



Redesign of Railway Carriages to Reduce Noise due to the Collision of Wheels with Rails using “Noise Housing”

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Abstract: Trains are one of the main forms of mass transportation that have proven to be a mainstay of public transportation in developed (England, Germany, the USA, Japan, etc.) and developing countries. Based on the results of an initial survey of 30 respondents who live near railway crossings in Indonesia, 70% reported disturbances, including hearing impairment, compared to residents farther from the crossings. This paper aims to redesign train carriages by using a bogie cover (Noise Housing) to reduce noise impact on passengers and residents around train crossings. An initial survey of traffic noise among the public/passengers and literature studies related to ride design and operations have been conducted. A Computational Aeroacoustics (CAA) far-field noise simulation was carried out to compare the noise generated by the collision of train wheels with the train tracks for existing designs and designs with the addition of Noise Housing at varying measurement distances of 3 m, 5 m, 8 m, and 15 m. The initial Noise Housing design using fiber material can reduce noise on average by 19.02 dB. Based on aerodynamic performance

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testing using Computational Fluid Dynamics (CFD) simulations, it appears that Noise Housing can also significantly reduce aerodynamic drag. It can be concluded that adding Noise Housing can reduce the impact of noise due to train wheel collisions and improve the train's aerodynamic performance.

Keywords: Noise Housing, rolling noise, human comfort, train, Computational Aeroacoustics (CAA)

1. Introduction

Trains are a mode of mass transportation that is the main choice for most of the people. The concept of future transportation development continues to be based on mass transportation, such as rail. The development of railroads will affect the surrounding environment, particularly through noise (PEKER & YILDIZ, 2022). The impact of noise from railroad crossings on settlements is exacerbated by the presence of settlements that violate the permitted distance. In Indonesia, under the provisions of Law No. 23 of 2007, Article 178 prohibits building houses, constructing walls, fences, or other structures, planting tall trees, or placing goods on railway lines that could interfere with free views and endanger train safety. Apart from that, there are many points along the railway tracks that lack noise barriers, so the impact on the surrounding community is greater. Improper noise barrier design can also increase noise in the train track channel, which in turn will increase noise inside the train carriage (Sugiono et al., 2020).

Research has been conducted to assess the impact of noise on residents near railroad crossings and to identify ways to mitigate it. In general, the source of noise on trains is generated from three main sources (Hamid et al., 2021): traction noise (dominant at train speeds < 30 km/h), rolling noise (dominant at train speeds 30 to 270 km/h), and aerodynamic noise (dominant at speeds > 170 km/h). Train noise significantly impacts residents living near train tracks (Tsukernikov et al., 2021; Khomenko et al., 2022; Smith et al., 2019). Noise from train tracks has a significant impact on both healthy and ill people; in addition, noise pollution is reported as the main cause of sleep deprivation among residents living near railway crossings (Thacher et al., 2022; Khan et al., 2018). Furthermore, it can increase blood pressure, affect the cardiovascular system, and interfere with daily activities (Roswall et al., 2018; Veber et al., 2022). Treatments

for reducing noise from rolling wheels have been carried out, such as the use of rail dampers (Dumitriu & Cruceanu, 2017), wheel shape optimization (Garcia-Andrés et al., 2020; Cui et al., 2019; Liu et al., 2020), the application of bogie casings (Jones et al., 1996), strengthening cargo with composite brake blocks (Obidiegwu et al., 2020), and developing damping solutions such as damper rings friction (Wang et al., 2019), spring-loaded wheels (Bouvet et al., 2000; Zaitsev, 2019), and sandwich-type dampers (Sun et al., 2020).

Noise Housing design to reduce noise due to wheel collisions with railroad tracks is related to understanding noise theory, train design, Computational Fluid Dynamics (CFD), Computational Aeroacoustics (CAA), and materials. The first thing to understand is noise: its causes and the impact on humans if they are exposed to excessive noise. Noise is a disturbance of sound or unwanted sounds. Noise intensity is expressed in decibels, or dB, while frequency is expressed in Hz. The maximum noise intensity humans can tolerate during working hours (i.e., approximately 8 hours) is 85 dB. High-intensity noise can damage human hearing by reducing hearing ability and leading to deafness. In addition, this can cause health problems such as increased blood pressure and heart rate, which can potentially cause workers to experience heart attacks and digestive disorders (Dahal, 2017). Meanwhile, low-intensity noise can cause stress, headaches, sleep disturbances, loss of concentration, and decreased work performance (Kim et al., 2020). According to the Occupational Safety and Health Administration (OSHA), the standard daily exposure time has been set (Kuijpers, 2005), where for noise of 90 dB the maximum allowable exposure time is 8 hours, 92 dB for 6 hours, 95 dB for 4 hours, 97 dB for 3 hours, 100 dB for 2 hours, 105 dB for 1 hour, and 110 dB for 30 minutes. Sound or noise pollution can be controlled by providing personal protective equipment, such as earplugs or earmuffs, and installing silencers on noise sources.

The existing bogie casing shows that shape optimization has not been carried out; the output is only a simple model, so it does not account for the optimal dimensions and shape. This is also related to aerodynamic performance, including noise, drag, and lift. Noise Housing design to control noise from wheel collisions with railroad tracks, especially on medium-speed trains, is essential. Research designs based on existing theories and prior research must account for aerodynamic and aeroacoustic working concepts, with the shape and material of the noise housing to be considered. Basic physics and mechanical dynamics approaches are needed to build good concepts. Apart from that, a basic understanding of the interaction between noise and body health through an ergonomics approach, and a good understanding of product design, are required. Furthermore, in developing the concept of noise reduction solutions through the creation of "Noise Housing", it is important to understand in depth the operation of railroad cars at railroad crossings and in contact with the surrounding environment, including natural and artificial noise barriers. The concept design of Noise Housing works in five principles of ergonomics (performance, comfort, ease of use, safety, and beauty).

