UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **DESIGN AND DEVELOPMENT OF INTEGRATED CHASSIS OF THREE WHEEL PROTOTYPE CAR USING ALUMINUM AND FRP**

SESI PENGAJIAN: **2010/2011**

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DESIGN AND DEVELOPMENT OF INTEGRATED CHASSIS OF THREE WHEEL PROTOTYPE CAR USING ALUMINUM AND FRP

NUR AFNAN BIN ABDUL HALIM

BACHELOR OF ENGINEERING

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2010

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Design and Development of Integrated Chassis of Three Wheel Prototype Car Using Aluminum and FRP*"is written by *Nur Afnan Bin Abdul Halim.* I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

MR. IDRIS MAT SAHAT	....
Examiner	Signature

DESIGN AND DEVELOPMENT OF INTEGRATED CHASSIS OF THREE WHEEL PROTOTYPE CAR USING ALUMINUM AND FRP

NUR AFNAN BIN ABDUL HALIM

Report submitted to the Department of Mechanical Engineering
in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

SUPERVISOR'S DECLARATION

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STUDENT'S DECLARATION

I hereby declare that the ideas, designs, analysis, results and conclusions in this project are entirely my own effort, except for quotations and summaries which have been indicated and acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature ....

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DEDICATION

Specially dedicated to

My beloved family and those who have

Encourage and always be with me during hard times

And inspired me throughout my journey of learning

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Dr Sugeng Ariyono for providing this interesting and exciting topic and then providing his guidance, assistance and encouragement throughout the duration of the project. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments.

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Special thanks to my lovely parents for their support, love, dream and sacrifice throughout my life. I would like to appreciate their devotion, support and faith in my ability to attain my goals.

ABSTRACT

This thesis presented about the design and development of integrated chassis of three wheel prototype car using aluminium and FRP. To improve the existing chassis design of three wheel prototype cars for Shell Eco Marathon competition, analysis of the existing chassis must be done. The analysis was carried out by using Finite Element Analysis (FEA). The parameters checked in the analysis are the displacement of the chassis structure when load applied and the weight of the chassis. Specifications of materials selection become a priority in order to construct the new chassis which can replace the ordinary design. A survey of the material used for the development of chassis design had been done in Kuantan area in order to get the most suitable material for the new chassis design. The best design was then identified based on the analysis determined from the Finite Element Analysis (FEA) technique. The specifications of the best design are the design which is light weight and has a minimum deflection of the structure when subjected on the load. The design of the final chassis design will be done by using SolidWork software which is suitable for making the 3D model of the car.

ABSTRAK

Tesis ini membentangkan tentang rekabentuk dan juga pengubahsaian untuk rangka bersepadu kereta roda tiga menggunakan aluminium dan FRP. Untuk penambahbaikan bagi rangka sedia ada kereta roda tiga untuk pertandingan Shell Eco Marathon, analisis terhadap rangka sedia ada dilakukan. Analisis tersebut di jalankan dengan menggunakan perisian Finite Element Analysis (FEA). Parameter yang di periksa dari analisis tersebut adalah seperti perpindahan lentur dari struktur rangka kereta apabila beban di kenakan terhadap rangka tersebut dan berat rangka tersebut. Spesifikasi pemilihan bahan menjadi keutamaan untuk pembinaan rangka baru yang dapat menggantikan rekabentuk asal. Tinjauan terhadap bahan yang ingin digunakan untuk pengubahsuaian rangka asal telah di buat di daerah Kuantan bertujuan untuk mendapatkan bahan yang paling sesuai untuk pembinaan rangka baru. Rekabentuk terbaik kemudian dikenalpasti berdasarkan analisis yang di buat dan ditentukan dari teknik Finite Element Analysis (FEA). Spesifikasi desain terbaik adalah desain yang ringan dan mempunyai defleksi struktur yang minimal ketika beban dikenakan pada struktur rangka tersebut. Rekabentuk rangka baru tersebut akan dilukis menggunakan perisian SolidWork di mana perisian ini merupakan perisian yang sesuai untuk melukis model kereta dalam tiga dimensi.

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LIST OF SYMBOLS

F	Force
σ	Stress
δ	Displacement magnitude
ρ	Material density
ν	Material volume
m	Mass
D	Diameter of the round tube
t	Thickness of round tube

LIST OF ABBREVIATIONS

AA	Aluminum Alloy
AISI	American Iron and Steel Institute
FEA	Finite Element Analysis
FRP	Fibre Reinforcement Plastics
GRP	Glass Reinforcement Plastics
ID	Inner Diameter
OD	Outer Diameter
SUV	Sports Utility Vehicles
TR	Torsional Rigidity

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The Shell Eco-marathon competition is divided into two categories which is Urban Concept and Prototype. Urban Concept Car category is referring to the design which is meet a series of roadworthiness criteria found in modern passenger cars such as having four wheels, a steering wheel, head and tail lights, a brake pedal, doors and else. For the Prototype category, the car designed is aimed to be the most aerodynamics and fuel-efficient car. The car in this category must have three or four running wheels. The winner of the competition is the team that goes the furthest distance using the least amount of energy.

In order to build the most energy efficient car, consideration of the types of the chassis that wants to design must be made. Basically, the types of chassis design consist of backbone, spaceframes, monocoque, ladder frame, and semi backbone. Each of chassis designs has their own strengths and weaknesses. Every chassis types are considered between weight, component size, complexity, vehicle intent, and ultimate cost. Even within a basic design method, strength and stiffness can vary significantly, depending on the designing. An ideal chassis is the one that has high stiffness with low weight and cost.

The chassis has to contain the various components required for the race car as well as being based around a driver's cockpit. The safety of the chassis is a major aspect in the design, and should be considered through all stages. The design also has to meet strict requirements and regulations set by Shell Eco Marathon organizers.

Many people think that the chassis which built from aluminum is the path to the lightest design, but this is not necessarily true. Aluminum is more flexible than steel. In fact, the ratio of stiffness to weight is almost identical to steel, so an aluminum chassis must weigh the same as a steel one to achieve the same stiffness. Aluminum has an advantage only when there are in very thin sheet sections where buckling is possible but that are not generally the case with tubing. The uses of aluminum and FRP in designing the chassis are helped to reduce overall vehicle weight, thereby reducing fuel consumption as well.

1.2 PROBLEM STATEMENT

Based on the previous Shell Eco Marathon competition, most of the design of prototype car is not satisfy these criteria:

i. Design the three wheel prototype car which maximum vehicle weight, without the driver, is 140 kg, the maximum height must be less than 100 cm; the wheelbase must be at least 100 cm, the maximum total vehicle width must not exceed 130 cm, the maximum total length must not exceed 350 cm.
ii. Existing design not enough strong due to heavy load.
iii. Ordinary design of three wheel prototype car is less fuel-efficient due to the weight factor of the vehicle.

1.3 OBJECTIVE OF THE PROJECT

After considerations are made corresponds to the project background and problem faced, it is decided that the objectives of the project are as such:

i. Design the new chassis of three wheel prototype car which able to withstand the load applied on the chassis structure with minimum bending displacement.
ii. Build the lightest three wheel prototype car chassis in order to maximizing the efficiency of the car that satisfies SHELL ECO MARATHON rules and regulations.

1.4 PROJECT SCOPES

This project is focusing on design and development of the integrated chassis of a three wheel prototype car which able to travel with less amount of energy. This focus area is done based on the following aspect:

i. Design a chassis of three wheel prototype car using aluminum and FRP.
ii. Find the aluminum type which suitable for chassis designing.
iii. Study on spaceframe chassis characteristic.
iv. Build vehicles chassis where the primary design consideration is light weight and reducing drag.

1.5 PROJECT METHODOLOGY

Methodology is one of the most important things to be considered to ensure that the project will run smoothly and achieve the objective. Project methodology will describe the flow of the project progress. The project methodology shows us how the project started, how data was collected, and how the next steps done.

Methodology process is related to the flow chart and Gantt chart. In order to complete this project, there will come out with several steps which should be followed through. The project methodology in the form of a flow chart is graphically shown in Figure 1.1.

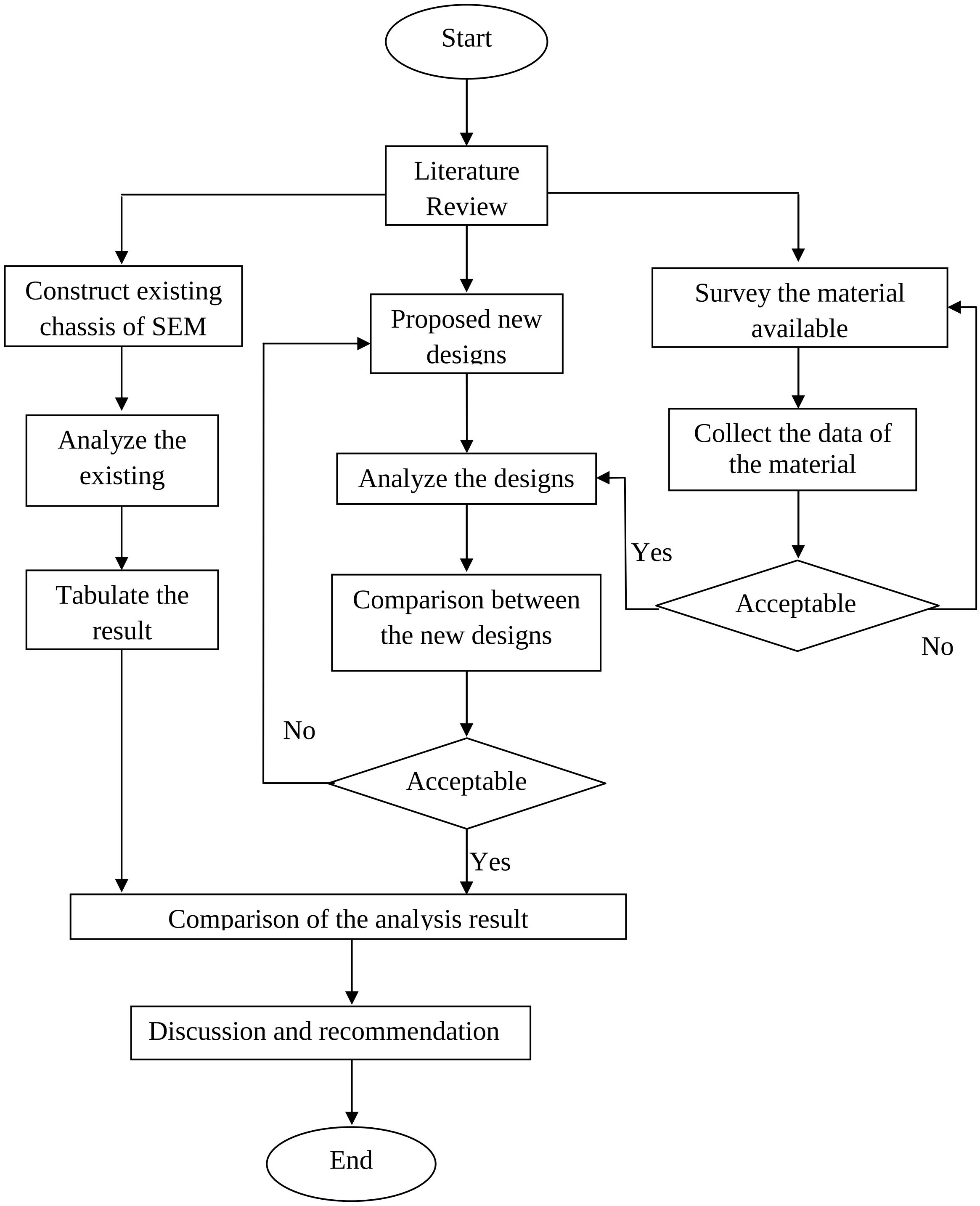


Figure 1.1: Flowchart

1.6 STRUCTURE OF THESIS

Chapter 1 introduces the background of the project which is design the new chassis of three wheel prototype car for Shell Eco Marathon competition, problems which relates to the project, the objectives and the scope of the project. In this chapter also briefly describe the types of chassis exist now a days. Chapter 2 presents the detail information of chassis type and the comparison between each type. In this chapter, the suitable chassis type for the new design is determined from the comparison. The characteristics of spaceframe chassis are determined followed by the literature analysis.

Chapter 3 includes the overview of existing chassis which design for previous Shell Eco Marathon competition. The analysis of the previous design is conducted in this chapter. After get the result from the analysis, the new chassis design is proposed to improve the previous design. Parameters such specification and selection of materials used is considered for the development of new design. Materials that used for the new design are aluminum and fiber reinforces plastic. Lastly, Chapter 3 enclosed with the designing process of the new chassis design.

Chapter 4 begins with the analysis of the new design. Results of the analysis are tabulated and the comparisons between existing chassis and the new chassis design are made followed by the discussion of the new chassis design. Chapter 5 presents the conclusion drawn from this project and recommendations for future works proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Basically chassis is considered as a framework to support the body, engine and other parts which make up the vehicle. Chassis lends the whole vehicle support and rigidity. Chassis usually includes a pair of longitudinally extending channels and multiple transverse cross members that intersect the channels. The transverse members have a reduced cross section in order to allow for a longitudinally extending storage space.

The chassis has to contain the various components required for the race car as well as being based around a driver's cockpit. The safety of the chassis is a major aspect in the design, and should be considered through all stages. Generally, the basic chassis types consist of backbone, ladder, spaceframe and monocoque. Different types of chassis design will result the different performance of each chassis.

2.2 TYPES OF CHASSIS

2.2.1 Backbone

A backbone chassis is the simplest structure design. It consists of a sturdy tubular backbone that joints the front and rear axle. These chassis is fully enclosed to be rigid structure and handle all loads (Keith J. Wakeham, 2009). It should be noted that the backbone chassis can be built through many types of construction. The space within the structure is used to place the driveshaft in case of front-engine, rear-wheel drive layout.

Further, the drivetrain, engine and suspensions are all connected to each of the ends of the chassis. The body is built on the backbone usually made of glass-fibre. Almost rear wheel drive and front engine vehicles use backbone chassis. Figure below shows the backbone chassis type.

Figure 2.1: Delorean backbone chassis

Source: Keith J. Wakeham, 2009

2.2.2 Ladder

A ladder frame is the simplest and oldest frame used in modern vehicle construction. It was originally adapted from “horse and buggy” style carriages as it provided sufficient strength for holding the weight of the components (Keith J. Wakeham, 2009). Larger beams could be used if there were higher weight capacity required. The engine of the vehicle using this ladder frame is placed in the front or sometimes in the rear and supported at suspensions points. Their constructions consist of two longitudinal rails interconnected by many lateral/cross braces, typically made from round or rectangular tubing or channel.

The longitude members are the main stress member. They deal with the load and also the longitudinal forces caused by acceleration and braking. It can use straight or curved members. The lateral and cross members provide rigidity to the structure because it provides resistance to lateral forces and further increase torsional rigidity. Body mounts are usually integral outriggers from the main rails, and suspension points can be well or poorly integrated into the basic design. Most SUV's are still use ladder chassis (Automotive Online, 2008). Figure below shows the type of ladder chassis.

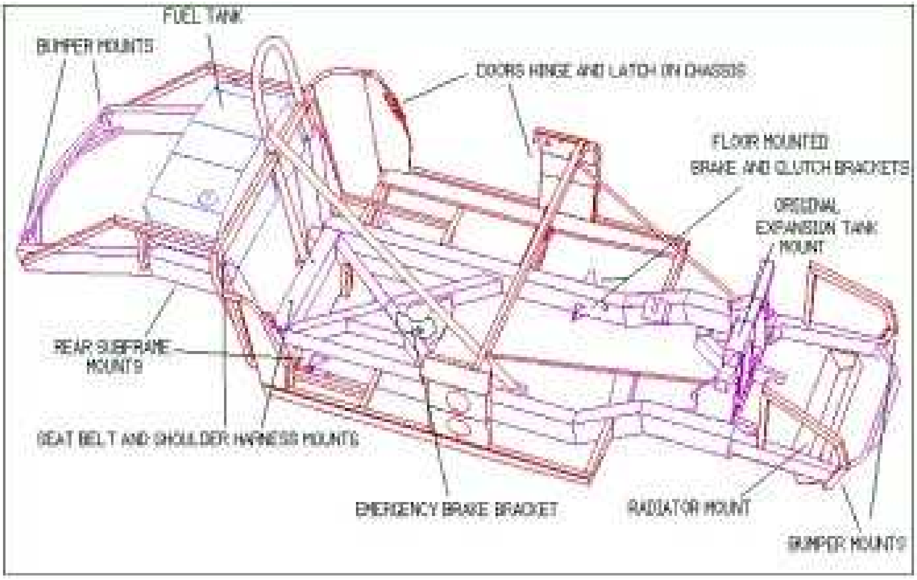


Figure 2.2: AC Cobra's chassis

Source: AutoZine Technical School, 1997

2.2.3 Monocoque

A monocoque chassis can be refer to the vehicle where the external body is load bearing (Keith J. Wakeham, 2009). Monocoque is a one-piece structure which defines the overall shape of the car. While ladder, tubular space frame and backbone chassis provides only the stress members and need to build the body around them, monoque chassis is already incorporated with the body in a single piece. It built by welding several pieces together. It’s different from the ladder and backbone due to the body construction as mentioned before. The floorpan, which is the largest piece, and other pieces are press-made by big stamping machines. They are spot welded together by robot arms some even use laser welding in a stream production line. The whole process just takes minutes. After that, some accessories like doors, bonnet, boot lid, side panels and roof are added.

