Shell Eco-marathon

OFF-TRACK AWARDS

VEHICLE DESIGN AWARD

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ID0008001

ITS TEAM SAPUANGIN

INSTITUT TEKNOLOGI SEPULUH NOPEMBER

ABSTRACT

Cars are one of the most widely used vehicles for daily activities. However, most cars use petroleum fuel which is a non-renewable energy source. The limitations of petroleum fuel and its negative impact on the environment have encouraged energy-saving vehicles. Therefore, it is necessary to develop cars that have high energy efficiency. The ITS Team Sapuangin is dedicated to improving vehicle energy efficiency by continuously innovating various aspects of our car, including the body, chassis, engine, and wheels, all of which contribute to the overall vehicle performance. The analysis was conducted using Ansys 2021 R2 and CATIA software. In terms of aerodynamics, the car achieved a drag coefficient of 0.14 and a drag force of 9.64 N, requiring 1,075,141.86 J of energy to complete one lap at the Losail short circuit. The ergonomic simulation yielded a score of 2 for intermittent conditions and 3 for repeated conditions. These values indicate that the seating position is ergonomically sound. Safety features were also carefully considered, including the safety belt, firewall, and roll hoop, which has a safety factor above 2, making it safe for use. Our latest innovation is a composite steering wheel made of carbon fiber with a balsa core, resulting in a maximum total deformation of 0.06 mm and a maximum shear stress of 2.4 MPa under load. The research results were obtained through experimental research and simulation methods. The research phases began with initial component design using Solidworks software to create 3D models. Subsequently, aerodynamic analysis was performed using ANSYS 2021 R2 with Computational Fluid Dynamics (CFD) simulation to evaluate air resistance performance. Ergonomic simulation was conducted using CATIA software with Human Modeling to obtain ergonomic scores. Safety analysis involved structural strength evaluation using Finite Element Analysis (FEA) to calculate deformation and stress on components such as the roll hoop and steering wheel. The obtained data was then verified through field testing to ensure consistency with simulation results.

Keywords : Aerodynamics, Ergonomics and Safety, Steering Wheels, Wood Core Material

1. Introduction

Fundamentally, a high-efficiency vehicle does not depend only on an engine that has low consumption of fuel but also depends on other supporting components. For example, the chassis and body must be as light as possible, while the body must be perfectly aerodynamic, though function must not be compromised. As well as Sapuangin ITS XI Evo 4 Team vehicle, which was engineered with comprehensive consideration of all factors that may influence its performance

A recent innovation applied to our car is the use of a steering wheel made from a carbon sandwich material with a wooden core, sourced from repurposed wooden shipping boxes. This approach aims to recycle unused materials into functional components that can be reused effectively. Innovation after innovation is continuously pursued to enhance the efficiency of this energy-saving vehicle. Through these efforts, we hope to make a significant contribution to advancing the understanding and practice of better vehicle design while driving innovation within the automotive industry.

2. Aerodynamics

The Sapuangin XI Evo 4.0 is an urban concept car that utilizes a double-layer carbon fiber material. With this material, the total weight of the Sapuangin IX Evo 4 is 109 kg, and the overall body weight is 14.8 kg. The body design of the Sapuangin XI Evo 4.0 features a noticeable inclination, resulting in a difference in ground clearance between the front and rear sections. This design is inspired by the Venturi effect, where the ground clearance is intentionally reduced to create a pressure difference between the front underside and the rear of the car. This effect increases the airflow beneath the car, leading to a pressure difference at the front, rear, and underside of the vehicle. As a result, the airflow velocity under the car becomes faster compared to the front and rear sections, as illustrated in the following picture.

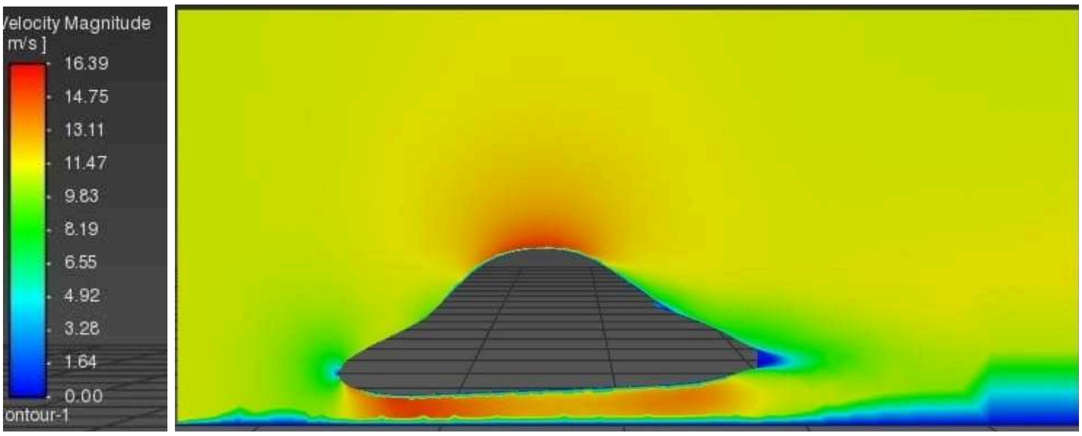

Figure 1. CFD by Velocity

Figure 1 shows the airflow pattern around the body of the Sapuangin XI Evo 4.0, analyzed through velocity simulation. The assumed velocity is 40 km/h. The various colors displayed represent different velocities, with notably high velocities observed in the underbody area due to the narrowing of the surface area available for air passage. At the rear of the body, there is a wake or turbulent region, which contributes to the vehicle's drag force.

