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Research paper

Effects of Quarter-Wavelength Resonators on Air Intake Module of an ICE Engine Using 1-Dimensional Method

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Abstract

Air intake module has a main purpose in an engine environment that is to provide sufficient and clean air to the engine. The module is a very critical function which affects the engine performance from pressure restrictions and acoustic performance. A good AIM reduces the engine noise to prevent it from contributing noise to the passenger cabin. To design a good AIM, several tests must be done to optimize the design for good performance notwithstanding the noise propagation. This paper focused on the One-Dimensional (1-D) approach to study the effects of quarter-wavelength resonators on the AIM of an ICE engine. AIM is rather a complex module as the air flows from snorkel to the engine, but at the same time the noise from the engine operations propagates on the different direction. AIM operates at rather wide frequency range where suitable design of ducts, resonators and volume of air box is important so that the system meets the targeted sound pressure level (SPL). Resonator is commonly added to ducting system to attenuate noise at desired frequency. Multiple resonators may be added to attenuate engine noise at wider broad band frequencies. In this paper, the effects of removing quarter-wavelength resonator on the original AIM designs of an ICE engine. The 1-D model is built in commercial simulation tool named GT-Power to measure the transfer function.

Keywords: *Quarter-wavelength; Noise measurement; Air Intake Module; Acoustic performance; Transfer function*

1. Introduction

Global automotive industries have major concern in reducing vehicle noise using many methods [1], and as the standard of noise emission control for vehicle increases, there is greater demand from manufacturers and consumers for lower engine noise emission. The air induction system plays the main role in controlling the engine sound emission. The air intake module could sometimes produce up to 5 dB higher sound emissions compared to the engine noise [2]. Thus, it may have a significance results in finding noise induction control to the noise produced [3].

AIM is the lung of the engine system intends to provide clean air for engine combustion process. The air enters through snorkel and went straight to air filter box before entering the engine intake manifold. Air filter box provides a filter from dust entering the combustion chamber to prevent performance drop and components lifetime. The clean air then enters the air duct straight to the intake manifold.

The clean air then enters the intake manifold when the intake valve opens to enter the combustion chamber. As the intake valve is closed, the accumulation or clean air at the intake manifold causes the high pressure to build up and travel backwards to the snorkel causing noises. A good AIM design reduces snorkel noise by attenuating the noise travelling backwards. Tuning of acoustic advantage needs many amendments of the AIM design. To simplify the design process, 1-D simulation tool could reduce significant amount of time and cost of the development [4]. Many past work have made their study on experimental base which require longer time and higher cost [5-8]. For this research, commercial tool named GT-POWER is used for simulation and the results were correlated with the actual test data.

Intake system design is the first to consider as they are many factors contributing to the noise emissions such as valve structure, air intake system design and others, while restrained for having high performance engine and fuel efficiency [9, 10]. The method to study the AIM design must be made during design phase to reduce manufacturing cost. Hence, prediction of noise via simulation before manufacturing the module is a better option to make the optimum design at faster time and lower build cost [11-13]. A good AIM design should provide clean air and low pressure drop for an excellent engine performance and at the same time attenuates the engine noise.

Many techniques to reduce the noise levels during simulation stage and to optimize the design of the AIM have been developed. However, ideal design of AIM needs a great amount of expertise in the field [10]. This paper focuses on the effects of quarter-wavelength resonators on the AIM of an ICE engine using 1-D method. Engine process are mainly 3-D, but it requires large computational time and better knowledge on how it performs. Thus simplified 1-D simulation is used in this study. The objectives are to construct a baseline 1600cc engine model, correlate the constructed model with the actual engine performance test, and conduct a test on the effect of removing quarter-wavelength resonators to the AIM performance.

2. Engine model development

Engine model development has been developed from the air intake module, engine, and exhaust system to represent the engine working principle and condition. In order to model the air intake module (AIM), 3D CAD geometries of these components were used. The 3D geometries were discretized to convert into one-dimensional environment model as shown in Figure 1. The diameter of each inlet and outlet including the connecting pipes is mentioned in the model for good modelling. The air box is defined in the model by its volume of the upper and lower part. Pressure loss of the air filter is shown in the system by presenting the discharge coefficient.