Most commercial vehicles today are of the monocoque variety but they generally will differ from the shape implied by road racing vehicle structure. Common vehicles such as the Honda Civic and Chev Impala are stamped from steel panels, these panels are then assembled and spot resistance welded together to build the car structure (Keith J. Wakeham, 2009). Monocoque chassis also benefit crash protection. Because it uses a lot of metal, crumple zone can be built into the structure. Although monocoque is suitable for mass production by robots, it is nearly impossible for small-scale production. The setup cost for the tooling is too expensive such as big stamping machines and expensive moldings. Figure below shows the type of monocoque chassis.

Figure 2.3: Volvo V70 Monocoque

Source: AutoZine Technical School, 1997

2.2.4 Spaceframe

As ladder chassis is not strong enough, motor racing engineers developed a 3 dimensional design - Tubular space frame. One of the earliest examples was the post-war Maserati Tipo 61 "Birdcage" racing car (AutoZine Technical School). Tubular space frame chassis employs dozens of circular-section tubes which provides the maximum strength and it’s positioned in different directions to provide mechanical strength against forces from anywhere. These tubes are welded together and form a very complex structure.

A spaceframe chassis uses a series of straight small diameter tubes to achieve strength and rigidity with minimal weight. The technique was formalized during the Second World War, when they were used for the construction of large frames in combat aircraft. This design was first developed by Barnes Wallis who was an English aviation engineer (Christoper, 2004). Now days, mostly there are two main types of chassis used in race cars which are tubular spaceframes and composite monocoque (Christopher, 2004). Spaceframes have been used in the construction of racing car chassis, since the introduction of car racing in the 1940’s (Christoper, 2004). Spaceframes chassis have been used since the start of the motor sport scene. A spaceframe consists of steel or aluminum tubular pipes placed in a triangulated format to support the loads from the vehicle caused by suspension, engine, driver and aerodynamics (Christopher, 2004).

Although the spaceframe type are look like the traditional style, but they are still very popular today in amateur motorsport. Their popularity maintains because of their simplicity, the only tools required to construct a spaceframe is a saw, measuring devices and welding equipments. The advantage of spaceframe compare to the monocoque type is it can easily be repaired and inspected for damage after a collision. Figure 2.3 below shows an example of spaceframe chassis.

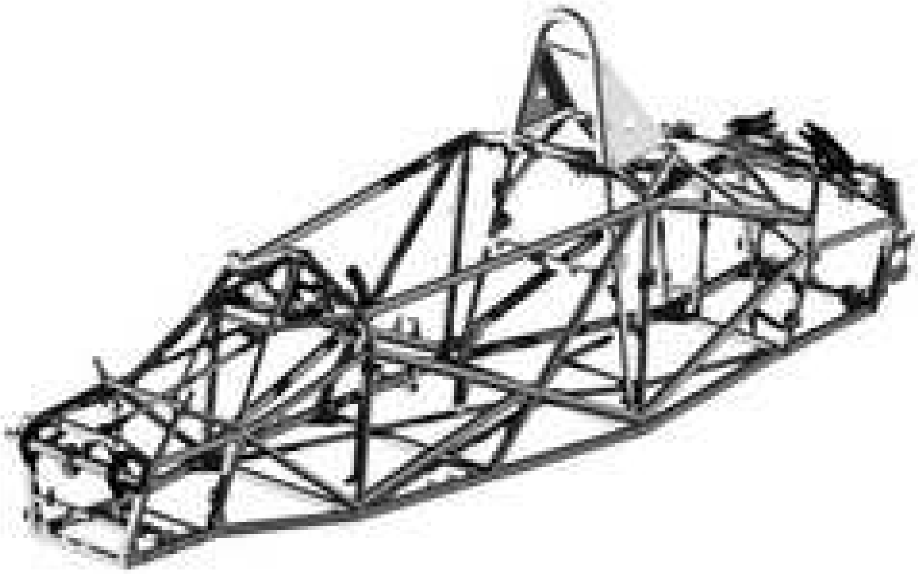


Figure 2.4: Spaceframe

Source: Keith J. Wakeham, 2009

Table 2.1: Comparison between four types of chassis

Type	**Advantages**	**Disadvantages**
Backbone	• Stong enough for smaller sports cars. • Easy to be made by hand thus cheap for low-volume production. • The most space-saving other than monocoque chassis.	• Not strong enough for high-end sports cars. • The backbone does not provide protection against side impact or off-set crash. • Cost ineffective for mass production.

Ladder	• Cheap to hand build. • More suited for heavy duty usage such as towing and off-roading; can be more durable. • Easier to design, build and modify	• Little torsional rigidity, that is because it is a 2D chassis. • Poor resistance to torsion • overall height will be higher due to the floor pan sitting above the frame • Center of gravity is usually higher - compromising stability and handling.
Monocoque	• Cheap for mass production. • Inherently good crash protection. • Space efficient.	• Monocoque construction does not suit all situations. • Damage to a skin of monocoque construction will weaken the whole construction.
Spaceframe	• Provide maximum strength and minimum deflection due to the support from tubular pipes • Spaceframe chassis systems are lighter than traditional steel • Provides significant economy in foundation costs • The high torsional rigidity can be achieved as well as its light weight	• Very complex due to their triangulated tubular pipes format. • Construction of spaceframe chassis is expensive and requires maximum time consuming to be built. • The construction is impossible for robotised production

2.2.5 Analysis Comparison Result

Since the spaceframe chassis is the most suitable chassis type used in the prototype car construction in SHELL ECO MARATHON compared to others chassis types, hence this concept is applied in this project.

2.3 CHASSIS DESCRIPTION

The main components of the spaceframe chassis are the front box, cockpit, engine compartment and rear box as shown in Figure 2.5. The front box is defined as any structural tubing from the front roll hoop, forward to the front bulkhead. The cockpit is defined as the area where the driver sits and consists of tubing from between the front roll hoop and the main roll hoop which including side impact bracing and seatbelt bracing. The engine compartment is where the engine mounts into the frame from the main roll hoop. The rear box is the part where the rear suspension points mount, and where parts of the drivetrain, including differential brackets and rear engine bracing are mounted.

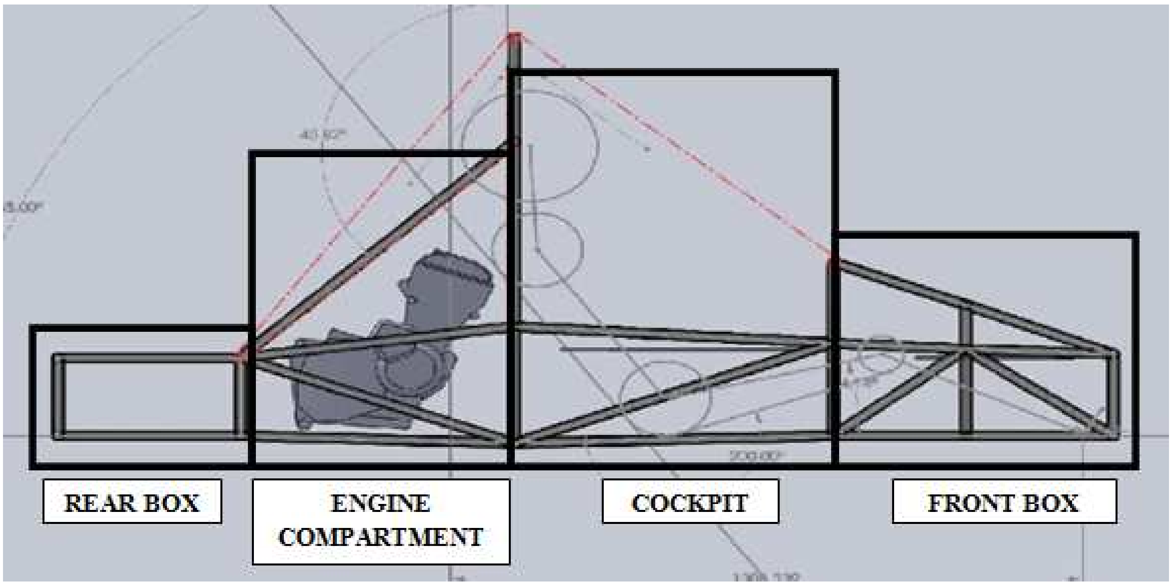


Figure 2.5: Spaceframe main sections

2.4 CHASSIS DESIGN PRINCIPLE

The fundamental principle of a chassis design states that the chassis is to be designed to achieve the torsional rigidity and light weight in order to achieve good handling performance of a race car (Weerawut, C., 2000). By the definition, torsional rigidity (TR) is refers to the ability of chassis to resist twisting force or torque. In the other words, torsional rigidity is the amount of torque required to twist the frame by one degree. These parameters also applied to spaceframe chassis. Generally, the effect of the torsional rigidity on spaceframe is different to the monocoque due to their construction format, but the structure is used to approximate the same results as the difficult to twist monocoque chassis. Figure below shows the torsional rigidity applies to race car chassis.

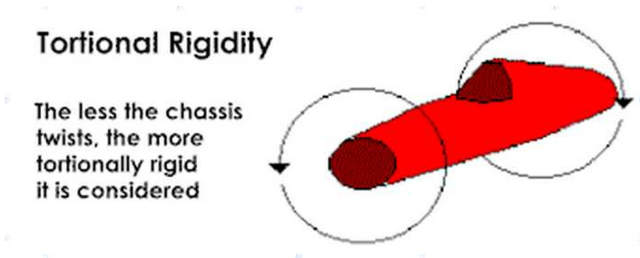


Figure 2.6: Torsional rigidity on race car chassis.

According to the statement above, chassis designed must have high torsional rigidity in order against the twisting force or torque. In order to increase torsional rigidity on the chassis, the format of tube pipes arrangement must be considered. By strategically positioning a frame member, torsional rigidity increase significantly (Matt Gartner, 1999). The principle is to place the frame members in a triangulated format as shown in figure below.

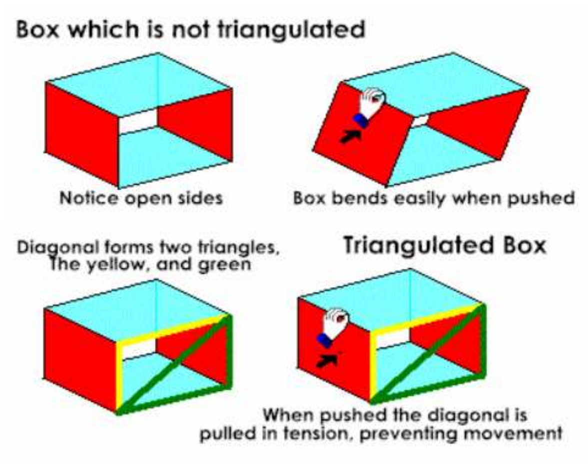


Figure 2.7: The strategy on positioning a spaceframe member.

The common theory behind spaceframe is to create a chassis frame in a triangulated format to provide minimum deflection and maximum strength (Reimpell, 2001). The triangulated box imparts strength by stressing the diagonal in tension and compression (Matt Gartner, 1999). As shown, the box will not easily deformed by bending force due to the triangulated format of frame. Hence, most race car chassis today designed in triangulated format.

2.5 LITERATURE ANALYSIS

Literature analysis is a combination among literature review and analysis of the previous project to be developed. The purpose of this literature analysis is to highlight the methods that used to find the information that related to project. This information is important in order to analyze and understand the project title which is understands the all concept of chassis design of three wheel car. The methods that used in the literature analysis are:

i. Surfing the internet
ii. Reference books
iii. Discussion with supervisor

2.5.1 Internet

From the internet, the overall information about the project can be found through the journal, technical paper, and others material form. All the information's gathered are from the trusted web page such as science direct and others World Wide Web information such 'How Stuff Works', Autozine.org, and others which explain more about the chassis design. The information that found from the internet source must be compared and reanalyzed with the reference book. There are several websites used to find the information related to this project:

http://www.gmecca.com/byorc/dtipschassis.html#ChasisGeneral
http://www.autozine.org/technical_school/chassis/tech_chassis.htm
http://www.fiberglasssales.com/index.php/why_use_fiberglass/

2.5.2 Reference Books

In order to get more information about the project title, reference books also being an important and trusted material. It is because the contents of the books are written by the professional person such as an engineer and doctor. They have a lot of experience about the topics which studied in the reference books and they are also expert in the course they have been. From the reference books, the information about methodology, concept and calculation method related to the project will found.

2.5.3 Discussion with Supervisor

Discussion with supervisor will be the other important method. It is because from the discussion, all the detail information about the project such project scope, analysis that must be performed, and others parameters will explain clearly. Weekly discussion will cause the new idea created as well as will improve the research about the project. Besides that, it is important in order to make sure the project smoothly in progress.

2.6 Summary

This chapter presents the detail information of chassis type and the comparison between each type. In this chapter, the suitable chassis type for the new design is determined from the comparison. The description of the spaceframe chassis are described in this chapter followed by the literature analysis. Spaceframe consists of front box, cockpit, engine compartment and rear box. Literature analysis contains the information about the sources gained in order to complete the project.

CHAPTER 3

EXISTING CHASSIS DESIGN AND DEVELOPMENT FOR NEW DESIGN

3.1 INTRODUCTION

Mostly the chassis type used in the construction of prototype car for SHELL ECO MARATHON is spaceframe. This is because due to the specification of the spaceframe which is more rigid than other chassis. But, certain of the chassis designed in the SHELL ECO MARATHON is not totally look like a spaceframe chassis, instead the design is integrated between monoque and spaceframe. It's mean that for the driver and engine compartment, the designer use the spaceframe chassis concept in order to support the load and combined with monoque concept to build overall body which made by FRP. The designer uses the combination between spaceframe and monocoque in order to reduce the weight of the car.

Theoretically, the chassis design concept state that the chassis designed must have the triangulated format of tubular pipes in order to increase the torsional rigidity of the chassis. But for the designing of the prototype car using spaceframe chassis for SHELL ECO MARATHON, it is not important to follow this concept because the goals of the design is to have a lightweight car which can cruise further by using less amount of energy. It's mean that, the car will not go faster and not facing the twisting force or torque. The project will ignore about the principle which is to place the frame members in a triangulated format as mentioned before. Figure below shows the existing design of the prototype car's category of SHELL ECO MARATHON.

Figure 3.1: Prototype chassis designed by University Malaysia Pahang

Source: Mechapro Team, UMP

3.1.1 Analysis of Existing Chassis Using Finite Element Analysis (FEA) Software

In order to develop the existing design, the analyses of the previous design are conducted and the weakness of the design identified. FAE software used to analysis the previous design. Finite element analysis is a tool used in engineering to determine the physical effects a given set of boundary conditions will have on a part. Boundary conditions can be forces, temperatures, hydrostatic pressures, centrifugal pressures, torques, and displacements (Jeff Schultz, 1997).

Finite Element Analysis (FEA) provides solutions to problems that would otherwise be difficult to obtain. In terms of fracture, FEA most often involves the determination of stress intensity factors. FEA, however, has applications in a much broader range of areas; for example, fluid flow and heat transfer. While this range is growing, one thing will remain the same: the theory of how the method works (Jason Midkiff, 1997).

Finite-element analysis is usually used to fine-tune the geometry of a design that is still on the drawing board, before working models are built and tested. FEA is also used to debug an existing prototype. The first approach is more cost-effective and can open the door to more creative solutions at an early stage in the design process.

The FEA modeling process requires three types of input data which is geometry, material properties, and loading. For the spaceframe chassis, "geometry" means the overall frame dimensions such as tube lengths, intersection points, and angles as well as the tubing specifications such diameters, wall thickness, tapers, ovals, etc. Linear beam elements are chosen to model the geometry of the chassis. The tube members are modeled using straight pipe elements with circular cross section for the roll bar and lower side impact member while for the engine compartment, side impact members and the front box using hollow rectangular elements. Figure below shows the finite element model of the previous chassis design. The chassis model was constructed of AISI Type 304 Stainless Steel with material properties given in table below.

