DESIGN IMPROVEMENT OF A PROTOTYPE ENERGY-EFFICIENT VEHICLE BODY

Haznam Putra[1a], Ismet Hari Mulyadi[1]

[1]Mechanical Engineering Department, Engineering Faculty, Universitas Andalas, Limau Manis, Padang, 25163, Indonesia

Corresponding:
[a]Mechanical Engineering Department, Engineering Faculty, Universitas Andalas, Limau Manis, Padang, 25163, Indonesia
haznamputra@eng.unand.ac.id

ABSTRACT

In order to achieve an energy-efficient vehicle, many aspects had to be considered, including the weight of the vehicle's body. The weight of the vehicle's body depends on its design and materials. As part of the energy-efficient initiatives, the design of the energy-efficient car developed by a Mechanical Engineering Team of Universitas Andalas needs to be redefined to improve its performance due to its active participation in national competition. Autodesk Inventor software's capability supported a reverse engineering strategy to enhance the car body design. Meanwhile, the appropriate car body material was selected using the Analytic Hierarchy Process (AHP). Furthermore, the improved car body design was evaluated using an academic version of ANSYS R1 and Fluent software. A weight reduction of 8 Kg is gained due to improving the new car body design and with the achievable thickness of 3.4 mm. Accordingly, it could minimize the Coefficient Drag (CD) of the new car body design to 0.066275. This result indicates a further improvement of the new energy-efficient car body design that would accelerate the car's performance and gain better results in the next national energy-efficient vehicle competition.

Keywords : Design, prototype energy-efficient car body, composite

1. INTRODUCTION

Sustainable energy policy has affected many sectors related to energy use. There are two main pillars: how to use energy efficiently and to increase the use of new and renewable energy sources to reduce or replace fossil-derived energy. Fossil energy sources are non-renewable, so their availability will run out in the future.

One sector that consumes much energy is the transportation sector. In Indonesia, the transportation sector will consume more than 63 million kiloliters in 2021[1]. It also contributes to carbon dioxide emissions that impact the global climate. Therefore, several programs and discourses are needed to reduce fossil fuel consumption. One of the steps to save the use of fossil energy sources is the creation of energy-efficient vehicles through optimal aerodynamic approaches, using lightweight materials and innovation in the manufacturing process[2].

Prototype-type energy-efficient vehicles are important for exploring energy-efficiency technologies, especially in competitions like the Contest for energy-efficient cars (KMHE). However, prototype vehicle designs often face aerodynamic efficiency and material compatibility challenges. Therefore, improving the design of this type of vehicle is very important to improve performance while reducing energy consumption.

This research aims to improve the body design of prototype-type energy-efficient vehicles by focusing on improving aerodynamic efficiency through computational fluid dynamics (CFD) using ANSYS R1 Academic Fluent software, weight reduction, and optimization of material selection using the Analytical Hierarchy Process (AHP) method as well as a structured, more accurate and precise vehicle body manufacturing process.

2. RESEARCH METHODS

This type of research is research and development (R&D)—data collection through observation and documentation of practical work. Designing and making a prototype energy-efficient car body is carried out in the Laboratory of the Department of Mechanical Engineering, Andalas University - Padang. Figure 1 shows the stages of work carried out in this research, including literature study, vehicle dimensional design, material selection (AHP Method), body aerodynamic testing, tools, and materials.

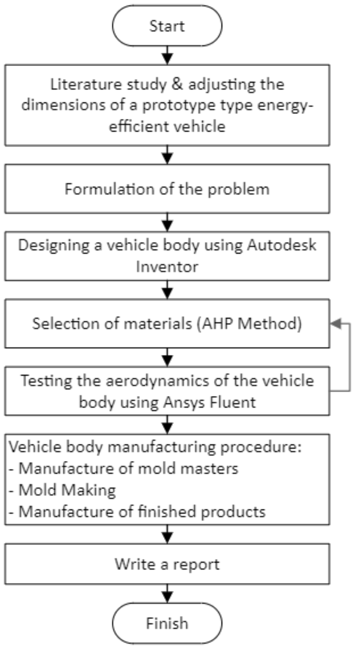

Figure 1. Flowchart

2.1 Literature Study

This stage is the stage of studying and deepening concepts related to the design, selection of materials, manufacture, and aerodynamic testing of energy-efficient car bodies from several sources, including the Internet, books, journals, etc.

