MAZUAN BIN IBRAHIM B. ENG. (HONS) MECHANICAL ENGINEERING MAY 2010

DESIGN AND FABRICATION OF A SIMPLE VEHICLE FOR COMPETITION IN SHELL ECO- MARATHON 2010 (VEHICLE FRAME AND BODY DESIGN)

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MECHANICAL ENGINEERING

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CERTIFICATION OF APPROVAL

Design and Fabrication of a simple vehicle for Competition in Shell Eco- Marathon 2010 (Vehicle Frame and Body Design)

by

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Approved by,

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(Ir Dr Masri Bin Baharom)

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TRONOH, PERAK

MAY 2010

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.

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MAZUAN BIN IBRAHIM

TABLE OF CONTENT

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ABSTRACT

The Shell Eco-marathon began in 1939 at a Shell research laboratory in the U.S. as a friendly wager between scientists to see who could get the most miles per gallon from their vehicles. From these humble origins, the organized competition for fuel economy evolved and moved to Europe. The Shell Eco-marathon in its current form began in 1985 in France, attracting thousands of young engineers and scientists from 20 European countries. [11]

The Shell Eco-marathon challenges students around the world to design, build, and test vehicles that travel further using less energy.

This report includes the methodology, starting with literature review of previous competitors, research work related to the frame and outer shell body design. Then continue with design and analysis stages, followed with fabrication stages. Finally, troubleshooting, modification and optimization of vehicle.

The principle of the Shell Eco-marathon is simple: to design and build a vehicle that uses the least amount of fuel to travel the farthest distance. Team can enter futuristic prototypes: streamlined vehicles where the only design consideration is reducing drag and maximizing efficiency.

The result of the project, including the result from design stages, analysis of the frame and outer shell body structure. Then the fabrication validated with several testing, such as load and thermal expansion testing. Finally, the fuel consumption testing result after the vehicle finished assemble by taking how far the vehicle can travel with a litre of gasoline.

LIST OF ABBREVIATIONS

CAD	Computational Aided Design
CAE	Computational Aided Engineering
CAM	Computational Aided Manufacturing
CFD	Computational fluid dynamics
AWTE	Automotive Wind Tunnel
NSMB	Navier-Stokes Multi-Block
ETH	Eidgenössische Technische Hochschule
SEM	Shell Eco-Marathon
BMEP	Brake Mean Effective Pressure

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPH

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The Shell Eco-marathon challenges students around the world to design, build, and test vehicles that travel further using less energy [11]. Weight and aerodynamic shape plays a big role to the fuel economy. If an object has to move thru the air, we'd like to use a body shaped like an elongated tear-drop shape that is five times longer than it is in diameter. Weight of the vehicle also contributes to the fuel economy of the vehicle. Therefore, material selection, design of the frame and optimization of frame give big significant to the weight of the vehicle and fuel economy.

1.2 Problem Statement

There are two major factors that effects fuel consumption of a vehicle which are weight of the vehicle and the aerodynamic drag. Weight of a vehicle is related to the forces act on the vehicle where increase of weight increases the tractive force to pull the car. The force on an object that resists its motion through a fluid is called drag.

In the early stage of the design process, it is really important to identify the design requirements. To achieve this goal, the rules of the contest need to be taken into serious consideration. A short overview is stated below. The challenge of Shell Eco-Marathon 2010 is to to design, build, and test vehicles that travel further using less energy. [11]. Following are the most important vehicle's specifications related to body and aerodynamic:

Driver Weight- Drivers of Prototype vehicles must weigh at least 50 kg in full driving gear.

Driver Comfort- It is recommended to properly ventilate the inside of the vehicle to provide cooling to the Driver during hot event condition.

Dimensions

- The maximum height must be less than 100 cm
- 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.
- The track width must be at least 50cm, measured between the midpoints where the tyres touch the ground.
- The wheelbase must be at least 100cm.
- The maximum total vehicle width must not exceed 130cm.
- The maximum total length must not exceed 350cm. The maximum vehicle weight, without the Driver, is 140kg.

Chassis / Monocoque Solidity

- The vehicle must be equipped with an effective roll bar that extends 5cm around the driver s helmet when seated in normal driving position with the safety belts fastened
- Any roll bar must be capable of withstanding a static vertical and horizontal load of 700N (~70 kg) without deforming.
- It is imperative for Drivers, fully harnessed, to be able to vacate their vehicles at any time without assistance in less than 10 seconds.

Visibility

- Inspector will check good visibility with seven 60cm high blocks spread out every 30° in a half-circle, with a 5m radius in front of the vehicle.
- The vehicle must be equipped with a rear-view mirror on each side of the vehicle, each with a minimum surface area of 25cm2 (e.g. 5cm x 5cm).

Two major factors that affect fuel consumption in frame and body design are aerodynamic drag force and weight of the vehicle [10]. Any physical body being propelled through the air has drag associated. In aerodynamics, drag is defined as the force that opposes forward motion through the atmosphere and is parallel to the direction of the free-stream velocity of the airflow. Drag must be overcome by thrust in order to achieve forward motion. [8]

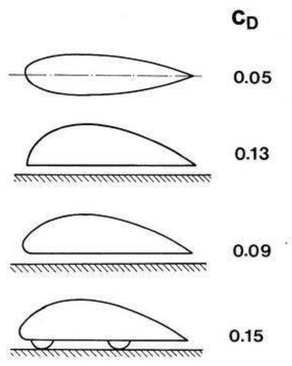


Figure 1: Drag Coefficient Measurement with 'half –bodies'

In aerodynamics, the word drag defines air's natural tendency to slow things down. It steals your vehicles energy and decreases your fuel economy. To be more efficient, the project aim to reduce drag by becoming more aerodynamic, much like a bird gliding through the wind [5]. Apply those lessons to create forms that work with wind, rather than against it.

1.3 Objective of Study

The objectives of the study are to;

- To select and design a suitable frame and body producing minimum weight frame and body and resulting minimum fuel consumption
- To design frame that have sufficient compartment for driver and all components
- To design body that have less aerodynamic drag & weight resulting minimum fuel consumption

1.4 Scope of Study

This project will cover on the study characteristic of design, analysis and fabrication of;

- Identify and study the SEM Asia 2010 rules and regulations that restricted design parameter.

- Benchmarking previous SEM competitor's frame and body design. Design frame and body related to SEM Asia 2010 rules and regulation
- Optimize frame and body design using analytical and numerical technique.
- Fabricate the frame and optimize the compartment usage

CHAPTER 2

LITERATURE REVIEW

2.1 Rules and regulation overview

In this competition, there are rules and regulation that need to be follow by the participant. List of articles is related to body and chassis design. All articles below need to consider during design stage.

Before designing and developing the vehicle body, we have to understand the fundamentals of vehicle frame technology and major components related to its mechanical system. Research papers will be the basis in the formulation of methodology and concept generation that applies the theoretical knowledge.

2.2 Maximize Fuel Efficiency Method (Chassis and Body Design)

There are many ways to maximize fuel efficiency of the vehicle. Methods to maximize fuel efficiency are by reducing aerodynamic drag force and reducing weight of the vehicle [10].

This report is about the development of previous aerodynamic design of the body shape of Shell Eco-marathon car. Major factors affecting the resistance of the three wheeled vehicle are weight, powertrain efficiency, the fuel cell system and aerodynamic drag. At an average speed of 30-40 km/h, aerodynamic drag generates between 20% and 30% of the overall drag figure.

In this literature review, design of several top participants and in production vehicle that has similar characteristic in this competition has been selected as benchmark for this project. One of the team has broken the most efficient car world record.

2.3 Benchmarking from the best fuel consumption record in Shell Eco-Marathon Competation-PAC-Car II

Figure 2.1: PAC-Car II CAD model, the world's most fuel-efficient vehicle

PAC-Car II is the world's most fuel-efficient vehicle. The world record was broken with a consumption of 5385 kilometres to one litre of petrol at the fuel economy competition Shell Eco-marathon in Ladoux (F) in 2005. As the body shape contributes significantly to the overall drag of the vehicle, it had to be reduced to the minimum. This was achieved using both experimental and numerical methods during the aerodynamic design process of PAC-Car II. [2]

The factor contribute to their fuel consumption was the weight of the vehicle. The overall weight of PAC-Car II was 30kg. Extremely light and high strength of monoque carbon fibre frame was using to minimize the overall vehicle weight.

The design of the body shape of PAC-Car II is constrained by qualitative and quantitative parameters. They originate from a number of sources, including the race regulations of the Shell Eco-marathon, ergonomics, and aerodynamics. After first preliminary designs several iterations were performed with the help of wind tunnel tests and CFD to find the ideal aerodynamic shape. For the wind tunnel tests wind tunnel models were used in scale 1:2, for CFD a Navier-Stokes- Multiblocks Solver was used. The results of CFD and of the wind tunnel showed good agreements.

The Center Aerodynamics supported the team to optimize the design. Both wind tunnel tests and CFD were applied to improve the aerodynamic shape. Wind tunnel tests were conducted at ETH in Zurich and in the Automotive Wind Tunnel (AWTE) using the rolling road feature. CFD simulations were performed using the Navier-Stokes Multi-Block Solver NSMB. Firstly, the car's outer shape was designed using CAD, taking space requirements for the pilot, power train and equipment into account. To validate the CFD code for the application, a 50% scale wind tunnel model was built and tested. The same geometry was also calculated with the NSMB. After this validation, the geometry was optimized in several steps, again using NSMB. Their engineers found that the wheel fairing design had a crucial impact on the aerodynamic drag of the car, especially under yaw conditions. After the last iteration of the development calculations, a revised shape was again built as a 50% scale wind tunnel model. The design started with a drag coefficient (C_D) for the initial shape of 0.095 and a drag area of 0.028m^2. During the design iterations, C_D was reduced below 0.08 and the drag area of the final shape did not exceed 0.019m^2. Note that the drag area for the earlier PAC-Car I vehicle was as high as 0.069 m^2.

2.4 Effects of Reducing Weight (Mass) in Fuel Economy

From research done by Ricardo Inc. entitle Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicle Architectures, they have done a study on the effects of weight reduction to fuel economy. Below is the result that they have gained on effect of reducing various size weight vehicles to fuel economy [12].

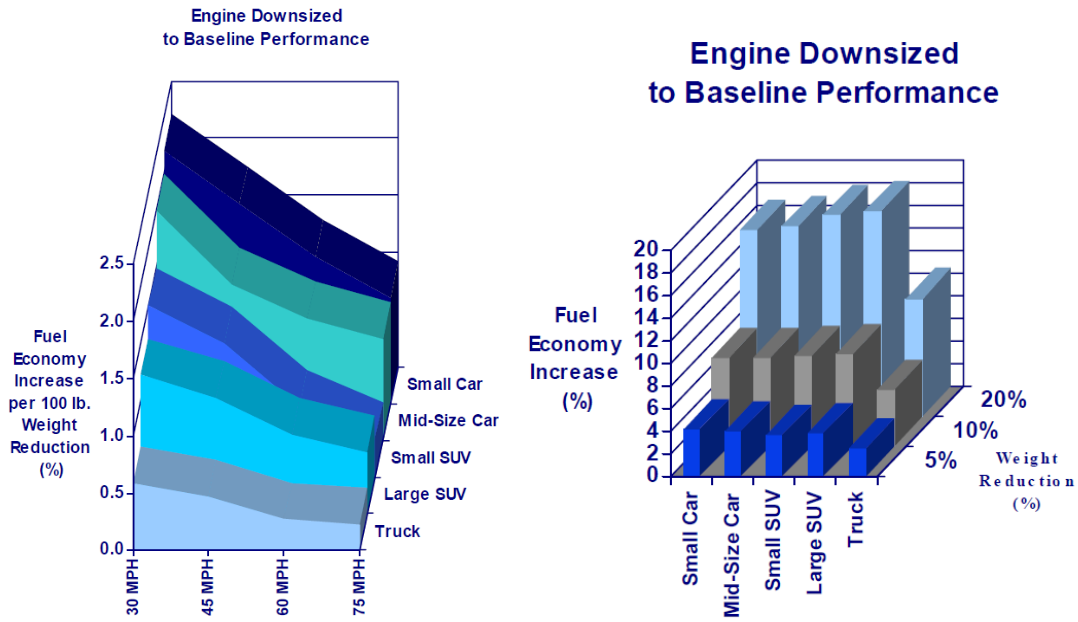


Figure 2.2: Effects of weight reduction to the fuel economy result conducted by Ricardo Inc.

From their study they have conclude that reducing vehicle weight (mass) results in less tractive effort required to accelerate the vehicle and less rolling resistance from the tires. Drive cycles with more acceleration events show greater fuel economy benefits from weight reduction than highway or steady state conditions. Also, at higher vehicle speeds the engine is typically at higher throttle operating points and provides less opportunity for improvement. Since the tire losses are a greater percentage of total tractive effort at lower speeds (aerodynamic losses increase by velocity squared) the potential for fuel economy gain from weight reduction is greater at lower vehicle speeds. Fuel economy results (and improvements) at the steady 30 MPH drive condition vary because most vehicles are not in top gear yet and are operating the engine at a higher speed / lower load point that is less efficient.
Less tractive effort results in less engine torque demand at a given point in the drive cycle. The lower load (throttle) demand puts the engine at a less efficient point with more pumping loss and lower brake specific fuel consumption (grams fuel / power produced). Reducing the engine displacement of the weight-reduced vehicle to equal baseline vehicle performance increases the brake mean effective pressure (BMEP) of

the engine operating points and improves efficiency. A final drive ratio change could also partially offset the pumping loss increase but was not investigated.

2.5 Material Selection for Shell Eco-Marathon Chassis

Materials play an important key role in the materialization of an idea or concept, and are important in the design process. Nowadays, the choice of materials is almost unlimited, which is simultaneously bad and good news to designers. It is good news because one can find the suitable, even optimal, compromise of design parameters for a specific product.

Start off with what factors are considered in frame tube construction. GT bicycle that produce most of the frame bicycle in market have stated there are five main areas considered in frame construction [9]. These areas are:

1. Material Density
2. Stiffness of material
3. Yield strength
4. Elongation
5. Fatigue and Endurance limits

Below are potential candidate of frame materials base on generally bicycle frame available in market.

- **Steel frames** have been, and to some extent still are, widely used in bicycles. Steel, also known as chromoly, is a dense (heavy) material. It is also not as stiff as other materials. Since steel is not as stiff it provides a smoother ride. It takes some strong forces to deform steel. This also depends on the thickness of the steel too. Steel has virtually limitless fatigue and endurance limits.
- **Aluminum frames** are not as dense or strong as steel. Thus aluminum frames are much lighter and easier to deform when compared to steel. Aluminum is, however, much stiffer. Which means the ride is can be more jarring. Unlike steel, aluminum does have a fatigue and endurance limit. The time before failure is long yet it can happen.