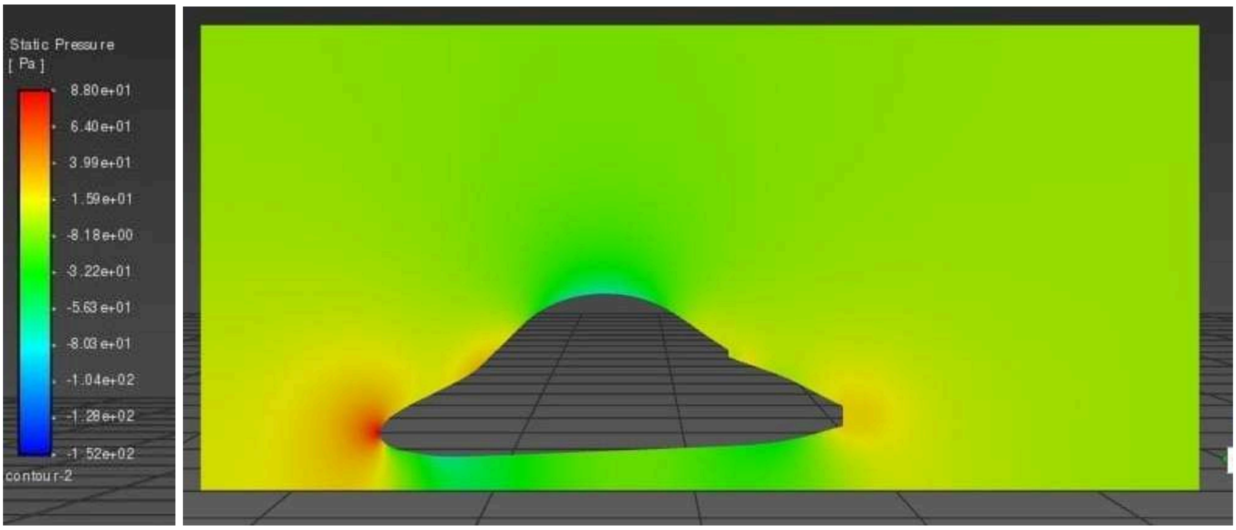

Figure 2. CFD by Pressure

Figure 2 displays the CFD simulation based on pressure distribution. Pressure and velocity are interrelated, where high pressure corresponds to low velocity, and vice versa. The pressure differential between the front and rear sections of the body is what generates the drag force.

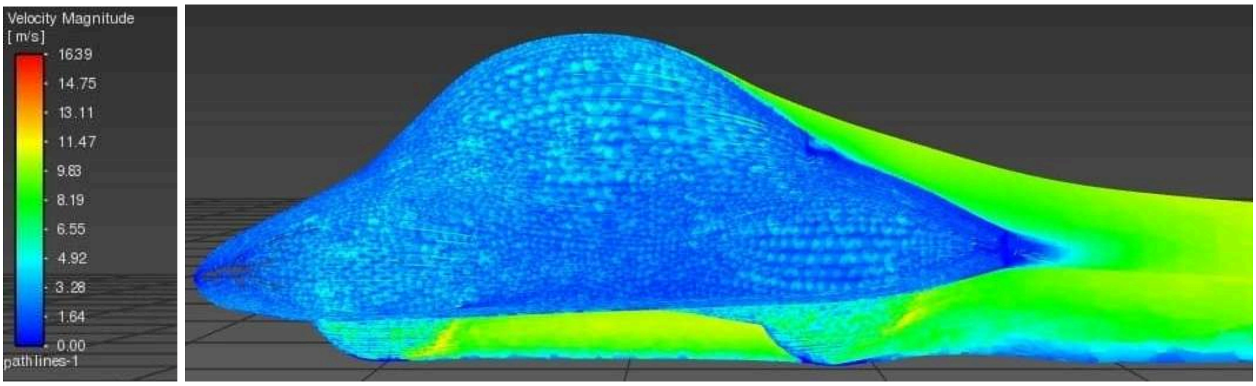

Figure 3. Wake Turbulence of Sapuangin XI Evo 4.0

Figure 3 illustrates the effects occurring on the body of the Sapuangin XI Evo 4.0, including the wake formation at the rear section of the vehicle body. Based on the CFD simulation results, the following data has been collected, as shown in the table below.

Table 1. CFD Results

Drag force	9,64 N (0,98 kg)
Lift force	-7,24 N (0,73 kg)
Frontal area	0,86 M
Drag coefficient	0,14
Lift coefficient	- 0,11
Drag / Lift Ratio	-1,27

The section shown in **Figure 3** highlights the wake region. This occurs because the airflow over the vehicle's body loses momentum, causing the air to create separation points where it no longer adheres to the body contour. This loss of momentum results in the formation of a wake behind the vehicle. The CFD simulation results also indicate a drag coefficient of 0.14. This drag coefficient reflects the efficiency of the car's performance. The calculation is as follows.

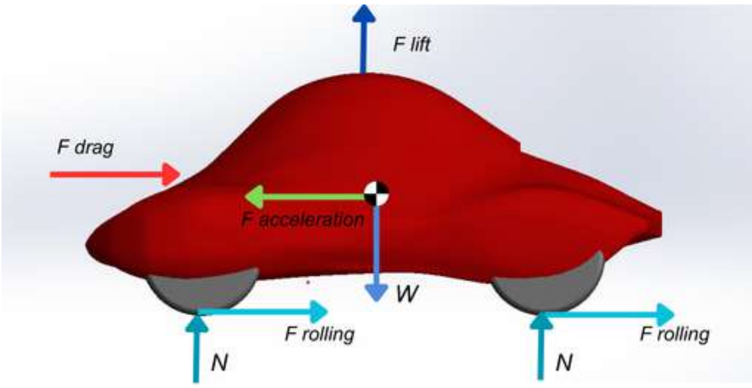

Figure 4. Wake Turbulence of Sapuangin XI Evo 4.0

- **Drag Force**

$$F_{drag} = \frac{1}{2} \times \rho \times A \times Cd \times V^2$$
$$F_{drag} = \frac{1}{2} \times 1,293 \times 0,88 \times 0,132 \times 40^2$$
$$F_{drag} = 8,43\ N$$

- **Rolling Force**

$$F_{roll} = ((m \times g \times cos(\theta)) - F_{lift}) \times Cr$$
$$F_{roll} = ((176 \times 9,81 \times cos(0)) - 8,4) \times 0,0013$$
$$F_{roll} = 2,23\ N$$

- **Acceleration Force**

$$F_{acceleration} = m \times a$$
$$F_{acceleration} = 176 \times 1,59$$
$$F_{acceleration} = 279,84\ N$$

- **Total Energy**

$$E_{total} = (F_{drag} + F_{roll} + F_{acceleration}) \times \Delta s$$
$$E_{total} = (8,43\ N + 2,23\ N + 279,84\ N) \times 3701$$
$$E_{total} = 1075141,86\ J$$

Based on the total energy calculation, it requires 1075141.86 J to complete 1 lap on the Losail short circuit.

