Comparative Analysis of Noise, Emission, and Performance of Shijiro Standard Racing Exhaust with Standard Exhaust on a 2020 Vespa Sprint 150 I-GET

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Abstract

This article presents a comprehensive comparative study of the standard and Shijiro Standard Racing exhaust systems on a 2020 Vespa Sprint 150 i-GET. This study aims to evaluate the efficacy of the exhaust system. The research objectives include a comparison of motorcycle performance, noise production and exhaust emissions, with adjustments made in accordance with Indonesian laws and regulations. The study also examines the airflow of the exhaust gas using Computational Fluid Dynamics (CFD) simulations. Testing procedures were conducted on the 2020 Vespa Sprint 150 i-GET, utilizing both standard and racing exhaust systems. These tests included performance, noise, and emission tests, conducted using a dynamometer, decibel meter, and gas analyzer, respectively. The data collected from these tests were analyzed to provide a comprehensive comparison between the standard and racing exhaust systems. The result is that even though it makes a louder sound, the racing exhaust still meets noise regulations in Indonesia. Both exhaust types met emission standards. The performance results revealed that standard exhausts outperformed in horsepower, while racing exhausts excelled in torque. The study also involved the use of reverse engineering to analyze the airflow in the exhaust and obtain design, dimension, and size information. The CFD simulations confirmed the influence of exhaust construction on sound, performance, and emissions. This research provides valuable insights into the performance of standard and Shijiro standard racing exhaust systems, contributing to the body of knowledge in this field.

Keywords: Exhaust, Noise, Emission, Performance, CFD

Abstrak

Artikel ini menyajikan studi komparatif yang komprehensif antara sistem knalpot standar dan Shijiro Standard Racing pada Vespa Sprint 150 i-GET tahun 2020. Studi ini bertujuan untuk mengevaluasi efektivitas sistem knalpot. Tujuan penelitian termasuk perbandingan kinerja sepeda motor, produksi kebisingan, dan emisi knalpot, dengan penyesuaian yang dilakukan sesuai dengan undang-undang dan peraturan Indonesia. Studi ini juga memeriksa aliran udara gas buang menggunakan simulasi Computational Fluid Dynamics (CFD). Prosedur pengujian dilakukan pada Vespa Sprint 150 i-GET tahun 2020, menggunakan knalpot standar dan racing. Pengujian ini meliputi tes kinerja, kebisingan, dan emisi, yang dilakukan menggunakan dinamometer, desibel meter, dan gas analyzer. Data yang dikumpulkan dari pengujian ini dianalisis untuk memberikan perbandingan yang komprehensif antara sistem knalpot standar dan racing. Hasilnya adalah meskipun menghasilkan suara yang lebih keras, knalpot racing tetap memenuhi peraturan kebisingan di Indonesia. Kedua jenis knalpot memenuhi standar emisi. Hasil kinerja mengungkapkan knalpot standar unggul dalam tenaga kuda, sementara knalpot racing unggul dalam torsi. Studi ini juga melibatkan penggunaan reverse engineering untuk menganalisis aliran udara di knalpot dan memperoleh informasi desain, dimensi, dan ukuran. Simulasi CFD mengkonfirmasi pengaruh konstruksi knalpot terhadap suara, kinerja, dan emisi. Penelitian ini memberikan wawasan berharga tentang kinerja sistem knalpot standar dan Shijiro Standard Racing, yang berkontribusi pada pengetahuan di bidang ini.

Kata kunci: Knalpot, Kebisingan, Emisi, Performa, CFD

1. Introduction

Indonesia ranks second globally after Italy in its number of Vespa communities and enthusiasts, with Vespa representing both a vehicle and a lifestyle icon [1]. This extensive user base has fostered a culture of customization among enthusiasts, including popular modifications like exhaust upgrades [2]. Discussions often focus on how these modifications affect motorcycle sound and acceleration. The primary function is to reduce both the engine's exhaust emissions and noise levels. It features chambers and passages that effectively lower the pressure and noise of exhaust gases. These gases, containing carbon monoxide, hydrocarbons, and nitrogen oxides, pose environmental and health risks. The muffler filters these emissions, decreasing their release into the atmosphere.

When motorcycle exhaust gases exit the system, they create back pressure, impacting performance, emissions, and fuel efficiency. The exhaust design and size determine how smoothly gases flow. Minimal obstruction reduces resistance for smoother flow, but excessive ease can diminish back pressure, crucial for utilizing combustion gases to aid piston movement [3]. Therefore, maintaining an optimal balance in exhaust design is critical for efficient engine operation. Replacing standard exhaust systems with racing exhausts offers a viable solution for enhancing motorcycle performance [4]. Studies consistently demonstrate significant advantages, such as improved engine responsiveness and increased overall performance, including enhanced power and torque output on various motorcycle brands and models using different racing exhaust configurations [5], [6].

In Indonesia, vehicle exhaust system replacements are allowed under regulations that specify permissible noise levels in decibels. Strict emissions regulations also ensure compliance with local and global air quality standards. Therefore, careful selection and installation of racing exhaust systems are essential not only to enhance vehicle performance but also to meet regulatory requirements.

Several automotive industries, including the Indonesian brand Shijiro, are developing various exhaust types. Shijiro's Standard Racing exhaust is designed to enhance performance while complying with Indonesia's noise regulations [7]. This study evaluates the Shijiro Standard Racing exhaust for the Vespa Sprint 150, focusing on noise, emissions and performance. Additionally, CFD simulations analyze acoustic values and exhaust operation, ensuring compliance with relevant noise and emission standards.

2. Literature Review

2.1 Vespa Sprint 150 i-Get ABS

Vespa Sprint 150 i-Get is equipped with a 154.8-cc 4-strokes 3 valve engine with an Electronic Injection Fuel Distribution System. This motorcycle uses an automatic transmission. The 2021 Vespa Sprint is equipped with a piston, boasting a diameter of 58 mm and a stroke of 58.6 mm. The engine features three valves, which include two intake valves with a diameter of 20 mm each, and one valve with a diameter of 22 mm [8].

2.2 Exhaust Systems

The exhaust system in motorized vehicles manages exhaust gases generated during engine combustion [9]. It collects gases (CO, HC, NOx, particles) from the combustion chamber through a manifold, directs them via an exhaust pipe to reduce pressure, treats them with a catalyst to lower pollutants, and expels them through a tailpipe, which also reduces noise. This system ensures safe gas removal, reduces emissions and noise levels, and supports engine performance and environmental protection.

