Design and Fabrication of the Body for Fuel Saving Prototype Car Which Caters For Aerodynamics Purposes

by

Mohd. Nazri Bin Jebar

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Ir. Dr. Masri Bin Baharom)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
August 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MOHD. NAZRI BIN JEBAR)

ABSTRACT

The purpose of this project is to establish the design and fabrication of the body for fuel efficient vehicle which caters aerodynamics purposes. Aerodynamic study is includes the study of the interactions of air with moving objects, such as car and airplanes, and of the effects of moving air on stationary objects such as building [2]. The components of aerodynamic comprise of drag force and lift force. This project is more concentrate on drag force since drag forces are parallel and opposite to the object's direction of motion and are caused largely by friction. The study of the shape of the car is very important to have less aerodynamic drag force to reduce the air friction. In addition, Ergonomics study is the applied science of equipment design which intended to maximize productivity by reducing operator fatigue and discomfort [1]. In other word, ergonomics is study of human in order to make the design fit with the human nature.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The rise of global warming nowadays creates awareness among us to save our earth. The emission of gases from factories, vehicles, forest burning and others keep producing the increasing of greenhouse temperature. Therefore, reducing the fuel consumption is one of the best methods to enhance our environment.

As the result, rise the ideas of Shell Eco-marathon to produce a high efficiency vehicle that run with less fuel consumption. This event also encourages the people to use the vehicle wisely for saving the environment and cost. This idea offers a glimpse to the future car design which caters for high fuel efficiency.

The Shell Eco-Marathon challenges the student to design, fabricate and run the ultimate fuel-efficient vehicle in order to win the competition. The main purpose of Shell Eco-Marathon is to build an energy efficient vehicle with low in fuel consumption [3]. Therefore, in this project, the author need to make some research on the body of the SEM vehicle that includes the ergonomics and aerodynamic study on it.

Previously on July 2010, UTP has send two teams for the Shell Eco-Marathon competition for the first time. However, we cannot meet our target to get good position for the competition. Hence, many research and improve should be made for Shell Eco-Marathon 2011. Therefore, our job is to ensure the enhance advancement on the UTP SEM car for the next competition. Learn from previous mistake for the betterment of the future.

1.2 Problem Statement

Commonly, for the first time join the competition, the team will face many unsuspected problem during the race. The previous design has claimed to be very heavy. Hence, the weight factor is very important to improve the fuel efficiency of the prototype vehicle. For better understanding, we can compare the vehicle between Perodua Kancil and Proton Waja. Perodua Kancil is lighter than Proton Waja. As the reason, Perodua Kancil uses smaller engine compare to Proton Waja which uses bigger engine that generate more horse power. Therefore, Perodua Kancil has used less fuel consumption and more cost saving.

The other factor affect the fuel consumption is aerodynamic drag force. The shape of the body for the prototype vehicle can reduce the air friction between the air and the car body. However, the optimum shape that suitable for the prototype vehicle needs to take into consideration. For instant, we can observe the bullet train in Japan that design to reduce the air friction between the air and the body of the train. The shape of the train plays very important roles which is design to be aerodynamic that can cut the air flow with low drag force on the vehicle.

1.3 Objectives and Scope of Work

The objective of the project is:-

- To optimize the previous design based on engineering test.
- To design the new fuel-efficient prototype vehicle which cater for ergonomics and aerodynamics purposes.
- To fabricate a complete ultimate fuel efficient vehicle with the integration of the other components such as braking system, steering system, power train system and etc.

In line with optimization the previous design of SEM vehicle, many research need to be conducted to identify the problem with the previous design. From there some improvement can be made for our current design. The design comprises sufficient compartment for driver and all other components that fit the ergonomic aim. Finally, the body of the SEM vehicle will be fabricated according to desired rules and regulation, design and analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 PAC-Car II

Guinness World Records (TM) have certified PAC-Car II, from ETH Zurich, as the world's most fuel-efficient vehicle. PAC-Car II reaches 5385 km/l gasoline equivalence during the Shell Eco-Marathon in Ladoux [4]. Hence, in order to produce the top fuel efficient vehicle, the PAC-Car II can be as reference to fabricate the vehicle.

The PAC-Car II used a rigid carbon fiber monocoque body which used the external structure to support all the component of the car [5]. This configuration can reduce the vehicle's weight without affecting the structural of the car. By using carbon fiber, the total weight without passenger of the vehicle is only 29 kilograms.

2.2 Aerodynamics

Aerodynamic drag was cited as being accountable for half of the power demand of a fuel economy vehicle cruising on a flat, level road. In reality, high-quality aerodynamics is clearly essential to such a vehicle's success. A vehicle's aerodynamic qualities depend on its drag coefficient c_X and its frontal area A, with the drag area of a vehicle [6].

There are two distinctive types of boundary layer which are laminar and turbulent boundary layers. Laminar is orderly fluid flow while turbulent is disorder fluid flow. On road vehicle, the laminar boundary layer is normally confined to the front part of the body; where sensible design it quite easy to maintain favorable pressure gradients. Favorable pressure gradient is from high pressure to a low pressure. The favorable pressure gradient not only inhibits separation, but also slows down the transition from laminar to turbulent [17].

The drag force is the total force resisting the forward motion of a road vehicle comes partly from the rolling resistance of the wheels and partly from the aerodynamic drag. Drag coefficient is a factor mainly depends on the shape of the vehicle which is the frontal area of the vehicle, the air density, and the square of the relative air speed [17]. This relationship between drag and these factors can be expressed by

$$\boldsymbol{Drag = \frac{1}{2}\rho V^2 A C_D}$$

Equation 2.1: Drag Equation

Where A is the frontal area
ρ is the density of the air
V is the speed of the vehicle relative to the air [17]

From the observation from all the design previous team enter SEM, all the vehicles are small and having streamline body shape. The driver lies down in the cockpit to reduce the height of the vehicle. Some of the vehicle covered the wheel of the car to reduce air turbulence created by the wheel rotation [6].

For example, the PAC-Car II is used teardrop shape, and wheel is fully covered. In term of aerodynamic, the PAC-Car has less aerodynamic drag force.

Figure 2.1: PAC-Car II

Another example is from Eco-Runner H_2 team from the Faculty of Aerospace Engineering of the Delft University of Technology [8]. Eco-Runner H_2 showed massive improvement with respect to the first version. This results in an extremely aerodynamic shape and a light weight of the vehicle. From the figure below, we can see the development from Eco-Runner 1 to Eco-Runner H2 especially in the aerodynamic shape of the car.

Figure 2.2: Eco-Runner 1

Figure 2.3: Eco-Runner 2

2.3 Types of chassis

Ladder Chassis

- having two longitudinal rails inter linked by several lateral and cross braces.
- very high in toughness and stiffness.

Monocoque Chassis

- one structure support overall shape of vehicle.
- Often those support form some of the exterior body panels

Backbone Chassis

- a large central structure that connects the front and rear.
- strong enough to support the smaller sports car body.
- easy to fabricate and cost effective

Space Frame Chassis

- one where every element is loaded only in tension or compression
- In that sort of structure every element is a truss and every part must be triangulated.

[12]

Figure 2.4: Ladder Chassis

Adveva team from France used ladder chassis made of carbon or aluminum square tubes assembled by pasting (and riveting). The chassis able to support alternatively 2 engine types. Having no steering function, the front wheels will present narrower active volumes and, with the same track as before, the projected frontal area of the vehicle will be lower thus allowing a reduced flow friction. [13]

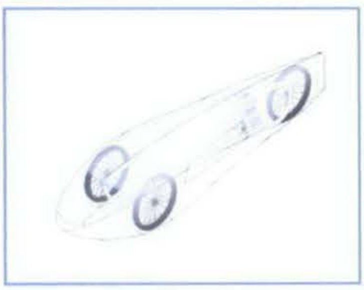


Figure 2.5: BackBone Chassis

The SMV Team used backbone chassis frame [7]. Although, backbone chassis frame is the simplest chassis, it is unfavorable due to the bending effect of the load upon the vehicle. Therefore, a strong material is used as the backbone of the vehicle which embraces additional weight to the vehicle.

Figure 2.6: Monocoque Chassis

Monocoque or unibody is commonly used in automotive industry. The world record holder PAC-Car II used monocoque body chassis because light weight and high stiffness of body [5]. However, monocoque chassis is very difficult to fabricate due limited equipment.

2.4 Wind Tunnel Test

Wind tunnel is device for studying the interaction between a solid body and an airstream. University Technology PETRONAS provides us the facilities for wind tunnel test. A wind tunnel simulates the conditions of a car model with the air stream. The model is mounted on three component balances to determine the drag force, the lift force and pitch force during the simulation test. For this experiment, we are focusing on the drag force of the car model. The paths of the airstream around the model can also be studied by injecting thin streams of smoke into the tunnel to render the airflow visible. [18]

Figure 2.7: UTP wind tunnel

Forces exerted on the model will be determined from measurement of the airflow of the model. In wind tunnels, the airstream is formed by large motor-driven vanes. In many instances, wind tunnels have been used with the computer to display the drag force and the stream velocity of the wind tunnel test.

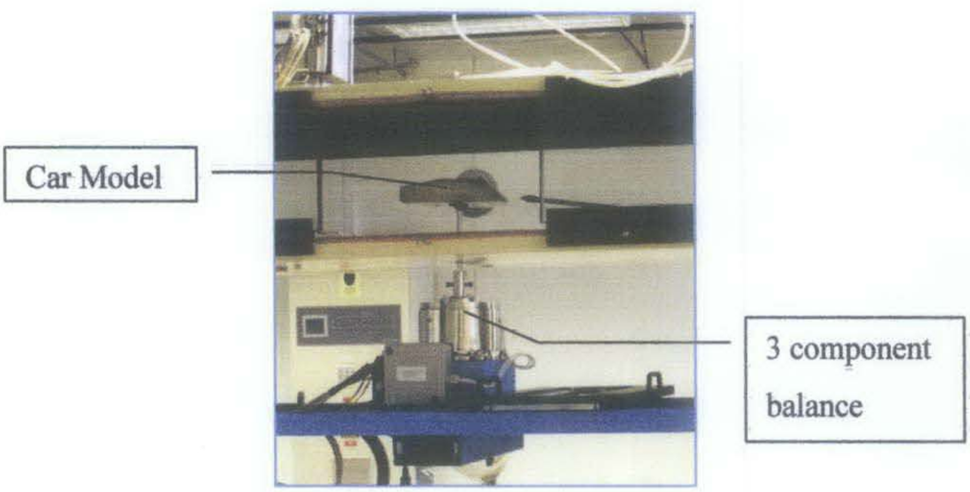


Figure 2.8: 3 Component Balances

2.5 Vacuum Resin Infusion

Vacuum resin infusion is one of the techniques for manufacturing high performance composite. This process is widely used by professional manufacturers for marine production of boat hulls.

In detail definition, Vacuum Resin Infusion is a process in which vacuum draws resin into a dry fiber laminate in a one sided mould. Then, a rigid or flexible film membrane is positioned over the top and sealed around the mould. Resin infusion is considered a "Closed Mould Process". [22]

Vacuum Resin Infusion has many advantages. When it is done correctly, this method can produce parts of incredible strength and quality of appearance. The combination of vacuum pressure along with carefully placed vacuum consumables (such as peel-ply and infusion mesh) produce the finished composite that have absorbed resin at the optimum resin-to-reinforcement ratio, avoiding resin-rich composites or variations in performance inevitable with traditional wet-lay manufacture. [24]

Another advantage of using resin infusion process is it can eliminate some of the problems that can impair wet-lay composites, such as air voids (caused where the reinforcement has bridged around tight corners) and tiny air bubbles caused by air trapped within the laminate. The quality of epoxy 'infusion resins' means that resin infused parts can be made with strength to weight ratios that can produce high strength but low in weight product. [24]

Traditional methods of bonding the core to the skin call for a polyester paste that is manually spread onto the cured surface of the fiberglass with the core being bedded into it. Clamping pressure is applied until the bonding material is cured. The integrity with this method relies upon the technician's skill level, the performance of the bonding paste and its ability to adhere to the cured skin. [23]

2.5.1 Fabrication Method

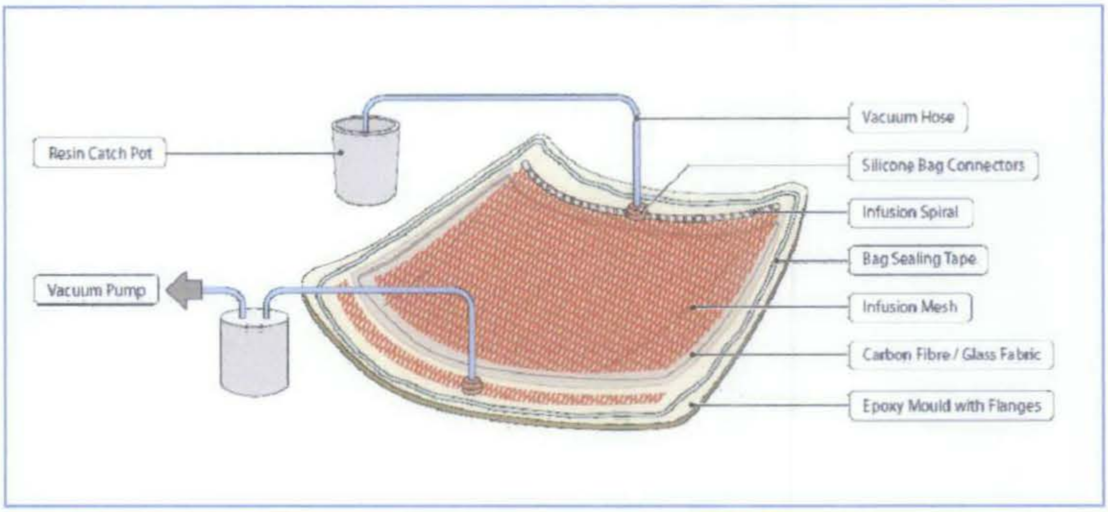


Figure 2.9: Resin Infusion Equipment Layout

The fabrication method can be categorized into 5 major steps;

2.5.1.1 Mould fabrication

The first step is to have a suitable mould. A mould suitable for resin infusion is much the same as a mould that would be used for conventional wet-lay fiberglass. [24]