2. Materials and Methods

An initial survey of train passengers in Indonesia shows that the majority still experience noise disturbances from

collisions between train wheels and the tracks. Measurements of train noise exposure at a distance of 7 m show almost all values exceed 120 dB, with the highest noise level around 138 dB. Meanwhile, if measurements were carried out 5 m from the train tracks, the average noise level was around 130 dB, with the highest value reaching 140 dB. Noise caused by passing trains comes from three main groups: traction noise, rolling noise, and aerodynamic noise. Traction noise is noise originating from the sound of a train locomotive, which is dominant for trains at low speeds. Rolling noise is generated by the movement of the railroad wheels due to friction with the railroad tracks, including during braking at medium speed. Ard Kuijpers explained the results of the research on the reduction of rolling noise through the use of bogie dampers and low barriers alongside the track, or 'Noise Housing' (Kuijpers, 2005). Meanwhile, for high-speed trains, speeds greater than 200 km/hour are dominated by wind noise. Figure 1 explains the relationship between train speed and the noise source it generates (Cai et al., 2018). Train traction motors are an important component that generates traction forces, but they also significantly influence the indoor and outdoor acoustic environment under running conditions. For this reason, research aimed at reducing traction motor noise continues. Train traction motors are usually designed with a cooling fan that rotates at high speed to dissipate heat generated inside the motor. This creates aerodynamic noise of very high intensity (Righi et al., 2016).

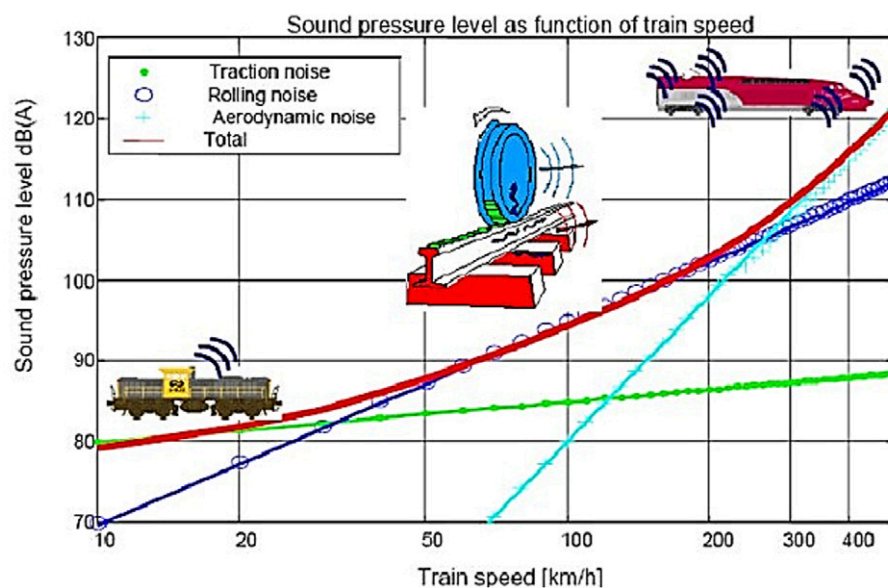


Figure 1. Relationship between train speed and noise sources.

The rolling noise of trains and highway traffic is very similar. Rolling noise is generated by vibrations caused by roughness (Kuijpers, 2005). Vibrations caused by roughness are caused by irregularities in the tread surface and the surface on which the wheels rotate. Roughness can be measured directly by measuring the roughness profile or indirectly by measuring derived quantities such as sound or vibration levels. Aerodynamic noise is sound caused by air flow due to turbulence or spiral vortex formation. The direction and shape of airflow can also affect noise levels from a particular source. In any work environment, there are many reasons to keep sound levels at an appropriate level. Sounds above this level are considered “noise”. Noise can distract workers, creating an unsafe work environment. Aeroacoustic investigations focus on sound sources caused by turbulence or aerodynamic surface displacement. Lighthill (Zannin & Ferraz, 2016) explains the basic theory of aerodynamic noise based on the Navier–Stokes equations.

The theoretical Lighthill-Curle equation for the basic theory of aerodynamic sound was devised by Lighthill in 1952. This equation is used to evaluate turbulent wind noise at low Mach numbers ($M \ll 1$). Meanwhile, the Lighthill-Curle equation is derived from the Navier-Stokes equation by combining conserved mass, energy, and momentum. Air current pressure fluctuations will form turbulent currents and sound waves, as described by the vortex configuration. The Fflowcs William-Hawkings acoustic model (FW-H) in ANSYS Fluent 6.3 is used to convert the time of pressure fluctuations into sound signals (Equations 1 to 4) (Serafin et al., 2018):

$$\begin{aligned}
 (\rho - \rho_0)H(f) &= \frac{\delta^2}{\delta x_i x_j} \int_{v(\tau)} \frac{[T_{ij}]}{4\pi c_0^2 |x - y|} d^3 y \\
 - \frac{\delta}{\delta x_i} \int_s \left[\frac{\rho v_i v_j - V_j}{4\pi c_0^2 |x - y|} + \frac{(p - p_0)(\delta_{ij} - \sigma_{ij})}{4\pi c_0^2 |x - y|} \right] dS_{j(Y)} \\
 + \frac{\delta}{\delta x_i} \int_{s(\tau)} \left[\frac{\rho v_j}{4\pi c_0^2 |x - y|} \right] dS_{j(Y)}
 \end{aligned} \tag{1}$$

where,

Quadrupole:

$$\frac{\delta^2}{\delta x_i x_j} \int_{v(\tau)} \frac{[T_{ij}]}{4\pi c_0^2 |x - y|} d^3 y \tag{2}$$