Components like the manifold, exhaust pipe, catalyst, muffler, and tailpipe work together in vehicle exhaust systems [10]. Backpressure occurs when exhaust flow faces obstacles, reducing efficiency in gas removal, impacting engine performance, fuel efficiency, and potentially causing overheating. Effective exhaust system design minimizes backpressure to maintain smooth gas flow while meeting emissions standards [11]. Sound-absorbing materials reduce the acoustic energy of sound waves by absorbing them as they pass through. This absorption phenomenon helps to lower noise levels emitted by motorized vehicles. Glass wool, made from glass fiber, is widely used in automotive applications for its ability to dampen sound and provide heat and acoustic insulation. [12]. The glasswool material itself has the following physical properties (Table 1).

Table 1. Glasswool Physical Properties [13], [14]

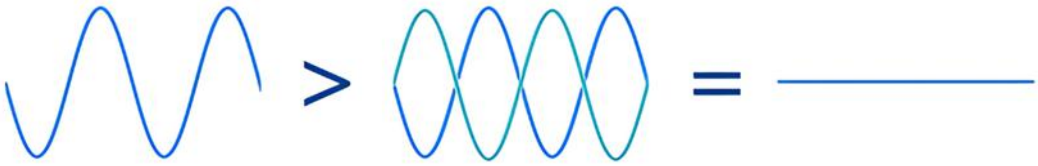
Glasswool Properties	Value
Thermal Conductivity (W/m.k)	0.036
Weightheat (J/kgK)	40
Density (kg/m^3)	840
Porosity	0.99
Tortuosity	1
Viscous Characteristic Length (m)	0.000192
Thermal Characteristic Length (m)	0.000384

2.3 Sound Waves and Vibrations

Sound waves propagate through mediums like air or water, creating alternating high and low pressure oscillations. These vibrations originate from sources such as musical instrument membranes or vocal cords, propagating through gases, liquids, or solids. Medium properties like density and elasticity influence sound speed; solids, due to higher density, allow faster sound transmission [15]. Interactions with boundaries cause sound reflection and absorption, impacting indoor acoustics. Human hearing converts sound waves into nerve signals processed by the brain for perception [16]. Noise characteristics include amplitude (dB) for loudness, frequency (Hz) for pitch, duration for temporal extent, pattern for rhythmic variations, and source identification (e.g., machinery, instruments).

Mufflers are integral in vehicle exhaust systems, positioned to reduce engine noise and emissions. Constructed from durable materials like steel with aluminum coatings, mufflers use destructive interference to attenuate noise from engine components. This involves creating opposing pressure waves within perforated tubes and chambers to cancel out exhaust noise, especially low frequencies, enhancing driving comfort [17], [18].

(a)



(b)

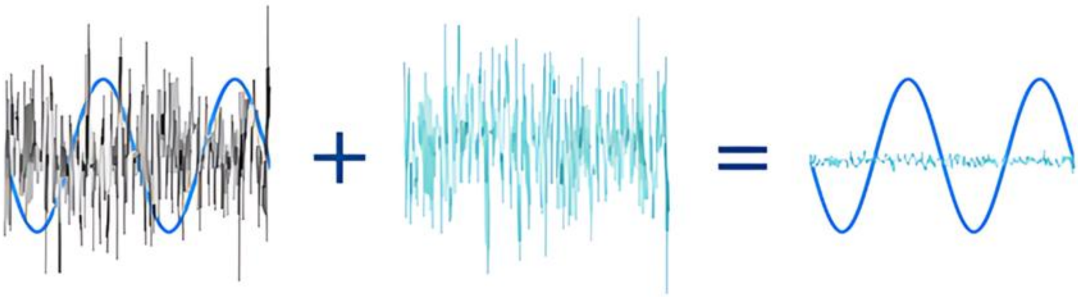


Figure 1(a). Waves of equal amplitude and opposite phase cancel out
(b). Recording and inverting noise leaves with desired signal

A decibel meter, or sound level meter, measures sound intensity in decibels (dB) by utilizing a sensitive microphone that detects pressure oscillations of sound waves in an environment. The meter converts these signals into dB units using the formula [17]:

$$IL = 10 * \log_{10}(P / P_{ref}) \tag{1}$$

Where IL = Intensity Level (dB)
P = Measured Pressure (Pa)
P_{ref} =Reference Pressure (Pa)

2.4 Performance

Engine performance evaluation includes critical metrics like torque, power output, fuel efficiency, and consumption, derived from manufacturer specifications. Power correlates with piston area, while torque relates to stroke volume, crucial for adapting to speed and load variations. Maximum power signifies peak engine performance, and torque at specific speeds indicates efficient airflow and fuel management. Evaluating operational duration is essential for overall fuel efficiency assessment. Horsepower, defined by James Watt, measures engine capacity as the force to lift 550 pounds by one foot per second (equivalent to 745.7 watts in SI units), impacting acceleration, top speed, and towing in automotive contexts. Torque enhances acceleration and drivability at lower speeds, with manufacturers optimizing torque for performance and competitive advantage in automotive engineering. The formula for torque is as follows:

$$T = F \times d \tag{2}$$

Where T = Torque (Nm)
F = Force
d = Distance

Dynamometers, essential tools in automotive performance tuning, assess and optimize high-performance vehicles by measuring key parameters like power output and torque [19]. By applying controlled resistance to engines during testing, dynos convert mechanical power into data through load cells, providing precise metrics crucial for maximizing acceleration and top speed. This method simulates real-world conditions, enabling engineers and enthusiasts to unlock a vehicle's full potential and achieve optimal performance. The formula is as follows:

$$HP = (T \times N) / 712 \tag{3}$$

Where HP = Horse Power
T = Torque (Nm)
N = Angular velocity (rpm)
712: the constant for unit conversion

This shows how torque and engine speed jointly determine horsepower, crucial for optimizing performance across vehicle types.

2.5 Computational Fluid Dynamic (CFD)

Computational Fluid Dynamics (CFD) involves numerically solving fluid flow equations to analyze complex interactions like fluid-fluid, fluid-solid, or fluid-gas dynamics. It discretizes the fluid domain into cells and can model heat transfer and chemical reactions by adjusting governing equations. CFD assesses design effectiveness, validates models, and explores scenarios hard to replicate experimentally, demanding significant computational resources, expertise, and rigorous validation. Originating from fluid dynamics quantification efforts, CFD has advanced with computing and numerical methods, finding wide application in aerospace, automotive, biomedical, civil, and environmental engineering [20].