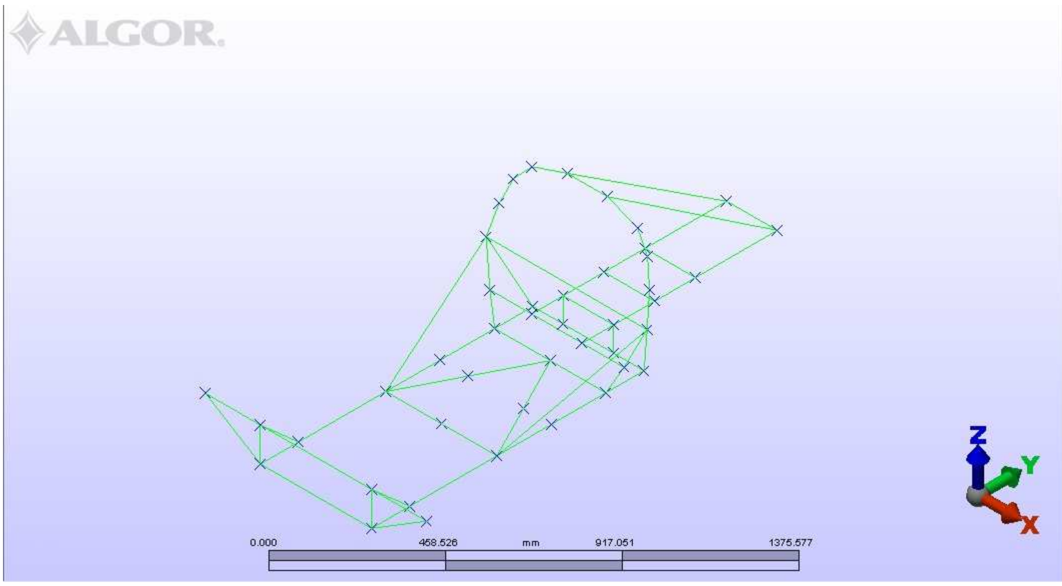


Figure 3.2: Finite element model of the previous chassis design

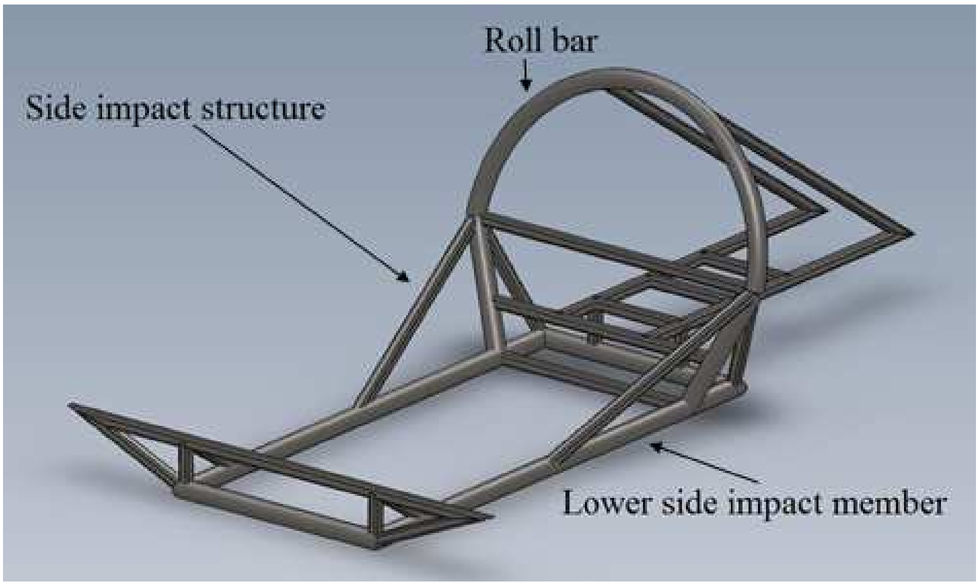


Figure 3.3: Solidwork model of existing design

Table 3.1: Technical specification of existing design

Configuration	**3 wheels**	
Weight	171.79 N	
Frame material	AISI Type 304 Stainless Steel	
Material dimension	Side impact structure	1”x0.065” (25.4x1.651mm) (square tube)
	Roll bar	1.25”x0.06” (31.75x1.524mm) (round tube)
	Lower side impact member	1.25”x0.06” (31.75x1.524mm) (round tube)

Table 3.2: Material properties of AISI Type 304 Stainless Steel

Mechanical Properties	Value
Yield strength	290 Mpa
Ultimate strength	580 Mpa
Modulus of Elasticity	193 Gpa
Poisson's ratio	0.29
Density	8000 kg/m^3

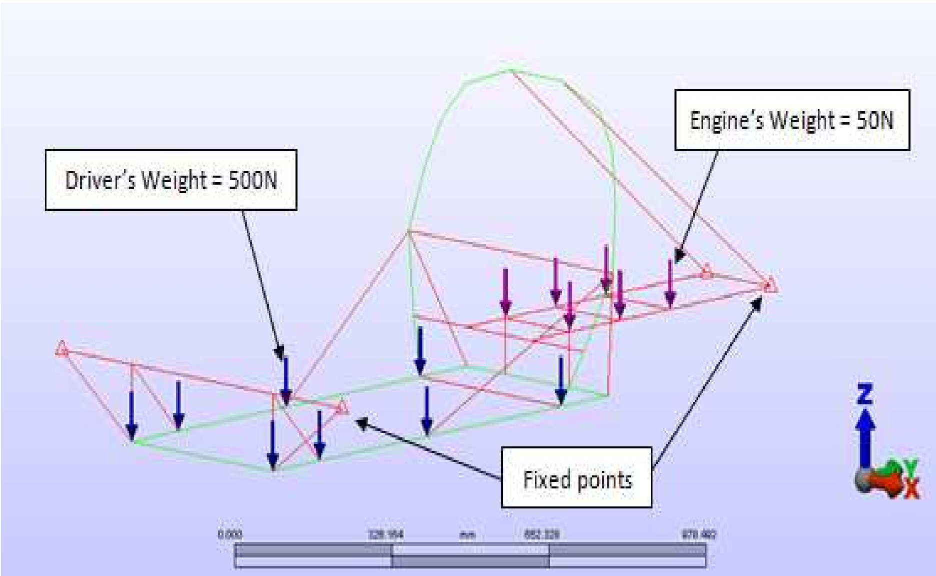


Figure 3.4: Applied force and fixed point of chassis

In order to evaluate the displacement and other parameters of the chassis, the specified structural boundary conditions are applied to the model as shown in Figure. At the front and rear tyre connection, the chassis is fixed in all x, y, and z direction. A force is applied to the driver compartment and engine compartment. A force F = 500 N is applied to the driver compartment while force F = 50 N is applied to the engine compartment. Force act to the driver compartment is consider to be 500 N cause for the minum weight of driver.

Recall back the objective of this project is to design the new chassis which light weight. The driver must have a weight as minimum as possible in order to reduce the overall weight of the vehicle so then it will reduce drag as well as fuel consumption. Force acting at engine compartment is estimated to be 50 N cause the weight for engine just about 30 N then plus with the additional parts which attach at engine compartment such sprocket, brackets of bearing and sprocket mounting which estimated weight of 20 N.

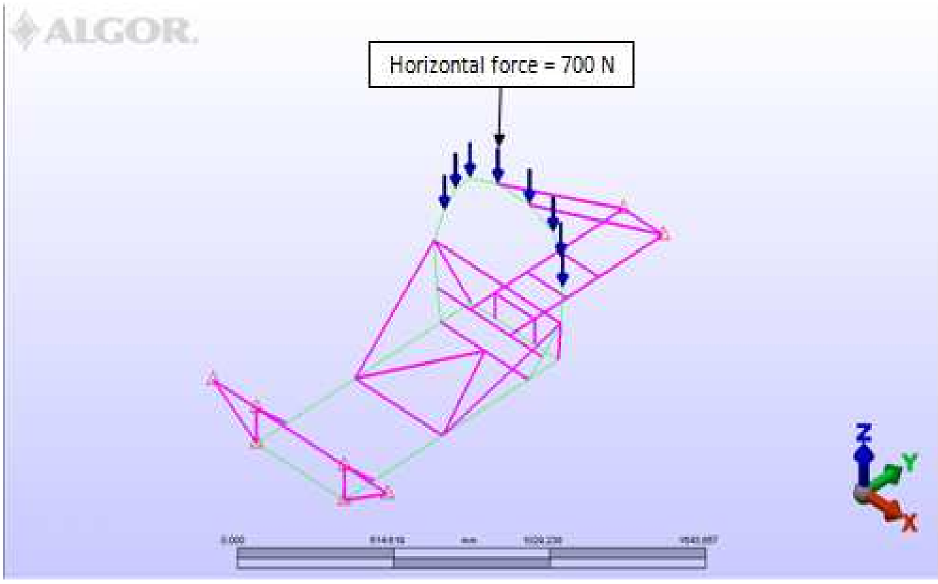


Figure 3.5: Force applied on roll bar

The analysis of the roll bar is also conducted in order to check whether the roll bar is quite strong or not to withstand the horizontal force. This analysis is important in case if the car is rolling. Force 700 N applied in z-direction and the value of force is required by the rule and regulation of Shell Eco Marathon. Result from the analysis tabulated in the table below.

Table 3.3: Result from analysis of existing chassis model

TEST	Max. Displacement (mm)	Max. Axial Stress (N/mm2)	Worst Stress (N/mm2)
Roll Bar	0.591606	3.411919	16.31738
Driver and engine compartment	0.418939	3.629341	16.76734

3.1.2 Roll Bar Testing

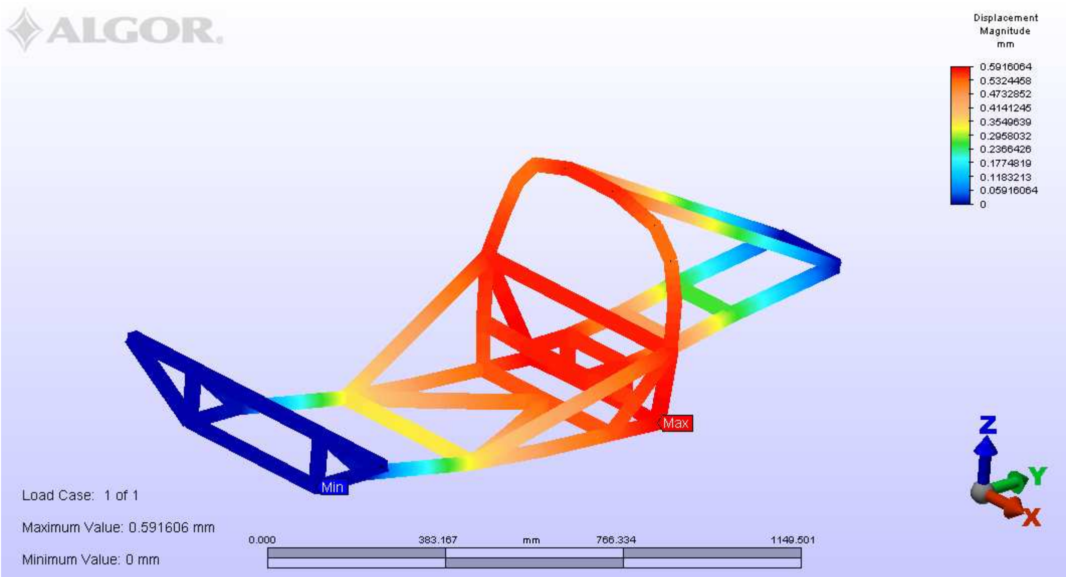


Figure 3.6: Displacement on roll bar test

Figure above shows the result from the roll bar test of existing chassis. It shows that the chassis structure undergoes bending when load applied on the roll bar. The magnitude of the maximum displacement occurs on the chassis structure is 0.591606 mm and represented with red region. The bending occurs almost at the lower side impact member which is at the driver compartment. The minimum bending displacement occurs at the tyre mounting which is fixed point and the magnitude of the minimum bending displacement is 0.05916064 mm and represented with blue region.

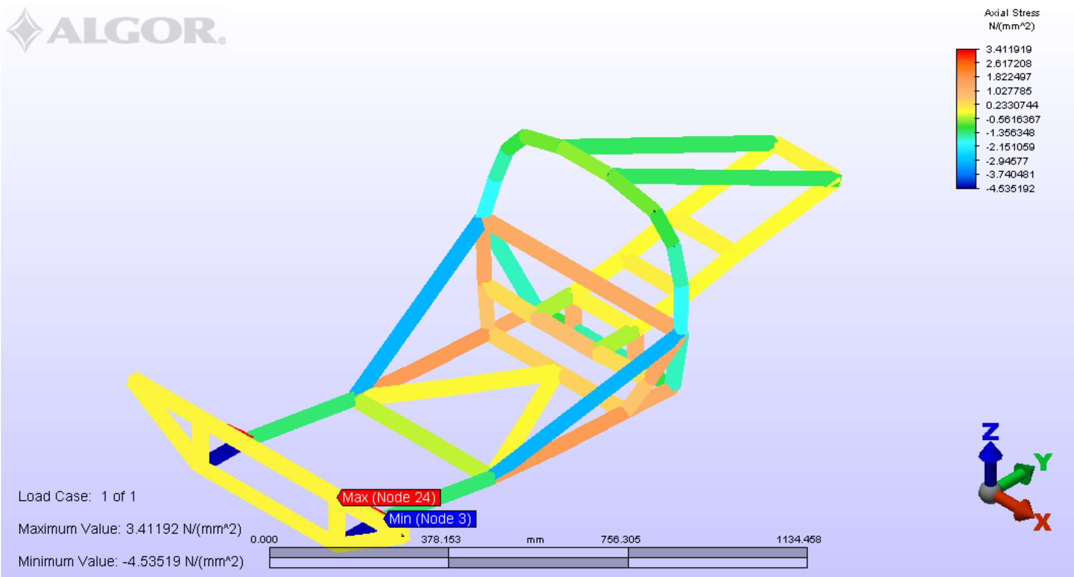


Figure 3.7: Maximum Axial Stress on roll bar test

Figure above shows the axial stress occurs on the existing chassis structure when load is applied at the top of the roll bar. The maximum axial stress observed occurs at the connection between lower side impact member and the support member of the tyre mounting which is tensile stress. The magnitude of the axial stress is 3.411919 N/mm^2. Structure that undergoing axial stress represented by red region. Axial stress occurs due to the axial load acting along the length of member. The minimum axial stress occurs at the lower side impact member which is at the connection between lower side impact members with the support member of the tyre mounting. The magnitude of the minimum axial stress is -4.535192 N/mm^2 and it is compression stress occurs at that cross section. The region which undergoing compression stress represented by blue region.

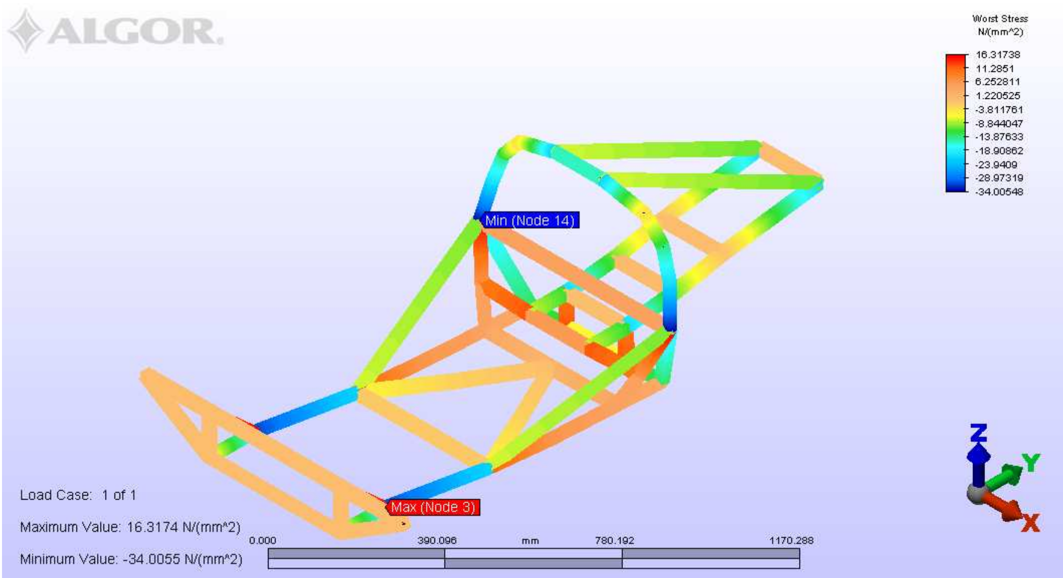


Figure 3.8: Worst stress on roll bar test

Figure above shows the worst stress of the chassis structure when the analysis of the roll bar test performed. Figure above shows the magnitude of the maximum worst stress is 16.31738 N/mm^2. The region which undergoing maximum worst stress represented by red region. The minimum worst stress occurs at blue region and the magnitude of the minimum worst stress is -34.00548 N/mm^2. The negative sign shows that the region undergoing compression stress. Worst stress occurs due to the various cross section of the chassis structure.

