DESIGN AND ANALYSIS OF THREE WHEEL PROTOTYPE CAR CHASSIS

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Thesis 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
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JUNE 2012

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.

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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

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ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisors Mr. Hadi Bin Abdul Salaam and Mr. Azim Bin Mohd Arshad 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.

Sincere thanks to all staff of the Mechanical Engineering Department, UMP, who helped me in many ways and providing equipment and information sources that assisted my studies and projects. To all my committee members, thanks for the comments and suggestions given which is crucial for the successful completion of this study.

Special thanks to my lovely parents Mr. Ramlan Bin Rumbili@Ramli and Mdm. Azizah Binti Musa, and family members 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 design and analysis of three wheel prototype car chassis for Shell Eco Marathon Asia 2012 competition. Base on the Existing Model, there have a few improvement to be done. First thing is to reduce the weight of the chassis where appropriate by designing more compact car. Secondly, this study also conduct to overcome the worst bending displacement where occur at driver cockpit, and lastly to provide extra large engine spaces where the Existing Design only have very limited spaces. Corresponds to the project background and problem statements, it is decided that the objectives of the project are to analyze and improve the existing car chassis based on Shell Eco Marathon Asia 2012 requirement, to redesign and proposed new chassis of prototype car which able to withstand the load applied on the chassis structure with minimum bending displacement, and to simulate the design using FEA software. The Project scopes are to study the concept of prototype car category for Shell Eco Marathon Asia 2012 Event, and evaluating with analysis the existing car design for previous competition. This project also covers to redesign three optional chassis of prototype car for Shell Eco Marathon Asia 2012, to analyze the optional chassis using FEA software, requirement to study was focus on static condition and stress simulation analysis only, and to select the best option which is capable to be fabricated at UMP. Three different chassis models have been designed by using Solidwork 2012. Then, analyzed by using Finite Element Analysis: Algor 23.1 software. Three parameters have been set up which are the weights of the chassis, the bending displacement of the chassis members, and the worst stress occurs on the chassis structure. The comparison result proves that the new proposed design in Model 2 is lighter than the Existing Model and the decrement is about 13.89% and the bending of the structure of new Design 2 was decreased too. Thus, the objectives of the project were achieved and the design has been proposed to Shell Eco Marathon Asia 2012 Team.

ABSTRAK

Tesis ini membentangkan tentang rekabentuk dan analisis mengenai rangka bersepadu kereta prototaip beroda tiga untuk pertandingan Shell Eco Marathon Asia 2012, Berdasarkan model sedia ada, terdapat beberapa penambahbaikan boleh dilakukan. Pertamanya adalah untuk mengurangkan berat rangka kereta dengan mereka bentuk kereta yang lebih padat. Kedua, projek ini bertujuan untuk mengatasi defleksi struktur yang paling teruk berlaku di ruangan pemandu, dan terakhir adalah untuk menyediakan ruang kawasan enjin yang lebih luas berbanding model yang sedia ada. Berdasarkan latar belakang projek dan pernyataan masalah, objektif untuk projek telah di buat iaitu untuk menganalisis dan menambahbaik rekabentuk chassis sedia ada berdasarkan ketetapan peraturan Shell Eco Marathon Asia 2012, untuk merekabentuk semula dan mencadangkan rekabentuk baru rangka kereta prototaip yang mampu menampung beban yang dikenakan ke atas struktur rangka dengan sesaran lenturan yang paling minimum, dan untuk simulasi rekabentuk dengan menggunakan perisian Finite Element Analysis (FEA) bertujuan memaksimumkan tahap kecekapan nisbah penggunaan minyak terhadap berat kereta tersebut. Antara skop projek adalah kajian tentang konsep untuk kategori kereta prototaip pertandingan Shell Eco Marathon Asia 2012, dan penilaian serta analisis rekabentuk model sedia ada untuk pertandingan yang lalu. Projek ini juga merangkumi merekabentuk semula tiga pilihan rangka kereta prototaip, menganalisis dengan menggunakan perisian Finite Element Analysis (FEA), keperluan untuk kajian hanya pada keadaan pegun dan simulasi tekanan sahaja, dan pemilihan yang terbaik dicadangkan mampu di bina di UMP. Tiga rangka model berbeza telah di rekabentuk dengan menggunakan perisian Solidwork 2012. Kemudian, dianalisis menggunakan perisian Algor 23.1. Tiga parameter ditetapkan untuk di analisis iaitu berat setiap rangka kereta, lenturan sesaran pada struktur rangka kereta, dan tekanan paling teruk berlaku di bahagian struktur rangka kereta. Keputusan dari perbandingan setiap model menunjukkan bahawa rekabentuk model 2 adalah paling ringan berbanding rekabentuk sedia ada iaitu dengan pengurangan sebanyak 13.89% dan struktur yang mengalami lenturan juga berkurangan. Kesimpulannya, objektif untuk projek ini berjaya dicapai dan rekabentuk Model 2 telah dicadangkan kepada pasukan Shell Eco Marathon Asia 2012.

TABLE OF CONTENTS

		Page
SUPERVISOR'S DECLARATION		ii
STUDENT'S DECLARATION		iv
DEDICATION		v
ACKNOWLEDGEMENTS		vi
ABSTRACT		vii
ABSTRAK		viii
TABLE OF CONTENTS		ix
LIST OF TABLES		xiii
LIST OF FIGURES		xiv
LIST OF SYMBOLS		xvi
LIST OF ABBREVIATIONS		xvii
CHAPTER 1	**INTRODUCTION**	
1.1	Project Background	1
1.2	Problem Statement	2
1.3	Objectives of The Project	3
1.4	Scopes of the Project	3
1.5	Expected Outcomes	3
1.6	Structure Of Thesis	4
CHAPTER 2	**LITERATURE REVIEW**	
2.1	Introduction	5
2.2	Shell Eco Marathon Asia 2012 Official Rules For Car Chassis Design.	5
	2.2.1 Vehicle Design	6
	2.2.2 The Body Requirements	6
	2.2.3 Aerodynamics	7
	2.2.4 Chassis Design	13
	2.2.5 The Chassis Requirements	14

2.3	Design Consideration of Chassis		14
	2.3.1	Determination of Chassis	14
	2.3.2	The Chassis Systems	15
	2.3.3	Chassis Description	15
	2.3.4	Component Restraints	17
2.4	Types of Chassis		18
	2.4.1	Backbone Chassis	18
	2.4.2	Ladder Frame Chassis	19
	2.4.3	Monocoque Chassis	20
	2.4.4	Semi Monocoque Chassis	22
	2.4.5	Space frame Chassis	23
2.5	Material Selection		25
	2.5.1	Alloy Steels	25
	2.5.2	Aluminium	27
2.6	Use of Cad And FEA Software		30
2.7	Conclusion		30

CHAPTER 3 PROJECT METHODOLOGY

3.1	Introduction		31
	3.1.1	Criteria of Good Chassis	34
	3.1.2	Analysis Comparison Result	35
3.2	Prototype Construction Of Chassis Frame		35
	3.2.1	Construction The Mock Up Model	36
	3.2.2	Driver Test Fit	40
3.3	Three Improved New Model For SEMA12		41
	3.3.1	Sketching The Chassis	41
	3.3.2	Modeling The Design	43
3.4	Technical Specifications Of New Models		45
3.5	Finite Element Analysis Of New Design		47
3.6	Load Applied on The Chassis		48
	3.6.1	Determination of Loads	48
	3.6.2	Static Load Paths	48
	3.6.3	Dynamic Load Paths	49
	3.6.4	Torsional Braking Loads	50
	3.6.5	Defined Loads	51

3.7 Stresses Criteria 52

3.7.1 Axial Stress 54
3.7.2 Deflection 56
3.7.3 Bending 56
3.7.4 Stress Analysis 57

3.8 Material Specification For New Design 58

3.9 Conclusion 59

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Introduction 60

4.2 Analysis Of Existing Chassis Using Finite Element Analysis 60

4.2.1 Discussion Based On The Analysis Of Existing Designs 64

4.3 Analysis Of Three Improved Chassis Designs 64

4.3.1 Analysis On Model 1 65
4.3.2 Analysis On Model 2 67
4.3.3 Analysis On Model 3 69

4.4 Result 71

4.5 Discussion 72

4.6 Conclusion 73

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion 74

5.2 Recommendations 75

REFERENCES 76

APPENDICES

A Comparison Between Most Popular Types of Chassis Car 77

B Summary on References Related to Project 78

C1 Blueprint Chassis Design 1 81

C2 Blueprint Chassis Design 2 82

C3 Blueprint Chassis Design 3 83

D Gantt Chart for Degree Final Year Project 2011/2012 84

E Calculation for Force Acted on the Body 86

LIST OF TABLES

Table No.	Title	Page
2.1	Standard Dimension Specified By Organizer	6
2.2	Drag Force in Relation to Drag Coefficient at Different Speeds	11
2.3	Work in Relation to Drag Coefficient at Different Speeds	12
2.4	Chemical compositions of some Alloy Steels.	26
2.5	Mechanical properties based on AA standard.	28
2.6	Typical Composition of Aluminium Alloy 6063.	29
2.7	Physical Properties of Aluminium Alloy 6063.	29
2.8	Material properties of Aluminium Alloy 6063-T6.	29
3.1	Technical specifications for Design 1.	46
3.2	Technical Specifications of Design 2.	46
3.3	Technical Specifications of Design 3.	47
3.4	Estimate Total Mass of Vehicle.	51
3.5	The related mass and respect material usage upon the Existing Design.	53
4.1	Technical specification of Existing Design for SEMA11.	62
4.2	The information was generated by Algor 23.1 Features for Existing Model	63
4.3	Physical properties of structure Model 1.	65
4.4	Physical properties of structure Model 2.	67
4.5	Physical properties of structure Model 3	69
4.6	Comparison between the improved models results with the Existing Model.	71
4.7	Technical specification of design Model 2	73

LIST OF FIGURES

Figure No.	Title	Page
2.1	Change in Drag and Friction with changing shape.	7
2.2	Frontal Pressure caused by flowing air.	8
2.3	Rear Vacuum caused my flowing air.	8
2.4	Common Drag Coefficients.	10
2.5	CAD, Aerodynamic Simulation.	12
2.6	General Concept of Prototype Vehicle.	13
2.7	Torsion rigidity on race car chassis.	16
2.8	The strategy on positioning the frame member.	16
2.9	Original Lotus Elan backbone chassis.	19
2.10	Universal ladder frame chassis.	20
2.11	SUV Ford Monocoque chassis.	21
2.12	Semi-monocoque fuselage construction.	22
2.13	Space frame main sections.	24
2.14	Space frame chassis.	24
3.1	Final Year Project Flow chart.	32
3.2	Isometric View of the prototype car.	33
3.3	Prototype car designed by University Malaysia Pahang.	33
3.4	Mock up model.	36
3.5	Chassis Bottom Supports.	37
3.6	Chassis Roll Loop and Rear Chassis Approximation.	38
3.7	Complete Chassis view.	38
3.8	Isometric view of wrapped chassis.	39

3.9	Wrapped rear chassis view.	39
3.10	Driver Test Fit 1.	40
3.11	Driver Test Fit 2.	40
3.12	(a) Sketch on Chassis 1.	41
	(b) Sketch on Chassis 2.	42
	(c) Sketch on Chassis 3.	42
3.13	Regulations related to front, main roll hoops and bracing.	43
3.14	(a) Model for Chassis 1.	44
	(b) Model for Chassis 2.	45
	(c) Model for Chassis 3.	45
3.15	The correspond load that acted upon the design.	49
3.16	Applied forces and fixed point of chassis.	52
3.17	SolidWork model of Existing Design applied to Algor 23.1 software.	53
3.18	Bending Stress.	57
4.1	Finite element model for existing chassis design.	61
4.2	Displacement magnitude occurs on Existing Models.	62
4.3	Worst stress occurs on Existing Chassis Design.	63
4.4	Displacement magnitude occurs on the Model 1.	65
4.5	Worst stress occurs on the Model 1.	66
4.6	Displacement magnitude occurs on the Model 2.	67
4.7	Worst stress occurs on the Model 2.	68
4.8	Displacement magnitude occurs on the Model 3.	69
4.9	Worst stress occurs on the Model 3.	70
4.10	Total parameter percentage versus models graph.	72

LIST OF SYMBOLS

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

LIST OF ABBREVIATIONS

3D	Three Dimensional view
AA	Aluminium Alloy
AISI	American Iron and Steel Institute
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CFD	Computational Flow Dynamic
C_d	Drag Coefficient
FEA	Finite Element Analysis
ID	Inner Diameter
Mechapro	Mechanical Professional Club
MIG	Metal Inert Gas welding
OD	Outer Diameter
RHS	Rectangular Hollow Section
SAE	Society of Automotive Engineer
SEMA12	Shell Eco Marathon Asia 2012
SUV	Sports Utility Vehicles
TIG	Tungsten Inert Gas welding
TR	Torsional Rigidity
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The vast growth of transportation nowadays is powered by fossil fuels. Scientists believe that the use of these fossil fuels has caused global warming due to atmospheric effects. Furthermore, due to the statistic of fossil fuels, it is estimated that in the next decade the price of oil will increase to $350 per barrel (Oil Price to reach US$ 350 in Near Future, 2007). It is not included the external costs that come with the production of coil, oil and gas. Corresponds to the negative effects of fossil fuel consumption, the present generation is against to head in a different direction. A future is desired in which the energy used to power vehicles is renewable and clean. Therefore, engineers are aiming to design more fuel efficient vehicles in which the least amount of energy is required to travel a certain distance. This is exactly what the Shell Eco-marathon contest is about. It provides the arena in which future engineers can innovative in trying to develop solutions to the efficiency problem of vehicles.

Shell eco Marathon is a competition in which student from all study background is invited to build up a car that able to complete the longest distance in track in minimum fuel consumption. The competition was categorized by how the system and types of running engine. There are two major categories that are prototype car and urban car concept. Prototype car is a car concept where it must be running in three or four tires, with a very basic mechanism yet ergonomic to the driver. While in urban car concept, the car is build in four running tire or in other words it is similar to the real car system. In this competition, the car invented has to complete the task by completing the circuit at Sepang International circuit Kuala Lumpur.

This competition is not only requiring the student to build the car, instead students are also needed to raise the fund for construction of the prototype. The process of the project starts from the end of September every year. This study covers about the design of car chassis for last year prototype category in Shell eco marathon Asia 2011 by UMP Mechapro team of 2011. The stress analysis of the chassis will decide the design of the chassis. At the end, this study shows the result of the car chassis to be proposed to the competition next competition of Shell Eco Marathon Asia 2012.

In order to develop the most fuel efficient car, consideration of the types of the chassis to be design must be made. There have few types of chassis design which is backbone, space frames, monocoque, ladder frame etc. Each of the chassis designs provides their own properties. Each of chassis types are considered between power to weight ratio, component size, complexity, vehicle intent, and ultimate cost. Based on the design, each chassis will have strength and stiffness that can vary significantly. The ideal chassis is the one that provides high stiffness with low weight and cost.

1.2 PROBLEMS STATEMENT

Base on the Existing Model of Shell Eco Marathon Asia 2012, there have a few improvement to be done. Currently, the Existing Model provides heavy weight of chassis, a huge value of bending displacement when load is applied on the chassis and the limited area of engine compartment. Thus, the improvement could be made such as to reduce the weight of the chassis where appropriate by designing more compact car. Secondly, this study also conduct to overcome the worst bending displacement where occur at driver cockpit, and lastly to provide extra large engine spaces for new suggested model. The purpose of Shell Eco Marathon competition is to design a vehicle within the competition rules that is as fuel efficient as possible. For this design study, it was focusing on the chassis of the vehicle. The purpose is to design a chassis that is as light as possible and has high stiffness with low weight.

1.3 OBJECTIVES OF THE PROJECT

Corresponds to the project background and problem statements, it is decided that the objectives of the project are:

(i) To analyze and improve the existing car chassis based on Shell Eco Marathon Asia 2012 requirement.
(ii) To redesign and proposed new chassis of prototype car which able to withstand the load applied on the chassis structure with minimum bending displacement.

1.4 SCOPES OF THE PROJECT

This project is focusing on redesign and analysis the 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) Study the concept of prototype car category for Shell Eco Marathon Asia 2012 Event.
(ii) Evaluate and analysis the existing car design for previous competition.
(iii) Redesign three optional chassis of prototype car for SEMA 2012 event.
(iv) Evaluate and analyze all the chassis using FEA software, Algor 23.1 version
(v) Study was focus on static condition and stress simulation analysis only.
(vi) Select the best option which is capable to be fabricated at UMP.

1.5 EXPECTED OUTCOMES

From this project, the expected outcomes are very useful for next UMP Mechapro 2012 team to develop and fabricate the competition's car. There are:

(i) Present and proposed the project results of three new improved designs of car chassis in term of reducing the weight and increase of structure strength.
(ii) Compare the project results of three optional designs with existing prototype car in term of improvement of fixed parameters.

(iii) Produce the best option of the design in term of lower cost and availability of materials where the chassis is capable to be fabricated at UMP.

1.6 STRUCTURE OF THESIS

Chapter 1 introduces the background of the study. It is continue with simple discussion about Shell Eco Marathon Asia 2012 competition, problems statement which related to the project, the objectives, scope of the project, the expected outcomes and the structure of the thesis.

Chapter 2 presents the information of Shell Eco Marathon Asia 2012 official rules for car chassis, design consideration of chassis, type of chassis, material selection, and software to be implemented in this project**.** In this chapter, the suitable chassis type for the new design is determined from the comparison between most popular car chassis. The characteristics of space frame chassis are determined followed by the literature analysis.

Chapter 3 includes the methods of project where it starts discussed with the construction of the prototype chassis frame. Followed by three improved new model for Shell Eco Marathon 2012 event, technical specifications of each new model, load applied on the chassis, stresses criteria and material specification for new designs. From discussion of Chapter 3, it was enclosed with the designing process of the new chassis design.

Chapter 4 begins with the overview of existing chassis which design for previous Shell Eco Marathon Asia 2011 competition. The analysis of the existing design is also conducted in this chapter and then, the result and analysis of three improved chassis designs. Parameters of the study also described in this part and all such specification and selection of materials used also considered for the development of new design.

Chapter 5 presents the conclusion drawn from this Final Year Project and the recommendations will beneficially for future works progress.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter covers the academic information about the process of the project. The chapter starts with the introduction of Shell Eco Marathon Asia 2012 official rules for design of the car, and then the design consideration of the car chassis will be discussed to guide through this project. Chapter two also covers about type of car chassis, comparison between the chassis, material selection of the car chassis, load test on the car chassis, and the use of computer aided design software for this project.

2.2 SHELL ECO MARATHON ASIA 2012 OFFICIAL RULES FOR CAR CHASSIS DESIGN.

The Shell Eco-marathon Asia (SEMA12) 2012 competition is divided into two main categories which is Urban Concept and Prototype concept. 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, and else. For the Prototype category, the car aimed to be the most aerodynamics and fuel-efficient car. The car in this category must have three or four running wheels. The principle of the Shell Eco-marathon Asia is simple:

"To design and build a vehicle that uses the least amount of fuel to travel the farthest distance." – Shell Eco Marathon (2012).

2.2.1 Vehicle Design

Vehicle bodies must not include any external appendages that might be dangerous to other team members; e.g. sharp points must have a radius of 5 cm or greater, alternatively they should be made of foam or similar deformable material. According to the rules, it is allowed to design a prototype car using three or four wheels. The decision has chosen to use three wheels, since it would reduce the overall weight of the vehicle which would improve the speed, handling, and fuel consumption of the prototype car.

2.2.2 The Body Requirements

A newly designed body which will encase the chassis and correspond to maximum dimension as specified by Shell is shown in Table 2.1.

Table 2.1: Standard Dimension Specified By Organizer.

Dimension	Standard
Maximum total height	1 m
Maximum total length	3.5 m
Maximum Total width	1.3 m
minimum track width	0.5 m
minimum wheel base	1 m
maximum vehicle weight without driver	140 kg

The goal of the Shell Eco Marathon in designing process is to achieve the highest fuel efficiency possible by designing a totally new body and frame with less rolling and aerodynamic resistance than previous designs. The drag coefficient for the body must be minimized. The goal is to design a body which has a drag coefficient smaller than 0.15, the approximate drag coefficient of the 2011 team. The length of the body and vehicle in general, will be decreased, therefore reducing weight. With weight reduction being a priority, aerodynamics may not be greatly improved over the 2011, but will not be compromised. Depending on the final budget, some components from the 2011 vehicle will be reused, such as wheels, bearings, and safety components etc (Shell Eco Marathon Asia, 2012).

2.2.3 Aerodynamics Concepts

A simple definition of aerodynamics is the study of the flow of air around and through a vehicle, primarily if it is in motion. Energy is required to move a car through the air; this energy is also used to overcome a force called drag. Drag is determined by vehicle speed, frontal area, air density, and shape (Alexis, J. et al, 2011). Figure 2.1 shows how the shape affects drag.

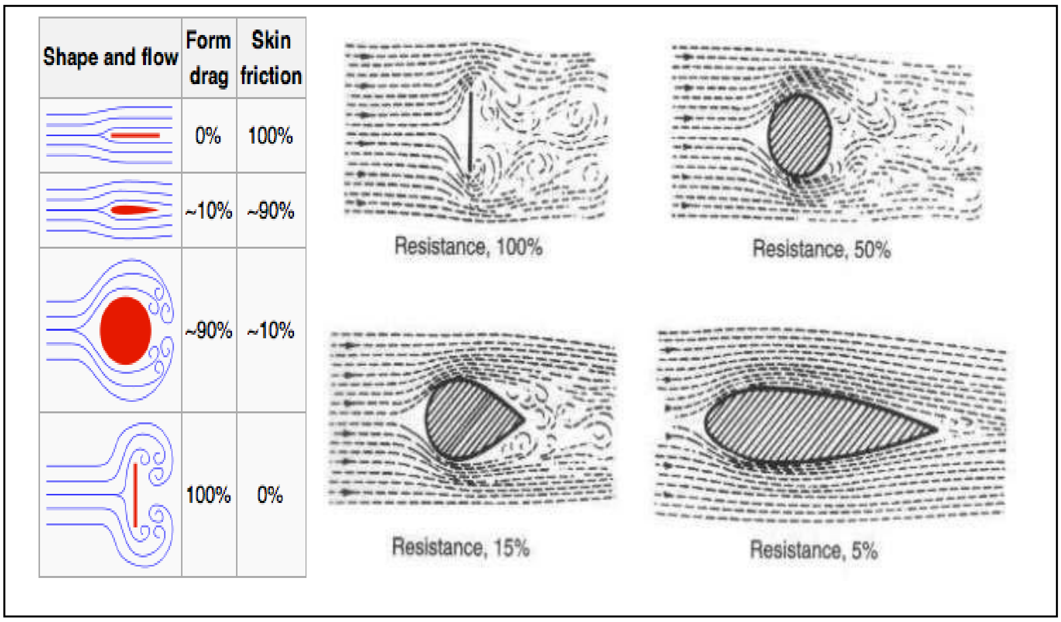


Figure 2.1: Change in Drag and Friction with changing shape.