Dipole:

$$- \frac{\delta}{\delta x_i} \int_{s(\tau)} \left[\frac{\rho v_i (v_j - V_j) + (p - p_0)(\delta_{ij} - \sigma_{ij})}{4\pi c_0^2 |x - y|} \right] dS_{j(Y)} \tag{3}$$

Monopole:

$$+ \frac{\delta}{\delta x_i} \int_{s(\tau)} \left[\frac{\rho v_i (v_j - V_j) + \rho_0 V_j}{4\pi c_0^2 |x - y|} \right] dS_{j(Y)} \tag{4}$$

For a Mach number flow $M \ll 1$ and , the far field sound pressure equation can be written as:

$$P_a = \frac{1}{4\pi} \frac{\delta}{\delta x_s} \int_s \frac{ni}{r} p \left(v, t - \frac{r}{c} \right) ds \tag{5}$$

where;

c = speed of sound (m/s)

P_σ = far-field sound pressure (Pascal)

P = surface pressure (Pascal)

r = the distance between the sound source and the observation point (m)

n_i = the outward unit vector normal to the boundary surface.

T_{ij} = the Lighthill’s acoustic

The Fflowcs William-Hawkings (FW-H) model is a far-field acoustic model that implements the Lighthill–Curle equation to determine the propagation of sound signals from a source to a receiver, with monopole, dipole, and quadrupole source types. In general, noise in aerodynamics is defined as sound pressure level (SPL). The SPL formulation is written in Eq. (6) under (Watson & Downey, 2008):

$$SPL(dB) = 20 \log_{10} (P/P_{ref}) \tag{6}$$

where;

$$P_{ref} = \text{sound power reference} = 2 \times 10^{-5} \text{ Pa}$$

Aerodynamics is a discipline that studies the interaction between CAD models (objects) and air, showing that only one, both, or neither is moving (dynamic) relative to the other. Fluid dynamics is a basic science that studies the effects of aerodynamics on car body design. Computational Fluid Dynamics (CFD) plays a powerful role as a design tool capable of solving complex aerodynamic problems. Historically, the initial development of CFD in the 1960s and 1970s was driven by the aerospace community’s needs

(Reeve, 2018). Today, CFD is not only used in military research but also in fields such as health, architecture, environmental studies, mechanics, and ergonomics. To improve the performance of modern vehicles with good environmental quality and fuel economy, among other goals, CFD tools are powerful for helping automotive engineers better understand the physical flow processes around a car body and, in turn, design better vehicles. The fluid works as a non-Newtonian fluid in the CFD simulation, with a nonlinear relationship between the shear stress σ_{ij} and the shear rate. The CFD software tool is based on a governing equation that contains the three laws of conservation of mass, momentum, and energy (Piechna, 2021).

The Finite Element Method (FEM), whose practical application is often known as Finite Element Analysis (FEA), is a numerical approach to finding and generating approximate solutions to partial differential equations and integral equations. Solution approaches are based either on eliminating differential equations entirely in steady-state problems or on using differential equations (nonlinear relationships) entirely in transient fluid dynamics. The standard technique for integrating ordinary differential equations is numerical integration using methods such as the Euler method and Runge-Kutta methods. Finite Element Analysis (FEA) is a computational program that uses a numerical method approach to model design and provides solutions to structural strain, thermal, vibration, fall impact, collision, etc. problems. Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who investigated the numerical analysis of the Ritz method and variational minimization calculus to obtain approximate solutions to system problems in a number of areas, for example, engineering, medicine, the military, etc. (Mehrtash, 2021; Sasaki & Sugiura, 2016).

FEA works with a complex system of points called 'nodes', which create a grid called a 'mesh'. This mesh is programmed to accommodate material and structural properties that determine how the structure will react to external and internal loading conditions. The nodes are assigned a specific density throughout the material, depending on the anticipated stress level in a given area. Areas that will receive large amounts of stress usually have a higher knot density than areas that experience little or no stress. Points of interest may consist of: fracture points of the previously tested material, fillets, corners, complex details, and high-stress areas. A mesh acts like a spider web, with a mesh element at each node that extends to each adjacent node. It is this vector mesh that brings material properties to objects, creating many elements. FEA

has become a good solution for predicting failure due to unknown stresses by pinpointing problem areas in the material and allowing designers to see all the theoretical vibrations within them (Saneebamol & Syed, 2015). This method of product design and testing is far superior to the manufacturing costs incurred if every sample were actually manufactured and tested. FEA analysis uses a CAD model of a material or design to simulate stress and analyze it for a specific purpose. It is used in the design of new products and improvements to existing products.

3. Research Methodology

Research has developed bogie covers called Noise Housing (NH) to reduce the impact of noise on passengers and residents. All stages of the research are depicted graphically in the flow diagram in Figure 2. It can be seen that the initial stage of the research is a literature review on train carriages, CAD 3D models, simulation, human noise (ergonomics), and optimization. ANSYS software was employed to create a 3D model of the NH design and was used to simulate the aeroacoustic behavior of train wheel and track collisions. The NH manufacturing process must pay attention to several space requirements and limitations in train bogies and carriages, including:

- The train bogie cover will be installed on the train carriage to ensure that strength can be applied.
- The size of train bogies must have a bogie movement tolerance of 7° to the right and left.
- The NH model is divided into two parts, right and left, to facilitate the installation and repair process.
- The NH material is fiber-based and coated with a thin sheet of sound-dampening rubber.