Next step is to make a discretization process for the intake and exhaust manifold as shown in Figure 2 and 3. Bend pipe model is used to present the bending of the pipes to represent the pressure loss because of the bending. Other dimensions such as diameters of inlet and outlet, angle and bending radius were also defined so that the runner is presented in the 2D modelling. Y-split part is used in the system to represent the intake plenum.

The combustion model used is SI Wiebe function because it is easier to study the effect of intake system to the engine performance based on engine intake characteristics. The non-predictive characteristics of the model use burn rate proportional to crank angle. Here, the burn rate was calculated from measured in-cylinder combustion pressure at various engine speeds with full load conditions.

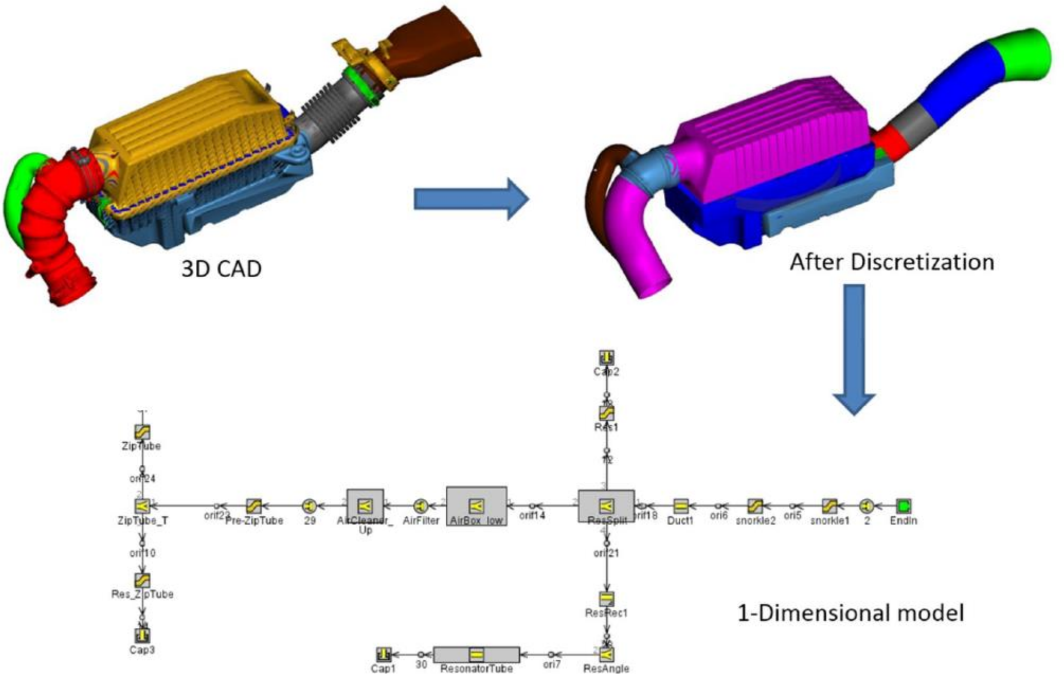


Fig 1: Discretization of air intake module

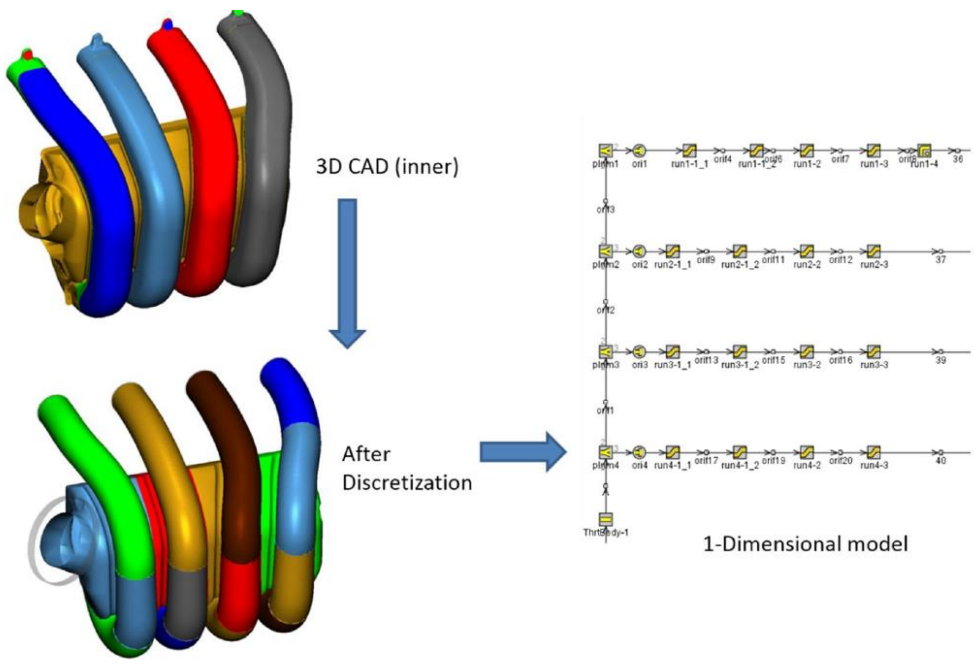


Fig 2: Discretization of intake manifold

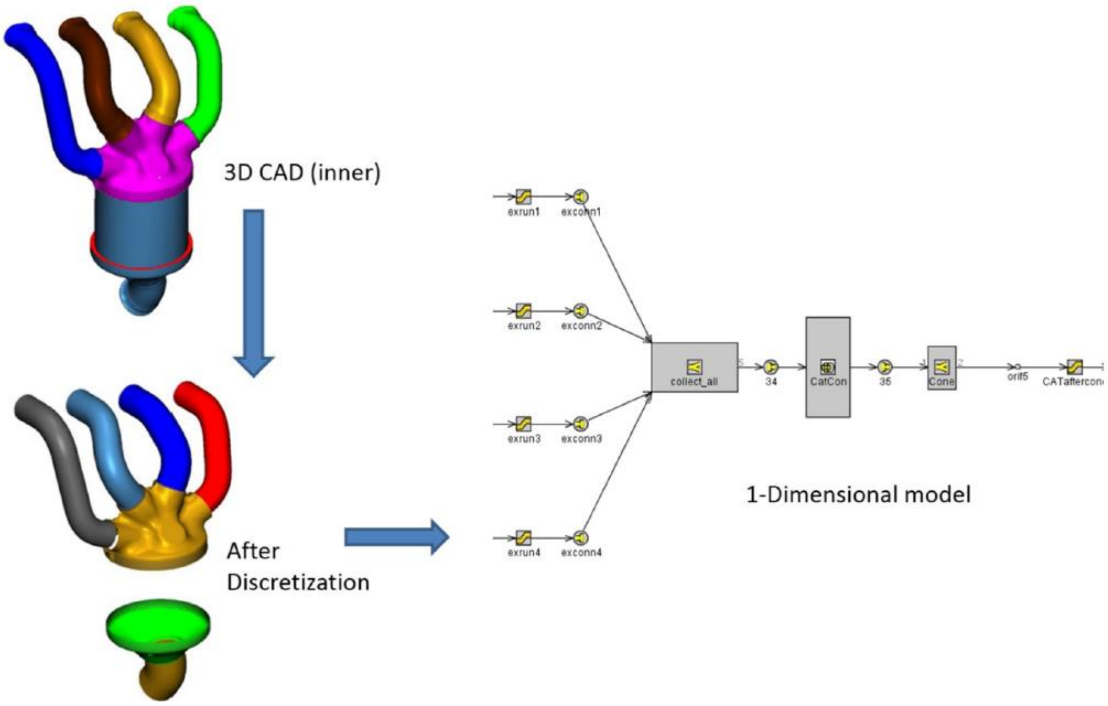


Fig. 3: Discretization of exhaust manifold

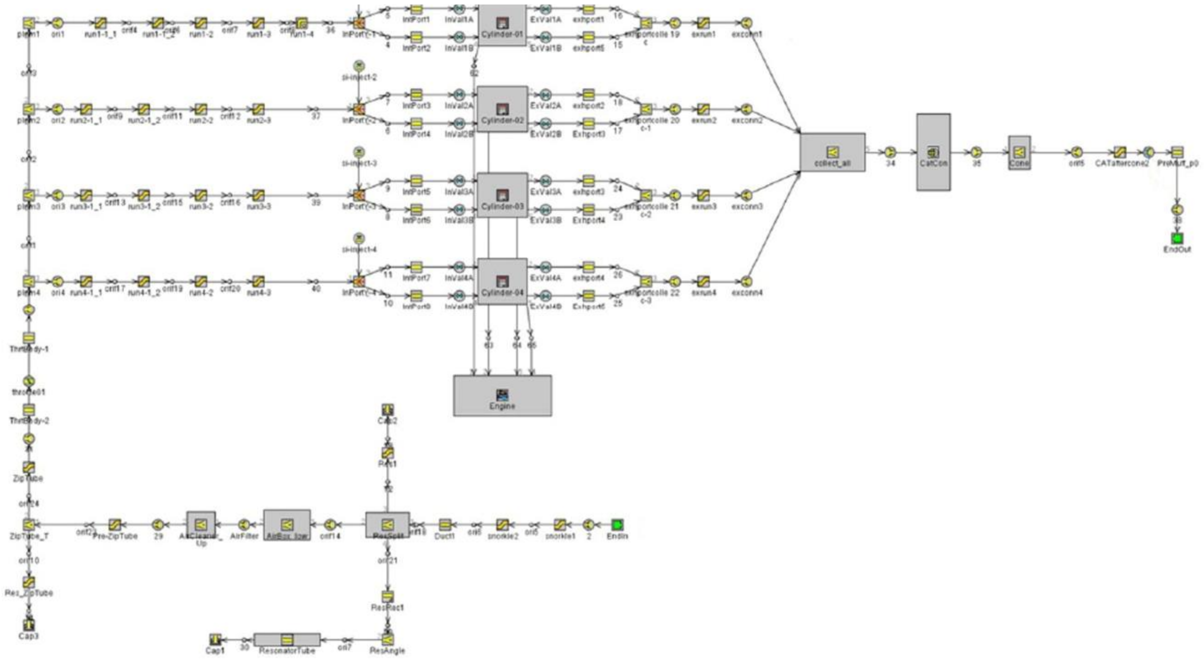


Fig. 4: Complete 1-D model of the engine

To complete the model, the engine valve on the intake and exhaust system is required to be model to define the characteristic such as its geometry, flow function, lift mechanism and profile. The model is made based on the original engine system. Figure 4 shows the complete constructed model of 1.6L NFE engine. The completed engine model is run at engine speed between 1000 to 6500 rpm at wide open throttle. After that, the result is then plotted and compared to the original engine performance to correlate the model.

3. Engine model correlation

The data obtained from previous sub-chapter has to be correlated before further investigation on the 2D-modelling can be done. The model has been well correlated to the original engine performance. In the engine modelling, the best practice is to make sure that the differences between measured and simulated data are less than 2% for the intake system and 5% for the exhaust system and for engine performance comparison.

Figure 5 shows the constructed engine model for 1.6L NFE was well correlated. All the comparisons were within recommended values. Thus, this correlated model can be used for further study on the acoustic of intake system.

