CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Universiti Teknologi PETRONAS (UTP)'s Formula Society of Automotive Engineer (FSAE) team has managed to send a race car to a competition in 2006 which was held in Australia but the results was not filled with vigour. The car sent has a lot of problems and safety issues. The problems that arise have given the idea for the author to initiate the project. Formula SAE "is competition for student to visualize, design, fabricate small formula-style race car. Some constrains and limitations need to be obeyed so that it will challenge student's creativity, knowledge and imagination" [9].

1.2. PROBLEM STATEMENT

Previous chassis design causes a lot of problems to the fully assembled race car. Improper analysis of the chassis was also the causes of the problems that occur to the previous chassis design. The problems faced by the car were poor handling, enormous chassis weight, poor straight line acceleration and imbalance power-to-mass ratio. The countermeasure of these problems is to design and properly analyse a new race car chassis. But to design the chassis it involves optimization between many different conflicting requirements.

The proposed design must able to contribute to car's mass reduction therefore providing good power-to-mass ratio and in turns give the car better straight line results. The design must possess features such as smaller wheelbase and track width, compact and lightweight without compromising the ergonomics requirements.

Another factor that contributes to a proper chassis construction is the manufacturing process take place during the fabrication process. In order to build a reliable chassis there must be a jig that can hold all the members together before it is welded. From the previous experience, UTP FSAE team lack of this crucial part which then causes the chassis that is fabricated not properly manufactured. The welded tube tends to expend when it colds and this causes the construction of the chassis encounter some flaws. Besides, the previous project used plywood as the jig. From the author's observation, the plywood jig does not provided proper support. The result is the chassis is not fabricated according to the desired design. For instance is the base of the chassis is not straight. Instead of straight, the base flex; this problem will lead to other problems where it will affect the geometry of the suspension. As the result, the handling of the car will be very bad and will affect the overall performance of the car. Thus, in this project, the author will proposed a proper jig construction which will be discussed in the second part (FYP 2) of the this project. Figure 1-1 shows an example of a proper jig use when fabricating a chassis.

Figure 1-1 Proper jig construction (Helsinki Polytechnic)

1.3. OBJECTIVES AND SCOPE OF THE PROJECT

1.3.1. To design a small race car chassis and optimize the design for optimum handling and power to-mass ratio.

1.3.2. To perform design and analysis iteration on the designed chassis using computer aided engineering tool (finite element analysis).

1.3.3. To propose suitable fabrication method for small scale production of the race car chassis.

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

2.1. CHASSIS DESIGN

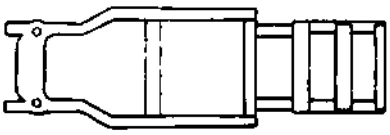
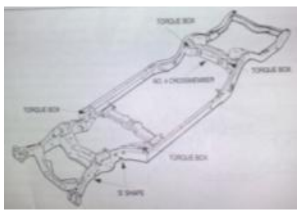
2.1.1. Type of chassis

For commercial vehicles, two types of frame design are available. There are: -

2.1.1.1. Body-over-frame (BOF)

This type of frame can be further classified into two general categories which are the **Ladder-type frame** or **Perimeter-type frame** [3]**.** Table below explain the construction of each type of the chassis.

Table 1: Frame design and construction for Ladder-type frame chassis and Perimeter-type frame chassis

Ladder-type frame	Perimeter-type frame
This type of chassis takes its name from its resemblance to a ladder. The construction of this chassis consist of two side rails and it is connected with the cross members. Figure 2-1 shows the construction of the ladder-type frame  **Figure 2-1: Construction of the Ladder-type frame**	The construction of this chassis is different where the front frame rails are curved inward to accept the engine mounts, hold front suspension and allow the front wheel to remove as required. Figure 2-2 shows the construction of perimeter-type frame  **Figure 2-2: Perimeter-type frame construction which consist of torque box (Ford Motor)**

2.1.1.2 Unitized body (Monocoque)

This type of chassis uses an integral body and frame. The most common construction method is to form the body by welding numbers of stamped metal panel to a platform-type floor pan of stamped metal. The floor pan consist series of ribs that start from rear of the vehicle and end at the firewall. Purpose of these ribs is to increase structural rigidity of the chassis [3]. Figure 2-3 shows the example of a unit body design and the floor pan.

