Design and Analysis of a Hybrid Composite-Steel Frame Chassis for a Small Race-car

by

Nurzaki Bin Ikhsan

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

JULY 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Design and Analysis of a Hybrid Composite-Steel Frame Chassis for a Small Race-car

by

Nurzaki Bin Ikhsan

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Dr. Ir Masri Baharom)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2008

CERTIFICATION OF ORIGINALITY

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

NURZAKI BIN IKHSAN

ABSTRACT

This dissertation includes an overview of the Final Year project. The title is “Design and Analysis of a Hybrid Composite-Steel Frame Chassis for a Small Race-car” this project will collaborate with the Formula SAE competition. This dissertation contains the objective of the project, scope of the study and problem statement. There is also a methodology part which is will explain about the step and method during designing and analysis the chassis. Beside, this dissertation also provides a literature review that’s consisting of the previous work or project done by other personnel that have similarity with the project proposed and also contain information and theory about the project and done by collecting it from various sources available such as journal, book and internet. The chassis was going through the side impact and longitudinal stiffness analysis as it result the improvement from the previous chassis design.

The goal of this project is to design and analysis a new hybrid composite –steel frame chassis. The idea is to design a monocoque chassis that optimize the chassis strength-mass ratio. This design also will be limited to Formula SAE rules.

ACKNOWLEDGEMENTS

First of all, Alhamdulillah the author would like to express the deepest gratitude's to Allah S.W.T for giving the strength and with His consent the author managed to complete the final year project.

The author also would like to express special thanks to his supervisor, Assoc Prof Dr. Abd Rashid Abd Aziz and Dr. Ir Masri Baharom and his Co. Supervisor Mr. Syaifuddin Mohd, which has been very helpful and supportive in term guiding the author to stay focus and also for all comment and constructive critics.

A bunch of thanks and appreciation also goes to the all UTP Formula SAE team members in their continuous support and have contributed directly and indirectly to the success of this Final Year Project.

Last but not least, the author would also like to express a special thanks to his family members for their priceless support, encouragement, constant love, valuable advices and their understanding. Without all of them, the author would not go further like where his standing right now. Thank you so much for being there trough out the study period.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

SF-01	: Steel Feather No. 1
SF-02	: Steel Feather No. 2
SAE	: Society of Automotive
FSAE	: Formula Society of Automotive
CFRP	: Carbon Fibre Reinforced Plastic

CHAPTER 1
INTRODUCTION

1.1 Background Of Study

There are numerous parameters and area to be considered about the race car such as stress on in order to achieve desirable performance. Instead of the boosting horsepower of the engine and the skills of the driver, another key area to be considered is the stability and strength of the car. These key areas basically depend on the design of the chassis. Chassis consist of a framework that supports an inmate object such as suspension, drive train, engine and many more.

Basically, the objective of Formula SAE competition is for student to have a small scale competition amongst themselves with the formula-style racing cars that have conceived, designed and fabricated prior to the race.

Thus, in conjunction with the development of Formula SAE race car for University Technology PETRONAS, there is a severe demand of a study on how to develop a good chassis in a context of race car. The development process consist of several engineering stages from its beginning until reach the best prospective.

1.2 Problem Statement

In order to improve the performance and handling of a small race car on a low-speed race track, the race car need to be designed with high power to weight ratio and superb handling characteristics. The proposed design will be based around a single cylinder aluminium engine and it is proposed that the new chassis design to utilize the combination of steel space frame structure and composite materials to reduce overall mass. Thus, the design and analysis process might be different since the previous chassis was a space frame type while the new design is hybrid composite- steel space frame chassis. The target mass of the car is around 200 kg.

1.3 Significant Of The Project

By doing research and designing, the final design will be apply to the UTP Formula SAE race car. The design and calculation will determine the performance of the car during the competition. Beside, students also able to apply the knowledge of the mechanics and fundamental of kinematic on their engineering field and improves the skill of using engineering software such as CATIA and ANSYS Workbench.

1.4 Objective And Scope Of Study

The main objective for this project are, to perform design and analysis for the proposed hybrid Composite-Steel Space Frame chassis and to optimize the chassis design for the best packaging, ergonomics, handling and chassis strength-mass ratio. Beside, the author also needs to propose fabrication processes for limited production of the chassis.

The projects start with the target specification of the overall Formula SAE car. The team member will cooperate to analysis and decide the specification required such the power of the car and torque. Then, the team members need to tally each other to make the design. The author needs to tally with the suspension and driver interface department since their part or system will be mounted at the chassis.

The stages of studying the previous design and analysis help to understand the vehicle ability and performance. Thus, the study will make the improvement for the new design chassis compare to the previous.The scope of work then is narrowed to the analysis of the chassis. These require a stress analysis method to get maximum chassis strength. By the analysis, the stress point can be determined and minor modification can be made.

CHAPTER 2
LITERATURE REVIEW

Literature review is the researches which are consist of the previous work or project done by other people that have similarity with the project proposed. Besides, it also contain information and theory about the project and done by collecting it from various sources available such as journal, book and internet.

2.1 Research Base Previous Design

During this year (2008) Formula SAE International Organization have made some race car competition among universities around the world. Basically, the score for the competition was divided by some category such as cost, presentation, design, acceleration, skid pad, autocross and endurance-economy. The locations for the competition during this year were [7]:

1. Michigan International Speedway
2. Virginia

And the results for the Formula SAE race car competition were:

No	Location	The winner
1	Michigan International Speedway	The University Of Western Australia
2	Virginia	University Of Wisconsin

Table 2.1: Formula SAE race car competition 2008 result

The further study about the chassis for the winner of Formula SAE Race Car competition 2008 will be discuss at the next sub-topic. Beside, the author also provides some chassis information from the RMIT (Royal Melbourne Institute Technology) and from the previous Universiti Teknologi Pertronas Formula SAE Race Car (SF-02).

2.1.1 The University Of Western Australia [9]

This racing car was made by full-one piece carbon fibre monocoque. The advantage of this type of chassis is it has greater power to weight ratio. However, it will cost higher than other type of chassis (ex. Space frame chassis). Although, this racing car still need to use AISI 4130 tubular steel tube as material for its main hoop and front hoop since it is a rule for the competition.

Figure 2.1: The University Of Wisconsin Formula SAE Race Car

Weight:	195 kg
Power:	100 hp
Engine:	Honda CBR600RR, custom fuel injection and exhaust, dry sump.
Drivetrain:	Custom 4-speed gear box with sequential shift. Chain RWD with Viscous LSD.
Chassis:	**Full one-piece carbon fibre monocoque.**
Wheels:	Custom cast aluminium rims, single nut fastening.
Tyres:	Goodyear Eagle D2692
Performance:	0-100kph: 3.2s, 0-75m: 3.7s

Table 2.2: The University of Western Australia race car specification

2.1.2 University Of Wisconsin [10]

This university chooses the AISI 4130 tubular steel tube as the chassis. This type of chassis is considered as space frame chassis. The advantage of using this type of chassis is, it easy to manufacture since it involve cutting, bending and welding process. Besides, it easy to design by using engineering software and it cost less to fabricate. However, it has less tensile strength and high density compare to the monocoque chassis.