3.1.3 Engine and Driver Compartment Testing

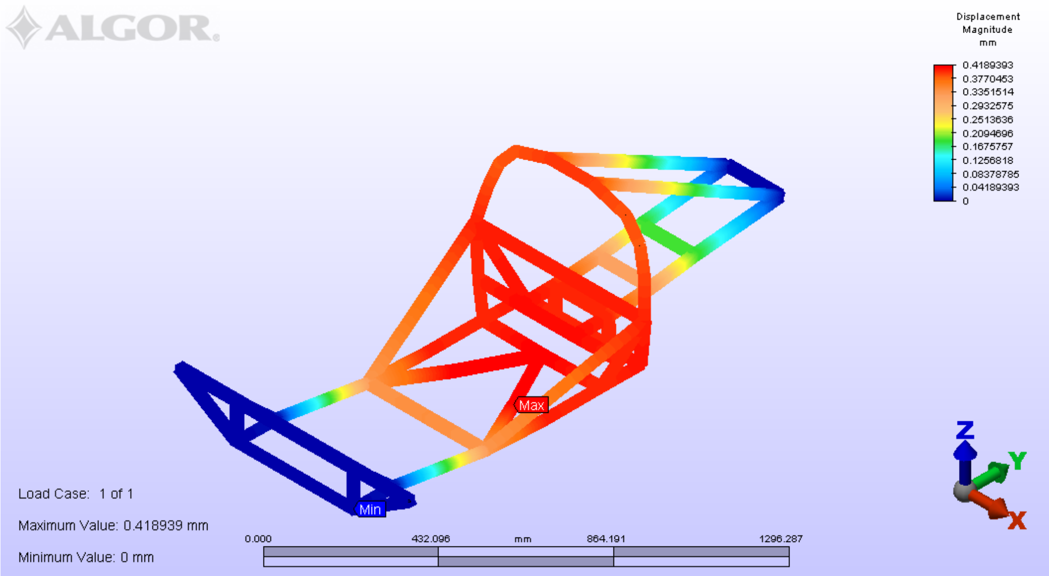


Figure 3.9: Displacement on engine and driver compartment test

Figure above shows the result of the displacement occurs on the chassis structure when load applied to the driver and engine compartment. Its shows that driver compartment undergoing maximum bending and represented by red region. Magnitude of the maximum displacement is 0.418939 mm, whereas the region which is near to the fixed point undergoes minimum displacement with magnitude 0.04189393 mm. This region represented by blue colour. The displacement of the chassis structure occurs due to the load from the driver and load from the engine.

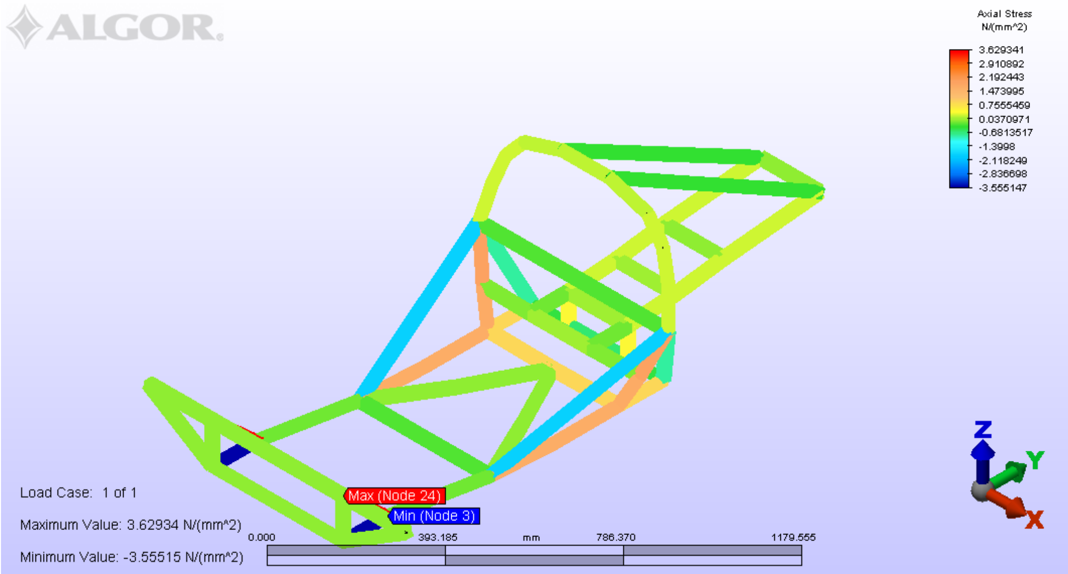


Figure 3.10: Maximum Axial stress on engine and driver compartment test

Figure above shows the axial stress occurs on the existing chassis structure when load is applied on the driver and engine compartment. The magnitude of the maximum axial stress is 3.629341 N/mm^2 and the maximum axial stress occurs at the support member which connected between tyre mounting member and lower side impact member. This section undergoes tensile stress. The minimum axial stress occurs at the lower side impact member which connected to the tyre mounting member with magnitude -3.555147 N/mm^2. This section undergoes compression stress.

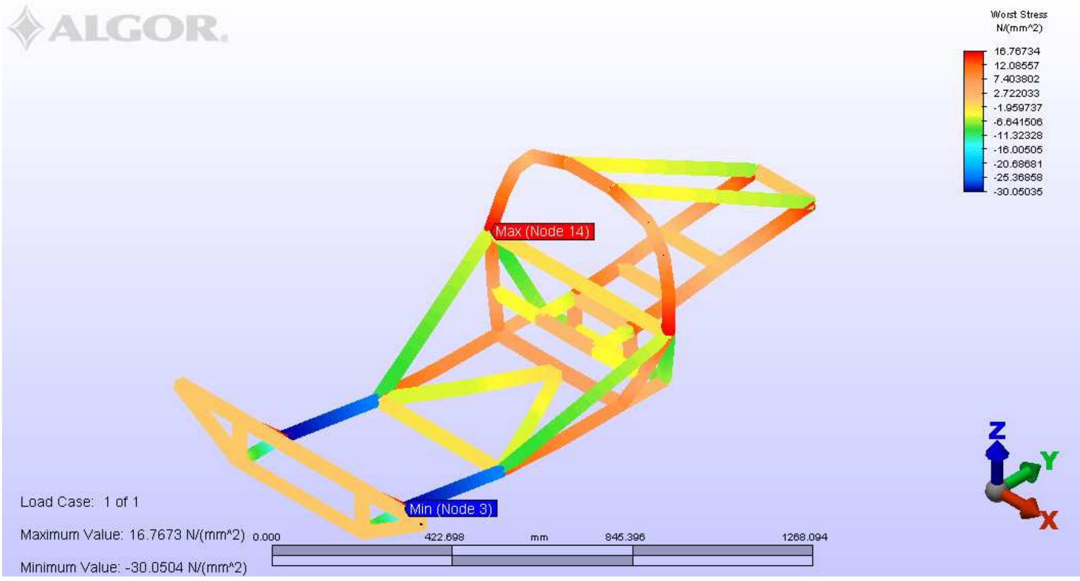


Figure 3.11: Worst stress on engine and driver compartment test

Figure above shows the worst stress result of the chassis structure for the engine and driver compartment test. Red region of the figure shows that the section undergoes maximum worst stress. The magnitude of the maximum worst stress is 16.76734 N/mm^2 and the minimum worst stress is -30.05035 N/mm^2. At the maximum worst stress, the cross section area of the chassis structure undergoes tensile stress whereas at the minimum worst stress, the cross section area of the structure undergoes compression stress.

3.1.4 Discussion

From the figure of the analysis, it shows various colours formation on the chassis structure. The various colours represent the various magnitudes of displacement occur on the chassis structure. The red region colour shows the maximum displacement of the structure and the minimum displacement represent by blue region. The displacements decreased correspond to the colours followed by yellow, green and blue. Almost red region occur at the middle of the structure which is at the driver compartment. This results show that driver compartment undergoes the bending due to the force acting on that section and the magnitude of the displacement is 0.418939 mm. Engine compartment have slightly difference magnitude of bending from the driver compartment. The result value observed is small and it shows that the structure is strong enough to stand the load apply on itself. Even though the chassis still can be used but the structures will not long lasting.

Moreover, the weight of existing design is too heavy which is 171.79 N. It will encourage the drag force of the car. Consequently, more fuel needed to produce high combustion in the engine in order to move the car from the stationary position as well as overcome the drag force.

Both figure shows that minimum displacement occur at the section which near to the fixed point of the chassis. There were no displacement occurs at the fixed point and represented by blue region.

3.2 DESIGNING PROCESS FOR THE ALTERNATIVE THREE WHEEL PROTOTYPE CAR CHASSIS

The engineering design process is the steps of chassis design and construction process. This process applied the basic science, mathematics and fundamental of engineering required in the project. Using the chassis design principle as a previously described, various structural modifications applied to improve existing design. Besides that, without ignore the objective of this project, weight for overall structure must also been consider in structural modifications in order to avoid the weight increment as well as reducing the drag force.

This chapter explains how alternative chassis were designed and how the simulations of the chassis were performed. This section starts with the material specification for new design, followed by the selection of material used to fabricate new design, and modeling process.

3.3 MATERIAL SPECIFICATION FOR NEW DESIGN

In order to develop the existing design of chassis for three wheel prototype car category for Shell Eco Marathon competition, the suitable materials used for construction of the chassis are decided. After that, the analysis for chosen material and make a comparison between existing design and the new design which proposed are made.

Although spaceframe have been extensively researched in the past, each style of vehicle is different and requires different characteristics, making the chassis requirements also differ for each type of vehicle. Spaceframe materials and fabrication techniques are generally universal across race vehicle categories. Spaceframe chassis are made from either rectangular hollow section tubes, round cross section tubes or in some cases a combination of both. When constructing the frame, rectangular or square tube are considerably easier to cut and weld at angles and provide ease in attaching brackets and flanges for other parts to attach.

Round tubes however, are stronger by unit weight than rectangular tubes, so the completed frame can be lighter. This advantage of round tubes over rectangular ones is offset by considerable drawbacks in the construction process. Every joint between two round tubes, even one as simple as two tubes meeting at a right angle, needs to be cut with a hole saw of the same outer diameter of the tube to form a curve in one tube, allowing it to sit flush against the other tube. Nodes where several tubes meet, often required for strength, are even more difficult to construct.

The size of a tube is specified by its outer diameter (O.D) and its wall thickness, which is the difference between the outer diameter and the inner diameter (I.D). A tube’s strength is primarily proportional to its outer diameter, but larger tubes are also correspondingly bulkier, heavier, harder to cut, and more expensive. One way to reduce the weight of large tubes is by decreases the tube’s wall thickness. Shrinking the wall thickness does give a little impact to the primary strength of the tube in term of compression, tension, or bending, but does greatly decrease the tube’s resistance to buckling which is the tube collapsing in on to itself from a point load. With proper design, buckling forces should not occur in responses to the normal stresses of solar car use, such as tight turn or pot holes, but in accident they could be problem, requiring caution when reducing wall thickness.

Before choosing the suitable types of materials for the fabrication, the important parameters that should be considered first are the diameter of the pipes tubes. This parameter is important due to the buckling effect which strongly relate with the diameter of tubes used. The outside diameter must be a minimum of 25.4 mm and have a wall thickness of 2.4 mm. Different sections of the chassis are allowed to be different diameters but for the construction simplicity, the chassis will be constructed from the same material.

When using larger diameter tubes, the preferred tube must have an equivalent, or greater buckling modulus than the baseline material. Baseline material is the suggested material used to construct the chassis. Ordinary design used 31.75 mm diameter and 1.524 mm thick AISI Type 304 Stainless Steel. The equation for calculate buckling modulus is;

$$\text{Buckling Modulus} = EI \tag{3.1}$$

Where;

E = Modulus of Elasticity
I = Area Moment of Inertia

Where I for tube is;

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) \tag{3.2}$$

And

d_o = outside diameter
d_i = inside diameter

3.4 MATERIAL SELECTION OF NEW DESIGN

Different chassis materials can reduce the weight of the vehicle, improving the vehicle power to weight ratio. Material selection can also provide advantages by reducing member deflection, increasing chassis strength and can determine the amount of reinforcement required. In order to propose the materials that want to use for the construction of new design, we must consider the limitation that have. Limitations such the cost for the material and availability for the material in market must to consider. Its means that the design and the development are useless if the materials that proposed are unavailable and high cost of purchasing. The materials which used to build the spaceframe chassis in this project are:

i. Aluminum
ii. Fiberglass

3.4.1 Aluminum

Aluminum is a nonferrous material with very high corrosion resistance and very light material compared to steels. Aluminum cannot match the strength of steel but its strength-to-weight ratio can make it competitive in certain stress application. Aluminum can also be alloyed and heat treated to improve it mechanical properties, which then makes it much more competitive with steels however the cost increases dramatically.

Pure aluminum is also a possible material and is reasonably affordable and very light but it is the weakest and will require extra reinforcement to produce a rigid chassis. Aluminum is very hard to work with as it requires very skilled welding and is an overall softer metal. Actually there are several types of aluminum available in daily use. But, not all types of aluminum are available for heavy construction. For example, construction of chassis need type of aluminum which have a good mechanical properties such high tensile strength in order to make sure the chassis able to withstand with the heavy load and also good workability and widely available.

Table below shows the types of aluminum available in market and the mechanical properties of each type.

Table 3.4: Mechanical properties based on AA standard

Source: Product Data, Sam's Metal, Kuantan, 2010

Alloy	**Temper**	**Thickness (mm)**	**Tensile Strength (Mpa)**				**Elongation % min in 50 mm**
			Ultimate		**Yield, 0.2% offset**		
			Min	**Max**	**Min**	**Max**	
1060	0	All	60	95	15	-	25
6060	T51	Up thru 3.20	150	-	110	-	8
	0	All	-	150	-	110	16
6061	T4	All	180	-	110	-	16
	T6	Up thru 6.3	260	-	240	-	8
	T5	Up thru 12.50	150	-	110	-	8
6063	T52	Up thru 25.00	150	205	110	170	8
	T6	Up thru 3.20	205	-	170	-	8

For this project, Aluminum Alloy 6063-T6 is chosen. Aluminium alloy 6063 is one of the most extensively used of the 6000 series aluminium alloys.

Aluminum Alloy 6063 is the least expensive and most versatile of the heat-treatable aluminum alloys. It has most of the good qualities of aluminum. It offers a range of good mechanical properties and good corrosion resistance. It can be fabricated by most of the commonly used techniques. In the annealed condition it has good workability.

The typical properties of aluminum alloy 6063 include medium to high strength, good toughness, good surface finishing, excellent corrosion resistance to atmospheric conditions, good workability and widely available. It is welded by all methods and can be furnace brazed. It is available in the clad form ("Alclad") with a thin surface layer of high purity aluminum to improve both appearance and corrosion resistance.

This aluminum type is used for a wide variety of products and applications from truck bodies and frames to screw machine parts and structural components. Racer teams also used common aluminum such as 6063 for a higher strength to weight ratio chassis (Peter J. Kindlmann, 2006). Furthermore, Aluminum Alloy 6063-T6 are easy to get and available at the aluminum store in Kuantan area.

Table 3.5, Table 3.6 and Table 3.7 below shows the typical composition, the physical properties and the mechanical properties of Aluminum Alloy 6063 respectively.

Table 3.5: Typical Composition of Aluminum Alloy 6063

Element	**% Weight**
Copper	0.10
Iron	0.35
Magnesium	0.49-0.95
Manganese	0.10
Silicon	0.20-0.60
Titanium	0.10
Zinc	0.10
Chromium	0.10
Others, each	0.05
Others, total	0.15
Aluminum	Balance

Table 3.6: Physical Properties of Aluminum Alloy 6063

Property	**Value**
Density	2.70 g/cm^3
Melting Range	615-655°C
Modulus of Elasticity	69000 N/mm^2
Electrical Resistivity	0.033 x 10^{-6} O.m
Thermal Conductivity	202 W/m.K
Thermal Expansion	23 x 10^{-6} /K

Table 3.7: Mechanical Properties of Aluminum Alloy 6063

Temper	**Thickness (m)**	**Ultimate Strength**	**Tensile (Mpa)**	**0.2% Proof Stress (Mpa)**		**Elongation (%)**		**Hardness (Vickers)**
		Min	**Typical**	**Min**	**Max**	**Min**	**Typical**	**Typical**
T5	Up to 12.5	150	210	110	-	8	-	75
T6	Up to 3.20	205	230	170	-	8	-	80
	Over 3.20	205	230	170	-	10	-	-

3.4.2 Fiberglass

As mentioned before, aluminum needs reinforcement in order to increase their strength. Hence, for this project, fiberglass is used as a reinforcement agent to increase the strength of the structure of new chassis design. In this project, the weakest parts of aluminum structure of chassis are integrated with the fiberglass.