2.2 Vehicle Dimensional Design

The body is one of the main parts of the prototype-type energy-efficient vehicle. The shape and dimensions of the vehicle are made by prioritizing and optimizing aerodynamic aspects with a slight drag coefficient to reduce air resistance[3]. In addition, the load from the body is also taken into account so that the resulting body is manageable for engine performance. So, a vehicle with a close-wheel type was built. The advantage of this type is that the vehicle becomes more stable and aerodynamic. This type of closed-wheel vehicle has a bullet-like shape. This form effectively breaks the air when the vehicle reaches maximum speed[4].

The body design using Autodesk Inventor software. By KMHE 2024 regulations, the maximum dimensions of a prototype-type vehicle are shown in Table 1.

Table 1. Maximum dimensions of a prototype-type vehicle [5]

Dimension	Maximum Value
Heigh	100 cm
Length	350 cm
Width	130 cm

2.3 Material Selection (AHP Method)

Body material selection using the analytical hierarchy process (AHP) method, as presented in Figure 2. The Analytical Hierarchy Process (AHP) method is a decision-making technique used to help select or evaluate alternatives in complex situations[6]. Thomas L. Saaty developed this method in the 1970s. AHP allows decision-makers to consider multiple criteria and alternatives in an organized hierarchical structure.

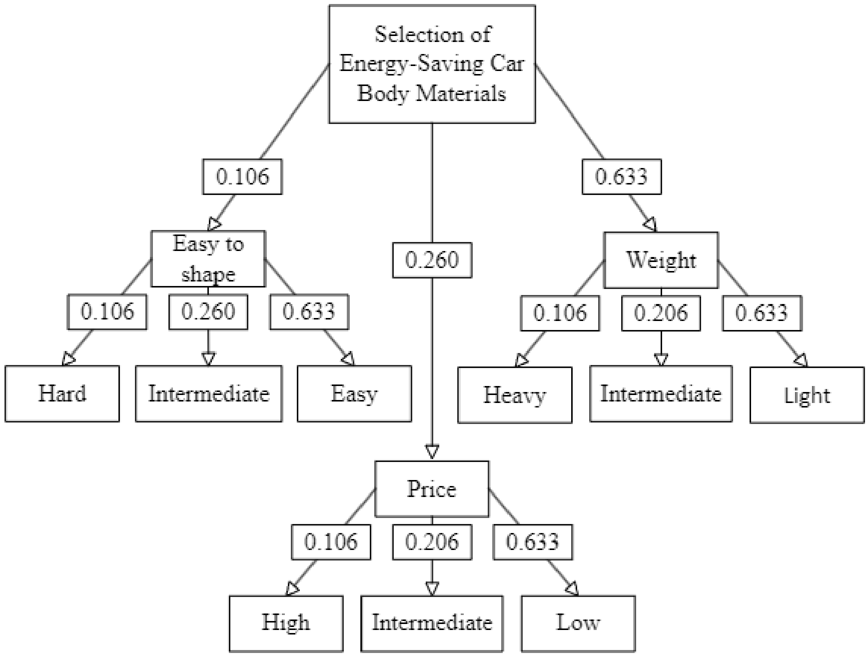

Figure 2. AHP hierarchical structure of car body material selection

Table 2. Final results of body materials selection using the AHP method[7]

	Easy to Shape	**Price**	**Weight**	**Total**	**Rank**
Aluminum	0.028	0.068	0.067	0.163	3
Carbon Fiber	0.011	0.028	0.401	0.440	2
Fiberglass	0.740	0.165	0.165	1.069	1

Based on the final results of material selection using the AHP method in Table 2. The material used for the body is a composite of fiberglass and carbon fiber. Fiberglass is the choice because it has a relatively low price, the material is strong and easy to shape, and it does not require special tools in its manufacture. The main ingredient of fiberglass is glass, which is more brittle (easily broken).

Carbon fiber is a composite material reinforced by fiber for carbon fiber or reinforced plastic materials. Epoxy is a type of plastic that is commonly used; besides that, some use polyester or vinyl ester. Carbon fiber is light, strong, and stiff. Carbon fiber is also easy to form. The advantages are directly proportional to the price. Both fiberglass and carbon fiber materials are considered when making the designed vehicle body[8].

