D model of Pressure Distribution of High Frequencies

1-D simulations are often used to develop an active noise control strategy. There are multiple commercial tools that are currently in the market that use used to do 1-D acoustic analysis such as AVL Boost, GT-Power, Ricardo Wave and Lamps [7]. These 1-D acoustic analysis are common in analyzing the acoustic performance of air intakes as well as exhausts. When developed properly, these analyses are able to construct an engine model that is able to simulate acoustic performance of an engine accurately [8].

2.3 Application of Resonators in Air Intake System

In a conventional ICE, 4 strokes cycles are used to create power, these 4 stokes are intake, compression, combustion and exhaust strokes. During the intake stroke, the intake valves open to allow for air and fuel mixture to enter the combustion chamber from the intake manifold. As the intake valves close during the compression stroke, pressure builds up in the intake manifold due to the closed valves. The increase in pressure forces air to travel out of the intake manifold back to the snorkel of the air intake, creating noise. This is visualized in Figure 5.

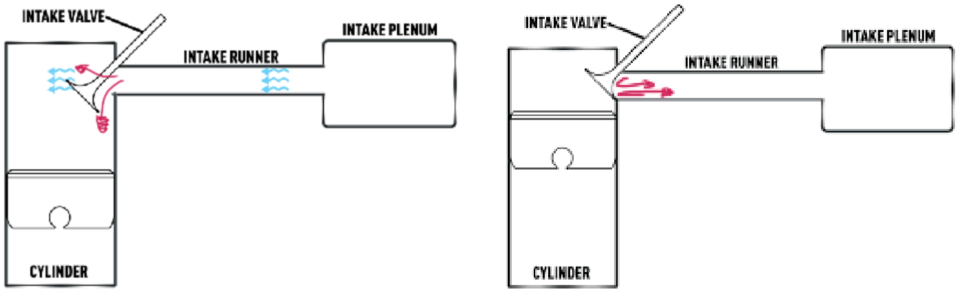


Figure 5: Image showing the pressure build up when valve closes during compression [9]

In this research [8], an engine model is developed and simulated in a 1-D simulation software, GT-Power. The simulation results for the shows that the engine model is accurate within 2% of the results of an actual engine. This is important to ensure the data gathered from this research can accurate represent an actual AIS. Baseline model of the AIS is simulated to obtain the SPL levels of the air intake without resonators. The results were compared with the actual acoustic performance of the AIS as shown in Figure 6.

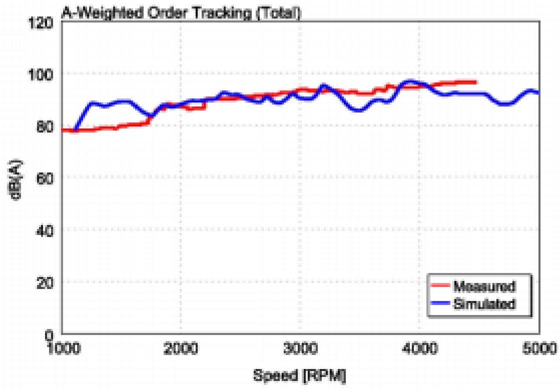


Figure 6: Comparison of SPL of simulated data and measured data [8]

Multiple configurations where tested in this research to understand the effects of the resonators on the acoustic performance of the AIS. In the first configuration as shown in Figure 7, multiple changes were made. 3 different resonators were removed in QW1, QW2, QW3 and a venturi was made, and the configuration was simulated and compared with the baseline model results.

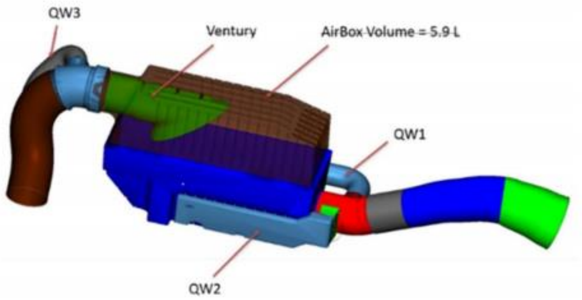
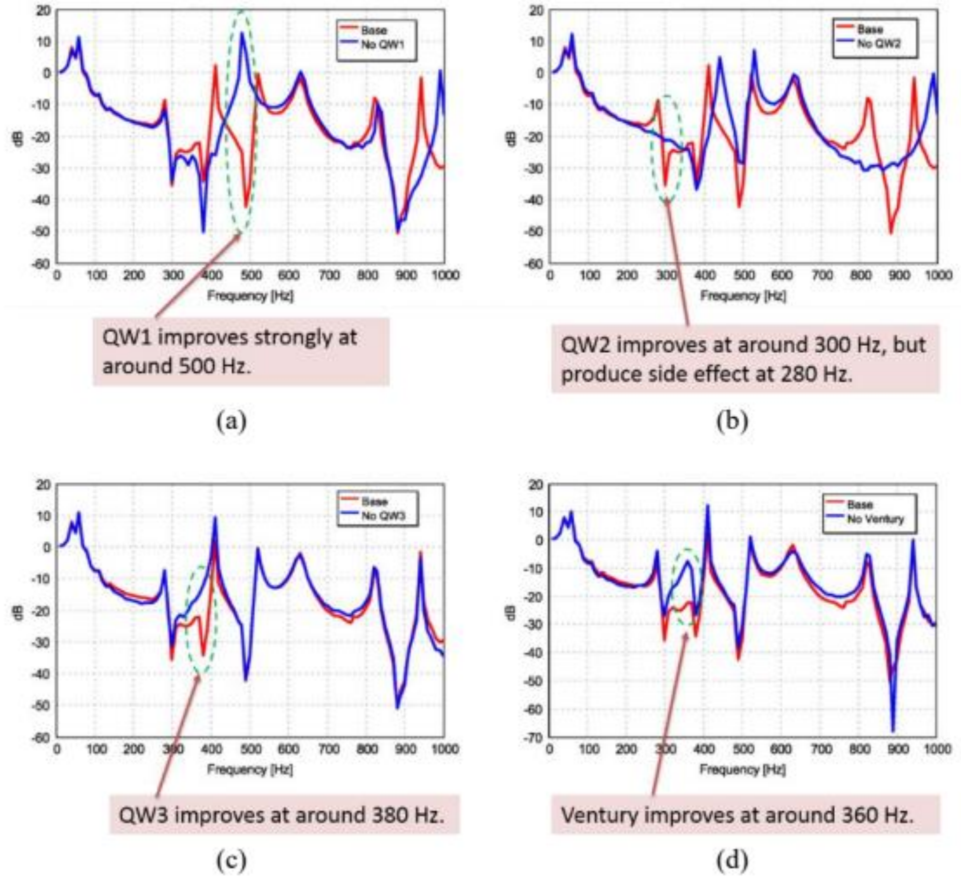


Figure 7: Air Intake System with resonator QW1, QW2 and QW3 [8]

As seen in Figure 8, removal of resonators in different positions in the AIS affected the acoustic performance significantly. The results also show that side effects are present when introducing a resonator into the AIS. Additional noise can be seen in Figure 8, with spikes in frequencies around the reduced frequency due to the addition of a resonator.



QW1 improves strongly at around 500 Hz.

QW2 improves at around 300 Hz, but produce side effect at 280 Hz.