It is very important that the surface of the mould that will be used for infusion is very smooth and less surface roughness. In order to get a better surface finish, we can use either an epoxy tooling gel coat, or just epoxy resin used as a surface layer. Manufacturer usually used polyester gel coat or polyester resin as a surface layer. Another alternative is to use a P.V.A. mould release agent. [24]

The resin infusion process requires the mould to have some additional flange area around the edges. This flange area is used to place the vacuum connectors, resin feed connector, infusion mesh and resin flow channels. [24]

2.5.1.2 Preparation

Prepare the mould surface. If the infused part is to be cure at ambient temperature then conventional mould release wax is a suitable release surface for the mould. Besides that, if the infused part is to be accelerated the cure process with elevated temperature then wax is not suitable and a temperature tolerant chemical release agent should be used instead. [24]

2.5.1.3 Layout Fiber Glass

1. **Cut and position the fiberglass.** The reinforcement fiber glass is cut to the appropriate size according to the mould. Where possible, always try to make the part using a single piece of fabric for each layer. Typical fiber glass product will use between 2 and 6 layers of fiber glass. Usually, 3 layers is often used for a small, light part. Ensure that the fabric is cut large enough to extends beyond the all the edges of the trimmed part. [24]
2. **Add the peel-ply layer.** Peel-ply is the first layer of the infusion 'bagging stack' and is a removable barrier that is peeled off the finished part, leaving a relatively consistent surface that is also ideal for bonding to. A slightly better peel ply is easier to remove and well worth the difference. Peel ply is usually applied in one single layer, positioned to completely cover all areas of the reinforcement. The peel ply does not need to overlap the edges of the reinforcement but it does need to cover it all so it is usually cut to be just fractionally bigger than the reinforcement. [24]
3. **Add the infusion mesh.** The infusion mesh or also known as 'flow media' is used to ensure that the resin can flow from the resin feed line and spiral tube freely through the laminate. The shape of the mesh means that even under total vacuum, there are still gaps through which the resin can flow. The infusion mesh is also applied in a single layer. It should be cut to be the same size as the reinforcement/peel-ply apart from at each end where the mesh should extend sufficiently to allow for the vacuum connector at one end, and the resin feed line at the other. [24]
4. **Position the resin feed spiral.** The resin feed spiral is spiral wrapped plastic tube that is used to improve the flow of the resin from the feed tube into the laminate. Resin will be expended along the spiral tube. Then, the resin is quickly distributed along one side of the mould and then advances more evenly towards the other side. It is essential that the resin feed spiral is positioned directly over the infusion mesh. This ensures that the resin can flow easily from the spiral into the mesh. The resin feed spiral is secure in position using a couple of small pieces of the bagging tack-tape. [24]

5. **Position the resin feed connector.** Feed connector is used to channel the resin to feed spiral. This allows resin to flow through the feed tube, through the connector and into the spiral. Position the resin feed connector in the centre of the resin feed spiral. [24]
6. **Position the vacuum connector.** Vacuum connector is used to allow free airflow from the connector into the material underneath the infusion mesh even under total vacuum. Position the vacuum connector on top of the infusion mesh at the opposite side of the mould to the resin feed spiral. The connector should sit on top of infusion mesh in an area beyond where the reinforcement ends. [24]
7. **Apply vacuum bagging tape.** Vacuum bagging 'tack-tape' is a type of very sticky gum tape. The tape is used extensively in all vacuum bagging processes where its pliable nature makes it highly effective at providing an air tight seal.
8. **Position and tape down the vacuum bag** is to enclose everything within the vacuum bag. A piece of bagging film is cut with large enough to cover all area about 50% larger than the mould area. Starting in one corner, peel the backing paper off some of the bagging tape and press the corner of the bagging film down onto the exposed tape. Move around the edge of the mould, removing backing paper from the tape and sticking down the bagging film. [24]
9. **Connect and seal the resin feed hose.** With all the bagging stack and reinforcement sealed within the vacuum bag, the next process is to connect the resin feed hose. A length of the clear PVC hose is cut long enough to run comfortably from where you will position your resin feed pot to the resin feed connector on the vacuum bag. The tube is sealed to the bag by wrapping a ring of the bagging tape around the tube. Then, it is pressed firmly to ensure the tape has made an airtight seal. [24]
10. **Connect and seal the vacuum hose.** The process from the previous step is repeated but this time using another length of PVC tube that will connect the catch-pot to the vacuum connector at the opposite end of the part to the resin feed connector. [24]
11. **Set-up the resin feed pot.** The resin feed pot should be securely positioned near the mould. It is absolutely vital that the resin feed pot does not fall over during the infusion; if it does, the part will certainly be ruined. Position the resin feed hose inside the feed pot so that the tube reaches all the way to the bottom of the pot. [24]

12. **Connect the vacuum pump and catch-pot.** The other end of the vacuum hose is connected to one of the push fittings on the resin catch-pot. Push the hose on firmly to ensure an air-tight seal. Next, a length of PVC tube is cut sufficient to run from the vacuum pump to the other push connector on the catch-pot. [24]
13. **Clamp the resin feed line.** Position the line clamp tube near to the start of the resin feed tube and turn the wing-nut to clamp the pipe shut. Ensure that you close the pipe properly to create an airtight seal. [24]
14. **Switch on the vacuum pump.** With everything in place, we are now ready to test the vacuum. [24]
15. **Evacuate the air and adjust the vacuum bag.** As the air is removed from the vacuum bag the bag will tighten around the mould surface. As the bag begins to become reasonably tight (certainly not full evacuated but not slack either) temporarily switch off the vacuum pump. This will allow you all the time you need to reposition the bag, working wrinkles towards where they're needed and ensuring that no-where on the mould is the vacuum bag 'bridging' a gap. [24]
16. **Test the vacuum.** Leave the pump on and wait as the needle approaches full vacuum. Keep adjusting the bag if necessary to ensure there are no 'bridges'. [24]

2.5.1.4 The Infusion

1. Gauge the correct amount of resin. The amount of resin that your project will need will vary upon its size and the amount of reinforcement you have used; more layers of reinforcement will be able to support more resin. [24]
2. Mix the infusion resin and add to the feed pot. The epoxy infusion resin supplied with the kit (and recommended for future projects) needs to be mixed at a ratio of X parts resin to X parts hardener. As with all resins, it is important that the correct ratio is accurately measured and thoroughly mixed. [24]
3. Unclamp the resin feed line. With the vacuum pump still running, gently start to unscrew the wingnut on the resin feed line clamp. [24]
4. Monitor the infusion. [24]

2.5.1.5 De-Moulding

The vacuum pump should stay on until the part is fully cured. When the part is fully cured the pump can be turned off and the vacuum bag cut away from the mould. In some cases you may choose to keep and re-use sections of the vacuum bag although the gum tape and infusion mesh are always thrown away. [24]

De-moulding steps:

1. Cut the bagging film around the edge and remove.
2. Remove the bagging tape from the edge of the mould (quick, sharp tugs are most effective)
3. Remove the silicone connectors and crack any cured resin off them. They are re-used indefinitely.
4. Remove and discard the infusion mesh
5. Pull the peel-ply off the back of the part. This will take a little bit of force.
6. Remove the part from the mould. Be careful not to damage the part or the mould, especially when force is required to remove the part. [24]

2.6 Fortis Saxonia

Fortis Saxonia (Latin for "Powerful Saxony") is a student research project within the Chemnitz University of Technology, in Germany. Fortis Saxonia develops and builds a lightweight and energy-saving vehicle. The drive is powered by a hydrogen fuel cell und an electro motor. They used advance vacuum resin infusion technology to build the body panel for their latest car, Sax 3. [25]

2.6.1 Moulding

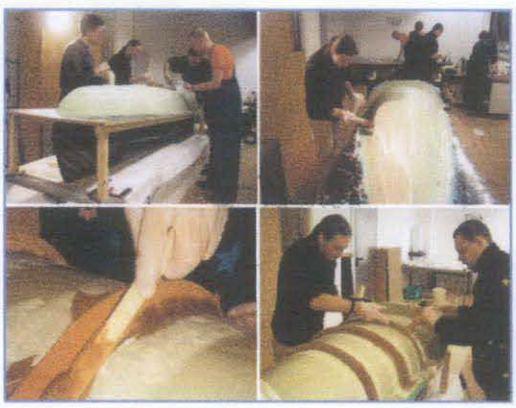


Figure 2.10: Construction of Female Mould

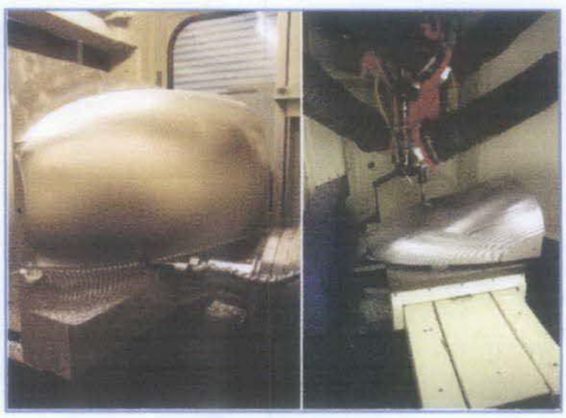


Figure 2.11: Milling for front window

2.6.2 Preparation

Figure 2.12: Surface Preparation Mould

2.6.3 Layout Fiber Glass

Figure 2.13: Fiber Glass Layout

2.6.4 Infusion

Figure 2.14: Resin Infusion and heating in chamber

2.6.5 De-moulding

Figure 2.15: After De-moulding or Final Product

CHAPTER 3

METHODOLOGY

This project can be divided into 8 phases which is shown in flow chart below.

3. 1 Information Resources

The information about the Shell Eco Marathon is gathered from available resources such as internet, books, or journal. The objective of this phase is to obtain some meaningful knowledge about the project and get some general idea to have a better insight about the project.

3. 2 Research & Data Analysis

Some of the information is not related to the project. Hence, at this stage, the information will be filtered and only useful information will be taken into consideration. The relevant information includes Carbon Fiber fabrication process, aerodynamics study, automotive frame, composite material reinforcement and so on.

3. 3 Concept Design

Some sketches or initial draft of the vehicle is made based on the study of the project. The general ideas can be made at this stage and a few improvements can be made to achieve the objective. The physical constraint and safety factor are determined for the design constraint and specification of the vehicle.

The concept design can be divided two components which are the frame of the vehicle and outline aerodynamic body.

3.4 Optimization & Verification

Optimization is to improve the design while verification is to prove the design meet all the requirement. From the design, finite element analysis is made to ensure the design meet all the specification. Some engineering mathematical calculation such as static load, stress analysis, bending force and etc. are applied to analyze the potential outcome that may appear during the race. From this analysis, we can determine the alternative solution and modification to the design in order to optimize the performance of the car. In this stage, computer simulation and modeling is important to determine the stress analysis of the body of the vehicle. Wind tunnel test will be conducted to analyze the aerodynamic characteristic of the vehicle.

3.5 Design selection

This stage is decision stage where all the possible solution is listed and the advantages and disadvantages of each concept design is discussed. The Catia software is used to design the vehicle based on the desired characteristic of the vehicle.

3.6 Design Integration

All the component of the vehicle will be assemble together into one complete UTP ultimate fuel economy vehicle. Therefore, the components such as wheel, chassis system, engine compartment and so on should fix together properly. The joints and fixtures is verify to ensure the compatibility of the integration.

3.7 Finalizing the design

Before proceeding to fabrication stage, the design will be checked and verify if there any minor or major adjustment to be made.

3.8 Fabrication

The fabrication phase is the most important part which is comprises many manufacturing technical and enthusiasm effort to produce the best fuel-economy vehicle. The fabrication of body frame, the outline aerodynamic body, the cabin and the other entire component will take into consideration. For this project, we used a new technique which is **Resin Infusion Technique**. The steps for Resin Infusion are shown in next section.

3.8.1 Preparation

Preparation is very crucial for the fabrication process. The equipment must be available and ready to perform the fabrication. For resin infusion fabrication process the items and equipments are;

No.	Items / Equipment	Function	Availability
1.	Fiber Glass	Main Element for the body panel fabrication	Available in Lab 17
2.	Peel Ply	Used to leave a relatively consistent surface that is ideal for bonding.	Not Available
3.	Netting	To ensure resin can flow to the fiber glass layer.	Not Available
4.	Tacking-Tape	To seal the vacuum bag for air tight seal.	Not Available
5.	Vacuum bag	To enclose everything inside the vacuum bag.	Not Available
6.	Spiral Tube	To ease the flow of resin to the netting layers.	Not Available
7.	Tube / Hose	Function as the connector for resin feed and vacuum.	Not Available
8.	Resin	Main Element for body panel fabrication.	Not Available
9.	Hardener / MEKP	To make the resin solidify.	Not Available
10.	Cobalt	Act as the catalyst for channeling process of fiber glass.	Not Available
11.	Cork	Act as frame to increase stiffness of the body panel.	Available at block N
12.	Seal tape	To secure the items on positions	Not Available
13.	Cup	Resin reservoir for infusion.	Not Available

14.	Vacuum Pump	Produce vacuum pressure to evacuate the air inside vacuum bag	Not Available
15.	Catcher	Place between vacuum bag and vacuum pump. Act as safety mechanism to place excess resin that flow through vacuum connector.	Not Available
16.	Weight gauge	Measure the weight of infusion resin.	Not Available
17.	Scissor	Cut the fiber glass, peel-ply, and netting.	Available at lab 17
18.	Marker Pen	Mark the position for fiber glass layout.	Available at lab 17
19.	Ruler	Measure the dimension of fiber glass according to the design.	Available at lab 17
20.	Mould release wax	Release agent that ease the de-moulding process.	Available at block N

After that, make sure the surface of the mould is clean. Then, mould release wax is applied on the surface of the mould to ease the process of de-moulding the fiber glass.

3.8.2 Layout Fiber Glass

Layout Fiber Glass is simple but troublesome job. Layout fiber glass is cutting the fiber glass with the shape of the mould. However, this process needs to repeat a few times to get multiple layers of the fiber glass. During perform this layout process, proper precaution need to take into consideration which is wearing mask, lab coat and glove. Inhale a small piece of fiber glass can bring serious impact to health problem. Layout process step are;

1. The fiber glass is cut and position on the mould. The fiber glass layout consists of six layers which is shown in figure below. In between the layer is the cork for the frame to increase the stiffness of the body panel. The cork is suitable material because it is very light compare to wood or Aluminum. During resin infusion process, the resin will flow through the cork and cause the cork become strong and stiff.
2. A peel-ply layer is cut and added on top of the fiber glass. The size of peel-ply is slightly bigger than the fiber glass layers.