Source: Wikipedia, Drag (2010)

The aerodynamic drag on cars are caused by pressures that act on the front area of the car, suction at the rear of the car, underbody regions and roughness of the vehicle surface such as protrusions and projections. Figure 2.2 and Figure 2.3 illustrate the frontal vacuum and the rear suction, respectively.

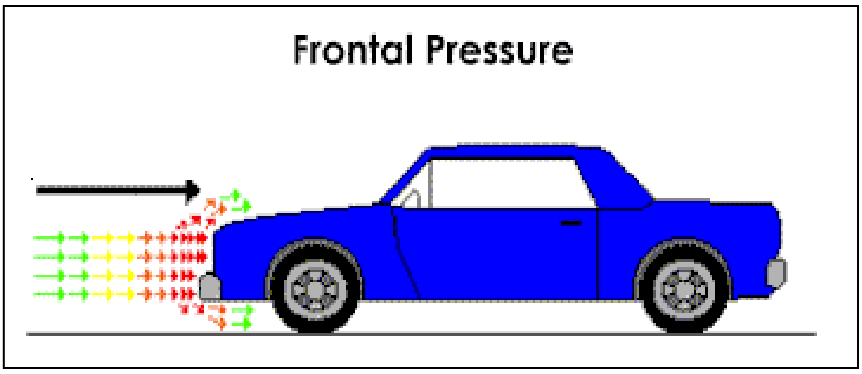


Figure 2.2: Frontal Pressure caused by flowing air.

Source: Wikipedia, Drag(Physics) (2010)

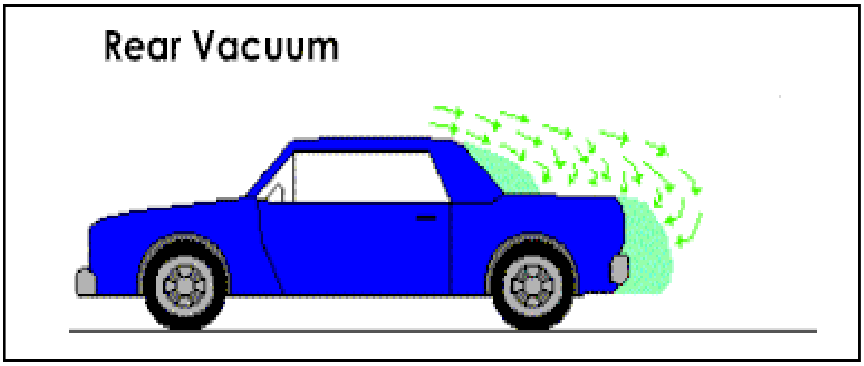


Figure 2.3: Rear Vacuum caused my flowing air.

Source: Wikipedia, Drag (Physics) (2010)

Drag on automobiles is calculated using the Eq. (2.1)

$$D_r = C_D \times S \times \frac{1}{2} \rho \times U^2 \quad (2.1)$$

Where:

D_r is drag force in Newton

C_D is drag coefficient

S is cross sectional area meters squared

ρ is air density kilograms per meter cubed

U is speed meters per second

In order to over come drag the car must exert a certain power, which is given by the Eq.(2.2)

$$P_D = \frac{1}{2} \times \rho \times V^2 \times \mathrm{A} \times C_D \tag{2.2}$$

When referring to the aerodynamics of a car, an important factor is; down force. It is the same as the lift experienced by airplane wings, only it acts to press down, instead of lifting up. Down force results from a presence of high pressure on the top of car and low pressure on the bottom of the car, this pressure differential creates the downward force, which pushes the car down to the surface. Down force can be calculated using the Eq. (2.3)

$$D = \frac{1}{2} \times (WS \times H \times A_o A) \times F\rho \times V^2 \tag{2.3}$$

Where:

D is down force in Newton

*W*S is wingspan in meters

H is height in meters

AoA is angle of attack

F is drag coefficient

ρ is air density in kg/m³

V is velocity in m/s

One aspect that needs to be considered when designing the body of the car is how aerodynamic drag is going to affect the fuel efficiency. Due to the fact that when the car passes through the air, it displaces some of it, causing the air to exert a force on the car. The drag force can be found by using Eq. (2.4)

$$F_D = \frac{1}{2} \times \rho \times U^2 \times \mathrm{C_D} \times \mathrm{A} \tag{2.4}$$

Where is the density of the fluid, u is the velocity of the object relative to the fluid, is the coefficient of drag of the object, and A is the total frontal area. The frontal area is the total area of the object in the path of the fluid flow. The density of air at room temperature is about 1.4 kg/m^3. The vehicle will be traveling between 30 km/h – 60 km/h. The coefficient of drag is estimated to be about 0.15 to 0.20. This number was chosen according to Figure 2.4 which shows the common drag coefficient of the car. Modern cars have drag coefficient between 0.25 and 0.45. Since our vehicle is more aerodynamic than a passenger car, but less so than a streamlined body (*Cd* = 0.04), a value between the streamlined body and modern cars was chosen.

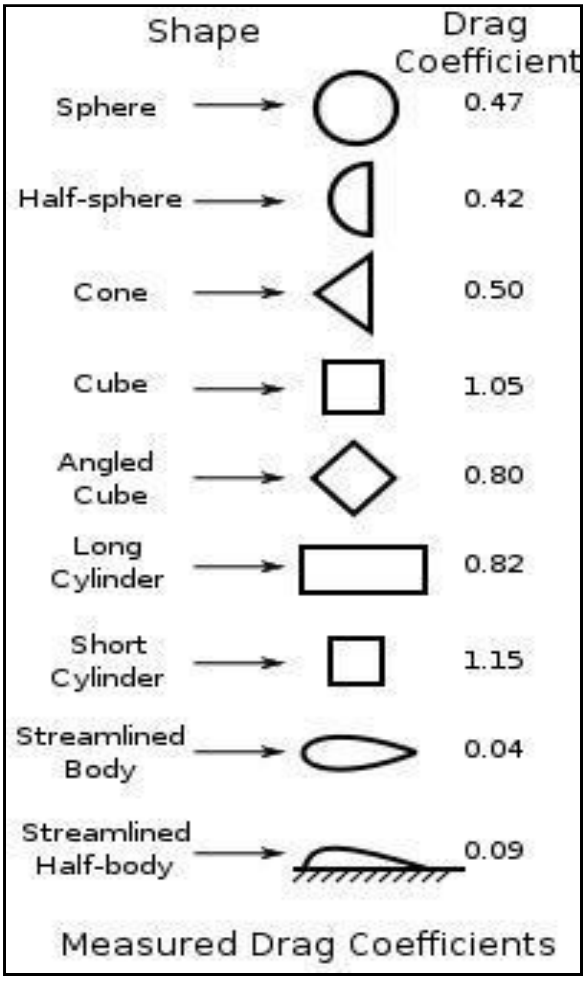


Figure 2.4: Common Drag Coefficients.

Source: Wikipedia, Drag (Physics), (2010)

Table 2.2 lists the calculated force due to drag when using the values of density, velocity, area and drag coefficient that were listed.

Table 2.2: Drag Force in Relation to Drag Coefficient at Different Speeds.

Velocity(m/s)	Cd	F (N)
10	0.15	13.65
	0.20	18.20
15	0.15	30.71
	0.20	40.95

Source: Alexis, J. Clarke, P. and Laurence III, R. (2011).

As can be seen immediately from the table, the values for the drag forces are small. Using a more conservative drag coefficient of 0.20 and traveling at 55 km/h (15 m/s), the theoretical drag force is 40.95 N. This is much lower than we initially thought. The true value of the drag force on the finished car will be higher than the current theoretical values, but these values seem like a good base number to start with.

The purpose of finding the drag force is the from there, the work required to overcome the drag can be calculated. To overcome the drag, the engine must perform an equal amount of work. If the work required from the engine to compensate for the drag is known, then the amount of fuel required to balance out the drag force can easily be calculated. The amount of work from drag can be found from Eq. (2.5)

$$W = F_D \times d \tag{2.5}$$

Where W is the work done on the car, F_D is the drag force and d is the distance traveled by the car while drag is acting on it. Since we are concerned with fuel economy, the distance chosen was 1 Kilometer. Table 2.3 lists the different values for the work of drag depending on the drag force.

Table 2.3: Work in Relation to Drag Coefficient at Different Speeds.

Velocity (m/s)	Cd	Work (N)
10	0.15	13650
	0.2	18200
15	0.15	30710
	0.2	40950

Source: Alexis, J. Clarke, P and Laurence III, R. (2011).

When a drag force of 40.95 N is used (*Cd* = 0.20 and Velocity = 15 m/s), the total work performed by aerodynamic drag over distance of one kilometers is only about 40950 N. Computer simulations can achieve testing the aerodynamic features of a car design such as solid works. The major advantage that CAD has above actual wind tunnel design is that numerous changes can be made to the design to achieve optimal aerodynamic result before a model is built. As it can be seen in Figure 2.5 the aerodynamic features of a design can be investigated during the design phase.

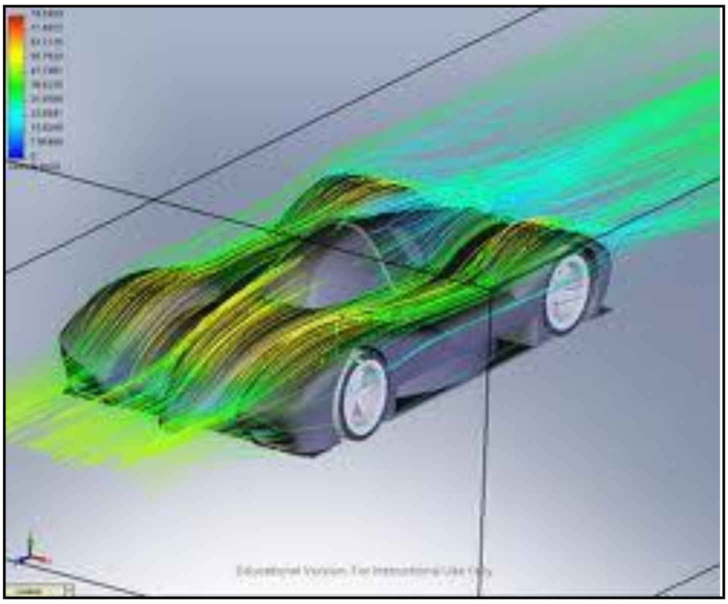


Figure 2.5: CAD, Aerodynamic Simulation.

Source: CAD- Computer Aided Design, 2010

2.2.4 Chassis Design

A newly designed chassis that will meet or exceed the safety standards as determined by Shell, and contain all structural support components needed for the engine, steering, wheels, and other crucial components. The chassis will be designed with the ability to withstand loads predetermined by Shell. This is to ensure driver safety in the event of an impact or rollover. Additionally, the chassis will be designed in combination with the body to produce significant gains in driver visibility. Driver visibility is required to be at least 180˚.

Another design factor with chassis of the vehicle is that it must be long and wide enough to protect the driver in a collision, and a roll bar must be welded to the chassis that extend 5cm over the drivers head and also have some clearance between the driver's shoulders. The roll bar must also be able to withstand a static load of 700 Newton (Quiceno, B. et al 2011). Figure 2.6 is a general picture of the basic design of the prototype vehicle.

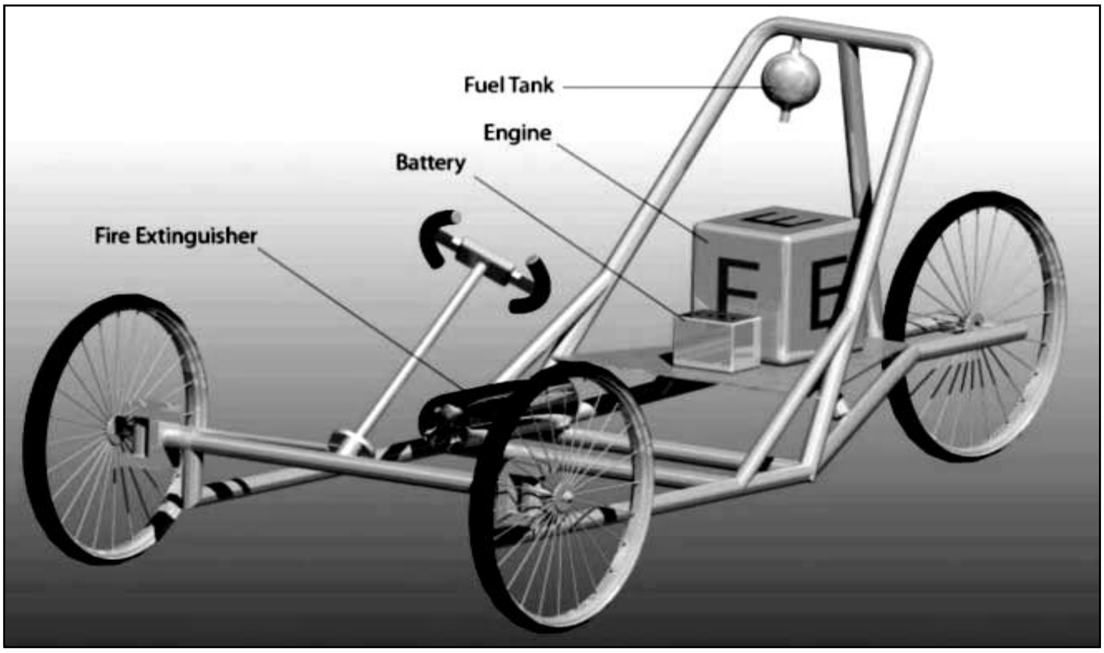


Figure 2.6: General Concept of Prototype Vehicle.

Source: Quiceno, B. Salamea, P. and Sampath, R. (2011)

2.2.5 The Chassis Requirements

Initial chassis considerations led to the selection of a space frame chassis base on Table 2.3: Comparison between most popular used four types of chassis car. The space frame concept would allow maximum stability, safety and minimum weight. To reduce material volume it was decided that a compact driver orientation was most suitable. A totally prone driver position results in a car that must be long, and as a result requires a stronger chassis material to withstand chassis bending. The design was determined to consist of a “cage” type design, with simple frame rails, and front and rear supports, with the firewall being the center point of the vehicle (Keith J. Wakeham, 2009).

The chassis will include a mandatory firewall; its design will be selected from a predetermined specification put forward by Shell. The chassis will be made of high strength aluminum alloy. This depends on the final budget of the project and design considerations. A combination of materials may be used to maximize the strength to weight ratio of the car. Teams must ensure that the vehicle chassis is solid.

2.3 DESIGN CONSIDERATION OF CHASSIS

Chassis in this topic mean the rectangular, usually steel frame, supported on springs and attached to the axles, that holds the body and motor of an automotive vehicle (Dictionary.LaborLawTalk.com, 2005).

2.3.1 Determination of Chassis

(i) Basic (stripped) chassis – an incomplete vehicle, without occupant compartment, that requires the addition of an occupant compartment and cargo carrying, work performing, or load-bearing components to perform its intended function

(ii) Chassis Cab – an incomplete vehicle, with completed occupant compartment, that requires the addition of cargo-carrying, work performing, or load-bearing components to perform its intended function.

(iii) Cutaway Chassis – an incomplete vehicle that has the back of the cab cut out for the intended installation of structure that permits access from the driver's area to the back of the completed vehicle

2.3.2 The Chassis Systems

(i) The frame structural, load carrying component that supports the car's engine and body, which are in turn supported by the suspension (HowStuffWork.com, 2004)

(ii) The suspension system – setup that supports weight, absorbs and dampens shock, and helps maintain tire contact.

(iii) The steering system – mechanism that enables the driver to guide the vehicle.

(iv) The tires and wheels – components that make vehicle motion possible by way of grip and/or friction with the road.

2.3.3 Chassis Description

The fundamental principle of a chassis design states that the chassis is to be designed to achieve the torsion rigidity and light weight in order to achieve good handling performance of a race car (Weerawut, C. 2000). Thus, torsion rigidity (TR) is defined to the ability of chassis to resist twisting force or torque. In general, the effect of torsion rigidity on space frame is different to the Monocoque chassis due to their construction format. Figure 2.7 shows the torsion rigidity applies to race car chassis.

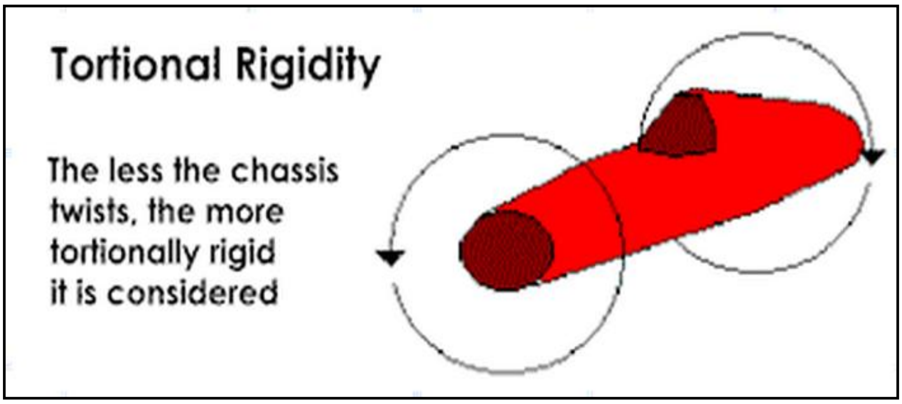


Figure 2.7: Torsion rigidity on race car chassis.

Source: Afnan, H. (2010)

According to the statement above, chassis designed will have high torsion rigidity in order to against the twisting force or torque. Thus, the format of tube pipes arrangement is considered. The principle is to place the frame members in a triangulated format as shown in Figure 2.8:

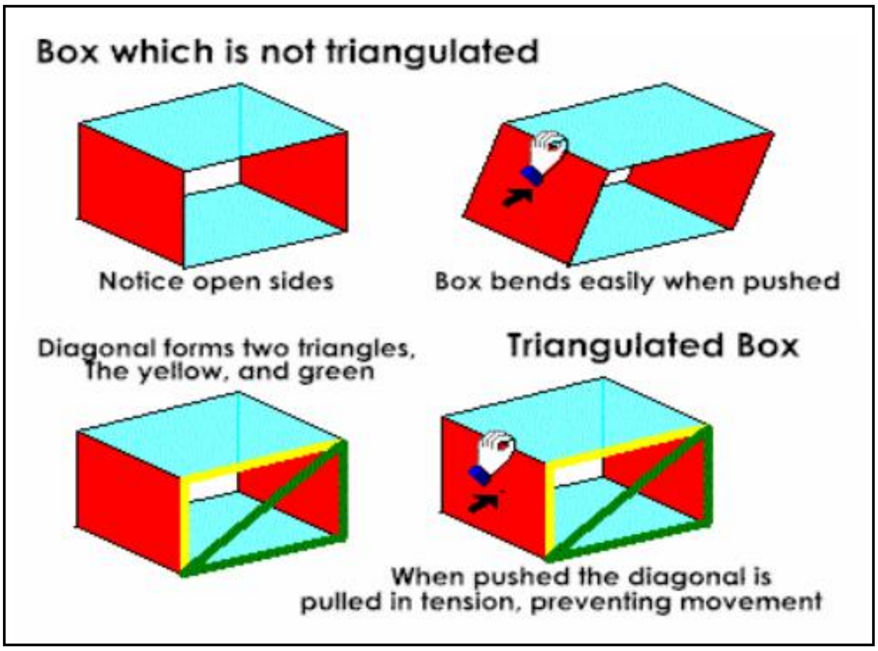


Figure 2.8: The strategy on positioning the frame member.

Source: Baker, C. S. (2004)

The theory behind space frame 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 in Figure 2.8, the box is difficult to deform by bending force due to the triangulated format of frame. Thus, most race car chassis today designed in triangulated format.

2.3.4 Component Restraints

When designing a chassis, it is not only important that the vehicle is designed to the regulations but it also be designed so that it can house the necessary components that are required in the vehicle. (Baker, C. S., 2004). These components include:

(i) Engine

Approximate engine dimensions for a 110cc motorbike engine are 300mm long, 250mm wide and 200mm high. The engine will also require custom mounting points on the chassis.

(ii) Drive Train

The chassis needs to accommodate the rear axle which is going to be approximately 300mm above the ground, the chassis also has to support bearing housing for the rear axle. The axle will have drive sprocket which will need to be inline with the pinion sprocket on the engine. There also needs to be a clear line between the drive sprocket and the pinion sprocket for the chain to run. A brake disk will also be attached to the rear drive shaft.

(iii) Suspension

The weight of the vehicle needs to be supported through the suspension. The wishbones for the front and rear suspension also need to be mounted to the chassis.

(iv) Human Factors

One of the main purposes of the chassis is to provide a cockpit for the driver. The chassis must provide comfortable leg room so the driver can reach the peddles. It must also provide clear vision forward of the vehicle. The front plane of the front hoop will have to house controls and driving instruments. The steering wheel must also be within easy reach from the drivers seat which is under the main hoop.