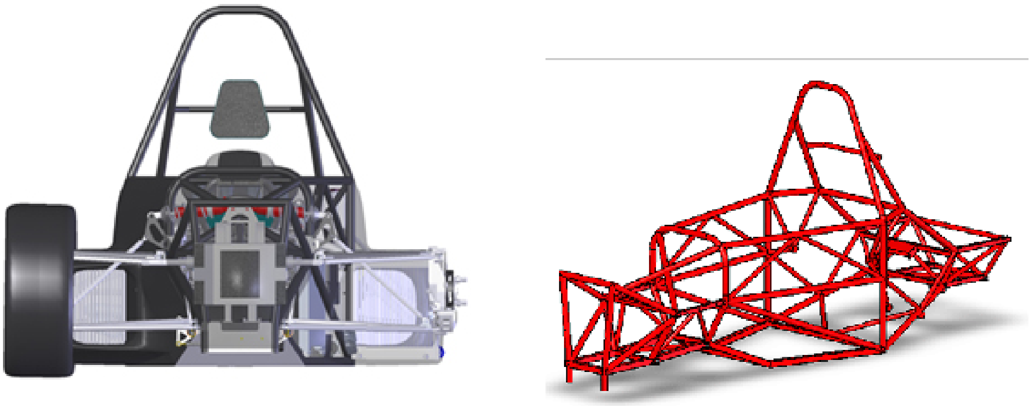


Figure 2.2: The car layout of University Of Wisconsin

Dimensions (l x w x h) (mm)	2725 x 1372 x 1080
Front/ Rear Weight (with 68kg driver)	118 / 156
Front/Rear Track (mm)	1194 / 1168
Wheelbase (mm)	1524
Weight of chassis frame (kg)	23.5
Construction	**4130 Tubular Steel Space Frame**

Table 2.3: University Of Wisconsin race car specification

2.1.3 RMIT (Royal Melbourne Institute of Technology) [8]

Figure 2.3: RMIT Formula SAE Race Car

Chassis:	Full Carbon Fibre Monocoque Single Seater • Prepreg Laiminate • 1/2" Aluminium honeycomb core
Unsprung	RMIT Racing developed Carbon Fibre 10" Wheels with aluminium centres
Driveine	Rear-engine, RWD (KAAZ LSD with custom housing)

Table 2.4: RMIT Racing R08 Race Car specification

2.1.4 Universiti Teknologi Petronas (UTP)

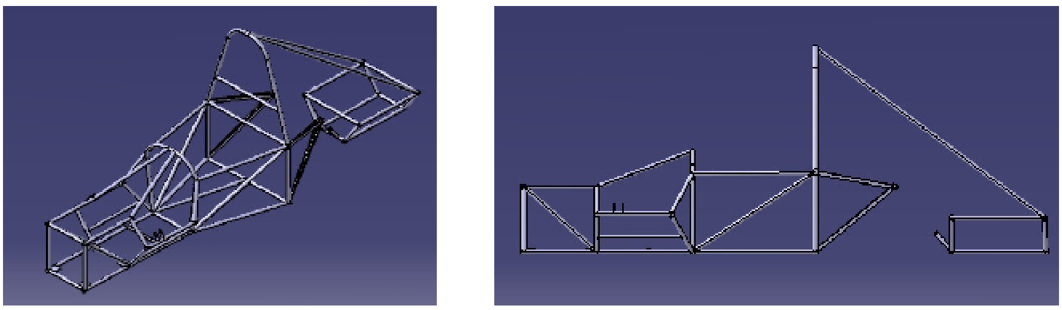


Figure 2.4: The UTP formula SAE race car 2006 [6] (SF-01)

a) Isometric view, b) Side view

Dimensions (l x w x h) (mm)	2708 x 645 x 1100
Weight (kg)	34.29
Construction	4130 Tubular Steel Space Frame

Table 2.5: UTP Formula SAE Race Car (SF-01) specification

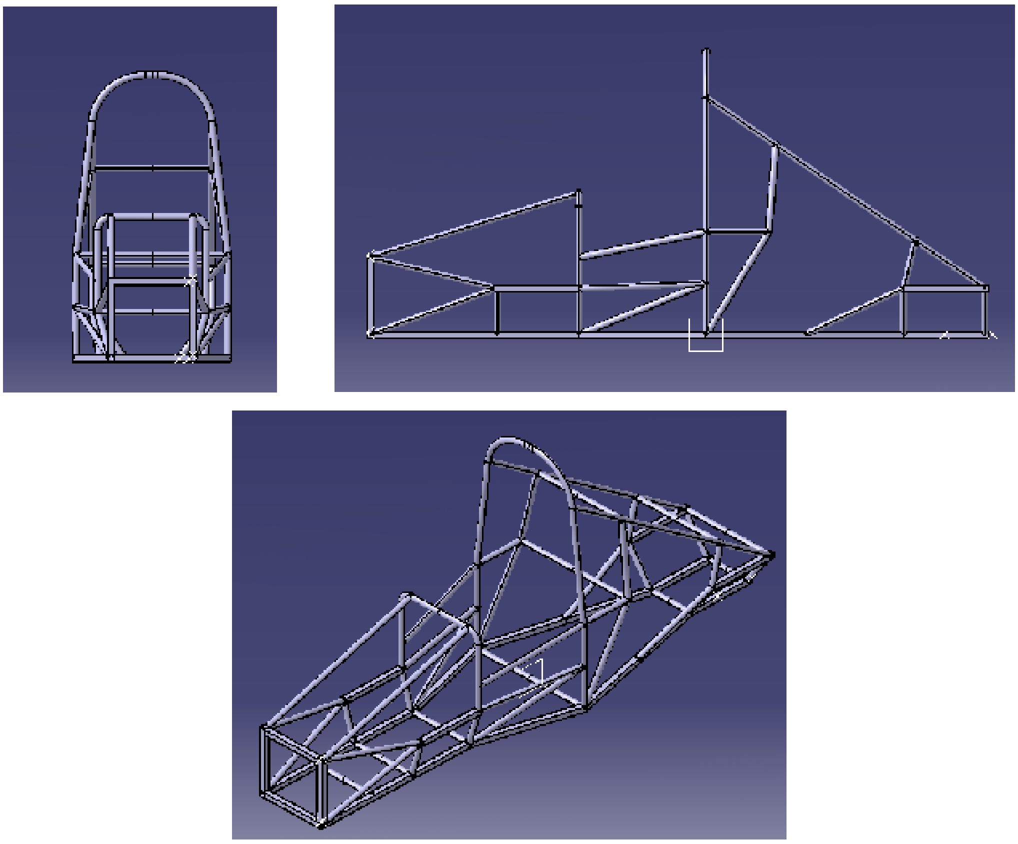


Figure 2.5: The UTP formula SAE race car [4] (sf-02)

a) Front view, b) side view, c) isometric view

Dimensions (l x w x h) (mm)	2296 x 586 x 1100
Weight (kg)	24.758
Construction	4130 Tubular Steel Space Frame

Table 2.6: UTP Formula SAE Race Car (SF-02) specification

As the project title, the author has proposed to design and analysis of the hybrid composite steel space frame chassis. This type of chassis is improvement for UTP Formula SAE Team which is used space frame chassis for the two racing car before. And absolutely, the carbon fibre that act as composite material for the chassis will reduce the weight of the car and result for the best power to weight ratio. Besides, it also has much higher tensile strength and lower density compare to the steel tube. Thus, it will increase the performance of the race car during the competition. It also much more helpful for the author to study and design the new chassis when some other university has made the same type of chassis for their race car.

2.2 Vehicle Loading

To appreciate the design of a vehicle's chassis, it is first necessary to examine the kind of conditions it is likely to meet on the road. There are four major loading situations which the chassis will experience, as follows:

i) Vertical bending
ii) Longitudinal torsion
iii) Lateral bending
iv)Horizontal lozenging.

2.2.1 Vertical Bending

If a chassis frame is supported at its ends (such as by the wheel axles) and a weight equivalent to the vehicle's equipment, passengers, and luggage is concentrated across the middle of its wheelbase, the side members will be subjected to vertical bending making them sag in the centre region.

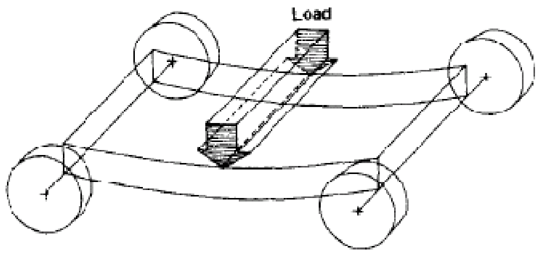


Figure 2.6: The vertical bending on the chassis

2.2.2 Longitudinal Torsion

When front and rear diagonally opposite road-wheels roll over bumps simultaneously, the two ends of the chassis will be twisted in opposite directions. Both the side- and the cross-members will thus be subjected to longitudinal torsion which distorts the chassis. The resistance to torsional deformation is often quoted as stiffness in Newton meter per degree of deflection. These translational displacements are needed to calculate the torsional stiffness of the chassis. The calculations of torsional stiffness are as stated below.