Exhaust gas velocity denotes the speed of exhaust gases within an engine's exhaust system, influenced by operational parameters, system design, and gas temperature. Studies like "Transient Flow Uniformity Evolution in Realistic Exhaust Gas Aftertreatment Systems Using 3D-CFD" utilize three-dimensional unsteady Reynolds-averaged Navier-Stokes (URANS) simulations to analyze flow and temperature dynamics in complex exhaust aftertreatment systems under dynamic conditions. Another investigation explores the impact of exhaust temperature and flow rate on heat transfer in marine diesel engines, revealing that heat transfer coefficients initially increase with flow velocity before declining with higher temperatures [21]. Calculating exhaust gas velocity (Vg) typically involves principles from fluid dynamics and thermodynamics, tailored to specific engine contexts and often dependent on crankshaft speed for accurate measurement [22]:

$$V_g = \frac{SN}{30000}\left(\frac{D}{d}\right)^2 \tag{4}$$

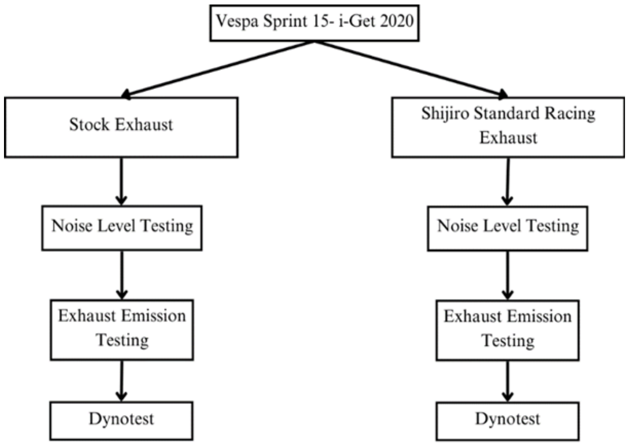
Where V_g = Average gas velocity (m/s)
S = Stroke of piston (mm)
N = Angular Velocity (rpm)
D = Piston diameter (mm)
d = Valve hole diameter (mm)

3. Method

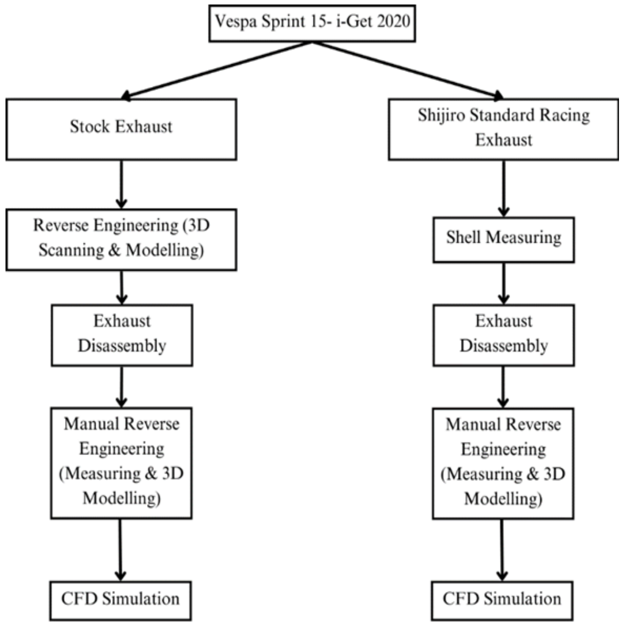
This study employs the experimental method and Computational Fluid Dynamics (CFD) simulation, particularly for noise analysis, to analyze and evaluate the characteristics of exhaust systems. The research aims to compare the performance, noise levels, and exhaust emissions between a standard Vespa Sprint 150 i-Get ABS exhaust and a racing exhaust, assessing compliance with predefined thresholds. Critical factors include instrument and material requirements, test concepts, and data collection techniques essential for exhaust testing.

The test necessitates the use of a suitable racing exhaust, specifically the Shijiro Standard Racing exhaust selected for evaluation. This exhaust type is chosen for its design similarity to standard exhausts but with internal modifications aimed at reducing noise and exhaust emissions. The Shijiro brand offers various sizes of this exhaust, determined by considerations of length and diameter to meet specific functional requirements and regulations.

The exhaust testing process goes through three test lines. The first test is to find out the noise level of each exhaust. The second is to find out how much exhaust gas is emitted from the exhaust. And the third is to determine the power produced by the motorcycle using each exhaust. The flowchart is exhibited in Figure 2a.



(a)



(b)

Figure 2 (a). Exhaust Testing Flow and (b) Exhaust Simulation Test Flow

To analyze the design and construction of the standard exhaust on the Vespa Sprint 150 i-Get 2020, a detailed examination of its internal structure is required. This involves disassembling the exhaust to measure and document the dimensions of each component, a process known as Reverse Engineering. This process includes manual disassembly to ascertain the internal layout and dimensions, complemented by digital imaging using a 3D scanner to capture detailed images. The complexity of standard exhaust designs necessitates such thorough techniques, in contrast to the simpler structure of racing exhausts. The process is illustrated in Figure 2b.

3.1 Data Collection

The data collection method compares the standard Vespa Sprint 150 i-Get 2020 exhaust with a racing exhaust, conducted at three locations: noise values at the University of Indonesia, emissions at Minyung Motor Klender in East Jakarta, and performance at HDR Tech Motor in Tapos, Depok. Emissions are tested once at idle. Noise testing follows two methods: the Indonesian government recommendation and a method used in Japan. Performance testing involves three trials with averaged results. The purpose is to compare performance, noise, and emissions to determine compliance with Indonesian regulatory thresholds. The Dynotest uses repetition to find maximum result, and both noise testing methods ensure threshold adherence. In this research, the tools for measuring sound are the Uni-T UT353 Decible Meter (Figure 3), Nanhua NHA-506EN Gas Analyzer (Figure 4) for emission testing and the Leads LSP-1 Dynamometer (Figure 5) for performance testing or Dynotest. All these tools have been calibrated accurately.

Figure 3. Uni-T UT353 Decible Meter

Figure 4. Nanhua NHA-506EN Gas Analyzer

Figure 5. Leads LSP-1 Dynamometer

Figure 6. Einscan Pro HD 3D Scanner

To analyze the exhaust's acoustic values and functionality, detailed data collection on its internal design and dimensions is essential. Key stages such as Reverse Engineering require specialized tools to gather necessary information for CFD simulations. This process involves 3D scanning (Figure 6), disassembly using tools like grinders to expose internal construction, and meticulous measurements of both internal and external parts of the exhaust**.**

3.2 Data Processing

Data processing is essential in the scientific method, organizing raw data to address research inquiries and test hypotheses. In sound noise testing, Microsoft Excel aids in basic calculations, data management, and graphing to analyze noise levels of the Vespa Sprint 150 i-Get 2020 standard exhaust and Shijiro Standard Racing exhaust. Tests follow Japanese and Indonesian methodologies, adhering to local noise regulations (Minister of Environment and Forestry Regulation Number P.56/2019). Emission tests using a gas analyzer assess compliance with Indonesian standards (Minister of Environment and Forestry Regulation Number 8/2023: 3% CO, 1000 ppm HC at idle). Dynotest trials evaluate vehicle performance, measuring maximum torque and power across 15 trials. Exhaust analysis involves 3D scanning, disassembly, and CAD-based processing for Computational Fluid Dynamics (CFD) simulations to assess airflow dynamics in each exhaust system.