2.4 TYPES OF CHASSIS

Basically chassis is considered as a framework to support the load act on the body, engine and other parts which make up the vehicle. Chassis holds the whole vehicle support and rigidity. Normally, chassis will include a pair of longitudinally extending channels and multiple transverse cross members that connecting the channels. The transverse members will have a reduced cross section area in order to allow for a longitudinally extending storage space. The chassis require containing the various components for the race car as well as being based around a driver’s cockpit. The safety condition of the chassis is a major aspect in the design, and should be considered in all stages. Generally, the chassis types consist of backbone, ladder, space frame and monocoque. Different types of chassis design will produce the different performance of the chassis.

2.4.1 Backbone Chassis

The backbone chassis is simplest structure design. It only 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). The backbone chassis may be built through many types of construction. The area cover within the structure is used to place the driveshaft in case of front-engine, rear-wheel drive layout. The drive train, engine and suspensions are all connected to each of the end of the chassis. The body racing purpose is built on the backbone usually made of glass-fiber. Almost front engine and rear wheel drive vehicles use backbone chassis. Figure 2.9 shows the backbone chassis type.

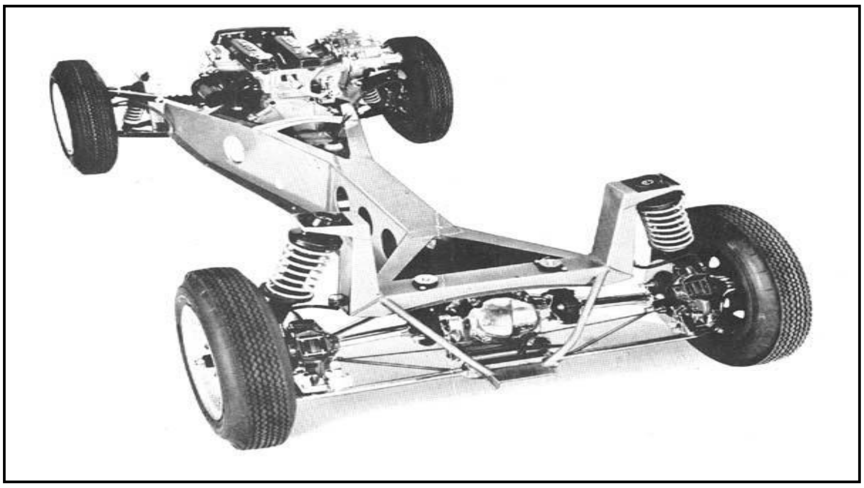


Figure 2.9: Original Lotus Elan backbone chassis.

Source: Keith J. Wakeham (2009)

2.4.2 Ladder Frame Chassis

A ladder frame is the simple and oldest frame applied in modern vehicle car. 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). If there were higher weight capacity required then the larger beam members could be used. Vehicle engine is placed in the front or sometimes in the rear and supported at suspensions points. The constructions of this chassis consist of two longitudinal rails interconnected by many lateral/cross braces, typically made from round or rectangular channel.

The longitude members are the main stress member where will deal with the load and the longitudinal forces caused by acceleration and braking. The lateral and cross members will provide rigidity where the resistance to lateral forces and further increase torsion rigidity. This design provides good beam resistance because it is continuous rails from front to rear, but poor resistance to torsion if simple and perpendicular cross members are used. The vehicle's overall height will be higher due to the floor pan sitting above the frame instead of inside it (Wakeham.K.J, 2009). 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 2.10 shows the type of ladder chassis.

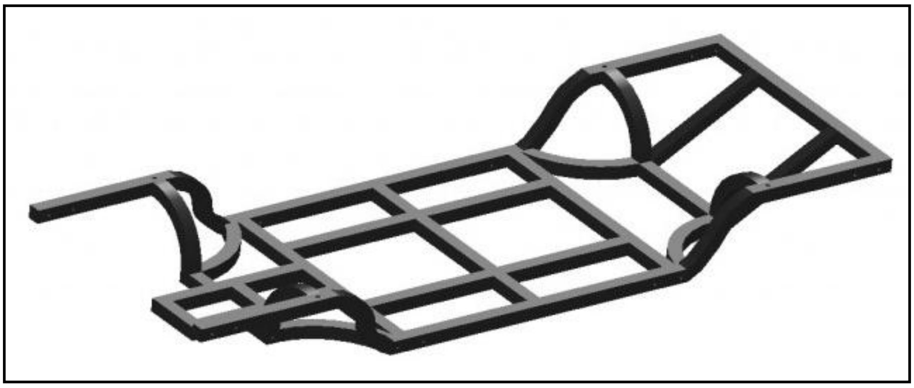


Figure 2.10: Universal ladder frame chassis.

Source: http://universalcarproject.com/images (2011)

2.4.3 Monocoque chassis

Monocoque chassis referring to the vehicle where the external body is load bearing (Keith J. Wakeham, 2009). It is a one-piece structure which determines the overall shape of the car. Monocoque chassis is already incorporated with the body in a single piece where made by welding several pieces metal sheet together. It’s different from others due to the body construction as mentioned before. The floor pan, which is the largest piece, and other pieces are press-made by huge stamping machines. The chassis then spot welded together by robot arms some even use laser welding in a stream production line. After that, some accessories like doors, bonnet, boot lid, side panels and roof are installed. Some parts of the skin like the grill, bumpers, fenders, front wing and rear diffuser are so far away from any load paths because only hold themselves. The doors and the hood only transfer a less amount of load across their gaskets, hinges, and bolts in normal driving situations. The rear door is a mini-monocoque made of the glass window and the metal frame (Lamar,P. 2001).

Monocoque designs are favored among high-performance cars and racing cars today for their overall structural integrity and the fact that one can design a monocoque out of lightweight materials such as carbon fiber and expect the resulting vehicle to be light, stiff, and stable at high speeds and in tight corners. These types of particularly advanced monocoques can even be molded to create diffusers and ground effects which generate huge amounts of downforce (Lamar,P. 2001). Most vehicles such as the Honda Civic and Chevrolet 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). This chassis also benefit for crash protection because it uses a lot of metal where crumple zone can be built into the structure. The setup cost for the tooling is very expensive such as big stamping machines and expensive moldings. Figure 2.11 shows the type of monocoque chassis.

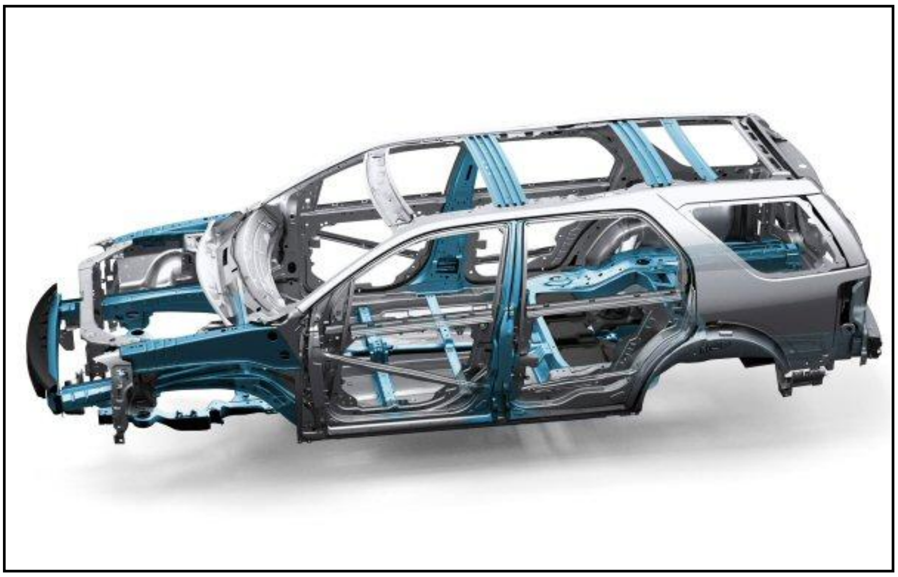


Figure 2.11: SUV Ford Monocoque chassis.

Source: AutoZine Technical School (1997)

2.4.4 Semi-Monocoque chassis

The semi-monocoque uses composite beams and bulkheads to support the loads and is integrated into a nonload bearing composite belly pan. The top sections of the car are often separate body pieces that are attached to the belly pan. A fuselage structure in which longitudinal members as well as rings or frames which run circumferentially around the fuselage reinforce the skin and help carry the stress. Also known as stiffened-shell fuselage. Figure 2.12 shows the Semi-monocoque fuselage construction.

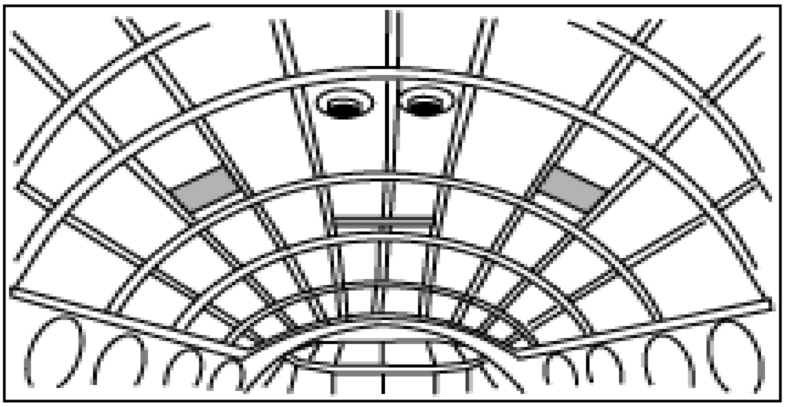


Figure 2.12 : Semi-monocoque fuselage construction.

Source: AutoZine Technical School (1997)

Semi-monocoque are referred to as "stressed skin" structures as all or a portion of the external load is taken by the surface covering. In addition, the entire load from internal pressurization is carried (as skin tension) by the external skin.Semimonocoque design overcomes the strength-to-weight problem of monocoque construction in addition to having formers, frame assemblies, and bulkheads, the semimonocoque construction has the skin reinforced by longitudinal member. It is constructed primarily of aluminum alloy, although steel and titanium The original GT40 - and our ERA GT - have a semi-monocoque chassis. The heaviest (steel) main panel on our ERA GT is only .045" thick, and most panels are only .032". Reinforcements are required at the suspension points where there are local high loads. With the rockers 10" high × 9" wide, the net result is an incredibly stiff structure.

2.4.5 Space frame chassis

Due to ladder chassis is not strong enough, engineers developed a 3 dimensional design called Tubular space frame chassis. One of the earliest examples was the post-war Maserati Tipo 61 "Birdcage" racing car (AutoZine Technical School, 1997). Tubular space frame chassis use dozens of circular-section tubes which offers the maximum strength and it’s positioned in different directions to provide mechanical strength against forces from anywhere. These tubes then welded together and form a very complex structure.

The space frame chassis is a series of straight small diameter tubes to achieve strength and rigidity combine 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 developed by Barnes Wallis who was an English aviation engineer (Baker, C. S. 2004). Space frames chassis have been used in racing car chassis, since the introduction of car racing competition in the 1940’s. A space frame 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 (Baker, C. S. 2004).

The main components of the space frame chassis are the front box, cockpit, engine compartment and rear box as shown in Figure 2.13. 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 drive train, including differential brackets and rear engine bracing are mounted.

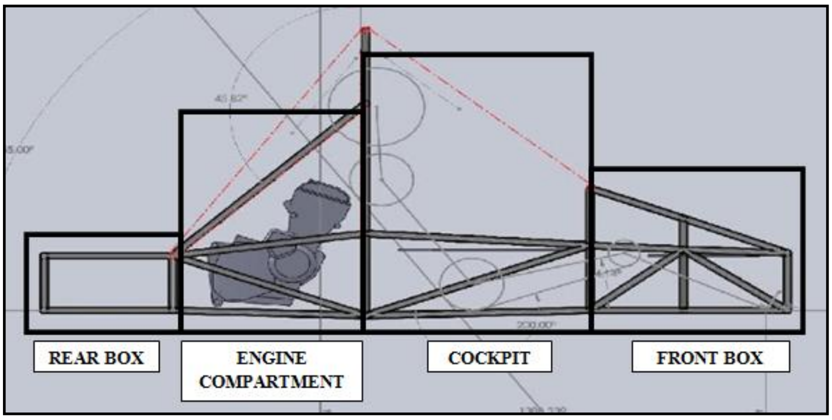


Figure 2.13: Space frame main sections.

Source: Afnan, H. (2010)

Space frame chassis are made from either Rectangular Hollow Section RHS steel, tubular steel or in some cases a combination of both. Tubular steel is found to be much more resistant to torsional loads because it has a constant axis for the moment of inertia, which is desirable in chassis performance. Although the space frame type are look like the traditional style, but they are still very popular today in amateur motorsport. The advantage of space frame compare to the Monocoque type is it can easily be repaired and inspected for damage after a collision. Figure 2.14 shows an example of space frame chassis.

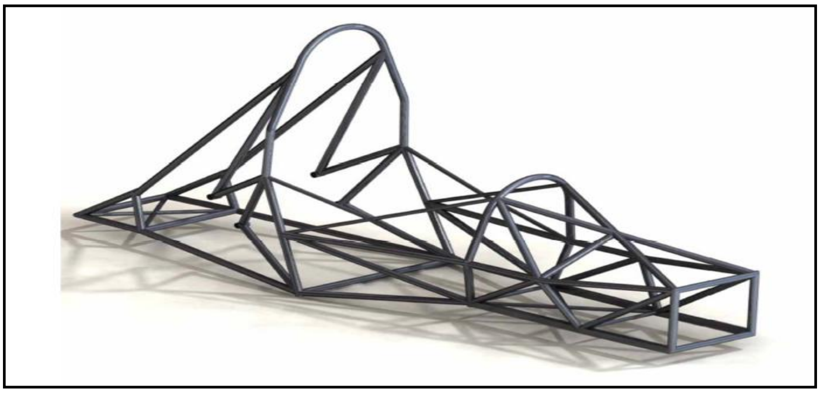


Figure 2.14: Space frame chassis.

Source: Keith J. Wakeham, (2009)

2.5 MATERIAL SELECTION

Motorsport is a highly contested competition where teams seek to find any advantage to increase their vehicles performance. Differerent 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 (Baker, C. S. 2004). The Shell Eco-Marathon Asia 2012 rules permits all other viable materials. Feasible construction materials for the frame would include: plain carbon Steels, alloy Steel, aluminum, Fibre composites etc. Different sections of the chassis are allowed to be different diameters but for fabrication 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. The Eq. (2.6) and Eq. (2.7) is used for calculating buckling modulus:

$$\text{Buckling Modulus} = EI \tag{2.6}$$

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) \tag{2.7}$$

Where
E is Modulus of Elasticity
I is Area Moment of Inertia
Do is outside diameter
Di is inside diameter

2.5.1 Alloy Steels

Alloy steels are iron-carbon steels that contain significant additional alloying elements. Alloy steels have superior mechanical properties to plain carbon steels. Common alloying elements that are added include Chromium, Manganese, Molybdenum, Nickel and Vanadium. The percentage of alloying elements added can influence mechanical properties to increase strength, hardness, hot hardness, wear resistance, fatigue resistance and toughness. Stainless Steel is the generic name for a number of different high alloy steels used primarily for their resistance to corrosion. The one key element they all share is that they must a minimum of 12% chromium. Although other elements, particularly Nickel and Molybdenum are added to improve corrosion resistance.

Chrome Molybdenum SAE4130 is a high alloy steel which contains Silicon, Chromium and Molybdenum. These alloying elements give the steel superior strength compared to other common steels. The alloying elements also provide a protective barrier within the steel to increase the corrosive resistance. Another advantage of chrome molybdenum steel is that it's weldability is very good. The disadvantages of chrome molybdenum steel is that it is brittle therefore can become fatigued when exposed to fluctuating loads. Chrome Molybdenum is also very expensive and hard to find a supplier. Table 2.4 shows the chemical composition of some Alloy Steels in market.

Table 2.4: Chemical compositions of some Alloy Steels.

SAE/AISI grade	C, %	Mn,%	P,% max	S,% max	Ni,%	Cr %	Mo%	V%
2340	0.38-0.43	0.70-0.90	0.035	0.04	3.25-3.75	-	-	-
3115	0.13-0.18	0.40-0.60	0.035	0.04	1.1-1.4	0.55-0.75	-	-
4027	0.25-0.30	0.70-0.90	0.035	0.04	-	-	0.20-0.30	-
4130	0.27-0.33	0.35-0.60	0.035	0.04	-	0.80-1.15	0.15-0.25	-
4340	0.38-0.43	0.60-0.80	0.035	0.04	1.65-2.00	0.7-0.9	0.20-0.30	-
5140	0.38-0.43	0.70-0.90	0.035	0.04	-	0.7-0.9	-	-
6150	0.48-0.53	0.70-0.90	0.035	0.04	-	0.8-1.1	-	0.15 min
8620	0.18-0.23	0.60-0.90	0.035	0.04	0.40-0.70	0.40-0.60	0.15-0.25	-
9255	0.51-0.59	0.75-1.00	0.035	0.04	-	-	-	-

Few advantages of alloy steels is considered such as greater hardenability, less distortion and cracking, greater ductility at high strength, greater high temperature strength, greater stress relief at given hardness, better machinability at high hardness, and high elastic ratio and endurance strength. while the disadvantages is tendency toward austenite retention, high cost of material, required special handling tools and method, and temper brittleness in only certain grades.

2.5.2 Aluminum

Aluminum is a nonferrous metal with very high corrosion resistance and is very light compared to steels. Aluminum cannot match the strength of steel but its strength-to-weight ratio can make it competitive in certain stress applications. 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. Aluminum alloys are also available but are very specialist materials. These alloys are extremely strong and light, compared to all other materials. They are also very expensive and not readily available in tube form. The primary use for aluminum alloys are for military, aircraft and space applications. 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 2.5 shows the types of aluminum available in market and the mechanical properties of each type.

Table 2.5: Mechanical properties based on AA standard.

Alloy	Temper	Thickness (mm)	Tensile Strength (Mpa)				Elongation % min in 50 mm
			Ultimate		Yield, 0.2% offset		
			Min	Max	Min	Max	
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

Source: Product Data, Sam's Metal, Kuantan, (2011)

For this project, Aluminum Alloy 6063-T6 is chosen. Aluminum alloy 6063 is one of the most extensively used of the 6000 series aluminum 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). Table 2.6, Table 2.7 and Table 2.8 below shows the typical composition, the physical properties and the mechanical properties of Aluminum Alloy 6063, respectively.

Table 2.6: 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 2.7: 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 2.8: Material properties of Aluminum Alloy 6063-T6.

Mechanical Properties	Value
Yield strength	215 Mpa
Tensile strength	240 Mpa
Modulus of Elasticity	68.9 Mpa
Density	2700kg/mm^2

2.6 USE OF CAD AND FEA SOFTWARE

Computer-aided-design (CAD) software allows the development of three dimensional (3-D) designs from which conventional two-dimensional orthographic views with automatic dimensioning can be produced. In this project, Solidworks software is used to generate the model. The process for modeling in Solidworks is relatively simple. By using the Weldments structural member feature, it is possible to quickly and simply create a model of tube, and trim connecting tubes to fit precisely onto each other. In this vein, tube relations must be defined appropriately off of each other to take advantage of the ability of the CAD model to update its self as parameters are changed (Soo, A. M., 2008)

Because of the complexity of the spaceframe chassis, hand numerical calculations would prove extremely lengthy. Therefore the numerical tests will be completed using finite element analysis (FEA) software. This software allows complex numerical calculations to be performed in feasible time. Property settings required to conduct FEA can often be complicated to simulate the real conditions. 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 (Midkiff, J. 1997).

2.7 CONCLUSION

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 space frame chassis is described in this chapter followed by the literature analysis. Literature analysis contains the information about the sources gained in order to complete the project. Appendix A is referred to the summary of the references used in this project.

CHAPTER 3

PROJECT METHODOLOGY

3.1 INTRODUCTION

This chapter discusses about process of development the suggested chassis designs for Shell Eco Marathon Asia 2012 competition. The flow of work progress is shown in Figure 3.1 and be detailed in Appendix B. The process started with sketching the general idea for the design. Secondly, the development of mock up model were took place as it is the important step for determining the exact dimension of the chassis and car, the cockpit area for the driver, the handling system style, the highest point of the roll bar and the total area for Engine compartment. Then, full scale for all three suggested designs was sketched. It is followed by modeling the design into Solidwork software. Technical specifications for all models also have discussed in this chapter. Lastly, all the design will be analyzed by using Algor version 23.1 in chapter 4. Mostly the chassis type used in the construction of prototype car for Shell Eco Marathon is space frame chassis. This is due to the specification of the space frame which is more rigid than other chassis.