3. Ergonomics and Safety

A. Ergonomics

In terms of ergonomics, the driver's seating position while operating the vehicle needs to be analyzed. To analyze the ergonomics of the driver's seating position, we chose to use CATIA software as our analysis tool. In CATIA, the driver - referred to as a manikin in the software - is positioned to replicate the actual driving position when operating the Sapuangin Evo 4 vehicle. The software then generates a score to evaluate ergonomic efficiency. The scoring range is from 1 to 7, where lower numbers indicate better ergonomic conditions. The score is determined not only by the seating position but also by how frequently the driver moves within a one-minute period, which is referred to as "Posture" in CATIA. CATIA classifies Posture into three categories: Static, when the driver remains motionless;

Intermittent, when the driver moves less than 4 times per minute; and Repeated, when movement occurs more than 4 times per minute.

Figure 5. Driver Seating Position

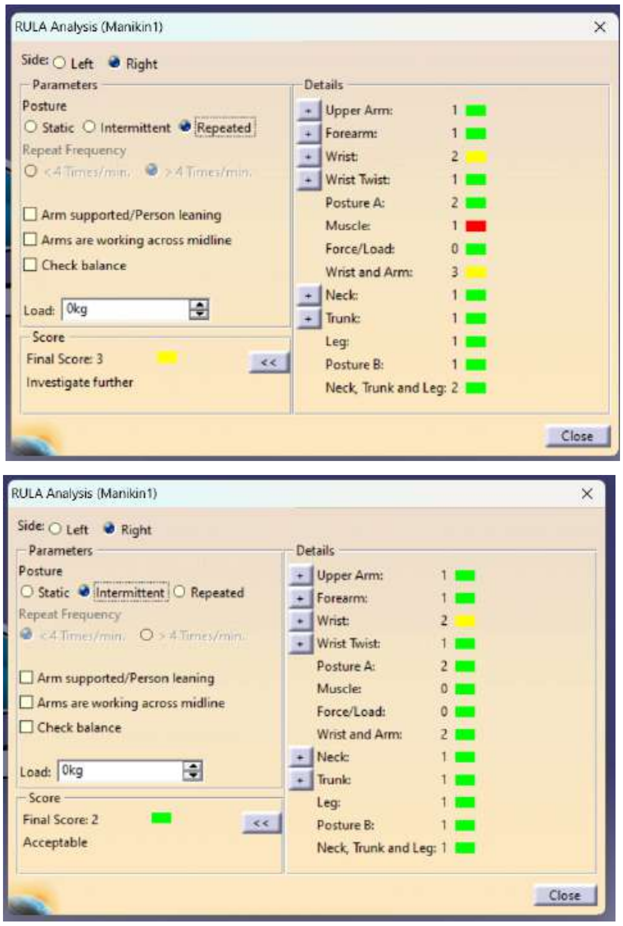

Figure 6. Ergonomic analysis results based on Repeated and Intermittent

After the manikin position was input according to the driver's position while driving the car as shown in **Figure 5**, ergonomic values of 2 for Intermittent conditions and 3 for Repeated conditions were obtained as shown in **Figure 6.** It can be concluded that the driver's position is already ergonomic in both types of posture, however, further evaluation is still needed, especially in repeated conditions.

B. Safety

The safety aspects are analyzed based on three critical factors: safety belt, fire wall, roll hoop

Body Works

The body is a vital component that functions as driver protection, especially in collision situations. Beyond protection, the vehicle body also serves to reduce aerodynamic drag, which helps improve fuel efficiency, and contributes to the vehicle's aesthetic appeal. According to the Shell Eco Marathon 2025 regulations, aerodynamic devices which adjust or are prone to changing shape due to wind are not allowed.

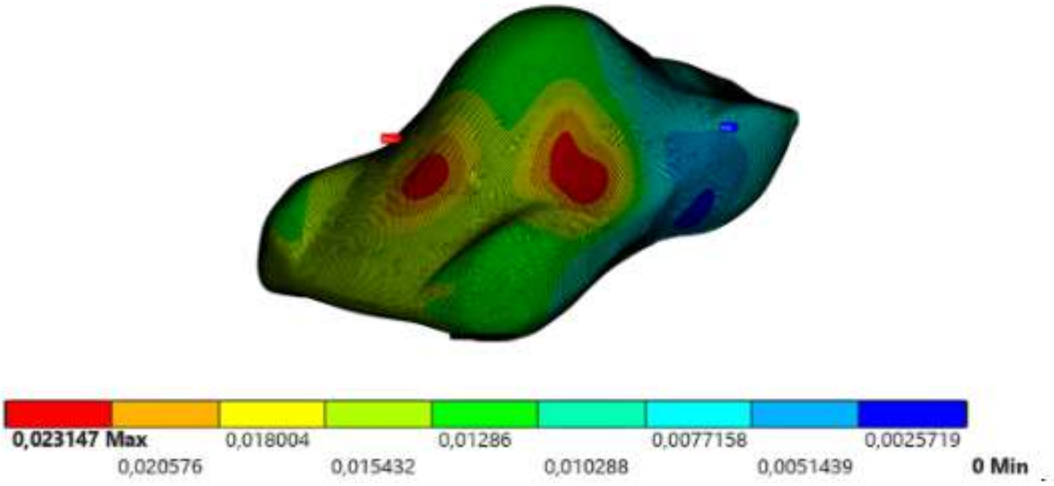

Figure 7. Ergonomic analysis results based on Repeated and Intermittent

In **Figure 7**, the loading can be seen distributed across the frontal area of the vehicle. This setup simulates wind impact on the front of the vehicle that directly collides with the body. In this simulation, a load of 20 N was applied, derived from the wind speed's resulting drag force. The vehicle body exhibited a total deformation of 0.023 mm in this simulation. With such a minimal value, it can be concluded that the Sapuangin IX's body experiences negligible deformation and still complies with existing regulations.