- **Titanium frames** are considered the most exotic and to some the pinnacle of bicycle frames. Titanium is very light yet it is extremely strong. Depending on the tube size of the frame will determine the stiffness of the frame. Like steel, titanium limits are virtually none existent. Thus a very long riding life can be expected which makes it a good choice for bicycle frame materials.
- **Carbon fiber frames** are a more recent addition to bicycle construction. These frames are very light and can be quite stiff. These frames are not as impact resistant as other frame materials. The beauty of carbon fiber is it can be fine tuned for strength during manufacturing. Additionally it has a very strong strength to weight ratio so when it comes to choosing the best bicycle frame materials to use carbon is high on the list.

2.6 Fabrication Technique

2.6.1 Bending

Stretching and Compression Principles

When a tube is bent, two things happen to metal (*Figure 1-a*). The outside wall is reduced in thickness due to the stretching of the material and the inside wall becomes thicker due to the compressing of the material (*Figure 1*). The material actually is formed approximately about the centreline of the tube. The material that forms the outside of the bend has further to travel and therefore is stretched; the inside of the bend has less distance to travel and is compressed.

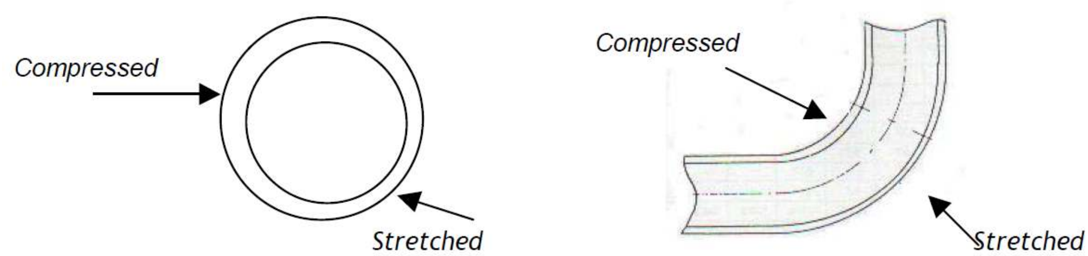


Figure 2.3: Effect of pipe's roll bending.

Figure 2.4: Manual Pipe Bending Tool (left) and roller bending machine (right)

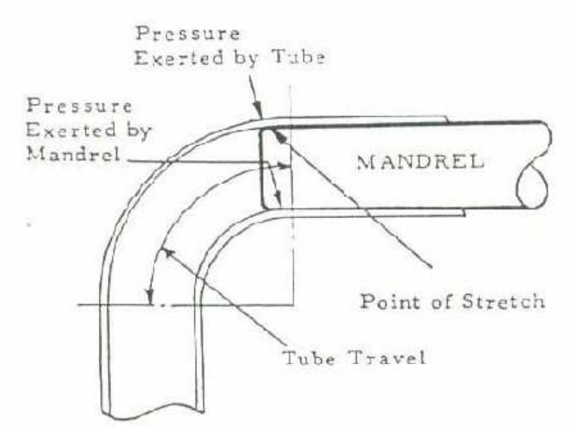


Figure 2.5: Mandrel For bending

Bending Tube with a Plug Mandrel

The purpose of a plug mandrel is to prevent the tube from flattening and to bend without wrinkles or kinks. The mandrel is held in a fixed position while the tube is pulled over it. The tube stretching process is localized on the outer radius of the bend and the material is workhardened to retain its shape and not flatten. The material stretching is done on the forward tip of the mandrel (Figure 5). This force, acting on the

2.6.2 Gas-metal-arc-welding

A TIG (GTAW) welder. Most sources say a TIG (Tungsten Inert Gas) welder, also called a GTAW (Gas Tungsten Arc Welder), is the best method of welding aluminium. Aluminium can also be welded with a MIG welder or a stick welder or even a with a gas torch. There are specific methods and parameter need to be consider during weld aluminium which are

- Preheating the aluminum workpiece can help avoid weld cracking. Preheating temperature should not exceed 230 F-use a temperature indicator to prevent overheating. In addition, placing tack welds at the beginning and end of the area to be welded will aid in the preheating effort. Welders should also preheat a thick piece of aluminum when welding it to a thin piece; if cold lapping occurs, try using run-on and run-off tabs.

- The push technique: With aluminum, pushing the gun away from the weld puddle rather than pulling it will result in better cleaning action, reduced weld contamination, and improved shielding-gas coverage.
- Travel speed: Aluminum welding needs to be performed "hot and fast." Unlike steel, the high thermal conductivity of aluminum dictates use of hotter amperage and voltage settings and higher weld-travel speeds. If travel speed is too slow, the welder risks excessive burnthrough, particularly on thin-gage aluminum sheet.
- Shielding Gas: Argon, due to its good cleaning action and penetration profile, is the most common shielding gas used when welding aluminum. Welding 5XXX-series aluminum alloys, a shielding-gas mixture combining argon with helium - 75 percent helium maximum - will minimize the formation of magnesium oxide.
- Welding wire: Select an aluminum filler wire that has a melting temperature similar to the base material. The more the operator can narrow-down the melting range of the metal, the easier it will be to weld the alloy. Obtain wire that is 3/64- or 1/16- inch diameter. The larger the wire diameter, the easier it feeds. To weld thin-gage material, an 0.035-inch diameter wire combined with a pulsed-welding procedure at a low wire-feed speed - 100 to 300 in./min - works well.

2.7 Ergonomics

According to PAC-Car II aerodynamic design [4], it was very important to pay special attention to ergonomics and such natural boundary conditions as the pilot's physical dimensions. The pilot needs to feel safe in the vehicle as well as comfortable enough to drive the vehicle without needing to maintain excessive concentration throughout the run. Intensive experiments about the ergonomics of the vehicle design were conducted, and the result contributed decisively to PAC-Car II's success. They had conducted driving position and visibility tests using numerous wheel positions (Figure 6) were tested and evaluated according to a variety of ergonomic and technical criteria, such as the pilot's field of vision, in order to define the best driving position. [4],

An important element considered during the preliminary design phase was the windshield. According to the theory of optics, the more perpendicular the windscreen is to the pilot's line of sight, the better the pilot's vision will be, as the effects of reflections and surface defects will be minimized. This theory had to be kept in mind designing the windshield.

Figure 2.6: Pac-Car II driving position and visibility tests. Overview of the experimental apparatus, with the mock-up chassis model in the foreground and the labels used to quantify the pilot's field of vision in the background.

2.8 Previous Participants Design Review

From morphology in chapter 3 , most of the team using two wheels front and one wheel rear, this is due to aerodynamic shape factor as the best aerodynamic shape is half teardrop shape where at front of the shape slightly bigger than rear [8]

There are many shape purpose by previous team base on their design terminology. Basically aerodynamic of the vehicle is not the biggest influence in this competition as the average speed permitted around 15 km/h to 30 km/h. but still the effect of aerodynamic need to be considered. Reduction of the weight is more important than aerodynamic as the forces act on the vehicle statically and dynamically.

Most of the team using CFRP and GFRP as their outer shell body as the properties of the material itself resulting to light construction of outer shell body and high in strength.

CHAPTER 3

METHODOLOGY

3.1 Methodology

Before proceeding with the study itself, steps were drawn out diagrammatically to clear out on the flow to ensure the study can be completed in the given time.

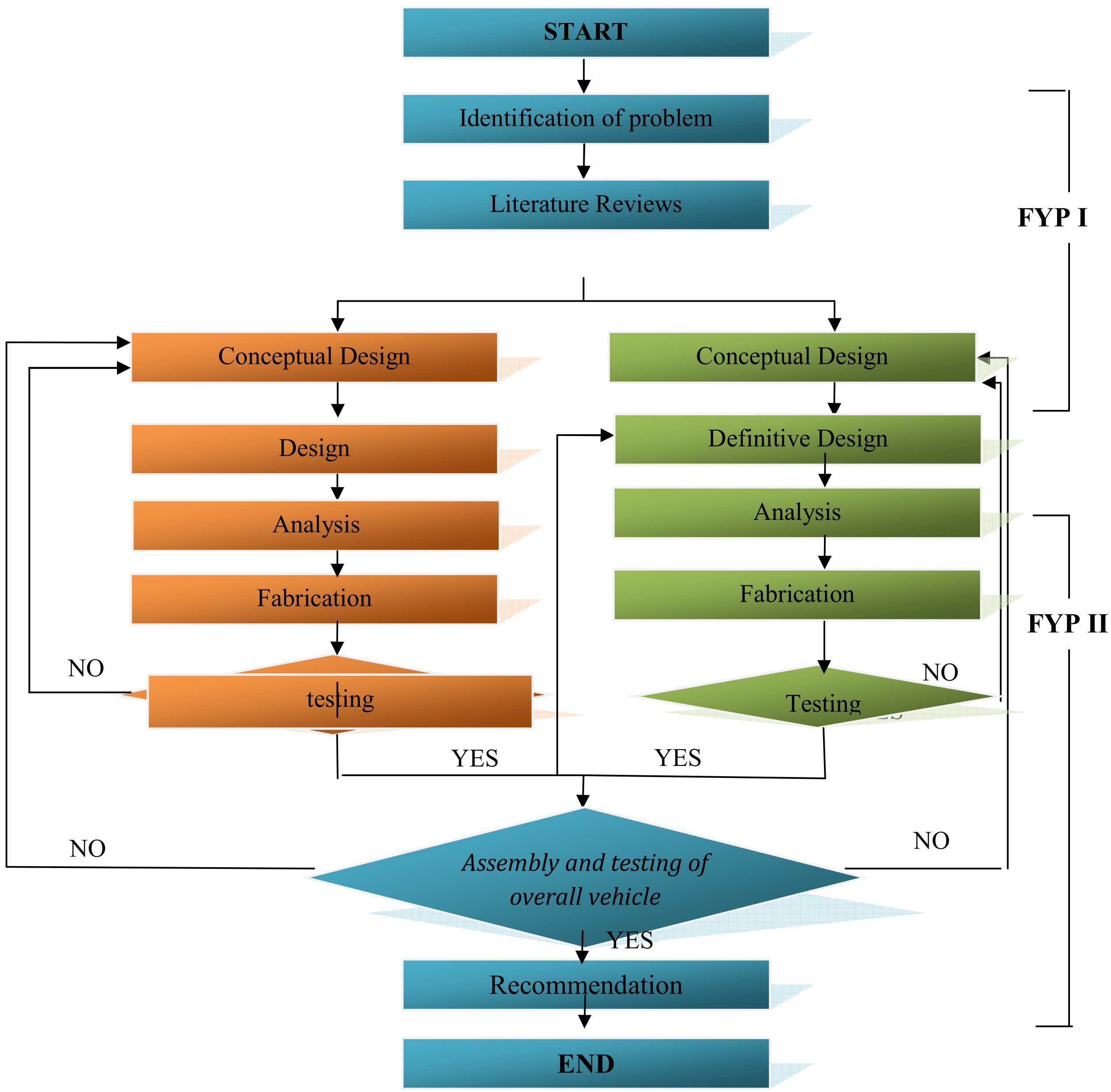


Figure 3.1: Flow Chart of Methodology

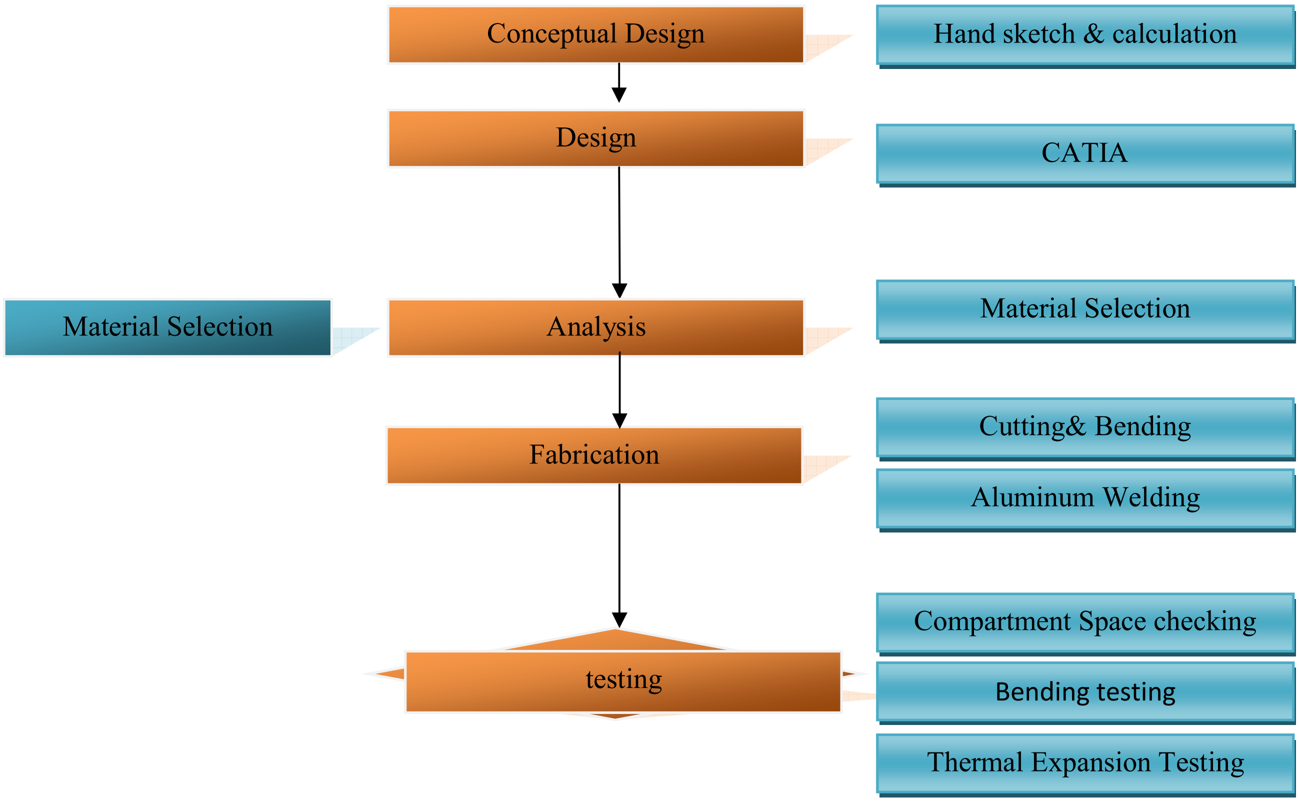


Figure 3.2: Flow Chart of Methodology (frame)