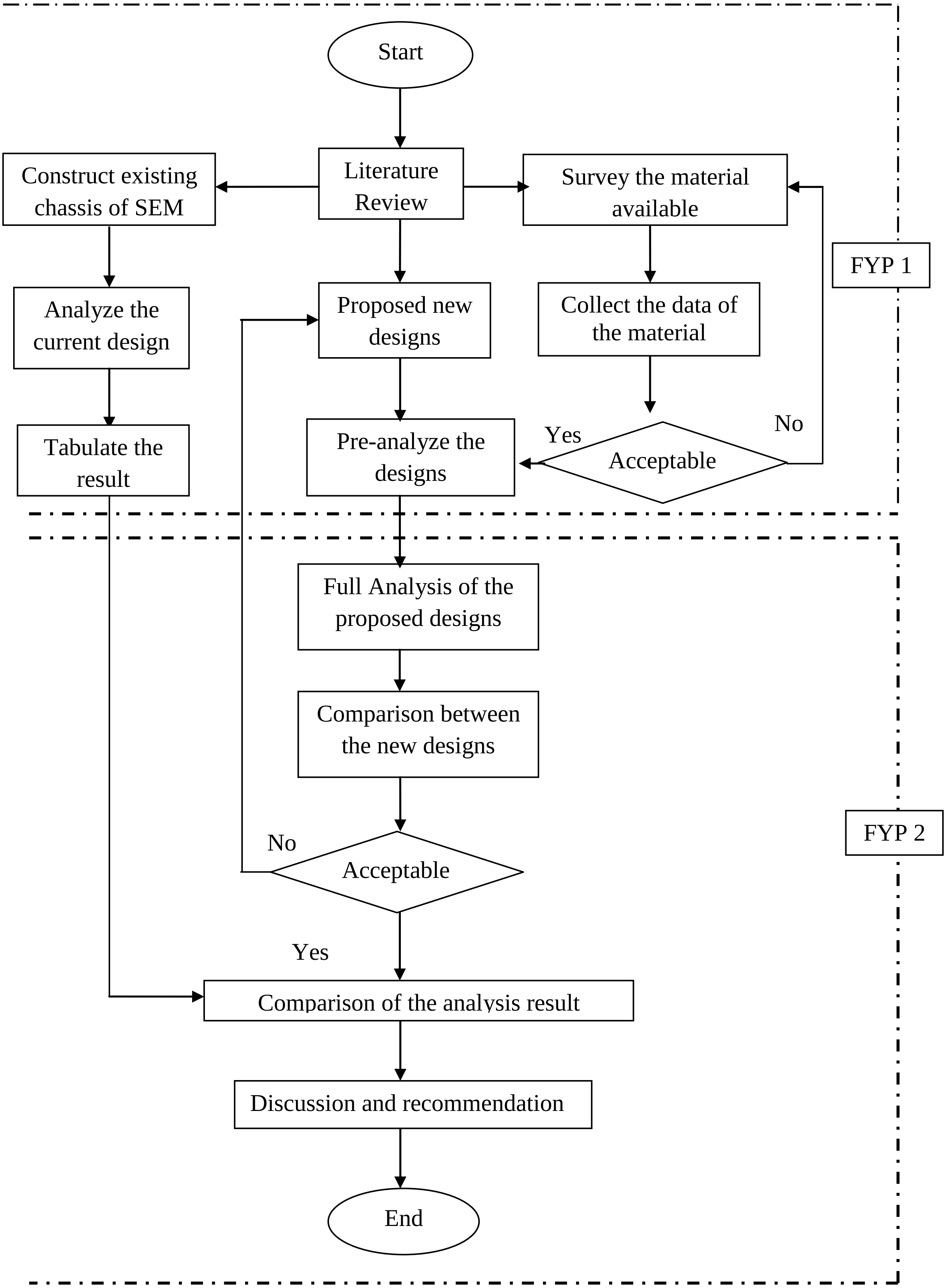


Figure 3.1: Final Year Project Flow chart

Theoretically, the concept of chassis design state that the designed must have the triangulated format of tubular pipes to increase the torsion rigidity of the chassis. But it is not important to follow this concept because the goals of the design in this competition is to have a lightweight car which can cruise further by using less amount of fuel. It's mean that, the car will not travel to fast 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 3.2 shows the Existing Design of the prototype car's category and Figure 3.3 shows the Isometric View of the prototype car of Shell Eco Marathon 2011.

Figure 3.2: Isometric View of the prototype car.

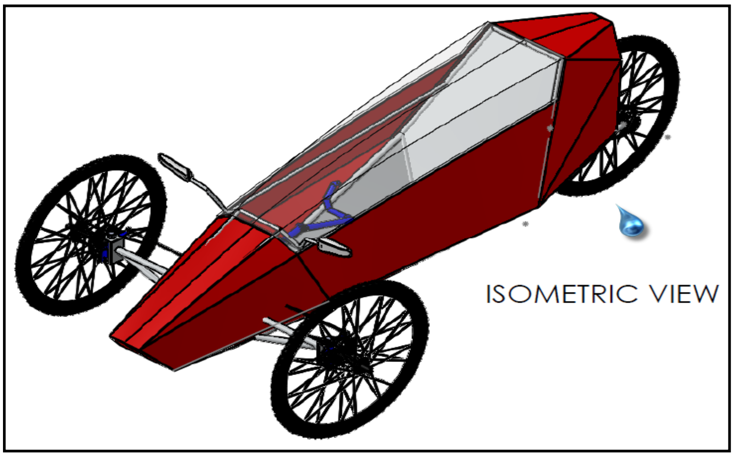


Figure 3.3: Prototype car designed by University Malaysia Pahang.

Source: Mechapro Team 2011, UMP (2011)

3.1.1 Criteria of Good Chassis

Any good chassis must do several things:

(i) Be structurally sound in the every way over the expected life of the vehicle and beyond. This means nothing ever breaks under normal conditions.

(ii) Maintain the suspension mounting locations so that handling is safe and consistent under high cornering and bump loads.

(iii) Support the body panels and other passenger components so that everything feels solid and has long reliable life.

In the real world, few chassis designs will not meet the criteria of Major structural failures, even in kit cars, are rare. Most kit designers, even if they're not engineers, will overbuild naturally. The penalties for being wrong here are too great. The trouble is, some think that having a "strong" (no structural failures) chassis is enough.

Structural stiffness is the basis of what we feel at the seat of our pants. It defines how a car handles, body integrity, and the overall feel of the car. Chassis stiffness separates a great car to drive from what is merely good (ERA Chassis, 2000). Different basic chassis designs each have their own strengths and weaknesses. Every chassis is a compromise between weight, components size, vehicle intent, and ultimate cost. And even within a basic design method, strength and stiffness can vary significantly, depending on the details. There is no such thing as the ultimate method of construction for every car, because each car presents a different set of problems (ERA Chassis, 2000). The comparison between most popular used four types of chassis is referred to Appendix C.

3.1.2 Analysis Comparison Result

The space frame chassis provided the advantages required to develop this chassis and the most suitable chassis type to use in the prototype car construction in Shell Eco Marathon Asia 2012 compared to others chassis types. Where the space frame chassis is good in vertical loading support and better in side impact horizontal loading, hence this chassis concept is applied in this project. Space frame chassis also provide a great flexibility in the section of support locations and allows to be applied for different geometrical shapes. The design / manufacture / installation process is completed in a very short interval due to the use of prefabricated components. Space frame systems are lighter than traditional steel and reinforced concrete structures. Therefore, it provides significant economy in foundation costs. Demountable steel elements are light and easy to handle, and their assembly is safe and time saver. Additional structures to support the heating, ventilating, electrical and other systems are not required for space frame structures. İt provides various alternative solutions in architectural areas for complex geometrical shapes (pyramid, triangle, dome, barrel vault e.t.c.)

3.2 PROTOTYPE CONSTRUCTION OF CHASSIS FRAME

The first prototype to make was of the chassis before construction of the actual chassis. This was a full size model that was designed to check the dimensions of current design. Having the dimensions on paper doesn’t do much when trying to see whether or not it will work with the driver. Thus, the full size model needs to be constructed. A scale mock-up was formed using 2.5 mm round Ferro wire. The mock-up allowed for the verification that the dimensions of the tubes selected would adequately accommodate to the person that will be driving the prototype vehicle. The mock-up gave a better idea of the actual chassis size and then the team decided to go with that model. One last note about the model: this was designed for the purposes of seeing what the dimensions come out as first hand, and as such the angles and lengths are not perfect, nor was any member of the model designed to withstand any sort of force. It is only for viewing and testing of driver size. Figure 3.4 shows the mock-up of the chassis.

Figure 3.4: Mock up model.

3.2.1 Construction the Mock up Model

The first step was constructing the bottom supports for the chassis. The following figure shows the layout of the bottom supports of the chassis. The wire was not cut to the dimensions specified; in fact, most of them are tighten out past the joints where they are connected together. That is because have been planned on using the wire again so as to be able to produce a scale model that will have the correct dimensions. This prototype is just a temporary one for the viewing purposes only and was not intended to be put on display. Bar were noted as number 1, 2, 3, 4, 5, 6, 7 and 8 are the bottom of the support member chassis as shown in Figure 3.5.

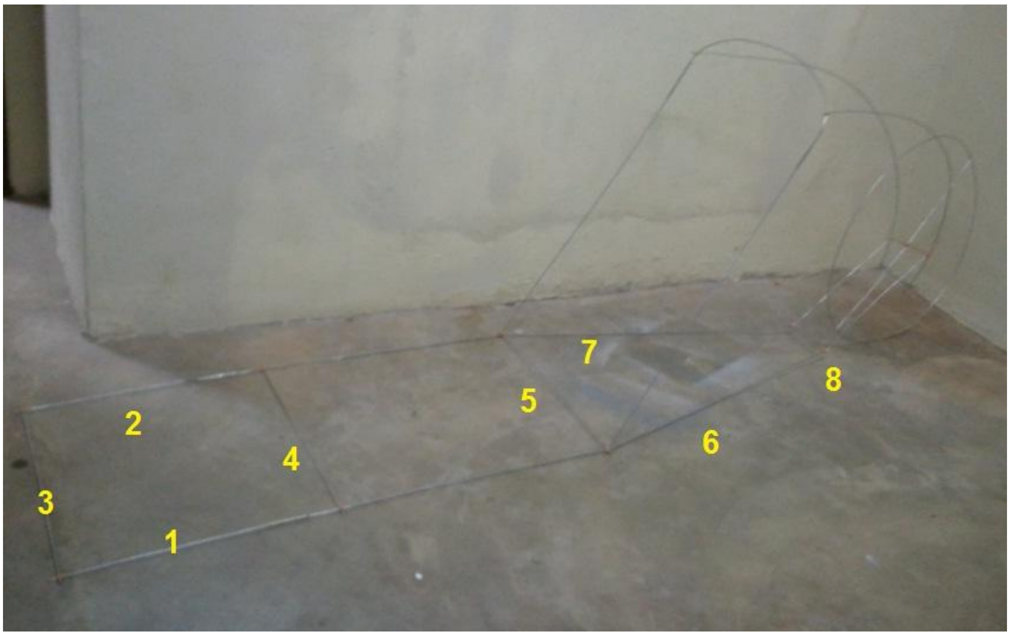


Figure 3.5: Chassis Bottom Supports.

Once the floor of the chassis was setup, the next part is assembled the roll loop and supporting bars. Bar 11 is tangent arc shape where represents the top of the roll loop. This way, it can see where the highest point on the roll loop is as compared to the rest of the chassis. Support 9 and 10 are the first set of supporting bars to help stabilize the roll loop. Once the roll loop was setup, and then proceeded with attaching the rest of the supporting bars for the chassis. The bar noted as 12 and 13 will be formed to support the roll bar from the rear axle of the chassis. It's shaped with tangent arc so that the area for engine bay can be fully utilized. The rear bottom area, bar 14 and 15 will connect to the bottom chassis (from bar 6, 7 and 8) to support the rear axle. The bar 16 is refer to the hub of the wheel, 17 is represent the actual radius of expected tire; ± 300mm, and the bar 18 in round shape will totally refer to the expected tire to be used. The Figures 3.6 and 3.7 are the rear chassis construction (engine bay) and totally complete chassis:

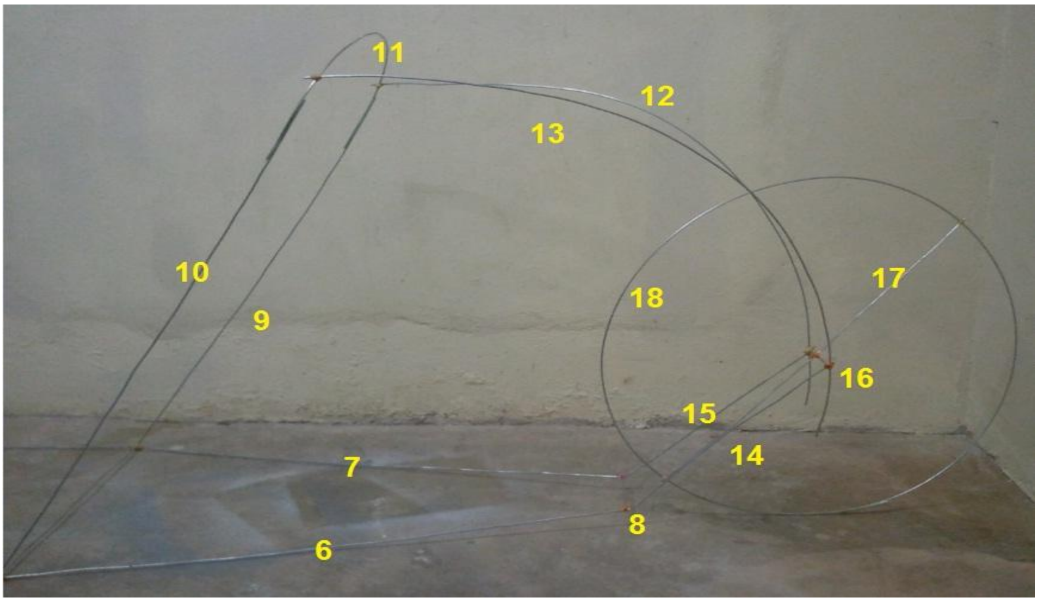


Figure 3.6: Chassis Roll Loop and Rear Chassis Approximation.

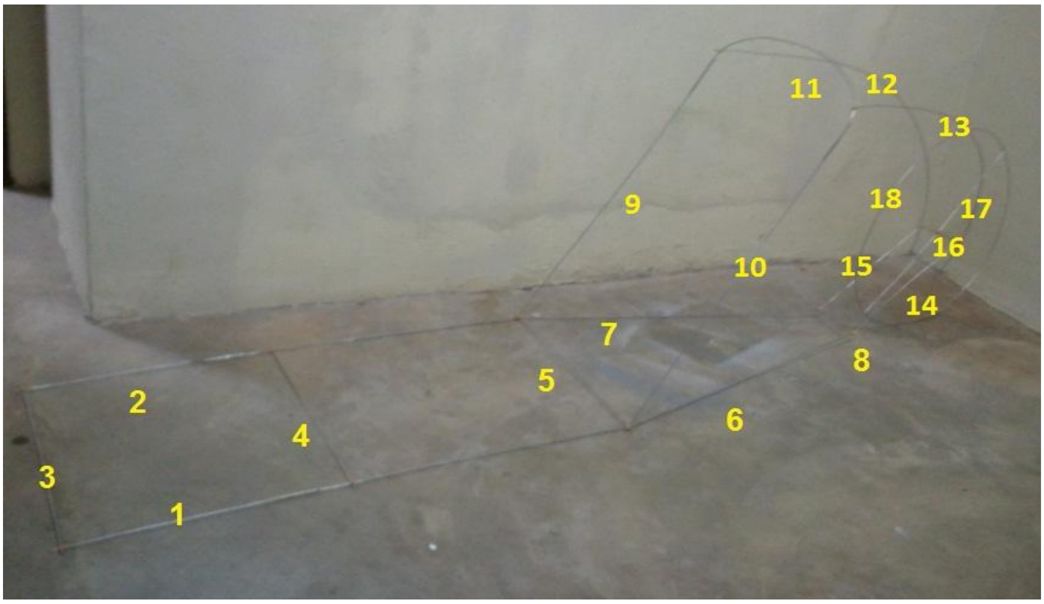


Figure 3.7: Complete Chassis view.

Once the structure of the model was fully assembled, the chassis then wrapped with paper so that it can clearly show the boundary of each compartment from driver area, engine bay and the rear tire area where the rear tire also will be installed in the body. Figures 3.8 and 3.9 below represent the wrapped chassis.

Figure 3.8: Isometric view of wrapped chassis.

Figure 3.9: Wrapped rear chassis view.

3.2.2 Driver Test Fit

After wrapping the chassis, it is tested out by having the driver sit inside. This process also performed emergency ingress/egress tests with the model. One of the technical requirements for the competition is that the driver needs to get in or out of the car in less than 10 seconds unassisted. The following Figure 3.10 and Figure 3.11 is the driver sitting position in the chassis.

Figure 3.10: Driver Test Fit 1.

Figure 3.11: Driver Test Fit 2.

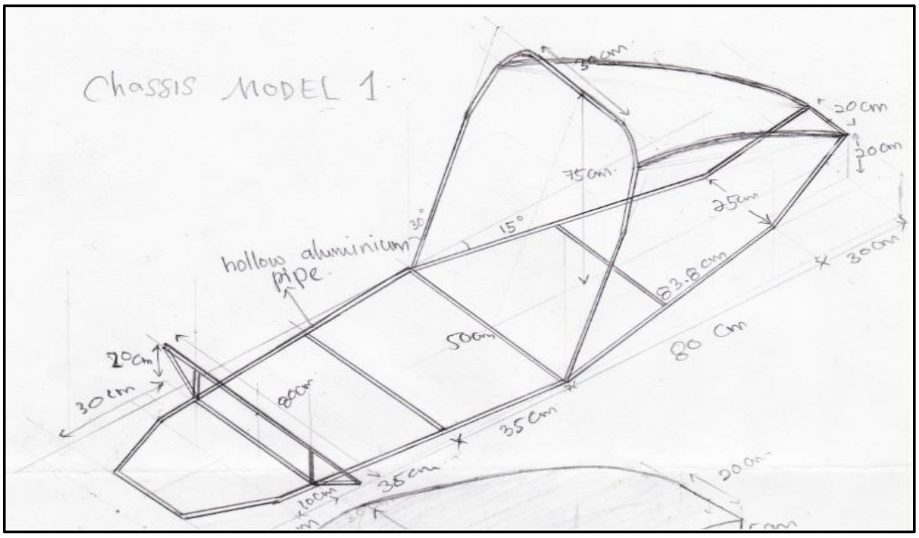
The first thing has been noticed after having the driver in the model car is that with the current dimensions, there is plenty of room for the driver. This is good because this was the whole purpose of making this model. The secondary purpose was just to be able to see what it would look like once it finally assembled the complete chassis from suggested material.

3.3 THREE IMPROVED NEW MODEL FOR SEMA12

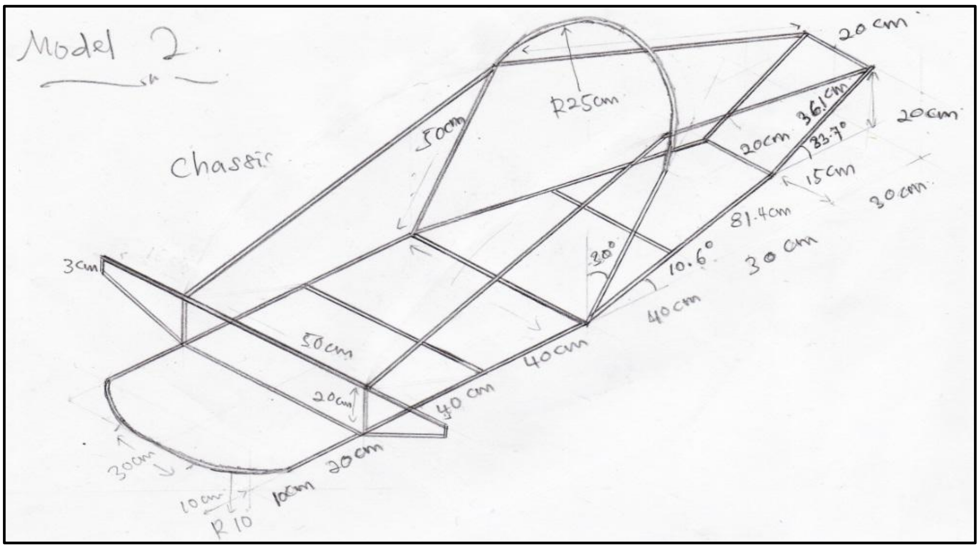
For this part, basic engineering drawing will be applied and Solidwork 2012 is used to create the models of the chassis which proposed for the new designs. Below explains how the sketching and modeling chassis design were performed.

3.3.1 Sketching The Chassis

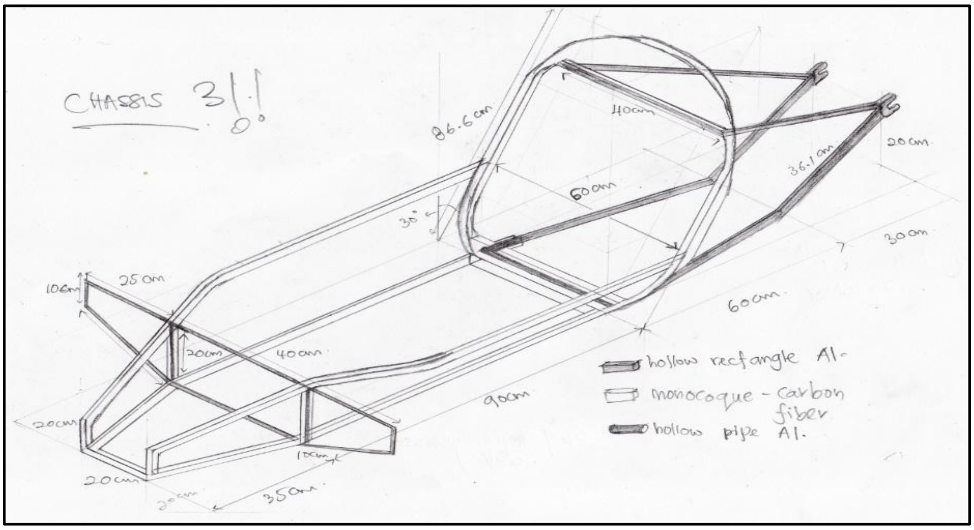
The rough idea of the new chassis design is described by sketching the chassis. The criteria's that must be considered in the sketching process are the shape of chassis, dimensions which provided in Shell Eco Marathon's rule and regulation, and the specification of previous design. The dimensions from mock up model totally being considered for the entire three models. Figure 3.12 shows the three sketching of the new chassis design.



(a)



(b)



(c)

Figure 3.12: (a) Sketch on chassis 1, (b) Sketch on chassis 2, (c) Sketch on chassis 3.

3.3.2 Modeling the Design

After sketching rough idea of all the chassis, next step is modeling process. Modeling process is a step of model the chassis using Solidwork 12 software according to the actual size. The process for modeling a single tube in Solidworks 12 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.