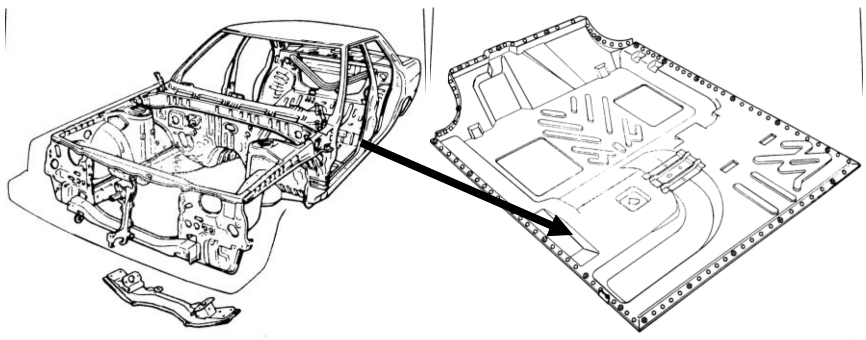


Figure 2-3: Construction of unit body design (Toyota) and position of floor pan (Kalton C. Lahue, 1995)

2.1.1.3 Space frame

Construction of this type of chassis consists of many small diameter triangulated tubes welded together to form a structure [2]. The design can be simple space frame or complex space frame. A popular design for space frame chassis in Formula SAE is the tubular space frame. This type of frame is efficient where there are a few specific highly loaded points to be connected such as engine mounts and suspension brackets. Figure 4 shows the example of tubular space frame chassis design.

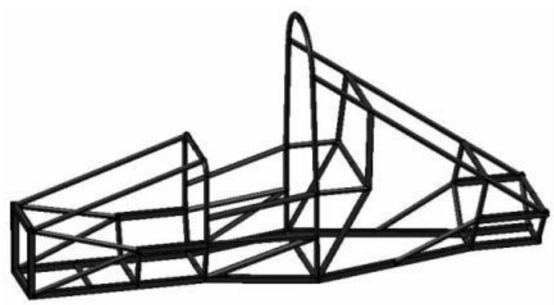


Figure 2-4: Previous FSAE tubular space frame chassis design

2.2. RULES AND REGULATION

The design of the chassis must abide the rules and regulation which stated in the Formula SAE Rules. In addition to that the design must able to meet to target specification. Some of the crucial rules that must be followed such as [10]:-

2.2.1 Ground clearance

The design car must have a minimum of 25.4mm (1 inch) of static ground clearance with the driver abroad. This is to prevent any portion of the car (except tyres) from touching the ground during events.

2.2.2 Wheelbase and vehicle configuration

The car must have four (4) wheels and not in a straight line. The wheelbase must at least 1525mm (60inches). Wheelbase is measure from the center of the ground contact of front and rear tires with wheel pointed straight ahead.

2.2.3 Vehicle track

The smaller track of the car (front or rear) must be no less 75% of the larger track. Other important rules can be found in FSAE Rules in the attachment section

2.3. THEORY

There are several factors that need to be considered when designing a structural construction; in this case space frame chassis. These factors will determine the reaction of the chassis towards the applied load and in turn will affect the performance of a race car. The factors that influence the design are:-

2.3.1. Longitudinal load transfer

During breaking or accelerating, type of force that acting on a chassis is the longitudinal load. Longitudinal load transfer can be calculated by using the following formula [7]: -

$$LLT = \frac{Long_{acc}\ x\ \ force\ at\ axle\ x\ h}{l} \qquad (1)$$

$Long_{acc}$ = Longitudinal acceleration, g

h = Center of gravity height, m   l = wheelbase, m

From the equation (1), longitudinal load transfer can be reduced by increasing the wheelbase of the car, lowering the height of centre of gravity, or providing a soft initial acceleration. Figure 2-5 shows the example of longitudinal load acting through vehicle's centre of gravity.