Torque applied, **T = [F] L**
[F=Force applied, L=Width of chassis]

Angle of twist, $\boldsymbol{\alpha = \tan^{-1} [(x) / L]}$
[x=displacement, L=width of chassis,]

Torsional stiffness = Torque applied / Angle of twist

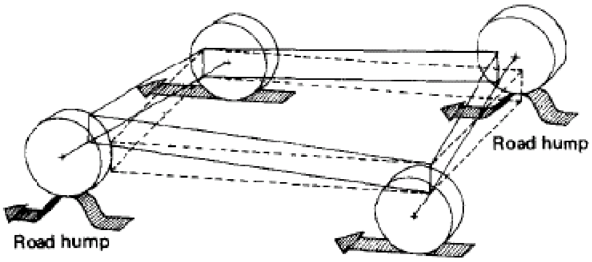


Figure 2.7: The longitudinal torsion

2.2.3 Lateral Bending

Under certain conditions, the chassis may be exposed to lateral (side) forces - due possibly to the camber of the road, side wind, centrifugal force as when turning a corner, or collision with some object. The adhesion reaction of the road-wheel tires will oppose these lateral forces, with the net result that the chassis side-members will be subjected to a bending moment which tends to bow the chassis in the direction of the force.

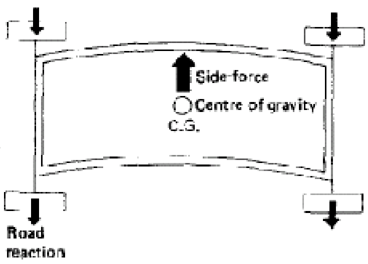


Figure 2.8: The lateral bending on the chassis

2.2.4 Horizontal Lozenging

A chassis frame driven forward or backwards will continuously be exposed to wheel impact with road obstacles such as pot-holes, road joints, surface humps, and curbs while other wheels will be providing thepropelling thrust. Under such conditions the rectangular chassis will distort to a parallelogram shape. This is known as 'lozenging'.

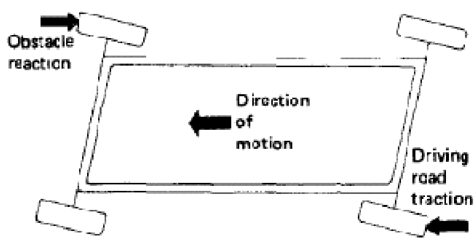


Figure 2.9: The horizontal lozenging

2.3 Materials

2.3.1 Alloy Steel AISI 4130

A proper selection of materials could help us in having a high torsional stiffness as the material itself has its own properties that able to sustain certain kind of load according to the strength per density ratio and stiffness per density ratio. For this project, the material use is alloy steel or AISI 4130.

The advantage of the alloy steel AISI 4130 are it has high strength due weight ratio and the ability to withstand fatigue due to vibration. [3]

The mechanical properties of the alloy steel AISI 4130:

Density (x1000 kg/m3)	7.86
Poisson's ratio	0.29
Elastic modulus (Gpa)	205
Tensile Strength (Mpa)	560.5
Yield Strength (Mpa)	360.6
Elongation (%)	28.2
Reduction in Area (%)	55.6
Hardness (HB)	156
Impact Strength (J)	61.7

Table 2.7:The properties of alloy steel AISI 4130

2.3.2 **Carbon Fiber** [1]

Carbon fiber is also sometimes called graphite fiber. It has the highest specific tensile strength of all the reinforcing materials and it has a high strength to weight ratio and low coefficient of thermal expansion. The density of carbon fiber is also much lower than the density of steel. Carbon fiber takes the form of several thousand long, thin strands of material, which are mostly composed of carbon atoms.

	Tensile Strength	Density	Specific Strength
Carbon Fiber	3.50	1.75	2.00
Steel	1.30	7.90	0.17

Table 2.8: The comparison of carbon fiber and steel properties

Carbon fiber is composed of many featherweight strands, containing mainly carbon, embedded in a resin. There are many different grades of carbon fiber available, with differing properties, which can be used for specific applications.

	Strength	Modulus
High Tenacity	4.00	240
Ultra High Tenacity	4.80	240
Intermediate	6.00	290
High Modulus	3.50	375
Ultra High Modulus	3.40	425
High Modulus / Tenacity	3.90	400

Table 2.9: Details on some of the properties of various grades of carbon fiber

CHAPTER 3
METHODOLOGY

In this chapter, the author will discuss the methodology upon completing the Final Year Project. Mainly it consists the project flow chart, Tools and software used and Gantt chart.

3.1 Project Flow Chart

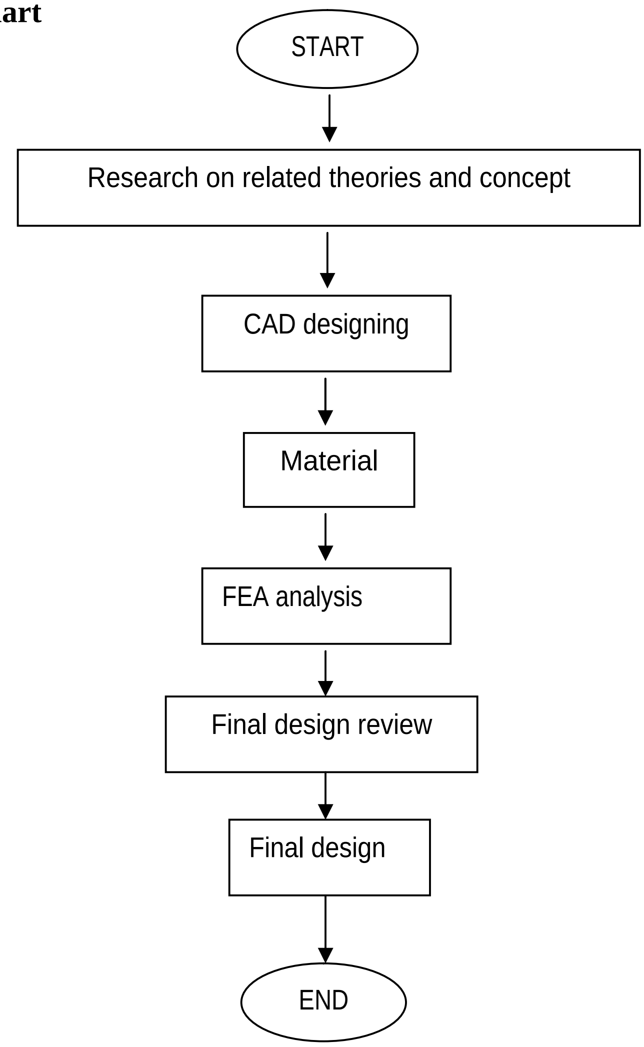


Figure 3.1: Project flow chart

3.2 Project Activities

3.2.1 Research On Related Theories And Concept

The project start with the understanding the concept and the characteristic of the Formula SAE race car. This includes the research about other university chassis design and UTP previous Formula SAE race car (SF-01 and SF-02). Beside, the study of the theories about chassis such as ergonomic design, loading and static analysis also done before the designing the new chassis start. To do this, the author use reading material such as journal and book, internet and personnel as references.

3.2.2 CAD Designing

After have some discussion with other department (braking, suspension and driver interface department), the data such as ergonomic data and some specification of the chassis (track width, height and wheelbase) were achieved. Thus, the designing of the chassis can be proceeding by using CATIA. However, during designing process, the author needs to tally with the suspension department as it affects the shape and design of the new chassis by repositioning the location of the suspension.

3.2.3 Material

In this project, the material was carbon fibre and AISI 4130 tubular steel tube.

3.2.4 FEA Analysis

In this section, the engineering software, ANSYS Workbench is use. This software use to compute the stress analysis on the chassis when particular load is applied. The analysis consists of vertical bending and the longitudinal torsion of the chassis.

3.2.5 Final Design Review

The minor modification of the chassis may require if the result of the chassis analysis is not as the author expect. After doing some modification, again, the chassis will be analyze by using ANSYS Workbench.

3.2.6 Final Design

This is where the author successfully completes p the design and analysis and come up with the new chassis (SF-03) for UTP Formula SAE Team.

3.2 Tool Use

During this project, several engineering softwares are being used. This softwares is used to assist the design process as well as the analysis of the project. The softwares are:

3.2.1 CATIA V5R14

CATIA is one of the popular CAD software where it is capable in modeling and designing.

3.2.2 ANSYS Workbench

ANSYS Workbench is the sub-component of ANSYS software. It is responsible in performing Finite Element Analysis (FEA) to the model.