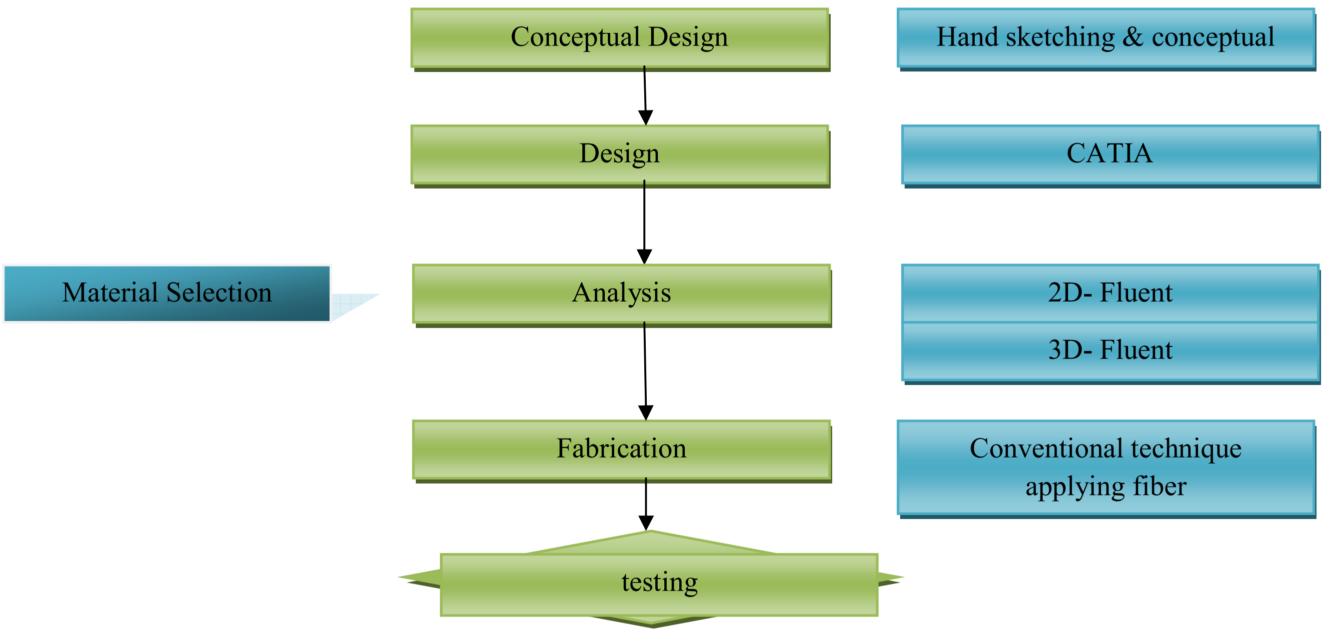


Figure 3.3: Flow Chart of Methodology (outer shell body)

Basically, in preceding the study, data acquisition of the previous Shell Eco-Marathon's body and chassis should be gathered by doing some research through the literature review from internet, books, journals and gathering information from the researches on the topic related. For this project, the suitable winning team will be used as a benchmark of research study to give effectiveness to the weight reduction and aerodynamic of the vehicle. Data collected will be used in doing experiments to observe the effects of weight reduction, aerodynamic to drag force, ergonomic of the pilot and structure analysis for the body frame.

The results from the data analysis of the aerodynamic, ergonomic and structure will proceed with definitive design using CAD software like CATIA. Once more the design will be analyze with CAE software in order to maximize the structure strength and the performance of each component before it will be fabricate. In this stage, CATIA static stress analysis used to give me feedback on the design that had been generated. This step is very important to minimize any failure occur in future and also allocate the weak area in the frame structure to be concentrated during fabrication stage.

Fabrication stages had to be chosen and concentrated as it will result the strength of the frame. The fabrication began purchasing suitable raw material base on material selection had been done before. Then follow with measurement and cutting process. Then aluminum bends using manual bending tool and roller bending machine. The proper method of bending tubing follows to minimize the changes of material properties. Then the frame fits base on measurement. Aluminum gas welding used to connected the frame's joints.

The best methods will be choosing in order to fabricate the body frame and outer shell. Then the shape will be analyzed again in wind tunnel to measure the drag coefficient of the prototype that have been fabricate. The result will be compared with the data get from CFD.

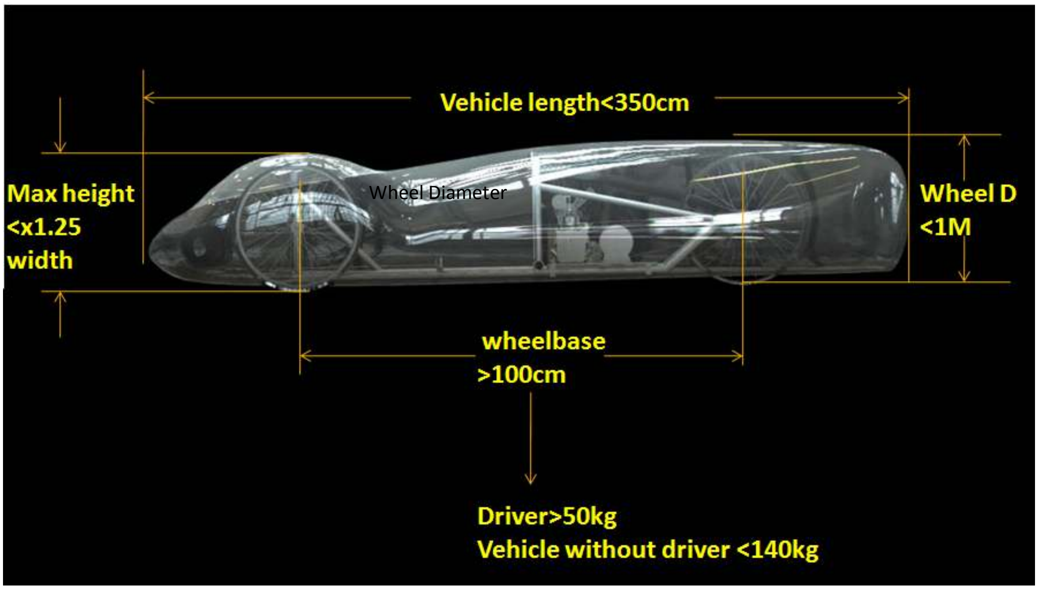
3.2 Tools/Equipment Required

The tools and equipments required for this study can be listed as below:

1) Wind tunnel
2) Manufacturing Facilities
3) Dynamometer
4) Software :
   - CATIA
5) Material Analysis Equipment

3.3 Rules and Regulation Overview

In order to complete this project, testing must be conducted to experiment the best shape of the vehicle. The important parameters have to be noticed earlier as it will result the performance of the car such as overall height and length.



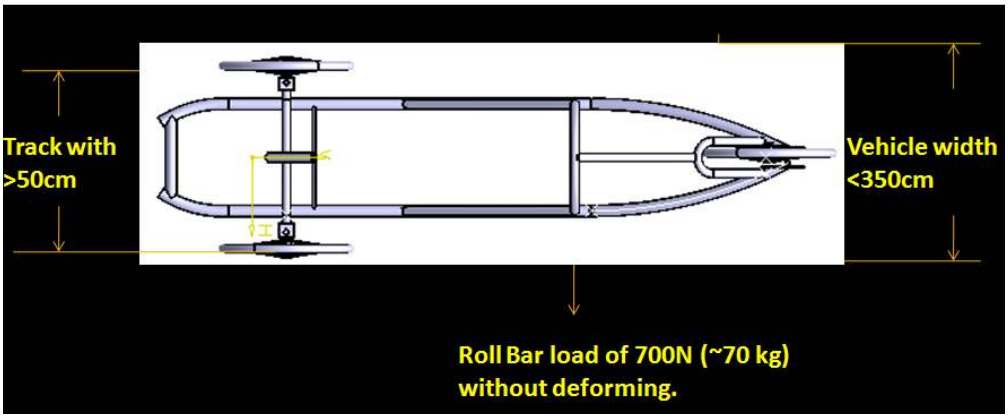


Figure 3.4: Important parameters during chassis design process

Above I have illustrated important parameter that need to be controlled in order to fulfil competition rules and regulation requirement:

1. Vehicle length and width
2. Wheelbase length and wheel track
3. Driver weight and Vehicle weight
4. Frame to ground height

In order to control all of the parameter, a certain test need to be conducted such as driving position and visibility tests. This test will control overall length, height and wide of the car dimension results the best aerodynamic shape.

Morphology Chart

no	Institution/ Team Name	Overall Ranking /Region	Fuel consumption Record (km/l)	Wheel Orientation	Wheel In/out body	Body/frame concept	Aerodynamic shape	Outer Shell Material	No. of Outer shell Segments
1	Laval University /Supermileage NTF 3.0	1/A	1172.2	2 F 1R	All Inside	Teardrop		CBRP	3
2	Eidgenössische Technische Hochschule /PAC-Car II	1/E	**5385**	2F 1R	All Inside	Teardrop		CBRP	3
3	Louisiana State University/LSU Eco-Marathon Team	16/A	459.4	2F 1R	Front outside/ Rear inside	Teardrop		GFRP	2
4	California State University	21/A	0.0	2F 1R	All inside	Teardrop		CBRP	2

5	State University of Minas Gerais / Team Sabia	19/A	98.5	2F 1R	All inside	Race car		CBRP	3
6	Universidad Nacional Autonoma Escuderia de Mexico Puma / Ahuicyani	17/A	108.8	2F 1R	Front outside/ Rear inside	Race car		Plastic	4
7	Grand Rapids Tech.Fast Indian	7/A	450.2	2F 1R	All inside	Teardrop		CBRP	3

*From overall 34 teams only 20 teams have finished the race.
A=American Region
E= Europe Region

Table 3.1: Previous competitor morphology chart

From morphology chart above, most of the team using two wheels front and one wheel rear, this is due to aerodynamic shape factor as the best aerodynamic shape is half teardrop shape where at front of the shape slightly bigger than rear [8]

There are many shape purpose by previous team base on their design terminology. Basically aerodynamic of the vehicle is not the biggest influence in this competition as the average speed permitted around 15 km/h to 30 km/h. but still the effect of aerodynamic need to be considered. Reduction of the weight is more important than aerodynamic as the forces act on the vehicle statically and dynamically.

Most of the team using CFRP and GFRP as their outer shell body in order to reduce overall weight as the material is lighter and have high strength. For frame structure, most of the team using aluminum rod or bar as the same reason which are light and high strength

3.5 Driving Position and Visibility Tests.

In CATIA software there is module that allows user build a human structure according to its measurement. By this module, it is easy to estimate driver position and ergonomic study. There are big possibility of high temperature during the event, in the event of hot weather conditions high temperatures could be attained inside the vehicle, potentially affecting Driver comfort and / or causing heat stress. It is recommended to properly arrange driver position in the car, therefore he/she will not lose focus on the competition.

In order to minimize car overall length, driver have been located in angled position. This position also helps driver to get better visibility to the track and surrounding. Driver leg bends to 45^o in angle to reduce vehicle length and also to avoid crashing between driver legs and steering system. By this ergonomic position, the car overall length have been reduce.

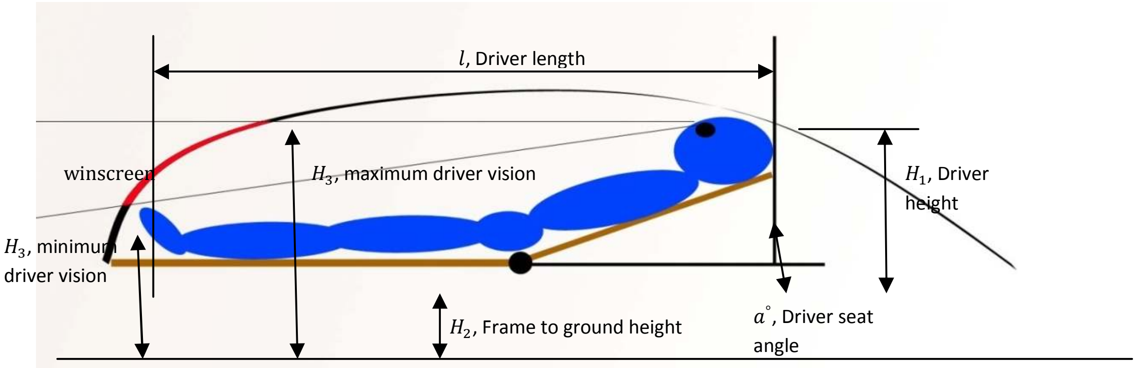


Figure 3.5: Driving position and visibility tests

Test Procedure for driving position and visibility test.

1. The model will be created as in figure 8, the tyre need to be place as it will block the visibility of the driver, therefore it is recommended to adjust the position of the wheels.
2. The test equipment needs to set up as shown in figure 9 below.
3. The test will be conducted in two changing parameter, driver seat angle and frame to ground height.
4. The test will be start with frame to ground height at 50mm with driver seat angle of 0°.
5. The test will be continuing with increment of driver seat angle15°.
6. In each increment, the view of the driver will be recorded the 60 cm block can be seen or not.
7. Increase the height of the frame at increment 50 mm.
8. Repeat step 4 to 8 until the height of frame to ground reach 40mm.

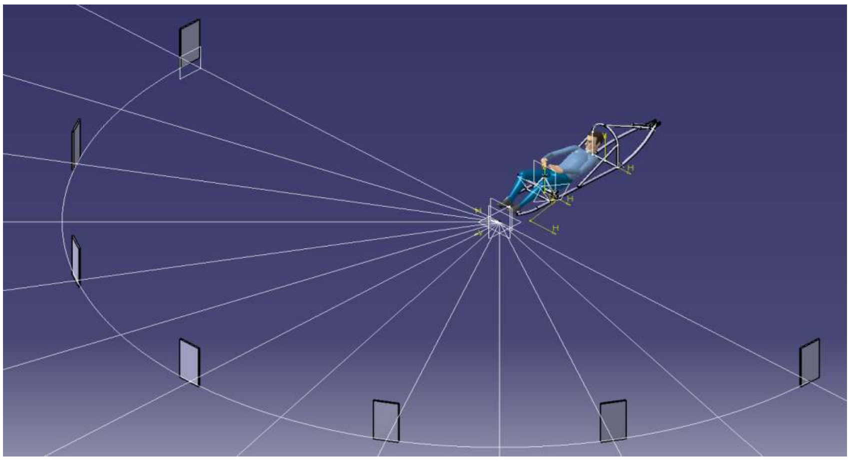


Figure 3.6: Driving position and visibility tests field

For example we want to test the driver visibility of 0^{o}. Analysis is done base on assumption below:

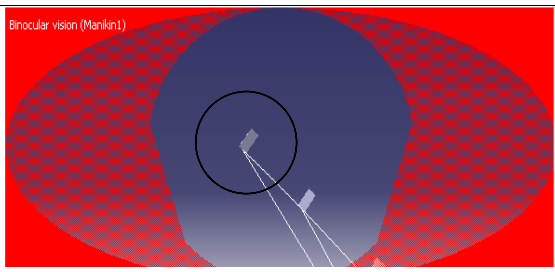
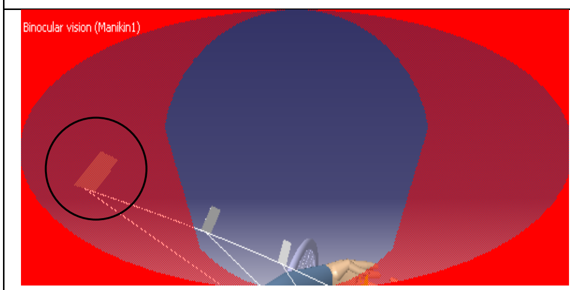
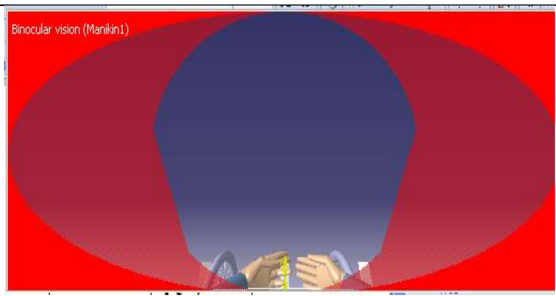
	If at the 0^{o} block is clearly seen in the middle area, it shows the block can be seen clearly by the driver. In result sheet, the data will be noted as 'X'
	If at the 0^{o} block is seen in the blur layer area, it shows the block still can be seen but not clear by the driver. In result sheet, the data will be noted as '0'
	If at the 0^{o} block is not seen in the picture, it shows the block cannot be seen by the driver. In result sheet, the data will be noted as '-'

Table 3.2: Driving position evaluation.