Safety Belt

In four-wheeled vehicles, a harness is a mandatory safety component that must be installed in every vehicle, particularly in four-wheeled automobiles. The safety belt serves a crucial function in driver safety, as it protects and restrains all occupants inside the vehicle from sudden movement or ejection during an accident. Consequently, this minimizes the potential for impact against hard surfaces, thereby reducing the risk of severe injury or fatality.

Figure 8. Safety Belt System in Sapuangin IX Evo 4.0

The Sapuangin IX Evo employs a 6-point safety belt system, which is subject to specific installation regulations. The safety belt installation in the Sapuangin IX Evo has been implemented in full compliance with existing standards, as illustrated in the above image.

Fire Wall

The firewall is crucial for driver safety, serving as a barrier that separates the engine compartment from the driver's cockpit. Its primary function is to protect the driver from fire and provide thermal insulation from the engine bay. The firewall must not have any gaps between the cockpit area and the engine compartment. The firewall implementation in the Sapuangin IX EVO 4 is as follows figure below:

Figure 9. Firewall in Sapuangin IX Evo 4.0

In addition to its primary function as a heat and fire barrier, the firewall plays a vital role in preventing engine compartment pollutants from entering the cockpit. During engine operation, various exhaust gases and hazardous particles are produced from the combustion process, including carbon monoxide, which is dangerous when inhaled. A well-designed and perfectly sealed firewall prevents these harmful gases from penetrating the cockpit, ensuring that the air in the driving compartment remains clean and safe for the driver to breathe. Furthermore, engine combustion gases entering the cockpit would significantly impair driver concentration due to their unpleasant odors.

Roll Hoop

The Roll Hoop is a crucial part of a vehicle, and this frame component is vital for protecting drivers from potentially severe injuries. The Roll Hoop's primary function is to protect the driver in the event of a vehicle rollover, and it also serves as the mounting point for the safety belt. According to Shell Eco Marathon Rules, the roll bar (roll hoop) must be capable of withstanding a static load of 700 N applied in vertical, horizontal, or perpendicular directions without experiencing deformation. As mentioned in Article 26, point B.