3.3 Gantt Chart

No.	Task/Actvity	Academic Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Previous report study/research														
	a. Understanding of Race vehicle Dynamics														
	b. Familiarization of FSAE Chassis Concept														
	*Submission of Preliminary Report (15/2)														
3	Seminar 1 (optional)														
4	Regulation familiarization														
5	Basic Vehicle Dimensions														
	a. Acquisition from other Departments														
	b. Space work (constraint) discussion														
	c. Optimization from previous design														
6	Design Discussion														
	a. Design Discussion with Suspension Department														
	b. Design Discussion with Driver Interface Department														
	c. Design Discussion with Braking Department														
	d. Implementation of vehicle geometry														

No.	Task/Activity	Academic Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
7	Design of Primary structure of Chassis														
	a. CAD Designing														
	*Submission of Progress Report														
8	Seminar 2 (compulsory)														
9	Chassis Design Continue														
	a. CAD Designing														
10	Model Assembly and Finalizations														
11	Critcal Design Review														
12	Component Assembly (build-up)														
13	Final Design Review														
	*Submission of Interim Report														
14	Oral Presentation (before Exam Week)														

	Milestone
	Process

Table 3.1: FYP Part 1 (JAN 08)

No.	Task/Actvity	Academic Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project work continue														
2	Previous report study/research														
	a. Understanding of Race vehicle Dynamics														
	b. Familiarization of FSAE Chassis Concept														
3	*Submission of Progress Report 1														
4	FEA analysis of chassis														
	a. Ansys														
5	*Submission of Progress Report 2														
6	FEA Analysis of chassis (con't)														
	a. Ansys														
	*Seminar														
7	*Poster Exhibition														
8	*Submission of dissertation (soft bound)														
9	*Oral Presentation														
10	*Submission of Project Dissertation (Hard Bound)														

	Milestone
	Process

Table 3.2: FYP Part 2 (JULY 08)

CHAPTER 4
RESULT AND DISCUSSION

4.1 Ergonomic Data

Ergonomics is the application where it concerns more towards the interaction between the human, design of objects, and the environment that the human use. As in a racing car, the chassis and the driver controls are the only interface between the human and the object; it is therefore particular details need to be considered it its design layout, packaging system in order to ensure the simplicity of the chassis structure while still considering the driver's safety and his comfort aspect. Thus, by compute the ergonomic data, the design process will be easier as the data was taken from the minimum and maximum range for the driver.

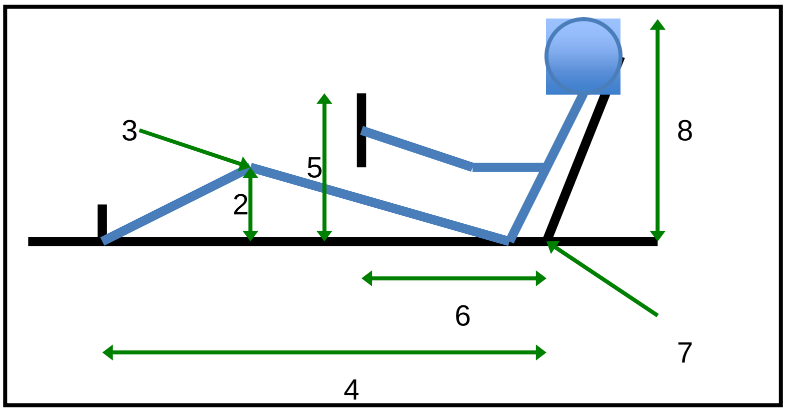


Figure 4.1: The schematic diagram to locate the ergonomic data.

NO.	DATA LIST	FIRST PERSON	SECOND PERSON
1	Driver height (mm)	1650	1750
2	Leg height (mm)	330	375
3	Leg angle (^{o})	125^o	110^o
4	Length of leg (mm)	945	1037
5	Steering height (mm)	570	610
6	Length from steering to driver body	530	535
7	Driver seat angle (^{o})	110^o	107^o
8	Height from driver head to the wrist	885	885

Table 4.1: The ergonomic data

4.2 Chassis Design

In this part, the author will explain about the new design of the new chassis for UTP Formula SAE team. The chassis design will be divided by two parts:

1. Monocoque body
2. Space frame

4.2.1 Monocoque Body Part

Monocoque body consists of the front bulkhead and driver cabin. This part is made by carbon fiber. During designing, this body was dividing by three part, which is, Nose, Front bulkhead, Side pod and Driver cabin

4.2.1.1 Nose

This part are use to cover the impact attenuator or crash protection that made from honeycomb which is attach and install at the front bulkhead.

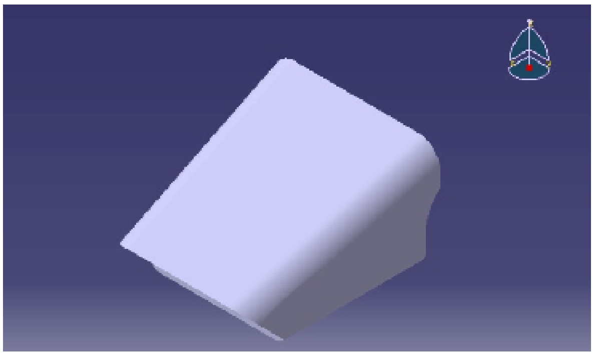


Figure 4.2: The impact attenuator cover

4.2.1.2 Front Bulkhead

It use to place the driver leg will be. Beside, acceleration and braking paddles also mount into this part. Other than that, the impact attenuator or crash protection will be place on the front of the bulkhead as a protection for the driver's legs also for absorbing crash impact in case accidents happen. The front suspension system also will be mounting at this part. Note that, there were trim regions at the top of this part to allow the front push rod to move independently. The front hoop also will be mounted at this part.

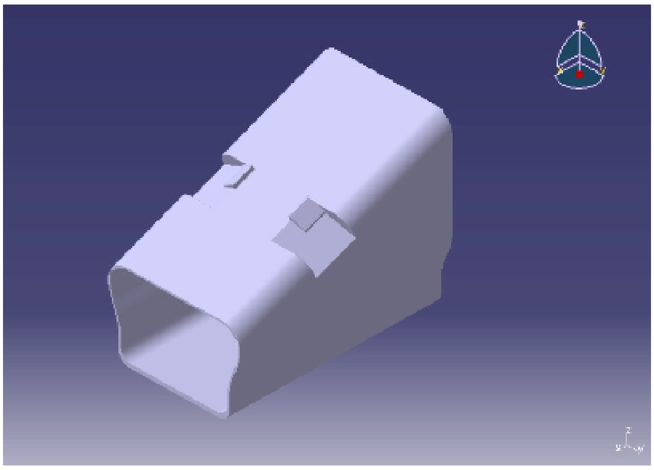


Figure 4.3: Front bulkhead of the monocoque body

4.2.1.3 Driver Cabin

The driver cabin is a place where the driver will be seat. The dimension of the driver cabin is base on the ergonomic data. This is important to ensure the drive comfort and confident when driving. Besides, this is the part where the monocoque and space frame body connect. Base on the design, the driver interface will be located at the front of the drive cabin.

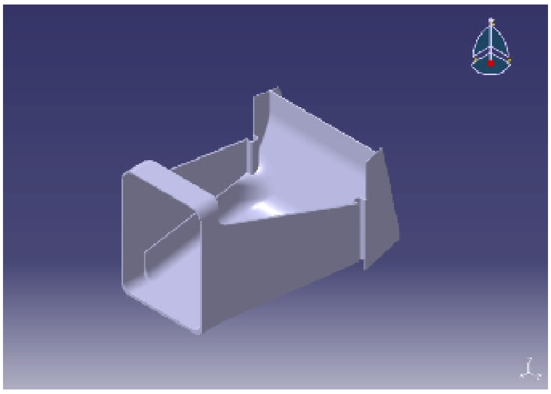


Figure 4.4: The driver cabin

4.2.1.4 Side Pod

This part is mounted at the left and right of the driver cabin. The side pod is use to cover some of the car part such as the radiator and electric circuit. Besides providing side impact protection to the driver, it also increases the rigidity of the chassis.