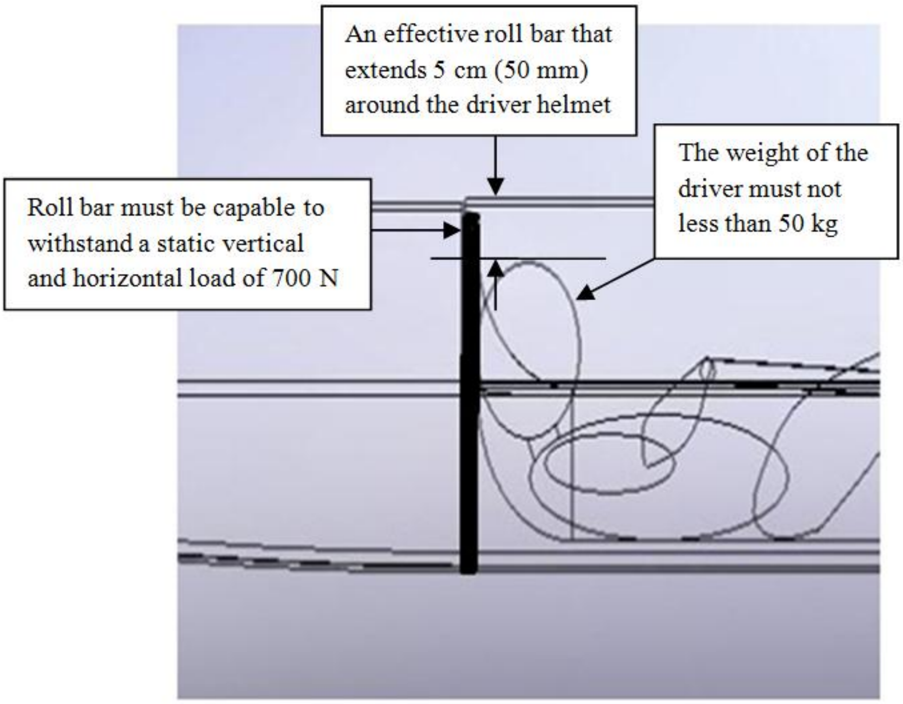
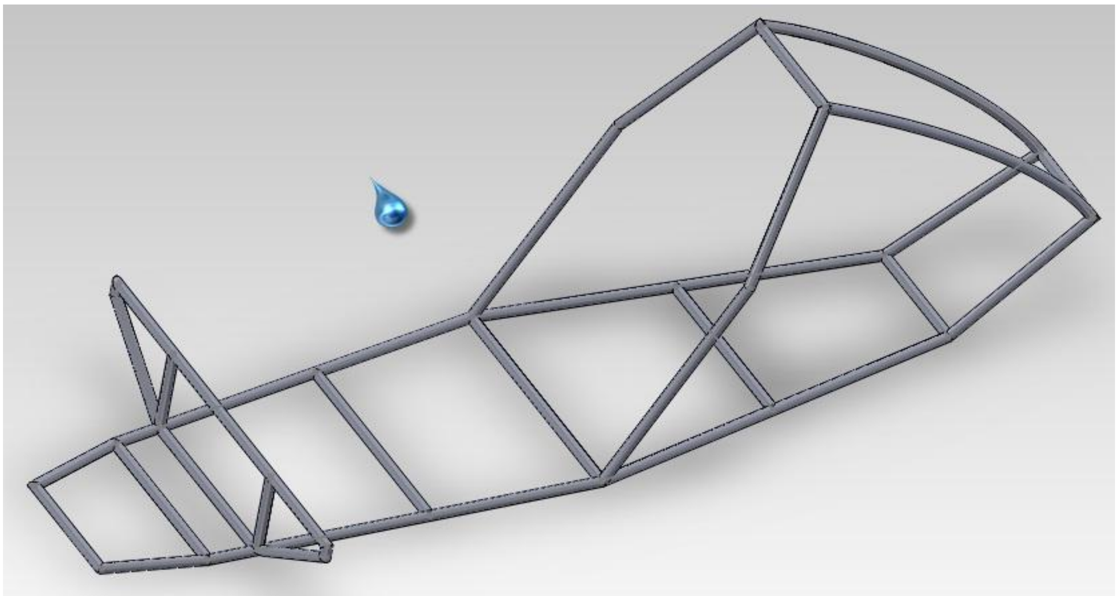


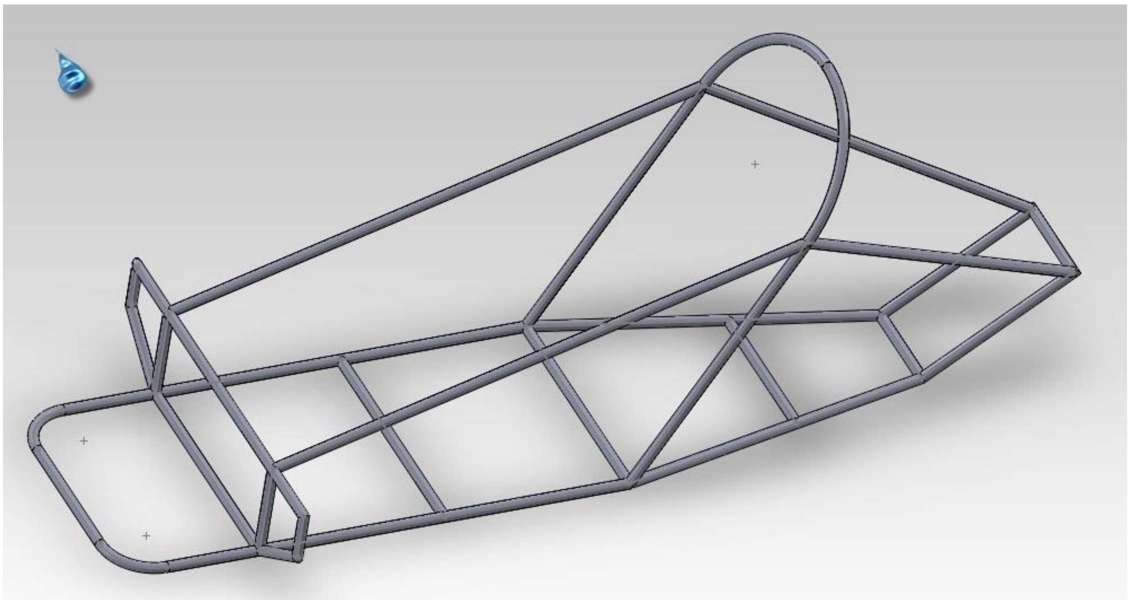
Figure 3.13: Regulations related to the front and main roll hoops and bracing.

Source: Shell Eco Marathon, Official Rules 2012 (2012).

Figure 3.14 shows the three proposed model of the new chassis design which done by Solidwork.

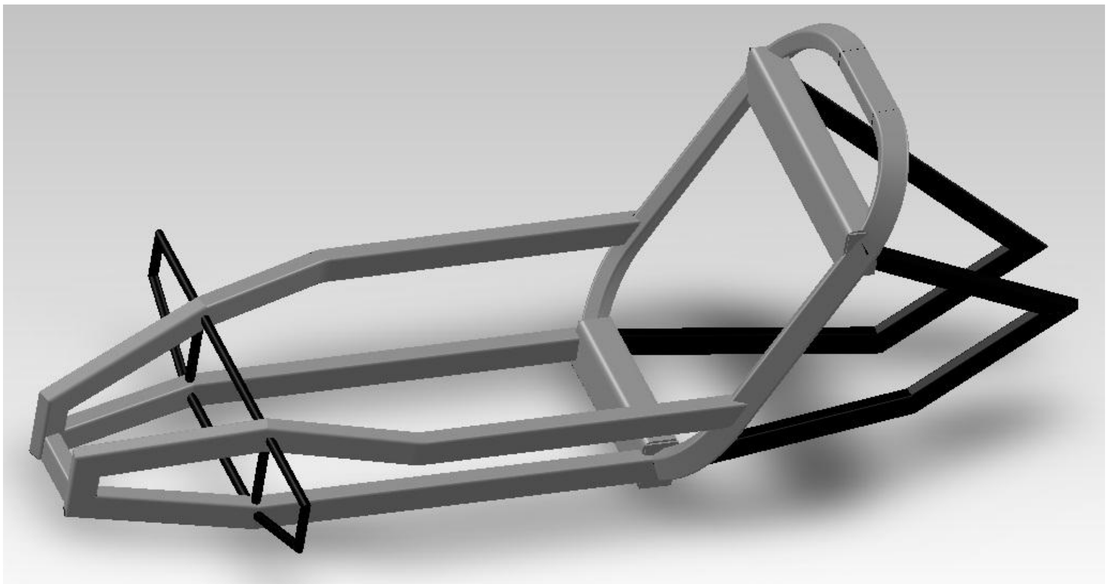


(a)



(b)

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



(c)

Figure 3.14: Continue.

3.4 TECHNICAL SPECIFICATIONS OF NEW MODELS

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 will tested and analyzed using the ALGOR 23.1 software in full report of chapter 4. 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 observed are the formation of the chassis when load applied, the stress of the chassis structure, and total weight of each chassis. Tables 3.1, 3.2 and 3.3 shows the three new designs and technical specification and material proposed for each design. Appendices D1, D2, D3 are referred to the trajectory view of each model.

Table 3.1: Technical specifications for design 1.

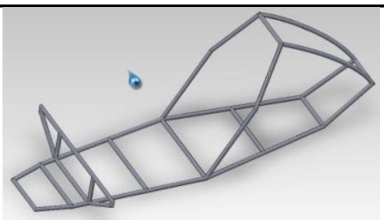
Configuration	3 wheels	
Chassis 1		
Body material	Polycarbonate	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	2.54 x 0.5 cm (round tube)
	Roll bar	2.54 x 0.5 cm (round tube)
	Lower side impact structure	2.54 x 0.5 cm (round tube)

Table 3.2: Technical Specifications of design 2.

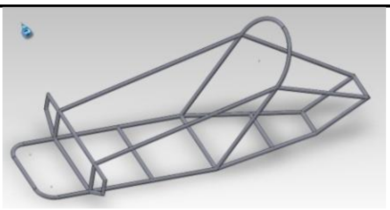
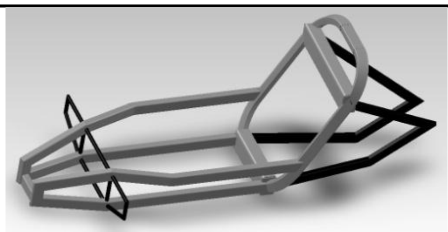
Configuration	3 wheels	
Chassis 2		
Body material	Fiber glasses	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	2.54 x 0.5 cm (round tube)
	Roll bar	2.54 x 0.5 cm (round tube)
	Lower side impact structure	2.54 x 0.5 cm (round tube)

Table 3.3: Technical specifications of design 3.

Configuration	3 wheels	
Chassis 3		
Body material	Fiber glasses	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	2.54 x 0.5 cm (round tube)
	Roll bar	2.54 x 0.5 cm (round tube)
	Lower side impact structure	2.54 x 0.5 cm (round tube)

3.5 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 will conduct for the three new designs which proposed are same as analysis done for the existing design. The material used is different for all design which is aluminum Alloy 6063-T6 only or integrated with combination of aluminum alloy and fiber glasses. 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 equal to 600 N will be applied to the driver compartment where represent the minimum driver mass is 60 kg. Force act to the driver compartment is consider to be 600 N cause for the minum weight of driver same as the previous analysis. While force F equal to 100 N will applied to the engine compartment where represent the mass of engine is 10 kg.

3.6 LOADS APPLIED ON THE CHASSIS

3.6.1 Determination of Loads

To design a chassis, assumptions need to be calculated as to the expected loads that could be experienced by the chassis. These loads should include the known static loads of the vehicle components such as driver and engine, while also including predicted dynamic loads which will occur through suspension and drive train components. Worst case loads should also be calculated and designed for to prevent the vehicle failing and injuring the driver. While the vehicle is stationery there are constant loads from the vehicle components and the self weight of the vehicle being transmitted through the suspension to the ground. Once the vehicle is in motion these components cause load paths that are much more complicated. When the vehicle is cornering, accelerating and braking these loads are then applied in different and varying directions. Radial forces are also produced throughout the chassis by rotating components (Baker, C. S. 2004).

3.6.2 Static Load Paths

When the car is stationary the loads from the vehicle have to transfer from the various components through the spaceframe to the wheels and to the ground. When designing the chassis, it is very important to be aware of these load paths so that the components are supported with minimal deflection (Baker, C. S. 2004). The main components that need to be focus are the mass of engine and the driver because these two masses is major in the total mass of the vehicle while minor components account for the remaining weight. In this subject of analysis, it is focused on the type of vertical load only which by clear means to take account the weight of the driver as well as the engine and equipment that caused the frame to sag. Suspension system is not applied due to simplicity of the design. In fact, the tire itself acts like a suspension on the road. This analysis is basically considering the static load which means it is do not observe the result in dynamic condition as shown in Figure 3.15.

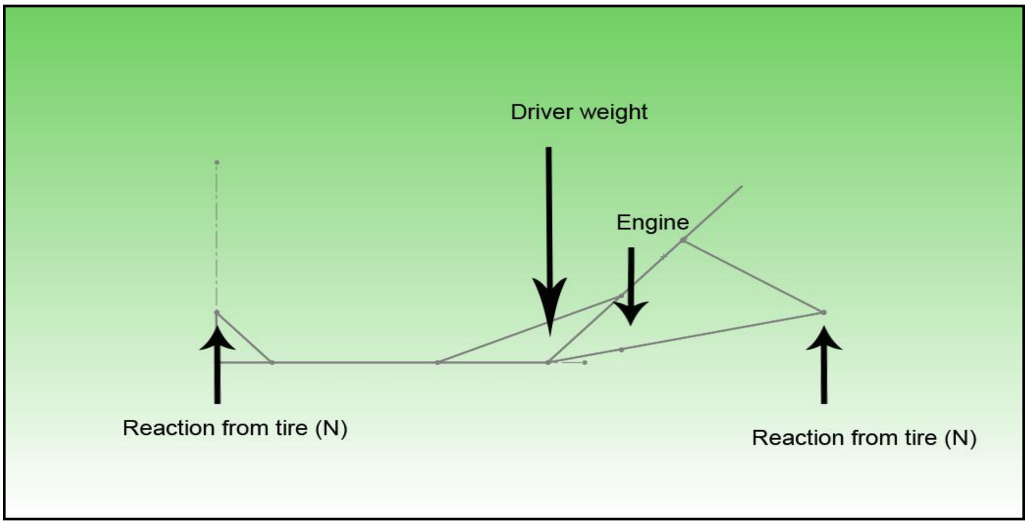


Figure 3.15: The correspond load that acted upon the design.

Source: Afnan, H. (2010)

3.6.3 Dynamic Load Paths

Dynamic vehicle loads are created from accelerating and braking, which are proved through Newton's law. When the vehicle is braking large forces are produced by the brake calipers pressing on the disk brakes. When analyzing these accelerating and braking forces, most of the analysis will be on the driver and engine using Newton's second law (Giancoli, 1991) as shown in Eq. (3.1).

$$F = m \times a \tag{3.1}$$

Where:

F is Applied Force

m is Mass of Component

a is Acceleration

From previous years results in the acceleration test, competitive vehicles have reached accelerations capable of 0 to 40km/hr in around 10 seconds. Assuming that the acceleration is constant the formula (Giancoli, 1991) as shown in Eq. (3.2).

$$a = \frac{v_f - v_i}{dt} \tag{3.2}$$

where:

a is Acceleration

vf is Final velocity

vi is Initial velocity

dt is time

3.6.4 Torsional Braking Loads

When the vehicle is braking large forces are produced by the brake calipers pressing on the disk brakes. These braking forces are the largest forces in the race car and produce a large moment due to the rotating nature of the brake disk. These loads are transmitted through the wishbones to the chassis on the front wheels and through the caliper mount on the rear wheels. Knowing the top speed of the vehicle and the time it takes while braking hard to come to rest, will provide sufficient data calculate the braking loads using the impulse-momentum theorem in Eq. (3.3).

$$F = \frac{mv_f - mv_i}{dt} \tag{3.3}$$

Where

F is Applied Force

m is Mass of vehicle

v is final and inital velocity

dt is time

3.6.5 Defined Loads

These are approximations of loads that may be experienced by the car spaceframe chassis. It should be noted that all of these loads are calculated on assumptions however they are generally similar to real loads produced. Values are obtained neglecting some minor factors and using worst case scenario values to produce maximum loads in all cases, this is so the chassis is capable of withstanding all possible situations with estimated total mass of the vehicle in Table 3.4. These loads will be applied in the direction of gravity through the engine mounts and through the seat. The suspension will hold the total mass of chassis as well as all components.

Table 3.4: Estimate Total Mass of Vehicle.

Static Loads:	
Mass of engine	10 kg
Mass of body	10 kg
Self mass of chassis	20 kg
Mass of driver	60 kg
Mass of equipment	10 kg
Estimate Total Mass of Vehicle	**110 kg**

3.7 STRESSES CRITERIA

In order to analysis all the parameters of the designs, the specified structural boundary conditions are applied to the model as shown in Figure 3.16. At the tire axle, the design was fixed in x, y, and z direction. Distributed force then applied to the driver's compartment and engine compartment. A distributed force of 600 N applied to the driver's compartment while forces about 100 N is applied to the engine compartment. Distributed forces act to the driver compartment is 600 N because considering the expected mass of the driver is 60 kg while the expected total mass of the engine is 10 kg. The force acting on engine's compartment is estimated to be 100 N because the weight for engine is about 70 N then plus with the additional parts such as sprocket, brackets of bearing and sprocket mounting which estimated weight of 30 N. In static load, it is assumed that frames acts as cantilever beam and its end is made fixed on the arm of the tire, which is two at the front and one at the rear of the chassis. Figure 3.17 shows the SolidWork model of existing design applied to Algor 23.1 software.

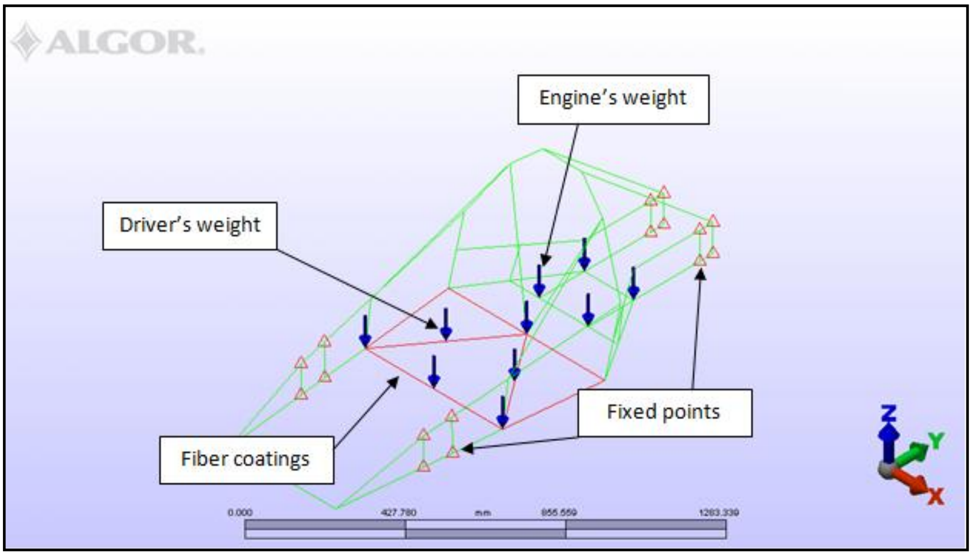


Figure 3.16: Applied forces and fixed point of chassis.

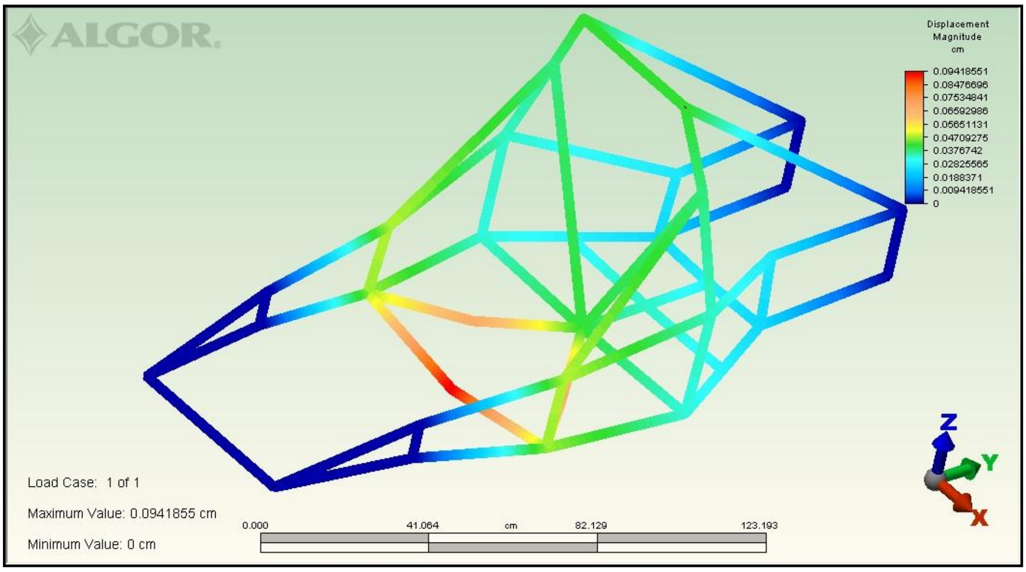


Figure 3.17: SolidWork model of Existing Design applied to Algor 23.1 software.

Table 3.5: The related mass and respect material usage upon the Existing Design.

Component	Material	Mass (kg)
Chassis	Aluminum Alloy 6063-T6	17.61
Car body	C-Fiberglass	10.89
Visible window	Perspex	1.70
Driver	NA	60.00
Equipment	NA	10.00
Engine	NA	6.00
	Total mass of car	**106.26 kg**

Excessive stresses on the chassis can cause deflection, buckling, plastic deformation and eventually failure. This is why it is important to understand the principles of stresses and how they are formed and transferred through the chassis. The understanding of load paths through the chassis can also substantially influence the design of stress members (Baker, C. S. 2004).

3.7.1 Axial Stress

Axial stress occurs when loads are applied parallel to the direction of the material and can be in two forms; tension and compression. Axial stress is very common in spaceframes as they are made from a series of straight members, many of which are in the direction of the applied forces.