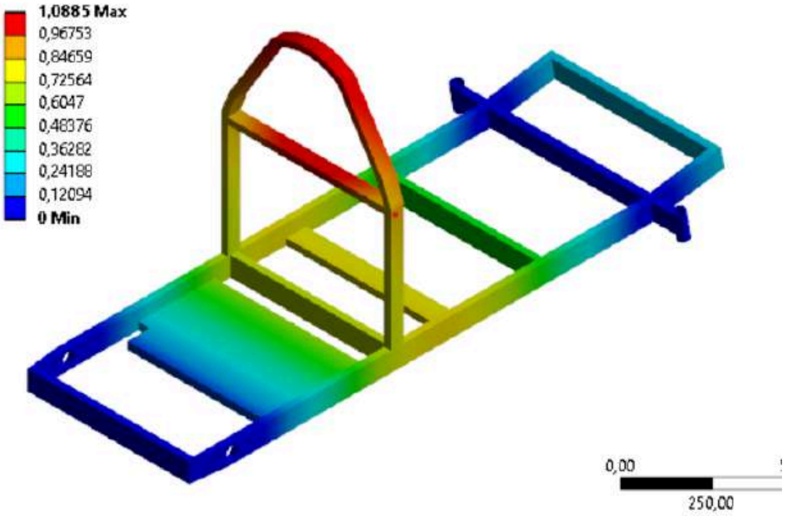

Figure 10. Safety factor and total deformation chassis given to -y direction

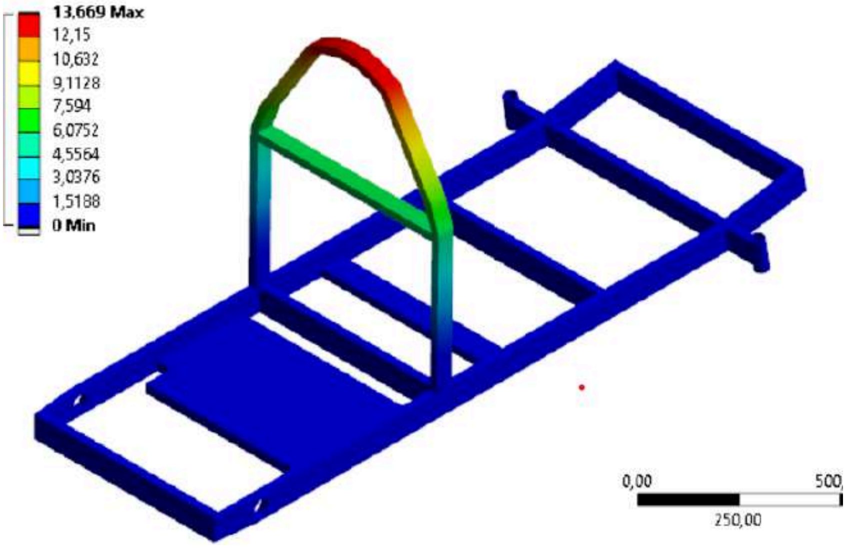

Figure 11. Safety factor and total deformation chassis given to -z direction

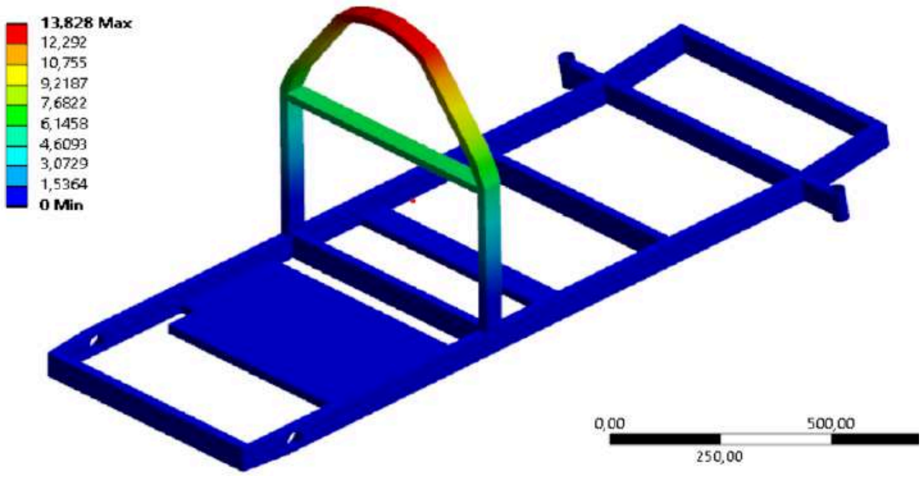

Figure 12. Safety factor and total deformation chassis given to z direction

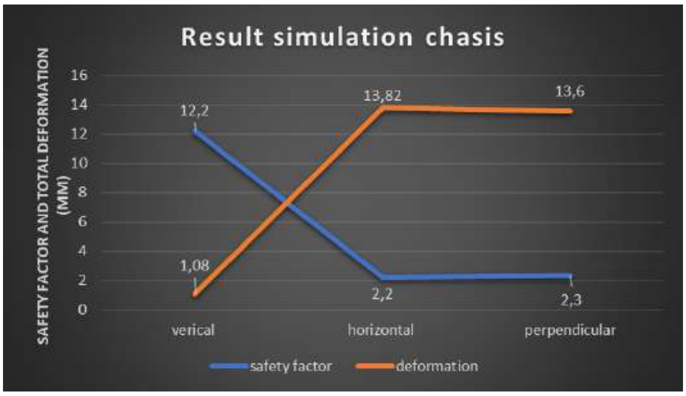

Figure 13. Safety factor and total deformation chassis given to z direction

The conclusion from this chassis design demonstrates that the average safety factor obtained remains above two (2). According to the book Design of Machine Elements by V.B. Bhandari, the recommended safety factor for static loads ranges from 1.5 to 2. Therefore, this chassis design can be considered safe as it meets the suggested safety factor standards.

4. Aesthetics

The Sapuangin XI Evo 4.0 vehicle draws inspiration from the aerodynamic design of aircraft wings or airfoils, which are renowned for their low drag coefficients. This design is engineered to minimize drag force, significantly enhancing the vehicle's efficiency. With reduced air resistance, energy consumption can be minimized, making this vehicle more fuel-efficient and environmentally friendly. This aerodynamic innovation serves as one of the key elements in supporting more efficient and sustainable vehicle performance.

Direct Front and Direct Rear

¾ Front and ¾ Rear

Right Side and Left Side

Top View and Cockpit View

5. Technical Feasibility

This part of the paper outlines the development process and organizational strategies for the Sapuangin XI Evo 4.0 project, a vehicle designed for the Shell Eco-marathon Asia Pacific and the Middle East 2025 competition. It provides a comprehensive overview of the project’s time allocation, teamwork structure, and collaboration methods, ensuring a systematic and efficient approach to achieving the project goals. Through detailed planning and coordination, the team aims to deliver a high-performance and innovative vehicle that meets competition standards.

Project Time Allocation, Team Structure, and Collaboration Method

The teamwork allocation for the Sapuangin XI Evo 4.0 project is organized into specific divisions with clear roles and responsibilities. This structured approach ensures effective collaboration and clarity in achieving the project's objectives.