A far-field noise simulation (3 m, 5 m, 10 m, 15 m, and 20 m from the bogie center) will be carried out to compare the noise that occurs on train wheels with and without NH. Simulations are conducted at several levels of economy-class train speeds in Indonesia, which generally range from 60 km/h to 100 km/h. The experiment ran at five types of speed levels: 40 km/h, 60 km/h, 80 km/h, 100 km/h, and 120 km/h. The simulation will also identify optimal materials to reduce noise. Optimization can be measured by producing noise to residents around the railway tracks (15 m distance) below 55 dB and by reducing the drag force. The final stage of the research, analysis, and discussion will analyze the simulation results and assess their impact on noise for residents around the railroad tracks. Moreover, the discussion explains the shape and dimensions of the Noise Housing and its impact on

the drag force of the train car as part of the energy efficiency needed to move the train.

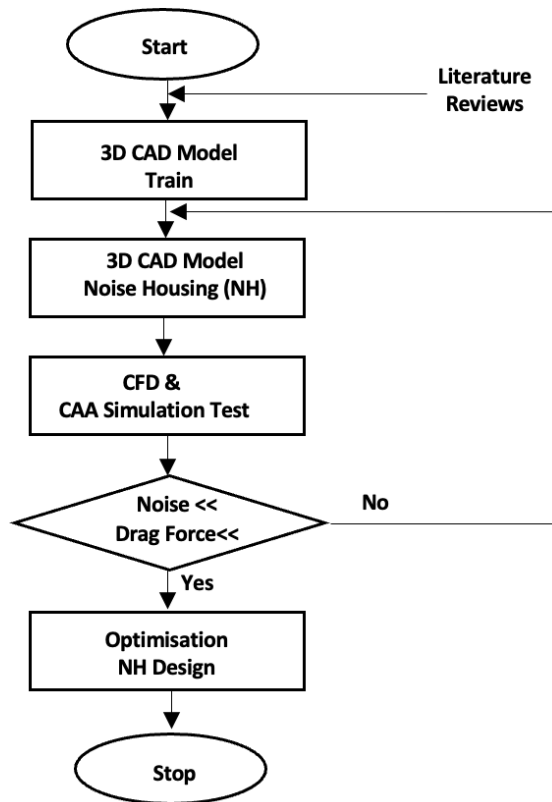


Figure 2. Flow diagram depicting all stages of the research.

4. Results and Discussions

To reduce the impact of noise caused by collisions between train wheels and train tracks, it is necessary to create a 3D CAD model in ANSYS software as the basis for system simulation and analysis. Figure 3a depicts one form of bogie used on trains in Indonesia. The technical

data are as follows: distance between bogie axes = 9.8 m, wheel spacing = 1.067 m, wheel diameter = 0.774 m, bogie load = 14,000 kg, and basic frame made of carbon steel. Figure 3b is a CAD model of a locomotive and two train cars. The existing model generally follows trains in Indonesia.

To carry out aeroacoustic simulations of the Noise Housing model to reduce rolling noise on train wheels, a 3D CAD model of the Noise Housing was created. Figure 4a shows the Noise Housing shape model and dimensions, which consist of two sizes: the first design is for locomotive Noise Housing, and the other is for train carriages. Data were added to the engineering data table as fiber properties on application. This material is applied in the regular automotive industry. Any store generally sells this material at a low price, but has sufficient capabilities. The Noise Housing material comes from MattWeb, which has properties shown below:

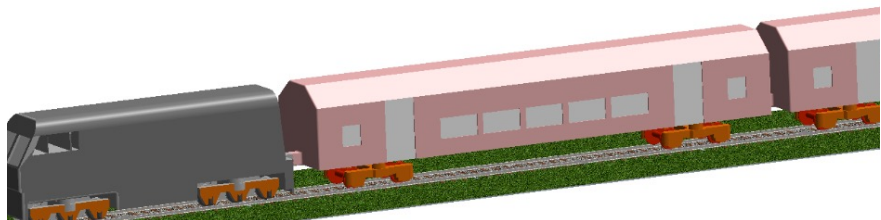
Table 1: Fiber properties source: MattWeb.

No	Properties	Metric
1	Density	2.44 g/cc
2	Tensile strength, Ultimate	3310 MPa
3	elongation at break	4,8 %
4	Modulus of elasticity	68.9 GPa
5	Poissons ratio	0.183
6	Shear modulus	29.1 GPa
7	Specific heat capacity	0.796 J/g-°C
8	Softening point	727 °C

Meanwhile, Figure 4b is a recommended model for installing the Noise Housing after adding connectors to strengthen it and enhance the train's aesthetic appearance, making it more ergonomic. The 3D CAD train model with Noise Housing installed will be used for the



(a)



(b)

Figure 3. Existing trains: (a) railroad bogies; (b) 3D CAD model of the existing train.