(i) Tension Members

A tension member is a straight member subjected to two pulling forces applied at either end (Johnston 1992). When the load within the tension member coincides with the longitudinal centripetal axis of the member, the stress distributed through the member can be assumed to be uniform and defined by using Eq. (3.4).

$$\sigma = \frac{P}{A} \tag{3.4}$$

where:

σ is Normal Stress

P is Load

A is Cross Sectional Area

When the normal stress of the tension member exceeds the yield strength of the material, the member will experience plastic deformation which is permanent to the material where the frame will be considered ruined. The plastic deformation can leave the chassis permanently bent and twisted. When designing a chassis the working stresses should be well clear of the yield strength to avoid this deformation. If normal stress of a tension member exceeds the tensile strength of the material, failure of the member will occur. Usually the tensile strength of the material is extremely high and should even be well above the stresses reached in a collision.

(ii) Compression Members

A compression member is a straight member subject to two pushing forces applied at either end: (Johnston, 1992). The fundamental theories of buckling apply to compression members as the member will fail due to buckling long before the yield strength of the material is reached. This is why compression members are the main concern when axial loads are analyzed. The length of the member is very critical when modeling buckling, because all members of chassis are welded at both ends the effective length can be reduced to Eq. (3.5).

$$L_e = 0.7 \times \mathrm{L} \tag{3.5}$$

This effective length can then be used in Euler's classical Eq. (3.6).

$$p_{cr} = \frac{(\pi^2 \mathrm{EI})}{\mathrm{Le}^2} \text{ (4.6)} \tag{3.6}$$

Where:
Pcr is Critical Load
E is Modulus of Elasticity
I is Area Moment of Inertia
Le is Effective Length

This equation assumes that the member is perfectly straight and homogeneous. If the member is subject to a load below the *Pcr* load it may deflect slightly but the internal elastic moment will remain adequate to restore straightness to the member when the load is removed. When the *Pcr* load is exceeded the lateral displacement will produce an eccentric bending moment greater than the internal elastic restoring moment resulting in the member collapsing and no longer being able to carry load.

3.7.2 Deflection

Previously have already explained the undesirable effects of deflection within the chassis. However, if the chassis was constructed so that no deflection would occur, it would require extensive amounts of material resulting in excess weight. Deflection can be caused by many different stresses, such as axial forces in either tension or compression and even torsional stress caused by twist or rotation. The analysis of deflection can then become increasingly complicated with the introduction of biaxial stressing as shown in Eq. (3.7).

$$\delta = \frac{PL}{AE} \tag{3.7}$$

where:

δ is Deflection

P is Load

L is Length

A is Cross Sectional Area

E is Modulus of Elasticity

3.7.3 Bending

Bending stresses occur when a member is subject to a rotational moment load. This moment causes one side of the member to be in tension while the other is in compression. The bending stress can be calculated using Eq. (3.8).

$$\sigma_b = \frac{M_x y}{I_x} \tag{3.8}$$

Where:

σ_b is Bending Stress

Mx is Bending moment about the neutral axis

y is Distance from the neutral axis

Ix is moment of inertia of the cross section about the neutral axis

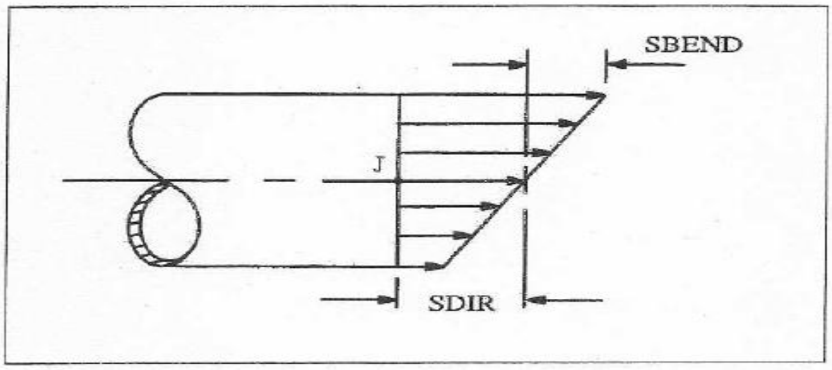


Figure 3.18: Bending Stress.

Source: Stress Analysis Study Book (2004)

As shown in Figure 2.16, the maximum bending stress occurs at the outer surface. For bending situations, it is only important to have material at the outer most edge of the member, as this is where the maximum stresses occur. This is why hollow section tubes are excellent materials for resisting bending stresses. Bending stresses are common in chassis due to the large rotational moments caused by components such as the engine and drive train as well as other dynamic forces caused by vehicle travel.

3.7.4 Stress Analysis

The common methods used are to physically apply loads to the chassis and measure the deflections by sight or by attaching strain gauges. When the deflection is known the stress can be calculated. Stresses can also be calculated using simple formulas and hand calculations but this usually requires many simplifications to be made. When complex structures such as chassis are analyzed, the formulas become very large and complex, therefore computer programs are required to calculate the stresses involved.

3.8 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 space frame 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. Space frame materials and fabrication techniques are generally universal across race vehicle categories. Space frame 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 hollow 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 may refer to Eq. (2.6) and Eq. (2.7).

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, we must consider the limitation that have. Limitations such the cost for the material and availability for the material in market must to consider. The materials which used to build the space frame chassis is Aluminum where have been discussed in chapter 2.5: Material Selection Process.

3.9 CONCLUSION

This chapter discussed the work progress in developing the designs of proposed chassis. This methodology also discussed the expected condition where physically evaluated for the new chassis designs from material of chassis will be use, and the material of body will be choose.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter 4 discuss about the existing model analysis and the result of new three optional designs for prototype car chassis. The objective of this chapter is to determine which one is the best design from all the optional design compared to existing design and will be proposed for the next participant of Shell-Eco Marathon Asia 2012 competition. The parameters to be observed in this study are the weight of the chassis structure, the deformation of the chassis when load applied, and the acting worst stress of the chassis structure. While the constant parameters are the type of material: aluminum alloy 6063-T6, size of tubular pipe with dimension 2.54 cm × 0.5 cm, and the applied load onto the chassis structure. This analysis will be focusing on the load test from the driver and engine compartment.

4.2 ANALYSIS OF EXISTING CHASSIS USING FINITE ELEMENT ANALYSIS

In order to develop any new design, the analysis of the existing design is executed by using Finite Element Analysis and the weaknesses of the existing design were identified and improved. FEA 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 is also used to debug the existing model. This first step is more cost-efficient and allow to more creative solutions at the early stage in designing process.

Modeling process requires three types of input data which are geometry coordinates, the properties of material, and types of loading. For the space frame chassis analysis, "geometry coordinates" means the overall frame dimensions such as tube lengths, intersection points and etc. The linear beam element is chosen for modeling the geometry of the chassis. The tubular members are modeled by using straight pipe elements with circular cross section of the roll bar, lower side impact member, side impact members and the front box chassis member. Figure 4.1 shows the finite element model for the existing chassis design were constructed of Aluminum Alloy 6063-T6 and Table 4.1 shows the technical specification of existing design for SEMA1.

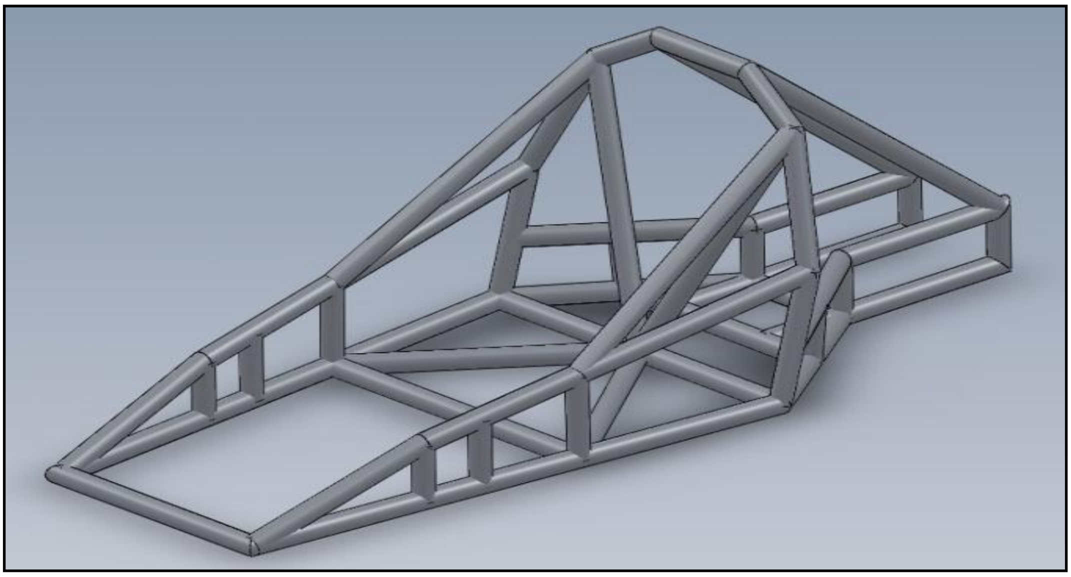


Figure 4.1: Finite element model for existing chassis design.

Table 4.1: Technical specification of existing design for SEMA11.

Analysis	**Chassis frame model**
Configuration	Three wheels
Material	Aluminum Alloy 6063-T6
Total chassis weight	176.1 N
Maximum deflection (Y-axis)	0.09418551 cm
Maximum worst stress	1509.169 N/cm^2
Mass of chassis	17.61 kg

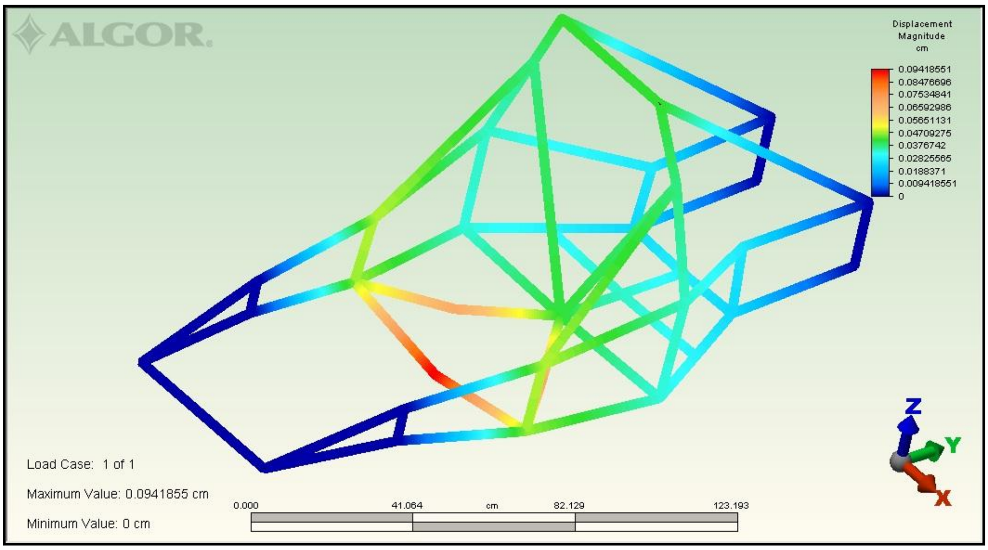


Figure 4.2: Displacement magnitude occurs on Existing Models.

Figure 4.2 shows the deflection occurs when the load applied to the driver and engine compartment on chassis structure. The maximum value of displacement magnitude is at 0.09418551 cm which is indicated on driver's compartment and represented by red region. The region which is near to the fixed point undergoes minimum displacement with magnitude 0.009418551 cm. This region represented by blue color. The center part of the chassis structure bears most loads due to existence of shorter side members where the displacement could not be distributed in a greater way compared to having long side beam members.

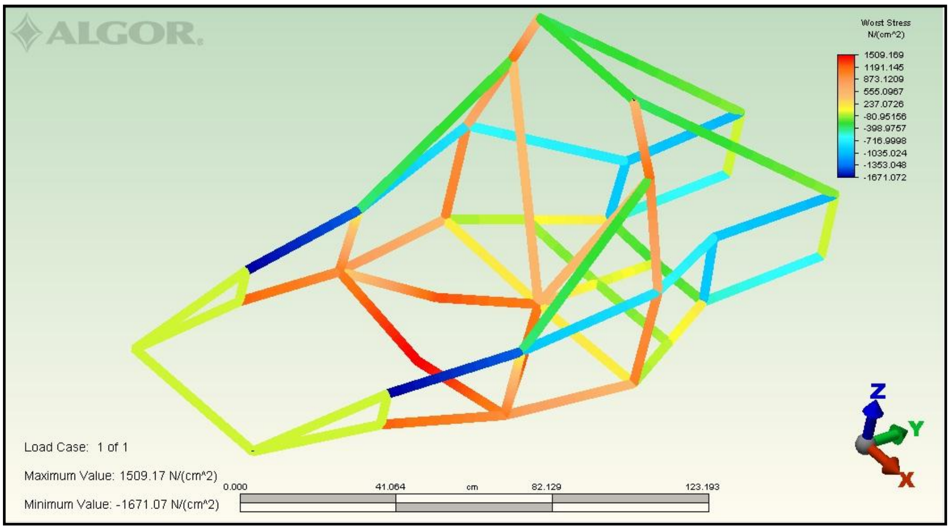


Figure 4.3: Worst stress occurs on Existing Chassis Design.

Figure 4.3 shows the analysis of the driver and engine compartment of the Existing Model. Results obtained show that the structure of chassis undergoes worst stress which is 1509.169 N/cm^2. Note that stress is the average amount of force exerted per unit area. It is the internal resistance a material offers to being deformed and is measured in terms of the applied load. Worst stress occurs due to the various cross section of the chassis structure. 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. Table 4.2 will shows the information was generated by Algor 23.1 features.

Table 4.2: The Information Was Generated By Algor 23.1 Features for Existing Model

Model Information :					
Volume cm^3		6.6465E+003	**Weight N**	1.7613E+02	
Center of Gravity cm		**Mass moment of inertia N*s^2*cm**		**Mass product of inertia N*s^2*cm**	
Xc	-2.1266E-16	**Ixx**	2.8331E+03	**Ixy**	-2.4425E-15
Yc	1.1217E+02	**Iyy**	2.7541E+02	**Ixz**	2.7756E-16
Zc	1.8115E+01	**Izz**	2.0897E+03	**Iyz**	4.1754E+02

4.2.1 Discussion Based on the Analysis of Existing Designs

Referring to data of analysis, it shows various formations of color on the design structure. The colors represent the several of magnitudes displacement occur in the structure. The red sector shows the maximum displacement of the structure and the minimum displacement represented by blue sector. The displacements occur decreased correspond to the colors followed by red, yellow, green and blue. Almost red sector occur at the center of the structure which is in the driver's compartment.

Results show that the driver's compartment undergoes bending stress due to the weight of the driver acting on that section and the maximum magnitude of the displacement is 0.09418551 cm and undergoes worst stress which is 1509.169 N/cm^2. The result on engine compartment observed is slightly smaller and it is proved that the structure is strong enough to stand the load apply in engine area. Even though, the chassis still being relevant to be used but the structures will not long lasting. Moreover, the mass of previous design is quite heavy which 17.61 kg is. In addition, more fuel required to produce high combustion in the engine in order to run the car from the stationary position as well as overcome the drag force. It will cause less fuel efficiency.

4.3 ANALYSIS OF THREE IMPROVED CHASSIS DESIGNS

There are three new designs of prototype car chassis which designed based on the specifications that required by the rules and regulations of Shell Eco Marathon 2012 competition. Target of the development is to have the result of light in weight of chassis structure, then observing the displacement magnitude and worst stress. All designs were modeled using SolidWork 2012 software, while it tested and analyzed by using Algor 23.1 software. The analysis of the new designs which proposed are conducted as same as analysis done to the existing design. The specified structural boundary conditions are applied to the models. The chassis structure is fixed in all x, y, and z direction at the front and rear axle connection where the fix point representing the mounting of the tires. Tables 4.5, and Figures 4.4, and 4.5 shows the result from the analysis of the driver and engine compartment test for model 1 using Algor 23.1 software.

4.3.1 Analysis on Model 1

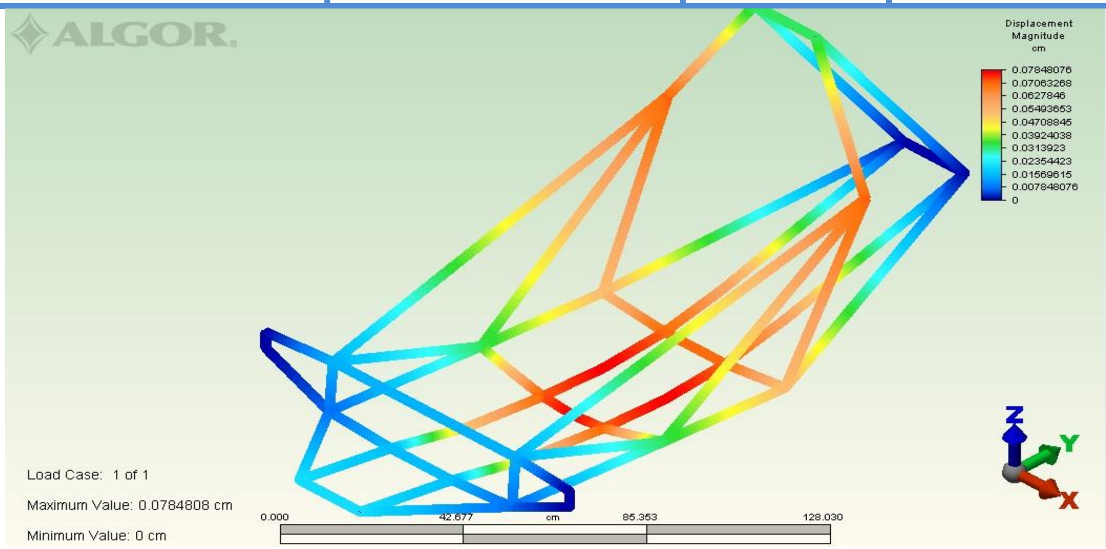
Table 4.3 below will describe about the physical properties of structure Model 1 where shows that the weight of the chassis is 177.85 N.

Table 4.5: Physical properties of structure Model 1.

Model Information :					
Volume cm³	6.7116E+03	**Weight N**		1.7785E+02	
Center of Gravity cm		**Mass moment of inertia N*s²*cm**		**Mass product of inertia N*s²*cm**	
Xc	-1.0000E+01	**Ixx**	2.4353E+03	**Ixy**	-1.7853E+02
Yc	9.8521E+01	**Iyy**	2.5011E+02	**Ixz**	-2.8853E+01
Zc	1.5922E+01	**Izz**	2.4381E+03	**Iyz**	3.6478E+02

Figures 4.4 and 4.5 shows the result of bending displacement and worst stress of the Model chassis 1 when load about 110 kg is applied on the chassis.

Name	Type	Min	Max
Displacement1	Displacement magnitude	0 mm Node: 11	0.07848078 cm Node: 362

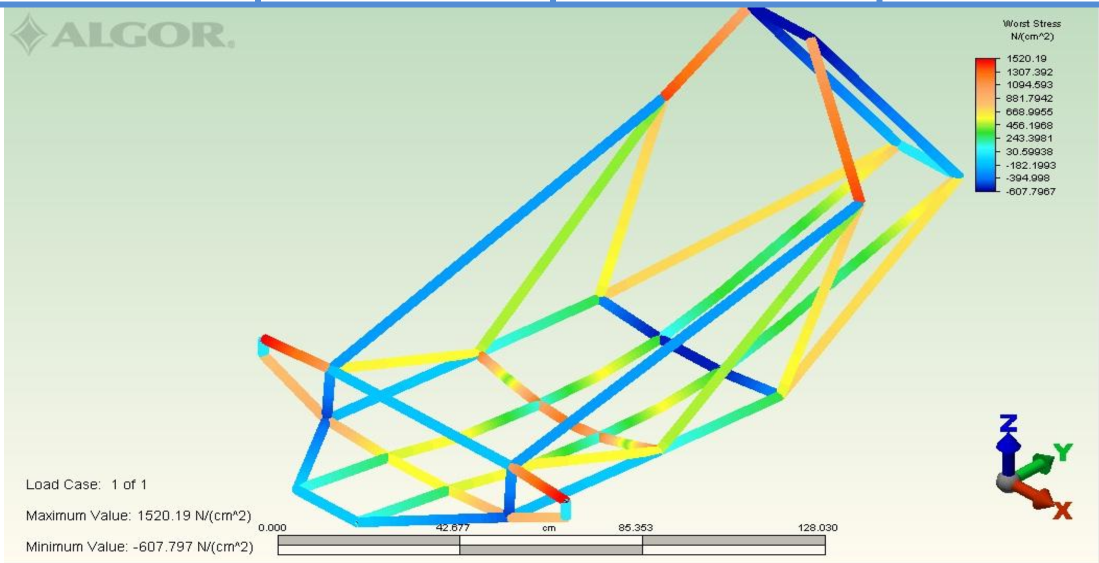


Model 1

Figure 4.4: Displacement magnitude occurs on the Model 1.

Figure 4.4 shows the analysis of the driver and engine compartment of chassis for design 1. Results obtained show that the structure of chassis undergoes bending on a maximum displacement magnitude which is 0.07848078 cm. The maximum displacement mainly focused underneath the driver's compartment. This is due to the long side beams provide strong support for side and back of the driver. Therefore, the displacement is about equally distributed.

Name	Type	Min	Max
Stress1	Worst Stress	0 N/m^2 Element: 11	1520.19 N/ cm^2 Element: 55



Model 1

Figure 4.5: Worst stress occurs on the Model 1.

Figure 4.5 shows the analysis of the driver and engine compartment of the Model 1. Results obtained show that the structure of chassis undergoes worst stress which is 1520.19 N/cm^2. This is a measure of the maximum force per unit area of a surface within the body on which internal forces act. These internal forces arise as a reaction to external forces applied on the body. Because the loaded deformable body is assumed to behave as a continuum, these internal forces are distributed continuously within the volume of the material body, and result in deformation of the body's shape. Beyond certain limits of material strength, this can lead to a structural failure.

4.3.2 Analysis on Model 2

Table 4.4 below will describe about the physical properties of structure Model 2 where shows that the weight of the chassis is 151.64 N.