(a)

(b)

QW3 improves at around 380 Hz.

Ventury improves at around 360 Hz.

(c)

(d)

Figure 8: Effects of removing QW1, QW2, QW3 and Venturi compared to the basline model [8]

As seen in Figure 8(a) and Figure 8(b), the red line represents the presence of a resonator in the analysis. For Figure 8(a), The removal of QW1 showed that QW1 was able to significantly suppress the noise at 500hz but this came with the side effect of added noise at 410hz. This can be similarly seen with Figure 8(b), with the presence of QW2 help improve noise levels around 300hz but it affected the noise at 280hz.

To combat this, a Helmholtz resonator was used to replace QW1 and the AIS was tested again. As seen in Figure 9, the Helmholtz resonator was able to improve the acoustic performance of a wider range of frequencies, but the side effect of the resonator was still present.

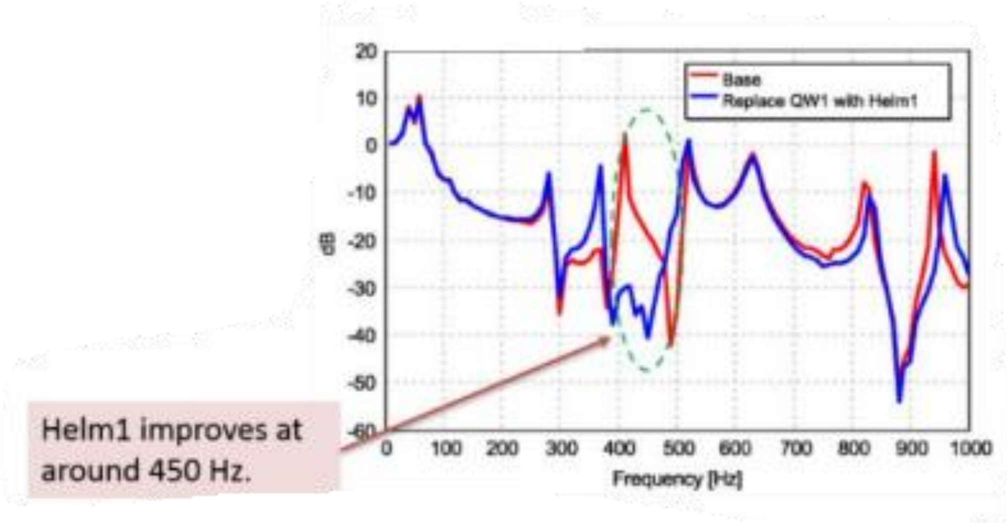


Figure 9: Effects of replacing QW1 with Helmholtz resonator [8]

Although removal of QW2 showed an improvement in acoustic performance, 2 configurations of the AIS were made to understand effects of QW2. The different configurations can be seen on Figure 10.

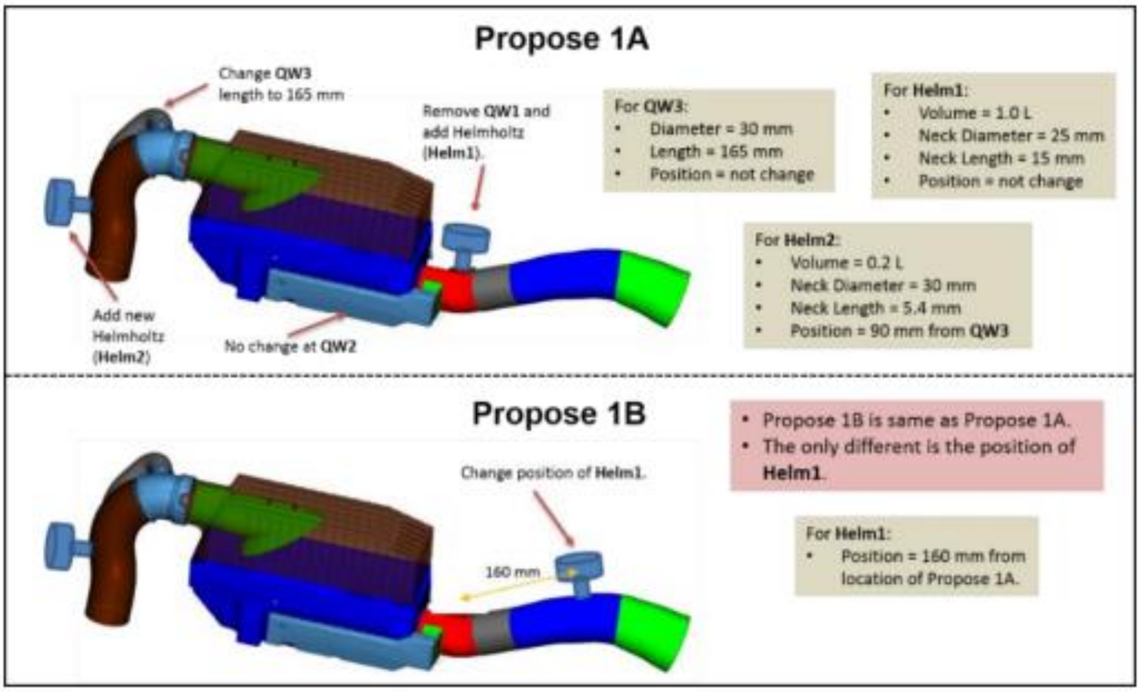
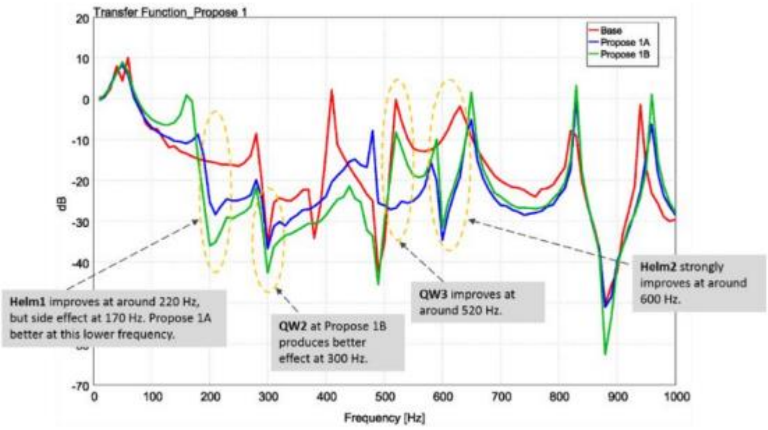


Figure 10: Configuration of AIS to investigate QW2 [8]

Results in Figure 11 show that although the removal of QW2 was able to improve the volumetric efficiency of the AIS, changes made in QW1 without the removal of QW2 gave a better result overall. This shows that resonators are able to affect the result of the AIS when placed properly.



Helm1 improves at around 220 Hz, but side effect at 170 Hz. Propose 1A better at this lower frequency.

QW2 at Propose 1B produces better effect at 300 Hz.

QW3 improves at around 520 Hz.

Helm2 strongly improves at around 600 Hz.

Figure 11: Comparison of Baseline Model, Removal of QW2 and reallocation of QW1. [8]

3 Research Methodology

As this project is entirely software-based, the flowchart in Figure 12 shows the process and setup that will be followed to complete the research. The geometry for the baseline air intake is provided and is to be exported into ANSYS [10] for meshing and simulation. Harmonic Acoustics analysis system of ANSYS will be used in research to analyze the acoustic response of the AIS and compared with the measured data to understand the accuracy of the simulation.