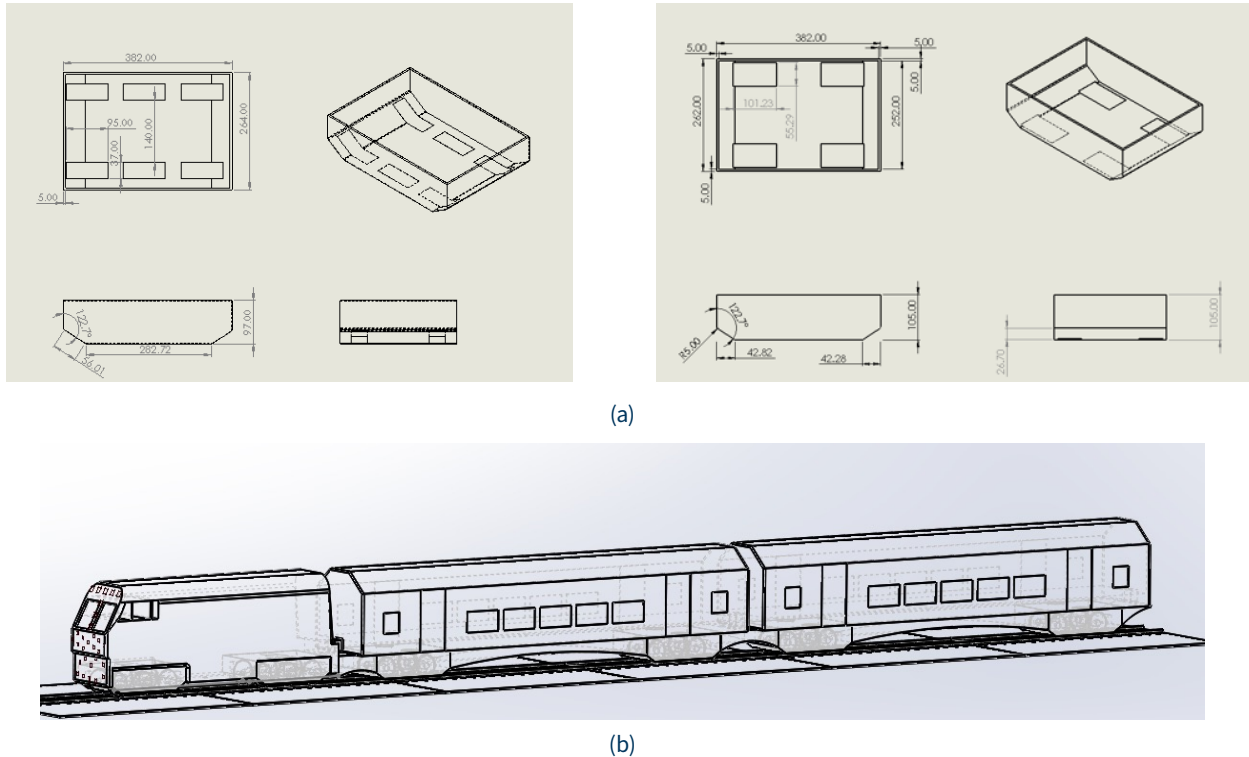


Figure 4. (a) Engineering drawings of Noise Housing for carriages and locomotives; (b) final 3D model of Noise Housing on wheels: train bogie.

simulation, with the same setup as the existing model. The simulation results for a train with Noise Housing show that the sound intensity level under the train is 117.55 dB. The maximum noise value occurs at the rear train wheels at a constant speed of 60 Km/J (16,667 m/s). When an object moves, a weight transfer event occurs, which causes the load to tend to shift backward. This is consistent with Newton's third law, which states that for every action there is an equal and opposite reaction. The load directed backward places a greater force on the rear wheels.

A simulation-based approach is used to determine the effect of adding Noise Housing. CAD drawings are created with the same dimensions as the original. In the process of creating a CAD model, a simple drawing structure is used to minimize simulation complexity. Figure 5 describes the setup of harmonic acoustics done in ANSYS software. The choice of material for the carriage body is stainless steel, fiber for the Noise Housing, "air" for the enclosure, and the rest is structural steel. The modal analysis method is first used to find the effective frequency of noise occurrence. The effective frequencies obtained from the modal analysis define the range for the harmonic response analysis.

The existing noise simulation is configured to reflect the appropriate design and environmental conditions. The simulation setup is configured by enabling a "no-separation" contact option between the train wheels and the rails, and by coupling the train wheels to the bogie. The "bounded" option is used to place the carriage body on a bogie. The structural option, a fixed support on the base of the rail, was chosen on the CAD drawings to keep the rails in a static state. An ambient temperature of 27 °C was used in the analysis.

Humans can hear sounds with frequencies from 20 Hz to 20,000 Hz. Thus, this range is used as a reference limit for frequency analysis in the simulation. Then, the results are used to identify responses based on the frequencies identified by harmonic response analysis. The frequency response is used as an excitation Noise Housing to analyze how much sound can be suppressed. The dimensions of an economy train carriage have a mass of 20,000 kg/train carriage. Figure 6a is a simulation of the collision of train wheels with train tracks, where the speed factor will change the magnitude of the impact on the train wheels. Figure 6b shows the simulation results for the dimensions around the train, arranged according

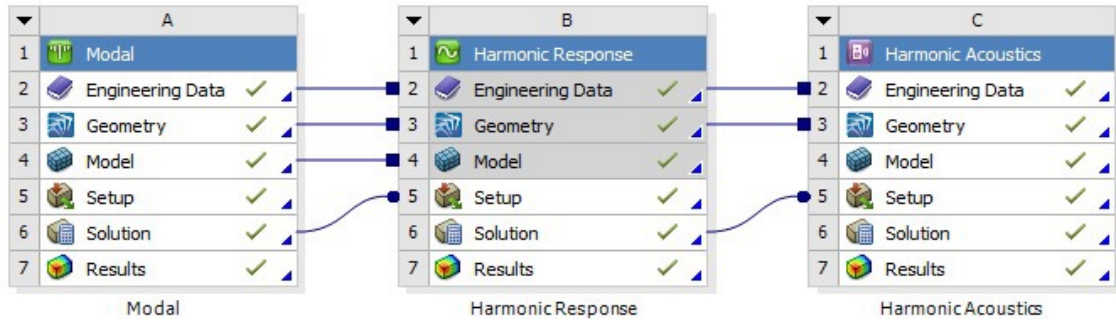


Figure 5. Aeroacoustic simulation setup for Noise Housing based on ANSYS software.