Data gain will be recorded and it will be useful during definitive design of the aerodynamic shape of the body. It will maximize the aerodynamic shape as we can control the critical parameter that need to be count in CATIA. For example the height of the vehicle, lowering the centre of gravity of the vehicle will maximize the aerodynamic shape and also the stability especially during taking cornering.

3.6 Frame Structure Sketches

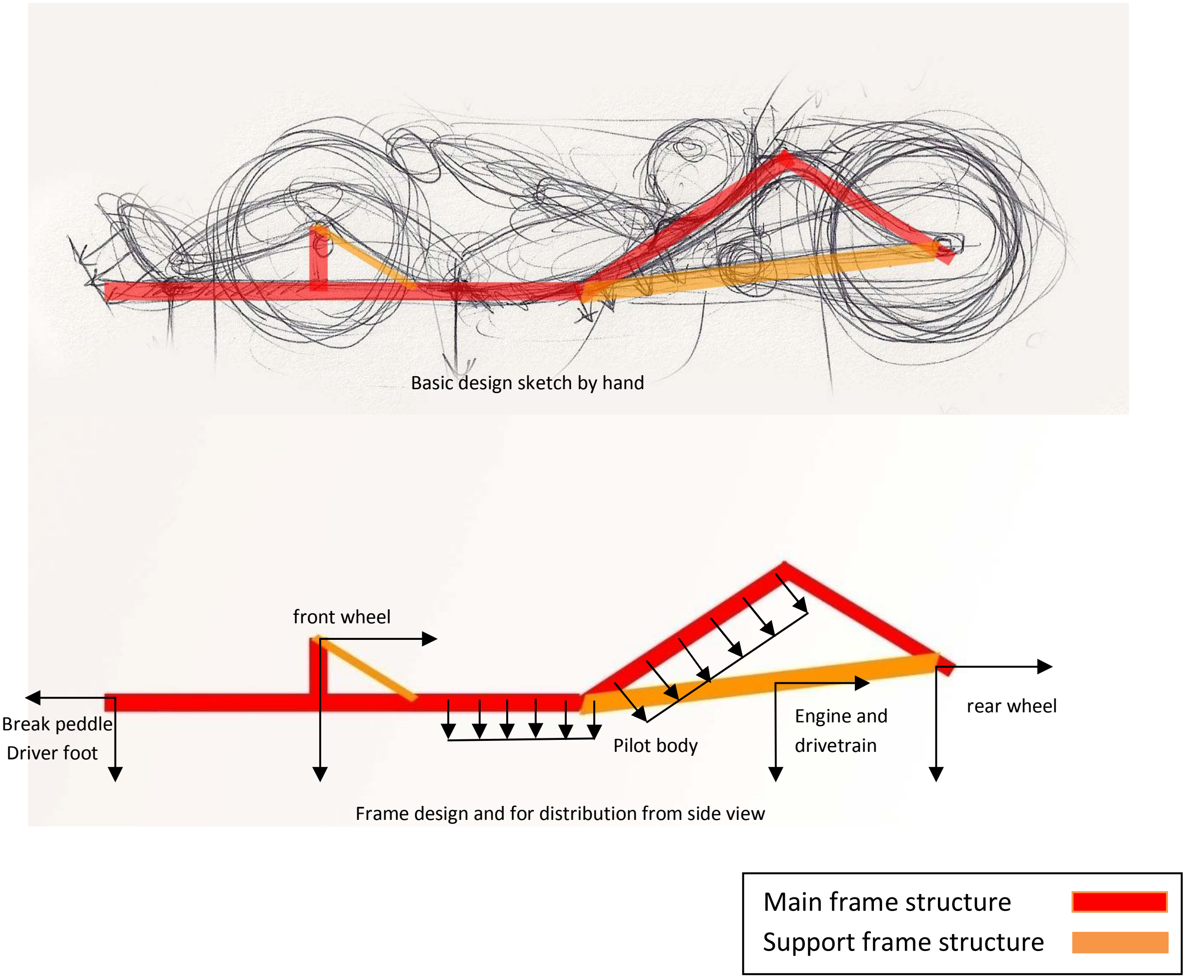


Figure 3.7: First Prototype Frame Design structure

In designing frame structure, it is better to have sketches from the previous design in order to maximize the useful of the design. Figure 11 shows the sketches converted to 2-dimensional design. Then the suspected load on the frame located in the sketches.

With the information above, high load area can be determine and modification can be made to the design.

3.7 Fabrication Stages-Frame

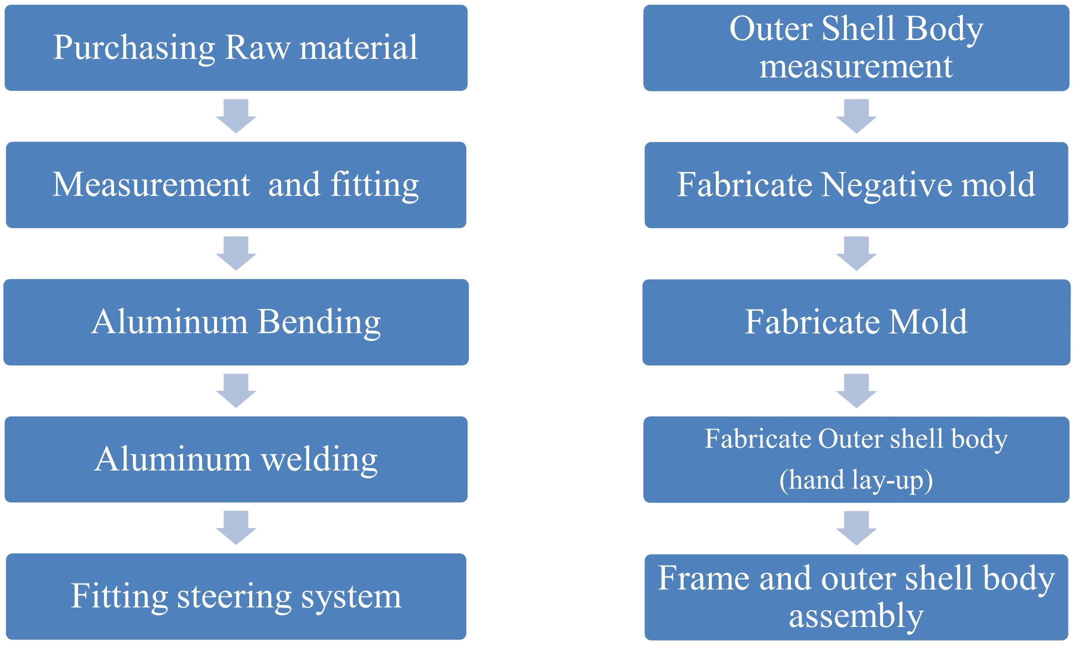


Table 3.3: Fabrication process for frame structure and outer shell body.

3.8 Fabrication Process

3.8.1 Frame Measurement, Cutting and Fitting

Measurement and fitting is very important in fabrication. It will give result in fitting between frame and outer shell body in assembly stage. The precision measurement device such as Vanier caliper and micrometer gave the best measurement.

In measurement also, need to consider the gap between joints where the gab will be fill with welding.

Figure 3.8: Measuring tool(left) and Frame fitting Process (right)

In fitting process, the frame structure joined using rope and additional structure to give support for the joints. Similarity between the right side and the left side of the structure needs to be concentrated as it will result the stability and handling of the vehicle.

Because of the frame used aluminum rod bar, some radius needs to be taken in count as it will prepare the rod bar before welding process began. The profile can fabricate by using half radius hand files to get smooth and best fitting between joint.

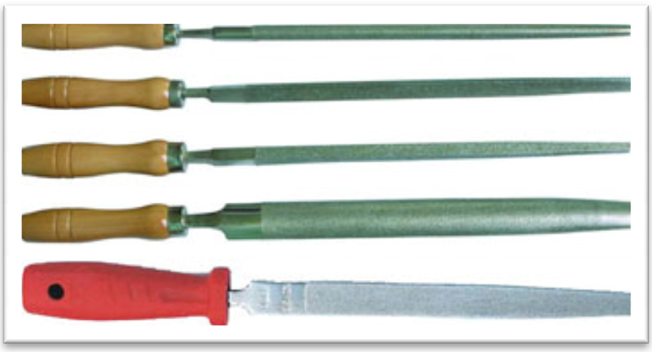


Figure 3.9: Various type of hand files

3.8.2 Aluminum Bending

Bending process need to be done in order to get the shape of frame. There were 9 points need to be bend as shown in figure xx. The most critical point is the anti roll bar where in rules and regulations stated the anti roll bar has to be designed where it can sustain 70kN load without deforming.

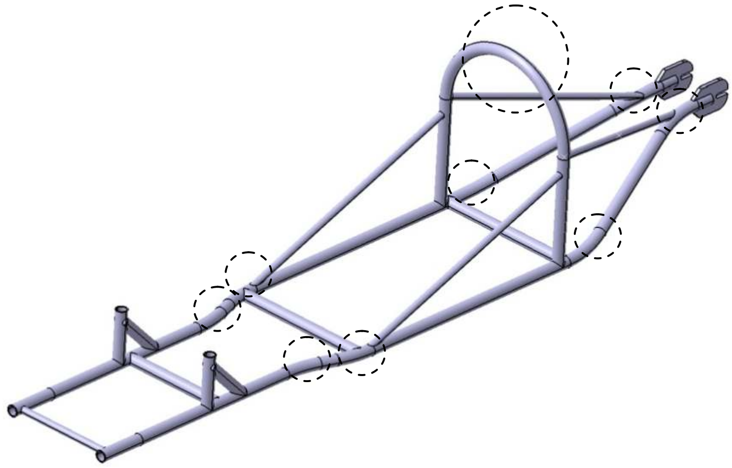


Figure 3.10: Bending area in frame structure.

As the radius of the anti roll bar is high (anti roll bar radius = 200mm, 180^{o} in circle), the available machining equipment was roll bending machine. Roll bending machine give a uniform compressed and stretched area. The top roll adjustment uses a fine thread that is calibrated by a scale. The fine thread allows for less physical effort under pressure when tightening the roll diameter during bending.

Figure 3.11: Roll bar bending process using roller bending mechine

The other bending points bend using hand bending tool. This was because the radius of the bending point6s is less than 150mm. The minimum radius roller dish for roll bending machine is just 150 mm in radius. Therefore, hand bending tolls used to bend small radius shape.

3.8.3 Aluminum Welding

To weld aluminum, operators must take care to clean the base material and remove any aluminum oxide and hydrocarbon contamination from oils or cutting solvents. Aluminum oxide on the surface of the material melts at 3,700 F while the base-material aluminum underneath will melt at 1,200 F. Therefore, leaving any oxide on the surface of the base material will inhibit penetration of the filler metal into the workpiece. To remove aluminum oxides, use a stainless-steel bristle wire brush or solvents and etching solutions. When using a stainless-steel brush, brush only in one direction. Take care to not brush too roughly: rough brushing can further imbed the oxides in the work piece. Also, use the brush only on aluminum work-don't clean aluminum with a brush that's been used on stainless or carbon steel. When using chemical etching solutions, make sure to remove them from the work before welding. To minimize the risk of hydrocarbons from oils or cutting solvents entering the weld, remove them with a degreaser. Check that the degreaser does not contain any hydrocarbons.

Figure 3.12: Aluminum welding using gas arc welding

3.8.4 Fitting Steering System

Steering system need to be rigid and have high stability. Therefore mild steel used as C joint of the steering system. It is week to weld between different material such as aluminum and mild steel. The suitable joint is by using bolt and nut as shown in figure 3.13

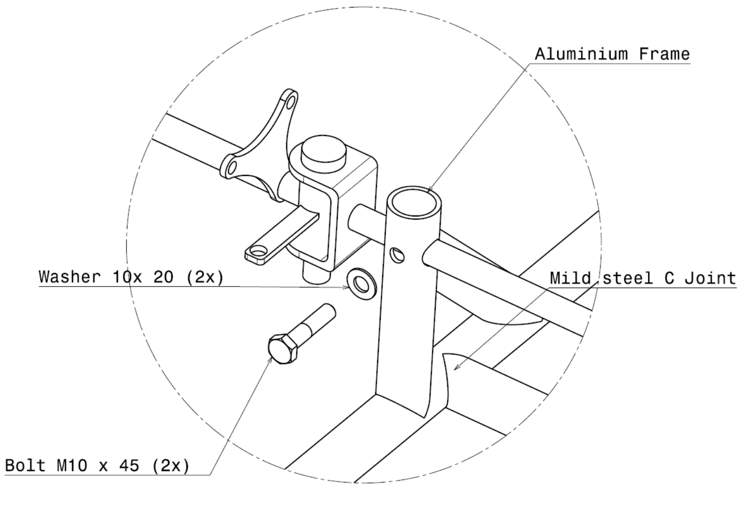


Figure 3.13: Technique used to joint aluminium frame and mild steel

As shown in figure xx, mild steel rod treaded with M10x 1.5 sizes. Bolt size M10x45 and washer used to joint and tighten between mild steel rod and aluminum frame.

