# Aerodynamic Impact Analysis of "Noise Housing" Installation for Railway Wheels

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## Abstract

Train is a mass transportation that can reduce congestion on the big city, but it also has an impact of noise to residential around the railroad tracks. One of the main sources of noise is the collision of the wheels with the railroad tracks, and this can be reduced by noise housings design. The purpose of this paper is to analyse the impact of adding house noising based on aerodynamic perspective, so that a better house noising design is produced. The first step of the research made a 3D model of the existing trains and trains with the addition of noise housing. Computational Fluid Dynamics (CFD) simulation is used to analyse changes in drag force values, lift force, drag force coefficient, and aerodynamic noise. The addition of noise housing on the wheels of the train bogies has an positive impact on reducing the value of aerodynamic train noise. Aerodynamics noise around existing locomotive wheels (far field noise 0.5 m from locomotive, train speed = 80 Km/h) produced an average noise of 15.19 dB, it reduced to 12.35 dB for train innovation using noise housing. The final noise housing design also improved the drag force coefficient from 0.95 to 0.78. Overall, the addition of noise housing was also able to improve the aerodynamic performance of the train.

*Keywords: aerodynamics noise. Noise Housing. Train. Computational Fluid Dynamics, drag force coefficient*

## 1. Introduction

The train is a mode of public transportation that is very helpful in breaking down traffic jams caused by too many cars on the road. However, one of the impacts of the existence of a railroad that must be considered is the emergence of noise that is exposed to residents around railroad crossings. Noise housing initiated by Jones et al. [1] and continued in this research, it is used to reduce rolling noise on train wheels. Improvements to the noise housing design are carried out by analysing the aerodynamic impact on the train. Many studies have suggested the risk of noise to the exposed population. A noise with high intensity can damage human hearing, for instance by lowering the hearing range up to deafness. Besides, it can cause health problems, such as increased blood pressure and heartbeat that are potentially leading workers to suffer from a heart attack and digestive problems [2.3.4]. Roman Golebiewski [5] in his research entitled "Influence of turbulence on train noise" argued that the propagation of outdoor noise is caused by several aspects, including air absorption, wave-front divergence, ground effect, diffraction at obstacles, aerodynamics turbulence, and refraction.

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Aerodynamics analysis on trains is very important to know the performance of the train when it is moving. Optimal shape design of locomotives and railroad cars is very important to improve aerodynamics performance and save fuel consumption [6]. There has been a lot of research related to the aerodynamics of trains, such as research on literature reviews related to the railway train/tunnel system [7,8], the effect of ground clearance on the aerodynamics of a generic high-speed train [9], the aerodynamic characteristics of the train–SENB (semi-enclosed noise barrier) system: A high-speed model experiment and LES study [10], and optimal design of lightweight acoustic metamaterials for low-frequency noise and vibration control of high-speed train composite floor [11].

Housing noise as an effort to reduce noise due to the collision of train wheels on the track has not been implemented in the world of railroads, especially in Indonesia. In general, noise sources on trains are generated from 3 main sources [12] namely traction noise (predominant at train speeds < 30 Km/h), rolling noise (dominant at train speeds of 30 to 270 km/h), and aerodynamic noise (dominant at speeds > 170 km/h). So housing noise is very suitable for further analysis, where trains in Indonesia are still dominated by low and medium speed trains. One way is to ensure that the aerodynamic impact that will be generated has been carefully calculated. This design analysis will be a reference for the company in implementing it on the railroad.

## 2. Materials and Research Methodology

Aerodynamics is a scientific discipline that studies the interaction between objects or products and air, in which only one or both of them are moving (dynamic) in relative terms. Atmospheric effects are a major factor in aerodynamic analysis. Computational Fluid Dynamics (CFD) software is a powerful tool to help engineers better understand the physical flow processes around objects and in turn design better objects. The fluid works as a non-Newtonian in the CFD simulation, with a nonlinear relationship between the shear stress $\sigma ij$ and the shear rate. The correlation of pressure configuration and velocity distribution can be explained using Bernoulli's equation which works on streamlined/no turbulence, steady conditions, constant density and no friction between the fluid and the environment. The equation is named 'conversion of energy' where the sum of pressure, potential energy and kinetic energy per unit volume is constant at every point [13,14].