to the experimental design, namely, with far-field noise listeners at distances of 3m, 5 m, 10 m, 15 m, and 20 m. The collision of the wheels with the train tracks is highly dependent on the train's speed and occurs at a vibration frequency between 20 and 100 Hz. This frequency is used as a range in harmonic acoustic analysis (Figure 6c). The loading applied to the application is expressed as surface velocity, set to 60 km/h (16.67 m/s). The results show a

plot of sound intensity that occurs under the carriage and then spreads throughout the surrounding environment. The sound intensity level produced in the SPL Mic test at a distance of 5 m was 106.57 dB.

Table 2 below is one of the results of a comparison of noise magnitude at various listening distances for existing train models and trains with Noise Housing, at the same speed of 60 km/h. Based on Table 1, the addition

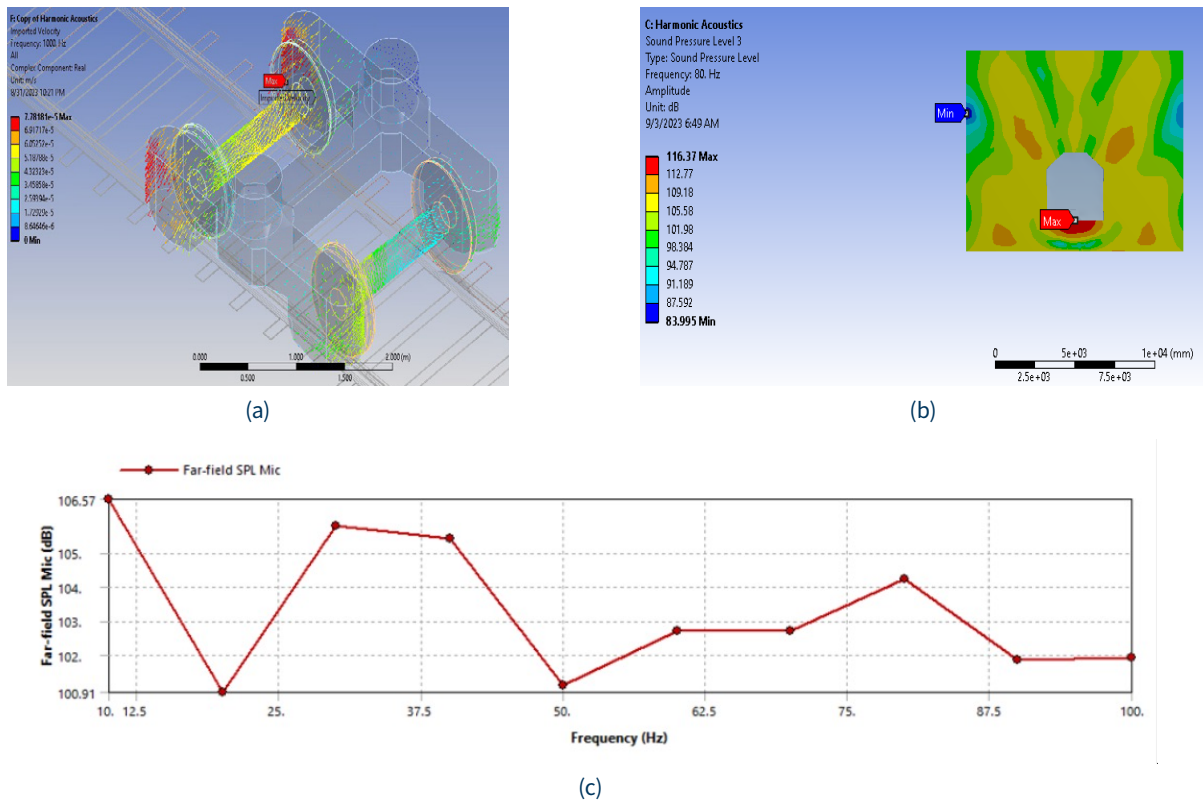


Figure 6. (a) Imported velocity on train wheels; (b) scatter plot of noise intensity levels; (c) 5-meter far-field SPL noise measurement.

of noise housing made from standard fiber significantly reduces noise, with an average reduction of 19.02 dB (22.99%). It is even more profitable and effective at higher train speeds, reducing noise by around 23.04 % at 80 km/h and 23.82 % with noise housing at 100 km/h. The results of this simulation have shown that the addition of Noise Housing effectively reduces the impact of noise on the surrounding community and has potential for further development, especially innovations in fiber materials that incorporate additional sound-dampening materials.

Table 2: Noise comparison of the existing model and the Noise Housing model for speed 60 km/h.

Position to noise source (m)	Noise intensity (dB), speed 60 Km/h	
	Existing model	Noise Housing
3	134,42	109,68
5	129,98	105,24
10	123,96	99,22
15	120,43	95,65
20	117,93	93,15

Noise optimization between railways and their wheels was conducted by the Noise Housing application. Additionally, 5 mm rubber layers were added to the inner side of the Noise Housing to increase noise reduction on wheels. The properties of rubber are shown in Table 3:

Table 3: Properties of rubber (source: Mattweb).