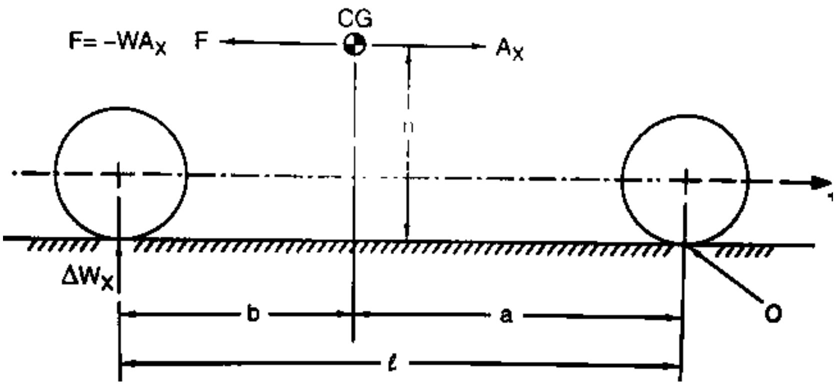


Figure 2-5: Longitudinal weight transfer (Anthony M O'Neill, 2005)

During breaking, the load is more to the front tyre and unloading the rear tyre. When excessive load is being transferred, due to unloading at the rear tyre breaking ability of a car will be reduced [1].

2.3.2. Lateral load transfer

A car is subjected to lateral load when cornering. Increasing of lateral load during cornering is caused by the centrifugal force. The load lateral load will further increase if the driver pushes the brake when taking a corner [8].

Lateral load acceleration cornering will cause lateral load transfer. This lateral acceleration will increase the vertical load on the outside and inside tyre by the same amount. Simplified equation for lateral load transfer can define as [8]: -

$$LT = \frac{A_Y \ x \ W \ x \ h}{t} \quad (2)$$

LT = Lateral load transfer for an axle, N

A_Y = Lateral acceleration, g's

W = Weight at center of gravity

h = Centre of gravity height, m

t = track or track width, m

Figure 2-6 below shows the effect of changing the parameter to the lateral load transfer.

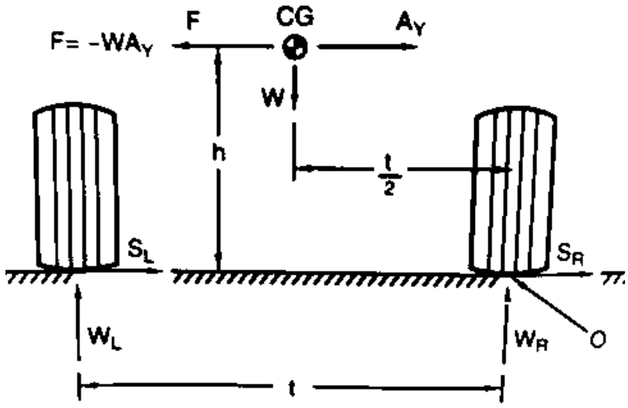


Figure 2-6: Total lateral load transfer (Anthony M O'Neill, 2005)

Other than effect of cornering, lateral load transfer can be generated by the following ways [1]:-

2.3.2.1 Physical compression of the outside spring and deflection of anti-roll bar if it is fitted.

2.3.2.2 Jacking effect by any independent suspension

2.3.2.3 Forces the generated by the tyre as it resist the centrifugal force. These forces are reacted on the sprung mass through roll centres.

2.3.2.4 Displacement of centre of gravity due to roll

Lateral force need to be transmitted from the ground to the chassis. In order to do that, there must be a point where all the resultant forces are acting and this point is known as the roll center. Roll center for the front and rear suspension is separated. Vehicle leans or rolls about these points due to centrifugal force in a corner [7]. Figure 2-7 shows the jacking effect and position of roll center on a car.

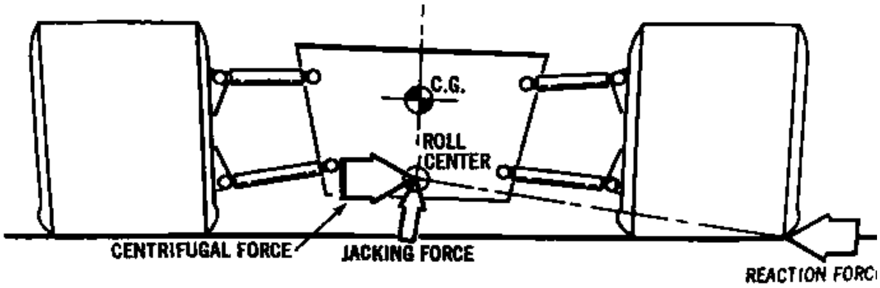


Figure 2-7: Jacking effect and roll center position (L.MILLIKEN, 1995)

From figure 2-7, the higher the roll center, the greater is the jacking effect. The best condition is the roll center and mass centroid axis is in parallel. When this occurs, the amount of lateral load transfer and roll generation will be about equals. Thus it will provide a desirable handling condition [7].