4. Result, Discussion, and Analysis

4.1 Determination and Selection

In determine a racing exhaust, muffler type and exhaust pipe length significantly impact engine performance and noise reduction. Larger, longer muffler designs are preferable for attenuating exhaust noise, while exhaust pipe length affects torque and peak power characteristics. Compliance with noise regulations, such as Minister of the Environment Regulation No. 56 of 2019, favors exhaust systems with larger mufflers to minimize loud noises. The diameter of the exhaust inlet is chosen to match engine specifications and optimize motorcycle performance. Shijiro provides inlet size options, with 38 mm selected for its compatibility with the motorcycle's standard condition, ensuring consistent performance and moderate sound levels compared to larger sizes like 45 mm, as recommended by Shijiro.

4.2 Testing Results

From the method used in this research, the data obtained from each test that has been carried out can be presented in the following table: Table 2 exhibits the result of noise test, Table 3 shows the result of emission test, and Table 4 shows the result of dyno test.

Table 2. Noise Test Comparison of Standard Exhaust and Racing Exhaust

Test Method	Result (dB)				
		Standard Exhaust		Shijiro Racing Exhaust	
	Mea.	**Max**	**Min**	**Max**	**Min**
Indonesian Police	1	67.4	65.5	78.7	76.7
	2	67.4	64.3	78.7	75.8
	3	67.4	64	76	75
Average Value		**67.4**	**64.6**	**77.8**	**75.83**
Exhaust Noise	1	66.5	63.2	74.7	62
	2	68.2	66.8	72.9	71.2
	3	67.3	65.9	70.6	67.7
Average Value		**67.33**	**65.3**	**72.73**	**66.97**

Table 3. Emission Tests Comparison for Standard Exhaust and Racing Exhaust

Parameter	Unit	Test Results		Treshold
		Standard Exhaust	Shijiro Racing Exhaust	
Engine Temp.	°C	80	80	
Engine Rev	rpm	700	700	
CO	%	0.14	0.79	3
CO (correction)	%	0.14	0.79	
CO2	%	15.08	9.79	
HC	ppm	14	48	1000
O2	%	2.03	5.6	
Lamda (λ)		1.09	1.34	

Table 4. Dyno Test Comparison of Standard Exhaust and Racing Exhaust

Test	Standard Exhaust			Shijiro Racing Exhaust		
	HP/RPM	Nm/RPM	Max. KMH	HP/RPM	Nm/RPM	Max. KMH
1	10.0/8604	11.80/5060	103.8	9.5/7211	12.18/4914	102.7
2	10.1/8405	11.80/5020	103.7	9.6/6668	11.99/5000	102.9
3	10.1/8927	11.70/4898	103.8	9.6/6912	11.96/5053	102.7
4	10.2/9001	12.04/5124	103.9	9.7/6705	12.37/5005	103.4
5	10.2/8768	**12.25/4777**	103.4	9.8/6914	12.10/5136	103.4
6	10.2/8522	11.79/4962	103.9	9.8/6813	12.35/5170	103.6
7	10.2/8481	12.15/4892	104.1	9.8/6925	12.33/5008	103.4
8	10.1/8843	11.89/4990	104	10.0/7070	12.55/4995	103.4
9	10.3/8253	11.94/4884	103.8	9.9/8639	12.27/5119	103.2
10	10.3/8666	12.07/4845	104.1	**10.0/6673**	12.41/5087	103.4
11	10.4/8700	12.04/4829	104.2	10.0/6840	12.53/4794	103.8
12	10.3/8551	11.60/5155	104.2	10.0/6991	13.06/4741	103.4
13	**10.4/8640**	11.64/5039	104.1	10.0/7131	12.68/4748	103.7
14	10.3/8868	11.98/4829	104.2	10.0/7064	13.12/4654	103.7
15	10.4/8949	12.00/4846	104.2	10.0/6794	**13.14/4657**	103.7

4.3 CFD Simulation

Before performing a CFD simulation, the dimensions of each exhaust part must be obtained by dismantling the exhaust. For standard exhausts, 3D scanning is used for the shell due to its complex design, while internal parts are measured manually. For the Shijiro exhaust, both the exterior and interior are measured manually. The following results are then obtained.