Grid independence test (GIT) is to be done for the meshing of the geometry to have a balance between accuracy and computing time for the simulation as the timeframe for this research is limited. GIT is the process where a graph is plotted for the number of elements against the result of the simulation. As the element size decreases, the accuracy of the result should converge and improvements on the accuracy will be almost similar as the element size decreases further. The convergence point will indicate the most optimum point where the mesh is a balance between accuracy and computing time.

Solidworks 2019 [11] will be used to design improvements that will be implemented in the prototype. The prototype will then undergo the same process of GIT meshing and simulation as the baseline model in ANSYS to obtain results for comparison.

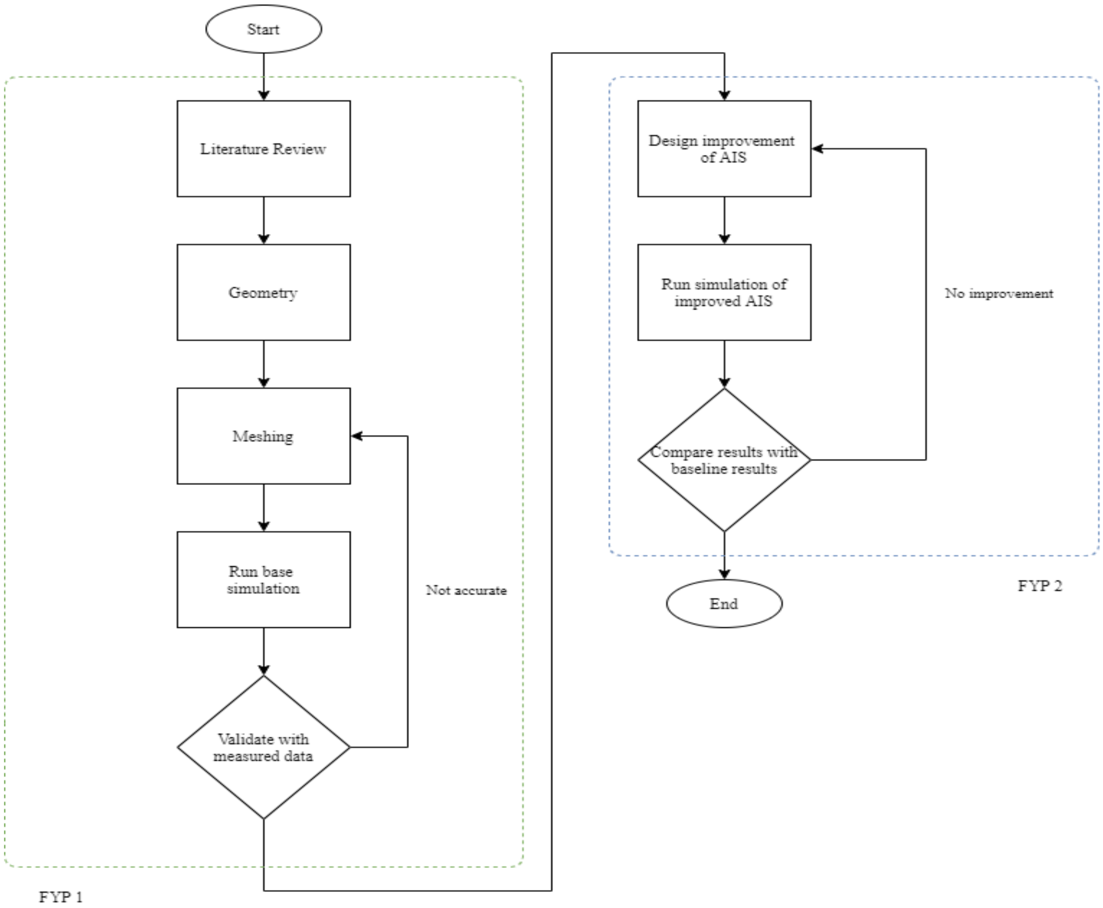
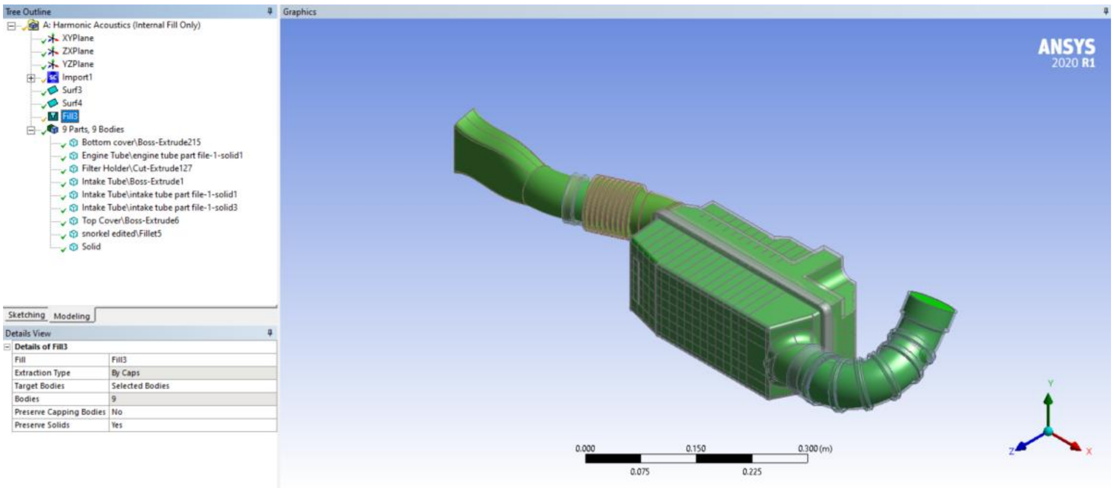


Figure 12: Flow Chart of the Research

3.1 Simulation Setup

The simulation is running under the Harmonics Acoustic analysis system in ANSYS [12]. An internal cavity was created from the geometry on the model designed by [3] which the main parameters of the design were provided by Proton as shown in Figure 13 to allow for the analysis system to run the simulation. For the initial simulation, the default mesh was used to understand the analysis system and gather preliminary results. The air intake used for this simulation includes the snorkel, intake box, and intake tube.