3.8.5 Thermal Expansion and Load Testing.

The frame needs to be checking the strength due to load and high temperature weather. Therefore a simple load and thermal expansion testing conducted to test the ability of the frame due to thermal expansion and high load. The procedure of the testing are:

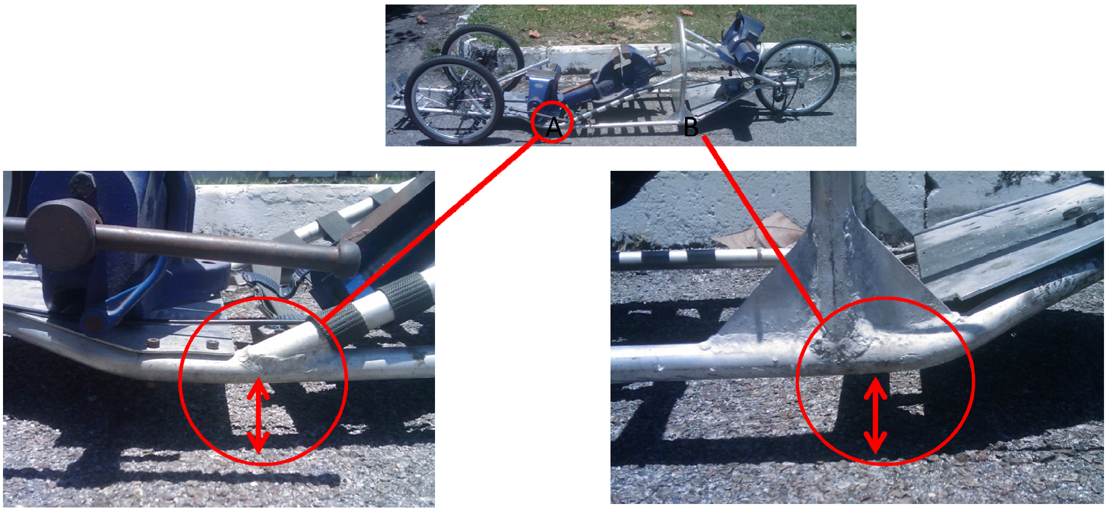


Figure 3.13.1: Thermal expansion and load testing.

1) Measure initial A and B displacement.
2) Applied 36kg load and measure displacement of A and B
3) Repeat 2nd step with load 72kg and 108 kg load
4) Wait 10 minutes and measure again A and B displacement
5) Repeat step 4th with interval 10 minutes until the time reach 40 minutes
6) Remove the load and cold down the frame and measure point A and B again
7) Plot graph from the result.

3.9 Outer Shell Body Fabrication Stages

3.9.1 Frame and Outer Shell Body Assembly

Hand Lay-Up Of Fiberglas Parts On A Mold

a. Preparing the Mold

Remove any dust and dirt from mold. If mold is of plaster, wood, or new fiberglass, apply soft wax and buff with soft towel. Spray or brush with PVA, parting compound and allow to dry. If mold material is glass, metal, ceramic, or well-cured fiberglass, apply three coats of hard wax, carnauba type, buffing between each coat.

Figure 3.14: Mold for outer shell body

b. Applying the Gel-Coat

1. If gel-coat is to be brushed on, allow first coat to cure and then apply the second coat to make sure there are no light spots. If gel-coat is to be sprayed on with a gel-coat gun, spray up to a thickness of .015” to 020”.

When gel-coat has cured long enough that your fingernail cannot easily scrape it free (test at edge of mold where damage will not show on part) then proceed with next step.

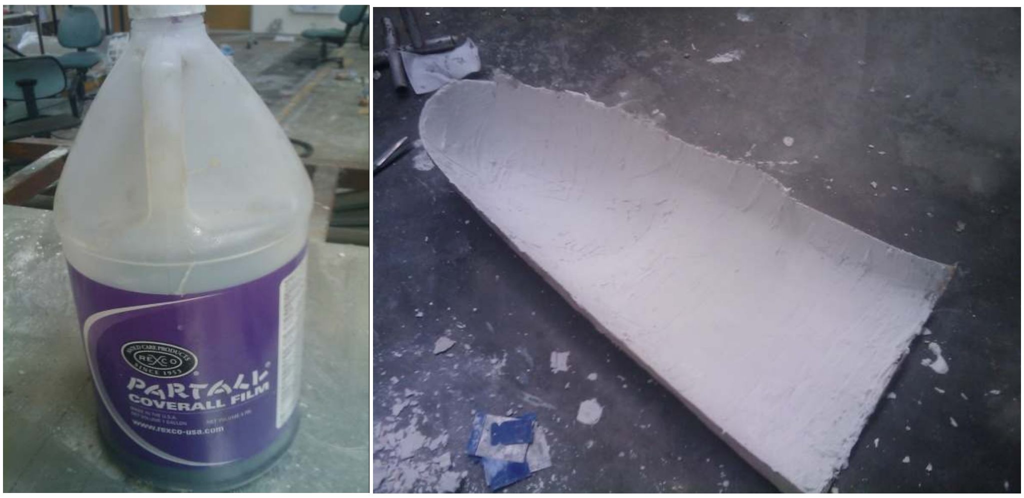


Figure 3.15: Gel-Coat (left) and Negative mold for outer shell body(right)

c. Lay-Up Skin Coat

Cut the. mat to cover part. Brush catalyzed resin over gel-coat, and then applies the mat. Work with roller adding more resin where necessary until all white areas in mat fibres have disappeared and all air bubbles have escaped. Resin-rich areas weaken the part. Where rollers will not reach, brushes must be used. When this step is complete, clean all tools in acetone. Allow skin coat to cure before next step.

Figure 3.16: Applying woven fibreglass at mold

d. Laying Fiberglass Reinforcement

Apply each layer as in stepc, it will not be necessary to wait for curing between these layers. Be sure to shake all acetone out of brushes and rollers before applying resin. Acetone drips can result in uncured spots in the lay-up.

Figure 3.17: Woven Fiberglass after applied polyester resin

e. Trim

On a small lay-up, the fiberglass laminate which hangs over the edge of the mold can be trimmed off easily with a razor knife if you catch the "trim stage," of the period after the lay-up has gelled but before it has hardened. On a larger lay-up, it can be trimmed with a saber saw and coarse sand paper.

f. Cure

May take from two hours to overnight, depending upon turnover desired, temperature, canalization, and nature of the part. If laid up in a female mold, longer cure will affect shrinkage and easier parting. In the case of the male mold, the part comes off more easily before it shrinks appreciably. If the part is subject to warping, a longer cure may be necessary. In any case, when the part is removed it should be supported in its desired shape until fully cured.

g. Remove Part from Mold

Figure 18: Finish part of outer shell body

First, examine the trim edge all the way around the mold and make sure there is no resin bridging the line between the mold and the part. Sand this edge where necessary. Then wooden wedges, such as “tongue sticks,” can be pushed into the edges to start the separation. Continue separation by pulling and flexing. In some cases it is necessary to drill a small hole in the mold and apply air or water pressure.

h. Finish

Trim edges and back of part may need to be fine-sanded and coated with surfacing resin or gel coat.

i. Gel-Coat Problems

Wrinkling of the gel-coat may be due to the following reasons:

1. Gel-coat is too thin in spots so it does not completely cure.
2. Insufficient hardener added, or hardener not mixed well enough. It is best to use twice as much hardener in gel-coat as in lay-up resin at the same room temperature since the gel-coat goes on thinner than a mat lay-up.
3. Gel-coat has not cured long enough before mat lay-up.
4. Acetone from tools drips onto gel-coat or into skin lay-up.

CHAPTER 4

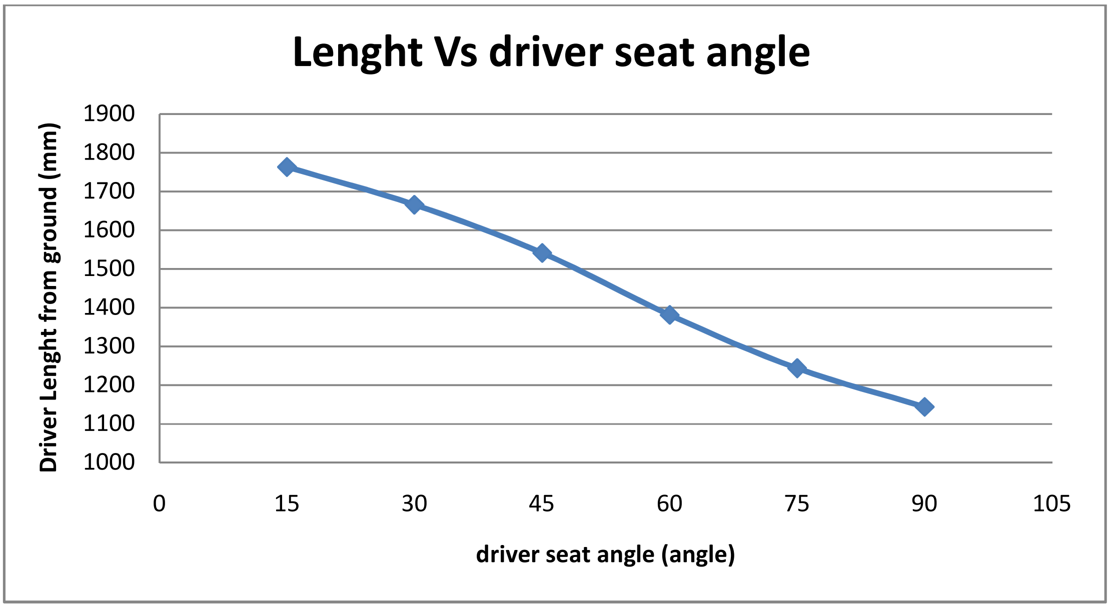
RESULT & DISCUSSION

4.1 Driver Position

4.1.1 Driving position test

Height (mm)	**Driver seat angle (x^o)**	**Driver height from ground (mm)**	**0** 	**30** 	**60** 	**90** 
50	15	447	X	X	-	-
	30	585	X	X	X	X
	45	700	X	X	X	X
	60	800	X	X	X	X
	75	825	X	X	X	X
	90	863	X	X	X	X
100	15	497	X	X	0	-
	30	635	X	X	X	X
	45	750	X	X	X	X
	60	850	X	X	X	X
	75	875	X	X	X	X
	90	913	X	X	X	X
150	15	547	X	X	X	X
	30	685	X	X	X	X
	45	800	X	X	X	X
	60	900	X	X	X	X
	75	925	X	X	X	X
	90	963	X	X	X	X
200	15	597	X	X	X	X
	30	735	X	X	X	X
	45	850	X	X	X	X
	60	950	X	X	X	X
	75	975	X	X	X	X
	90	813	X	X	X	X

Table 4.1: Driving position test result



Graph 4.1: Length Vs driver seat angle

Discussion

From the data above, with driver height from ground of 150mm and driver seat angle of 15 ^{o} is the best combination for this car. As shown from graph 1, there are 10 combination of height and driver seat angle after considering rules below;

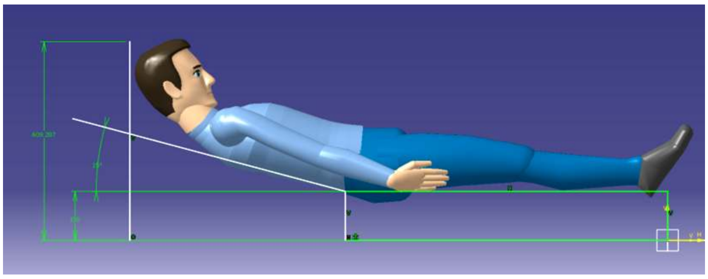
- maximum height of the vehicle must not exceed 1m
- the anti roll bar must have clearance of 5cm radius from driver helmet
- Safety helmet thickness ~ 5cm
- Anti roll bar diameter + outer shell thickness ~ 10cm

Limit set as 800mm after consider above rules and regulation.

The selection criteria for driving position is base on overall dimension that is;

Height x length x wide

Graph shows the overall length of the driver in angled position. As the driver is same in each testing, so wide of the driver is consider as 1. Graph 3 show us the area of height x length of the driver in angled position. The possible combination from graph 1 which is below the limit line calculated and graph plotted as shown in graph 3. From graph 3, the best combination of driver seat angle and height from ground is at 150mm height and 15 ^{o} which has the smallest total area of height times length which is 9.6x10^{5} mm^{2} or 0.943 m^{2}.



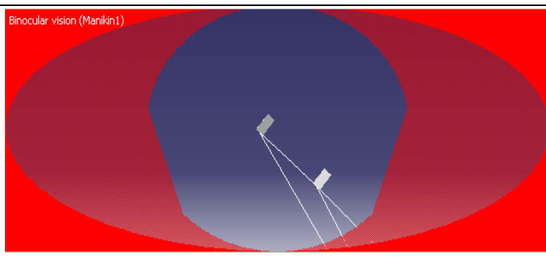
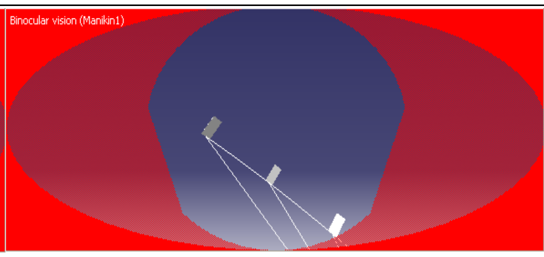
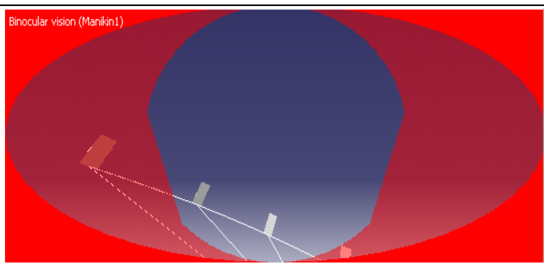
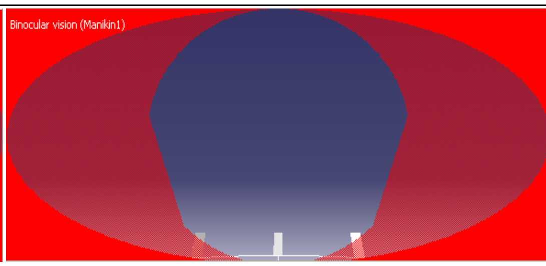
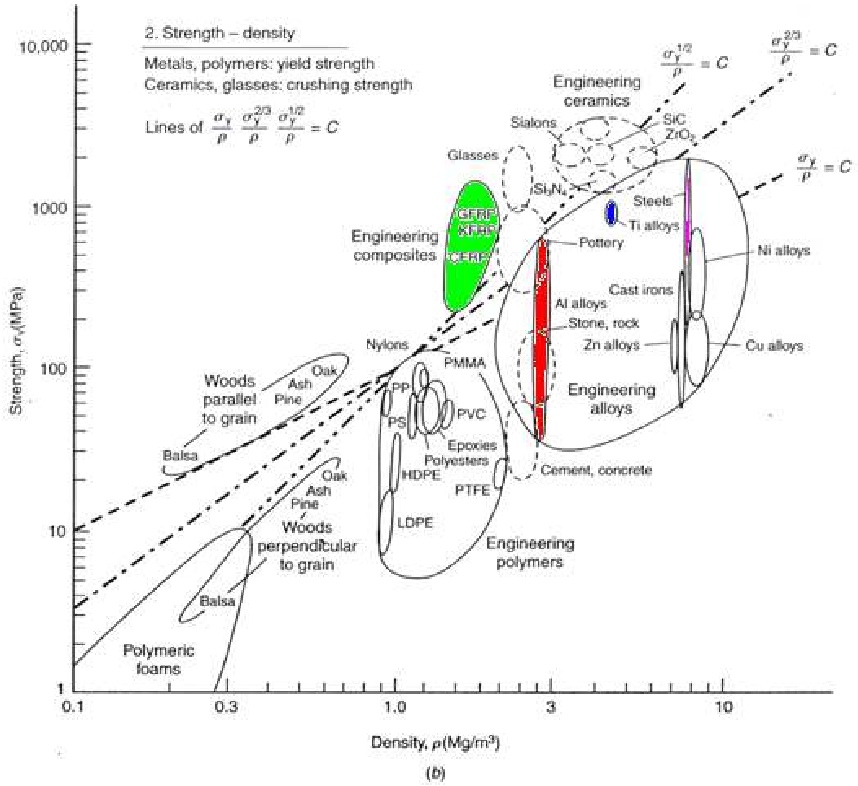
Final Driving test Result	
	
0^{0} Angle	**30^{0} Angle**
	
60^{0} Angle	**90^{0} Angle**

Table 4.2: Final Driver Position Result View

4.2 Material Selection for Shell Eco-Marathon Frame

Ashby Chart (Strength vs Density)



Graph 4.2: Ashby Chart (Strength vs Density)

From Ashby Chart above, there are several materials candidates for frame structure. As highlighted above, five materials selected base on design criterion which are;

1. Aluminium alloys
2. Steels
3. Titanium alloys
4. Carbon fibre reinforced proxy (CFRP)
5. Glass fibre reinforced proxy (GFRP)

In order to minimize the number of material, two materials have been eliminating from the list which are titanium and carbon fibre. These are base on two factors:

- Titanium:

  Material is not available in form of tube and need to be fabricate

  Cost per feet is too expensive

- Carbon Fibre

  The facilities to make the mould are not available and the cost of raw material for carbon fibre is too expensive.