Figure 7. 3D Scan Results

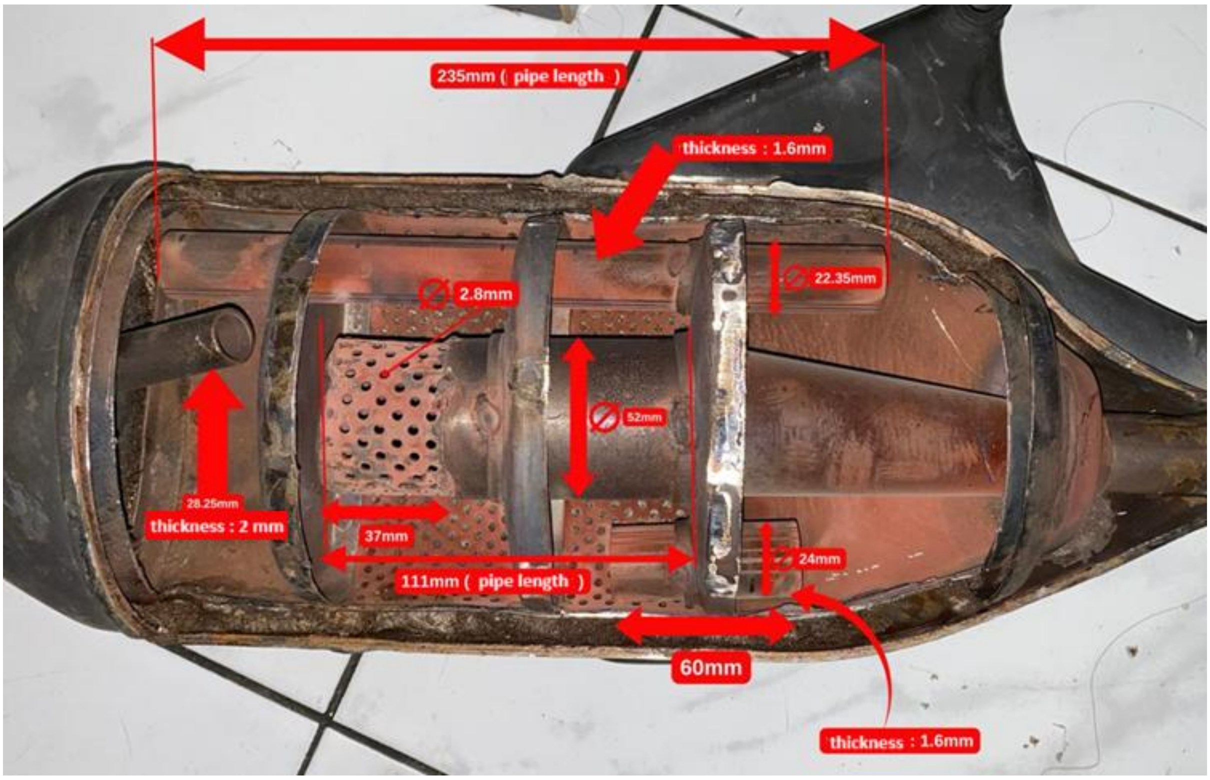


Figure 8. Standard Exhaust Inner Construction Measurement Result

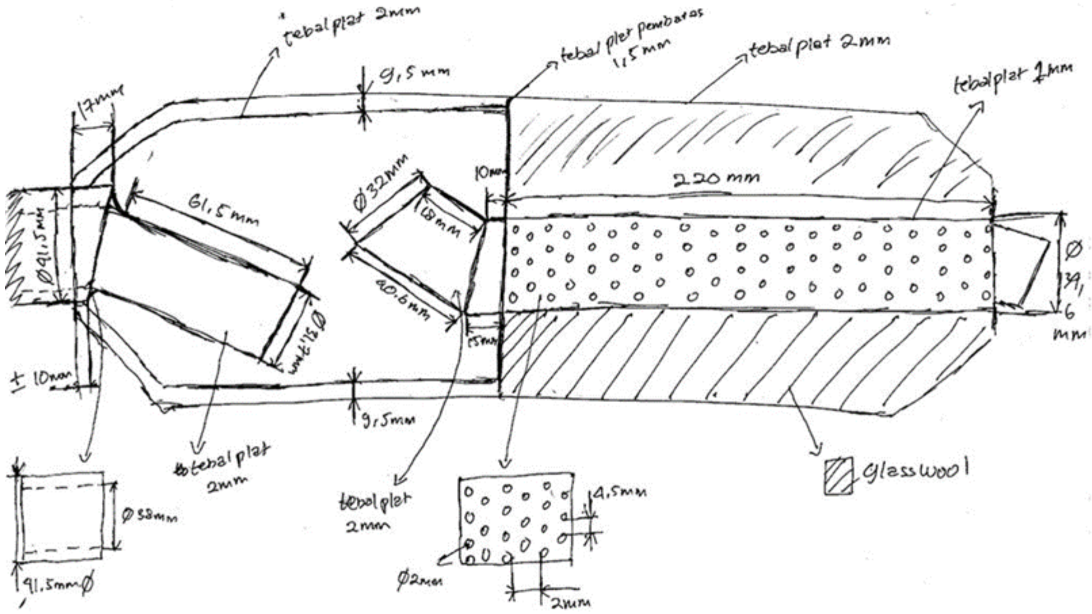


Figure 9. Shijiro Exhaust Measurement Result

3D modeling starts with precise measurements to create the outer casing, internal structure, and exhaust pipe using Solidworks and Catia. The standard exhaust's outer surface is refined from 3D scans, while the inner structure is manually modeled in CAD. Subsequently, all components are assembled into a complete 3D exhaust model.

Figure 10. Standard Exhaust 3D Model

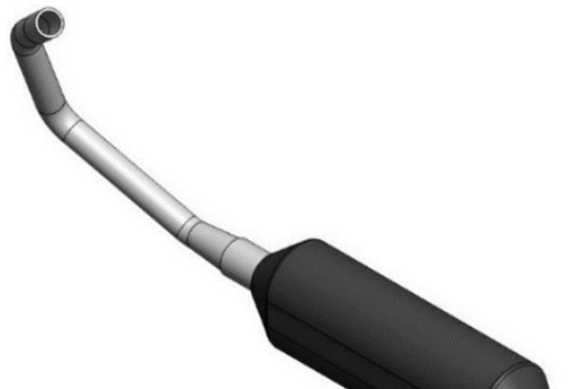


Figure 11. Shijiro Exhaust 3D Model

The CFD simulation compared the acoustic levels and exhaust gas velocities of the two exhausts under different conditions. Testing involved simulations at 1500 rpm and 7500 rpm engine speeds. At 1500 rpm, the gas velocity input was 20.36471 m/s, while at 7500 rpm, it was 101.82355 m/s. This value is obtained from the following calculation using formula (4):

$$V_g = \frac{SN}{30000}\left(\frac{D}{d}\right)^2$$

$$V_g = \frac{58.6 \times 1500}{30000}\left(\frac{58}{22}\right)^2$$

$$V_g = 20{,}36471 \text{ m/s}$$

Results analyzed parameters such as sound levels and exhaust gas flow velocities to evaluate performance differences between the exhausts.