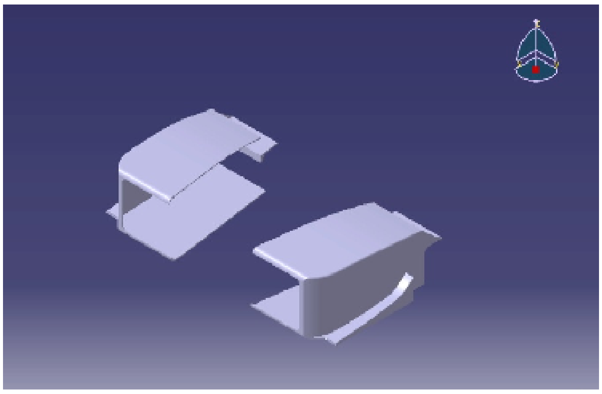
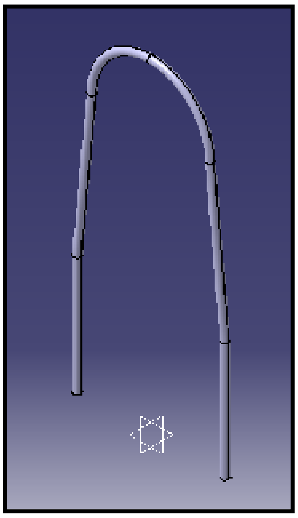
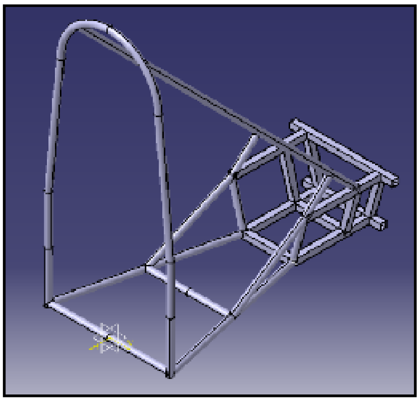
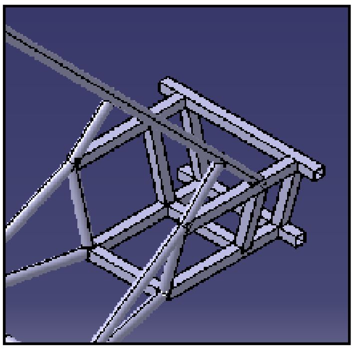


Figure 4.5: The side pod

4.2.2 Space Frame

Design	Explanation
	The early stage of design is designing the main hoop. The structure must be build using only one tube. It provides safety to the driver in case of rollover of the car. According to the FSAE rules, the height of the main hoop must provides allowance of 2 inch from the top of the driver head including the helmet to the top of the hoop.
	Then, the design is completed by joined all the part such rear bulkhead and the main hoop. The round steel tubing was use for main hoop, engine mounting location and rear bulkhead, which is places the drive trains.
	While, The square section steel tubing is only use for mounting part of the rear suspension system. It is easier to mounting the suspension system by using the square section steel tubing.

4.2.3 Chassis Properties

In this part, the author will show the properties of the previous design (SF-02) and the latest design (SF-03) of the UTP Formula SAE team chassis.

4.2.3.1 SF-02

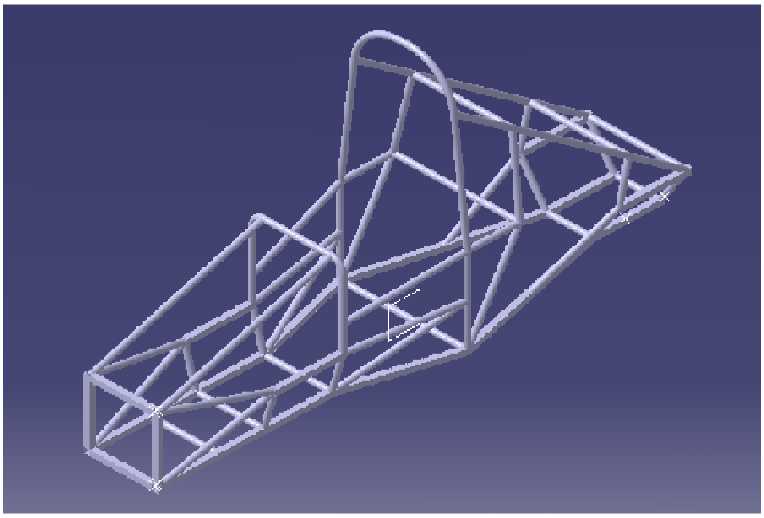


Figure 4.6: SF-02 chassis

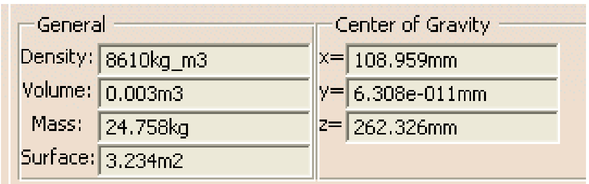


Figure 4.7: The properties of the SF-03 Chassis

4.2.3.1 SF-03

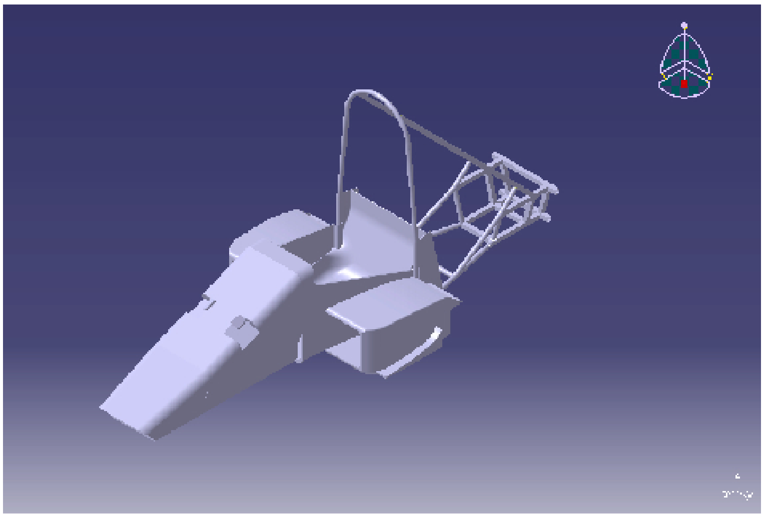


Figure 4.8: The full assemble of the SF-03 Chassis

Characteristics		Inertia center	
Volume:	0.026m3	x:	-414.914mm
Mass:	46.064kg	y:	-4.641e-006mm
Surface:	8.921m2	z:	188.935mm

Figure 4.9: The properties of the SF-03 Chassis

Note that, even though the mass of SF-02 is approximately half than SF-03, the SF-02 still need to cover the space frame chassis with body that made from fiber glass. Basically, the area of SF-02 chassis that need to cover is at the front bulkhead. In addition, there is also a side pod that mounted at the right and left of the driver cabin. The weight of this of these two parts (front bulkhead cover and side pod) is approximately 25kg. Thus, the total weight of the SF-02 is 49.758kg. This value is higher than total weight of SF-03 chassis.

4.3 Chassis Analysis

For the analysis, ANSYS Workbench is used. From the analysis the author can determine the accuracy of the calculated value of side impact and longitudinal torsion. Furthermore it helps in visualization the stress area with the information of Von Misses stress.

4.3.1 Side Impact Analysis

The side impact analysis is the one of analysis that need to compute to ensure the side body can withstand with the load that coming from the left or right of the driver. The analysis is done when the front and rear chassis is clamped. The 50N until 700N load with increasing 50N load is applied from the side of the chassis and will be analyze without the side pod. The result of Von Misses Stress is shown below.