From the design concepts generated in the previous phase, all concepts are evaluated and the best concept is picked using the weighted decision matrix based on several criteria. Following are the criteria for evaluation and its weight in percentage:

- **Weight (32%):** Frame structure design should have as lighter as possible in order to maximize the performance of the car and also fuel consumption.
- **Durability & Reability (37%):** Capability of the frame structure withstands the load applied on the car without failure and also safety precaution of the competition.
- **Material Cost (22%):** Reasonable price per length material cost of the raw material. Material cost also need have sense of future transportation solution if the concept is acceptable.
- **Manufacturing (10%):** Availability and possibility of fabrication technique and time consuming to fabricate the structure.
- **Availability (9%):** Availability of the raw materials in specific form. Example hollow rod, L shape and sheet.

Design Criterion	Weight Factor	units	Steel frames (Steel Alloy 1040)			Aluminium frame (Alu. Alloy 2024)			Glass Fibre frame (E-glass fibre Epoxy)		
			Mag.	Score	Rating	Mag.	Score	Rating	Mag	Score	Rating
Material Cost	0.22	$US/feet	2.45	8	1.76	6.6	7	1.54	22	5	1.1
Weight	0.32	g/cm^3	7.85	5	1.6	2.77	8	2.56	2.1	9	2.88
Durability	0.27	Yield strength MPa	490	7	1.89	345	6	1.62	-	7	1.89
Manufacturing	0.1	Hours	-	7	0.7	-	7	0.7	-	5	0.5
Availability	0.09	Experience	easy	9	0.81	middle	7	0.83	hard	5	0.45
					6.76			**7.35**			**6.74**

Table 4.3: Weight decision matrix for Shell Eco-marathon Frame Structure material

Table above shows the weight decision matrix for Shell Eco-marathon Frame Structure material. Base on the final rating sum calculation, aluminum alloy is the best material for the frame structure. Aluminum has low density and high strength properties, these properties can give a light frame and have a very strength structure.

List below show comparison of weight between 4 different materials applied on CATIA model to validate weight decision matrix result;

- Titanium - 10.200 kg
- Aluminum Alloy - 6.089kg
- Iron - 17.682kg
- Steel - 17.659kg
-

4.3 Frame Structure Stress Analysis

Load Cases

For time being, we just need to simulate the static analysis of the structure. Dynamic and reaction load are not considered yet at this stage. The dynamic analysis will be conducted for comprehensive analysis once the final design had been selected. At this stage, static analysis will be performed to investigate the stress concentration and weaknesses of the design for comparison to another design. By doing this, the design with high strength will be selected for final design. Load Cases applied basically is the weight of the parts in Newton.

For time being, we just need to simulate the static analysis of the structure. Dynamic and reaction load are not considered yet at this stage. The dynamic analysis will be conducted for comprehensive analysis once the final design had been selected. At this stage, static analysis will be performed to investigate the stress concentration and weaknesses of the design for comparison to another design. By doing this, the design with high strength will be selected for final design. Load Cases applied basically is the weight of the parts in Newton.

Powertrain Load Cases = Weight of engine + gears + mounting + starter motor +battery

Running Chassis Load Cases= Weight of Steering System + Break system

Outer Shell Body Load Cases = Estimate from CATIA modeling

Driver Load Cases = Driver estimated weight + accessories (helmet, driver suit)

no	Load Cases	Materials	Estimated Mass(kg)	Weight (N)
1	Steering system	Plastic, Aluminum alloy, Steel	1.909	18.72729
2	Frame	Aluminum	13.76	134.9856
3	Wheels and tires	Aluminum, Rubber, Steel	6.592	64.66752
4	Outer Shell Body	Glass fiber reinforce proxy	16.493	161.79633
5	Driver	NA	55.00	539.55
6	Engine & powertrain	NA	21.819	214.04439
Total weight			**115.573**	**1133.7711**

Table 4.4: Overall load cases for frame analysis

To compare stress analysis result, the frame applied with two different variables which is different thickness of the aluminium rod that available on the market.

1. Diameter= 1 ¼ inch Thickness= 3 mm
2. Diameter= 1 ¼ inch Thickness= 1.59mm
3. Diameter= 1 inch Thickness= 3 mm
4. Diameter= ¾ inch Thickness= 1.59mm

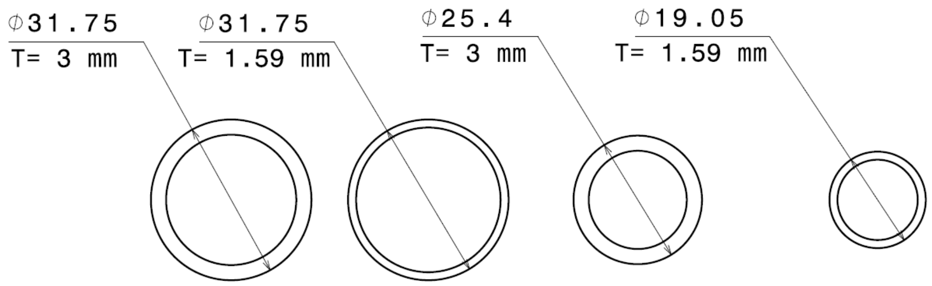


Figure 4.1: various radius aluminium rod bar dimension.

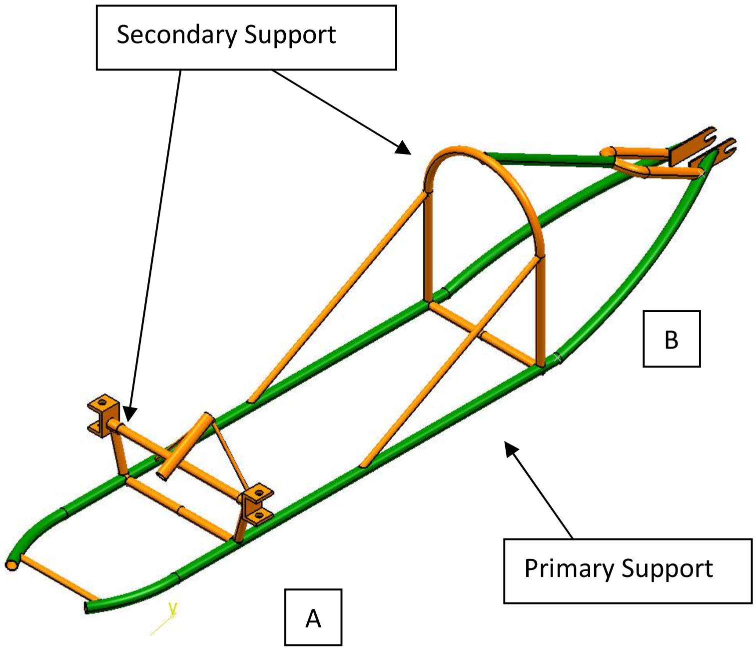


Figure 4.2: Combination of various radius aluminium rod bar

In designing frame structure, several options were taken in order to optimize the usage of the material. Table below show possible combination of aluminium rods base on the available size:

Support type	**Candidate Aluminium Rod**	**Possible Combination**
Primary support	**1 2**	**1 & 3, 1 & 4** **2 & 3, 2 & 4**
Secondary support	**3 4**	

Table 4.5: Combination of various radius aluminium rod bar

Base on the combinations above, the data applied in CAD model to compare the overall weight of the frame structure. Then 3 combinations that have lightest weight will be taken and proceed to static analysis in CATIA in order to check stress on the frame structure.

Two critical areas take, to compare the combination of different aluminium rod thickness and diameter. Maximum Von Mises Stress value take in record as the design should not exceed the maximum stress in order to avoid any failure during compatation

4.4 Frame Structure Analysis

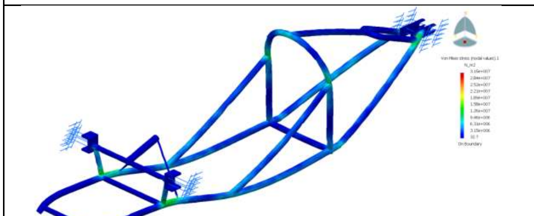
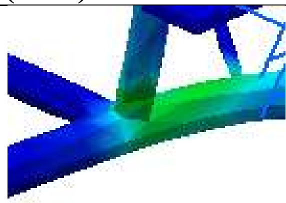
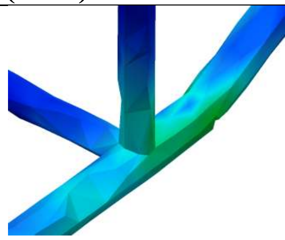
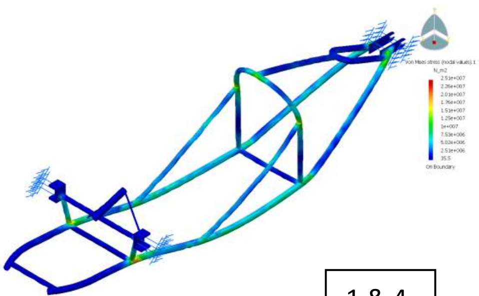
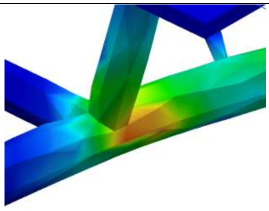
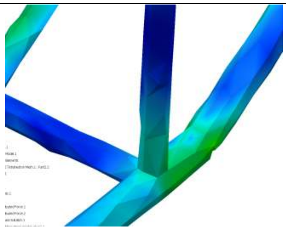
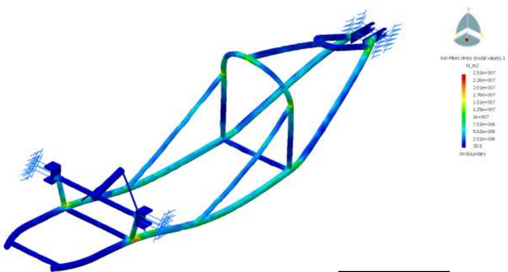
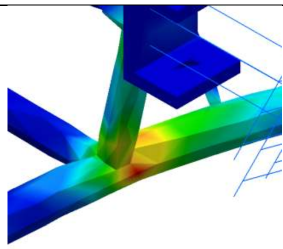
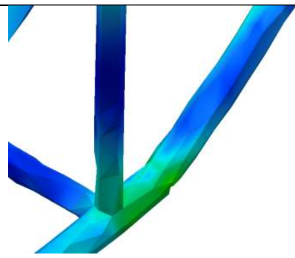
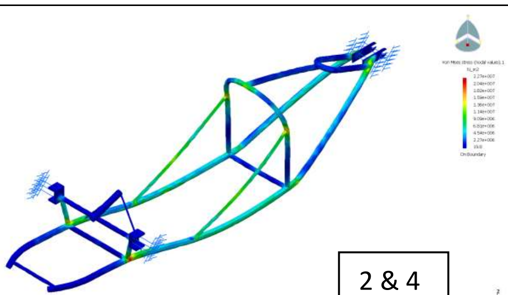
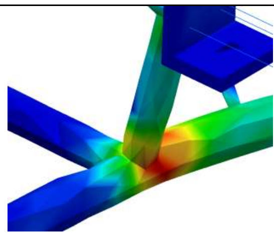
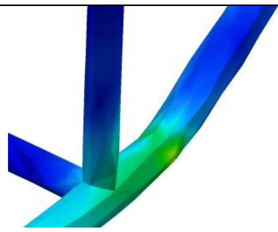
Combination	Point A Maximum Von Mises Stress (MPa)	Point B Maximum Von Mises Stress (MPa)
 1 & 3	 $9.61x\ 10^{6}$	 $8.61x\ 10^{6}$
 1 & 4	 $1.91x\ 10^{7}$	 $1.91x\ 10^{7}$
 2 & 3	 $1.98x\ 10^{7}$	 $9.49x10^{6}$
 2 & 4	 $2.15x\ 10^{7}$	 1.5x10