Table 4.4: Physical properties of structure Model 2

Model Information :					
Volume cm³		5.7223E+03	**Weight N**	1.5164E+02	
Center of Gravity cm		**Mass moment of inertia N*s²*cm**		**Mass product of inertia N*s²*cm**	
Xc	3.5929E-16	**Ixx**	2.2424E+03	**Ixy**	-3.5527E-15
Yc	1.0196E+02	**Iyy**	1.8589E+02	**Ixz**	-1.7764E-15
Zc	1.5702E+01	**Izz**	2.2242E+03	**Iyz**	3.0420E+02

Figures 4.6 and 4.7 shows the result of bending displacement and worst stress of the Model chassis 2 when load about 110 kg is applied on the chassis.

Name	Type	Min	Max
Displacement1	Displacement magnitude	0 mm Node: 39	0.09329168 cm Node: 229

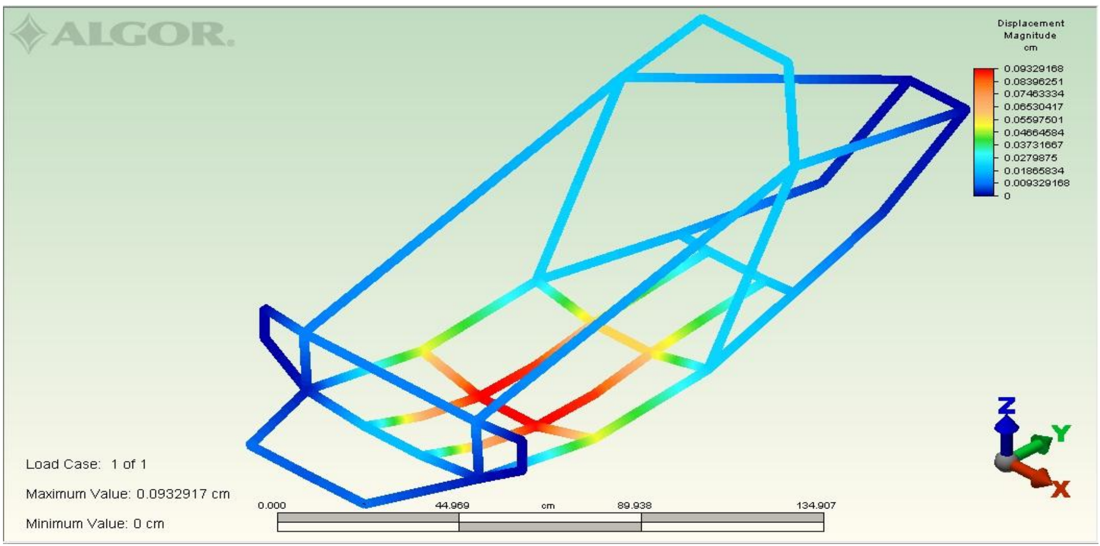


Figure 4.6: Displacement magnitude occurs on the Model 2

Figure 4.6 shows the analysis of the driver and engine compartment of chassis for model 2. Results obtained show that the structure of chassis undergoes bending on a maximum displacement magnitude which is 0.09329168 cm. The maximum displacement also focused below the driver's compartment. This is due to the long side beams provide strong support for side and back of the driver where characterized the behavior of a slender structural element subjected to an external load applied perpendicularly to a longitudinal axis of the element.

Name	Type	Min	Max
Stress1	Worst Stress	0 N/m^2 Element: 356	1612.237 N/ cm^2 Element: 418

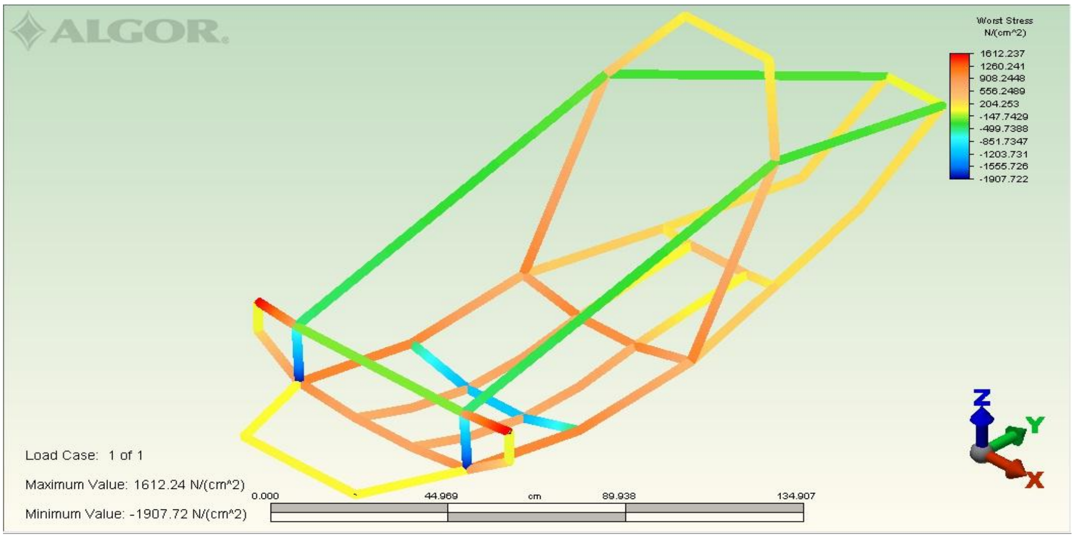


Figure 4.7: Worst stress occurs on the Model 2

Figure 4.7 shows the analysis of the driver and engine compartment of the Model 2. Results obtained show that the structure of chassis undergoes worst stress which is 1612.237 N/cm^2. This concentrates due to the large force on the driver compartment support. Therefore, the design should be considered to have extra support on driver's position load so that will reduce the value of the worst stress occur.

4.3.3 Analysis on Model 3

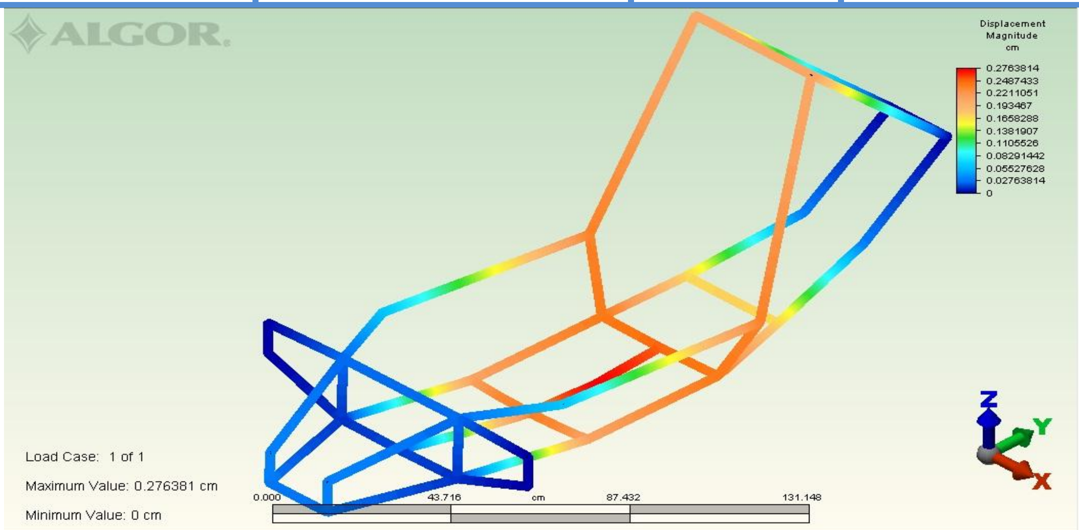
Table 4.5 below will describe about the physical properties of structure Model 3 where shows that the weight of the chassis is 136.30 N.

Table 4.7: Physical properties of structure Model 3.

Model Information :					
Volume cm³		5.1434E+03	**Weight N**	1.3630E+02	
Center of Gravity cm		**Mass moment of inertia N*s²*cm**		**Mass product of inertia N*s²*cm**	
Xc	3.9973E-16	**Ixx**	2.0729E+03	**Ixy**	7.1054E-15
Yc	1.0104E+02	**Iyy**	1.6599E+02	**Ixz**	0.0000E+00
Zc	1.7164E+01	**Izz**	2.0213E+03	**Iyz**	3.2719E+02

Figures 4.8 and 4.9 shows the result of bending displacement and worst stress of the Model chassis 3 when load about 110 kg is applied on the chassis.

Name	Type	Min	Max
Displacement1	Displacement magnitude	0 mm Node: 1	0.2763814 cm Node: 194

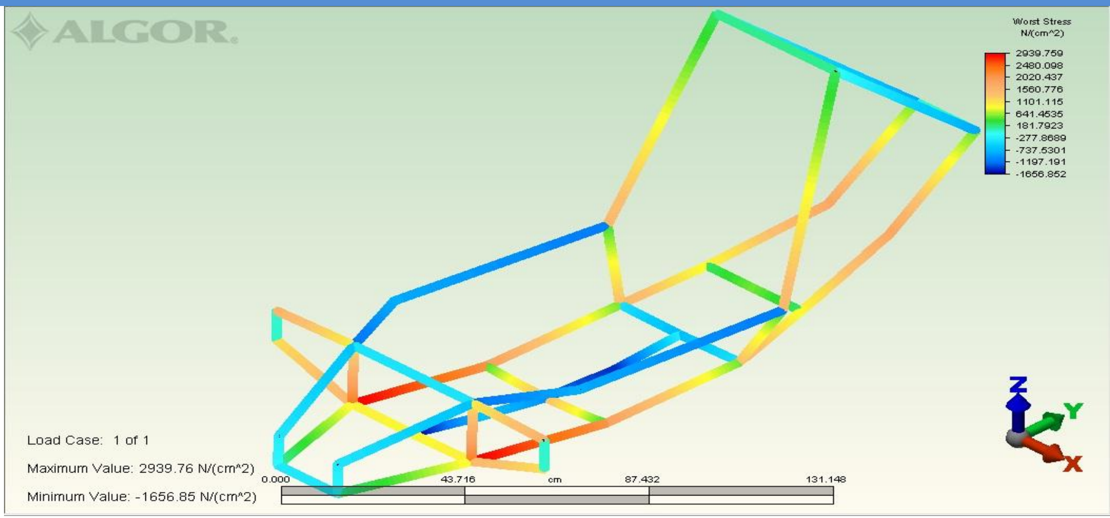


Model 3

Figure 4.8: Displacement magnitude occurs on the Model 3.

Figure 4.8 shows the analysis of the driver and engine compartment of chassis for model 3. Results obtained show that the structure of chassis undergoes bending on a maximum displacement magnitude which is 0.2763814 cm. The maximum displacement mainly focused underneath the driver’s compartment. This is due to the long side beams provide strong support for side and back of the driver. Therefore, the displacement is about equally distributed.

Name	Type	Min	Max
Stress1	Worst stress	0 N/m^2 Element: 1	2939.759 N/ cm^2. Element: 411



Model 3

Figure 4.9: Worst stress occurs on the Model 3.

Figure 4.9 shows the analysis of the driver and engine compartment of the Model 3. Results obtained show that the structure of chassis undergoes worst stress which is 2939.759 N/cm^2. This concentrates due to the large force on the driver compartment support. The load applied was focused on the same point of the structure. Hence the load will not distribute equally along the side member. Consequently, the displacement focused on the centre of the chassis.

4.4 RESULT

After analyzing the three improved model based on its characteristic and regulation required to compete in Shell Eco Marathon 2012, the best one then compared to the Existing Chassis Model. The best selected from improved design of the chassis must have the lowest value of maximum displacement in order to overcome the bending effect of the chassis structure. In addition, the best design of the chassis must have lightest weight. It is important in order to avoid the drag force. Table 4.6 shows the summary of the chassis design for all three wheel prototype car proposed for Shell Eco Marathon Asia 2012 Competition and Figure 4.10 shows the total parameter percentage versus models graph.

Table 4.6: Comparison between the improved models results with the Existing Model.

Configuration	Existing Model	Model 1	Model 2	Model 3
Frame material	Aluminum Alloy 6063-T6			
Mass of chassis, kg	17.61	17.785	15.164	13.63
Displacement magnitude, cm	0.94185751	0.07848076	0.79392168	2.763814
Worst stress, N/cm^2	1509.169	1520.19	1612.237	2939.759

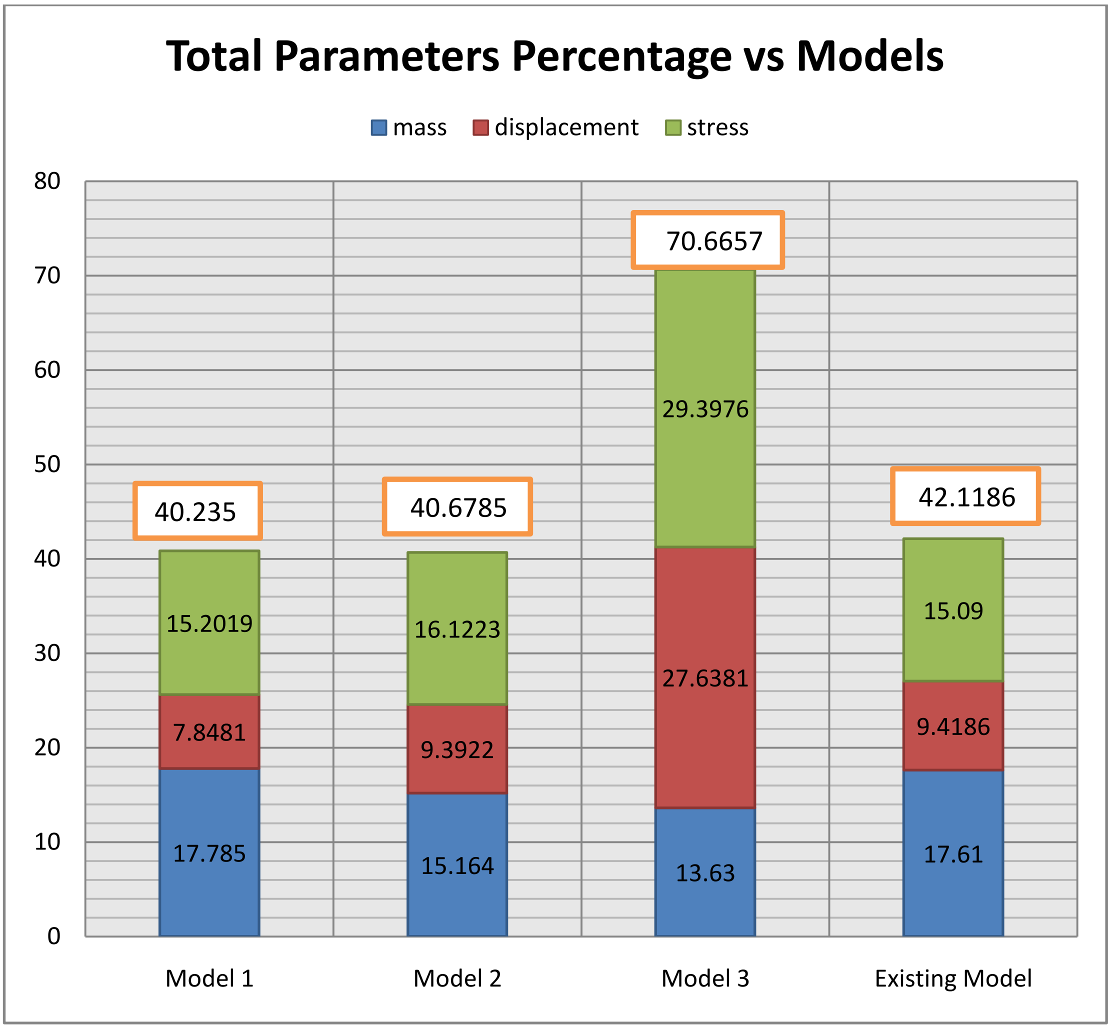


Figure 4.10: Total parameter percentage versus models graph.

4.5 DISCUSSION

Design for Model 2 is the best chassis design to propose for Shell Eco Marathon Asia 2012 competition purpose based on the results from Table 4.6. Based on Figure 4.11 also prove that design 2 provide the most advantages in parameters comparing result between each model. The lowest percentage value is the suitable design to be proposed. Design Model 2 follows all the criteria which required by the rules and regulation of the competition 2012. Design 2 provides relevant mass of the chassis which is 15.164 kg compare two designs 1 and 3 which is 17.785 kg and 13.63 kg respectively. The design 2 shows the decrement about 13.89 % of mass compared to the Existing Model. Furthermore, the design contributes medium bending displacement result when load applied in the driver and engine compartment which is 0.09392168 cm respectively. The maximum displacement magnitude for design 2 is slightly reduced compared to the previous model: 0.09418551 cm. The worst stress for design 2 also is the relevant about 1612.237 N/cm^2 comparison to design 1 is 1520.19 N/cm^2 and design 3 is 2939.759 N/cm^2. In addition, design 2 provides the increment of maximum worst stress about 6.8 % compared to the previous design. Thus, the design for Model 2 is the most suitable to be chosen for production purpose and Table 4.7 shows the technical specification of design Model 2.

Table 4.7: Technical specification of design model 2

Configuration	3 wheels	
Weight	15.164 N	
Frame material	Aluminum Alloy 6063-T6	
Material dimension	Side impact structure	(2.54 x 0.5 cm) (round tube)
	Roll bar	(2.54 x 0.5 cm) (round tube)
	Lower side impact member	(2.54 x 0.5 cm) (round tube)

4.6 CONCLUSION

Chapter 4 discuss about the analysis of Existing Chassis design of Shell Eco Marathon Asia 2011 competition. From the analysis, result obtained shows that existing design using material by Aluminum 6063 T6 is able to withstand on the load applied. Even though 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 and worst stress is observed and the value obtained is small. After comparing with the selected new design which is designed for Model 2, there have a lot of effective improvement can be achieved which is in reducing the weight of the chassis, slightly reducing the maximum displacement magnitude of the chassis and the increasing the maximum worst stress on the chassis structure. Thus, the design for Model 2 is proposed to be constructed for next Shell Eco Marathon Asia 2012 competition purpose.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of this study is to design and develop a chassis for three wheel prototype car where the design to be proposed for the next team member of Shell Eco Marathon Asia 2012 participant. The analysis on the existing chassis was executed in order to improve the weaknesses of the chassis structure. The results from the analysis of the existing design were assisting in the improvement process of the new proposed designs. Other objectives of these projects are redesigning the existing chassis of prototype car which able to withstand the load applied to the chassis structure with minimum bending displacement and simulate the design using Algor 23.1 software. The considered criteria of the new development are weight reduction purpose, reducing the bending displacement of chassis structure and to have the lowest or relevant worst stress on the chassis structure. The comparison result proves that the new proposed design in Model 2 is lighter than the existing design and the decrement is about 13.89% and the bending of the structure of new design 2 was decreased too. Thus, the objectives of the study were achieved.

Aluminum alloy 6063-T6 is suggested because it is most suitable material to be implemented on the new design Model 2 where the material has a high tensile strength. Moreover, the specifications of the aluminum such the diameter required for the project is available to get in Kuantan area. Besides that, the cost for purchasing the aluminum is cheaper than other materials. This material also is advantaging due to easy to join with tungsten inert gas, TIG welding.

5.2 RECOMMENDATIONS

The design and technical specifications of the chosen chassis design shows that the final design of the chassis is not enough in 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 the structure also will decrease if the structure of the chassis is improved. It means that by the addition of round tube in triangulated format. The chassis will not easily deformed by bending force due to the triangulated format of the frame.

Is should 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 space frame type to fully Monocoque chassis (Fiber glasses coating chassis type). It is due to the strength that provided in the structure of honeycomb monocoque is almost similar with the strength of the space frame. But the cost of the construction is too expensive. Improvement also can be made by applying integrated chassis between Monocoque and space frame chassis where the output will be better in the strength of the structure and the lightest weight to be produced.

Another recommendation is using the aluminum that's more lightweight and reinforced than the aluminum that's been proposed like chrome steel 4130 and Aluminum 7075. However this material is not being sold in ordinary market at Malaysia, so it need to be ordered and cost of required it is really high and need to be imported from another country.