There are two basic parameters that describe fluid flows on objects: Reynolds number (Re) and viscosity ($\mu$). The Reynolds number describes the transition between two states or boundary layer current states. The behaviour of the fluid layers is strongly influenced by the pressure, which varies along the direction of the current. Viscosity is an important component for studying fluid flow behaviour. Studying fluid flows cannot leave environmental influences e.g. ambient temperature. Technically, the aerodynamic resistance of the train design has been divided into two categories, namely drag force coefficient (Cd) and lift force (Fl).

*1.) Drag coefficient (Cd)*

A drag coefficient is defined as a horizontal aerodynamic resistance force which depends on parameters of: fluid density ($\rho$). speed of fluid crash the train ($V$). and frontal area of train (A). The ideal train design aims to produce the lowest drag coefficient while generating high acceleration and great fuel economy. The drag coefficient equation is shown in equation 1 and it is non dimension parameter [14].

$$Cd = \frac{2Fd}{\rho V^2 A} \qquad 1$$

Where:

Cd = drag force coefficient
Fd = Drag force (N)
$V$ = speed of air relative to car (m/s)
ρ= density of air (Kg/$m^3$)
A = frontal area of vehicle ($m^2$)

*2). Lift force (Fl)*

The lift force parameter is used to investigate the aerodynamic influence on the weight of the train. It will change the fuel consumption and the train stability. Equation 2 defines the lift force equation as an aerodynamics restriction affecting the function of density. speed. frontal area and lift force coefficient [14]. As long as the total lift force coefficient is a negative value. it is experiencing down force in the train model.

$$FL = \frac{1}{2}\rho V^2 A\, C_L \qquad 2$$

Where;

$C_L$ = Lift Force coefficient

The lift force is generated when the average pressure at the top of a train is lower than underneath the train which is described by pressure coefficient (Cp) configuration. Lift force will reduce the tyre load on the track and substantially lessen the grip. Low tyre load will have a positive effect on fuel economist target. but conversely. it will also produce unfavourable effects on handling characteristics.

The CFD software simulated drag coefficient and lift force. The CFD solver works in complex current from incompressible (low subsonic) to middle compressible (transonic) to highly compressible (supersonic and hypersonic) currents. It uses the finite-volume method to solve the governing equations for a fluid current. It provides a capable method to work in different models such as incompressible or compressible medium. inviscid or viscous fluid. laminar or turbulent current. etc. There are some standard steps to solve the CFD problems:

*Step 1: Preparation step*

Designing the model or geometric object is an activity that should be completed in predefine step. Dimension. complexity model and quality of CAD model will influence the total time of the simulation test and the precision of the CFD's results. The quality of CAD model is presented by how the model can describe the important parameters of the train performance in external aerodynamic investigation.

*Step 2: Predefine step*

In predefine step. the user puts all the information that is needed into CFD simulation test. The information contains: the kind of fluid current (external or internal fluid current). environment condition (pressure. temperature. air density. etc.). mesh quality of fluid domain (coarse. medium or fine). real wall model. simulation's goals (lift force. pressure configuration. vortices. velocity configuration. mach number. drag coefficient. etc.) and etc.

*Step 3: Solver step*

The CFD software works in convergence target which fluid dynamic content of non-linearity processes. dealing with inherently un-controllable phenomena of turbulence current. Due to its non-linearity. analytical techniques can not be used to solve the fluid dynamic problem in the equation set. which necessitates the requirement for a numerical method. The solution technique of convergence uses an interactive solution to successively improve a solution. In the execution process. the user can monitor the simulation convergence process of drag coefficient and lift force.

*Step 4: Post processing step*

Post processing step will deliver the CFD results. Contour. graph and table will completely show the CFD test results. The user can show the particle's current around the car body model as a function of velocity configuration. pressure configuration. etc.

The investigating of aeroacoustics is mainly focused on noise sources generated by turbulence and moving aerodynamic surfaces. M.J. Lighthill [15] published the basic theory of aerodynamic noise which was based on an understanding of Navier-Stokes' equations. In Lighthill's equation the acoustic sources are treated as a distribution of equivalent point sources. whose strengths are obtained from Lighthill's stress tensor $T_{ij}$. where $T_{ij}$ is gained from the derivations of the properties of the unsteady or turbulent current field. The theory assumes a solid boundary and hence insignificant back reaction of the sound produced on the current field itself (i.e. the sound produced is so weak relative to the motions producing it that no significant current-acoustic interaction can be expected).