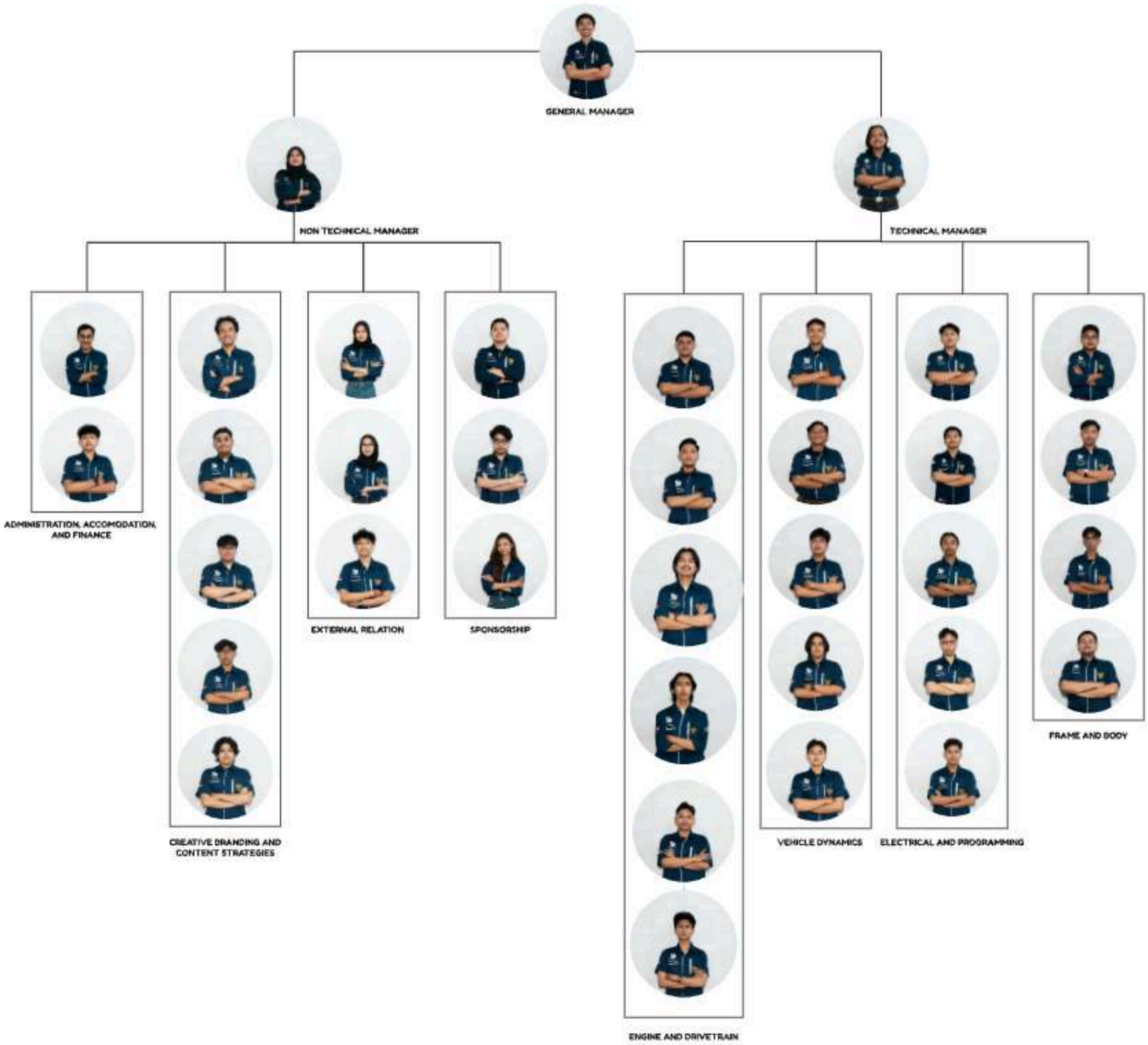

Figure 14. ITS Team Sapuangin Organizational Structure

The above image represents the organizational structure of our team working on developing our urban concept vehicle for the Shell Eco-marathon Asia Pacific and Middle East 2025 competition. The Sapuangin team structure is divided into several divisions, each with specific responsibilities. At the helm of the organization stands the General Manager, who oversees two primary branches: the Technical and Non-Technical divisions, each led by their respective managers. The Non-Technical branch comprises four essential divisions.

- Administration, Accommodation, and Finance division manages operational logistics and fiscal responsibilities.
- Creative Branding and Content Strategies team develops and maintains the team's image and communication materials.
- External Relations division facilitates partnerships and community engagement.
- Sponsorship team secures and maintains vital funding relationships necessary for the team's sustainability and success.

On the technical front, four specialized divisions work collaboratively to bring our urban concept vehicle to life.

- Engine and Drivetrain division focuses on powertrain development and optimization.
- Vehicle Dynamics specialists ensure optimal performance and handling characteristics.
- Electrical and Programming team handles all electronic systems and software integration.
- Frame and Body division is responsible for the vehicle's structural integrity and aerodynamic design.

This comprehensive organizational structure ensures that every aspect of our project receives dedicated attention from specialized team members. The clear delineation of responsibilities, coupled with strategic integration between technical and non-technical divisions, positions the Sapuangin Team to effectively compete and excel in the Shell Eco-marathon challenge. Each division is staffed with qualified team members who bring their expertise and commitment to their respective areas, working in harmony toward our common goal of innovation and excellence in sustainable mobility. The project time allocation for the Sapuangin XI Evo 4.0 is divided into four key phases. This timeline ensures a structured approach to completing the project efficiently.

Table 2. Vehicle Production Timeline

Timeline Allocation Vehicle Production																					
Project	Person In Charge	Man Hours (Week)	Percentage Done	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
				August	September					October				November				December			
Evaluating for improvement vehicle	Tri	2	4.35%																		
Rewiring designing	Ilmi	3	6.52%																		
Quality control checks for Chassis and Body	Nico	2	4.35%																		
Engine selection	Paksi	2	4.35%																		
Enginine assembly	Rifky	3	6.52%																		
Transmission assembly	Adit	3	6.52%																		
Installation of exhaust system	Hanif	3	6.52%																		
Quality tetsing of assembled powertrain	Satria	4	8.70%																		
Installation of brake system	Aldi	3	6.52%																		
Installation of steering system	Rama	3	6.52%																		
Wheel and tire mounting	Kyle	4	8.70%																		
Wiring installation	Idris	2	4.35%																		
Seat installation	Nico	2	4.35%																		
Wheel alligment	Reza	3	6.52%																		
Fluid filling	Satria	1	2.17%																		
Battery installation	Andi	1	2.17%																		
Final quality inspection	Yudis	1	2.17%																		
Test drive	Tri	4	8.70%																		

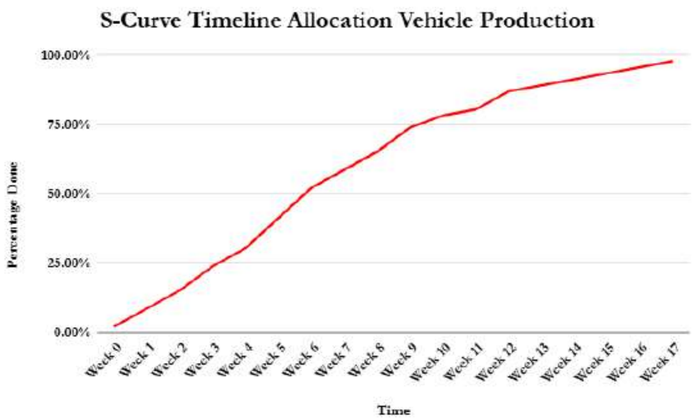

Figure 15. S-Curve Vehicle Production Timeline

Table 3. Non-Technical Timeline

Non-Technical Timeline																										
Project	Person In Charge	Man Hours (Week)	Percentage Done	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
				Agustus	September					Oktober				November				Desember					Januari			
Preparing Administration for SEM APME 2025 Registration	Rani	9	14.52%																							
Preparing for Offtrack-Award Competition	Rafif	5	8.06%																							
Cost Funding	Uji	16	25.81%																							
Forwarder selection for Shipping	Barok	11	17.74%																							
Exhibition Event	Nabila	5	8.06%																							
Launching of Sapuangin XI Evo 4.0 Urban Car	Rinda	1	1.61%																							
Accomodation Preparation	Kepin	5	8.06%																							
Packing Vehicle and Tools	Pasha	4	6.45%																							
Shipping of Vehicle	Barok	4	6.45%																							
Purchasing Tickets Accommodation Vehicle to Qatar	Jaki	1	1.61%																							
Submit Off-Track Award Report	Rani	1	1.61%																							