Like any material, fiberglass has advantages and disadvantages, but in applications such as corrosion, low volume production, very large parts, contoured or rounded parts and parts needing high specific strength, fiberglass is the material of choice. Fiberglass is a material which made from extremely fine fibers of glass. It is used as a reinforcing agent for many polymer products and resulting composite material known as fiber-reinforced polymer (FRP) or glass-reinforced plastic (GRP). It's called as fiberglass due to popular usage. Fiber reinforced polymer (FRP) composites are thin laminates that are externally bonded to structural members using epoxy adhesive. The FRP significantly increases the members' load carrying capacity. These structural strengthening systems are made of high strength fibers (such as glass, kevlar, and carbon) embedded in a resin matrix. The resin protects the fibers, maintains their alignment, and distributes the loads evenly among them.

FRP has high degree of design flexibility. The practical uses of FRP are virtually endless. Its unique physical properties allow it to be easily tooled, molded and manufactured to meet almost any specifications. Because there are few constraints on size, shape, color or finish, the styling and appearance can take precedence over manufacturing costs. This design freedom and the easiness to work make FRP an economical alternative for the manufacture of any component or finished product in any quantity. Basically, there are several types of glass fiber. Table below shows the comparison of typical properties between the types of glass fiber.

Table 3.8: Typical properties and the mechanical properties of some common fiber

Materials	Density (g/cm^3)	Tensile Strength (MPa)	Young Modulus (GPa)
E-Glass	2.55	2000	80
S-Glass	2.49	4750	89
Alumina (Saffil)	3.28	1950	297
Carbon	2.00	2900	525
Kevlar 29	1.44	2860	64
Kevlar 49	1.44	3750	136

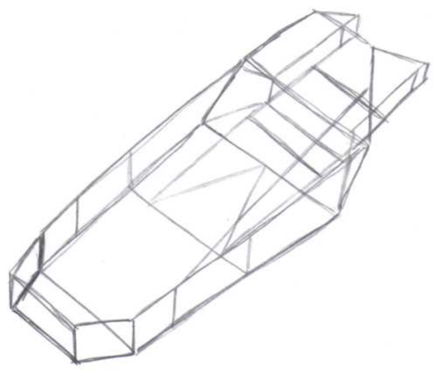
For this project, E-glass fiber type is used for the development of chassis design. E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass. Some other materials may also be present at impurity levels. The properties that have made E-glass so popular in fiberglass and other glass fiber reinforced composite include low cost, high production rates, high strength, and high stiffness, relatively low density, and non-flammable, resistant to heat, good chemical resistance, relatively insensitive to moisture, able to maintain strength properties over a wide range of conditions and good electrical insulation.

3.5 SOLIDWORK MODELING

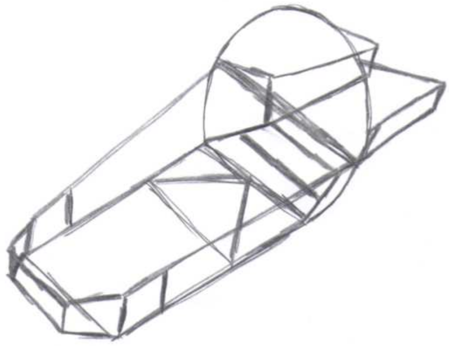
Before get the final chassis design, several steps should be considered in order to get the best design. For this part, SOLIDWORK 2009 is used to create the model of the several chassis which proposed for the new design. Below explains how the modeling chassis design is performed.

3.5.1 Sketching

The rough idea of the new chassis design is described by sketching the chassis. The criteria's that must be considered in the sketching process are the shape of chassis, dimensions which provided in Shell Eco Marathon's rule and regulation, and the specification of previous design. Figure below shows the three sketching of the new chassis design.



(a)



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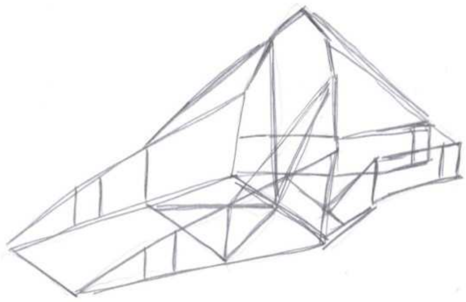


(c)

Figure 3.12: (a) Sketching 1, (b) Sketching 2, (c) Sketching 3

3.5.2 Modeling

After sketching for rough idea of chassis, next step is modeling process. Modeling process is a step of model the chassis using Solidwork software according to the actual size. The process for modeling a single tube in Solidworks is relatively simple. By using the weldments structural member feature, it is possible to quickly and simply create a model of a tube, and trim connecting tubes to fit precisely onto each other. The first step is to add the specific profiles of the tubes being used. There are have the cross sectional drawings of tubes. Then the centerline of the tube can be sketched in Solidworks. Then by using the weldments tool, the profile can be extended to create 3D model of the tube with the appropriate diameter, wall thickness, and geometry. The criteria's that must be consider in modeling the chassis through Solidwork are the rules and regulations which required by Shell Eco Marathon. To make a modeling process more easily, all the dimension of the existing chassis is referred. Figure 3.13 shows the criteria which must followed in the modeling process.

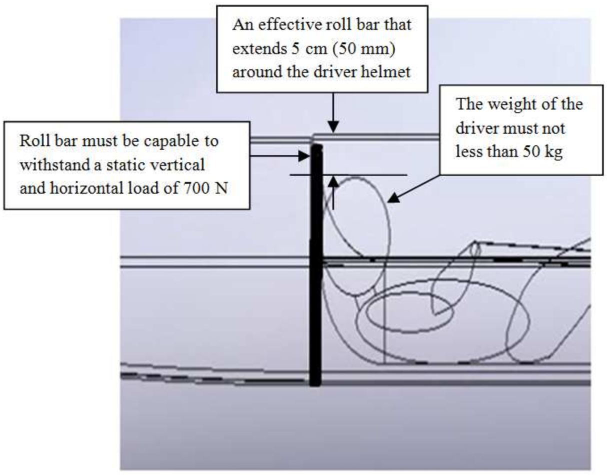
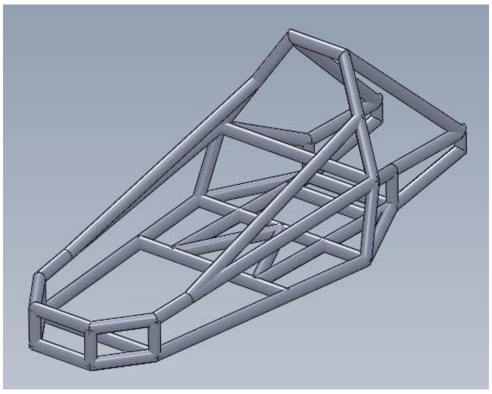


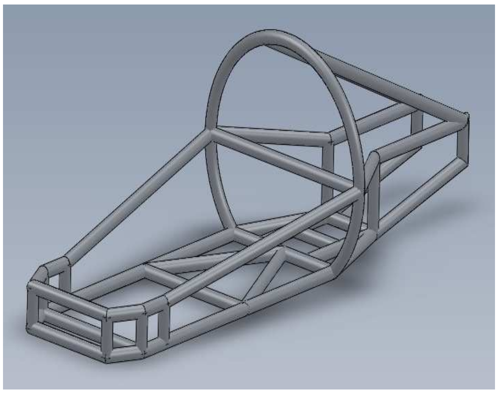
Figure 3.13: Regulations related to the front and main roll hoops and bracing

Source: Shell Eco Marathon, Official Rules 2010, Article 21 & Article 27

Figure shows the three proposed model of the new chassis design which done by Solidwork.



(a)



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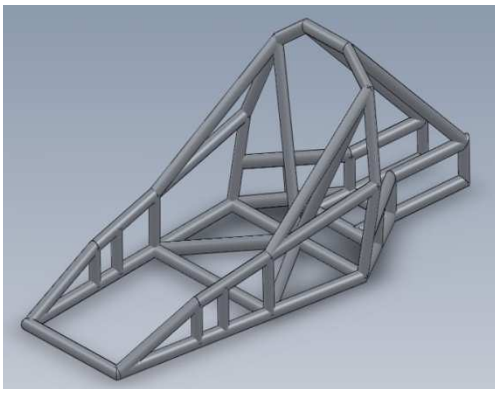

(c)

Figure 3.14: (a) Model 1, (b) Model 2, (c) Model 3

3.6 Summary

Chapter 3 discuss about the existing chassis design of Shell Eco Marathon 2010. From the analysis, result obtained shows that existing design using AISI Type 304 Stainless Steel able to withstand load applied. Eventhough the structure is able to withstand with the load applied but the weight of the structure is not effective and will effect to the drag force. The result of displacement, axial stress and worst stress is observed and the value obtained is small. The result of analysis of existing design will be compared with the result from analysis of new chassis design in Chapter 4.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter discuss about the result collected from the analysis of the new design of three wheel prototype car chassis. The objective of this chapter is to determine which one is the best design of chassis frame among the 3 design that proposed.

4.2 ANALYSIS OF NEW CHASSIS DESIGN

There are 3 new designs of prototype car frame which designed related to the specifications that required from the rules and regulations of Shell Eco Marathon competition. All 3 designs were tested and analyzed using the ALGOR 23.1 software. The objective of the analysis is to observe the parameters which related to the mechanical deformation of the chassis.

The parameters that want to be observe such as the formation of the chassis when load applied, and the stress of the chassis structure. This analysis will be focusing on the roll bar test and load test from the driver and engine compartment. Figure below shows the three new designs and technical specification of each design.

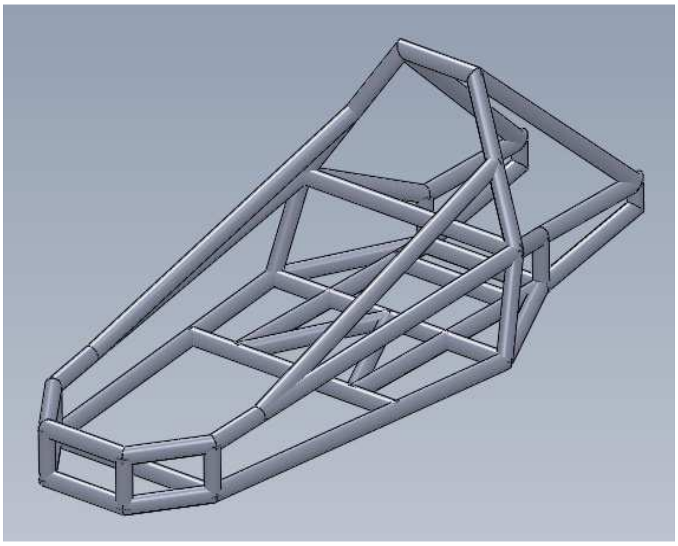

Figure 4.1: Design 1

Table 4.1: Technical specifications of design 1

Configuration	**3 wheels**	
Weight	100 N	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Roll bar	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Lower side impact member	1.5”x0.0472” (38.1x1.2mm) (round tube)
Reinforcement	E-Glass Fiber	3.0 mm thickness

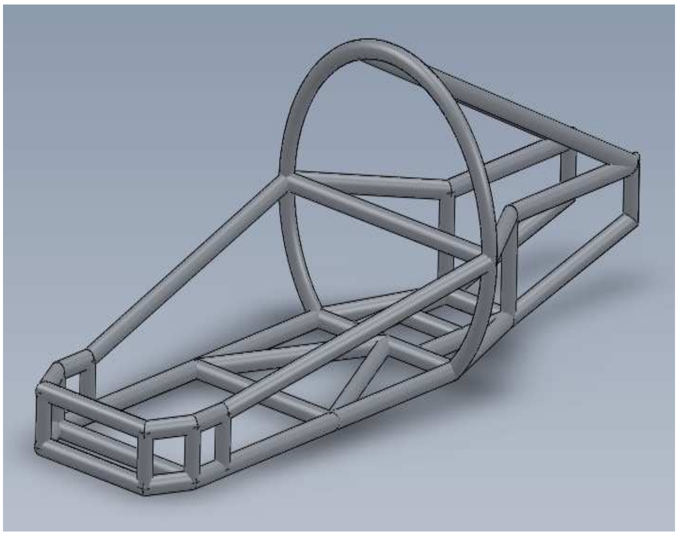

Figure 4.2: Design 2

Table 4.2: Technical Specifications of design 2

Configuration	**3 wheels**	
Weight	86.554 N	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Roll bar	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Lower side impact member	1.5”x0.0472” (38.1x1.2mm) (round tube)
Reinforcement	E-Glass Fiber	3.0 mm thickness

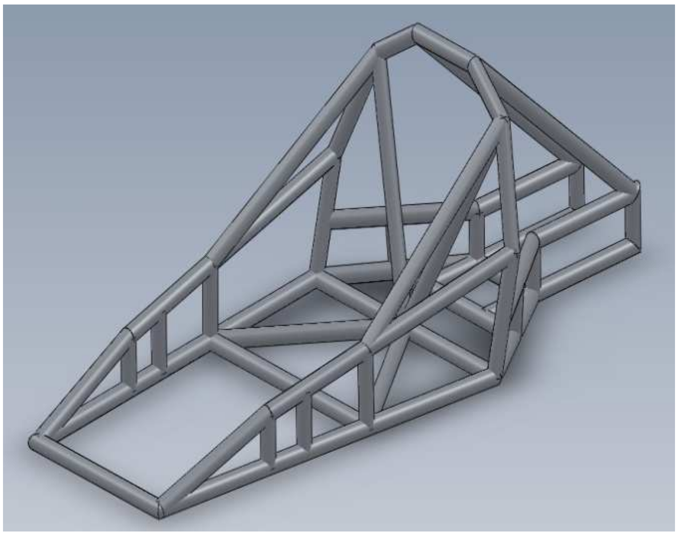

Figure 4.3: Design 3

Table 4.3: Technical specifications of design 3

Configuration	3 wheels	
Weight	84.38 N	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Roll bar	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Lower side impact member	1.5”x0.0472” (38.1x1.2mm) (round tube)
Reinforcement	E-Glass Fiber	3.0 mm thickness

4.2.1 Finite Element Analysis of New Design

The new design of the three wheel prototype car chassis is the development of the previous design structure. The goal of the development is to get the result of light in weight of chassis structure other than observing the displacement magnitude and worst stress.

The analysis conducted for the three new designs which proposed are same as analysis done for the existing design. The material used is different from previous design which is Aluminum Alloy 6063-T6. The specified structural boundary conditions are applied to the model. The chassis is fixed in all x, y, and z direction at the front and rear tyre connection. Fix point represent the mounting of the tyres.

A force F = 500 N is applied to the driver compartment while force F = 50 N is applied to the engine compartment. Force act to the driver compartment is consider to be 500 N cause for the minum weight of driver same as the previous analysis. The fiber is coated to the lower side impact member in order to reduce the bending of the chassis structure. Figure below shows the force act on the chassis structure, fiber coating section and fixed point.

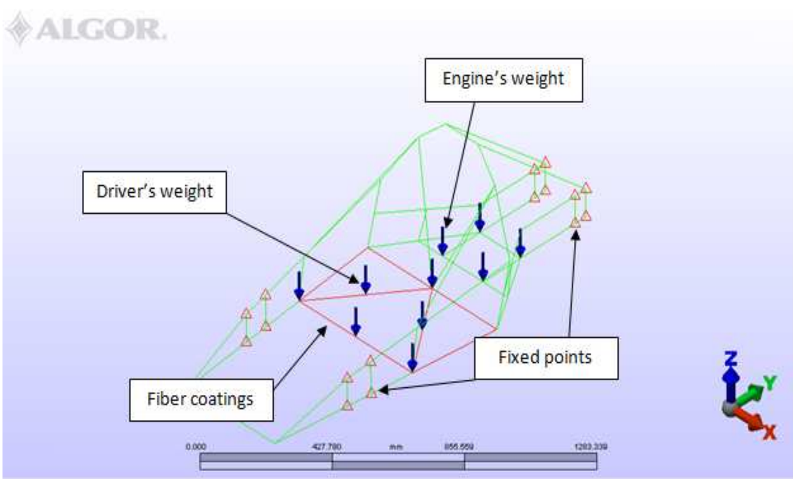

Figure 4.4: Applied force, fiber coating and fix point of structure

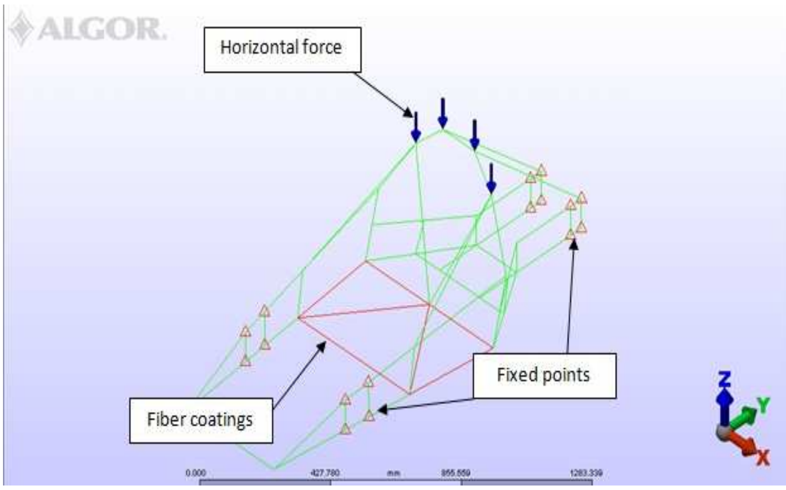

Figure 4.5: Horizontal force, fiber coatings and fixed points

4.2.2 Roll Bar Test

Tables and figures below show the result from the analysis of the chassis roll bar test respectively using ALGOR V23.1 for frame design 1, 2 and 3.