When chassis roll occurs, it will lead to the undesirable chamber angle which in turn resulting in the instability and inconsistency in the vehicle handling behaviour. Chassis roll can be reduced by applying stiffer suspension, usage of the anti-roll bar and raising the roll center relative to center of gravity [1].

2.3.3. Torsional rigidity and stiffness

Previous section discussed about the load transfer on a vehicle. Being able to control the load transfer distribution is the key to get the favourable handling condition. But, it is only if the chassis is stiff enough to transmit the torque produced [1].

Torsional rigidity can be defined as the ability of the chassis to flex when it is subjected to different direction of load. For instance, one side of wheel experience upward force meanwhile the other front wheel subjected to downward force; but at the same time the rear of the vehicle is anchored [7]. This situation can be observed during cornering.

Figure 2-8 below shows the value for torsional stiffness of the previous chassis design:-

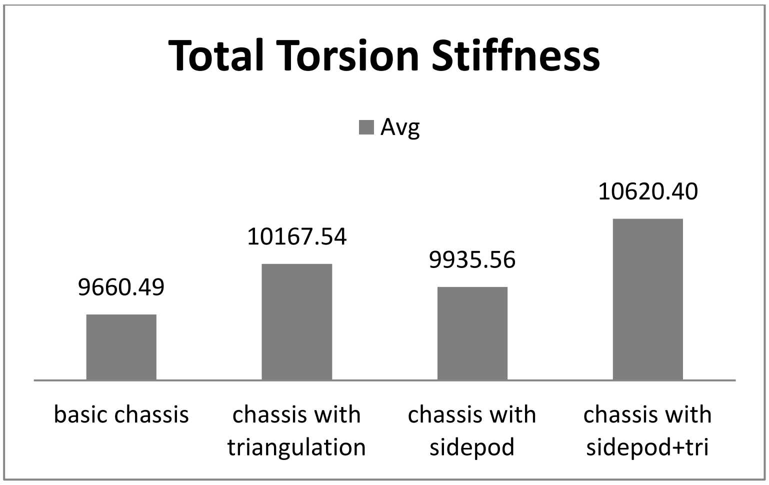


Figure 2-8: Torsional stiffness for previous chassis design (Azizan, Mohamad Hafiz Nor, 2007)

The value seems like too high compare to other's university. The result maybe causes by the improper analysis or over exaggerating some parameters when conducting the analysis. For references, University of Southern Queensland they claimed that their car has the torsional stiffness of 214Nm/degree and they have done a physical testing. University of Missouri SAE race car has a torsional rigidity of 2900Nm/degree and meanwhile for Laval University's SAE car has a torsional rigidity of 2000Nm/degree [1]. For reference, "current small formula cars may be 3000 lb-ft/degree (or equivalent to 4064.7Nm/degree)" (L.MILLIKEN, 1995).

Effect of the torsional stiffness to the car is, one will be able to predict the handling if the chassis is stiff enough. A race car can improve its handling capability by the following methods [7]:-

2.3.3.1. If the fabricated chassis is too flexible, diagonal members can be added to the structure. These diagonal members strengthen and function effectively at the load point such as suspension and spring mounting.

2.3.3.2. Engine as the stress member provided that the loads are not so high.

2.3.3.3. The usage of plate reinforcements used to connect joint if the tubes must be used in bending. The purpose is to pass the load more effectively. (see figure 2-9)

2.3.3.4. Additional cross members to the structures.

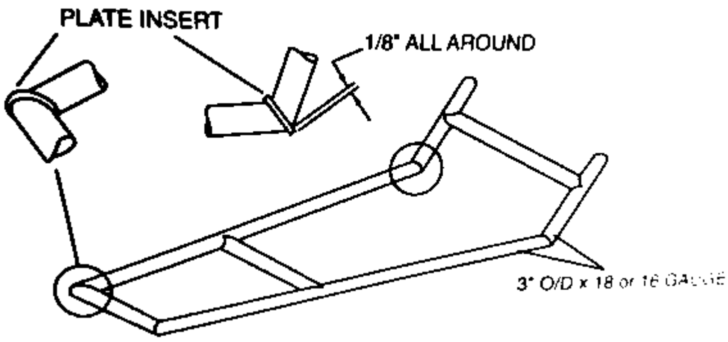


Figure 2-9: Stiffening up tubing bending (L.MILLIKEN, 1995)