Table 4.6: Static analysis of various combination of aluminium rod bar

Table 5: Von Mises Stress Analysis Comparison

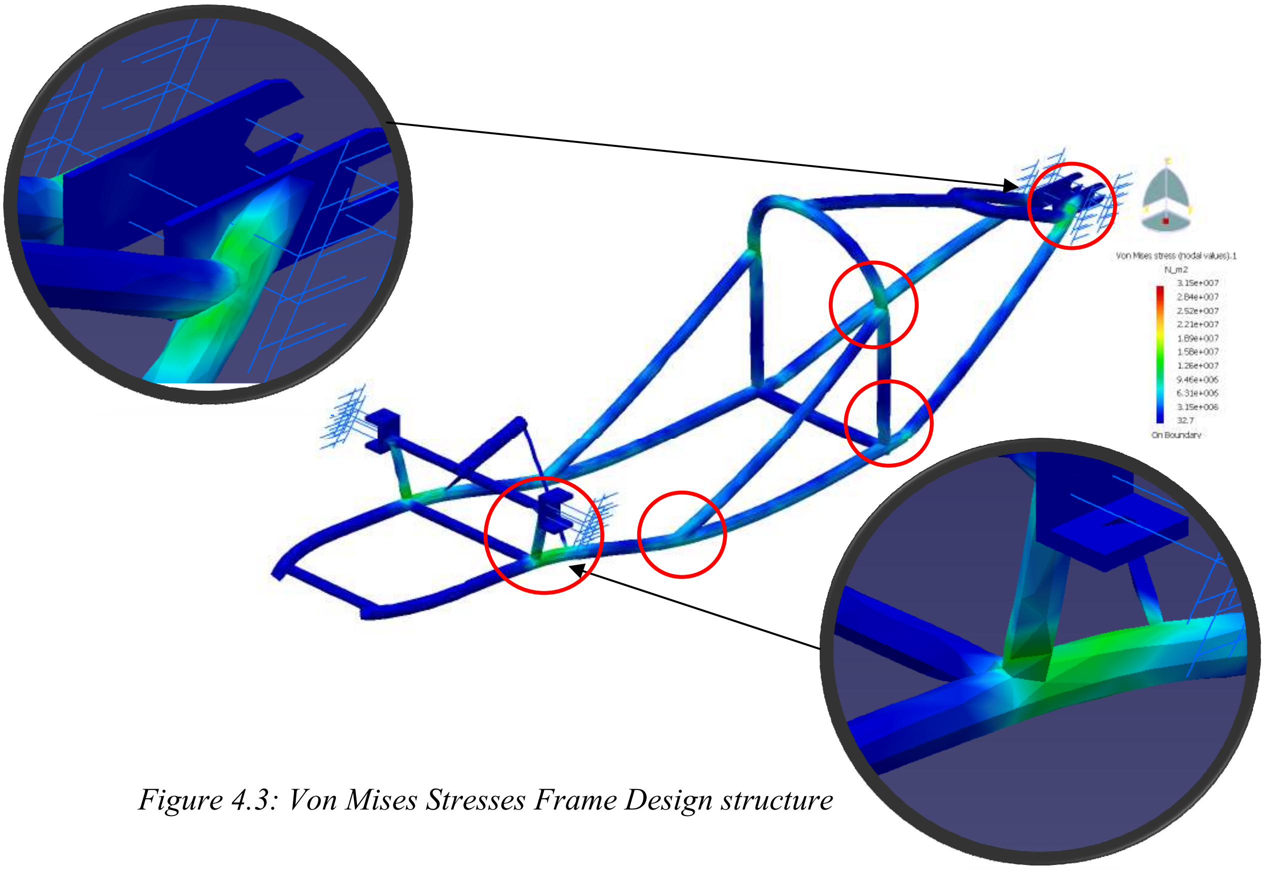


Figure 4.3: Von Mises Stresses Frame Design structure

The figure above shows the distribution of Von Mises Stresses generated by the software. The values of the stresses are according to the color region distribution shown on the right side of the figure. The maximum value of Von Mises stresses will appear in color range from yellow to red while the lowest value of stresses will remain the same. In this frame design there are two places spotted have high Von Mises stresses which are at bending part on engine compartment and structure connecter. This occurs due to bending process from to the original material. The grain structure and direction have been change causes the area has high possibility of fracture if applied with high load forces. The Von Mises stress option allows you to view Von Mises stress field patterns. Base on stress analysis above, the best combination is aluminum rod Diameter= 1 ¼ inch Thickness= 3 mm & Diameter= ¾ inch Thickness= 1.59mm

4.5 Outer Body Shell Design

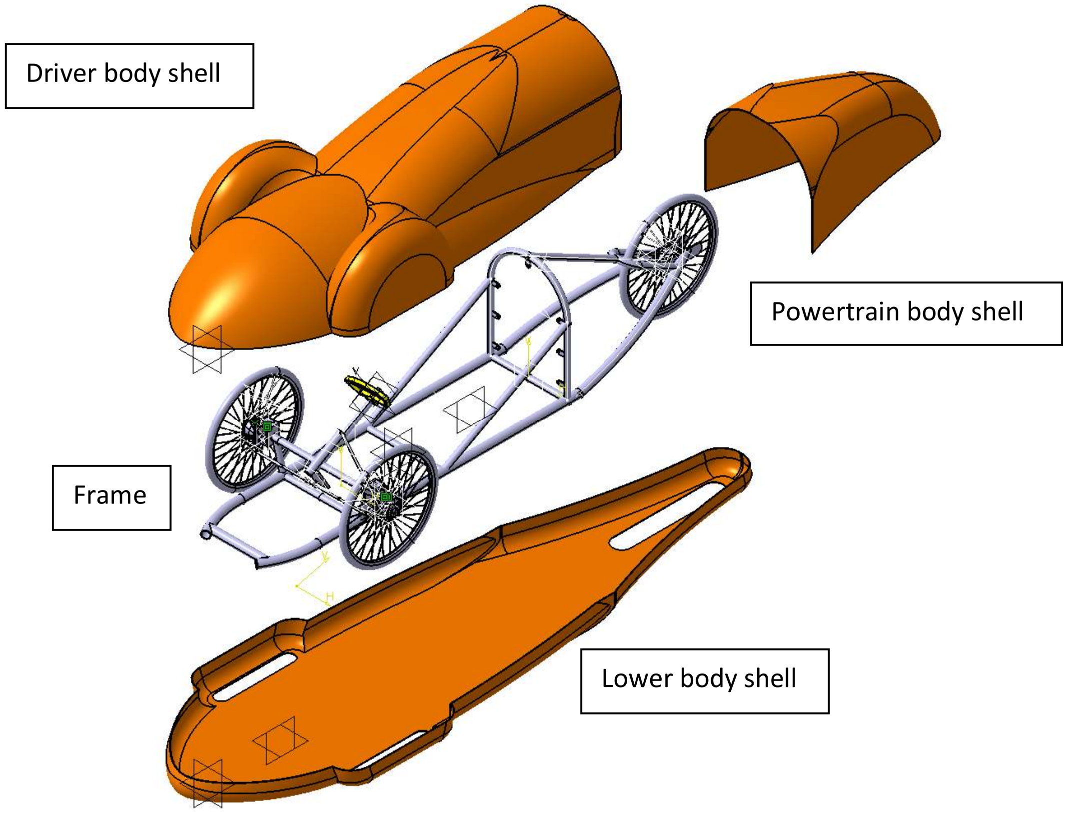


Figure 4.4: Prototype Frame Design Assembly

The outer body shell separated in 3 segments. The segment separated for different purposes which are mainly for the accessibility to engine and driver compartment. There are some cases where the team need to access in the powertrain compartment for troubleshooting purpose. It will be easier just open half of the outer shell rather than open overall cover. The segments divided in three major parts which are:

1. Powertrain body shell
2. Driver body shell
3. Lower body shell

Two outer body design where purposed which have different dimension and surface topography. Table below show the specification and differences of these two outer body designs;

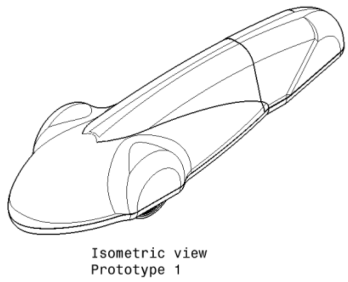
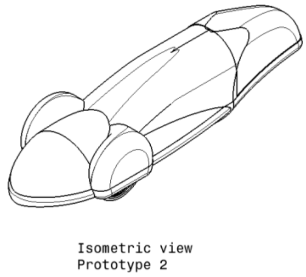
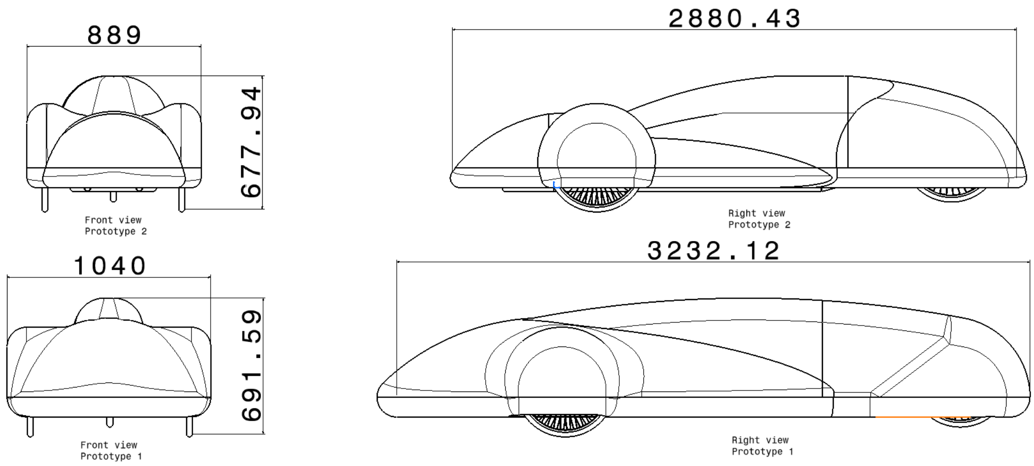
<table>
<tr><th>Prototype 1</th><th>Prototype 2</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Dimension (mm)

</td></tr>
<tr><td>Frontier surface area - 0.504m^2</td><td>Frontier Surface area - 0.425m^2</td></tr>
<tr><td>Wheelbase length - 1670 mm
Ratio wheelbase and vehicle length i =0.58</td><td>Wheelbase length – 2000 mm
Ratio wheelbase and vehicle length i =0.69</td></tr>
</table>

Table 4.7: Comparison between prototype 1 and prototype 2

4.6 Troubleshooting and Modification.

4.6.1 Weight Reduction Vs Reduce Aerodynamic Drag.

Reduce weight and reduce aerodynamic drag is the two major factor that have to take in count in design stages. These two factors have it own weighing factor. In this competition, between reduce weight and reduce aerodynamic forces, weight reduction is more important because:

- Low speed is the best speed to maximize fuel economy. The best speed for low volume engine is around 30-40km//l.
- Aerodynamic drag give big significant to the vehicle speed at high speed. In low speed the effects of aerodynamic drag is small.

Therefore, the design of the vehicle had been modified. The major modification has been made on the outer shell body is by putting the front wheels outside the frame structure. This is due to the high weight reduction, where if the wheels at the outside outer shell body, the wheels cover and the inner fender can be eliminated. Additional, it will give a better vision to the driver. To minimize the drag force from the rotating wheels, plastic wheel cover added.

4.6.2 Frame Banding

One problem occurs after the fabrication of the frame is the frame bend when applied load more than at the driver compartment. The failure points are at the bending area. This is due to improper bending technique. During the bending process, inside the aluminium rod there is no support that called ‘mandrel’. Mandrel is used to avoid uneven stretch and compress area at the bending area.

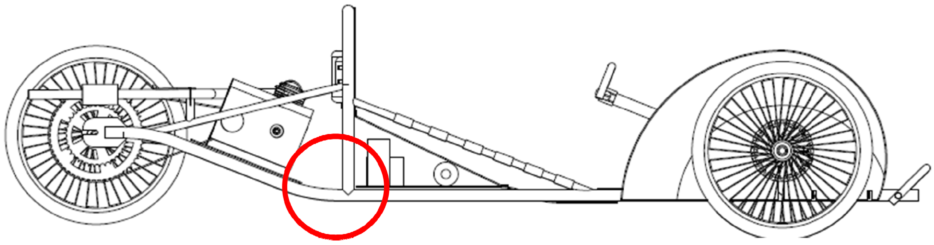


Figure 4.5: Fail area due to improper bending technique

During analysis stage, the area has been allocated have a high possibilities of failure. To solve this problem, four additional ribs added at the bending area in CATIA model. Static load analysis confirms the bending area has reduce in von mises streses.