For design of train purposes. fundamentally. noise is defined as unwanted sound. The noise is caused by air vibration waves. the sound sources of which the human ear can detect. The sources of sound can come from the machine. aerodynamic effect and tyre friction. Noise health effects are the health consequences of elevated sound levels. The aerodynamics noise can cause hearing impairment. hypertension. ischemic heart disease. annoyance. sleep disturbance. and decreased school performance. Producing noise has also been known to stimulate tinnitus. hypertension. vasoconstriction and other cardiovascular impacts. Beyond these effects. elevated noise levels can create stress. increase workplace accident rates. and stimulate aggression and other anti-social behaviours [16].

The main unit of noise sound is decibel (dB) as a logarithmic function. Generally. the noise in aerodynamic problem is defined as Sound Pressure Level (SPL). SPL formulation is written in Equation 3 below [17]:

$$SPL(dB) = 20\log_{10}(P / P_{ref}) \qquad 3$$

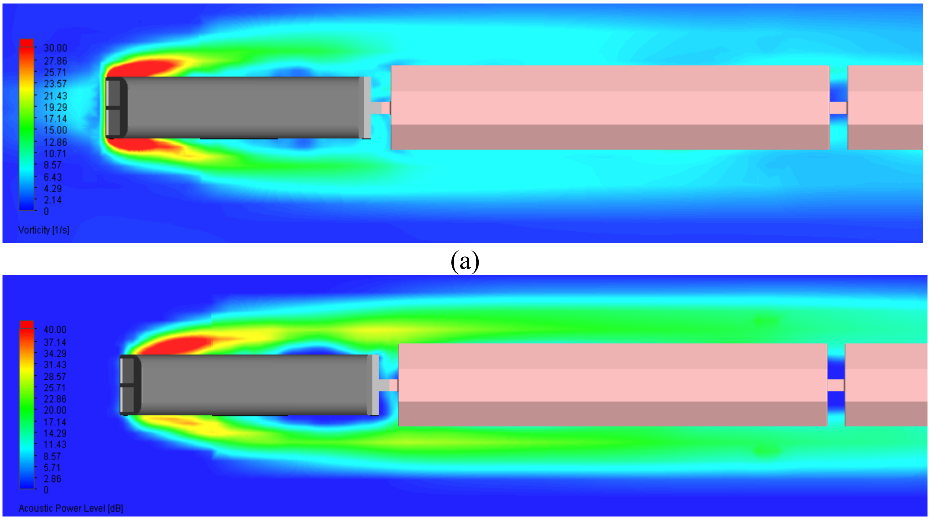
Where;

$P_{ref}$ = sound power reference (=2. $10^{-5}$ Pa)

Sound Pressure Level varies in frequency and over time. Frequency (Hz) is defined as oscillation per second. Normal young people can hear all sound frequency in the range of 20 to 20.000 HZ [18].

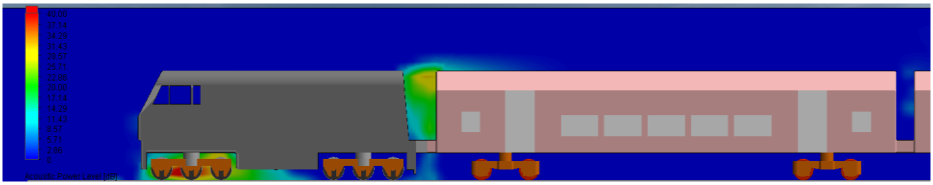
## 3. Results and Discussion

Testing the effect of wind hitting the train is very important to determine the aerodynamic performance of the train itself. Aerodynamic performance can be in the form of wind resistance known as drag force and drag force coefficient, as well as lift force for impact lift. In addition, it also causes changes in noise caused by changes in train design, especially the addition of noise housing on the wheels and train bogies. Computational Fluid Dynamics (CFD) simulation will compare the impact of aerodynamics on trains with and without noise housing. Figure 1 shows the results of the aerodynamics simulation regarding trains with a locomotive and two cars at a train speed of = 80 Km/h or = 22.22 m/s. The contour for the top view is taken at a height in the middle of the train wheels, while the side view contour is taken at the midpoint of the train. Based on Figure 1a, it is found that the vorticity profile is very dominant around the locomotive. Vorticity is a vortex of air which is proportional to the value of sound (noise). So that the biggest contribution of aerodynamic noise on trains is also generated from the locomotive design. Figures 1c and 1d are views of the aerodynamic noise profile respectively from the top view and the side view of the train. The figure shows that the noise caused by the air flow on the train is dominated around the train locomotive.