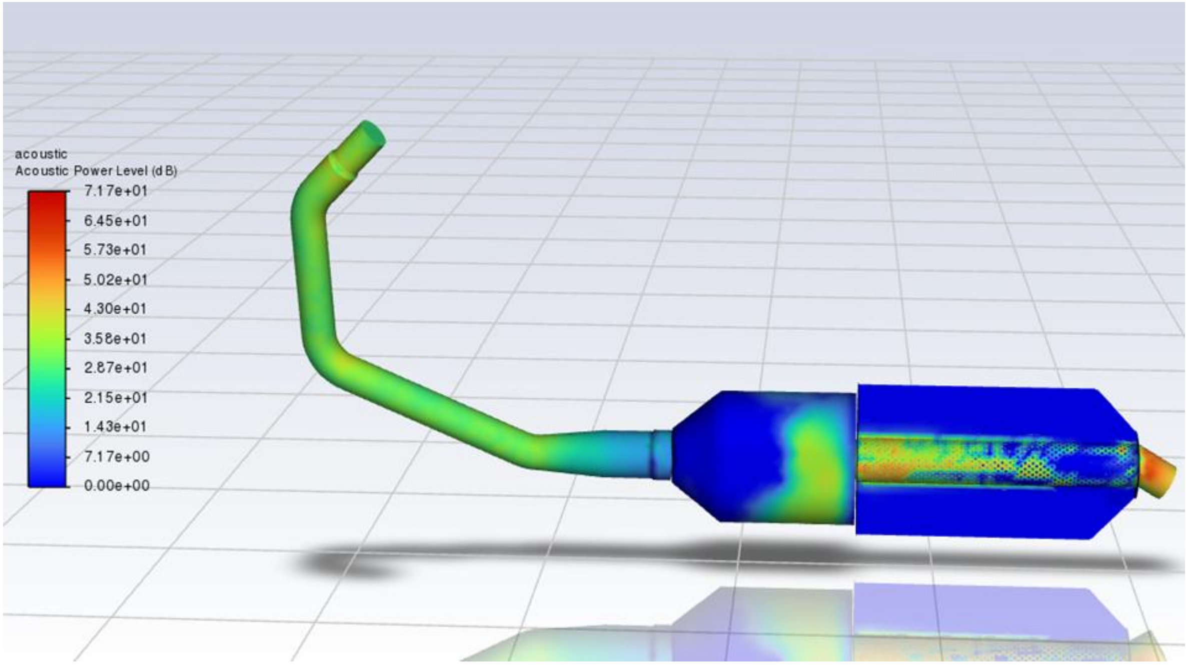


Figure 12. Shijiro Exhaust Acoustic Level at 1500 RPM

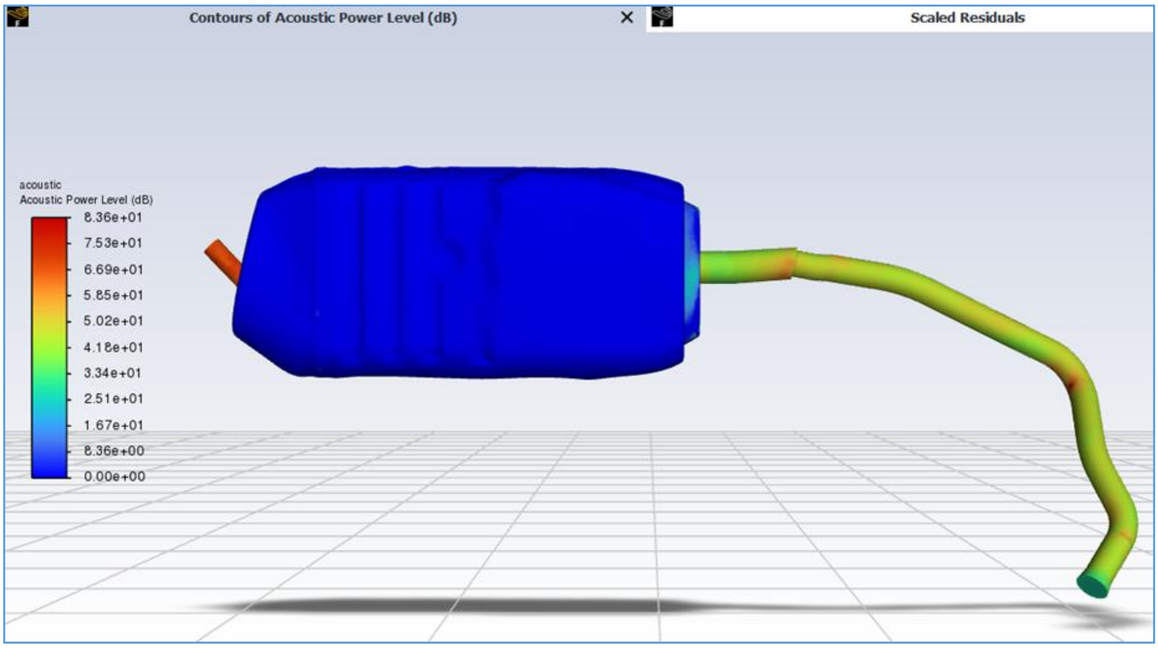


Figure 13. Standard Exhaust Acoustic Level at 1500 RPM

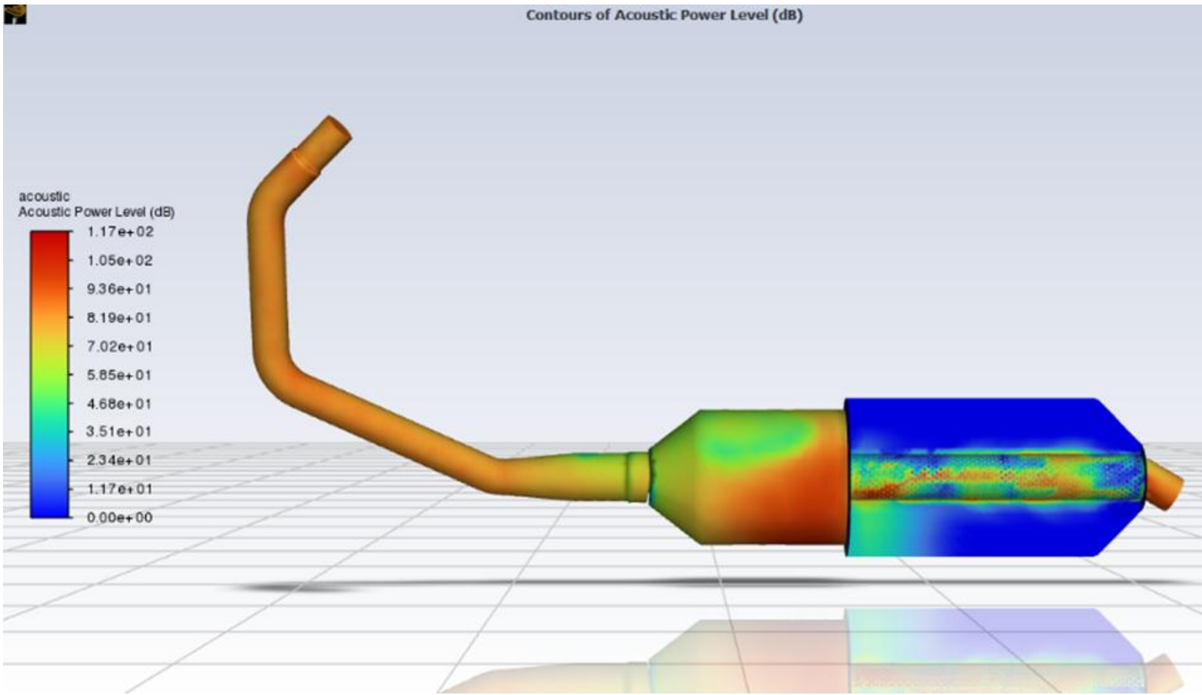


Figure 14. Shijiro Exhaust Acoustic Level at 7500 RPM

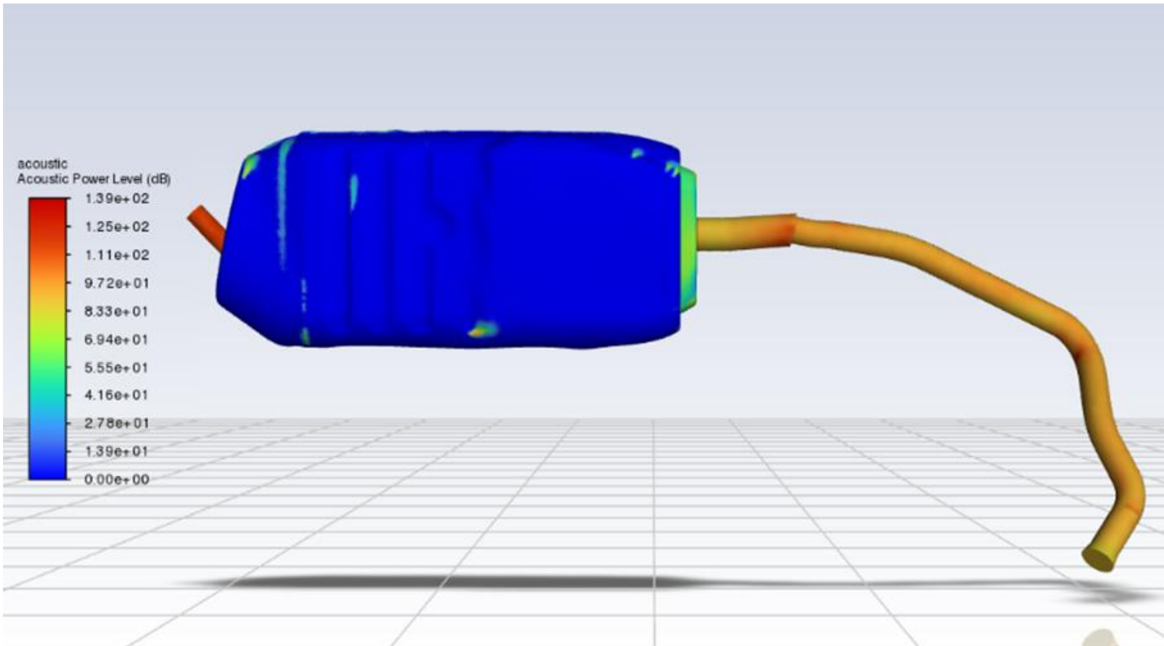


Figure 15. Standard Exhaust Acoustic Level at 7500 RPM

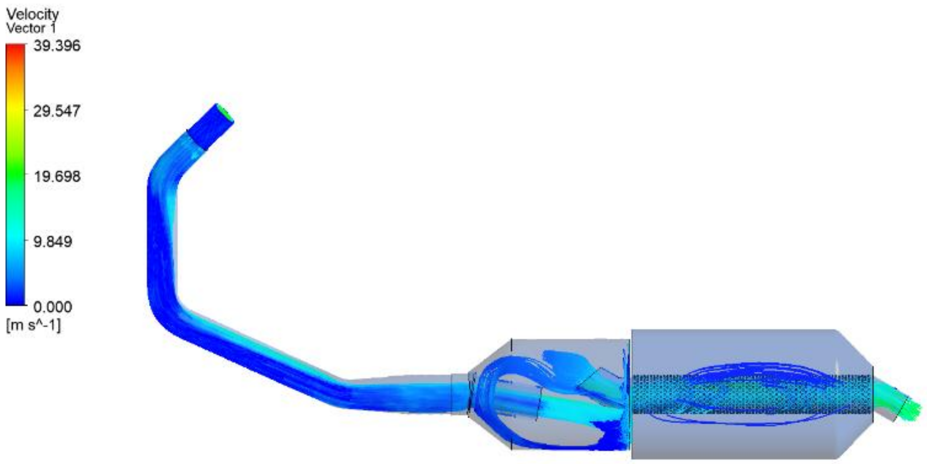


Figure 16. Shijiro Exhaust Airflow at 1500 RPM

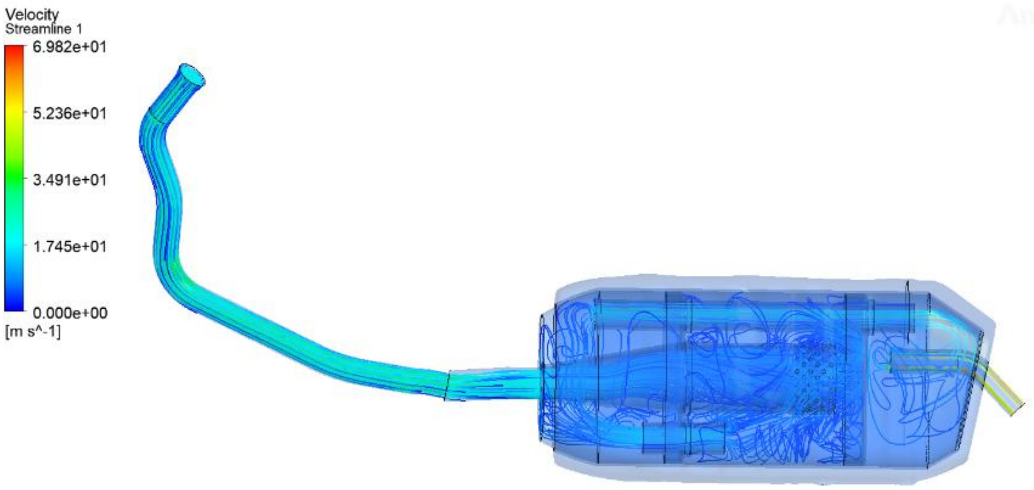


Figure 17. Standard Exhaust Airflow at 1500 RPM

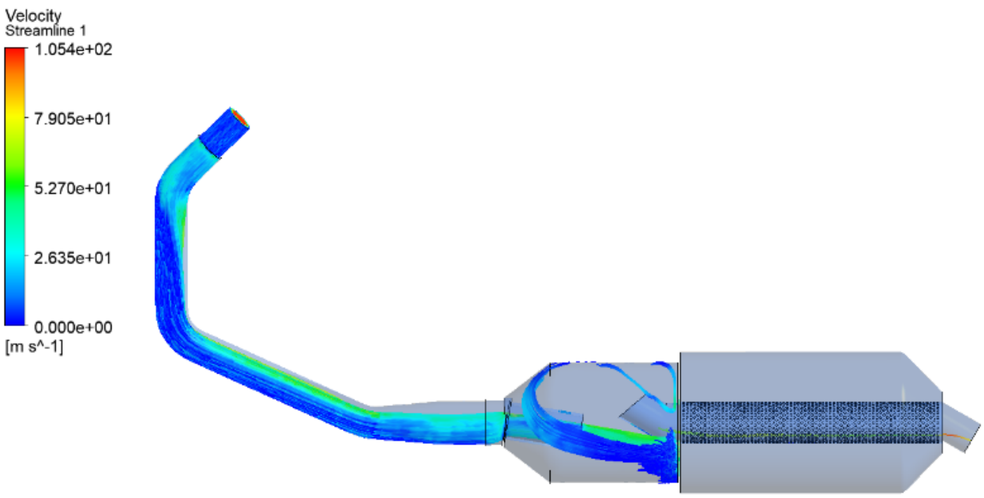


Figure 18. Shijiro Exhaust Airflow at 7500 RPM

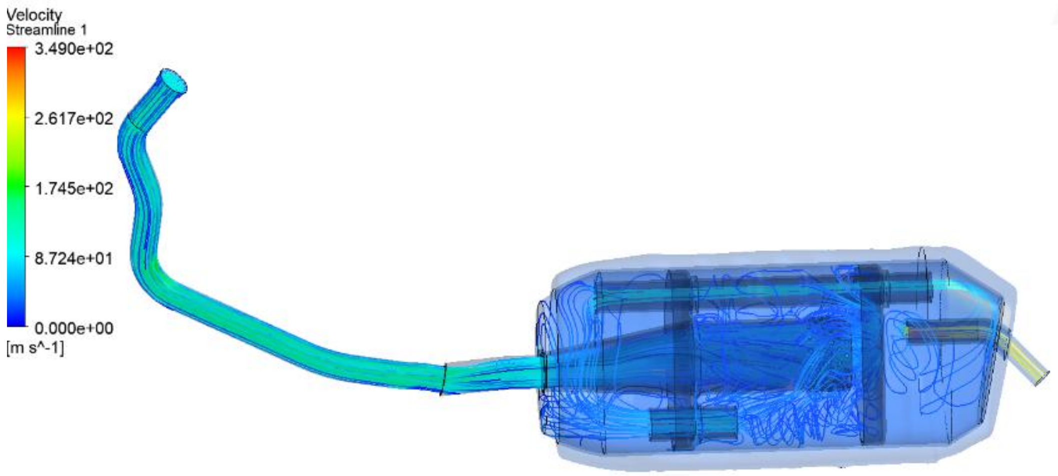


Figure 19. Standard Exhaust Airflow at 7500 RPM

The CFD simulation results revealed the following acoustic values for each exhaust configuration:

1. At 1500 rpm, the Shijiro Racing Exhaust had a maximum acoustic value of 71.7 dB, reaching 117 dB at 7500 rpm.
2. At 1500 rpm, the Standard Exhaust had a maximum acoustic value of 83.6 dB, reaching 139 dB at 7500 rpm.

The standard exhaust uses multiple chambers to induce air rotation and collisions, effectively reducing noise. In contrast, the simpler Shijiro exhaust design allows for brief air rotation in a single chamber before entering a noise-dampening hollow pipe lined with glass wool. This design results in lower exhaust gas velocities than the standard exhaust. The simulations highlight how exhaust construction influences sound, emissions, and power.