Torsional stiffness is given by to following formula [8]: -

$$\frac{Torque}{57^\circ}\, x\, \frac{Spread\ distance}{Deflection} \quad (3)$$

Where

Spread distance = distance measure from the support

57° = value to convert vertical deflection into an angular measurement

2.3.4. Angle of twist

This angle indicates how rigid the car is. When the chassis subjected to a load the members will experience deflection with some angle. This angle should be as low as possible which in turn will give higher torsional stiffness. Figure 2-10 below defines the angle of twist.

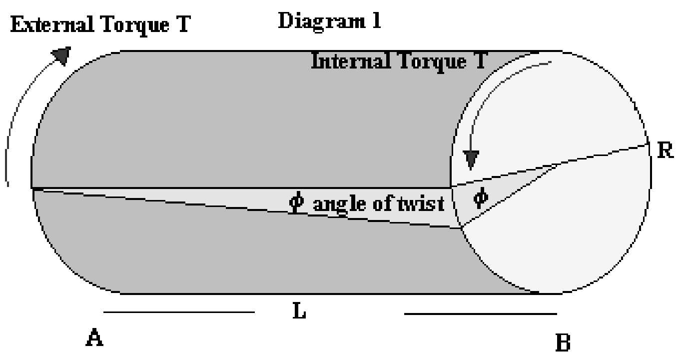


Figure 2-10: Angle of twist

Angle of twist can be calculated with the following equation [2]: -

$$\emptyset = \frac{TL}{JG} \quad (4)$$

Where;

T = the internal torque in the shaft
L = the length of shaft being "twisted"
J = the polar moment of inertia of the shaft
G = the Modulus of Rigidity (Shear Modulus) for the material

2.4. DESIGN CONCEPT

Basically, there are three options in considering the design of the final product which is the small race car for formula SAE. Each option has its own advantages and disadvantages. Thus in order to determine which design path will be considered, decision matrix was used. This process is to determine which design is feasible

First option that is available is the current design approach which is to use the four cylinder 600cc engine, space frame chassis. The advantage about this approach is it allows the car to have higher top speed. One of the disadvantages is the overall weight of the car can be too heavy like what has the UTP Formula SAE experiences. The car has a total weight of nearly 300kg. But with proper planning and design, the average weight should be around 200 to 220 kg. Example of university that has managed to use this approach is Sophia University, Japan.

Second design approach is space frame chassis with single cylinder engine. Obviously, the advantage of this design approach will be at the overall weight of the car. The usage of the single cylinder engine might be the advantage since the track layout does not required high speed. Capability of the engine to produce high torque enables the car to accelerate faster. The set back of this design is it cannot reach high top speed. Example of university that has used this approach is the Tokyo Denki University.

Final approach that is available is a full carbon fibre monocoque chassis and either single cylinder engine or four cylinder engine. The advantage will be the total weight of the car. The overall weight of car with this design approach is less than 200kg. The disadvantages will be the cost and technology used to fabricate the chassis. It will be burden to a university which plan to use this approach if they do not have enough resources. University of Western Australia (UWA) and Royal Melbourne Institute of Technology (RMIT) are the example of universities that have successfully implemented this design approach.