Physical Properties	Metric
Density	0.0400 - 3.80 g/cc
Viscosity	0.700 - 1.30e+7 cP
Tensile strength, Ultimate	0.138 - 165 MPa
tensile strength, Yield	0.0448 - 145 MPa
Elongation at break	5.00 - 1490 %
Elongation at Yield	0.000 - 900 %
Modulus of elasticity	0.000517 - 0.0621 GPa
Compressive modulus	0.000200 - 0.00590 GPa
Poissons ratio	0.500
Shear modulus	0.00183 - 1.83 GPa
Shear strength	0.200 - 6.05 MPa
Tensile set	2.00 - 10.0 %

Aeroacoustic simulations were carried out using the far-field noise method at varying distances from the sound

source and with the same train movement speed of 60 km/hour. The simulation results show quite significant improvements in noise reduction for adding a rubber layer to the Noise Housing. At a measurement distance of 3 m, it produces noise of 107.61 dB; at a distance of 5 m, it produces noise of 102.56 dB; at a distance of 10 m, it produces noise of 96.54; at a distance of 15 m, it produces noise of 93.01; and at a distance of 20 m, it produces noise of 90.51 dB. Based on the simulation results, it can be concluded that this modification will increase the average damping by 27.84% compared to the existing model (without Noise Housing) and by 2.59 % compared to Noise Housing with fiber layers only. Figure 7 illustrates an aeroacoustics simulation for Noise Housing design using rubber-coated fiber materials.

The design results need to be tested for aerodynamic performance, including aerodynamic noise, drag force coefficient, and lift force, which affect train balance. Figure 8a and 8b show the results of aerodynamic simulations - Sound Pressure Level (SPL) on a series of existing train carriages and modified train carriages with noise housing. The contour is taken from the top view at the height of the middle of the train wheels. Figure 8a is the SST simulation result for existing trains, and Figure 8b is for a train with noise housing. Based on the image, it can be seen that the addition of the noise housing will improve the aerodynamic noise performance, which is better even with a lower value. Based on calculations using the far-field noise method, a significant reduction in noise was obtained for trains at 80 km/h, from an average of 15.19 dB to 0.80 dB.

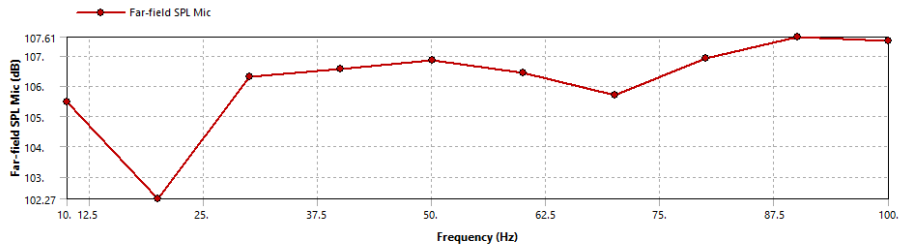
Meanwhile, noise housing testing for drag and lift force coefficients was conducted over various speed ranges, starting at 40 km/h, 60 km/h, 80 km/h, 100 km/h, and 120 km/h. The drag force coefficient value is calculated using the formula $C_d = 2 \times F_d / (A \times V^2 \times \rho)$, where F_d is the resistance force in the direction of the X axis, A is the frontal area of the train, v is the relative speed of the wind towards the train, and ρ is the mass air density. As an example, the drag force coefficient for an existing train at a speed of 40 km/h is calculated as follows:

$$C_d = 2 \times F_d / (A \times V^2 \times \rho) = 2 \times 776,48 / (11,03 \times 11,11^2 \times 1,16) = 0,95 \tag{7}$$

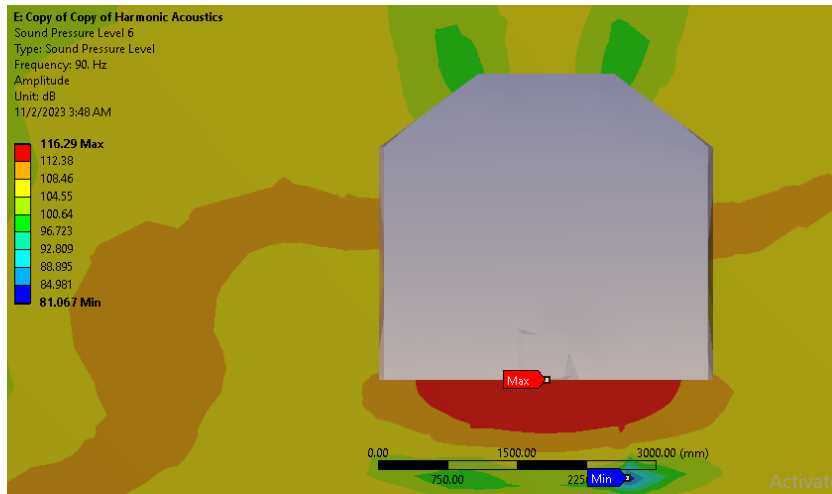
where:

Cross area (A) = 11,03 m²

ρ = air density = 1,16 (kg/m³)