The project timeline spans approximately six months, from August to January, encompassing various critical activities related to vehicle production and competition preparation. The project's progression followed an S-curve timeline allocation, demonstrating a gradual increase in completion percentage during the initial weeks, followed by accelerated progress in the middle phase, and finally tapering towards completion at approximately 100% by week 22. This distribution pattern aligns with typical project management methodologies, ensuring efficient resource allocation and milestone achievement throughout the project lifecycle.

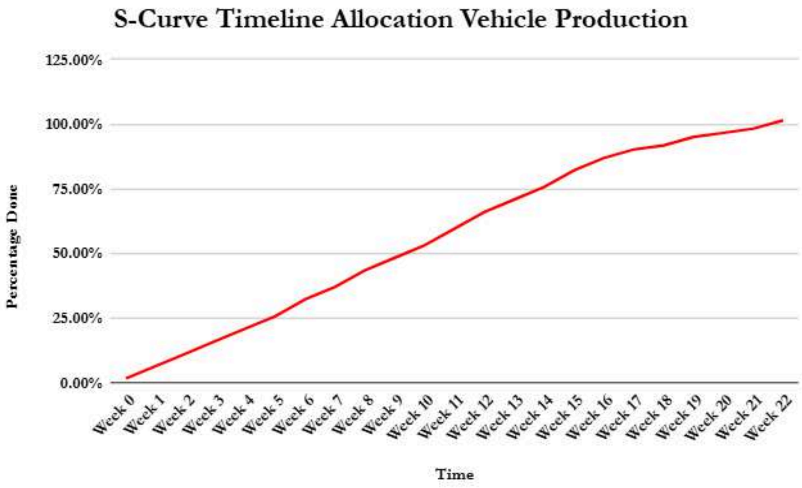

Figure 16. S-Curve Non-technical Timeline

6. **Sustainability Practices During the Vehicle and Production Process**

In Sapuangin IX Evo 4 vehicle, the steering wheel is constructed using composite materials, combining carbon fiber with a balsa core. This core material is made from reclaimed wood sourced from discarded wooden shipping boxes. The process of utilizing this recycled wood aims to engineer the material properties of the components used, specifically in the steering system, to achieve an optimal balance between strength, rigidity, and weight reduction. The use of this balsa core not only provides advantages in terms of material performance but also supports sustainability principles by utilizing materials previously considered as waste

Figure 17. Core material steering balsa wood

Figure 17 shows wood sourced from wooden shipping boxes, which has been repurposed as core material in the manufacturing of the steering system. For the manufacturing process, this steering component is produced using the hand lay-up method, a composite fabrication technique where carbon fiber and resin are manually arranged layer by layer, ensuring optimal strength and weight efficiency. The type of carbon used is carbon twill 240 gsm, combined with epoxy resin.

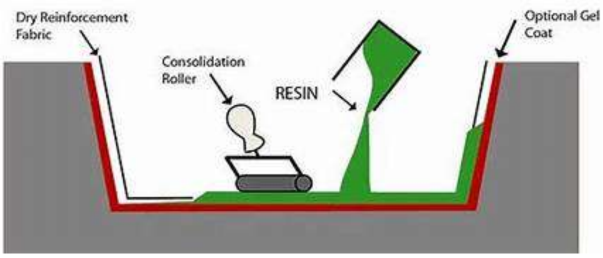

Figure 18. Hand Lay-up Method

Figure 18 shows wood sourced from wooden shipping boxes, which has been repurposed as core material in the manufacturing of the steering system. For the manufacturing process, this steering component is produced using the hand lay-up method, a composite fabrication technique where carbon fiber and resin are manually arranged layer by layer, ensuring optimal strength and weight efficiency. The type of carbon used is carbon twill 240 gsm, combined with epoxy resin.

Figure 19. Steering wheels

To determine the feasibility of the steering wheel, analysis is required to assess whether the steering wheel is strong enough to withstand forces from the driver, particularly during steering wheel rotation. To determine the magnitude of force required to rotate the steering wheel, several calculations are necessary. The following is a breakdown of these calculations.

- Calculation of Wheel Friction Force with the Road

  $Fgesek = Nd\mu$

  $F_{gesek} = 800{,}5\ \mathrm{N} \times 0{,}7$

  $F_{gesek} = 560{,}35\ N$

- Calculation of Torque for Turning a Wheel

  $T = Fgesek \times xscrub$

  $T = 560{,}35\ N \times 0{,}034\ m$

  $T = 19{,}05\ Nm$

- Calculation of Forces on Ears

  $Fgesek \times xscrub = Fkupingan \sin\theta \times xkupingan$

  $$F_{kupingan} = \frac{F_{gesek} \times x_{scrub}}{x_{kupingan} \times \sin\theta}$$

  $$F_{kupingan} = \frac{560{,}35\ N \times 0{,}034\ m}{0{,}093\ \sin(74{,}48)}$$

  $$F_{kupingan} = 212{,}61\ N$$

- Calculation of Forces on Ears

  $Tsteering = Fkupingan \times xplat$

  $T_{steering} = 212{,}61\ N \times 0{,}03629\ m$

  $T_{steering} = 7{,}72\ Nm$

- Calculation of Force to Rotate the Steering Wheel

  $Tsteering = Fsteering \times Rsteering$

  $$F_{steering} = \frac{T_{steering}}{R_{steering}}$$

  $$F_{steering} = \frac{7{,}72\ N}{0{,}13\ m}$$

  $$F_{steering} = 59{,}35\ N$$

The force generated by hands to rotate the steering wheel is 59 N. In this condition, you added a safety factor of 3, where the resulting force is multiplied by 3, yielding 177 N. The simulation results for the steering wheel are as follows:

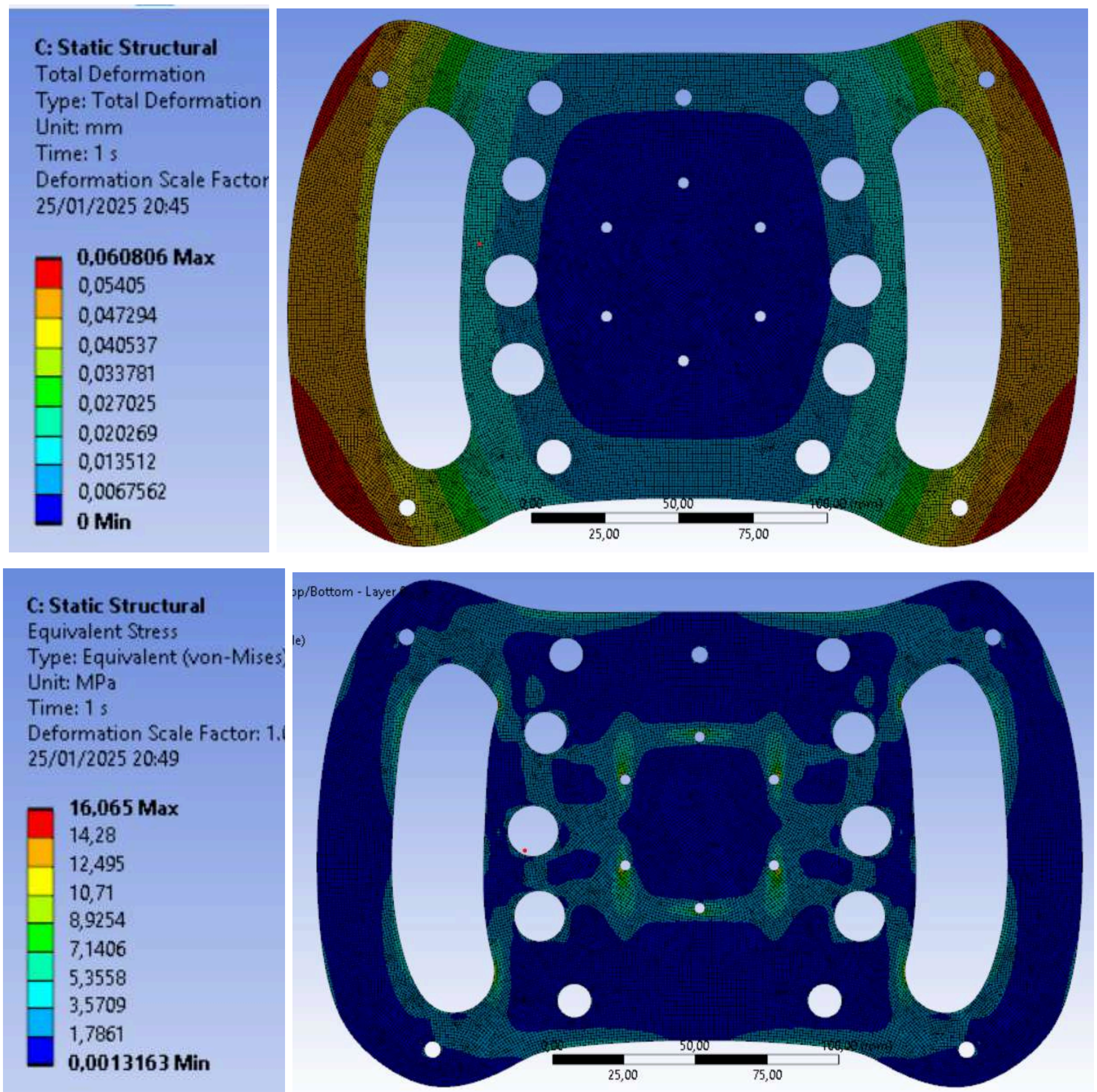

Figure 20. Shear stress and total deformation in composite steering wheel sandwich with balsa wood core material

Based on the results shown above with the force applied to the end of the steering with rotational direction and fixed support on the 6 holes in the middle, it produces a maximum total deformation of 0.06 mm, then the maximum equivalent stress resulting from this loading is 16 MPa, and a maximum safety factor of 19 was found. According to the book (Design of Machine Elements written by V B Bhandari), the recommended safety factor for static loads is between 1.5 to 2, so it can be confirmed that this steering wheel meets the standards and is safe to use.

7. Conclusion

Based on the analysis of the SAPUANGIN IX car, there are several significant achievements in terms of design and performance aspects. The vehicle body design has been carefully engineered considering various SEM 2025 regulations, including dimensional aspects, ergonomics, security, and safety features. In terms of ergonomics, the seating position design has met the expected comfort standards, receiving positive assessments from an ergonomic perspective. The results of Computational Fluid Dynamics (CFD) simulation show promising performance, with the SAPUANGIN IX car recording a drag coefficient of 0.14, and energy consumption of 1,075,141.86 Joules to cover a distance of 3,701 meters at the Losail short circuit. Sustainable innovation is also demonstrated through the development of a steering wheel using environmentally friendly core materials from recycled materials. The application of the sandwich composite method produces components that are not only lightweight but also have superior structural durability, as evidenced by minimal total deformation of 0.06 mm and an excellent safety factor of 19.