The fiberglass that is chosen is the type of E-glass where its properties are :

- Density 2,58 g/cm³
- Tensile Strength 3450 Mpa
- Elasticity Modulus 72,5 Gpa

The chemical composition of the E-glass type fiberglass is 54 % SiO_2, 14% Al_2O3, 22% MgO+CaO, 10% B_2O_3, and 2% Na_2O+K_2O. It is known that the general composition of E-glass fiberglass is SiO_2. The higher the SiO_2 value, the higher the hardness value of the composite, and the lower the water absorption capacity.

Based on the fiber orientation, the type of fiberglass used is woven roving. Where the fibers are arranged perpendicular to each other, the fiber directions 0° and 90° have the highest strength in this arrangement. Figure 3 shows the woven roving used: woven roving 600 with a thickness of 600gr/m² for making prints and woven roving 400 with a thickness of 400gr/m² for making finished products.

In addition, chopped strand mat-type fiberglass is also used to manufacture finished products.

Figure 3. Woven Roving

In composites, the main requirement for the matrix used is that the matrix must be able to transmit the load so that the fibers can attach to the matrix and be compatible between the fibers and the matrix, meaning that there are no disturbing reactions. Therefore, the selected epoxy resin with mechanical properties as follows:

- Density 1,11-1,40 g/cm³
- Tensile Strength 27,6-90 MPa
- Elasticity Modulus 2,41 GPa

One of the additional materials used is a catalyst. Where the function of the catalyst is to accelerate the drying reaction at room temperature; however, mixing the catalyst into the resin must comply with the rules recommended by the resin manufacturer so as not to affect the properties of the composite material. The type of catalyst used is adjusted to the brand and type of epoxy resin itself.

In addition, additional release agent ingredients are also used. The release agent is a material that functions as a lubricant in the manufacture of composites, making it easier to release the surface of the glass mold evenly before printing the composite begins. One that is used is mirror glass and PVA (Polyvinyl Alcohol).

Overall, the targeted body weight is no greater than 20 kg. This is because the body is designed as a car coating to break up the fluid flow, thereby increasing fuel efficiency, and with this light body it will not aggravate engine performance, as well as the mechanical properties of fiberglass composites and epoxy resin according to the literature are :

- Tensile Strength 1020 MPa
- Elasticity Modulus 45 GPa
- Density 2,1 gr/cm³

2.4 Body Aerodynamic Testing Simulation

Aerodynamics is an essential part of the prototype-type energy-efficient vehicle body design, where fuel efficiency and vehicle performance can be maximized with good planning.

Savings on fuel consumption and vehicle stability can be increased if the value of drag or Cd (drag coefficient) owned by the vehicle is small. The design is done by making the vehicle's body have a round and straight shape, starting from the front cabin to the rear body, a streamlined shape resembling an airplane design (airfoil shape). When viewed from above, the vehicle design is also gradually made narrower when approaching the rear area (boat model) to reduce the turbulence area in the rear area when the vehicle moves[9]. The drag coefficient of the prototype-type energy-efficient vehicle body must be lower than a typical vehicle's drag coefficient, as seen in Table 3.

Table 3. Classification of car types based on drag coefficient [10]

No.	Car Types	Drag Coefficient
1	Saloon Car	0,22-0,4
2	Sports Car	0,28-0,4
3	Light Van	0,35-0,5
4	Buses and coaches	0,4-0,8
5	Articulated trucks	0,55-0,8
6	Ridged truck & drawbar trailer	0,7-0,9

Based on the vehicle design, a three-dimensional aerodynamic analysis was carried out using ANSYS R1 Academic Fluent software to see whether the vehicle design met the standards for making cars with a drag coefficient and small resistance to increase the efficiency of the vehicle.

2.5 Tools and Materials

Table 4 presents the tools and materials used to manufacture the energy-efficient car body prototype.

Table 4. Tools and Materials

Tools	Materials
Saw	Carbon Fiber
Hammer	Plywood
Measuring cup	Clay
Stirrer	Epoxy Resin
Print master	Woven Roving (Fiberglass)
Brushes	Chopped strand mat
Vacuum cleaner	Catalyst
Mold	Talc
	Erosil
	Color Pigment
	Mirror glaze
	PVA
	Putty
	Paint
	Thinner
	Nails
	Sandpaper

3. RESULT & DISCUSSION

According to the KMHE regulations, in Figure 4 the dimensions of the prototype-type vehicle are designed as follows. The vehicle height is 72 cm, the vehicle width is 68 cm, and the vehicle length is 272 cm.