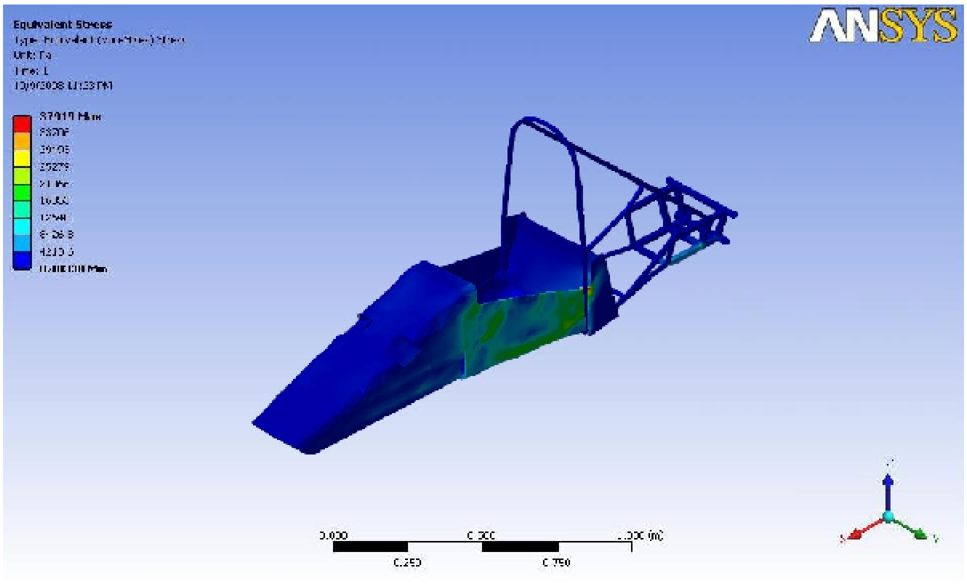


Figure 4.10: Von Misses Stress for side impact analysis of the SF-03 chassis

Load (N)	Deflection (mm)
50	0.063
100	0.12
150	0.19
200	0.24
250	0.32
300	0.38
350	0.44
400	0.53
450	0.57
500	0.63
550	0.69
600	0.75
650	0.83
700	0.88

Table 4.2: SF-02 deflection data

Load (N)	Deflection (mm)
50	0.035
100	0.052
150	0.074
200	0.093
250	0.13
300	0.17
350	0.21
400	0.25
450	0.297
500	0.34
550	0.385
600	0.421
650	0.48
700	0.53

Table 4.3: SF-03 deflection data

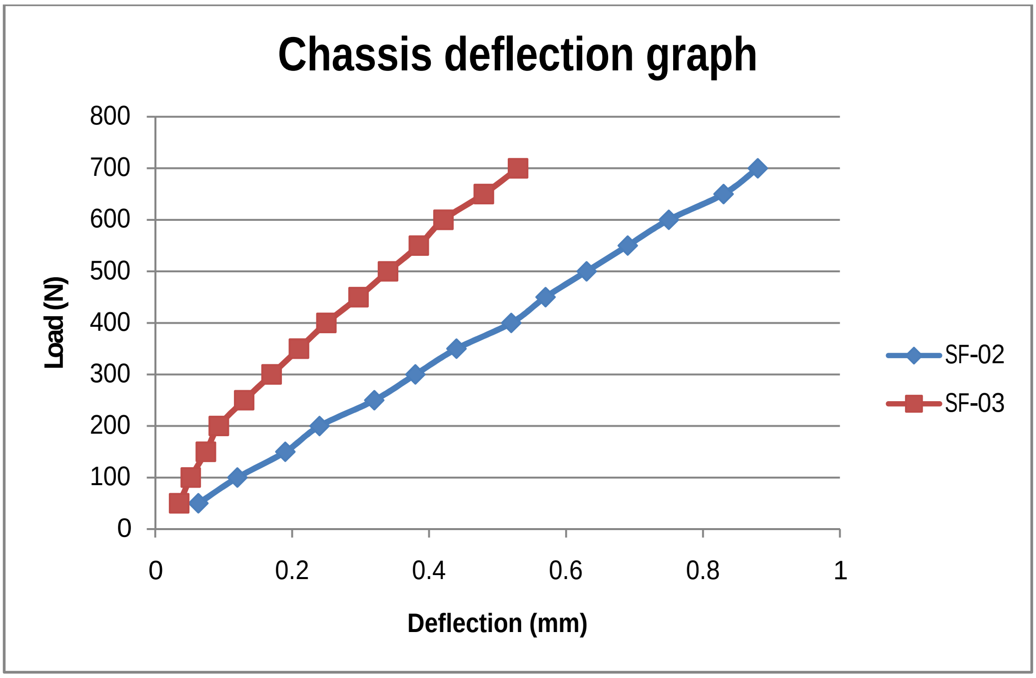


Figure 4.11: Chassis deflection graph

4.3.1 Longitudinal Torsion

We can determine the torsional stiffness base on the longitudinal torsion analysis. The torsional stiffness data can be calculated manually base on the deflection that has been identify using ANSYS Workbench. The first thing before doing this analysis, the author need to determine the value of force applied, in this case, the author set range 100N until 2500N to be the force applied.

Torque applied, **T = [F] L**

[F=Force applied, L=Width of chassis]

Angle of twist, $\boldsymbol{\alpha = \tan^{-1} [(x) / L]}$

[x=displacement, L=width of chassis,]

Torsional stiffness = Torque applied / Angle of twist

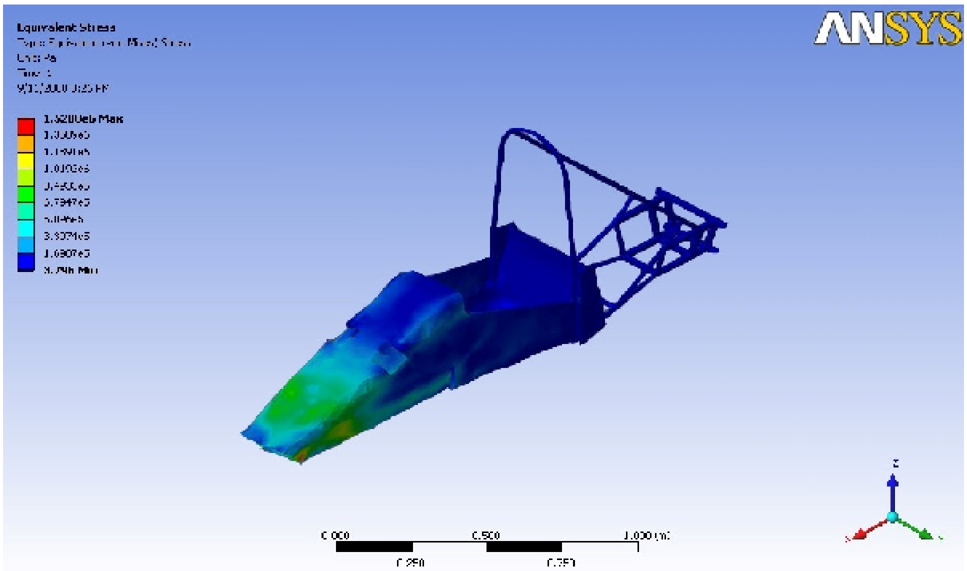


Figure 4.12: Von Misses Stress for longitudinal torsion analysis of the SF-03 chassis

4.3.1.1 SF-02 Torsional Stiffness Data

Taken [49.758kg x 9.81m/s^2 = 488.13N] load to show the calculation of the torsional stiffness.

**the value of 49.758kg is the mass of the chassis.*

Torque applied, **T** **= [F] L**

= 488.13N x 0.586m = 286.04Nm

Angle of twist, α **=tan^{-1} [(*x*) / L]**

= tan-1 [0.000180 / 0.586m) = 0.0176deg

Torsional stiffness = Torque applied / Angle of twist

= 286.04Nm / 0.0176deg

=16272.72 Nm/deg

Load (N)	Width of the chassis (m)	Torque applied (Nm)	Deflection (mm)	Angle of twist (deg)
100	0.586	58.6	0.037	0.003617652
200	0.586	117.2	0.074	0.007235303
300	0.586	175.8	0.111	0.010852955
400	0.586	234.4	0.148	0.014470606
488.13	0.586	286.04	0.180	0.017599385
500	0.586	293	0.185	0.018088257
600	0.586	351.6	0.222	0.021705909
700	0.586	410.2	0.256	0.025030237
800	0.586	468.8	0.299	0.029234533
900	0.586	527.4	0.332	0.032461087
1000	0.586	586	0.365	0.03568764

Table 4.4: The torsional analysis data for SF-02

4.3.1.2 SF-03 Torsional Stiffness Data

Taken [46.064kg x 9.81m/s^2 = 451.88N] load to show the calculation of the torsional stiffness.