4. Results and discussion

The 1D analysis was performed to understand the effect of intake resonators on the sound quality at snorkel. In this simulation, the effect of each resonator on the transfer function and sound pressure level were performed. Figure 6 shows the AIM which include

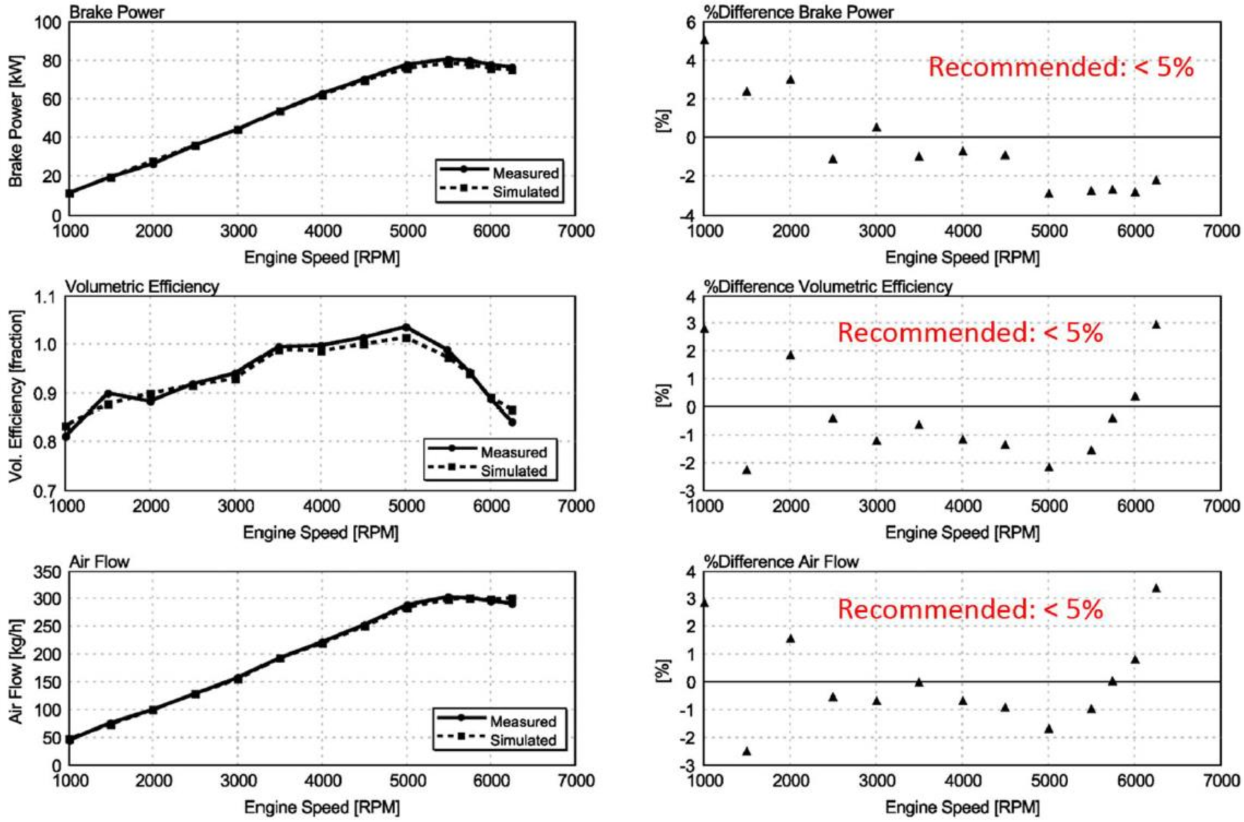


Fig. 5 Engine Performance Model Correlation

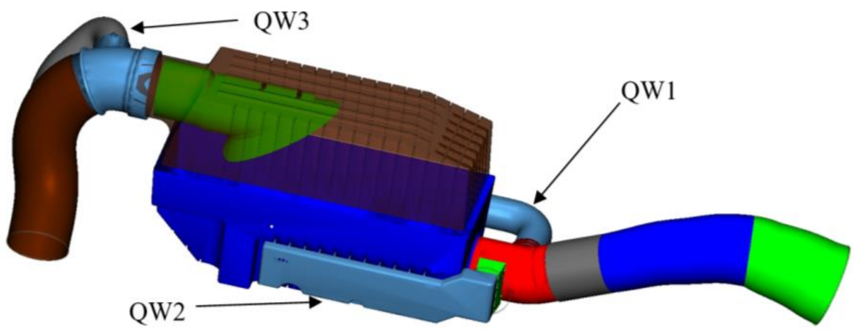


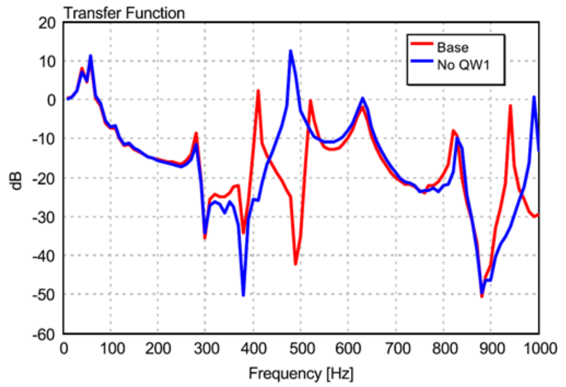
Fig. 6: Air intake module of a baseline 1600cc engine

three quarter-wavelength resonators. The model is modified by removing each resonator to study their effects on resonance frequencies. Figure 7 shows the performance of the AIM after the removal of each quarter-wavelength resonator.

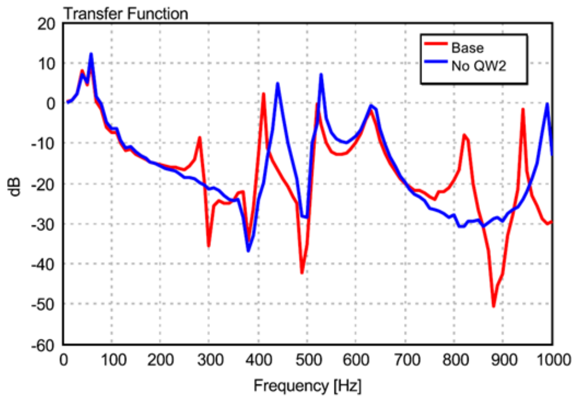
Figure 7 shows the effects on transfer function when removing quarter-wavelength at snorkel, lower and box and air duct after air box. When removing quarter-wavelength 1, the effect can strongly be seen during 500 Hz where it improves the performance of the AIM compared to baseline. Next, when quarter-wavelength 2 is removed, transfer function improves at around 300Hz, but gives negative impact at 280 Hz. When quarter-wavelength 3 removed, the transfer function improves at around 380 Hz.

