Designing an Energy-efficient Prototype Vehicle by the Mandalika Desantara Racing Team

Hendry Sakke Tira[a,]*, I Made Nuarsa[a], Renaldy[a]
[a]Department of Mechanical Engineering, Faculty of Engineering, University of Mataram
Jalan Majapahit No 62, Mataram 83115 Nusa Tenggara Barat Indonesia
*hendrytira@unram.ac.id

Abstract

In order to participate in the international fuel-efficient vehicle competition, a team from the Mechanical Engineering department of Mataram University has prepared a prototype vehicle. The competition is The Shell Eco-Marathon, held at the International Pertamina Mandalika Circuit in Lombok in July 2023 and attended by several teams from abroad. For this purpose, the team has developed an energy-efficient prototype vehicle using a two-wheeler engine. The team has modified the two-wheeler engine to achieve more fuel-efficient consumption compared to conventional vehicles. The study involves checking the two-wheeler engine's condition, conducting engine startup experiments, and analyzing engine performance. The Mandalika Desantara racing team reduced the piston diameter to minimize the combustion chamber volume. The results of the engine modification on the prototype vehicle show a fuel consumption rate of 71.66 km/l when driving on the Mandalika circuit. However, this figure has not yet reached the desired level of efficiency, considering that the estimated fuel consumption of vehicles with conventional motor engines is around 40-50 km/l.

Keywords: mandalika desantara, prototype vehicle, sheel eco-marathon, fuel consumption

Abstrak

Dalam rangka ikut serta dalam kompetisi kendaraan hemat bahan bakar tingkat internasional, tim dari jurusan Teknik Mesin Universitas Mataram telah menyiapkan satu unit kendaraan prototipe. Kompetisi yang dimaksud adalah Shell Eco-Marathon, yang diselenggarakan di Sirkuit International Pertamina Mandalika di Lombok pada bulan Juli 2023 dan diikuti oleh beberapa tim dari luar negeri. Untuk itu, tim telah mengembangkan sebuah kendaraan prototipe hemat energi menggunakan mesin motor. Tim telah memodifikasi mesin motor tersebut untuk mencapai konsumsi bahan bakar yang lebih efisien dibandingkan dengan kendaraan konvensional. Studi ini melibatkan pemeriksaan kondisi mesin roda dua, percobaan menghidupkan mesin, dan analisis kinerja mesin. Hal yang dilakukan adalah mengurangi diameter piston untuk meminimalkan volume ruang bakar. Hasil modifikasi mesin pada kendaraan prototipe menunjukkan tingkat konsumsi bahan bakar sebesar 71,66 km/l saat berkendara di sirkuit Internasional Pertamina Mandalika. Namun, capaian ini belum mencapai tingkat efisiensi yang diinginkan, mengingat bahwa perkiraan konsumsi bahan bakar kendaraan dengan mesin motor konvensional adalah sekitar 40-50 km/l.

Kata kunci: *mandalika desantara, kendaraan prototipe, shell-eco marathon, konsumsi bahan bakar*

1. Introduction

The Shell Eco-marathon is an open event for all students. More than 70 student teams from 13 countries in Asia and the Middle East, including China, Malaysia, Qatar, Thailand, and Vietnam, are ready to compete at the Mandalika Pertamina International Circuit in Lombok, West Nusa Tenggara, Indonesia, from July 4th to 9th. As the host country, Indonesia is sending over 40 student teams, the most from any other country. In 2023, the annual competition returns for the first time since the pandemic as a regional event, providing a significant opportunity for more student teams to participate in the competition. The regional Shell Eco-marathon challenge aims to push experienced teams to break new boundaries and encourage innovation and new approaches to achieve energy efficiency.

During the Shell Eco-marathon Asia-Pacific and Middle East 2023, students will compete with ultra-efficient vehicles they have designed and built themselves in two categories: Prototype and Urban Concept, to cover the longest distance using the most efficient fuel. The Prototype category is intended for ultra-efficient, lightweight vehicles, typically with three wheels, designed to reduce resistance and maximize efficiency, while the Urban Concept category focuses on energy efficiency in the design of four-wheeled vehicles resembling conventional passenger cars designed for use on highways. Participants must then choose one of three types of fuel: electric batteries, hydrogen fuel cells, and internal combustion engines (gasoline, ethanol, and/or diesel).

Energy-efficient vehicles play a crucial role in reducing environmental impact by reducing harmful exhaust emissions such as carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter. By decreasing these emissions, energy-efficient vehicles can help protect the air quality we breathe daily, reduce air pollution, and minimize their negative impact on human health and the surrounding ecosystems. Additionally, energy-efficient vehicles can reduce dependence on fossil fuels, which are limited energy sources contributing to global warming and climate change [1-2]. By promoting the use of energy-efficient vehicles, we can move towards a more sustainable and environmentally friendly future.