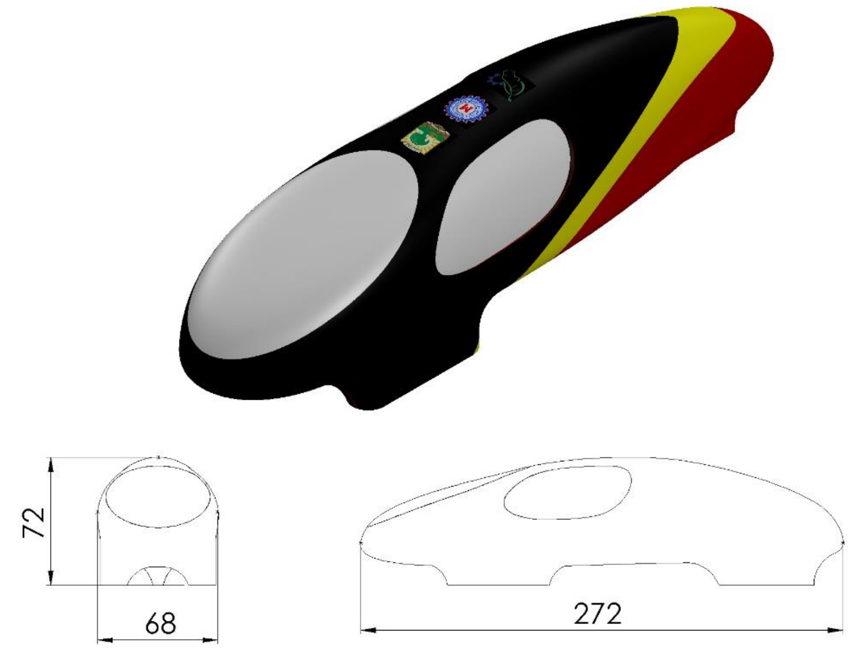

Figure 4. Three-dimensional body

3.1 Body Aerodynamics Simulation Results Analysis

Figure 5 shows the aerodynamic test results on the body of this prototype energy-saving vehicle as follows.

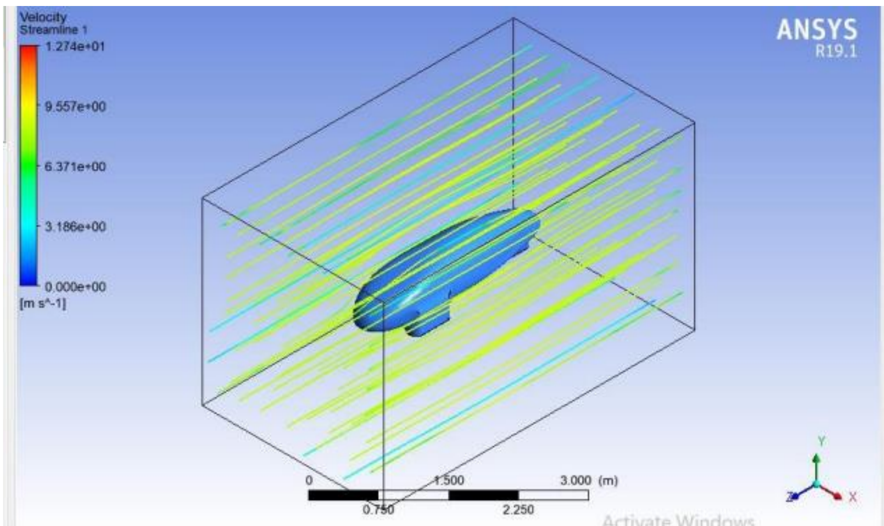

Figure 5. Aerodynamic Analysis of a Prototype Energy-Saving Car with a Vehicle Speed of 8.3 m/s Viewed in 3D

Figure 6. Calculation of Cd in the Body

Based on the aerodynamic simulation results with ANSYS Fluent software above, in Figure 6, the drag coefficient is obtained with an average of 0.066275 from 200 iterations. This result is better than the previous type. It can be seen that fluid flow can easily flow through the car body. This is because the shape of the car body is designed to follow the direction of fluid flow (streamline). The aerodynamics of this body will reduce the friction between the body and the air. Wind resistance in the vehicle can affect the vehicle's direction's stability. The smaller the drag coefficient of a vehicle, the smaller the air resistance and the less impact on fuel consumption. Likewise, in the case of vehicle stability, if the drag coefficient gets smaller, the vehicle stability will also be better. Based on the analysis above, it can be concluded that the vehicle body has a slight drag coefficient, so fuel consumption is small and has good vehicle stability[11].