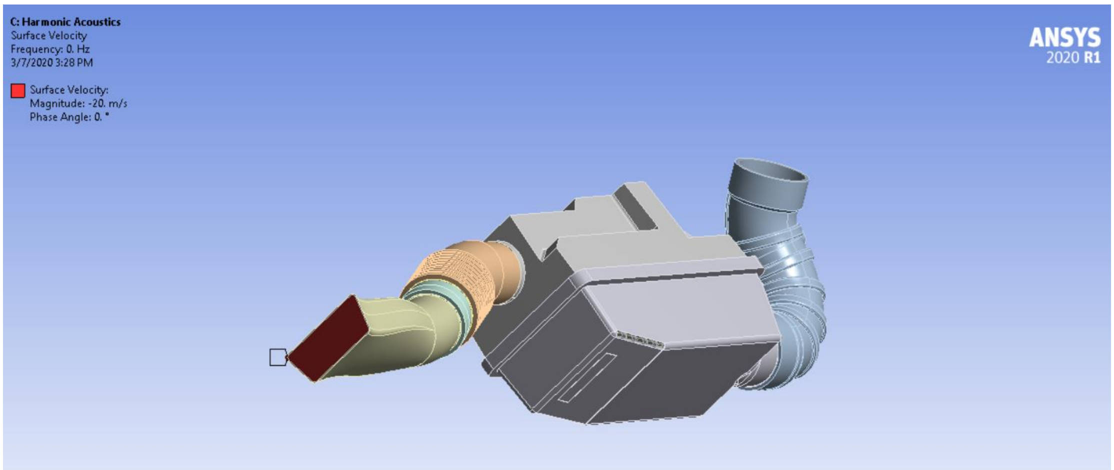
Details of Fill3	
Fill	Fill3
Extraction Type	By Caps
Target Bodies	Selected Bodies
Bodies	9
Preserve Capping Bodies	No
Preserve Solids	Yes

Figure 13:Creation of Internal Cavity of Air Intake System in ANSYS

Multiple assumptions were made for the initial simulation to get an understanding on how different properties affected the results of the simulation. The parameters set and the assumptions made in this initial simulation are as follows:

- Material of internal cavity: Air
- Temperature of internal cavity: 60°C
- Acoustic Source: 20 ms^{-1} surface velocity at snorkel

The material set for the meshed body was air as it represented the internal cavity of the air intake. The temperature of the body was set at 60°C to simulate the temperatures that may be present in an engine bay during operation. As for the acoustic source, a 20 ms^{-1} surface velocity was placed at the snorkel as shown in Figure 14. The frequency range of the simulation was set at a range of 0 Hz to 1000 Hz. This frequency range was set to replicate the frequencies analyzed in [8]. An interval of 1000 was set for the simulation to have a data point for each frequency.



C: Harmonic Acoustics
Surface Velocity
Frequency: 0. Hz
3/7/2020 3:28 PM

🟥 Surface Velocity:
Magnitude: -20. m/s
Phase Angle: 0. °

Figure 14: Acoustic Source at Surface of Snorkel

3.2 Obtaining Results

Several types of results were collected from this simulation to allow for a comparison with experimental data from Proton. These results were:

- Transmission Loss
- Frequency Response

3.2.1 Transmissions Loss

Transmission loss is measured by the difference of sound levels between two points [13]. The graph shows the ability of the medium in absorbing sound at a specific frequency. When looking the data from the simulation, a peak indicates a strong absorption of the sound where a dip in graph indicates inefficiency in reducing noise at specific frequencies.

To obtain the results of transmission loss, ports need to be defined in the analysis module. A port surface is selected at the surface of the snorkel while another port surface is selected at the surface of the intake tube. Both ports will share the same surface body. The setup can be seen in Figure 15. When setting up the results for transmission loss, the inlet is defined at the snorkel while the outlet is defined at the intake tube as seen in Figure 16.

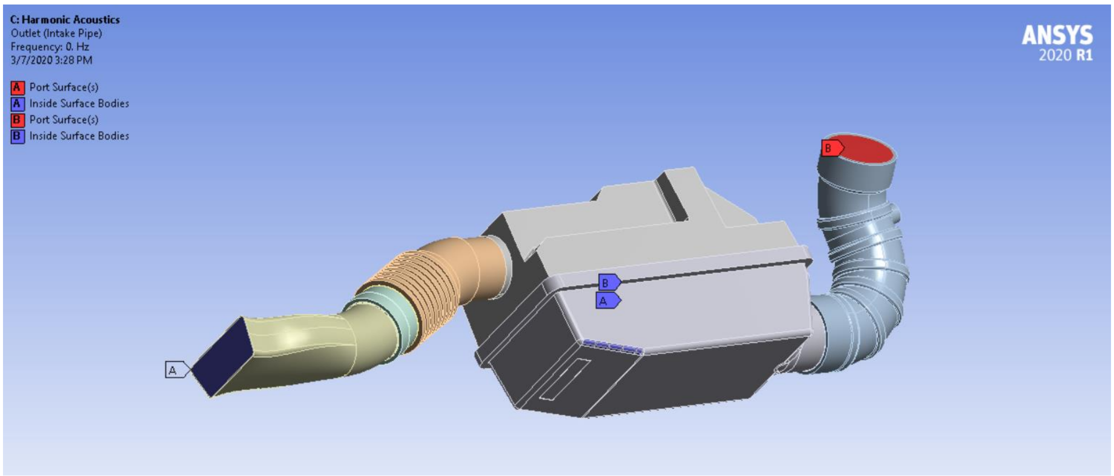
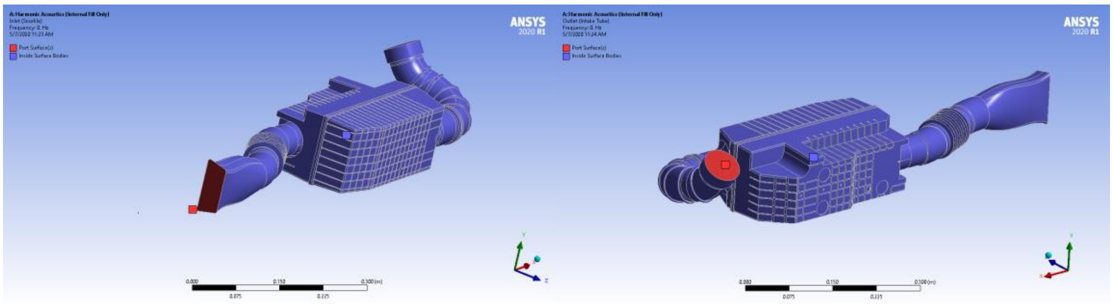


Figure 15: Placement of Ports on Air Intake System



(a) (b)

Figure 16: Configuration of (a) Input and (b) Output Port for Transmission Loss

3.2.2 Frequency Response

The frequency response of the AIS can be captured at desired surfaces. For the initial results of the simulation, frequency response of the AIS is captured at the surface of the intake tube and the surface of the snorkel as seen in Figure 17 and Figure 18. Measuring the frequency response of the AIS will allow for the visualization and understanding of the noises coming from the air intake.