In addition to environmental benefits, energy-efficient vehicles also make a significant contribution to energy sustainability. By utilizing more efficient technology and energy sources, energy-efficient vehicles can reduce fuel consumption and improve energy use efficiency [3-4]. This not only benefits the environment but also provides economic advantages by lowering vehicle operational costs and reducing dependence on imported fuel. Moreover, the shift to energy-efficient vehicles can stimulate innovation and investment in new technologies supporting energy sustainability, create new job opportunities, and drive sustainable economic growth [5-6]. Therefore, energy-efficient vehicles are not only a solution to reduce environmental impact but also a crucial step towards a more sustainable and environmentally friendly energy future.

Engine modification plays a pivotal role in improving the performance and efficiency of energy-efficient vehicles. One crucial aspect of this modification is reducing engine displacement or cylinder size, aiming to conserve fuel consumption. Several studies have shown the direct correlation between engine displacement and fuel efficiency. For instance, researches have been conducted to demonstrate that decreasing engine displacement by optimizing cylinder size and combustion chamber design can lead to significant fuel savings without compromising performance [7-8]. Similarly, a study has been conducted on engine modifications focusing on reducing cylinder volume, resulting in improved fuel economy and reduced emissions. These findings highlight the importance of engine modifications in achieving higher efficiency levels in energy-efficient vehicles [9].

Furthermore, engine modifications not only enhance fuel efficiency but also contribute to overall vehicle performance. By optimizing engine components such as fuel injection systems, turbochargers, and exhaust systems, energy-efficient vehicles can achieve better power delivery, acceleration, and responsiveness while maintaining lower fuel consumption [10]. Another work explored the impact of engine modifications on vehicle performance and concluded that targeted modifications, such as reducing engine displacement and improving combustion efficiency, can lead to a more balanced and efficient performance profile. Therefore, the significance of engine modification cannot be overstated in achieving both fuel efficiency and enhanced performance in energy-efficient vehicles [11].

Therefore, in this research aimed at creating a prototype vehicle to compete in the Shell Eco-marathon competition, the team from the Mechanical Engineering Department of University of Mataram will modify the existing vehicle's engine displacement with the intention of conserving fuel consumption.

2. Materials and methods

The two-wheeler engine used for the competition is from a 1997 Honda Astrea Grand motorcycle. Table 1 shows the technical data of the engine.

Table 1. Engine specification

Engine specification	Data
Engine type	4-stroke, OHC, air cooling
Engine arrangement	1 cylinder, cylinder bank angle 80°
Bore/stroke	47 x 49.5 mm
Displacement volume	97.1 cm^3
Compression ratio	8.8 : 1
Rated power	7.5 hp / 8.000 rpm
Lubricant oil capacity	0.70 liters
Clutch type	Dual clutch
Gear settings	N-1-2-3-4-N (rotary)
Ignition system	CDI (non-platinum type)

The Mandalika Desantara racing team's task begins with checking the condition of the motorcycle engine to be used. Subsequently, the activity continues with conducting experiments to start the engine, observing and analyzing its performance until the engine reaches an idle or steady state, and determining the components that need to be overhauled or modified. The team reached a decision that the modifications will involve reducing the piston diameter, decreasing the volume of the combustion chamber, creating packing in the cylinder block, and also creating mounts for the CDI (capacitor discharge ignition) and battery.

In designing the prototype vehicle for the competition, there are several rules set by the organizers that must be adhered to by all teams. These regulations guide the Mandalika Desantara team in designing the prototype vehicle so that it can pass the feasibility test before the competition. Some of the important rules related to engine modifications carried out by the team include: only using fuel provided by the organizers and not consuming any engine oil (engine). Furthermore, in the Shell Eco-marathon rules, it is not allowed to use electric fuel pumps commonly used in injection vehicles that are widely marketed. Therefore, the Mandalika Desantara team has created a pressurized air system as shown in Figure 1.