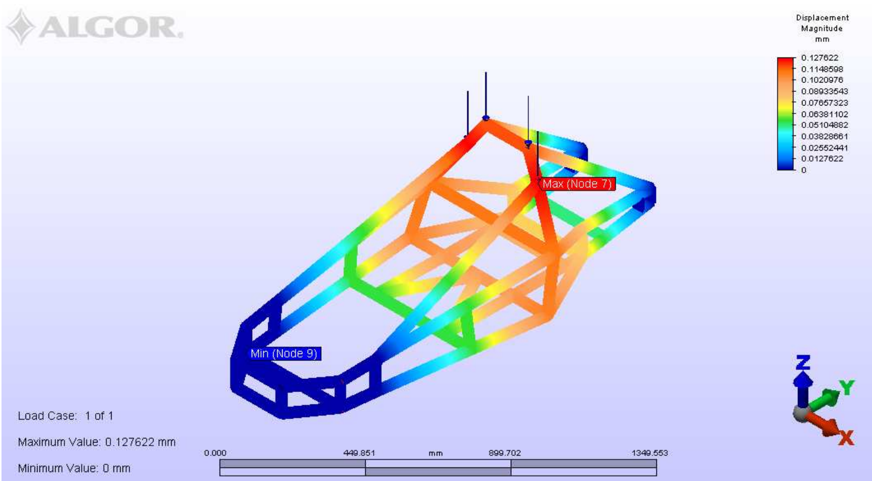

Figure 4.6: Roll bar testing for design 1

Figure above shows the force acting on the roll bar of chassis design 1. Result of the analysis shows that chassis 1 undergoes bending which is about 0.127622 mm and that is the maximum value of the bending occur on the roll bar of the chassis structure.

Maximum bending occurs at the red region of the figure analysis and the minimum bending occurs at the front box of the structure and labeled with blue region. The minimum bending is about 0.0127622mm. The section of the structure which undergoes maximum bending is at the connection between the roll bar and the support member. This section is directly subjected to the force and this section is the main sections which are responsible to the impact when the car is roll over.

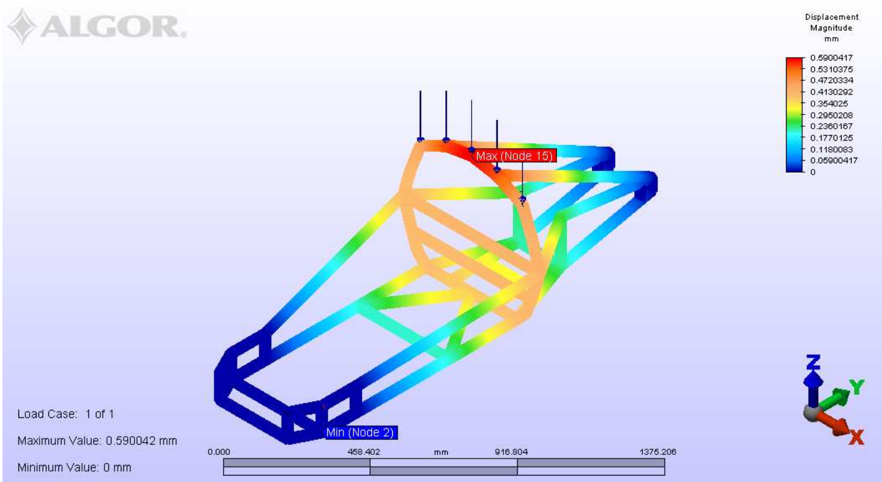

Figure 4.7: Roll bar testing for design 2

Figure above shows the result of the analysis of the roll bar of chassis design 2. When load 700N applied vertically on the roll bar of the structure, 0.5900417 mm bending occurs on the top of the roll bar. Chassis design 2 has higher bending compare to the chassis design 1. This result obtained due to the support member which attach to the roll bar. Chassis design 2 has less roll bar support from the driver compartment compare to the chassis design 1. The force acting on the roll bar of chassis structure will distribute through the roll bar to the support member. The magnitude of the force will distribute equally to the support member which attached on the roll bar. Its means that the more support member attached to the roll bar, the less force acting to each support member. Chassis design 2 has not enough support members so then the force acting to each member will high. Then the roll bar will not able to withstand the force applied. Consequently roll bar of chassis design 2 undergoes bending more than chassis design 1.

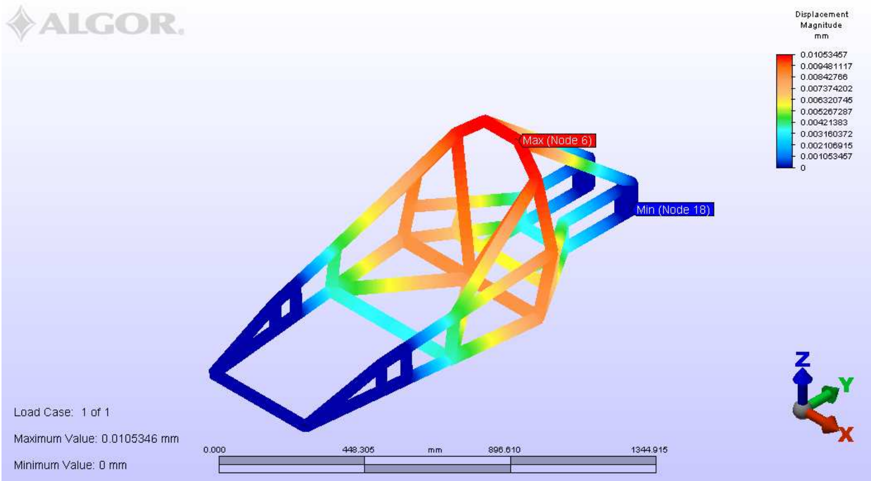

Figure 4.8: Roll bar testing for design 3

Figure above shows the result from the analysis of chassis design 3. The structure of chassis undergoes less bending compared to the chassis design 1 and 2. The magnitude of the bending occurs on the roll bar of chassis design 3 is 0.010535 mm. Chassis design 3 has minimum bending on the structure due to the strategically arrangement of the support members.

Table 4.4: Roll bar Test

TESTING	**CHASSIS**		
	1	**2**	**3**
Max. Displacement (mm)	0.127622	0.590042	0.010535
Max. Axial Stress (N/mm^2)	1.078853	3.858648	0.043560
Max. Worst Stress (N/mm^2)	5.542724	15.788766	0.342339

Roll bar analysis is basically analysis which roll bar been pressurized with 700 N force according to the technical regulation for Shell Eco Marathon 2010. This testing is important because it will test about strength of the material used and displacement after the impact can injure the driver or not.

From the analysis above shows that each chassis design have different results for each pattern according to the structure welded and also the weight of chassis. Chassis 3 shows the minimum displacement of the chassis structure when load apllied on the roll bar which is 0.010535 mm followed by chassis 1 which is 0.127622 mm and chassis 2 which is 0.590042 mm. This is because the structure of chassis 3 more strong compares to chassis 1 and 2. The force at the roll bar will exert more expanding on the other area than a smaller size which has a small area for force to exert on. Also the maximum axial stress is small for the chassis 3 due to the support member connect to the roll bar. Biggest size of round tube also make the maximum axial stress more small compare to the smallest size of round tube which has bigger maximum axial stress and strain.

However there are certain major decrease of weight chassis which is cause by the material that been welded on the side impact structure is smaller than the base frame ones. Although there are major difference in term of the weight of chassis but in term of maximum displacement give a minor difference to the other chassis. This pattern also can be applied to the other parameters.

From this we can see frame design 3 give a smallest maximum displacement on the roll bar compare to the other 2 frame designs. Moreover the weight of frame design 2 is lightest compare to the other 2 designs. The recommended frame design to use for roll bar testing is chassis frame 2 because it provides smallest displacement on chassis structure compare to chassis frame 1 and chassis frame 2.

4.2.3 Driver and Engine Compartment Testing

Tables and figures below show the result from the analysis of the driver and engine compartment test respectively using ALGOR V23.1 for frame design 1, 2 and 3.

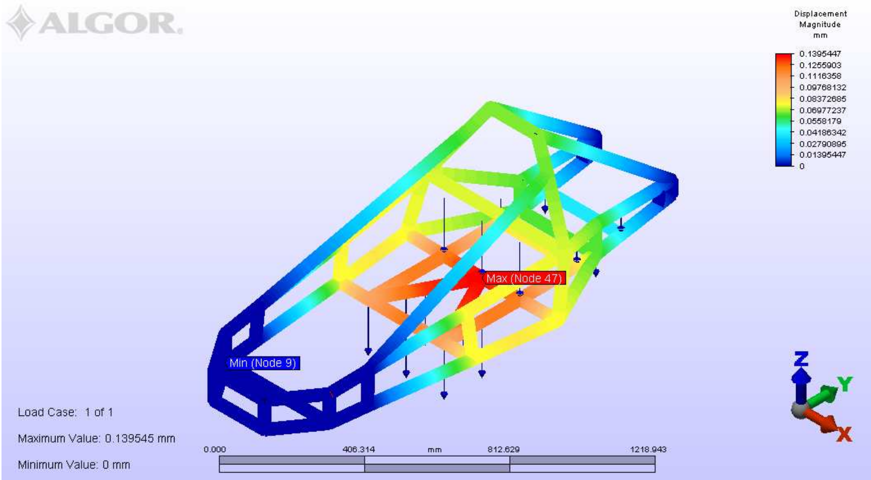

Figure 4.9: Driver and Engine Compartment testing for chassis 1

Figure above shows the analysis of the driver and engine compartment of chassis design 1. Results obtained reveal that the structure of chassis design 1 undergoes bending which is 0.1395447 mm. The displacement mainly focused underneath driver compartment. This is due to the long side beams provide ample support for side and back of driver. Therefore, displacement is equally distributed.

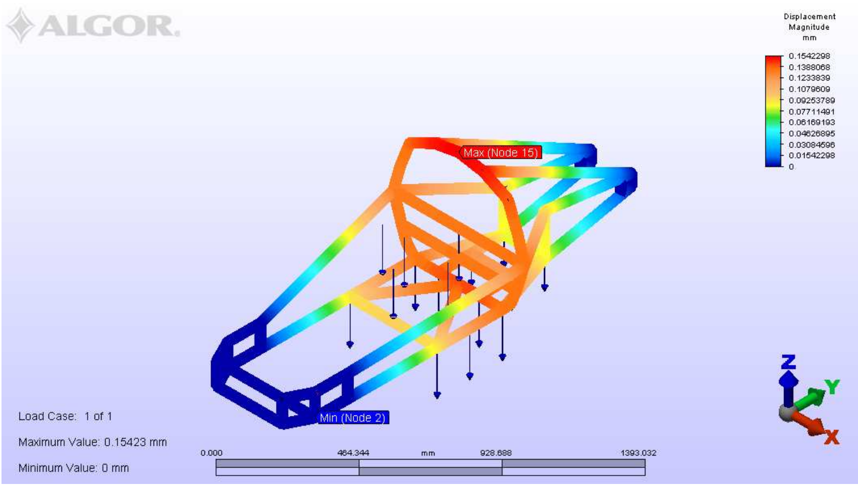

Figure 4.10: Driver and Engine Compartment testing for chassis 2

Chassis design 2 undergoes maximum bending at the roll bar when load was applied on the engine and driver compartment. The magnitude of the displacement is

0.1542298 mm and the displacement is more than displacement occurs on the chassis design 1. This is due to the location between engine and driver compartment. The location of engine for chassis design 2 is nearer to driver compartment compare to the chassis design 1. The load applied was focused on the same point of the structure. Hence the loads will not distribute equally along the side member. Consequently, the displacement focused on the centre of the chassis.

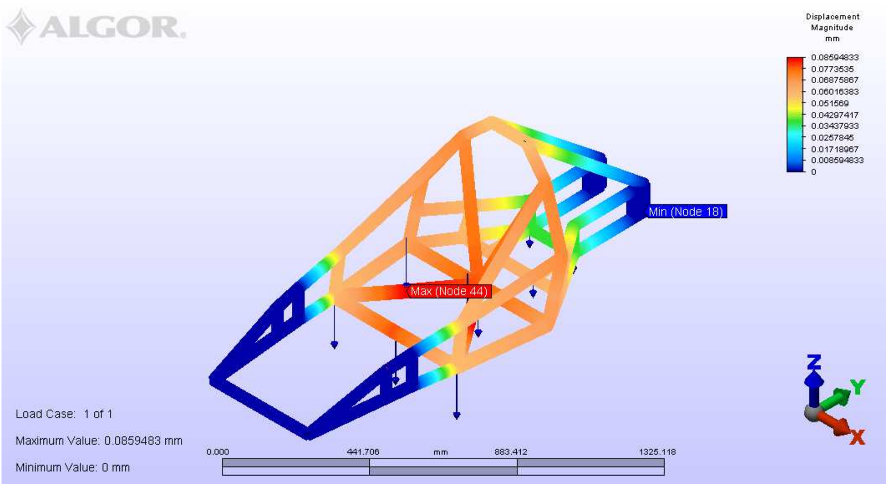

Figure 4.11: Driver and Engine Compartment testing for chassis 3

Figure above shows the result from the analysis of chassis design 3. The magnitude of the bending occur when load 500N applied on the driver compartment and 50N applied on the engine compartment of the chassis structure is 0.085948 mm. Central part of the chassis structure bears most load due to existence of shorter side members. Therefore the displacement could not be distributed in a greater way compared to having long side beams

Table 4.5: Load from engine and driver compartment test

TESTING	CHASSIS		
	1	**2**	**3**
Max. Displacement (mm)	0.139545	0.154230	0.085948
Max. Axial Stress (N/mm^2)	0.939657	1.476046	0.584645
Max. Worst Stress (N/mm^2)	6.799791	4.458775	8.586575

Table above shows that the lowest value of maximum displacement when load at driver compartment and engine compartment is applied is occur at chassis 1 which is 0.139545 mm followed by 0.15423 mm chassis 2 and 0.085948 mm chassis 3.

From the results shown in the figures, the new chassis design is build with a simple structure compared with the existing design. The decision of proposing a simple design is made after considering the rule and regulation during competition. The chassis of three wheel prototype car are not suggested to use suspension since the vehicle accelerates less than 30 km/hour. The vehicle only needs to consider the weight in order to increase the acceleration and decrease the fuel consumption.

Weight saving is important particularly for aircraft and aerospace structures, for automotive bodies and components, and for other products where energy consumption and power limitations are major criteria. Substitution of materials for the sake of weight saving and economy is a major factor in the design both of advanced equipment and machinery of consumer products such as automobiles.

4.3 RESULT

After analyzing the chassis structure, the final chassis will be chosen based on its characteristic and regulation required to compete in Shell Eco Marathon 2011. The best design of chassis must have lower value of maximum displacement in order to overcome the bending of the chassis structure. Furthermore, the weight of the best design chassis must light weight. It is important in order to avoid the drag force. Below are the specifications of the chassis design for three wheel prototype car proposed for Shell Eco Marathon Competition.

Table 4.6: Technical specification of design 3

Configuration	**3 wheels**	
Weight	84.38 N	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Roll bar	1.5”x0.0472” (38.1x1.2mm) (round tube)
	Lower side impact member	1.5”x0.0472” (38.1x1.2mm) (round tube)
Reinforcement	E-Glass Fiber	3.0 mm thickness

4.4 DISCUSSION

Design 3 is the best chassis design for the Shell Eco Marathon competition. The design follows the criteria which required from the rules and regulation of the competition. The design contributes lowest displacement of bending when load applied in the driver and engine compartment which is 0.085948 mm compare to the chassis design 1 and 2 which is 0.139545 mm and 0.15423 mm respectively. Furthermore, design 3 is a lightest chassis which is 84.38 N compare to design 1 and 2 which is 100 N and 86.554 N respectively.