3. Four layer of netting is cut and added on top of peel-ply layer. There is a special type of infusion mesh for resin infusion process. However, infusion mesh is very expensive. Therefore, we used four layer of netting as the alternative for the infusion mesh. The function of this layer is to allow the resin to flow through peel-ply layer and then to the fiber glass layer.
4. The resin feed spiral tube is position on the mould. The spiral tube is place at both end of the mould which is the feed resin position and vacuum position which is shown in figure below.
5. The resin tube connector is placed at the centre of the resin spiral tube to channel the flow of the resin into the fiber glass.
6. The vacuum connector is placed at the centre of the other end of resin spiral tube to guide the flow of air to the vacuum pump.
7. The tacking-tape is applied around the fiber glass layer. The tacking-tape provides air seal for the resin infusion process. Tacking-tape is also apply around the resin feed tube connector and vacuum tube connector to make ring shape around the tubes. Then, a few tacking-tape is also apply on the tacking-tape layout which is position with the resin feed connector and vacuum connector tube.
8. The vacuum bag is cut slightly bigger than the tacking-tape outline. Then, the vacuum bag is tape down to enclose everything inside the vacuum bag.
9. The resin feed connector is clamped and blocked by using tacking-tape.

Figure 3.1: Layout Fiber Glass

Figure 3.2: Vacuum Bag

10. The vacuum pump is switched on to evacuate the air inside the fiber glass layers.
11. The vacuum bag is adjusted and ensures that the tacking-tape is seal the air properly. Hissing sound is the best indicator for the open seal position.

12. The pump is leave for a few minutes until the vacuum pump gauge reach up to -15 bars. The vacuum bag is keep to adjust as the vacuum pressure increase to ensure air tight seal of the vacuum bag.

3.8.3 Infusion

Infusion is the most significant process of resin infusion technique. This process determines the result whether good or worse. Proper planning and technique is very important to get a better result of the final product.

The critical aspects in infusion process are the cure time of the resin and the flow of the resin inside the vacuum bag. For this project, a longer cure time is required to ensure the resin flow through entire fiber glass layers. The flow of the resin is random since it depends on the porosity of the layers. Hence, if one portion of the fiber glass is not filled by the resin, an incision is made at the area by placing a new resin feed connector to fill the unfilled resin at the portion.

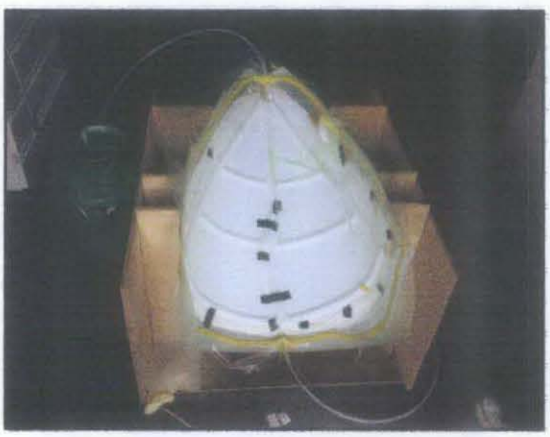


Figure 3.3: During Resin Infusion Process

1. The amount of resin, MEKP, and Cobalt is gauged correctly according to the percentage ratio.
    a. Resin = 98.9 %
    b. MEKP = 1%
    c. Cobalt = 0.1%

Figure 3.4: MEKP and Cobalt

The method of calculation for the ratio is for instant if the weight of the resin is 350 g.

Hence, weight of MEKP is: $$\frac{1}{100} \times 300 \div \frac{98.9}{100} = 3.03 \text{ grams}$$

Weight of cobalt is: $$\frac{0.1}{100} \times 300 \div \frac{98.9}{100} = 0.303 \text{ grams}$$

2. The infusion resin is mix properly and added to the feed cup.
3. The resin feed connector is unclamp and place into the feed cup so that the resin will flow into the vacuum bag through the feed connector.
4. The infusion is monitor to make sure the resin goes through the entire fiber glass layers.

4.8.6 Demoulding

The whole infusion resin and mould is placed under the heat from the sun. The UV light and heat causes the channeling process of fiber glass is rapidly increase. The proper cure time takes only two days. Demoulding steps is the last steps consist of;

1. The vacuum bag, spiral tube, connectors and tacking-tape is removed from the mould.
2. The netting layer and peel-ply layer is removed properly leaving only fiber glass layer.
3. The part is removed from the mould well. Precaution on the sharp edge of the resin part during removing the fiber glass product.

3.9 Gantt Chart

3.9.1 Final Year Project 1

Table 3.1: Project Flow FYP 1

No	Project Detail / Week	1	2	3	4	5	6	0	7	8	9	10	11	12	13	14
1.	Selection of project title															
2.	Research Work (Preliminary Report)				•											
3.	Concept Design															
4.	Design selection															
5.	Optimization (Progress Report & Seminar)									•						
6.	Verification / Testing															
7.	Design Integration															
8.	Finalizing Design (Interim Report final draft)															•
9.	Fabrication	Final Year Project II														

3.9.2 Final Year Project 2

Table 3.2: Project Flow FYP 2

No	Weeks / Activities	January				February				March				April			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Planning (Chassis)																
2.	Build Mock-Up Chassis																
3.	Planning (body panel)																
4.	Preparation Equipment for mould																
5.	Body Panel Mould Fabrication																
6.	Preparation Equipment for resin infusion																
7.	Body Panel Resin Infusion Fabrication																
8.	Door Fabrication																
9.	Finishing																

CHAPTER 4

RESULT AND DISCUSSION

This section will be discussed from the analysis of previous design and some design concept for the new prototype car to finalizing the vehicle. For the first part of this section is to analyze the previous design and the major factor of failure on the previous design. Then, the next section will be discussed about the design concept which is including the morphology chart and some sketches design on the prototype vehicles. After that, wind tunnel test analysis comes into picture to discuss the best aerodynamic shape for the prototype car. Then, definite stress analysis is used to verify the best design which can reduce the slanting problem of the previous design. After stress analysis, bending test and visible test is performed to optimize the new chassis meet the requirements. Finally, fabrication process is conducted using resin infusion technique which comprise of mould fabrication, body panel fabrication and finishing.

4.1 Analysis of Previous Design

The previous team has send two vehicle for the competition. Analysis on the weakness of the previous design is made to improvise the design to meet required design for fuel efficient prototype vehicle.

Figure 4.1: Previous SEM 1

Figure 4.2: Previous SEM 2

4.1.1 High bending elongation

The body for the previous design is high in bending elongation. Based on the design, the wheel is place on the front platform beam. This design will produce not only bending force on the beam but also moment force to the platform.

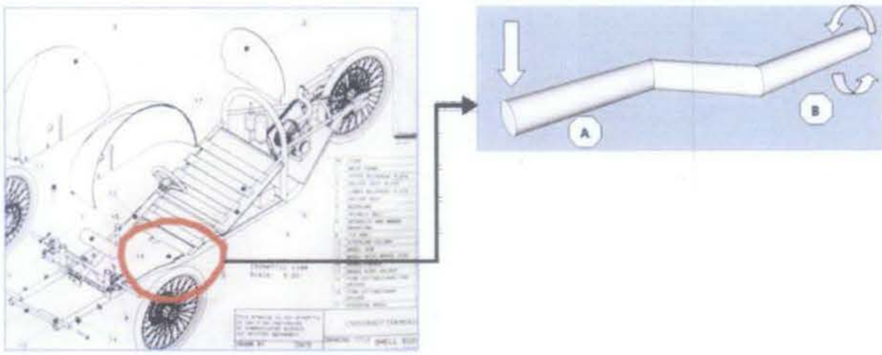


Figure 4.3: Bending Elongation factor of previous design 1

From the figure above, the force on point A will result a twisting force of the point B. In other word, torque is produced on point B which will cause high bending elongation on point A. Therefore, for the next design, we want to eliminate those possibilities that produce torque to the SEM vehicle frame.

Moreover, previous design 2 has very good chassis since the chassis low bending elongation compare to previous design 1. Hence, we can use again the chassis to cut the total cost of the project.

4.1.2 Weight Factor

The weight is the major concern for designing the prototype vehicle. The weight not only include of the weight of the body frame but also the weight of the driver, the engine, and many other components to complete the vehicle. The volume or size and the material used to make the vehicle are much related to the weight factor that we want to discuss. The bigger the size of the vehicle will make the higher the weight of the car.

Previous design used aluminum alloy for the frame of the car while the body panel is made from fiber glass. Typical fiber glass has density of 2.5 g/cm^3 and carbon fiber is 1.8 g/cm^3 while Aluminum 6061 has density of 2.7 g/cm^3 [15],[16]. However, carbon fiber is very expensive and it is one of the control items.

Based on the observation, there is no problem on the weight of the chassis of the vehicle. The body panel for previous design 1 is improper procedure of fiber glass fabrication. The thickness of the body panel is about 5 mm. Besides that, the body panel for previous design 2 is lighter but the body panel has low in stiffness. For this reason, we should come out with the solution to overcome the problem of low in stiffness and heavy weight of the body panel.

4.1.3 Engine Compartment

In the previous design, the engine position is slanting to the front inside the engine compartment. This design is not good for the oil system which is used to reduce the friction between the piston and the cylinder.

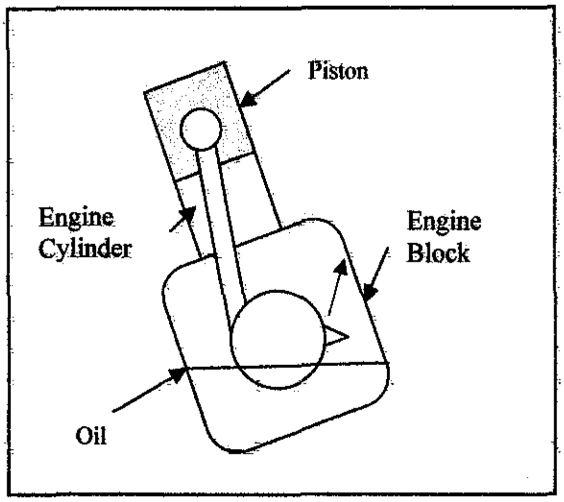


Figure 4.4: Improper Installation

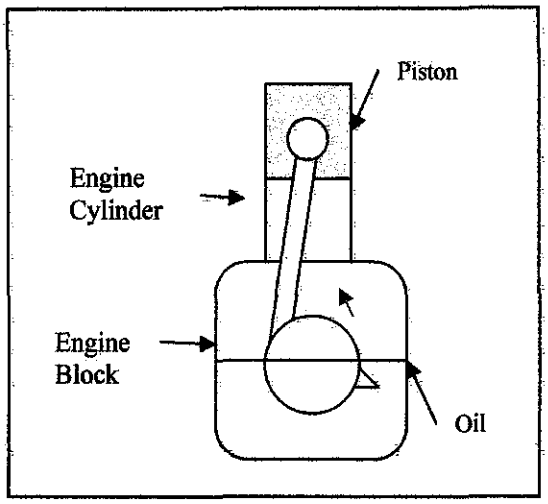


Figure 4.5: Proper Installation

The slanting position of the engine cause the oil drop not directed to the engine cylinder. This may cause damage to the engine system because the high friction between the piston and the cylinder. High friction of the engine piston also brings to high fuel consumption. The optimum position of the engine is based on the manufacturing position by the manufacturer. In other word, if the manufacturer design engine to be placed vertically, the SEM vehicle engine should also place vertically.

4.1.4 Ventilation System

The previous design has no ventilation system in the driver compartment and engine compartment. The previous driver complained that inside the car was very hot even though that there is small holes is place on body panel. The small holes cannot function efficiently to cool down the engine and the driver. For that reason, the new design has ventilation system on the engine and driver compartment for ergonomic purposes. We decided to leave the basement open so that the air can flow into the vehicle.

4.2 Design Concept

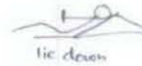
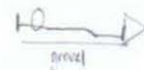
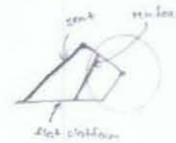
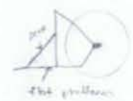
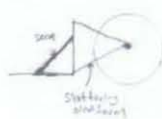
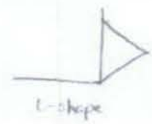
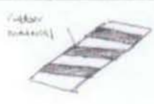
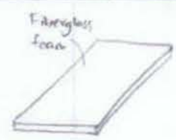
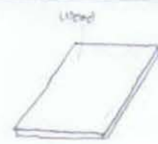
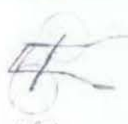
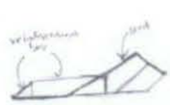
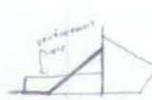
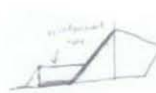
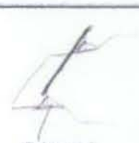
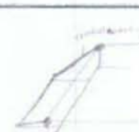
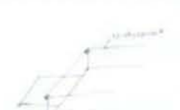
4.2.1 Design Constraint

The design constraint is based on Shell Eco-Marathon 2011 rules and regulation which is related to the body panel and frame chassis of the prototype car [11].

1. Drivers of Prototype vehicles must weigh at least 50 kg in full driving gear, including communication devices (Article 23A).
2. Vehicles must have three or four wheels, which under normal running conditions must be all in continuous contact with the road (Article 25).
3. Windows must not be made of any material which may shatter into sharp shards. Recommended material: Polycarbonate (Article 25).
4. Dimensions (Article 26)
    a. The maximum height must be less than 100 cm.
    b. The maximum height measured at the top of the Driver's compartment must be less than 1.25 times the maximum track width between the two outermost wheels.
    c. The track width must be at least 50cm, measured between the midpoints where the tyres touch the ground.
    d. The wheelbase must be at least 100cm.
    e. The maximum total vehicle width must not exceed 130cm.
    f. The maximum total length must not exceed 350cm.
    g. The maximum vehicle weight, without the Driver, is 140 kg.
5. The Driver must have access to a direct arc of visibility (ahead, and to) 90° each side of the longitudinal axis of the vehicle (Article 28).
6. It is imperative for Drivers, fully harnessed, to be able to vacate their vehicles at any time without assistance in less than 10 seconds (Article 30).