(a)

(b)



(c)

Figure 1. Aerodynamics simulation results on a train without noise housing at a speed of 80 km/s: (a) vorticity contours. (b) noise contour – top view, and (c) noise-side view contours.

The overall results of the aerodynamic performance of existing trains at a train speed of 40 Km/h. 60Km/h. 80 km/h. 100Km/h, and 120 Km/h can be seen in table 1. The CFD simulation setup assumes that the airspeed is 0 Km/h, where air resistance is based solely on the speed of the train. From the table, it can be explained that the drag force value of the existing train is an average of 0.954. In addition, from the simulation results it can also be seen that the drag force follows a polynomial addition pattern (R = 1) with the equation $y = 188.68x^2 + 394.63x + 194.57$ with a value of 3,076.34 N at a speed of 80 Km/h. While in general the existing design provides an exponential addition pattern (R = 1) with the equation $y = 17.901x^2 + 36.395x + 45841$ for the lift force value. The following equation is an example for calculating the drag force coefficient value manually on a train with a speed of 40 Km/h:

$$\begin{aligned} Cd &= 2 \times Fd / (A \times V^2 \times \rho) \\ &= 2 \times 776.48 / (11.03 \times 11.11^2 \times 1) \\ &= 0.95 \end{aligned}$$

where:

Cross area of train (A) = 11.03 $m^2$
Air density ($\rho$) = 1.16 ($Kg/m^3$)

Table 1. Aerodynamics simulation results of existing train design.

| No | Speed (Km/h) | Drag force (N) | Lift Force (N) | Drag Force Coefficient |
|---|---|---|---|---|
| 1 | 40 =11.11 m/s | 776.48 | 45896.08 | 0.96 |
| 2 | 60 = 16.67m/s | 1741.45 | 45984.72 | 0.96 |
| 3 | 80 = 22.22 m/s | 3076.34 | 46112.43 | 0.95 |
| 4 | 100 = 27.78 m/s | 4789.78 | 46273.44 | 0.95 |
| 5 | 120 = 33.33 m/s | 6886.11 | 46470.74 | 0.95 |

The graph in figure 2 illustrates the noise value along a railroad locomotive, where the measurement is made at a distance of 0.5 m from the train wheels and is in the middle of the train wheels. A locomotive with uncovered wheels will generate a noise of about 7 dB for the front wheels and 30 dB for the rear wheels. This shows that the wind impact on the locomotive wheels plays a very important role in increasing the noise value produced.

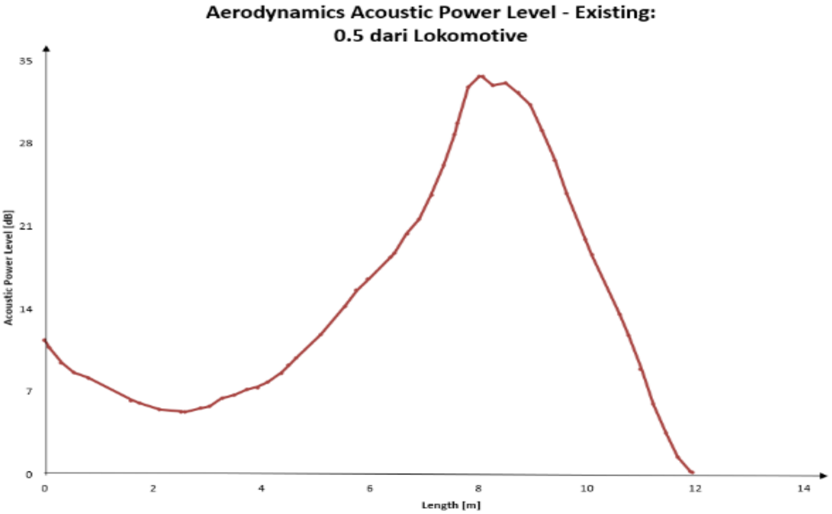
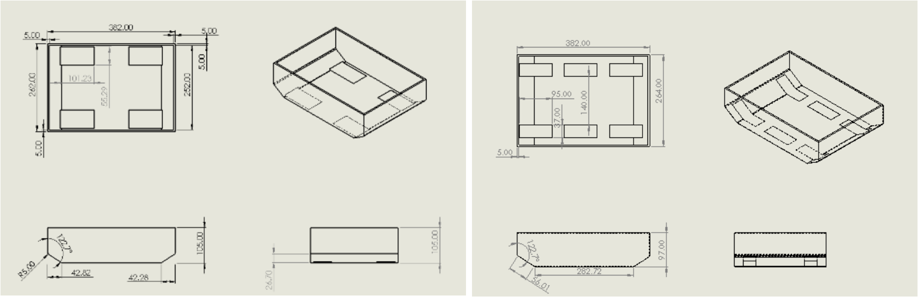


Figure 2. Noise value profile along the locomotive with a data collection distance of 0.5 m beside the locomotive and in the middle of the train wheels.