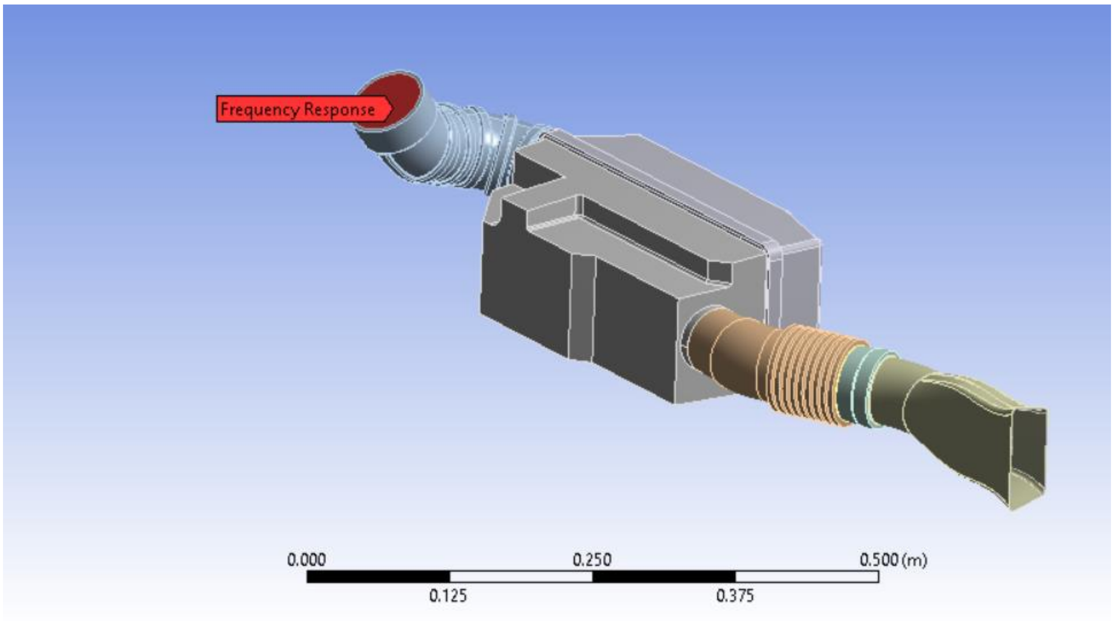


Figure 17: Frequency Response Measured at Surface of Intake Tube

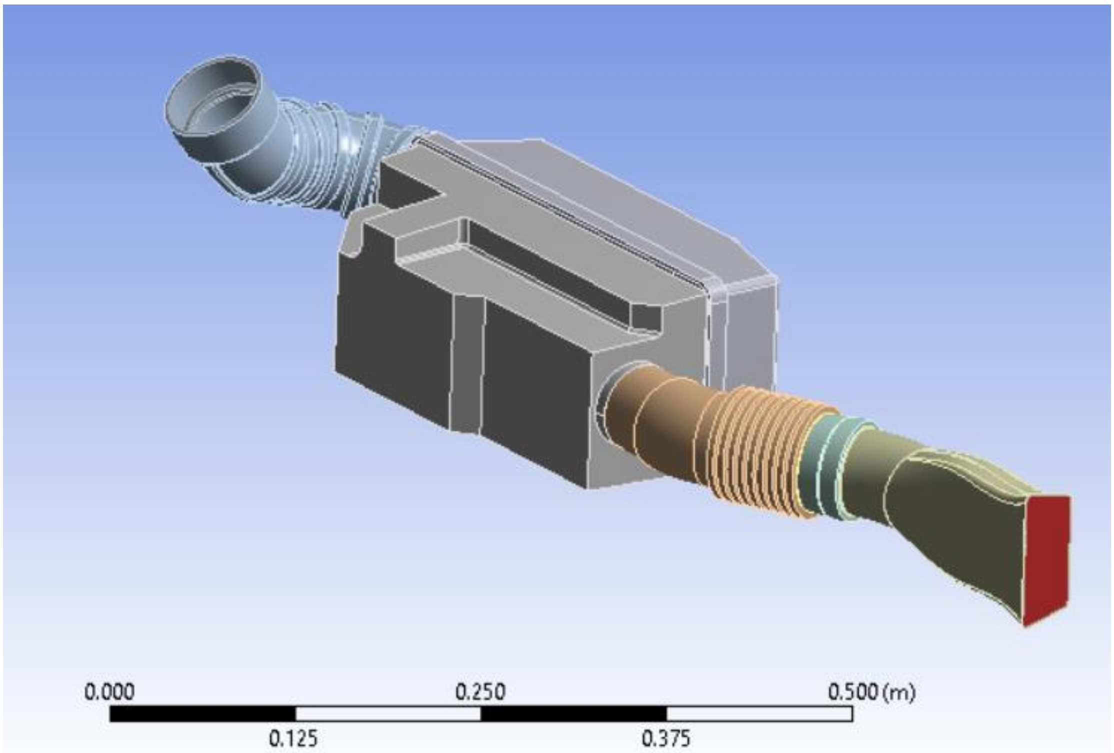


Figure 18: Frequency Response Measured at Surface of Snorkel

4 Initial Results and Discussion

The results gathered in this simulation is to ensure the simulation is set up correctly and to understand the parameters that are needed to ensure data collected is accurate. From the initial simulation, transmission loss of the air intake and sound pressure levels can be taken.

4.1 Transmission Loss

The results obtained from the initial simulation can be seen in Figure 19. The results show that there are 5 points in this AIS that have a weak transmission loss. These points are 197 Hz, 304 Hz, 548 Hz, 645 Hz and 854 Hz. The frequencies with weak transmission loss indicate the presence of higher noise at these frequencies. Resonators can be designed and placed along the air intake system in order to improve the transmission loss at the required frequencies.

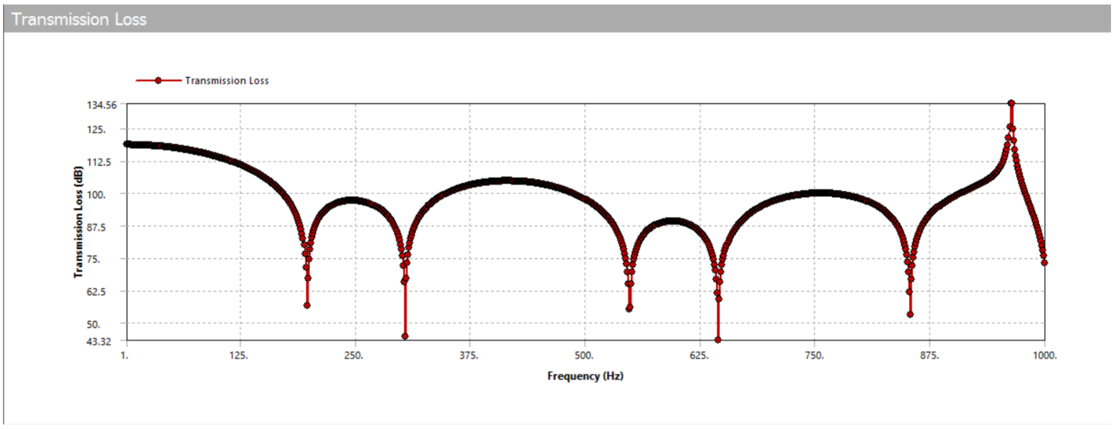


Figure 19: Graph showing the Transmission Loss of Initial Experiment

4.2 Frequency Response

The frequency response of the AIS can be seen in Figure 20 and Figure 21. In Figure 20, the frequency response was recorded at the intake tube. The frequency response result taken from the intake tube show a similar pattern with the result of the transmission loss of the AIS. Where transmission loss shows the effectiveness of the AIS in reducing noise across the AIS, and the frequency response shows the peak noise generated by the AIS.