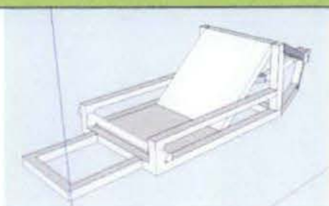
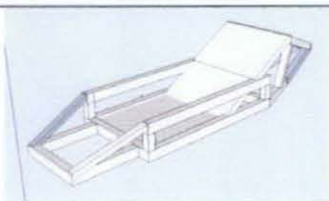
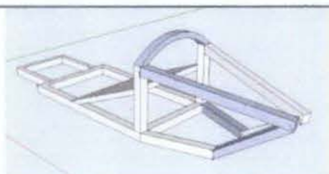
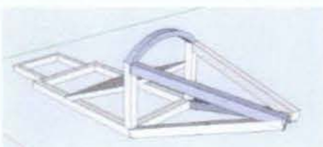
4.2.2 Morphology Chart

Table 4.1: Morphology Chart

	Parameter	Previous Design	Option 1	Option 2	Option 3
1.	Seat position	 Sit down	 Sit down	 Lie down	 Grovel
2.	Engine Compartment				
3.	Driver Compartment				
4.	Chair or Seat Material	 Rubber	 Rubber	 Fiber Glass	 Wood
5.	Chassis Position				
6.	Body Material	 Aluminium	 Aluminium	 Fiber glass	 Duralumin
7.	Body Shape				
8.	Reinforcement Bar for Seat				
9.	Reinforcement Bar for Chassis				

4.2.3 Chassis Design Concept

Table 4.2: Frame Concept Design

	Sketches	Seat Position	Engine Compartment	Driver Compartment	Chair or Seat Material	Chassis Position	Body Material	Reinforcement Bar for Seat	Reinforcement Bar
Concept 1		2	3	3	1	2	2	2	3
Concept 2		2	2	3	2	2	2	1	2
Concept 3		2	3	3	3	2	1	3	1
Concept 4		2	1	1	1	1	2	3	1

4.2.4 Body Panel Design concept

Aerodynamic principles had to be considered early in the design process since the body shape design and its resulting aerodynamics are based on the vehicle topology [[6]]. As mentioned in literature review section, a vehicle's aerodynamic qualities depend on its drag coefficient and its frontal area.

Two prototypes are made which are shown in figure 4.6 and figure 4.7. These prototypes are made from soft wood because soft wood easy to shape into desire design. The prototype is mounted on a flat and thin aluminum plate to reduce the turbulent force act upon the prototypes during aerodynamic test.

Figure 4.6: Aero Prototype 1

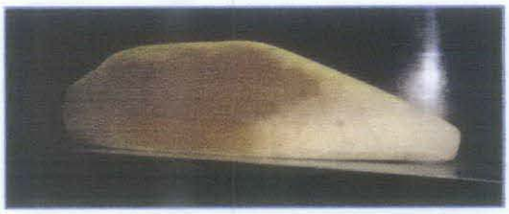


Figure 4.7: Aero Prototype 2

4.3 Aerodynamic Test

Wind tunnel is a device for producing a controlled stream of air to study the effects on objects such as car moving through air.

The objective of the wind tunnel testing is to calculate the drag force and then determine the drag coefficient of the prototypes. Besides that, smoke test is implemented to determine the flow characteristic of the air when flow through the prototypes.

In these experiments, we assume that there is no external wind velocity that assist or oppose the velocity of the airstream. The other assumption is the experiment is conducted under 25°C.

4.3.1 Experiment 1: Drag Force Wind Tunnel

The preparation for the wind tunnel test is very simple. With the help from Mr. Zailan Alang Ahmad, technician for Mechanical Engineering lab, the setup for placing the prototypes into the chamber inside the wind tunnel test is properly managed by the author. Firstly, the prototypes required to mount properly in place. Then, the prototype is placed on the 3 component balances. The 3 component balances is a sensor devices to determine the drag, lift, and pitch forces. Last step is to on the wind tunnel system at the control panel. The data for drag force and velocity can be obtained from the computer at the control panel.

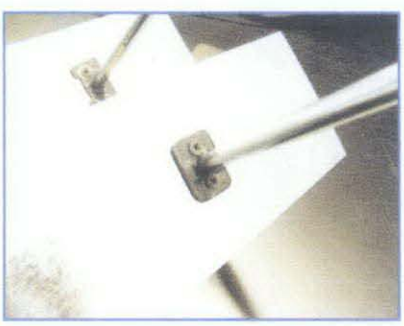


Figure 4.8: Mount the prototype properly by screw

Figure 4.9: Handling Data at Control Panel

The result and data collection is shown in below:-

Table 4.3: Parameter in Wind Tunnel Test

Parameter	Prototype 1	Prototype 2
Density of air @ 25°C	1.23 kg/m^3	1.23 kg/m^3
Frontal Area	5.5 x 10^{-4} m^2	4.7 x 10^{-4} m^2
Scale	1:10 (cm)	1:10 (cm)

Table 4.4: Data Collection Wind Tunnel Test

Velocity (m/s)	Drag Force Prototype 1	Drag Force Prototype 2
	Drag Force (N)	Drag Force (N)
10	0.09	0.02
12	0.11	0.06
14	0.25	0.13
16	0.30	0.00
18	0.40	0.28
20	0.51	0.58
22	0.58	0.77
24	0.68	0.70
26	0.74	0.72
28	1.19	1.06
30	1.19	1.40

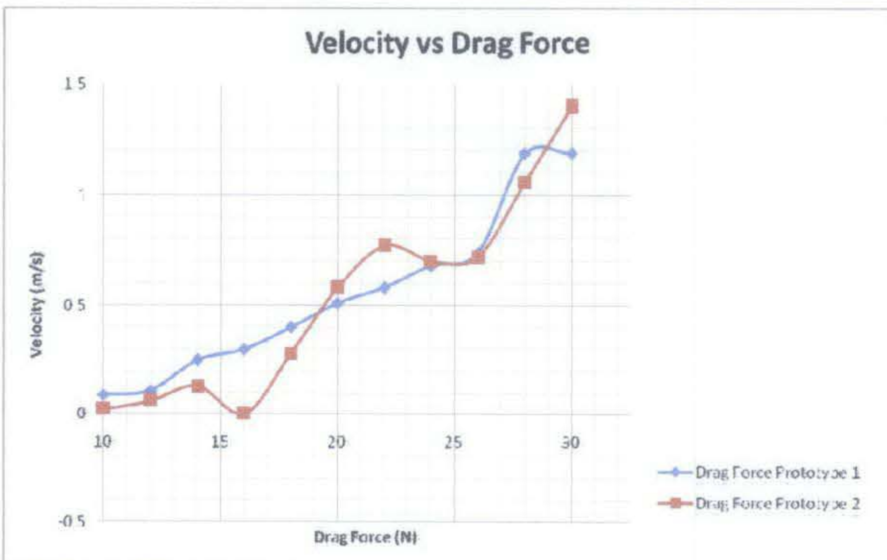


Figure 4.10: Graph Air Stream Velocity vs Drag Force

From the graph above, aero prototype 1 and aero prototype 2 has increment value of drag force. This means that, the drag force increase with increase of velocity of the airstream. In the same manner, when velocity of airstream is increasing, the drag force acting on the car is increasing cause an opposite direction of force acting on the body. From this graph, it is difficult to determine which one is better in aerodynamic performance because the increment value is similar. Hence, the next step is to determine the coefficient of drag force, C_D to determine which one is better in term of aerodynamic performance.

The calculation for this experiment is to get the value of coefficient of drag, C_D

$$F_D = \frac{1}{2}\rho V^2 A C_D$$

$$C_D = \frac{2F_D}{\rho V^2 A}$$

$$A = \frac{x}{\text{circumference of circle}} \times \text{area of circle}$$

$$= \frac{x}{2\pi r} \times \pi r^2$$

$$A = \frac{x}{2} \times r$$

Where,

F_D = Drag force (N)

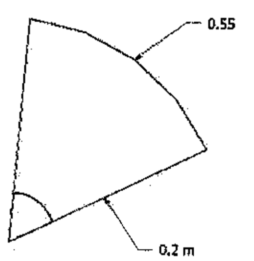
ρ = Density of air (1000 kg/m^3)

V = Velocity of airstream (m/s)

A = Frontal Area (m^2)

C_D = Coefficient of drag

Prototype 1



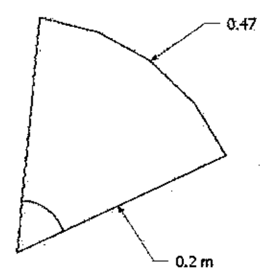
$$A = \frac{0.55}{2} \times 0.2$$

$$= 5.5 \times 10^{-2}\ \text{m}^2$$

$$C_D = \frac{2(0.25\ \text{N})}{(1.23\ \text{kg/m}^3)(14\ \text{m/s})^2(5.5 \times 10^{-2}\ \text{m}^2)}$$

$$= 0.0377$$

Prototype 2



$$A = \frac{0.47}{2} \times 0.2$$

$$= 4.7 \times 10^{-2}\ \text{m}^2$$

$$C_D = \frac{2(0.13\ \text{N})}{(1.23\ \text{kg/m}^3)(14\ \text{m/s})^2(4.7 \times 10^{-2}\ \text{m}^2)}$$

$$= 0.0229$$

From the calculation, prototype 2 has lower value of drag coefficient, C_D compare to prototype 1 because the frontal area of prototype 2 is smaller than prototype 1. This represent that, prototype 2 has less drag compare to prototype 1. By the way, both prototypes have very small value of drag coefficient which proves that teardrop shape is very aerodynamic shape.

4.3.2 Experiment 2: Smoke test -Wind Tunnel

The preparation for the smoke test is same as the first experiment but this experiment needs the smoke generator to produce the smoke that flow in the stream line. No calculation involves in this experiment; the result is the observation of the flow characteristic at certain velocity. The observation is shown in table below:-

Table 4.5: Comparison flow characteristic Wind Tunnel Test

Prototype 1		Prototype 2	
Velocity (m/s)	**Flow Characteristic**	**Velocity (m/s)**	**Flow Characteristic**
1.37	Turbulent	0.00	Turbulent
3.10	Transition flow	2.26	Transition flow
5.07	Laminar	4.31	Laminar

From the above data collection, prototype 1 needs higher velocity to get from turbulent to laminar flow which is about 5.07 m/s. However, for prototype 2 are in Laminar flow at 4.31 m/s which is lower than prototype 1.

Based on observation, prototype 2 has higher turbulent effect compare to prototype 1. This is due to the shape at the back of the prototype 2 create turbulent effect as shown in figure below. Therefore, the tapered shape at the back part just like prototype 2 is more preferable. Hence for this design, we choose aero prototype 1 as the preferable choice for the based design for the prototype car fabrication.

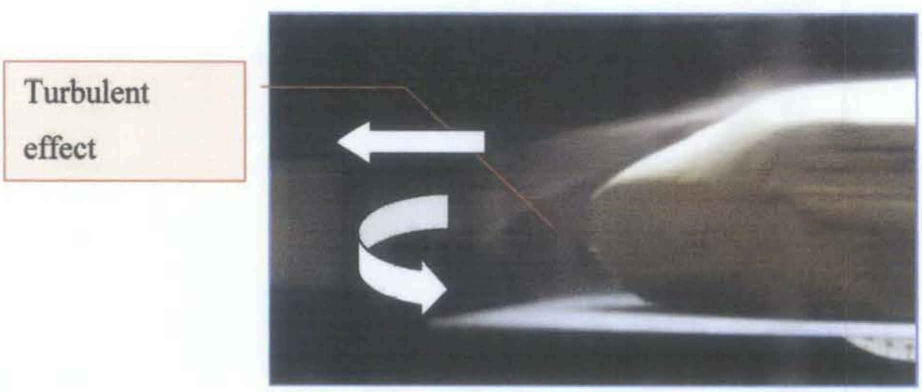


Figure 4.11: Rear Turbulent effect on prototype 2

4.4 Stress Analysis

4.4.1 Ergonomic Measurement

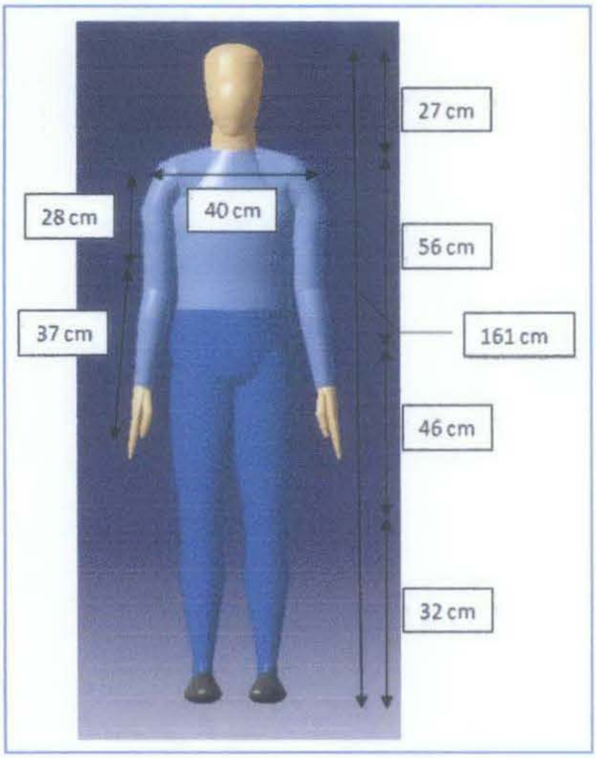


Figure 4.12: Ergonomic Measurement

Before proceeding to design stage, ergonomic test on the driver for the SEM vehicle is done to measure the body measurement of the driver. Our team has decided Mohd Farhan Harun as the first driver for the SEM car because his weight is 50 kg which is the minimum weight for the SEM driver. This ergonomic measurement is very important to ensure the design is fit to the driver body measurement.

After taken the ergonomic measurement, the minimal width of the car can be obtained by taken the measurement of the shoulder which is 40 cm. The length of the car is less than 161 cm which is the height of the driver. The length of the cabin or the driver compartment can be divided by two which are the back seat to support the back of the driver and the leg compartment. The measurement for the back support is 70 cm and for the leg compartment is 80 cm. The topology of the driver inside the car is shown in figure.