**the value of 46.064kg is the mass of the chassis.*

Torque applied, **T** **= [F] L**

= 451.88N x 0.48m =216.9Nm

Angle of twist, α **=tan^{-1} [(*x*) / L]**

= tan-1 [0.0000832m / 0.480m) = 0.009931deg

Torsional stiffness = Torque applied / Angle of twist

= 216.9Nm / 0.009931deg

=21840.11 Nm/deg

Load (N)	Width of the chassis (m)	Torque applied (Nm)	Deflection (mm)	Angle of twist (deg)
100	0.48	48	0.0185	0.002208275
200	0.48	96	0.037	0.00441655
300	0.48	144	0.0555	0.006624824
400	0.48	192	0.074	0.008833099
451.88	0.48	216.9	0.0832	0.009931268
500	0.48	240	0.0925	0.011041374
600	0.48	288	0.111	0.013249649
700	0.48	336	0.128	0.015278874
800	0.48	384	0.1495	0.017845247
900	0.48	432	0.166	0.01981479
1000	0.48	480	0.1825	0.021784332

Table 4.5: The torsional analysis data for SF-03

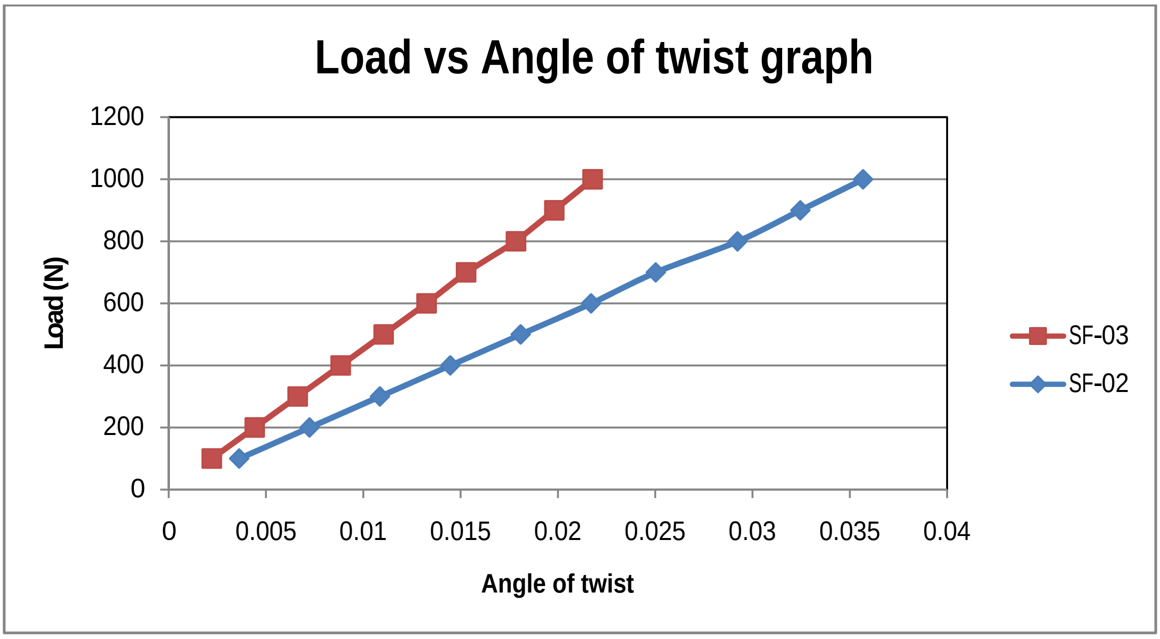


Figure 4.13: Load vs Angle of twist graph

4.4 Discussion

4.4.1 Deflection

Referring to the figure 4.10, the graph clearly shows the comparison of deflection between SF-02 and SF-03 chassis. The iteration starts with load 50N and end at 700N. For SF-02, the deflection maximum point is approaching 0.88mm while for the SF-03 maximum point is approaching 0.53mm. This evidence indicates that there is tremendous improvement in design that provides more rigid chassis. Base on the graph, the difference in load capacity with deflection shows that the SF-03 chassis can withstand 300N more than the previous chassis at the same amount of deflection which is 0.53mm.

4.4.2 Angle of twist

Referring to the table 4.3 and 4.4, and figure 4.12, it can be concluded that the angle of twist of SF-03 chassis was reduced approximately 40%. This reduction is an indication of improve in flex resistance on the SF-03 chassis. Basically, the factors that affect the value of the angle of twist are material selection and width of the chassis. By having a smaller angle of twist, higher torsional stiffness can be archived.

4.4.3 Torsional stiffness

The easy understanding of torsional stiffness can be relate with equation below,

$$\boldsymbol{F} = \boldsymbol{kx}$$

$$\text{Arrange, } \boldsymbol{k} = \frac{\boldsymbol{F}}{\boldsymbol{x}}$$

Where **F** is a force applied, **k** is the constant (stiffness) and **x** is a deflection.

Thus, the above equation clearly shows that the value of stiffness will be large when the value of deflection becomes smaller when same load applied. Thus, as shown at table 4.3 and 4.4, SF-03 has a greater value of torsional stiffness and small deflection compare to the SF-02 at the same load applied. The larger value of torsional stiffness is much better since it reduce the deflection of the chassis when the load applied.

4.5 Fabrication Process

4.5.1 Monocoque Body [2]

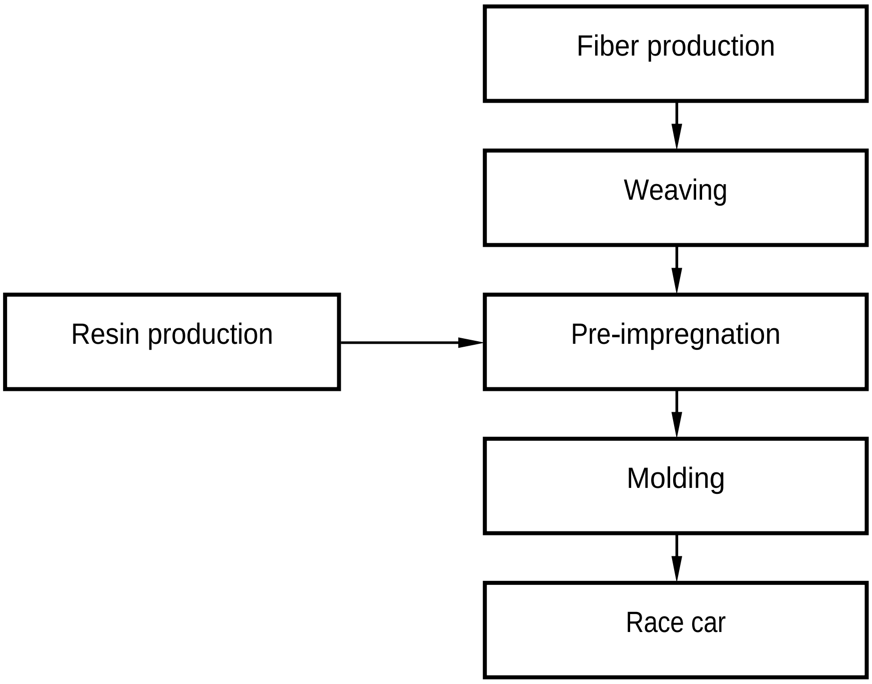


Figure 4.14: CFRP composite component fabrication process

4.5.1.1 Textile weavers

Individual carbon fibers are made up into tows, similar to what is done with any textile fiber. To enable the carbon to be pre-impregnated and laid up, it is then proceed into cloth or mat. The straighter the fibers, the better they are able to carry the tensile loads. However, weaving tends to put crimps into the fiber, detracting from optimum strength and stiffness. The number of tows in any given direction determines the number and extent of crimping and hence the properties of the resultant laminate in that direction.

A number of different weaves have been developing, with different structural properties and capabilities. In increasing order of strength/stiffness, the weaves most commonly use in race care component are:

- Plain weave
- Twill
- Satin unidirectional
- Unidirectional

For ultimate strength and stiffness, unidirectional fiber is used. Very high performance is possible in the direction of the fibers, but there is little strength in other directions.