Based on previous research, that to reduce the impact of train noise due to the collision of the wheels with the railroad tracks is to add a noise housing. A project funded by the British Railways Board and Rail track in 1995 which was the initial concept of making noise housings for bogies can reduce noise by 5 dB on one bogie tested. This research has not yet informed the material used and the great opportunity to be able to optimize the shape of the designed noise house. Besides that, the mechanism for making a noise house also really needs to be done to facilitate operations, including repairs. The addition of a noise housing of course also has an impact on changes in noise due to the aerodynamics that are generated and also has an impact on drag force (resistance to movement in the direction the train is moving) and changes in lift force (the amount of force to reduce or increase the weight of the train in the direction of earth's gravity). An efficient method to describe the impact of noise housing design is to perform aeroacoustic and aerodynamics simulations.

The noise housing design consists of two main parts, namely the noise housing for the wheels of the locomotive parts and the design for the wheels of the railroad cars. In general, they have the same shape but differ in size according to the size of the bogie and the wheels. Figure 3 below is a 2D model image for the two noise housings. The material for the noise housing is generic fiber glass. The fiber material was chosen because basically this material is formed from a collection of fibers. Where the fiber type material has the ability to absorb sound with a wide frequency range. This collection of fibers is then spun to form sheets, which are then resinized so that the density level that is formed is also higher. In addition, fiber also has a very high resistance to vibration, cheap price and anti-corrosion, so it is suitable for use as a noise dampening material. The following is an illustration of the noise housing used for locomotive parts and train car parts. From each of these models, a framework of 304 stainless steel Hollow pipe mirror luster / hairland HL size 4 cm x 4 cm, 1.5 mm thick is given. The addition of this frame is expected to strengthen the structure and reduce the level of vibration caused by the movement of the train due to uneven terrain.



(a) (b)

Figure 3. 2D Noise Housing Model: a. Locomotive. b. Railway carriage

Figure 4 below is a 3D CAD model of a train after being installed with a noise housing to reduce noise due to the collision of the train wheels with the railroad tracks. Noise housing mounted on a train bogie is connected by a connector with another noise housing in one carriage with the aim of reducing the drag force coefficient.

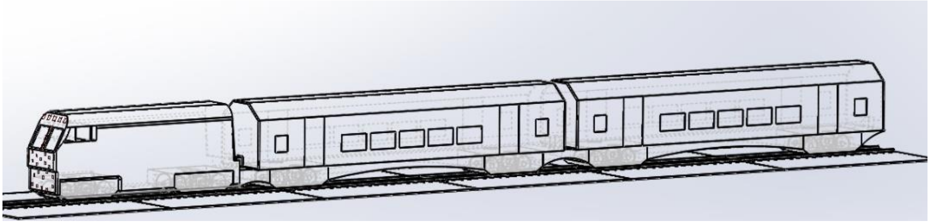
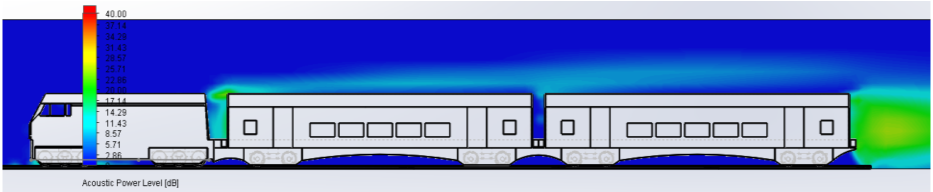
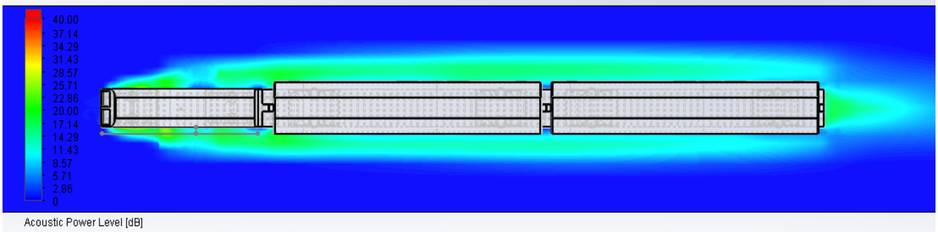