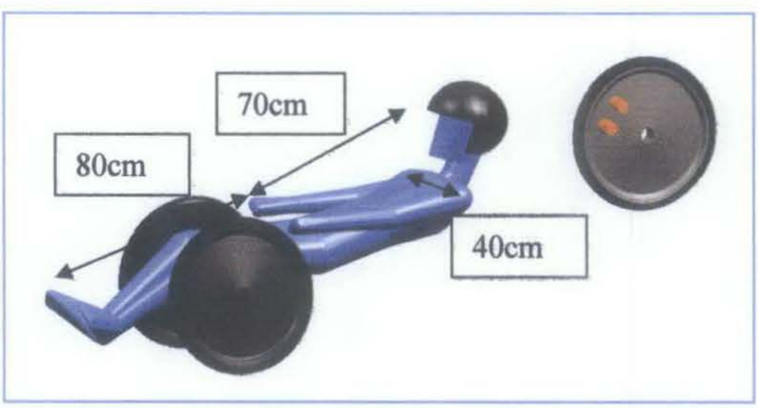


Figure 4.13: Driver topology [6]

4.4.2 Types of Chassis Selection

Based on the concept design, the design of the frame of the car caters for the strength and toughness of the car chassis. At the same time, the measurement of the previous design is obtained as the reference to design the frame. For new prototype car, we decide to use ladder chassis with supportive bar to prevent the bending due upon the load on the vehicle. Hence, the design should include the design with supportive bar and without supportive bar to compare the bending and maximum stress on the car.

The backbone chassis and the monocoque chassis are excluded from design as they are not feasible for this project. The backbone chassis need a strong material such as stainless steel to support the whole body of the car. As the result, the car will be heavier since stainless steel is very heavy material. The monocoque chassis is without doubt the best chassis available for a small and light-weight vehicle. However, the complexity to design and fabricate a monocoque chassis is far beyond our project's scope. The lack of tool and expertise is the major factor monocoque chassis is not selected. Moreover, carbon fiber is commonly used to increase the performance of the vehicle. However, carbon fibers are very limited, very expensive, and require a professional expertise to fabricate. Hence, taking all the consideration, monocoque and backbone chassis is not feasible to use in the project. From decision matrix table, we decide to use ladder chassis because it is lighter compare to space frame chassis. Space frame is heavier due to the many number of members chassis. Ladder chassis is simple make it is easy to fabricate compare to space frame.

Table 4.6: Decision Matrix - Ladder vs Space frame

		Ladder Chassis		Space Frame Chassis	
Criteria	Weight	Rating	Score	Rating	Score
Fabrication feasibility	2	2	4	1	2
Weight factor	3	3	9	1	3
Strength of Chassis	2	2	4	3	6
Analyses feasibility	1	1	1	3	3
		Total score	18	Total score	14

4.4.3 Finite Element Analysis

Before proceeding to the static stress analysis, the loads that the chassis will experience are required to define first. Even though these loads are calculated on assumptions, but they are generally similar to actual load in order to get the actual acting force on the chassis. The mass approximation is listed below;

- Mass of engine = 15kg
- Mass of driver = 50kg
- Mass of brake system and steering system = 30kg
- Gravity acceleration = 9.81m/s^2

Stress analysis is an engineering principle to determine the stress in materials and structures subjected to static or dynamic forces or loads [19]. The aim of the analysis is usually to determine whether the element can safely withstand the specified forces. The simplest way to conduct stress analysis is by using finite element analysis or FEA. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results [20]. FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. Therefore, for this project, Catia V5 software is used to make the finite element analysis of the stress to analyze the body maximum stress location and make the comparison between the designs. For this FEA analysis, aluminium material is used as the material for the frame.

There are 4 design concept need to undergo FEA analysis which are shown in figures below.

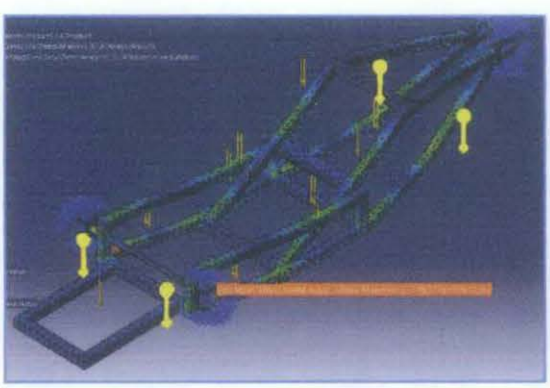


Figure 4.14: FEA design 1

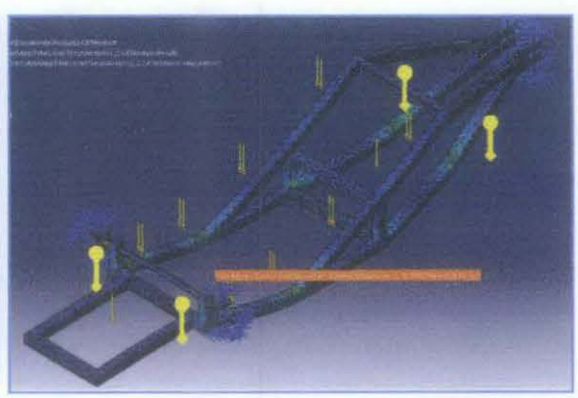


Figure 4.15: FEA design 2

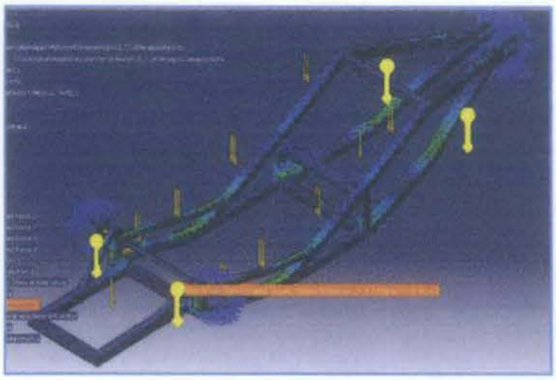


Figure 4.16: FEA design 3

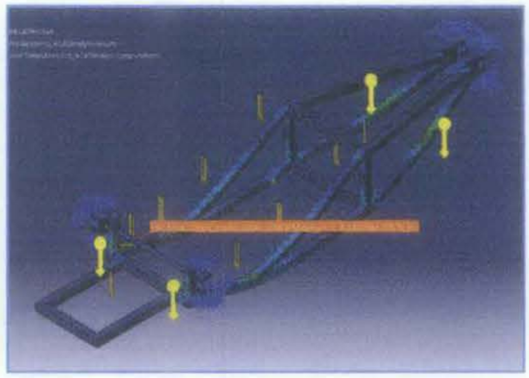


Figure 4.17: FEA design 4

From the analysis we obtain some information regarding each design for the SEM 11 vehicle.

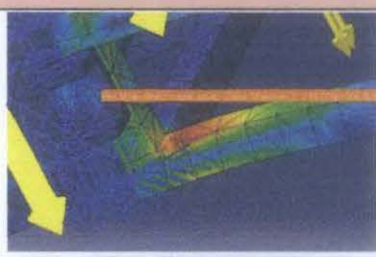
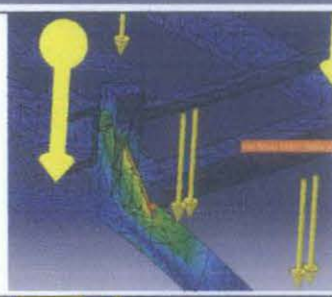
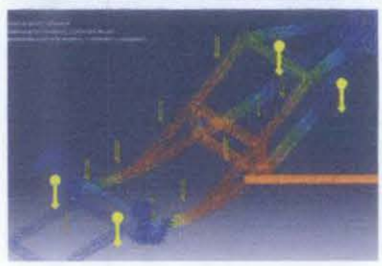
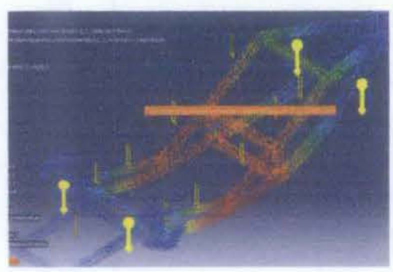
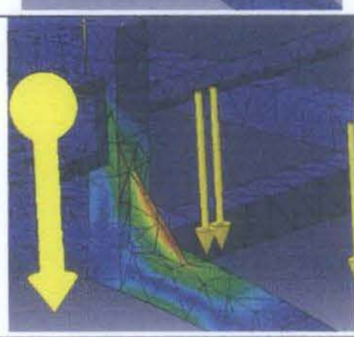
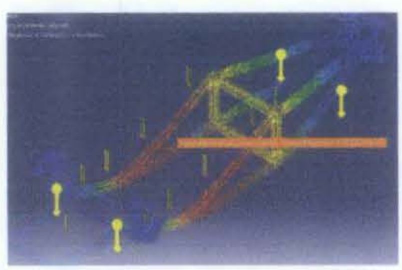
Design	Location of stress concentration	Bending Elongation
Design 1		
Design 2		
Design 3		
Design 4		

Table 4.7: FEA analysis result

Criteria	Design 1	Design 2	Design 3	Design 4
Von Mises Stress	7.96777×10^6 Nm^2	9.14529×10^6 Nm^2	8.23564×10^6 Nm^2	8.13339×10^6 Nm^2
Translational Displacement Vector	0.278941 mm	0.169679 mm	0.219921 mm	0.181775 mm
No. of members	22	18	20	18

The von Mises stress is equivalent to tensile stress. In other word, von misses stress is a scalar stress value that can be computed from the stress tension. In this case, a material is said to start yielding when its von Mises stress reaches a critical value known as the yield strength. The von Mises stress is used to predict yielding of materials under any loading condition [21]. Therefore, the lower value of von mises stress is better and representing that the design has lower critical value. In simple word, the design is good in stiffness.

Number of members of the car frame is representing the weight of the car. The higher the number of members means that the car is heavy. Although, the number of the member is not very accurate as the indication for weight since many aspect can contribute to the weight such as density of material, the volume of material and etc. but the number of member can be use as the first indicator as the comparison designs of the car.

The displacement option in Catia V5 allows us to view the translational displacement of the model based on the loads that were applied upon the model. This option is important for visualizing how the part will behave under given load conditions.

4.4.4 Chassis Design Selection

Based on the finite element stress analysis, we find out that the design required with rib on the body is better to distribute the stress upon it. Design 2 and design 4 have good distribution of stress. In other word they have less distribution of high stress which is the red color located at the rib. Hence, the next car should have rib to increase the stiffness of the body frame.

The bending elongation of the car frame depends on the translation displacement from the FEA analysis. Design 2 has lowest translation displacement which is 0.17 mm. Translation displacement represents the how the part react when load applied upon it.

The von Mises stress is the maximum stress react after load is applied upon the model. In this case, design 1 has the lowest value of von Mises stress which is about 7.97×10^6 Nm^2. In addition, the lower value of von Mises stress is the good sign that the design has good stress distribution throughout the whole body frame. Since aluminium material has 9.5×10^7 $N.m^2$ of yield strength, all the design is far below the maximum yield strength. Hence, this indicates that, the design recovered after load is applied on it.

Table 4.8: Decision Matrix for FEA analysis

		Design 1		Design 2		Design 3		Design 4	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Von Mises Stress	3	3	**9**	1	**3**	3	**9**	2	**6**
Translational displacement vector	3	1	**3**	3	**9**	2	**6**	2	**6**
Location of stress concentration	2	2	**4**	3	**6**	2	**4**	3	**6**
No. of members	1	1	**1**	3	**3**	2	**2**	2	**2**
		Total score	**17**	**Total score**	**21**	**Total score**	**21**	**Total score**	**20**

Based on the decision matrix table above, we decide to choose design 3 as the new design for the body frame of SEM 11 car. To reduce von mises stress, the supportive bar is added on the body frame.

4.5 Chassis Fabrication Modification

For the first concept design, we choose design as shown in figure below. This design is based from Fortis team and PAC-Car team which used only a plate of chassis. This design consists of a plate that has 3 layers which is first and third layer is made from fiberglass and second layer is made from honeycomb. This design has high in stiffness and very light because the honeycomb give adding strength properties to the material as well as low in weight.

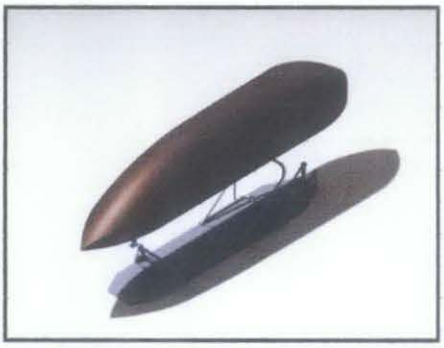


Figure 4.18: First Design Concept

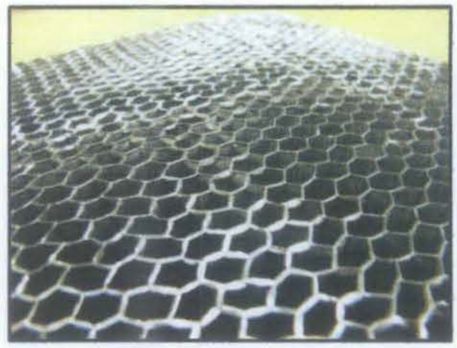


Figure 4.19: Sample of Aluminum Honeycomb

However, after much consideration this design is not applicable because we do not have enough technology, facilities and also expertise to create a larger scale fiber glass – honeycomb product. Moreover, the availability of honeycomb is limited and very complicated to fabricate by our own.

Hence, we used chassis form previous design from the second team. The previous second team has similarity with the design for new chassis which is FEA design 3 from the previous stress analysis. Therefore, we need to modify the chassis so that it matches with the new chassis design part such as front body panel and steering system. The main reason to reuse the previous chassis from second team is modify the old chassis is cheaper compare to fabricate a new chassis.