4.4 Result Analysis

Based on the study, the analysis shows:

1. The standard exhaust is quieter than the Shijiro Racing exhaust, both meeting Indonesia's noise limit of 80 dB for motorcycles with 80-175 cc capacity. CFD simulations align closely with actual test results, indicating effective noise reduction mechanisms in the standard exhaust through internal reflections and glasswool insulation. The simpler design of the Shijiro exhaust results in slightly louder noise levels, requiring regular maintenance to comply with noise regulations.
2. The standard exhaust emits lower CO (0.14%) and HC (14 ppm) compared to the Shijiro exhaust (0.65% CO and 34 ppm HC), but higher CO_2 (15.08% vs. 9.79%). Both exhausts comply with Indonesian standards for CO and HC emissions post-2018, benefiting from well-designed flow dynamics that enhance combustion efficiency and reduce back pressure.
3. The Shijiro Racing exhaust demonstrates superior torque (13.14 Nm at 4657 rpm) over the standard (12.25 Nm at 4777 rpm), despite slightly lower peak power (10 HP at 6673 rpm vs. 10.4 HP at 8640 rpm). CFD simulations illustrate how exhaust gas circulation affects motorcycle performance, with minor differences between the exhausts in this regard. Both designs ensure efficient gas flow, crucial for optimal engine performance.

Of all the tests and simulations that have been carried out, it is summarized in the Table 5 below:

Table 5. Comparative Conclusions from All Tests and Simulations.

Test	Items	Standard Exhaust	Shijiro Standard Racing Exhaust	Meet Regulations