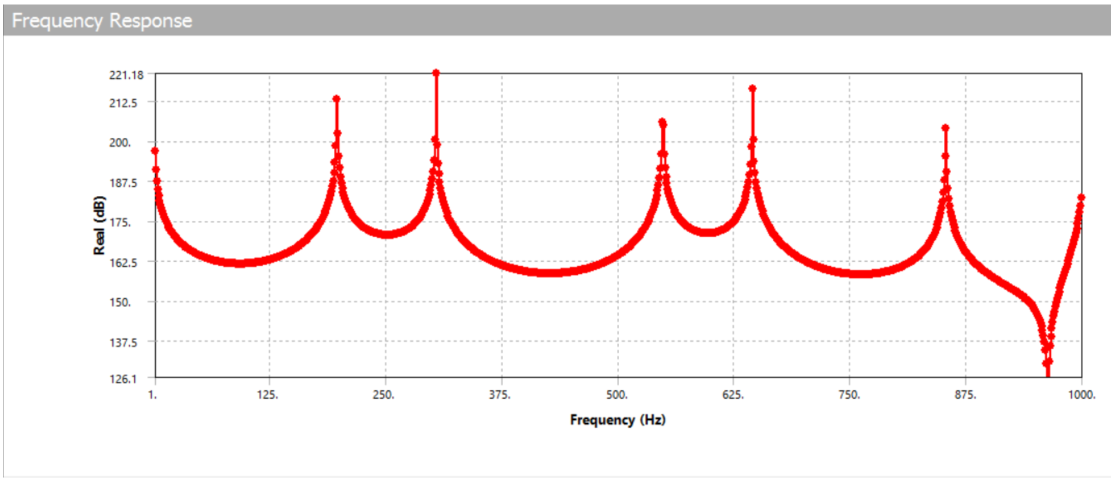


Figure 20: Graph showing the Frequency Response measured at Intake Tube

The frequency response of the AIS was also taken at the snorkel as shown in Figure 21. The result recorded here does not follow the pattern similar to transmission loss of the AIS. The difference may be due to transmission loss is measured across the input port and the output port.

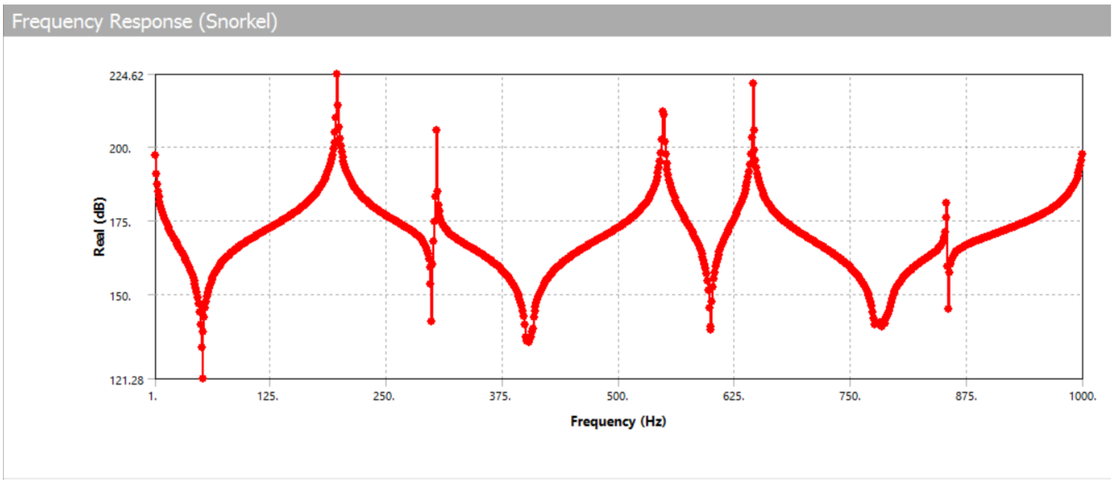


Figure 21: Graph showing the Frequency Response measured at Snorkel

To understand this further, a visual contour was created to understand the different patterns present as shown in Figure 22. The contour allows for a visual understanding of the noise levels along the AIS. The contour taken in Figure 22 is at 963 Hz. When measuring the frequency response at the intake tube, there is a lower noise present at this frequency. But when the frequency response was measured at the snorkel, the noise level is significantly higher when compared to the intake tube. This finding is important to understand as to reduce the perceived loudness of the AIS. Similarly to a muffler in an exhaust system, the noises need to be muffled before exiting the system, which shows a greater emphasis on the frequency response measured at the outlet.

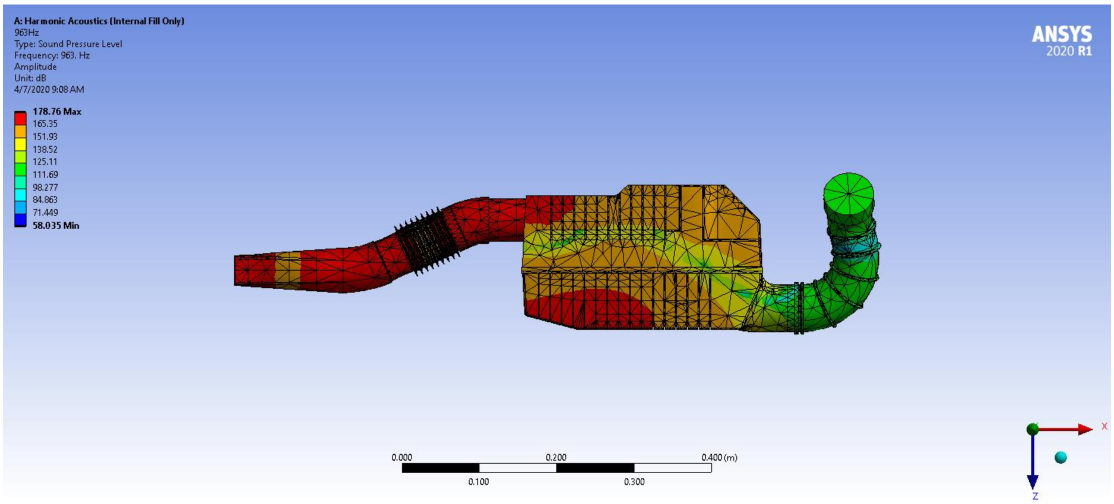
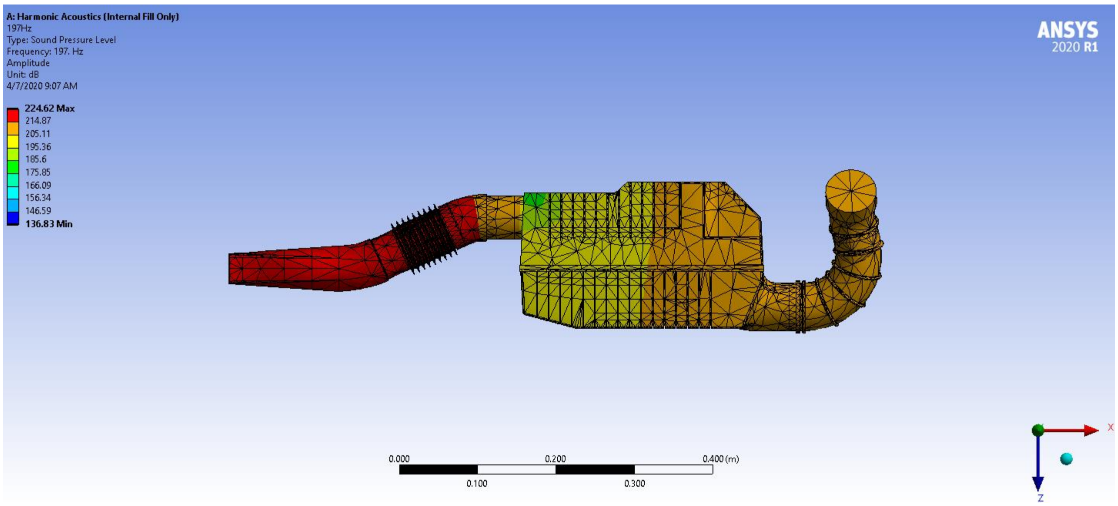
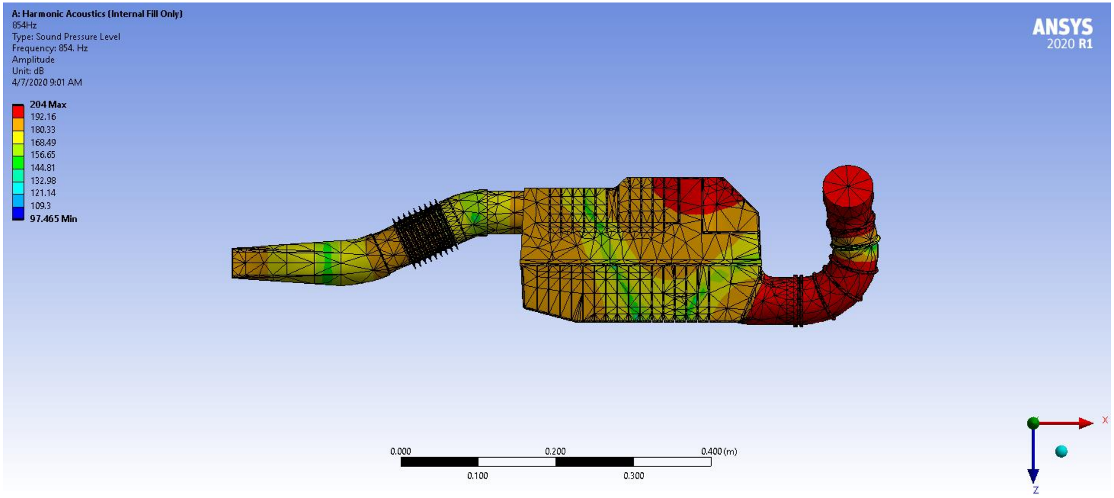