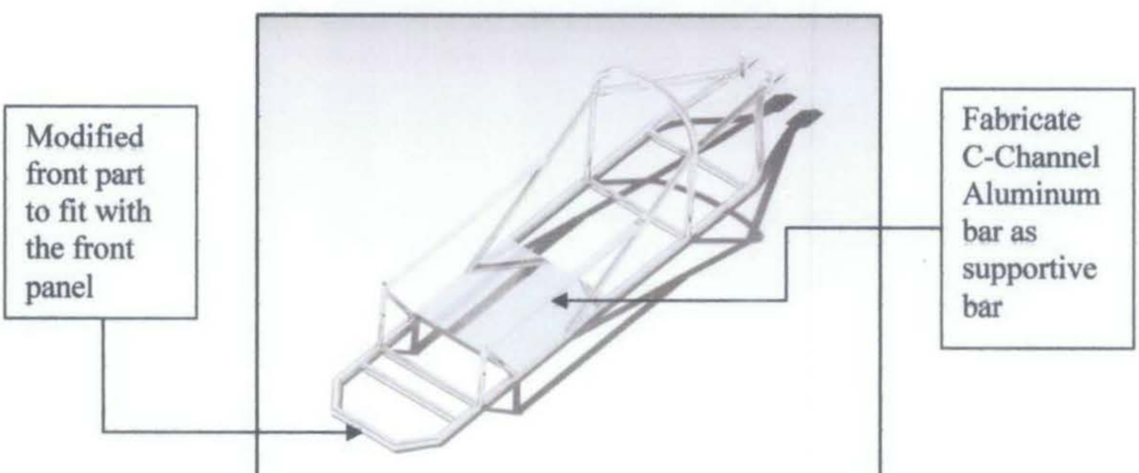


Figure 4.20: Modified Chassis

4.6 Bending Test

Figure 4.21: Bending Test

Bending test is conducted to determine the ductility or the strength of a material by putting a load on the material. For this bending test, a load of 50 kg is put on top of the chassis to find out the maximum elongation of the chassis. Location A, B and C is specified on the chassis based on the critical location the bending will be occurred. Bending test is conducted during hot weather which is about 32°C to verify the bending strength of the chassis under hot temperature.

Table 4.9: Bending Test Data

Time (min)	Elongation (cm)			Remarks
	location A	location B	location C	
0	10.0	10.4	10.0	No load added
0	9.5	9.7	9.2	50 kg load added
15	9.5	9.6	9.2	
30	9.3	9.5	9.1	
45	9.3	9.5	9.1	
60	9.3	9.4	9.1	
75	9.3	9.5	9.1	
90	9.3	9.4	9.1	
105	9.3	9.4	9.0	
120	9.3	9.4	9.1	
135	9.3	9.4	9.1	
150	9.3	9.4	9.0	

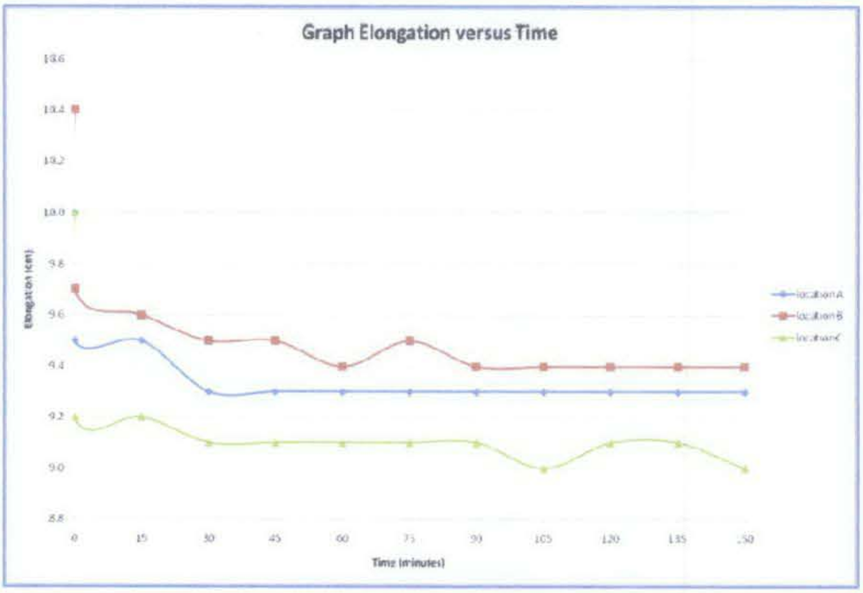


Figure 4.22: Graph Elongation vs Time

The calculation for maximum elongation is the original displacement minus the maximum displacement:

Location A

$$\text{max. elongation} = \text{original displacement} - \text{max. displacement}$$
$$= 10\text{ cm} - 9.3\text{ cm}$$
$$= 0.7\text{ cm}$$

Location B

$$\text{max. elongation} = \text{original displacement} - \text{max. displacement}$$
$$= 10.4\text{ cm} - 9.4\text{ cm}$$
$$= 1\text{ cm}$$

Location C

$$\text{max. elongation} = \text{original displacement} - \text{max. displacement}$$
$$= 10.0\text{ cm} - 9.0\text{ cm}$$
$$= 1\text{ cm}$$

$$\text{Average Max. Elongation} = \frac{0.7\text{ cm} + 1\text{ cm} + 1\text{ cm}}{3} = 0.9\text{ cm}$$

From the original displacement of location A, B and C, the displacements show the chassis is slanting upward a little bit giving extra strength on the chassis itself.

From the result above, the maximum elongation of the chassis is 0.9 cm for 150 minutes. This result has shown that the chassis has high in strength and it can sustain the rigidity and firmness of the vehicle body.

4.7 Visibility Test

Visibility of the driver is very important during driving the prototype car. Visibility is part of safety measurement to ensure the driver can see the way to move the car. The objective of visibility test is to check the design meet the requirement of the visibility safety measurement. The criteria of the visibility of the driver are ahead front view and 90 degree for both left and right view [11].

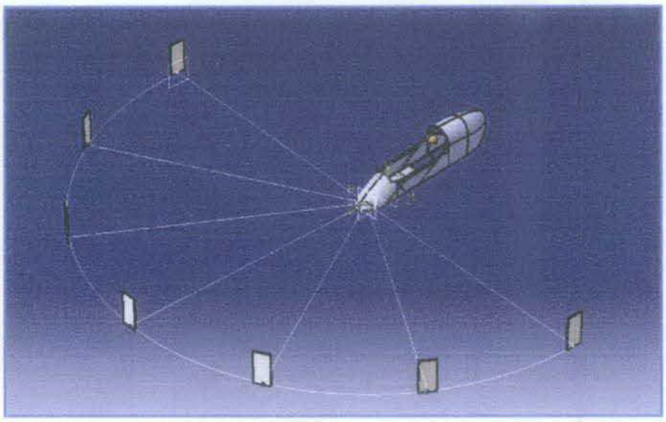


Figure 4.23: Visibility Test on Catia

Figure 4.24: Ahead View

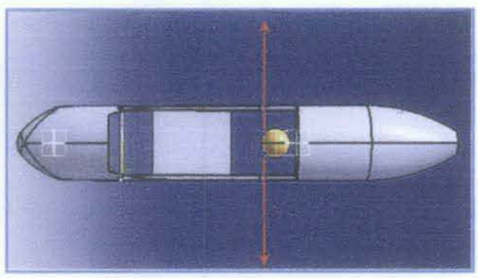


Figure 4.25: 90 degree side view

The window for the prototype car is fabricated based on the visibility test on catia software. We decide to use a complete transparent window made from PETG plastic. PETG plastic or also known as Polyethylene terephthalate is a thermoplastic polymer resin of the polyester family and is used in plastic bottle, food and other liquid containers [26].

In order to maintain the shape of the PETG, aluminum frame is made according to the design of the window. Although this part is very difficult to fabricate since fiber glass body panel and window is two separate materials, we manage to fit the window into the body panel entirely. Hence, a transparent window provides better visual for the driver during the race.

Figure 4.26: Window made form PETG plastic

4.8 Body Panel Fabrication Result

4.8.1 Body Panel Design Finalize

Body Panel design is inspired from the shape of the previous wind tunnel testing which are Aero Prototype 1 and Aero Prototype 1. Both designs give a low value of coefficient drag force. But in making the decision to choose which one is better is based on many factors. One most important factor is design integration with the steering system and power train system from other team member. The rear wheel is using 25 inch rim or approximately 630 mm. Hence, Aerodynamic Body 1 is chosen because it fit to the steering system and the power train system.

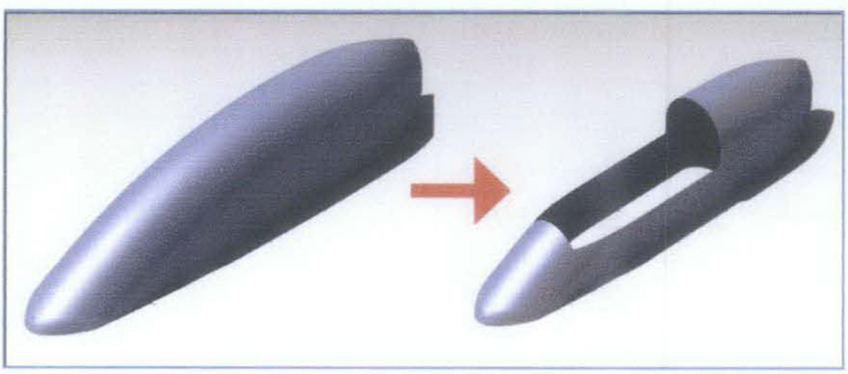


Figure 4.27: Body Panel Shape

For this project, we manage to fabricate the body panel based on the design planning. Even though that the design not 100 percent same with the design, the important criteria of aerodynamic is imbedded to the body panel fabrication. The major key point is to fabricate a car with smaller frontal area to reduce the drag force. The previous Wind Tunnel analysis proved that smaller frontal area produce smaller coefficient of drag force.

Figure 4.28: Smaller Frontal Area

Figure 4.29: Larger Frontal Area

4.8.2 Female Mould Fabrication

Mould fabrication is the critical part of body panel fabrication. The dimension of the mold must in shape with the chassis of the vehicle. Therefore, before proceeding to the fabrication, we need to design the mould with the proper dimension with the vehicle chassis.

For the first plan, we decided to make a whole-body mould. However, Mr. Ridwan Abd Latiff, Lecturer Material Engineering cum our fabrication supervisor advised us to divide the mould into three parts because the resin infusion equipment which is vacuum pump is only capable of doing small product. Therefore, the mould comprise of three parts which are front mould, side mould and back mould. One important advice from Mr. Ridwan is the mould must be a female mould and the surface of the mould must be smooth to get better result.

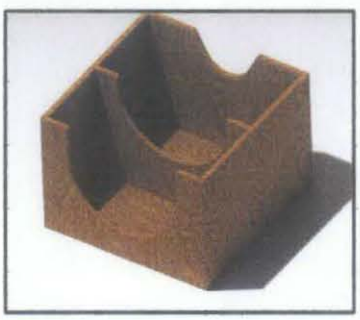


Figure 4.30: Front Mould Design

Figure 4.31: Front Mould Actual

Figure 4.32: Back Mould Design

Figure 4.33: Back Mould Actual

The surface finish of the fiber glass product depends on the surface of the mould. Besides that, female mould is fabrication the standard procedure for making fiber glass product. Previous team did not fabricate the female mould. Moreover, the surface of the female mould should be smooth to get better surface finish. In this project, we used zinc sheet metal since it has smooth surface and easy to bend. As shown in figure below, front panel is made from front mould by using Resin Infusion Technique has better surface finish.

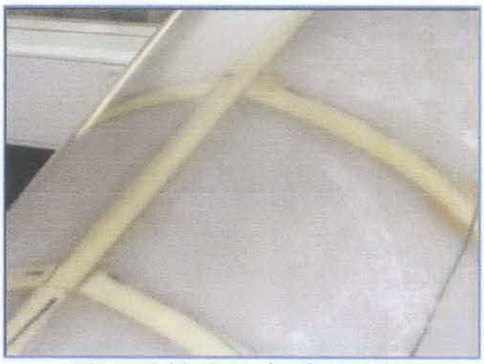


Figure 4.34: Good Surface Finish

Figure 4.35: Previous Surface Finish

4.8.3 Engine compartment separation

Previous design has attached the engine compartment or the back body panel to the front body. This results the difficulty to the team to repair the other component inside the engine compartment. They have to open the entire body panel so that they can repair the engine part which is wasting their time. Hence, for new prototype car, we fabricate the back body panel to be removable entirely for better flexibility features on the new car.

Figure 4.36: Easy access engine to compartment

Figure 4.37: Difficult access to engine compartment

As the result, flexibility of back body panel to be removed and attached to the chassis help the team to work in convenient way for engine compartment part.

4.8.4 Body Panel Stiffness

For the new body panel, we used a bunch of foams to create a layer of frames to increase the stiffness of the body panel. The foam frame layer is place in between the fiber glass composite which is shown in figure below.

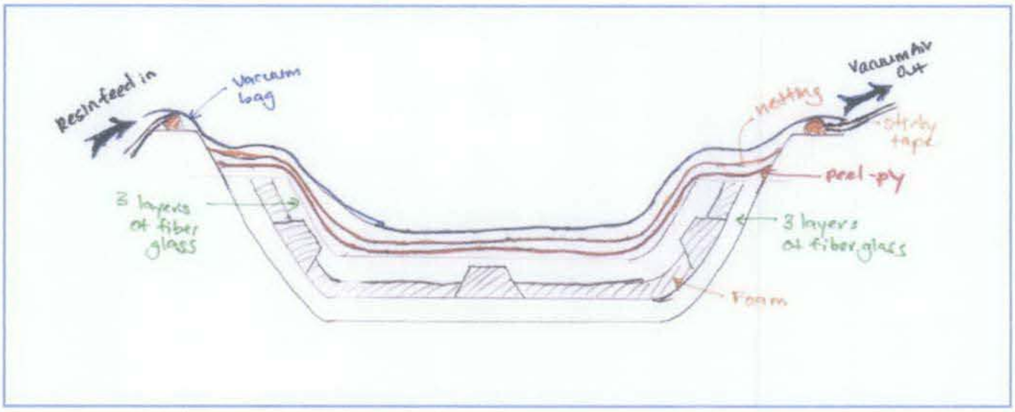


Figure 4.38: Resin Infusion Layers

During infusion, the resin feed into the vacuum bag through the layers of the fiber glass. The resin also feed into the foam frame resulting the foam to be stiff after solidify. This stiff foam frame creates better stiffness of the body panel.