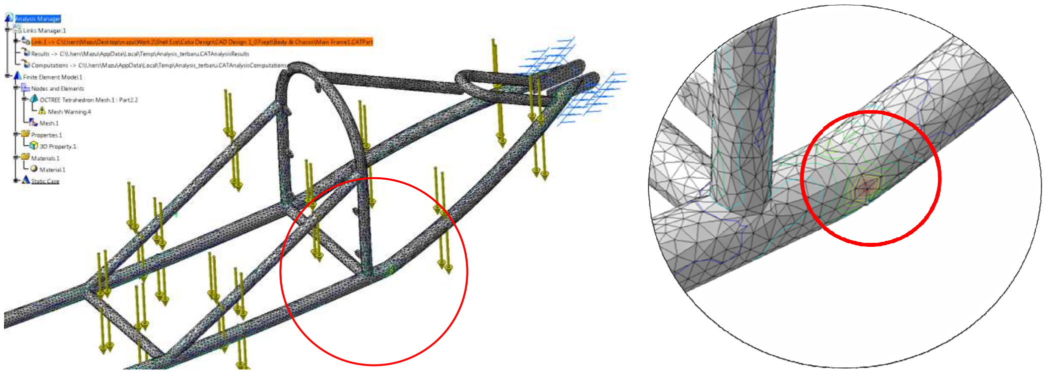


Figure 4.6: Static stress analysis affected area without ribs

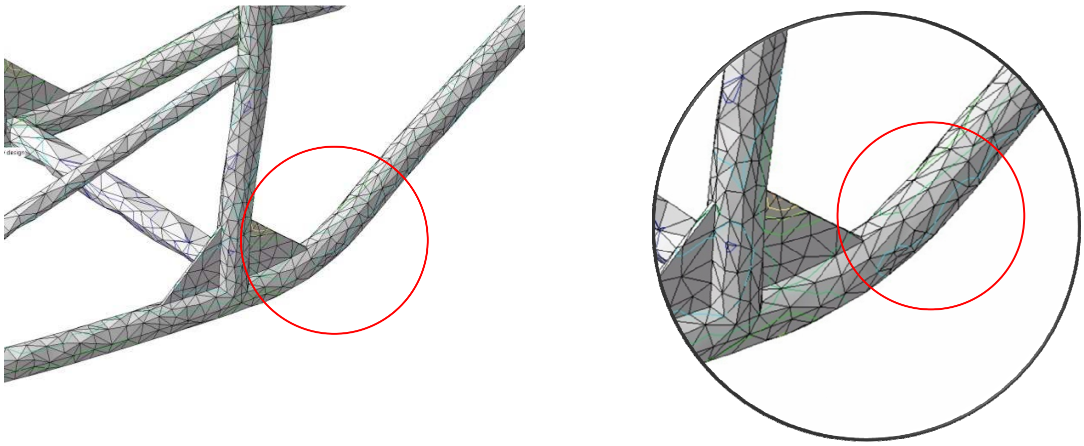
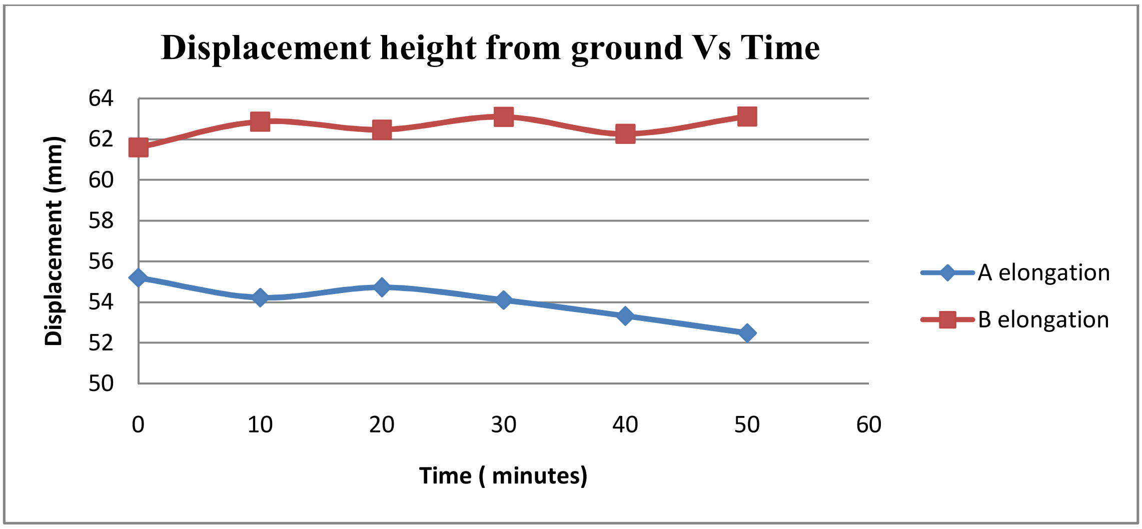
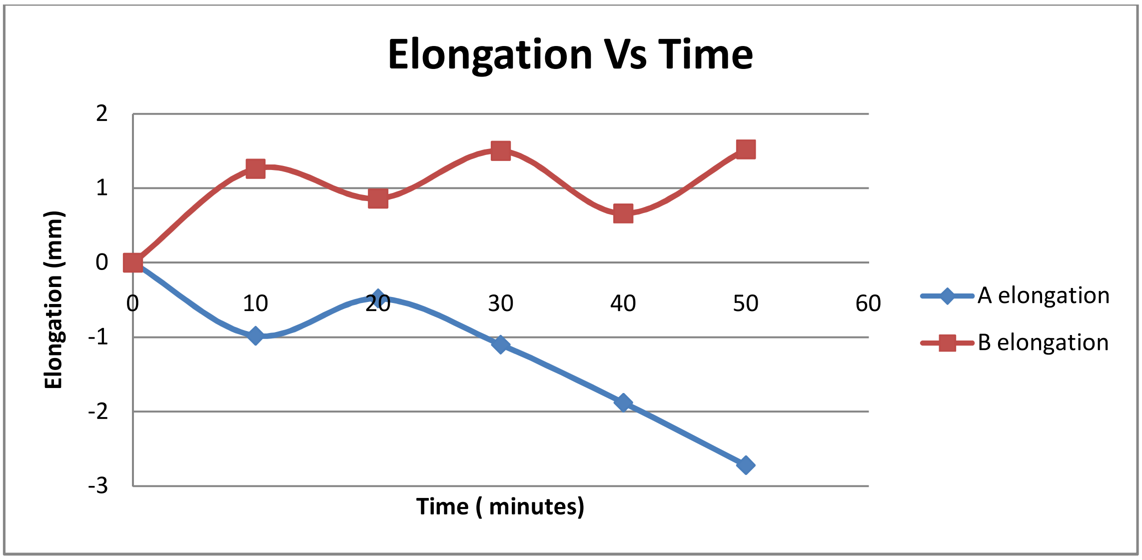


Figure 4.7: Static stress analysis affected area with ribs

4.6.2.1 Frame Thermal Expansion and Load testing result



Graph 4.3: Graph Displacement height from ground Vs Time



Graph 4.4: Graph Elongation Vs Time

From the result above, after adding ribs to the structure, the elongation due to thermal expansion and load is safe where the maximum displacement 4 mm during hot temperature weather. The frame also can sustain load up to 1.5 safety factor.

4.6.3 Remodelling outer shell body

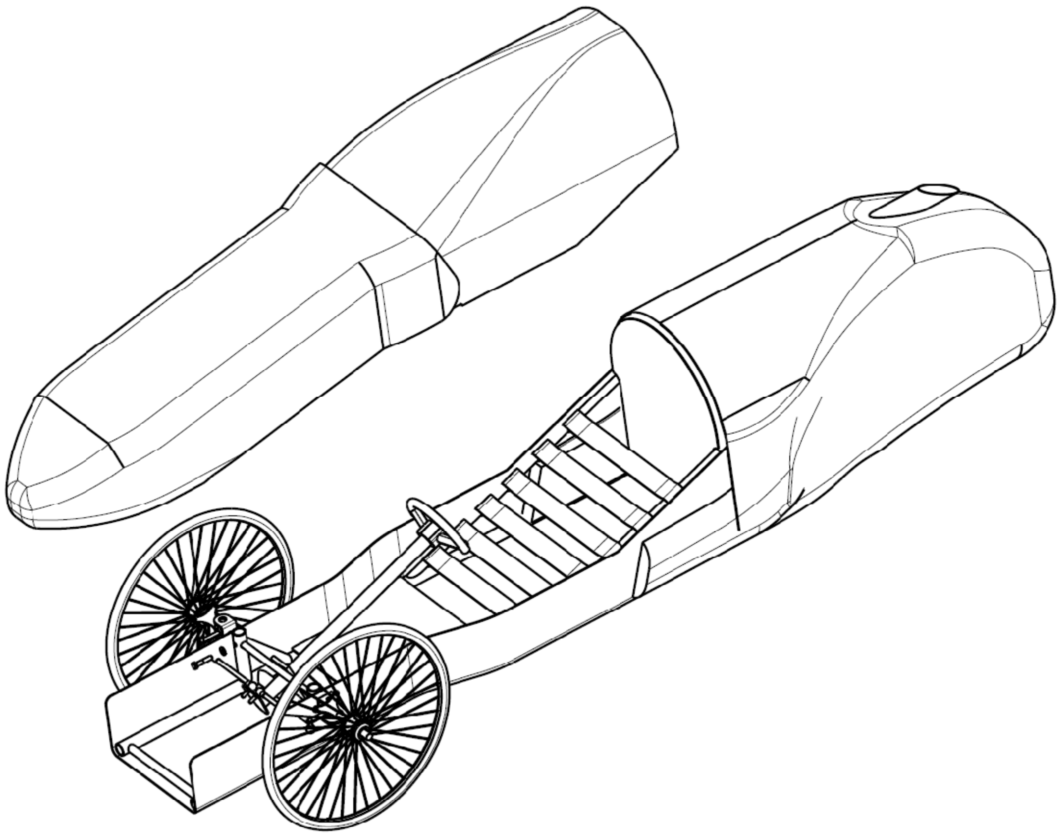


Figure 4.8: Final Prototype Frame Design Assembly

The design of the vehicle had been modified. The major modification has been made on the outer shell body is by putting the front wheels outside the frame structure. This was due to the high weight reduction, where if the wheels at the outside outer shell body, the wheels cover and the inner fenders can be eliminated. Additional, it will give a better vision to the driver. To minimize the drag force from the rotating wheels, plastic wheel cover added. The new design has reduced the weight and the frontier area. Additional it has better ventilation system for the engine compartment.

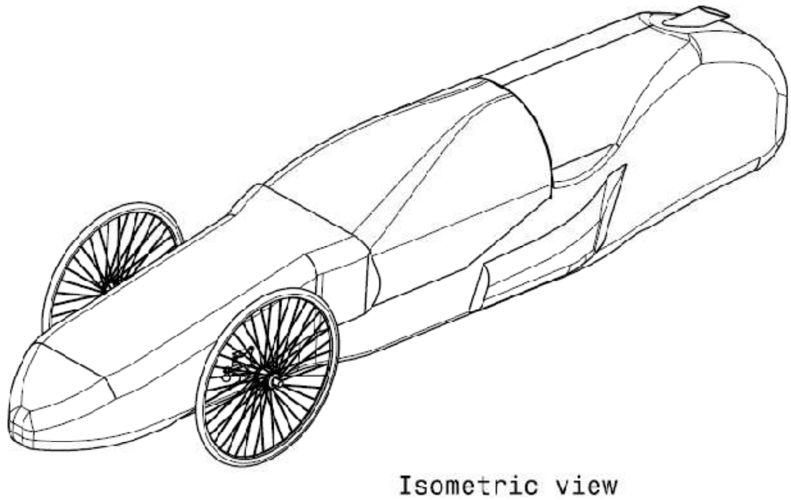
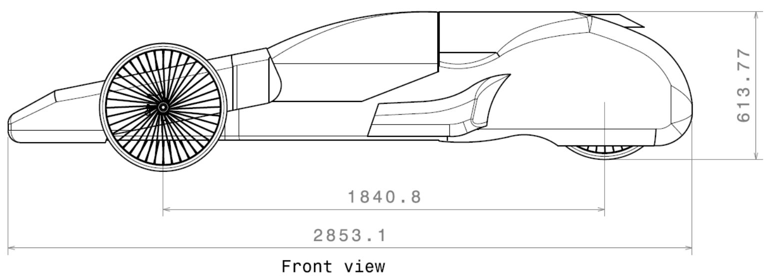
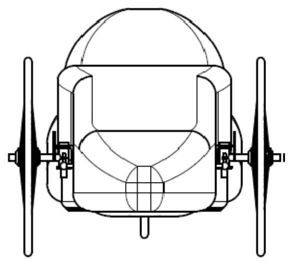
Final Prototype Design

Dimension (mm)
 
Frontier surface area - 0.2404
Wheelbase length - 1840.8 mm Ratio wheelbase and vehicle length *i =0.65*

Table 4.8: Final Prototype Frame Design Assembly

4.6.4 Ventilation System for engine compartment

As there are possibilities the event conducted at high temperature weather, it is better to design the outer shell body with proper ventilation system. The flow field and temperature inside the passenger compartment of a vehicle have a strong influence on the thermal comfort of the passengers. Additional, vehicle engine also need a good intake and exhaust system. Heat transfer need to be managing to avoid engine from overheated. For this vehicle, it was using the natural cooling system. As the vehicle travel in certain speed, the air flow from the outside of the vehicle enters the vehicle compartment and cooling vehicle, especially in engine compartment. The air enter and exit the vehicle need to be mange carefully to avoid turbulent flow inside the vehicle that can cause drag.

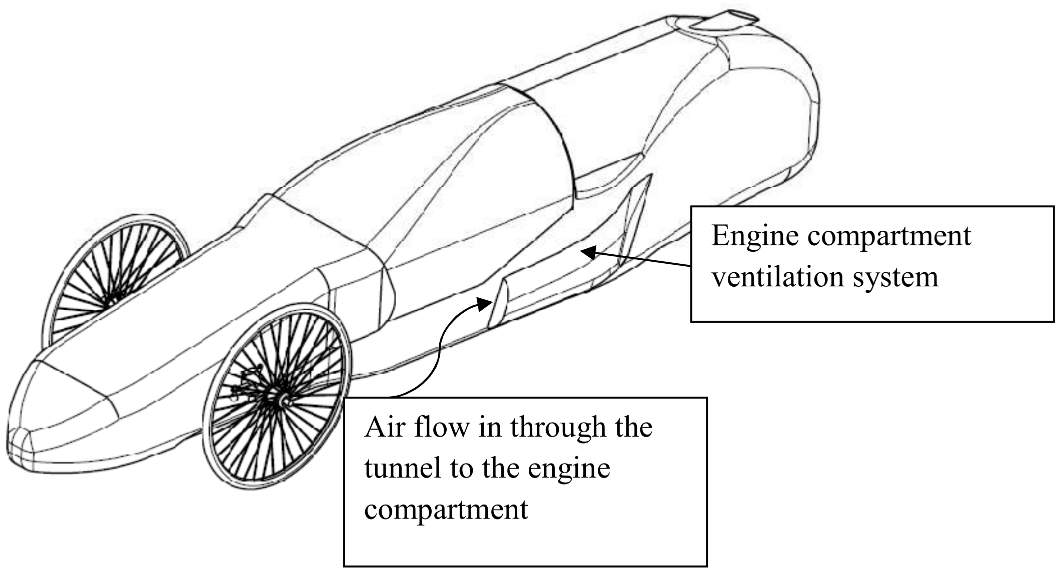


Figure 4.9: Ventilation system of the final prototype design.

4.7 Final Product

Figure 4.10: Final product of UTP-SEM Team-A car.

4.8 Optimizations

To get better fuel economy result, optimization on the car needs to be done. In reducing the weight of the vehicle can be done by removing some part in frame and outer shell body that not have not function in the vehicle.

For the first prototype design and fabrication, we decided to build a simple frame using available material in market such as steel and aluminium. The availability of the material is very important for us in order to go next stage of this project. Plus with the fabrication process is not too complicated and does not need special manufacturing technique. We need to study the behaviour of the chassis with all components installed inside such as engine, drivetrain and running chassis. Further analysis has been made such as maximum loading, stress analysis, and frame structure force analysis. For the next prototype we can maximize the strength to weight ratio of the frame using the data gain from the first prototype.

Analysis for outer shell design will be validating with ANSYS software in future. For now, we just come out with several possible designs in order to get best aerodynamic shape. On FYP2, all outer shell design will be compared with its drag area, drag force, and weight. The detail of the outer shape, connection method between segments and strengthen strategies will be conducted on FYP2.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, after we had successfully finished discussed on the results of the analysis, we had understands the phenomena of the structure of the part. The first objective of the project to understand the effect of material selection on body and chassis relative to weight reduction and strength had successfully achieved. The design was based on the available parts that had been bought. During the designing process, the constraint, limitation and requirements has been taken into consideration and the dimensions of the mounting were specified by other team member.

The second objective of this project was also achieved where the first design of the frame structure was successfully simulated and analysed. The static analysis had been performed with defined material, load cases and boundary condition. CATIA had been used to investigate the static analysis for the part even though the software is not really reliable to perform FEA. The modification of the design was also based on the results generated. For the next project which is FYP 2, critical design review studies will be conducted and come out with several potential designs for an improvement of the drivetrain system. Then, comprehensive FEA will be done with broadened load cases, boundary condition and dynamic analysis. Then, the finalize design will be chosen and fabricated for the frame structure.

5.2 Recommendation

The objectives for FYP 2 are successfully achieved for this semester. However, the objectives of the projects are not achieved yet. From the results obtained from this project, the results are not finalized yet and the design is also not finalized yet. The weaknesses of this design are obvious since there are a lot of potential improvements could be made.

The validation of the FEA results have been done at the beginning of the process and the result was quite big. For the next analysis, it is recommended to utilise pure analysis software to investigate the stress of the part. CATIA is just a drawing software and not really suitable and reliable to perform a static analysis. But for the next design, CATIA software will be used but the format will be converted to suit ANSYS software thus, will make the process and procedure much easier and faster.

There are many constrain in fabrication of the frame anad oute shell body of the vehicle such as the availability of the equipment especially in fabricate the mould for the outer shell body. There is a big different between making the mould using hand lay-up and CNC machining especially surface finih of the vehicle.

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APPENDIX A

TABLE 5.8
Evaluation scheme for design objectives

11-point scale	Description	5-point scale	Description
0	Totally useless solution	0	Inadequate
1	Very inadequate solution		
2	Weak solution	1	Weak
3	Poor solution		
4	Tolerable solution	2	Satisfactory
5	Satisfactory solution		
6	Good solution with a few drawbacks		
7	Good solution	3	Good
8	Very good solution		
9	Excellent (exceeds the requirement)	4	Excellent
10	Ideal solution		