5. Conclusion

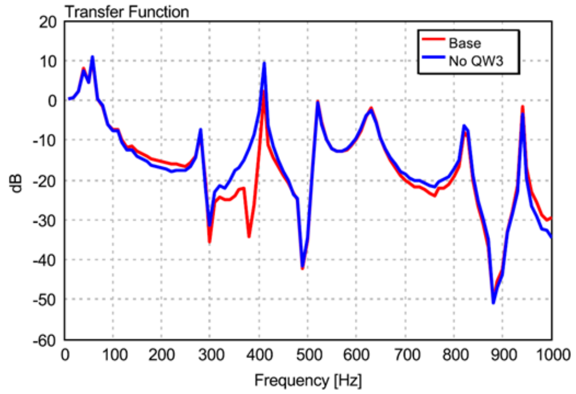
In conclusion, the 1-D method in designing the engine, exhaust and intake module has proved to have a very good correlation to the actual test data measurement with error still in acceptable range. The volumetric efficiency and brake power is well under error recommendation. In this paper, the effect of removing quarter-wavelength resonator from the original AIM design is study to predict such resonators' acoustic behaviour. It is found that the quarter-wavelength has a very narrow frequency range of controlling the acoustic performance. A further detailed study on the AIM design could be made for proposing better performance without compromising engine performance and fuel efficiency using the 1-D simulation model method.



(a)



(b)



(c)

Fig. 7: Effect on transfer function when removing quarter-wavelength at a) snorkel; b) lower air box; and c) air duct

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