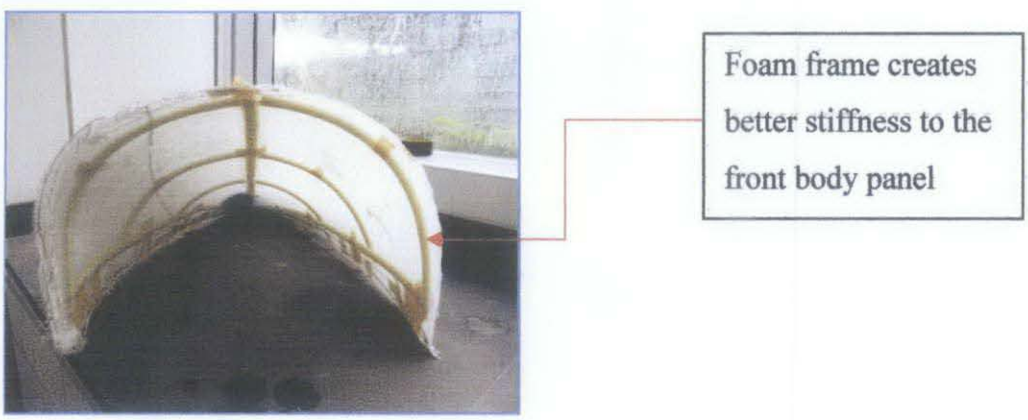


Figure 4.39: Front Panel Foam Frame

4.8.5 Finishing Appearance

Finishing is the last step of the body panel fabrication purposely to make better appearance of the vehicle. However, we have some problem regarding the expertise on spraying the body panel and resources or sponsorship for finishing the product. It is a waste when we buy expensive car plaster, spray color, and other equipments for finishing the product but we do not have expertise on spraying smoothly of the body panel. Moreover, we have already tried using white spray on the front body panel but the appearance is not as we expected. Some void appear on the surface of the body panel due to the absorption of the spray liquid by the fiber glass trough the some poles on the body panel surface. This causes us to spend about RM100 just for the front body panel.

After much consideration, we decided to use a fully sticker finishing for the entire body panel. This decision is made because we can solve the void appearance problem since the sticker creates a layer of protective on the body panel. The cost of using sticker is much cheaper compare to buy spray color. The themes color for the body panel is blue and white.

Figure 4.40: Sticker Finishing

Figure 4.41: Spray Finishing

4.9 Weight of the Vehicle

4.9.1 Total Weight of New Prototype Car

Design constrains mentions that the weight of the car without driver must be below 140 kg. The total weight of the prototype car is only **56.5 kg** without driver on it. This weight is including the weight of the engine, steering system, power train system and other equipments. Based on estimation, the weight of the prototype car for body panel and chassis is shown in calculation below.

Weight of body panel & chassis = Total Weight - Weight of Engine - Weight of moving system components

$$= 56.5kg - 15kg - 25kg$$
$$= 16.5kg$$

This proves that, resin infusion technique success to produce light weight fiber glass body panel.

4.9.2 Resin infusion versus Conventional Technique

Resin infusion technique is a new way of fabricating fiber glass produce. Resin infusion product claim to be better quality product compare to conventional technique. How far this statement to be true? Hence, I have made a simple research to prove the resin infusion is better than conventional technique in term of the weight of the product.

Two 100mm × 100mm sample is taken from new prototype car and previous prototype car. For the previous prototype, a good sample is taken so that the data will be valid. Then, the weight of the two samples is weigh to determine the weight different for resin infusion sample and conventional sample.

$$\text{Weight of Resin Infusion sample} = 20.37\text{ g}$$
$$\text{Weight of Conventional sample} = 30.05\text{ g}$$
$$\text{Percentage Different} = \frac{30.05g - 20.37\ g}{20.37g} \times 100\% = 47.52\%$$

From the calculation, the percentage different is only 47.52%. Hence, resin infusion technique is proven to produce lighter weight of fiber glass product. By the way, a proper conventional technique is also giving a good result if we follow the right procedures of the fabrication.

The resin infusion technique is better in term of weight factor and rigidity because this technique provide a compression to the surface of the fiber glass layout due to the suction of air inside the vacuum bag. This compression force acting on the surface of the fiber glass cause the layer of fiber glass to be as thinner as possible. Therefore, this will provide enough space for the resin to feed into the vacuum bag to cover the entire of the fiber glass layers.

Too much resin in the fiber glass layers does not mean better rigidity and strength of the product. The fiber glass is the element of strength in composite material fabrication. Previous fabrication used too much excess resin during the body panel fabrication. This will produce a heavier product and low in stiffness.

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the project completion, we managed to optimize the car from the previous prototype car. From the aerodynamic test, current design is proven to be more aerodynamic because it has smaller frontal area and streamline shape. Hence, new prototype car has smaller drag force due to the streamline shape.

From the FEA analysis and bending test, current chassis is verified to be high in strength and rigidity. Moreover, we also manage to fabricate the prototype car with cost efficient way. Most of the part is reused back from previous car and modified to fit into the new prototype car such as the chassis. Hence, we can use the resources more on the critical parts such as brake system, power train and engine system.

In term of weight factor, we manage efficiently reduce the weight to only 56.5 kg by using resin infusion technique for fabrication of the body panel. Besides that, the body panel has better stiffness, rigidity strength and surface finish.

In ergonomic point of view, the window is made from transparent PETG plastic for better visualization. Hence, it helps the driver to drive efficiently for the race. Furthermore, current design has better feature to access to engine compartment. Therefore, the technical team can do the works in convenient way.

5.2 Recommendation

The first recommendation for the future reference is used a tubular bar instead of circular bar. The tubular bar has better in stiffness and strength. This recommendation is for chassis is obtain from SEM 2011 since most of the team use a tubular as supportive for the body of the car.

The second recommendation is to fabricate the whole body panel first to cut most the time of the fabrication. However, fabrication of the whole body panel is required a better resin infusion equipment such as more horse power suction pump, better sticky tape, and better sealant equipment.

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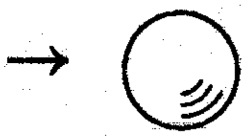
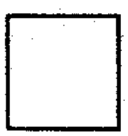
APPENDICES

APPENDIX 1

Drag Coefficient value based on 3-D shape

Table 2.2 C_D values for simple three-dimensional shapes. Note that for some of these shapes, the drag coefficient varies significantly with Reynolds number. The values are typical for Reynolds numbers in the range 10^4–10^6.

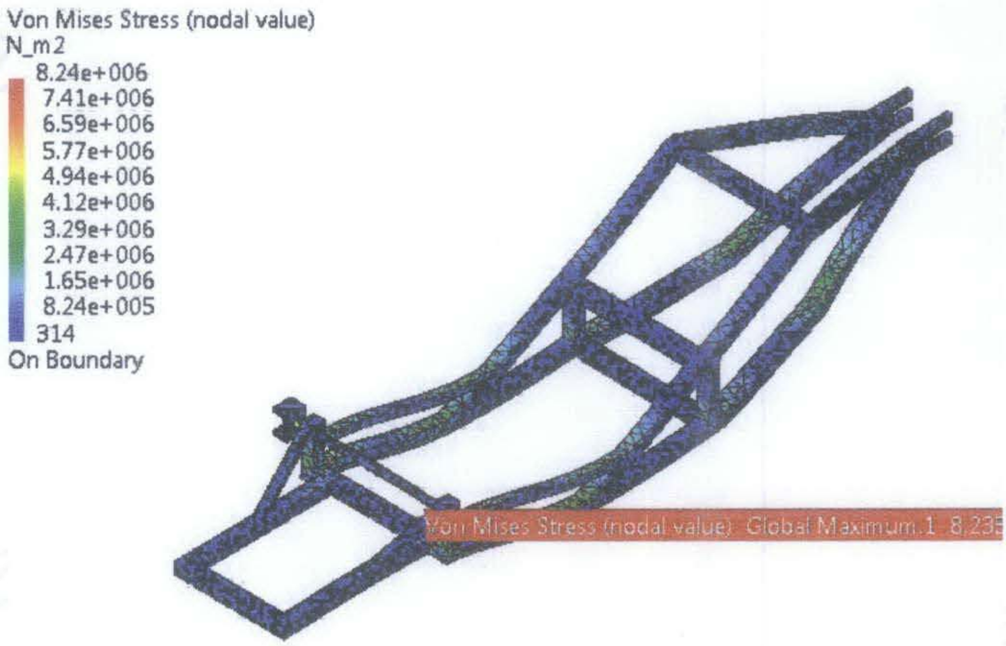
Shape		C_D
	Sphere	0.47
	Hemisphere	0.42
	60° cone	0.5
	Circular plate	1.17
	Cube	1.05
	Teardrop [t/c = 0.25]	0.05

(Based on data from various sources presented in Hoerner[6])

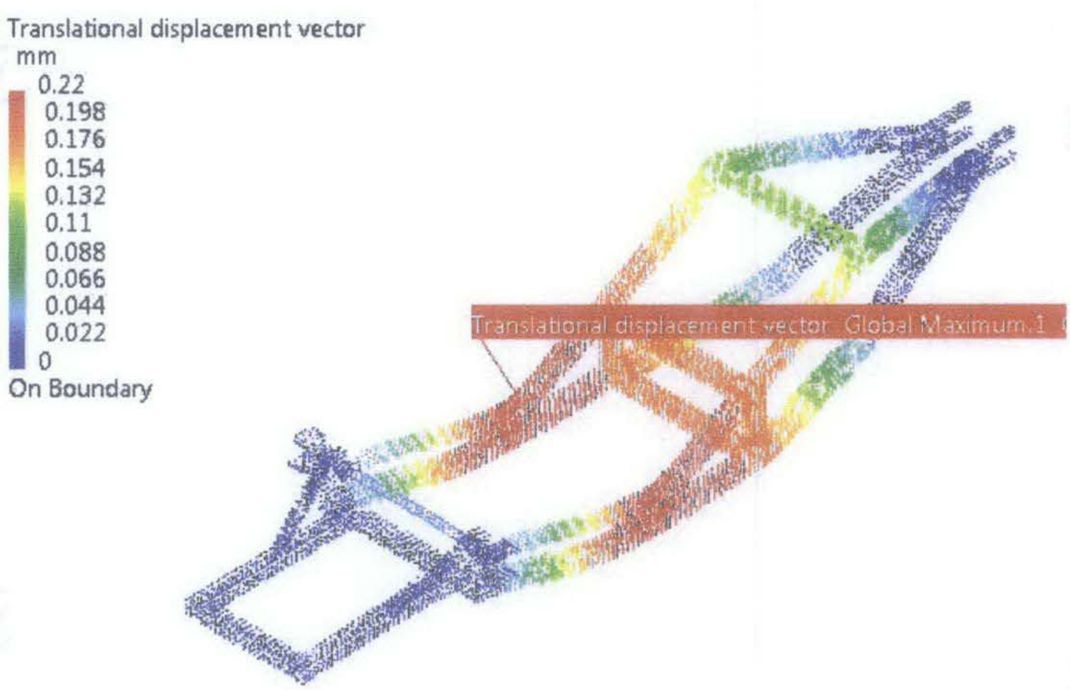
APPENDIX 2

FEA analysis design 3

Von Mises Stress (nodal value)

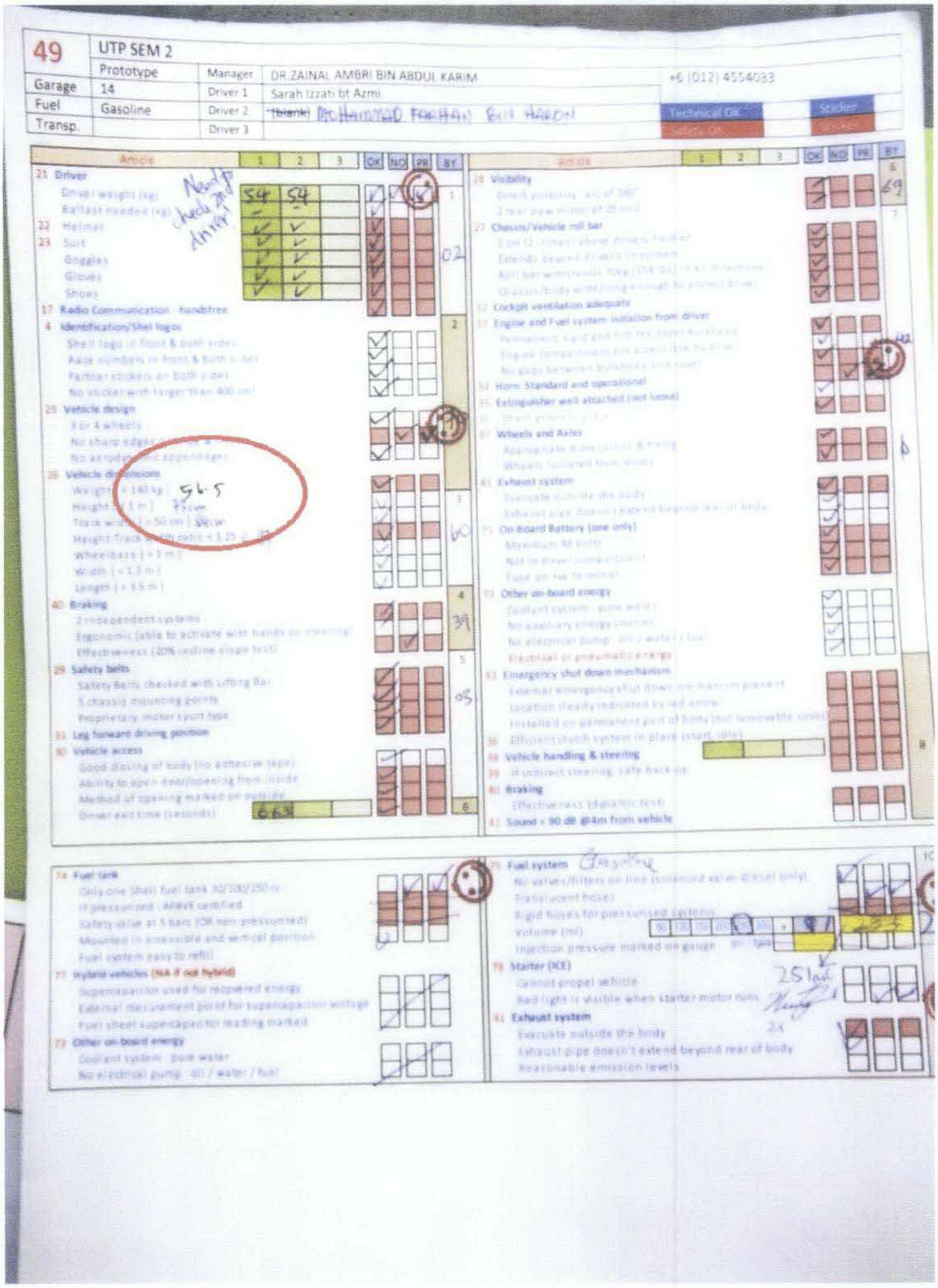


Translational displacement vector



APPENDIX 3

Shell Eco-Marathon Asia 2011 Inspection Form



49	UTP SEM 2			
	Prototype	Manager	DR ZAINAL AMBRI BIN ABDUL KARIM	+6 (012) 4554033
Garage	14	Driver 1	Sarah Izzati bt Azmi	
Fuel	Gasoline	Driver 2	~~(blank)~~ MOHAMMAD FARHAN BIN HARON	Technical OK / Sticker
Transp.		Driver 3		Safety OK / Sticker