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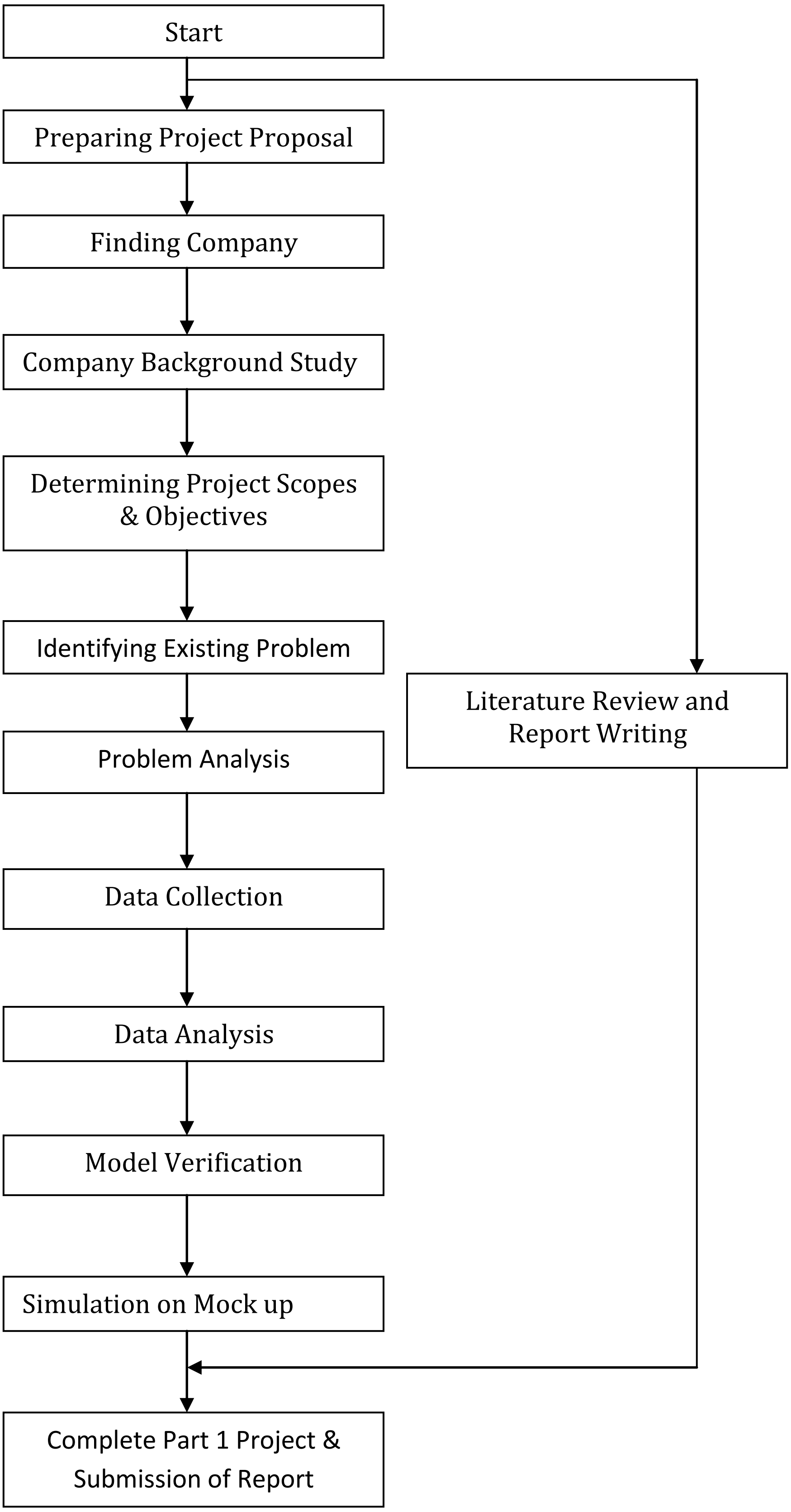
APPENDIX A

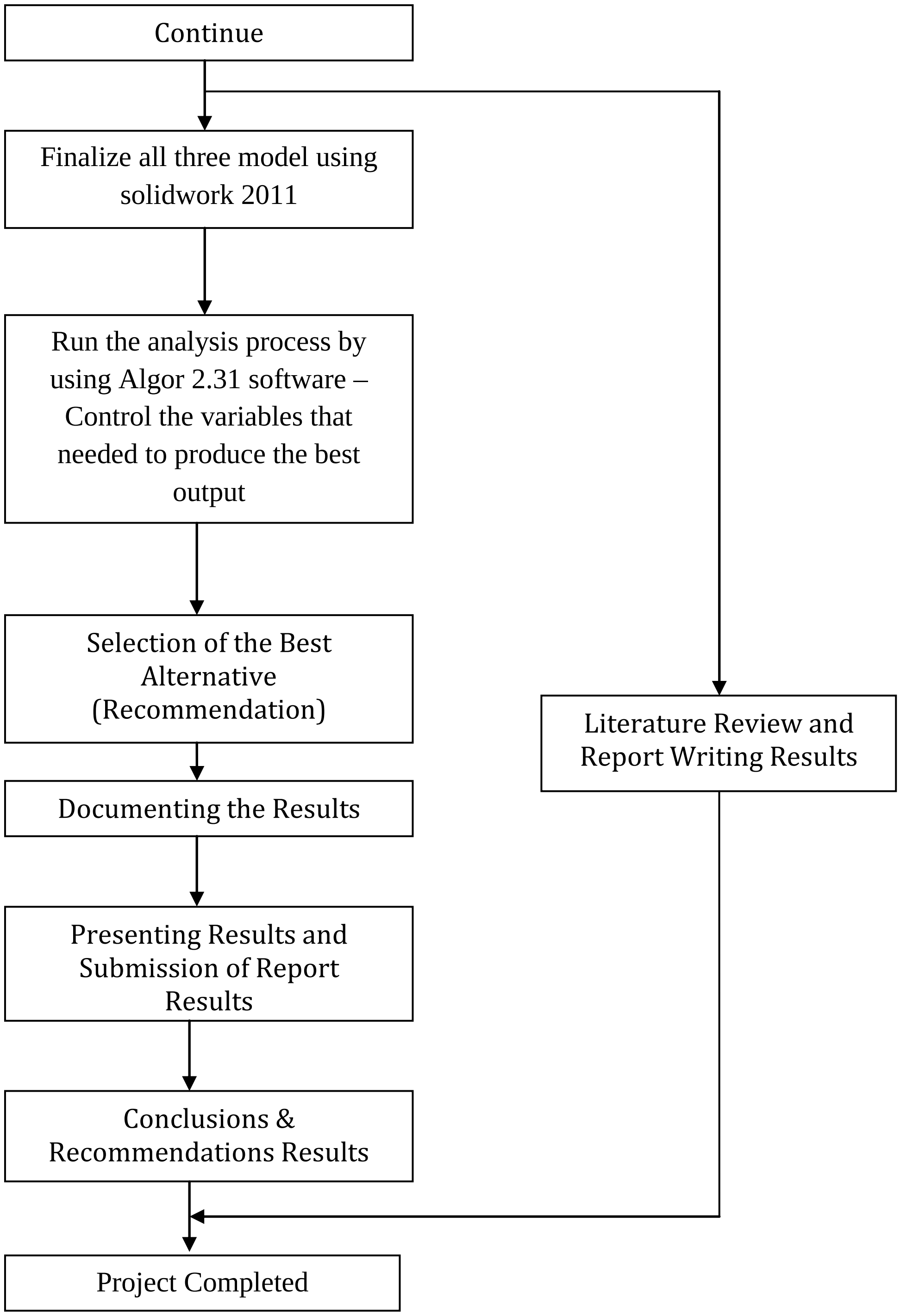
No	Title	Author	Method	Result
1	Design and development of integrated chassis of three wheel prototype car using aluminum and FRP	Nur Afnan Abdul Halim (2010)	• Spaceframe Alluminium alloy chassis integrated with Fiber glass • Algor Modelling system	• The lowest bending displacement of the design when load applied is 0.085948 mm compare to the priveous chassis which is 0.139545. • The design is lightest which is 84.38 N compare to previous design which is about 100 N.
2	Design and fabrication of a student competition based racing car	A. A. Faieza*, et al (2009)	• steel space frame structure. • Catia solid modelling system	• The vibration that was felt on the drivers body and steering wheel was reduced by half (50%) as compared to previous engine mounting setting.
3	Carbon fiber monocoque for a hydrogen prototype for low consumption challenge	A. Airale, M. Carello, A. Scattina (2011)	• Monocoque chassis with carbon fibre in combination with structural foams. • Altair Hypermesh v9.0 pre-processing software.	• The innovative monocoque solution lead to a mass reduction of approximately 12 kg compared to the previous prototype's body. • The result is a well made car body integrated with all the sub-systems. • Bending maximum displacement value of about 9 mm was obtained.

No	Title	Author	Method	Result
4	FIU SAE Supermileage	J. Alexis, P. Clarke, R. Laurence (2011)	• Spaceframe chassis Alluminium 6061. • Algor Modelling system	• maximum value of stress is 9884.83 psi and the Ultimate Strength properties of 6061 Al 40,000 psi and Yield Strength is 45,000 psi
5	FoES Formula SAE-A Space Frame Chassis Design	Christopher Scott Baker (2004)	• Spaceframe chassis of medium carbon steel. • ANSYS finite element analysis software	• The torsional stiffness measurement appears to show that the chassis is very stiff which will allow for superior performance. • The maximum deflection from ANSYS was recorded to be 16mm for a load of 850N.
6	Shell Eco Marathon Competition Final Report	B. Quiceno, P. Salamea, R. Sampath (2011)	• Spaceframe chassis • Body shell: Carbon fiber reinforced plastic • CAD simulation system	• Total vehicle weight is less than 100 pounds. • Using aluminum for steering system. • Shell is fully enclosed with all wheels inside the body.
7	Design, manufacturing and verification of a steel tube spaceframe chassis for Formula SAE	Alexander M. Soo (2008)	• Spaceframe 4130 chromo steel tubing chassis • CAD and FEA software.	• Spaceframe is the reliable and strong frame manufacturing for component mounting.

No	Title	Author	Method	Result
8	Introduction to chassis design	Keith J. Wakeham (2009)	• Suggested software: Solidwork for design purpose. FEA for simulation purpose (Algor / ANSYS)	• The key to good chassis design is that the further mass is away from the neutral axis the more ridgid it will be. • The design section of the book talk more about these items in relation to the types of chassis but the first part is the theory.
9	Design and analysis multipurpose vehicle chassis	Mohd Fisol Jusoh (2006)	• CAD modeling system and analysis the design. • CATIA V5also used	• The lowest bending displacement is 0.15467 mm for 150kg load. • Using aluminum alloy for chassis development.
10	Carbon fiber reinforced steel spaceframe techniques	A.Henningsgaard, C. Yanchar (1998)	• carbon fiber sandwich boards to reinforce a tubular steel spaceframe. • Monocoque structure • panel from aluminum and carbon fiber sandwich material	• A direct comparison of stiffness per mass and ultimate strength of test specimens of similar size in identical loading situations, indicates that a carbon fiber reinforced frame can exceed steel spaceframe performance. • Rivet and bolt spacing proved critical in the ability of loads to transfer • from the steel to the stiffer, carbon fiber panel.

APPENDIX B

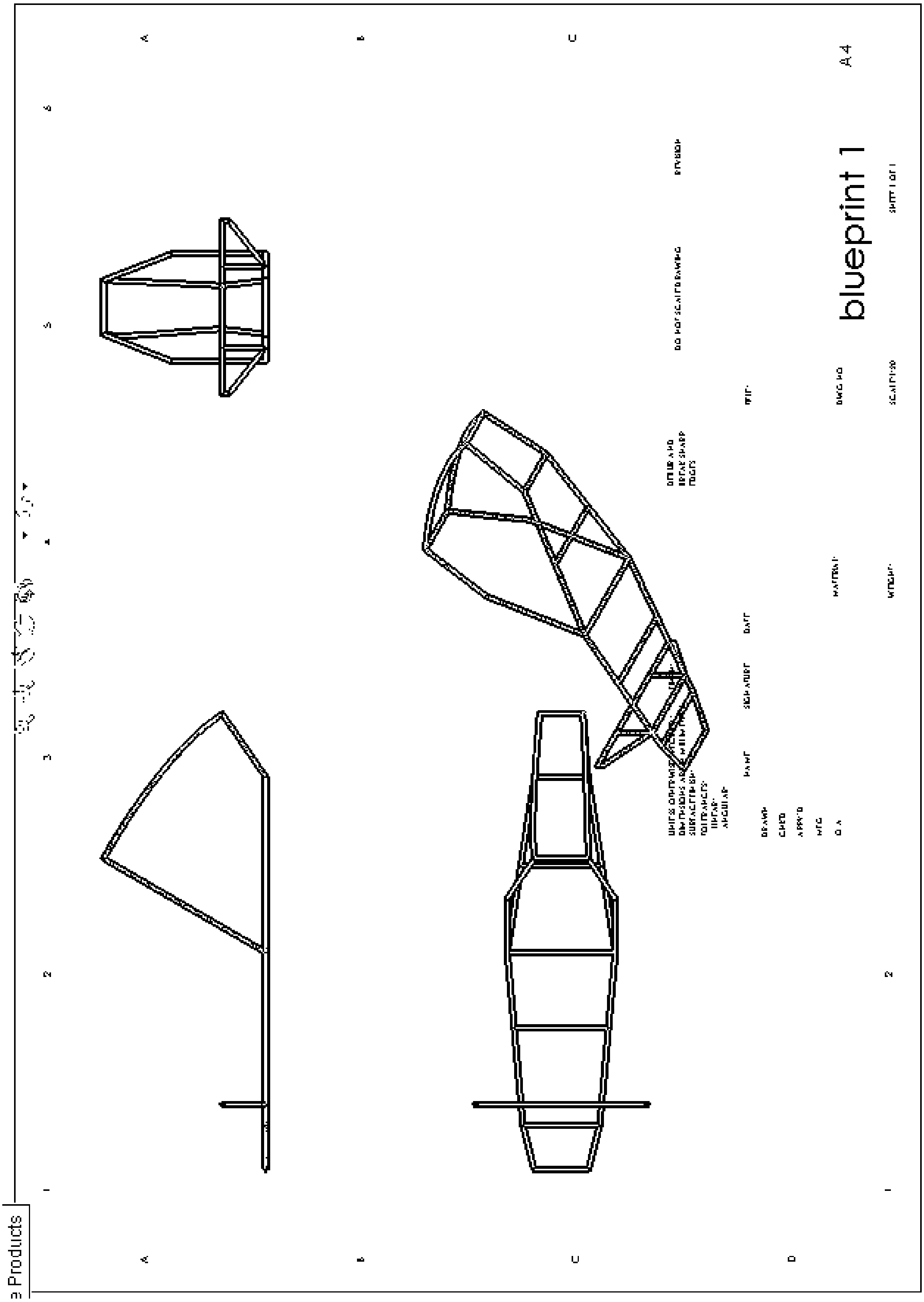

Start
Preparing Project Proposal
Finding Company
Company Background Study
Determining Project Scopes & Objectives
Identifying Existing Problem
Problem Analysis
Data Collection
Data Analysis
Model Verification
Simulation on Mock up
Complete Part 1 Project & Submission of Report
Literature Review and Report Writing


Continue
Finalize all three model using solidwork 2011
Run the analysis process by using Algor 2.31 software – Control the variables that needed to produce the best output
Selection of the Best Alternative (Recommendation)
Documenting the Results
Presenting Results and Submission of Report Results
Conclusions & Recommendations Results
Project Completed
Literature Review and Report Writing Results

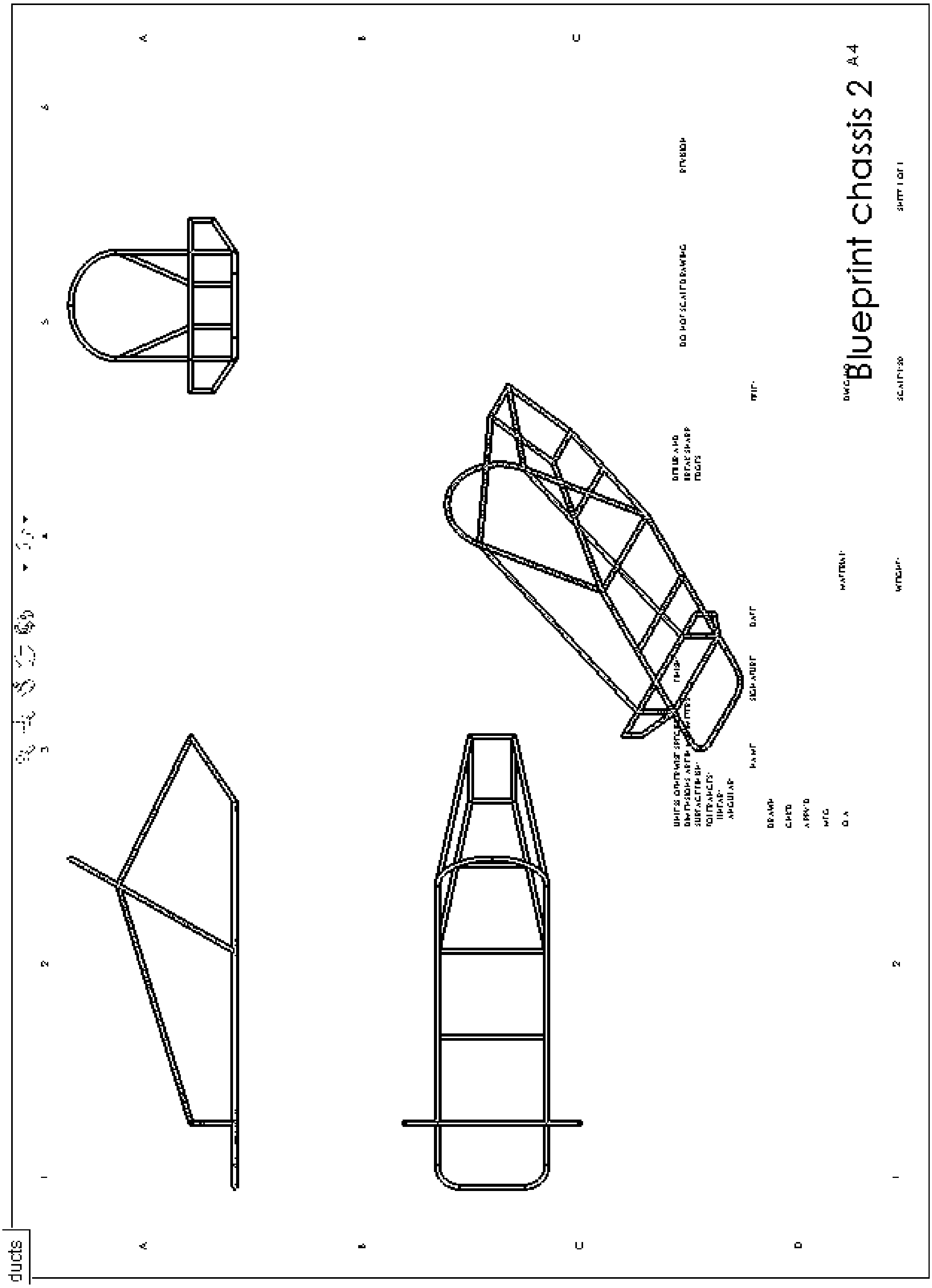
APPENDIX C

Type	Advantages	Disadvantages
Backbone	• Strong 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 torsion 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 entire construction.
Spaceframe	• Provide maximum strength and minimum deflection due to the support from tubular pipes • Space frame chassis systems are lighter than traditional steel • The high torsion rigidity can be achieved as well as its light weight	• Very complex due to their triangulated tubular pipes format. • Construction of space frame chassis is expensive and requires maximum time consuming to be built.

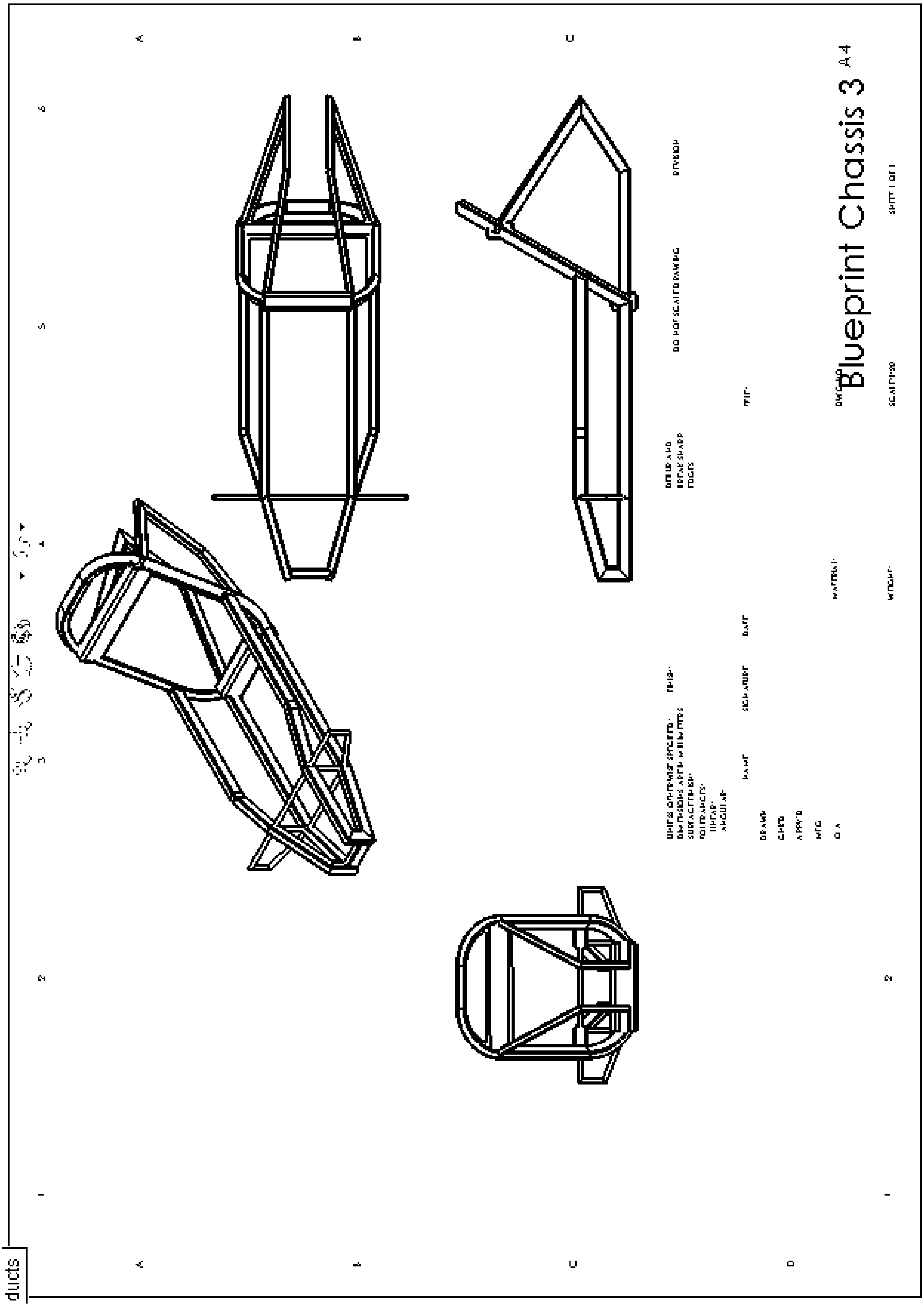
APPENDIX D1



APPENDIX D2



APPENDIX D3


Blueprint Chassis 3
A4
DO NOT SCALE DRAWING
REVISION
SHEET 1 OF 1

APPENDIX E

Assuming that the braking deceleration can be 40km/h to 0km/h in 10 sec with mass = 140kg:

When 40km/hour = 11.111m/s and the initial velocity is 0:

$$a = \frac{11.111 - 0}{10} = 1.111 \text{ m}/s^2$$

$$\text{F} = \frac{[(140 \text{ x } 0) - (140 \text{ x } 11.111)]\text{kg x m}/s}{10s} = 155.554 \text{ N}$$