Noise Test	Indonesian Police Method	67.4 dB	77.8 dB	✓
	Exhaust Noise Method	67.33 dB	72.73 dB	
CFD Noise Simulation	1500 RPM	83 dB	71.7 dB	
	7500 RPM	139 dB	117 dB	
Emission Test	Carbon Monoxide (CO)	0.14%	0.79%	✓
	Carbon Dioxide (CO2)	15.08%	9.79%	
	Hydrocarbon	14 ppm	48 ppm	
Dynotest	Max. Power	10.4 HP at 8640 rpm	10 HP at 6673 rpm	
	Max. Torque	12.25 Nm at 4777 rpm	13.14 Nm at 4657 rpm	

5. Conclusion

Based on the study, the conclusions are as follows: (a) The standard exhaust is quieter than the Shijiro Racing exhaust, meeting Indonesia's 80 dB noise limit for motorcycles of 80-175 cc capacity. The standard exhaust uses intricate design and glasswool insulation for effective noise reduction, while the simpler Shijiro exhaust produces slightly louder sound, requiring regular maintenance for noise compliance. (b) The standard exhaust emits fewer emissions compared to the Shijiro Racing exhaust, meeting Indonesian standards. Design features such as optimized gas flow, exhaust chamber volume and shape, mufflers, and resonators contribute to reducing harmful emissions in the standard exhaust. (c) Performance tests and CFD simulations indicate the Shijiro Racing exhaust delivers superior torque and faster peak power compared to the standard exhaust. Both exhausts facilitate efficient exhaust gas circulation, with minimal impact on overall motorcycle power. This analysis effectively correlates motorcycle performance with CFD simulation results.

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