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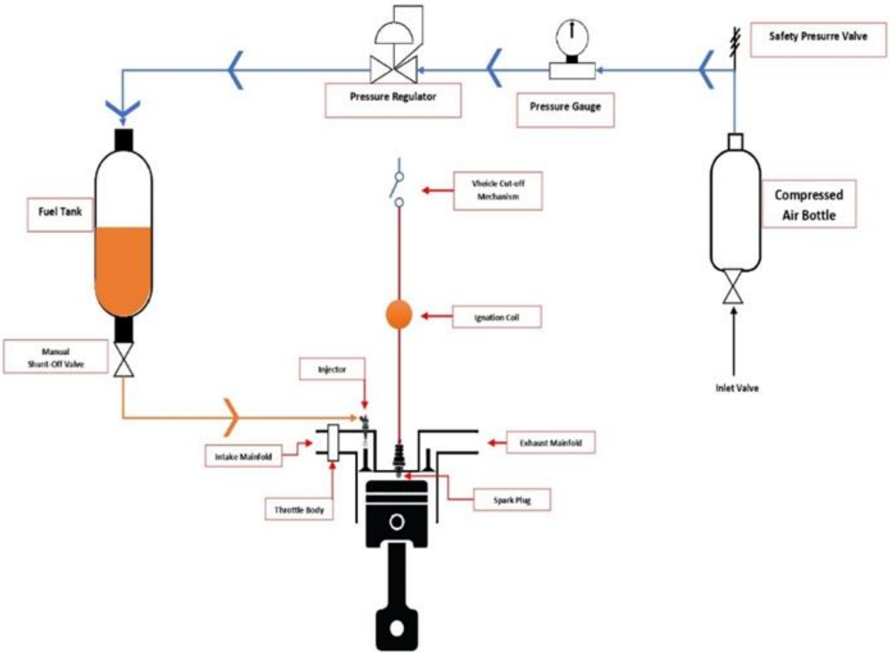

Figure 1. Energy supply diagram

3. Results and discussion

After preparing the motorcycle engine for modification, several changes were obtained, which are presented in this discussion section. The results of the modification to the energy-efficient prototype vehicle engine by the Mandalika Desantara racing team include, firstly, reducing the piston diameter. The reduction of the piston diameter aims to decrease the cylinder volume of the vehicle, where the smaller the cylinder volume, the lower the fuel consumption. Additionally, it is expected to increase the responsiveness and performance of the vehicle. Engines with smaller cylinder volumes tend to have faster combustion cycles and more direct responses to gas input. This can improve vehicle responsiveness and provide better performance, especially in acceleration and maneuvers [12].

The reduction in piston diameter leads to a decrease in the cylinder volume. The extent of the cylinder volume reduction is recorded at 31.6% compared to the original cylinder volume. Due to the reduced cylinder volume, the compression ratio decreases as the combustion chamber volume remains constant. This is highly undesirable as lower compression ratio results in a decrease in vehicle performance. The consequences include increased fuel consumption, decreased combustion efficiency, and reduced vehicle performance [13]. Inadequate compression due to a low compression ratio leads to low temperature and pressure of the fuel-air mixture in the combustion chamber, thereby making the combustion process less efficient. Furthermore, this leads to poor conversion of fuel energy into kinetic energy, resulting in lower vehicle performance [14].

To avoid such occurrences, it is essential to decrease the volume of the combustion chamber, ensuring that the compression ratio remains stable. This reduction in combustion chamber volume is achieved by shaving the outer surface area of the cylinder head and decreasing the size of the intake and exhaust valves. All of these modification works are carried out in the production process laboratory of the mechanical engineering department at the University of Mataram. The purpose of these modifications is to increase the compression ratio of the engine. Increasing the compression ratio in the engine serves several purposes, including improving thermodynamic efficiency. By increasing the compression ratio, the engine can achieve higher thermodynamic efficiency. This is because a higher compression ratio can improve the energy conversion efficiency from fuel to kinetic energy and reduce the amount of energy wasted in the form of heat [15]. Additionally, it is expected that an increase in the compression ratio will reduce fuel consumption. A higher compression ratio can enhance combustion efficiency in the engine, resulting in more power output from the same amount of fuel. This can reduce fuel consumption and improve the fuel economy of the vehicle [16]. The increased compression ratio of the engine after modification is presented below. With these modifications, there is an increase in the compression ratio by 18.2%. To determine the compression ratio, the volume of the combustion chamber or clearance volume (V_c) was first measured, resulting in 6 ml. After measuring the displacement volume (V_d), it was determined to be 56.6485 ml. Therefore, the compression ratio (CR) of the modified engine is 10.44 as shown in calculation equation 1 below.

$$CR = \frac{V_c + V_d}{V_c} = \frac{6 + 56.6485}{6} = 10.44 \tag{1}$$

After the engine modification was completed, the modified engine was then installed in the prototype vehicle that will be used in the competition. The shape of the Mandalika prototype vehicle can be seen in Figure 2.