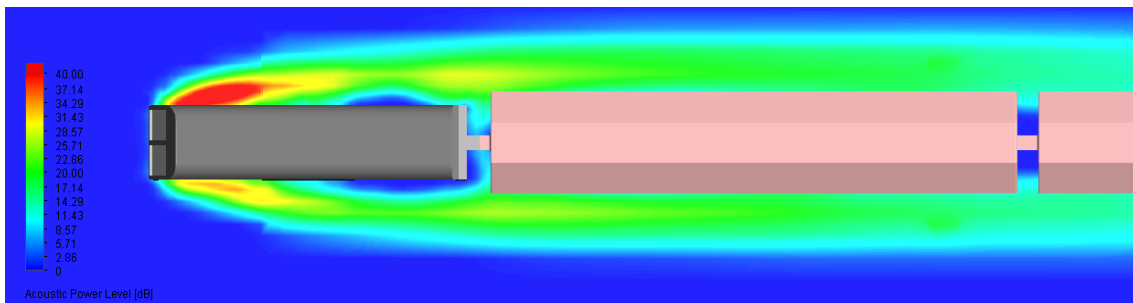


(a)

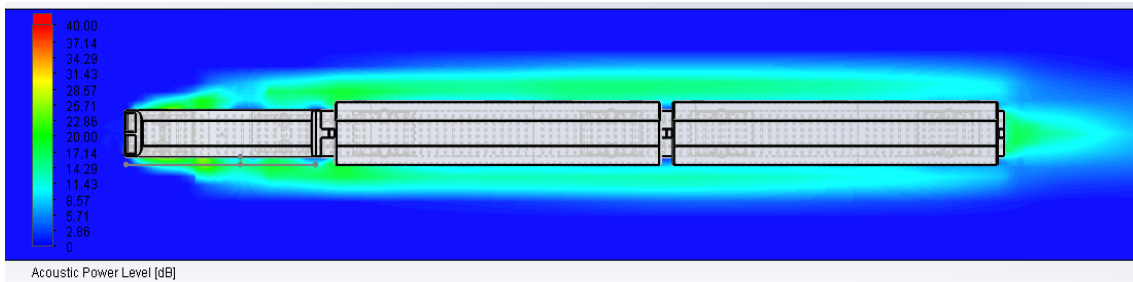


(b)

Figure 7. (a) Far-field mic at 5 m simulation; (b) noise distribution at the center of the train car.



(a)



(b)

Figure 8. Contour acoustics power level train speed: 80 km/h: (a) existing trains; (b) trains with noise housing.

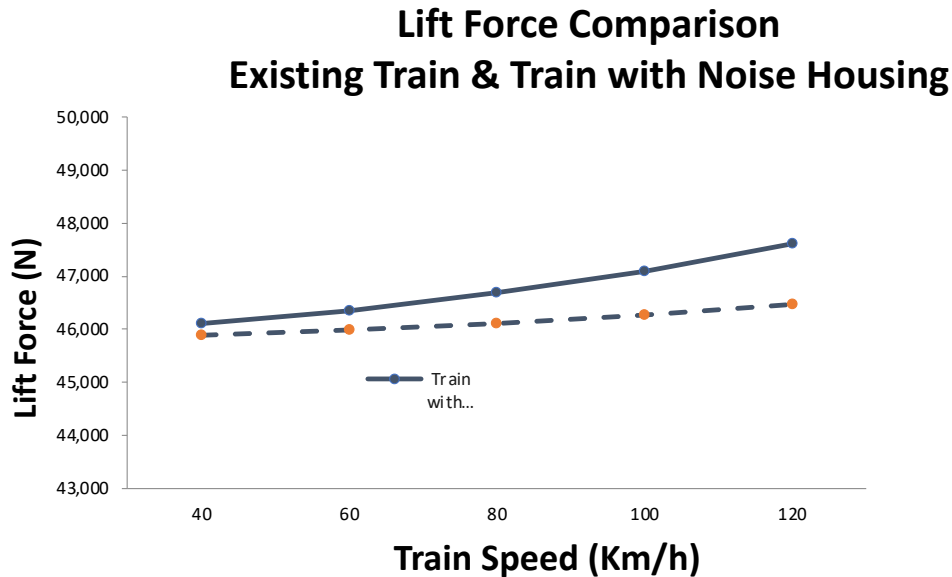


Figure 9. Lift force graphs on existing trains and modified trains due to the addition of noise housing and connectors.

Overall, the drag force coefficient of modified trains with the addition of a noise housing can reduce the existing model from 0.96 to 0.78, a decrease of 23.08%. Reducing the drag force coefficient is very helpful in saving locomotive kinetic energy that must be expended (Kumar & Kulkarni, 2021; Galamboš et al., 2024). Meanwhile, the lift force, which is related to aerodynamic effects on the train's weight, is shown graphically in Figure 9. From the graph, it can be concluded that aerodynamic noise will reduce the train's weight, which is not large; for example, the average increase in train weight at a speed of 80 km/h is 57.46 kg for 1 locomotive and 2 train cars. So, it can be concluded that the addition of noise housing from the weight change aspect does not change significantly, and therefore it does not impact fuel wastage or the stability of the train when operating.

Conclusions

The comfort of train passengers and residents near train crossings is greatly influenced by the noise from passing trains. A noise house, used to reduce noise caused by the collision of train wheels with train tracks, can reduce noise by 19.02 dB at 60 km/h, with the housing material made of fiber, like the body of a car. Effectively, the noise housing can also control noise as train speed increases; for example, at 100 km/h, it will reduce noise by 23.82%. The results of the noise housing model and the

connectors in the train carriage can also improve the drag force coefficient from 0.95 to 0.78, or a decrease of 17.9%. This can help save energy that must be expended by the train's driving machine. Apart from that, the aerodynamic performance with the addition of noise housing does not change the weight of the train significantly, to disrupt the stability of the train in its operation. Operational testing of the noise housing is required to ensure that the addition is also feasible for operation on railway tracks, including testing its vibration and durability.

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Conflict of interest

The authors declare that they have no conflicts of interest to disclose.

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