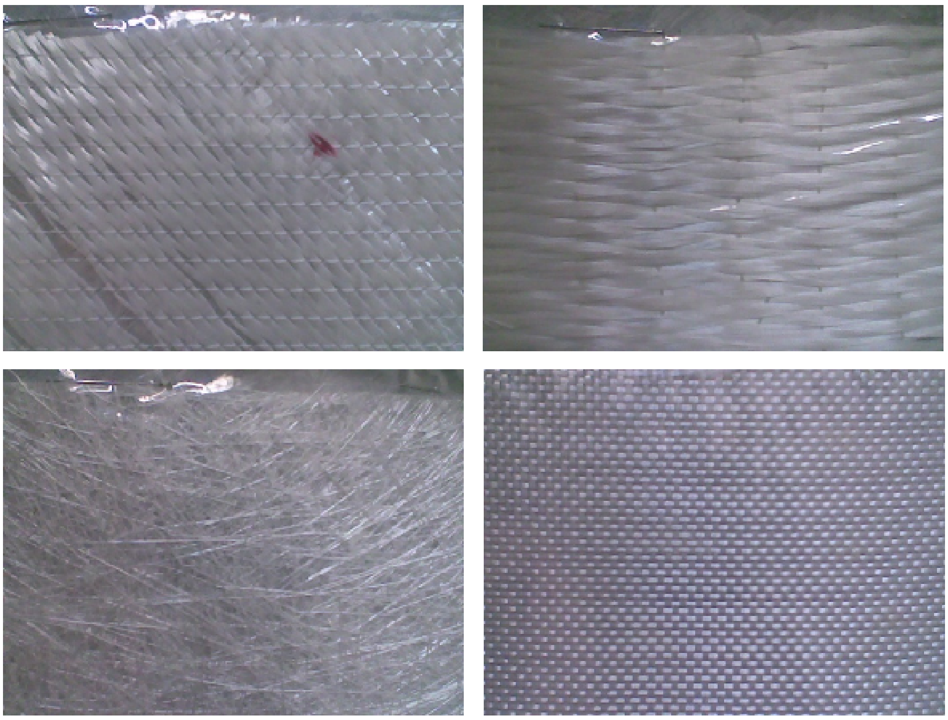


Figure 4.15: Varieties of carbon fibre

4.5.1.2 Resin and pre-impregnation

Resin system used in motor racing is almost exclusively epoxies. Since the early days, the temperature characteristics have changed the most. Initially, 100^{o}C was roughly the maximum unstable temperature, and the component had to be cured in the mold to that temperature to archive this heat-deflection temperature. Now, toughened epoxies can be cure at low temperature and can archive up to 400^{o}C by being heated to that temperature in use. Typically, monocoque uses a resin system that has good properties up to 150^{o}C to cater for the temperature at the rear of the structure.

Pre-impregnation of the cloth with the chosen resin is a highly controlled process, ensuring a precise resin-to-fiber ratio. The resin is stable for several month at low temperatures (pre-pregs are stored in a deep freeze) but cures slowly at room temperature. Elevated temperatures are use for actual curing)

4.5.1.3 Molding

Tooling for CFRP components must be strong enough to withstand the temperature and pressure of the curing cycle. Have similar thermal expansion to CFRP, and easy to shape and finish to high gloss. Materials include:

- Aluminum – easy to machine and strong, but offers greater that CFRP thermal expansion
- Graphite – easy to machine but structurally poor, with similar thermal expansion
- CFRP – used for molded tools, strong with similar thermal expansion

When the component is laid up in the tool, with each layer of cloth or unidirectional fibers aligned according to the specification laid down by the designer, aluminum insert are incorporated, and core materials are placed where required. It is then consolidated and cured. A monocoque may comprise dozens of individually tailored pieces of various cloths and unidirectional fibers. Cores are typically aluminum honeycomb (good shear strength and impact absorption) or Nomex honeycomb (good drape ability but use mainly for nonstructural components). Depending on the resin system, a glue film may be placed between the honeycomb and the skin to ensure adequate bonding.

Prior tu curing, the whole lay-up is covered with a release film (perforated with a number and size of holes according to how much resin bleed is required), followed by a breather/bleed mat to spread the vacuum and absorb the resin bleed, and finally the vacuum bag which is sealed to the mold. If no resin bleed is required, a gas permeable PTFE release film is used.

Vacuum is applied to consolidate the laminate prior to curing in the autoclave. An autoclave is in effect a large oven that is able to withstand pressures in excess of 8 bars. Pressure of 7 bars for solid laminates and approximately 3 bar for sandwich panels (to prevent collapse of the core) are applied to further consolidate the laminate and promote resin flow. The temperature is raised progressively at approximately 2^{o}C per minute, to approximately 8^{o}C at which point the resin become liquid and flows, ensuring good fiber wet-out and interlayer adhesion. It is held at 80^{o}C for 20-30 minutes, and then ramped up to typically around 135^{o}C and held for 1.5 hours for full curing. On cooling, the laminate can be released from the mold, trimmed, machined and finished.

4.5.2 Space frame body

The fabrication process for the space frame chassis involved few stem that shown below:

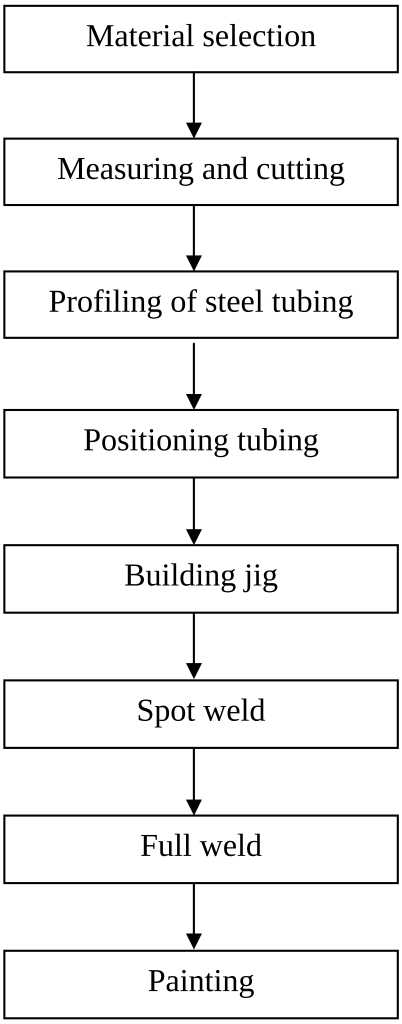


Figure 4.16: Fabrication process for space frame body

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The author has managed to accomplish the objective of the project which is to perform design and analysis for the proposed hybrid Composite-Steel Space Frame chassis and to optimize the chassis design for the best packaging, ergonomics, handling and chassis strength-mass ratio. The author has finished and completes designed the new type of the UTP Formula SAE race car chassis. There also some analysis that clarify the deflection of the chassis when side impact occur and torsional analysis that determine the torsional stiffness of the chassis. From the analysis, the optimization of the chassis has been achieved and performance of the car was improved compare to the previous chassis design. The author also proposed the fabrication process of the chassis which is will lead to be a reference during the chassis process start.

Furthermore, for better analysis, the experimental test for the carbon fibre should be done in the lab. This would help for the student to understanding the fabrication process and behaviour of the carbon fibre when doing the experiment.

In aspect of the chassis type, the author feels that there are still a lot of improvement and study to taken care of. The design of the chassis can be develop to be more compact to reduce weight and at the same time to have good ergonomics and packaging. There is also need to make a mock up prototype for the chassis before proceed to the real fabrication. The prototype will go through the static or dynamic testing and some modification can be made and apply for the real chassis.

Overall, the objective of this project has been achieved in term of designing and the analysis point of view.

REFERENCES

1. Herb Adams. (1993) Chassis Design, Building & Tuning For High Performance Handling, CHASSIS ENGINEERING, The Berkley Publishing Group.

2. Peter Wright (2001) Formula 1 Technology., Society of Automotive Engineers, Inc

3. John Fenton (1998) Hanbook of Automotive Body Construction and Design Analysis, Professional Engineering Publishing

4. Mohamad Hafiz Bin Nor Azizan, 2007, *Design And Analysis of a Space Frame Chassis for Race Car,* Universiti Teknologi Petronas.

5. 2008 Formula SAE Rules. SAE International

6. Design Report for SF-01 Team UTP Formula SAE 2006

7. Formula SAE website, 5July 2008 <http://students.sae.org/competitions/formulaseries/fsae/teamsites/>

8. RMIT (Royal Melbourne Institute of Technology) website, 15 October 2008 <www.fsae.rmit.edu.au/>

9. The University Of Western Australia Formula SAE website, 15 October 2008 <http://www.motorsport.uwa.edu.au/>

10. Website refer to University Of Wisconsin Formula SAE website, 15 October 2008 <www.uwracing.com/

APPENDICES