3.2 Body Manufacturing Process

The process of making the body is divided into three main stages, as shown in Figure 7: making the master mold, making the mold, and making the finished product.

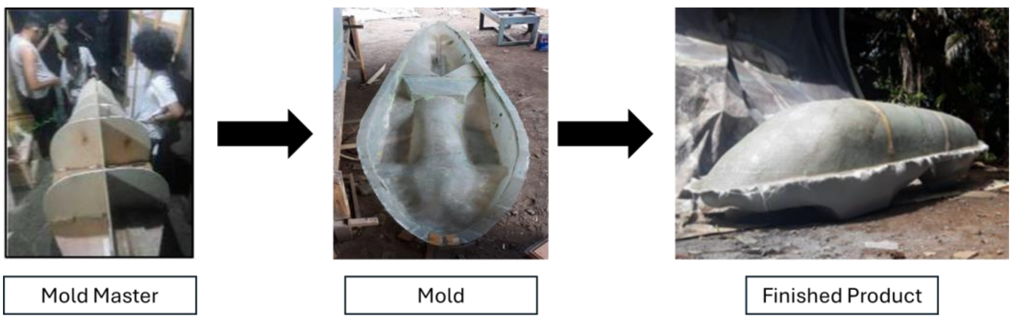

Figure 7. Body Manufacturing Process

3.2.1 Mold Master Making

The master mold is used to help make the main mold. The main material for making the mold master is plywood with a thickness of 9 mm and 3 mm, which is used to make the partitions, and the clay is used to fill the partitions. Additional materials are putty, nails, and sandpaper sizes 80 and 150. The tools used in this process are saws, hammers, and putty brushes. To create a mold master, prepare a 9 mm plywood board, divide the car body into four equal quadrants, draw a body sketch, cut parts, and assemble the main part. Sketch the necessary sides for detail, and ensure sufficient insulation from 3 mm plywood. Cut and paste the insulation on the main part to create the desired shape.

3.2.2 Mold Making

Molds are molds that can be used repeatedly. The main condition of the mold is that it must be stronger than the product to be made. The main materials are epoxy resin, fiberglass, and chopped strand mats. Additional materials include catalyst, talc, erosil, color pigment, mirror glaze, PVA, sandpaper, putty, paint, and thinner. The tools used are print masters and brushes. To create a mold, mix 1.5-2 liters of resin with talc, add a catalyst if too thick, and add erosil and color pigment. If it is too thick, add more catalysts. Polish the surface with mirror glaze, coat it with PVA, and lay up layers of chopped strand mat, carbon fiber, and base material. Add up to 3 fiber layers, four base layers, and one mirror glaze layer for easy removal. To achieve better results, wait for the mold to dry, which can be done in the sun. After drying, clean the surface and remove carbon fiber if hardened. In the final refinement stage, sand, caulk, and paint the print.

3.2.3 Manufacturing of Finished Products

The finished product is the body that will be used in the vehicle. The main ingredients are chopped strand mats, carbon fiber, epoxy resin, and catalysts. Additional materials, namely, PVA, mirror glaze, color pigments, talc, and erosil. The tools used are vacuum cleaners, molds, and brushes. The finished product involves smearing a mold surface with mirror glaze and PVA, then evenly distributing the basic dough/mixture, waiting for half-drying, applying chopped strand mat, covering 400 woven rovings, and then the base material. The coating consists of one layer of roving, one layer of mat, three layers of base material, one layer of PVA, and a mirror glaze. Basting dough prevents air bubbles, ensuring fiberglass durability. Thicker layers of chopped strand mats and reinforcement like iron or plywood are used. Rolling is used to adjust indentations or grooves, and drying in the sun speeds up the process.

4. CONCLUSION

Three results are obtained in the manufacturing process, namely Master Mold, Mold, and Finished Product. The finished product follows the pre-planned design. Aerodynamic simulation results obtained a drag coefficient of 0.066275 from 200 iterations. The prototype energy-efficient car is made of fiberglass and carbon fiber composite. The final body weight obtained is 17 kg (8 kg lighter than the previous model) and 3.4 mm thick.

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