Figure below shows the solidwork drawings of the best design model of three wheel prototype car for the next Shell Eco Marathon competition.

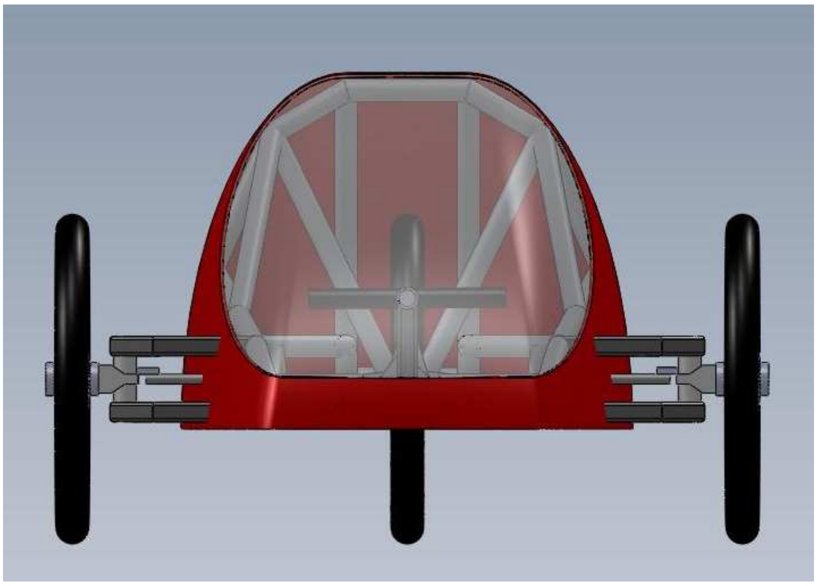

Figure 4.12: Front view

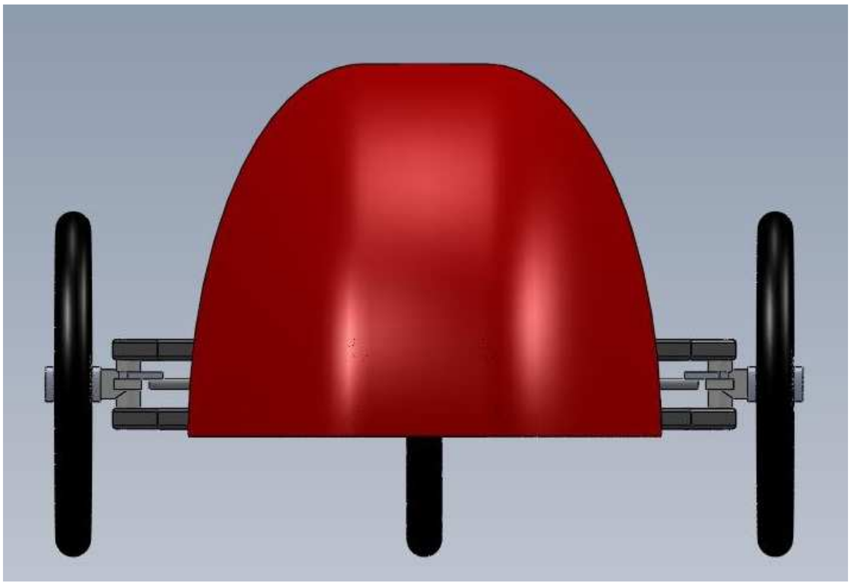

Figure 4.13: Rear view

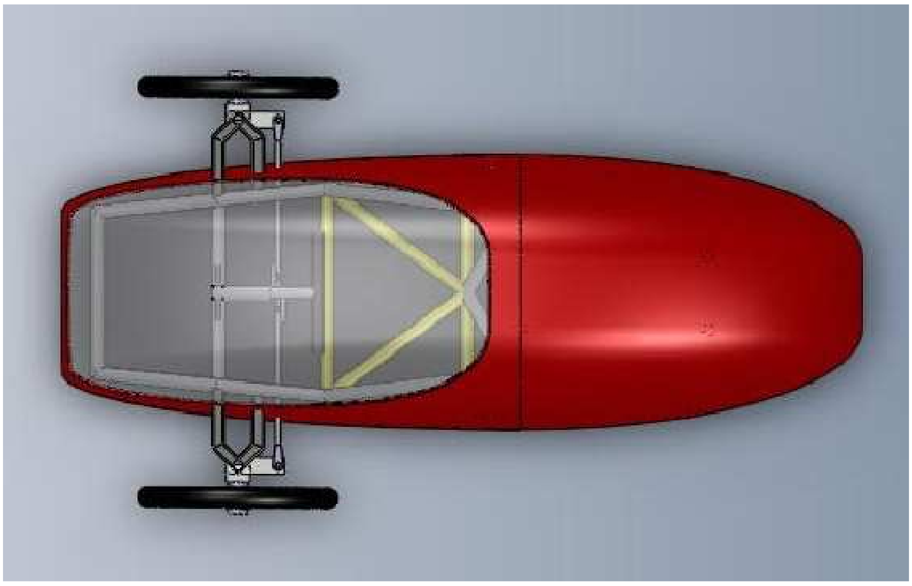

Figure 4.14: Top view

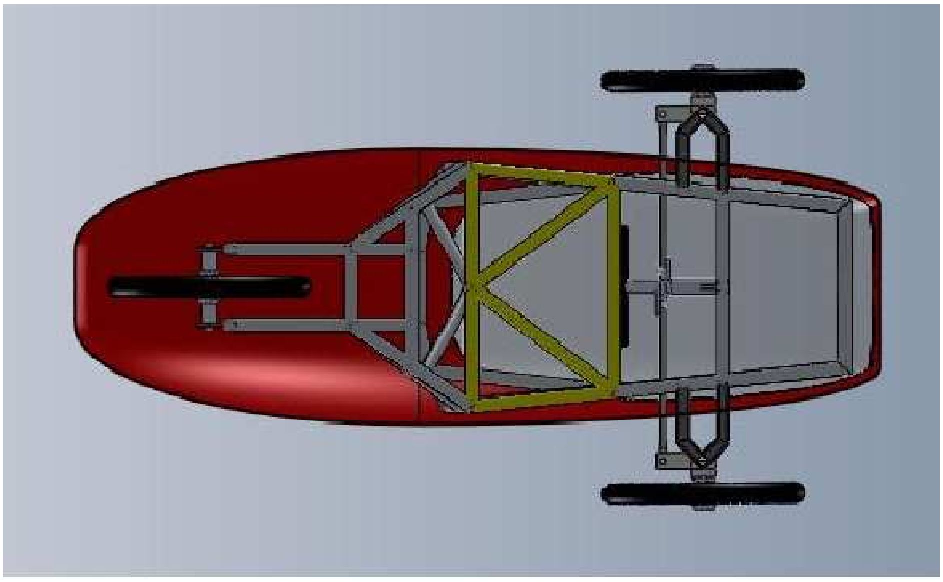

Figure 4.15: Bottom view

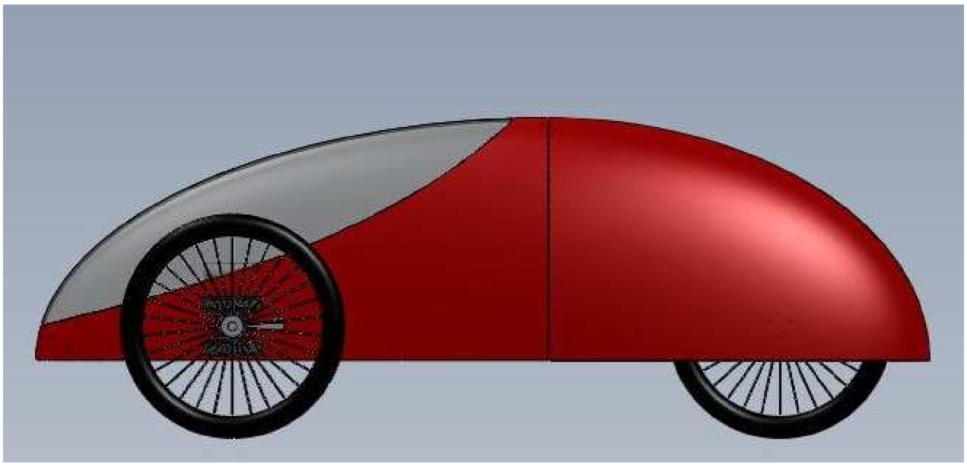

Figure 4.16: Left view

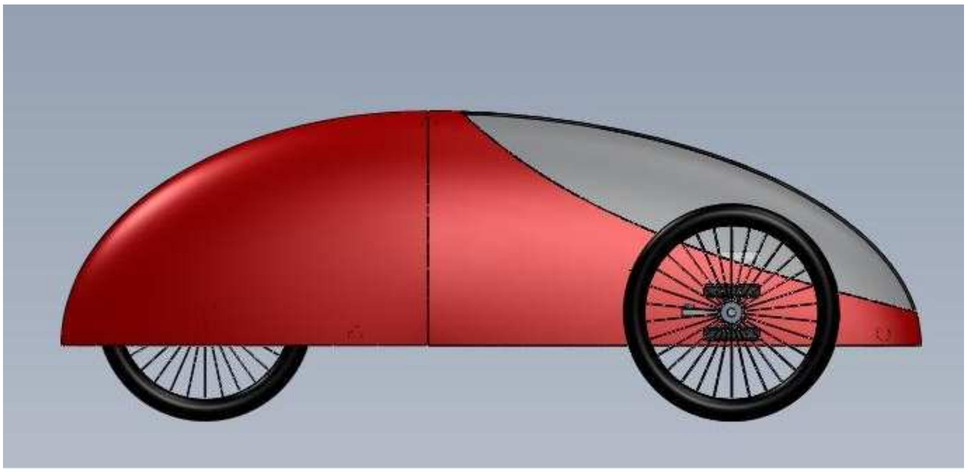

Figure 4.17: Right view

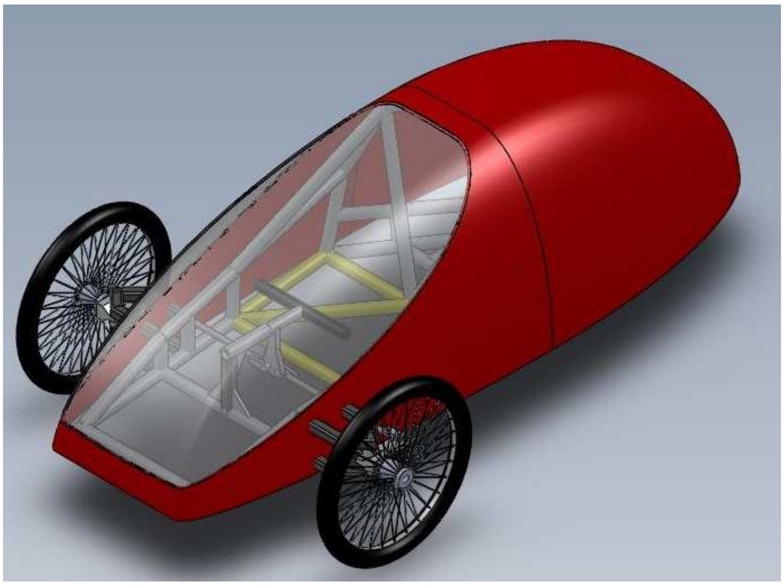

Figure 4.18: Isometric view

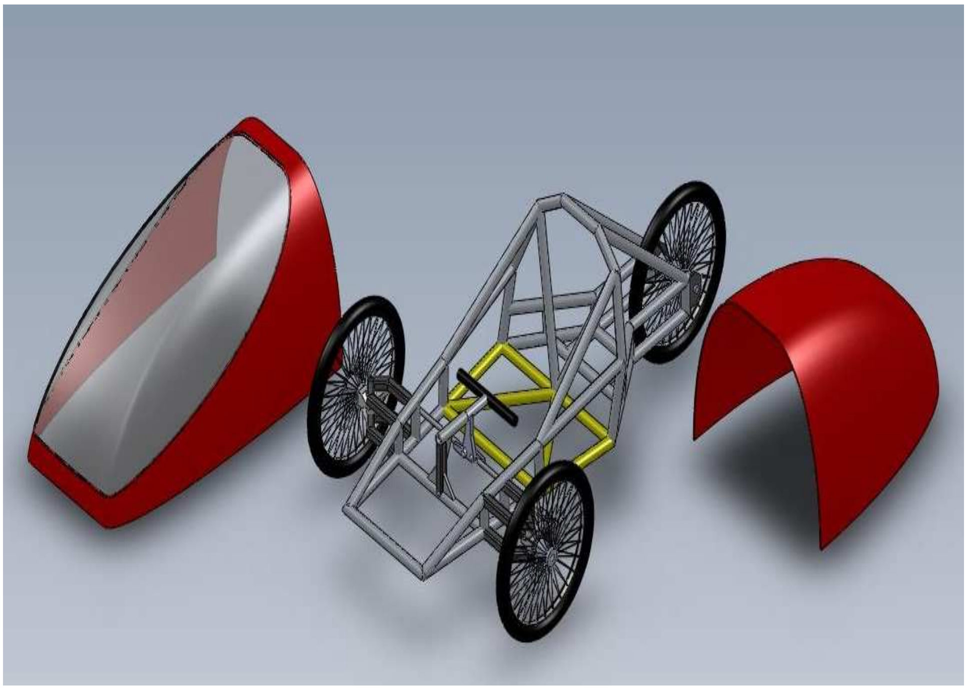

Figure 4.19: Exploded view

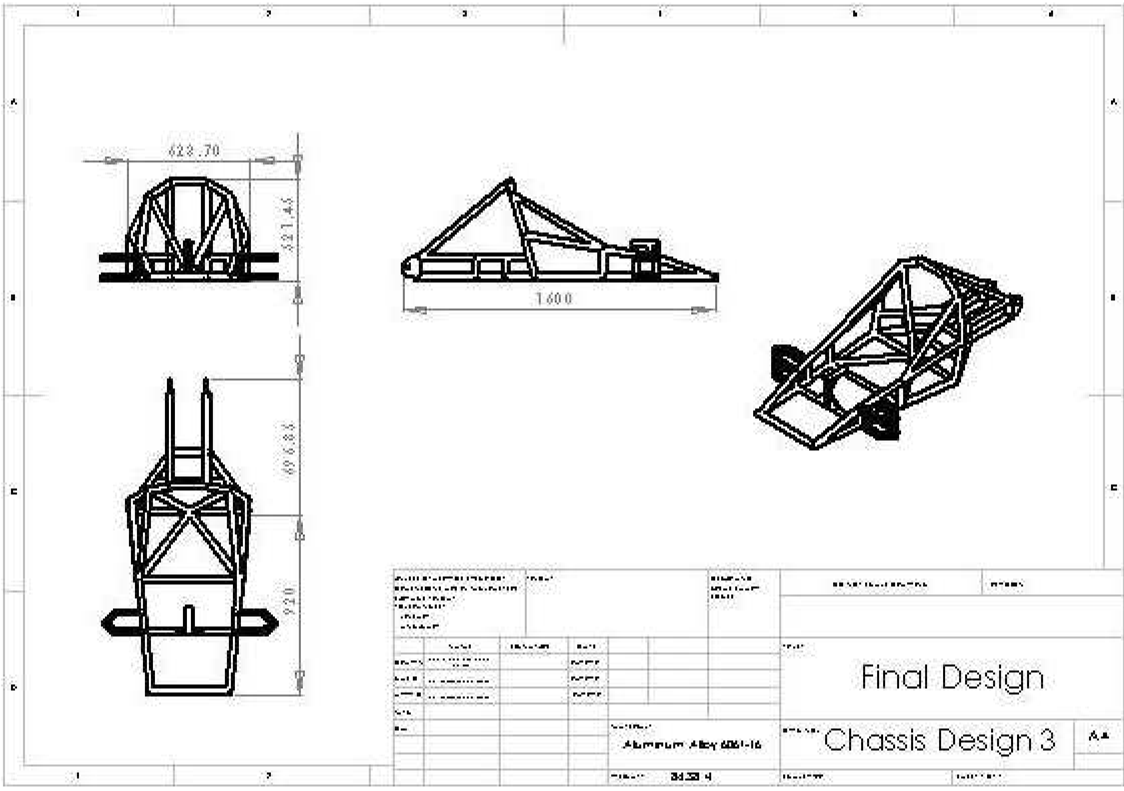

Figure 4.20: Blueprint of final chassis design

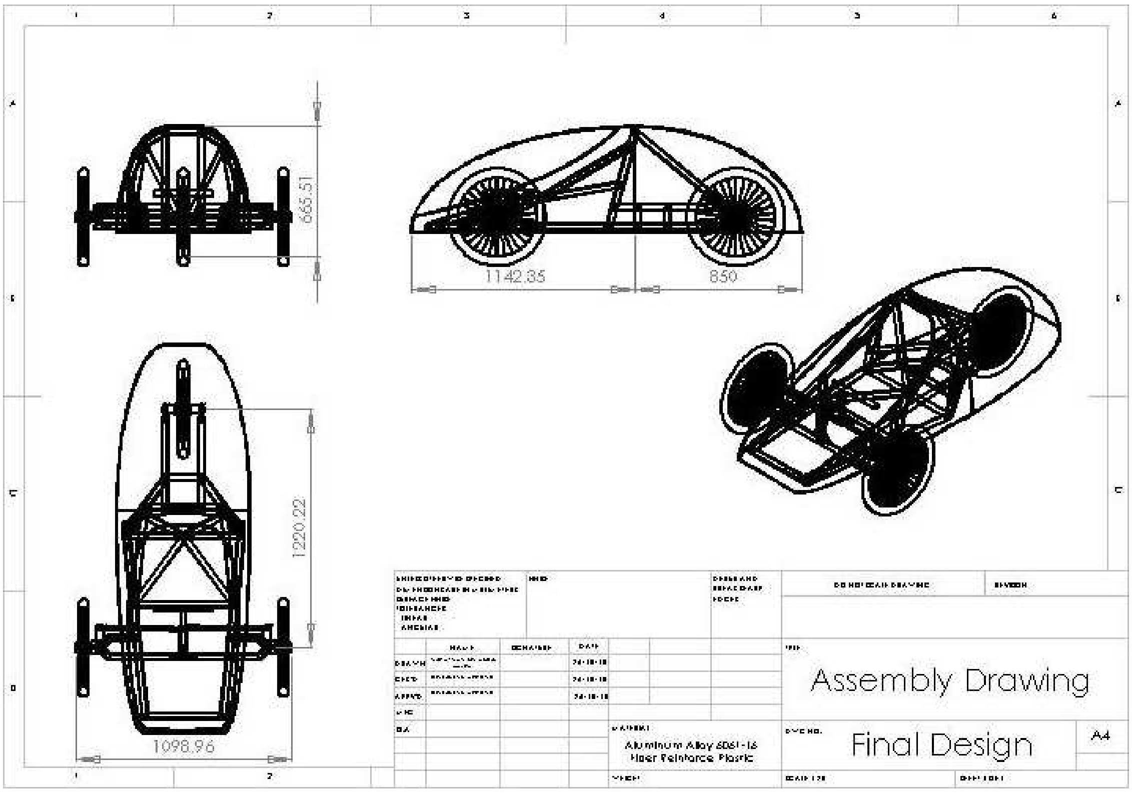

Figure 4.21: Blueprint of assembly drawing of final chassis design

4.5 Summary

This chapter discusses the result get from the analysis of new chassis design. After get the result, the decision of the final design are made. Chassis 3 is the best design proposed for the next Shell Eco Marathon competition due to the characteristics that it has. The design also follows the rules and regulations which required from the organizer.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of this study is to design and develop an integrated chassis for three wheel prototype car using aluminum and FRP. The analysis of the existing chassis was done in order the check the weakness of the chassis structure. The results from the analysis of the existing design were helping for the improvement of the new design. The objective of the project is to design and development of the three wheel prototype car for Shell Eco Marathon competition. The considered criteria's of the development is weight reduction and reducing the bending displacement of chassis structure. Comparison result shows that the new design is lightest than existing design and the bending of the structure of new design decrease. The objective of the project was achieved.