Figure 22: Contour of Frequency Response at 963 Hz

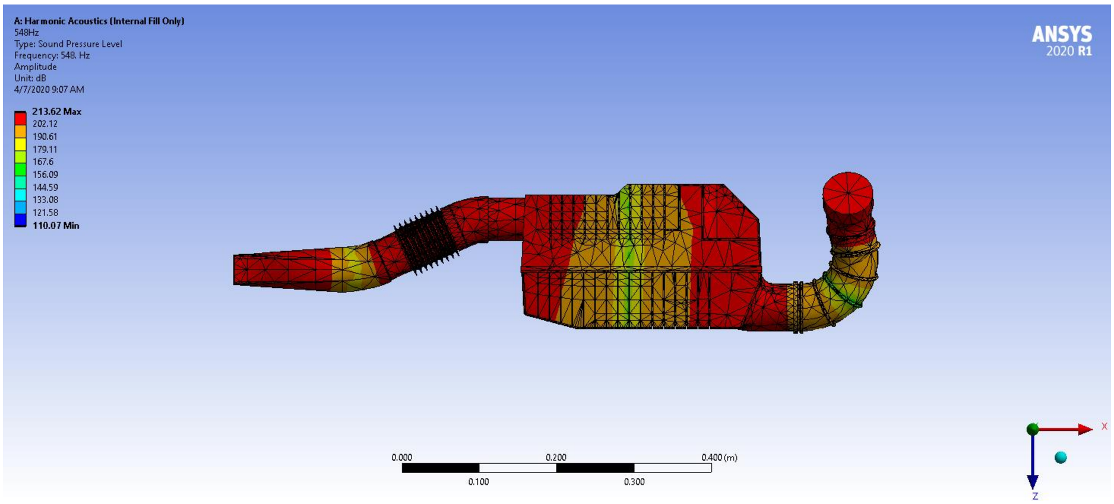
Contours were also generated at frequencies 197 Hz, 304 Hz, 548 Hz, 645 Hz and 963Hz to understand the peaks at these points as shown in Figure 22.



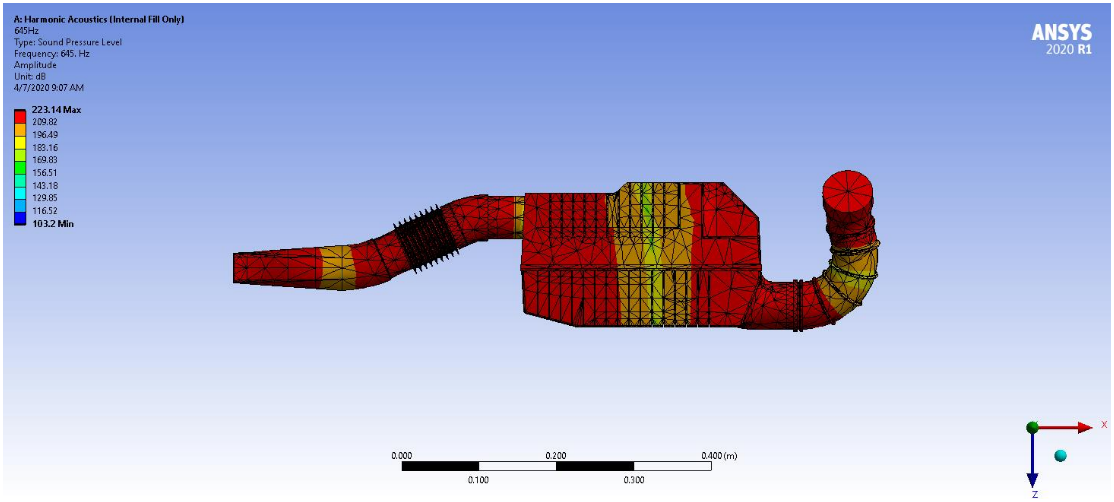
(a)



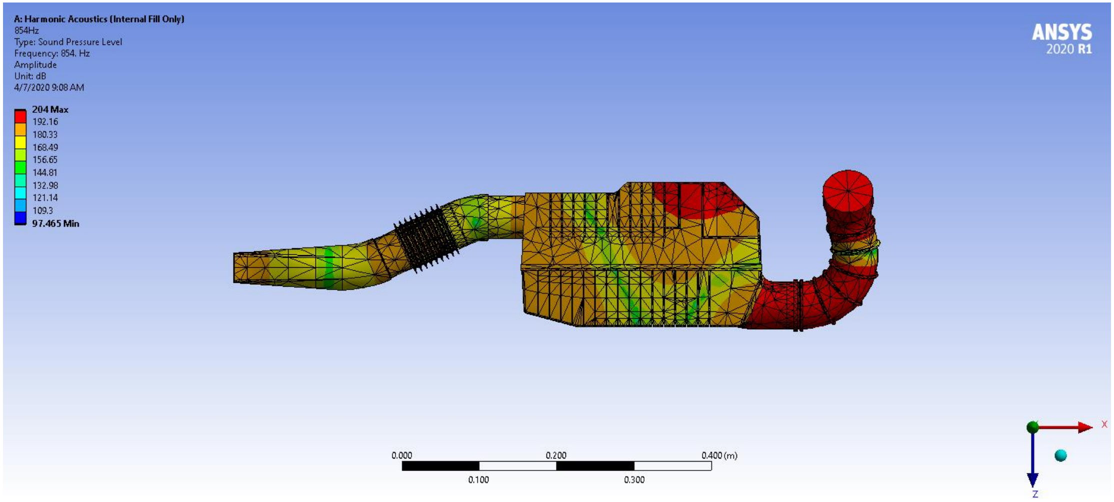
(b)