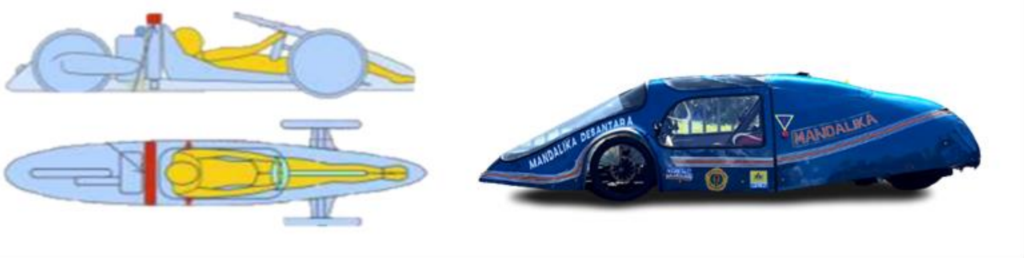

Figure 2. Prototype vehicle

Subsequently, the next testing phase involved evaluating the fuel consumption of the vehicle. Table 2 presents the fuel consumption data of the Mandalika prototype vehicle from the field testing. Five engine settings were tested to determine the optimal fuel usage setting. The engine setting that resulted in the lowest fuel consumption will be applied on the day of the competition. After five adjustments and fine-tuning, especially on the fuel supply mechanism, the best modification was finally achieved as shown in Figure 3. The results indicated that engine setting number five exhibited the best fuel efficiency.

Table 2. Fuel Consumption Testing Data.

Fuel volume (ml)	Fuel consumption time (minute)	Fuel consumption rate (l/hour)	Engine settings	Distance traveled (km/l)	Engine speed (rpm)
100	23.5	0.256	1	117.18	1400
100	35.04	0.171	2	175.44	1400
100	35.47	0.169	3	177.51	1400
100	40.26	0.149	4	201.34	1400
100	42.33	0.141	5	212.76	1400

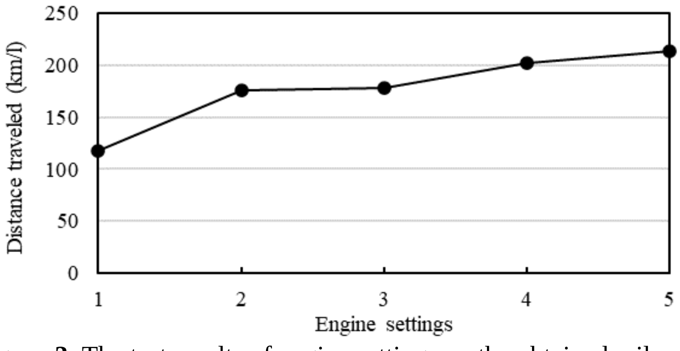

Figure 3. The test results of engine settings on the obtained mileage

The length of the International Pertamina Mandalika circuit track is 4.32 km, and in this energy-efficient competition, each participating vehicle is required to complete three laps within 30 minutes. Therefore, based on the data in Table 2, it can be determined that the minimum average speed for participants to meet the target set by the committee is 26 km/h.

Table 3. Race results data

Parameter	Data
Fuel volume used	250 ml
Remaining fuel	160 ml
Initial air pressure in the compressed bottle	4.5 bar
Remaining air pressure in the compressed bottle	3.5 bar
Average vehicle speed	30-35 km/hour
Mileage	6.45 km

Furthermore, on the day of the Shell Eco-Marathon Asia Pacific and Middle East 2023 competition, team of Mandalika Desantara achieved the results as presented in Table 3.

Based on the data above, it is found that the fuel consumption used in this competition is 90 ml or 0.09 liters. Therefore, the specific fuel consumption used is 71.66 km/l. The result obtained is far from the achievement obtained during the pre-race testing as shown in Table 2. Furthermore, since the air pressure used to pump the fuel is 1 bar, the fuel consumption ratio to pressure is 0.09 l/bar. From the fuel volume allocation given by the committee and the 3 required laps of the circuit, Team of Mandalika Desantara could not use all of their fuel due to a technical issue. However, the overall performance of the modified engine made by the team can function well.

4. Summary

Based on the engine modifications on the prototype vehicle by racing team of Mandalika Desantara, the fuel consumption achieved while racing on the International Pertamina Mandalika circuit is 71.66 km/l. This achievement is considered quite good but not yet optimal. This is because the estimated fuel consumption of vehicles with conventional engines is around 40-50 km/l, so the fuel consumption of the team has not doubled yet. Therefore, further modifications are needed on the engine to achieve an energy-efficient and environmentally friendly vehicle as desired in this competition, in addition to reducing the cylinder volume.

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