The best design of the three wheel prototype car is design 3. The design is a lightest design compare to another three design proposed. Besides that, the design has a minimum displacement of bending when the load applied to the chassis structure. Aluminum alloy 6063-T6 is a most suitable material used to the new design because the material has a high strength. Moreover, the specifications of the aluminum such the diameter required for the project is available and able to get in Kuantan area. Besides that, the cost for purchasing the aluminum is cheaper than other materials. The reinforcement of the fiber to the chassis structure was improving the strength of the structure. Reinforcement of the fiber contributes lower bending of the chassis structure with small increases of the chassis's weight. Both materials involved in this project are available in Kuantan area.

5.2 RECOMMENDATIONS

The design and technical specifications of the new chassis design shows that the final design of the chassis is not enough weight reduction. It means that, the weight of the structure is able to reduce stress as much as possible. Lightweight of the chassis structure will reduce the normal force acting on the car. Besides that, the bending displacements of structure also will decrease if the structure of the chassis is improved. Its means that by addition of round tube in triangulated format. The chassis will not easily deformed by bending force due to the triangulated format of frame.

Notice that when the number of the round tube increased, it will also increase the weight of the chassis. Hence the best way is to change the spaceframe type to monocoque chassis type. It is due to the strength that provided in the structure of monocoque is almost similar with the strength of spaceframe. But the cost of the construction is too expensive.

Another recommendation is using the aluminium that more lightweight and reinforced than the aluminium that been proposed like chromoly steel 4130 and Aluminium 7075. However this material is not been sold in ordinary market at Malaysia, so it need to be order and cost of required it is really high and need to be import from other country.

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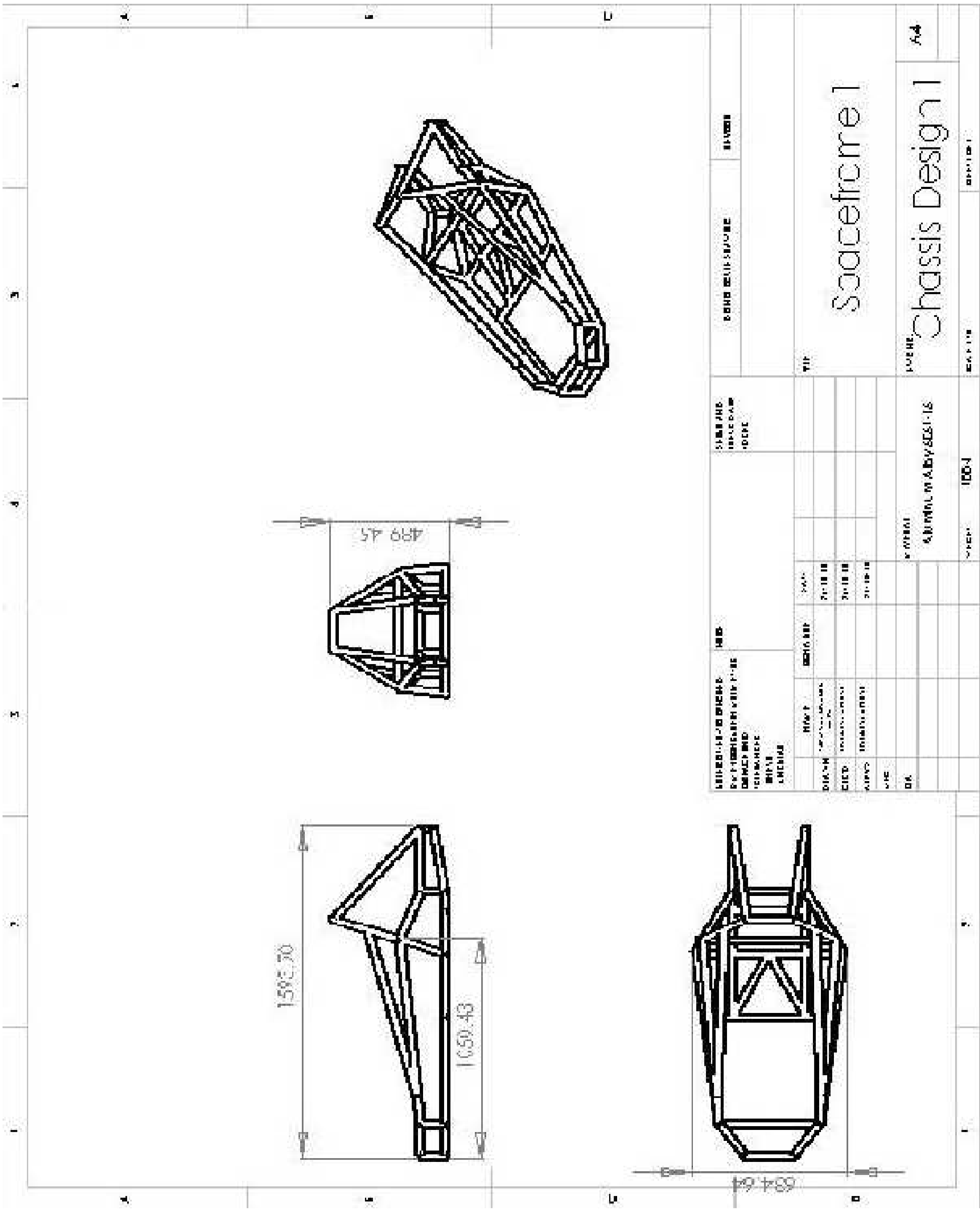
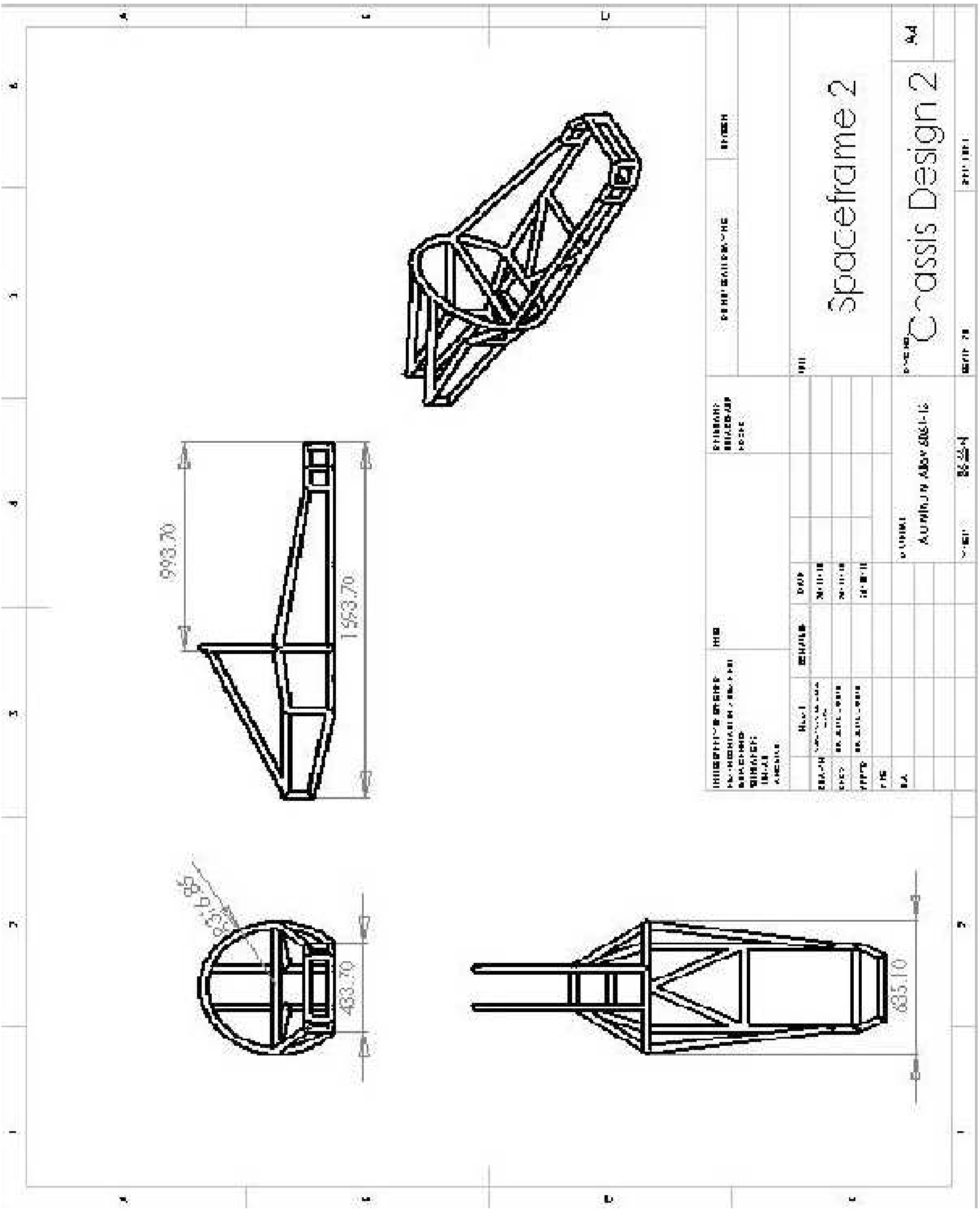
APPENDIX A1

BLUEPRINT CHASSIS DESIGN 1



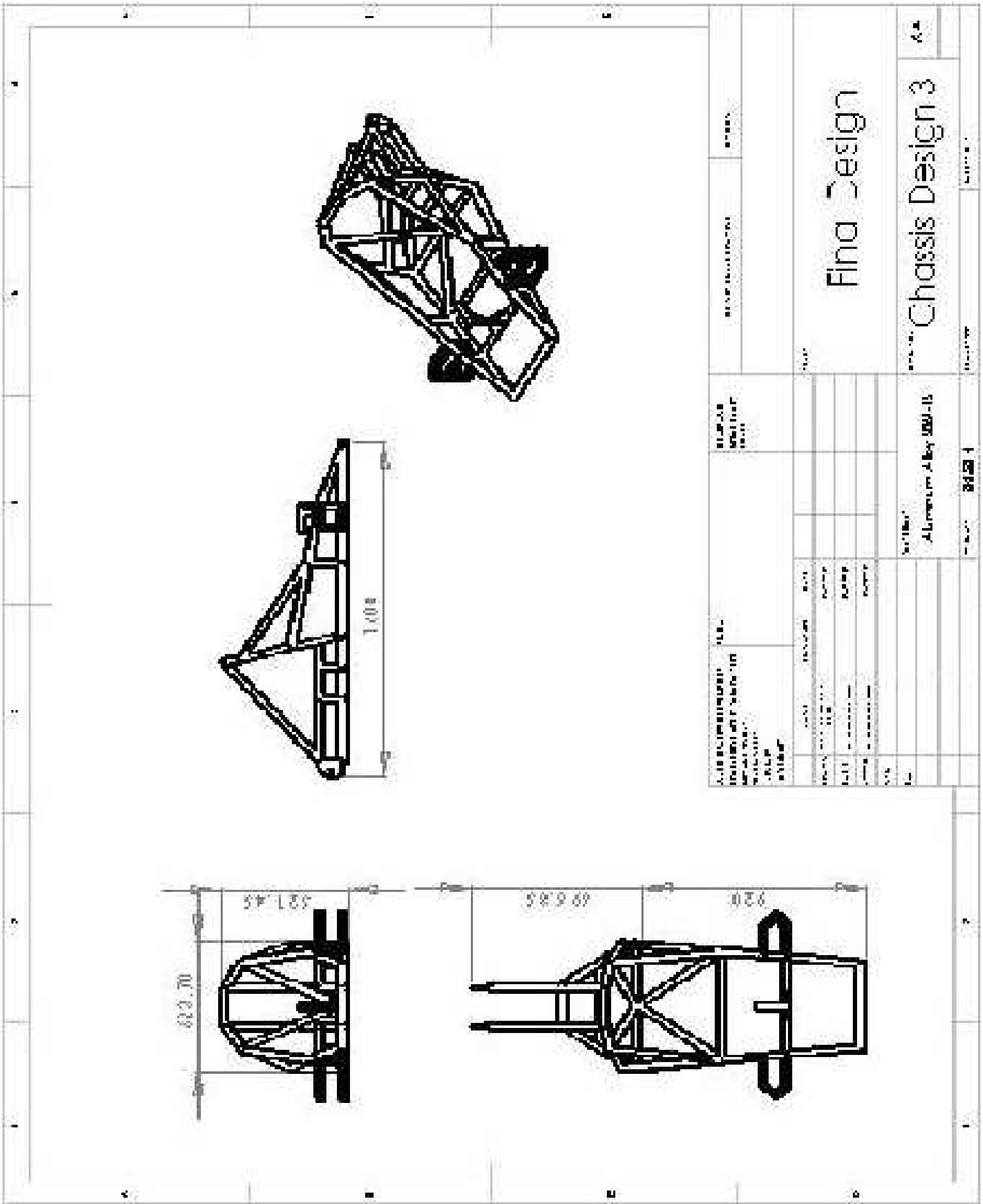
APPENDIX A2

BLUEPRINT CHASSIS DESIGN 2



APPENDIX A3

BLUEPRINT CHASSIS DESIGN 3



APPENDIX A4

BLUEPRINT FINAL DESIGN