(c)



(d)



(e)

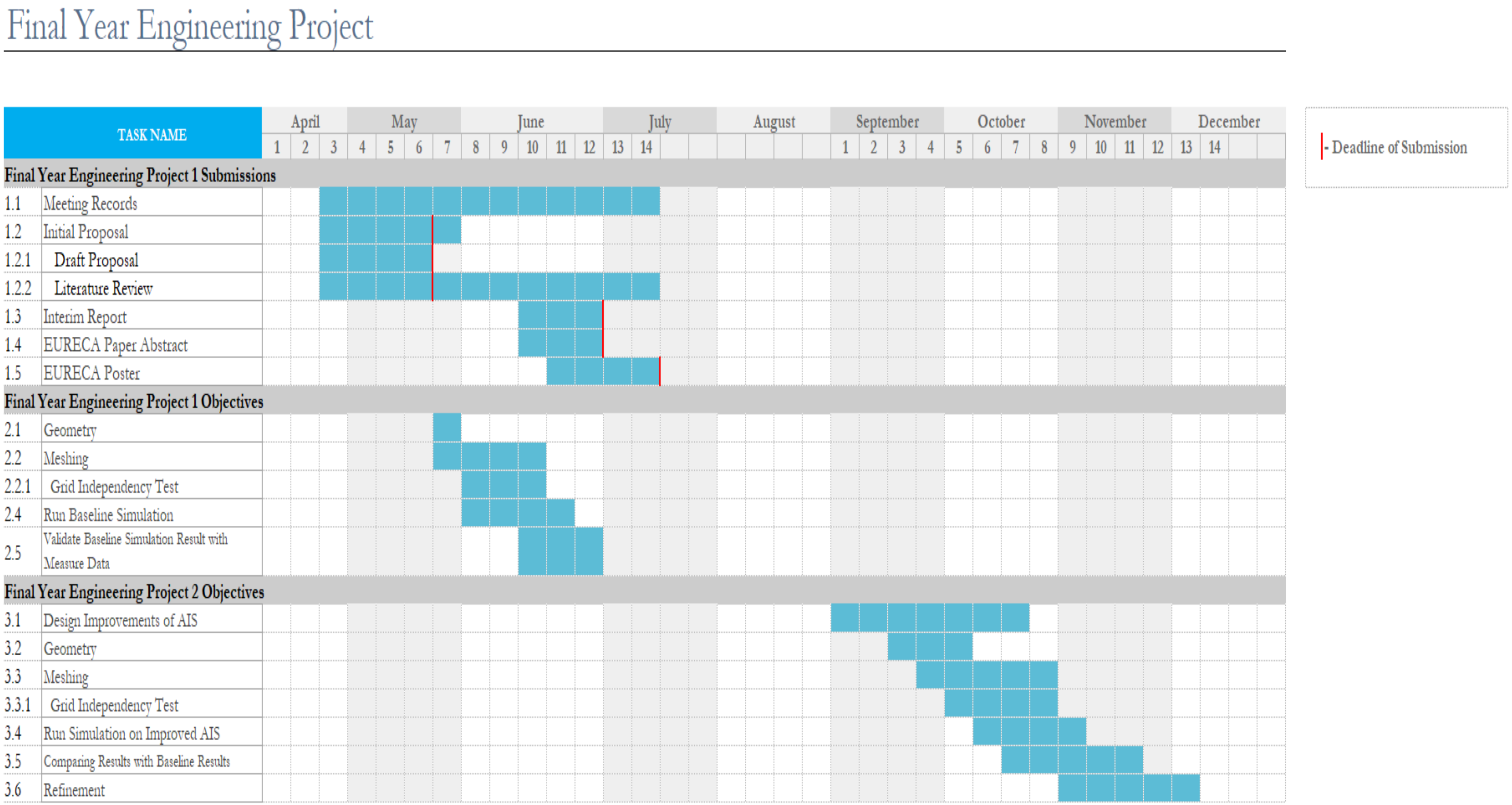
Figure 23: Contours of frequency response at (a)197 Hz, (b)304 Hz, (c)548 Hz, (d)645 Hz and (e)963 Hz

4.3 Future Work

To improve the accuracy of the simulation model, parameters of the simulation that was done at Proton was taken. These parameters will be used in future simulations to replicate the methodology used by Proton. The data obtained from this future simulation will also be compared with the experimental data from Proton to understand the accuracy in this simulation and understand the changes that need to be made to improve on the accuracy of the simulation. Changes to be made to the simulation are to have the acoustic source at the intake tube and the measurements taken at the snorkel. This is because the snorkel is the opening of the AIS to the environment, muffling the noise exiting the snorkel will improve the acoustic performance of the AIS.

A grid independent test will be performed to produce a result independent to the mesh. Although the pattern of the frequency response of the AIS will be similar with finer mesh, a finer mesh will show a more accurate amplitude of the noise generated.

A modification of the AIS is needed to improve the acoustic performance of the AIS. Resonators will need to be designed for the frequencies with the highest noises and be placed along the AIS. The location of the resonators will need to be determined through calculations and simulation to verify the effectiveness of the resonator in improving the acoustic performance of the AIS. When improvements are made to the AIS, the model will be simulated and compared to the results of the experiments conducted by Proton to verify the improvements made to the AIS.



Final Year Engineering Project

❘ - Deadline of Submission

TASK NAME		April			May				June					July				August				September				October				November				December			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14							1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Final Year Engineering Project 1 Submissions																																					
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3.1	Design Improvements of AIS																					🟦	🟦	🟦	🟦	🟦	🟦	🟦									
3.2	Geometry																							🟦	🟦	🟦											
3.3	Meshing																								🟦	🟦	🟦	🟦	🟦								
3.3.1	Grid Independency Test																									🟦	🟦	🟦	🟦								
3.4	Run Simulation on Improved AIS																										🟦	🟦	🟦	🟦							
3.5	Comparing Results with Baseline Results																											🟦	🟦	🟦	🟦	🟦					
3.6	Refinement																													🟦	🟦	🟦	🟦	🟦			

Figure 24: Gantt Chart of FYP

5 Conclusion and Expected Outcome

In conclusion, the harmonics acoustic study was able to allow for the familiarization of the analysis system. Initial results gathered was able visualize the correlation of transmission loss and frequency response of the AIS.

One of the expected outcomes of this project is to be able to produce a simulation module that is within 20% error margin of the experiment conducted by Proton. To achieve this, the simulation will need to be set up similarly to the parameters set by Proton. Changes to the position of the acoustic source will need to be changed.

The second expected outcome for this project is to be able to locate the positions along the air intake that resonates a higher noise. The current system that is used to measure the effectiveness of the resonators is by trial and error. This takes up a lot of time and requires a high cost. The ability to accurately determine the location of the placements of resonators will significantly reduce the cost and time needed to validate the effectiveness of resonators.

The third expected outcome for this project is to improve on the AIS design by adding resonators at set positions to improve on the acoustic performance of the AIS. With results collected from the simulations and the position of the resonators determined, a resonator designed to the specifications required will improve the acoustic performance of the AIS.

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