Figure 4. Final 3D model of noise housing on wheels – train bogie

The final noise housing design on the train bogies will produce a better drag force coefficient value of 0.78 than before without noise housing of 0.95 or a decrease of 17.9% which is a big figure for fuel economy. While the lift force decreased by 4,211.61 N (or decreased by around 421 Kg) from 7,320.09 N to 3,108.48 N, at a speed of 80 Km/hour with one locomotive and 2 railroad cars. The aeroacoustics performance shown in Figures 5a and 5b. The figure explains that the distribution of noise due to aerodynamics is lower and spreads throughout the train cars. It is clear that the noise housing is able to eliminate the noise on the bogies - the main train wheels at the front of the locomotive.



(a)



(b)

Figure 5. Aeroacoustics simulation results on interconnected housings at a speed of 80 km/s: (a) side view noise contours. (b) noise top view contour.

The graph in figure 6 illustrates the noise value along a railroad locomotive, where the measurement is made at a distance of 0.5 m from the train wheels and is in the middle of the train wheels. A closed-wheel locomotive will generate about 10 dB of noise for the front wheels and 7 dB for the rear wheels. In sort, the noise housing design of train model can reduce the aerodynamics noise impact, as example for exiting train on speed 80 Km/h will produced noise around locomotive wheels at averages 15.19 dB compared to locomotive train with using noise housing produced noise at averages 12.35 dB.

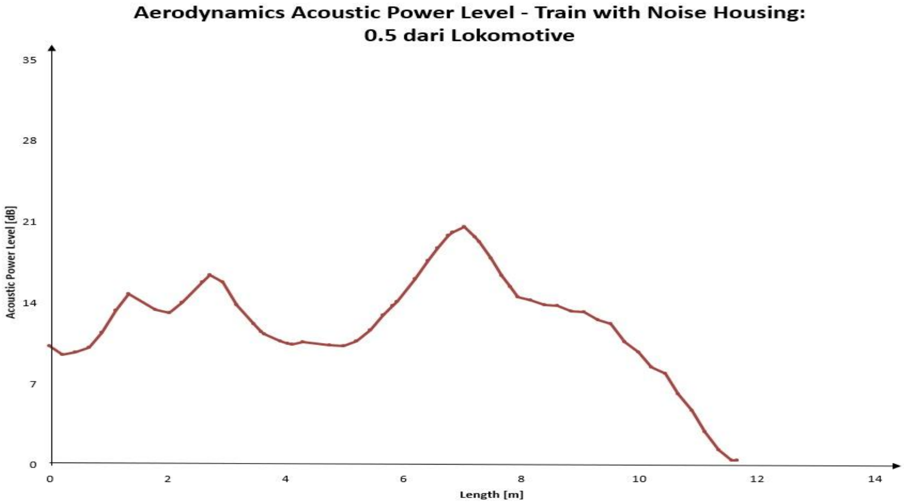


Figure 6. Graph of Noise Values Along a Train Locomotive with Noise Housing with a Data Retrieval Distance of 0.5 m.

## 4. Conclusions

The comfort of train passengers and residents around railroad crossings is greatly influenced by the noise factor due to passing trains. Making a noise housing that is used to reduce noise due to the collision of the wheels of the train with the railroad tracks needs to be tested for its aerodynamic and aeroacoustics impacts. Based on the simulation results, it was found that the addition of noise housings with proper shapes and connectors between noise housings was able to improve (decrease) the drag force coefficient value of 17.9%. Besides that, based on the value of the lift force performance, it is able to reduce the weight of the train significantly. At a speed of 80 Km/h, the proposed new design with the addition of a noise housing is capable of producing a reduction in lift force of 421Kg for 1 locomotive and two train cars. Meanwhile, aeroacoustics performance, with the addition of a noise housing, is able to reduce the average noise value by 23%. Future research is very important to determine the impact of adding weight due to noise housing materials and the impact of aerodynamic lift due to noise housing related to the balance of the train in moving on the railroad track.

## 5. Acknowledgement

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