Article | 1 | 2 | 3 | OK | NO | PR | BY

21 Driver
Driver weight (kg) 54 54
Ballast needed (kg)
22 Helmet
23 Suit
Goggles
Gloves
Shoes
Need to check 2nd driver
17 Radio Communication - handsfree
4 Identification/Shell logos
25 Vehicle design
26 Vehicle dimensions
Weight 56.5
40 Braking
29 Safety belts
31 Leg forward driving position
30 Vehicle access

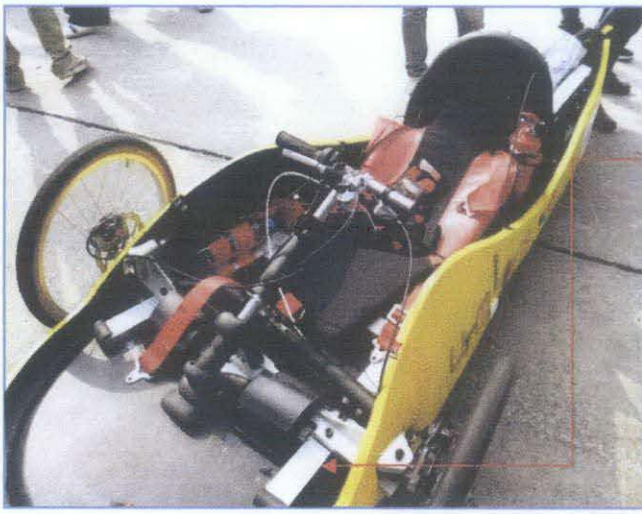
28 Visibility
27 Chassis/Vehicle roll bar
32 Cockpit ventilation adequate
33 Engine and Fuel system isolation from driver
34 Horn: Standard and operational
35 Extinguisher well attached (not loose)
37 Wheels and Axles
41 Exhaust system
71 On-Board Battery (one only)
73 Other on-board energy
43 Emergency shut down mechanism
38 Vehicle handling & steering
40 Braking
42 Sound < 90 dB @4m from vehicle

74 Fuel tank
77 Hybrid vehicles (NA if not hybrid)
73 Other on-board energy

75 Fuel system Gasoline
78 Starter (ICE)
41 Exhaust system
Execute outside the body
Exhaust pipe doesn't extend beyond rear of body
Reasonable emission levels

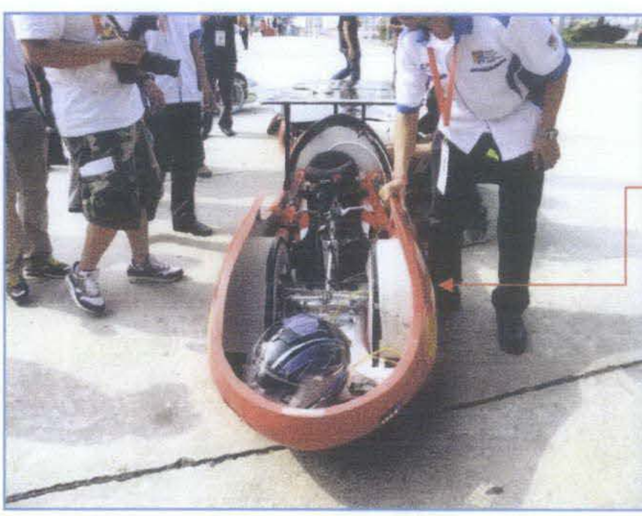
APPENDIX 4

Shell Eco-Marathon recommendation and reference for future team



Use tabular chassis to support the entire body

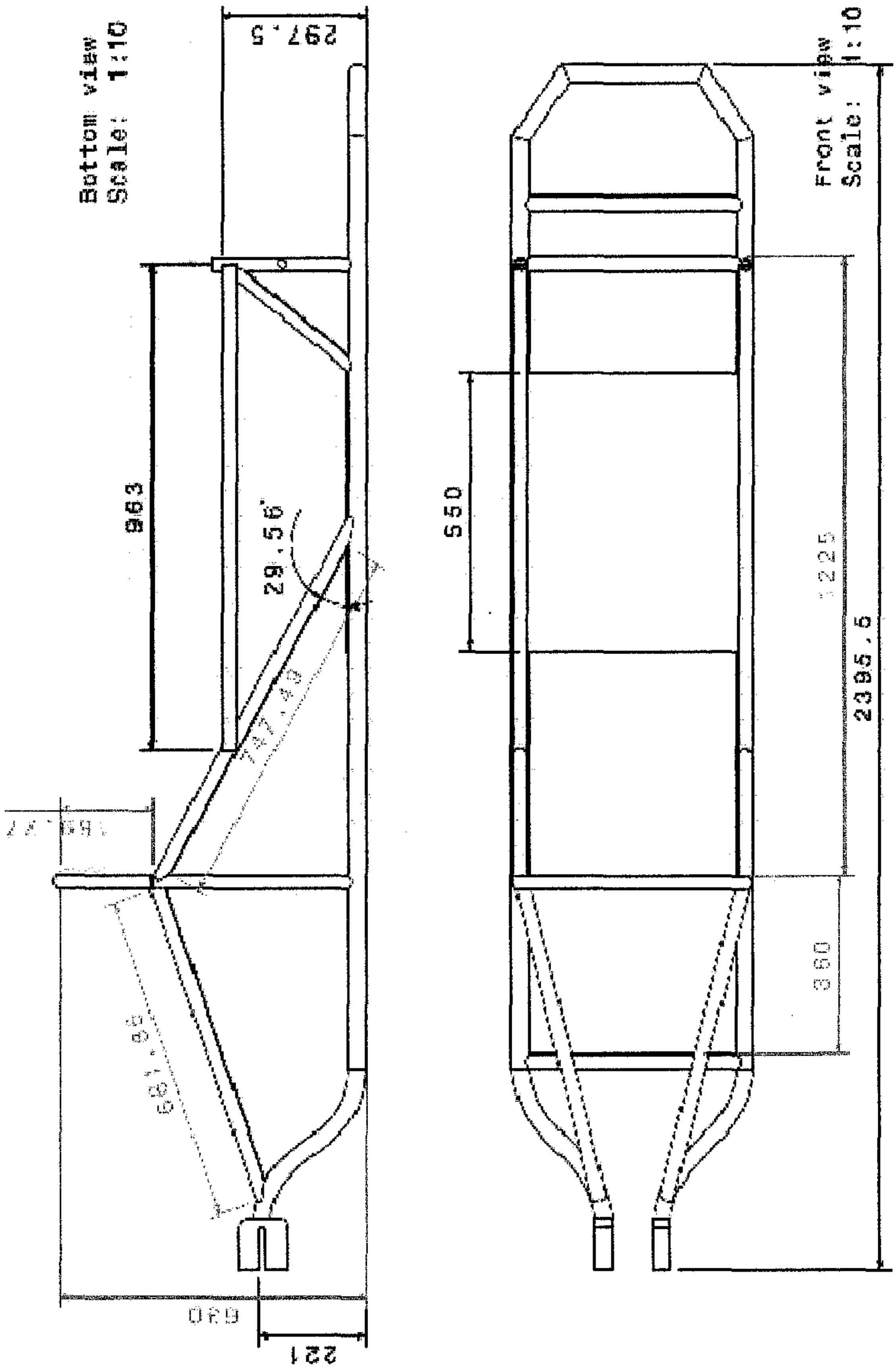
Unique design – Only used plastic to cover the chassis.



Cover the front wheel to reduce the air turbulence created by the wheel rotation

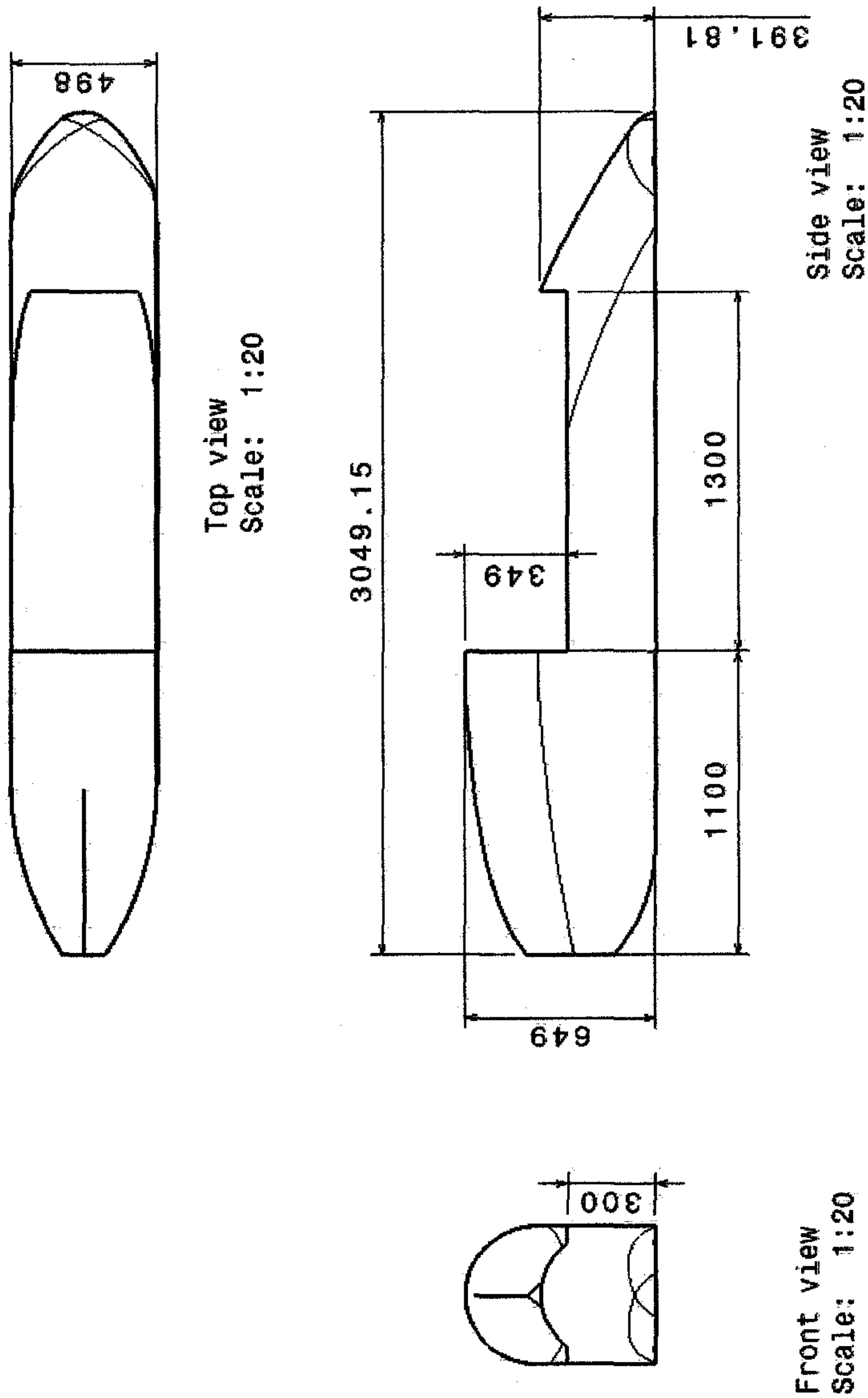
APPENDIX 5

Detail drawing chassis frame



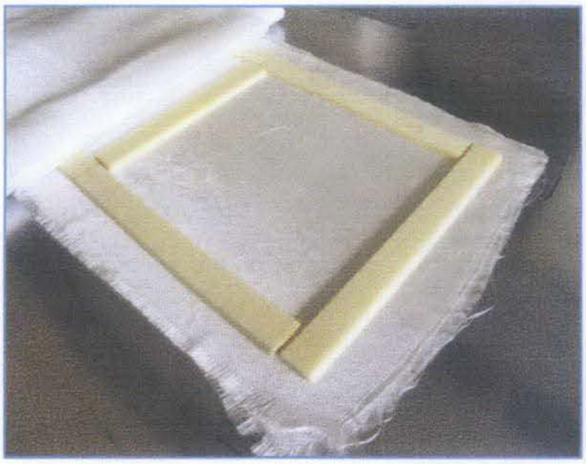
APPENDIX 6

Detail drawing body panel



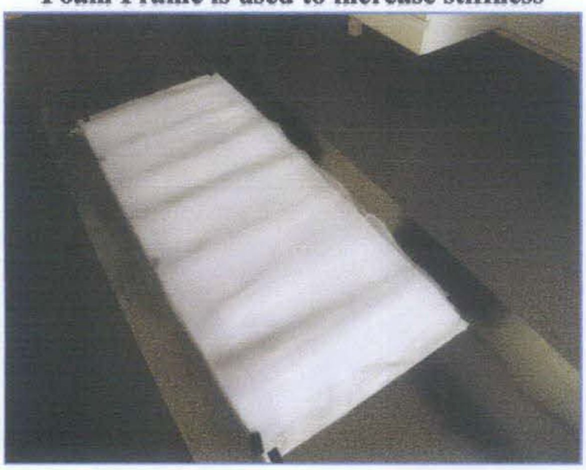
APPENDIX 7

Body Panel Resin Infusion Fabrication



Foam Frame is used to increase stiffness

6 layers of fiber glass



Peel-ply and infusion mesh on top fiber glass layer

During Infusion fabrication

Side panel fiber glass product

Final body panel prototype car