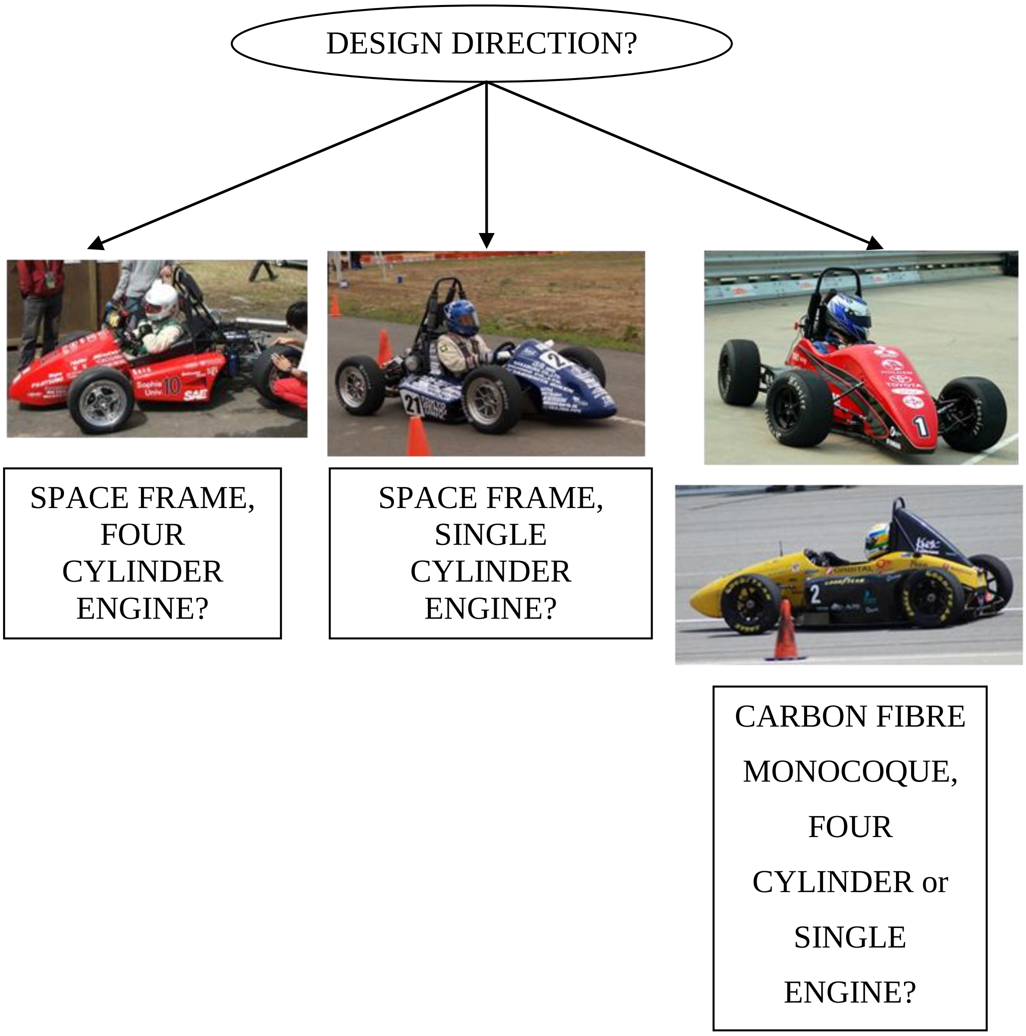


Figure 2-11: Three types of design approaches

2.5. MATERIAL

2.5.1. Suitable material list

From the research and study that has been conducted, most of the FSAE team will use the material ranges from Aluminium, low carbon steel, and alloy steel. To be more specific, the type of Aluminium use is the 7075-T6, SAE 4130 chromoly alloy for alloy steel and SAE 1020 low carbon steel [1]. With all these material short listed as the possible material to be used for the construction, these materials will be evaluated base on several criteria. The criteria use is the properties of the material, economic consideration, and availability of the material.

2.5.2. Properties

In order to get optimum performance of the car, selection of material is one of the important criteria. The material chose should posses' properties that enable the car to be subjected to several types of loads. Proper material selection will also assist to achieve the objective of fabricating a race car body frame which is lightweight, high in strength and stress. The properties include the mechanical, physical, and chemical. Refer appendix-4 for the required properties of each material must posses. Table 2 shows the comparison of the properties for each material.

Table 2: Material properties [5]

Property	SAE 1020	7075-T6	SAE 4130
Density	$7870 \frac{kg}{m^3}$	$2810 \frac{kg}{m^3}$	$7872 \frac{kg}{m^3}$
Modulus of Elasticity	200GPa	71.7GPa	205GPa
Thermal expansion	$11.9(10^{-6})°C^{-1}$	$23.3(10^{-6})°C^{-1}$	$11.2(10^{-6})°C^{-1}$
Specific heat capacity	$0.599 \frac{J}{g.°C}$	$0.96 \frac{J}{g.°C}$	$477 \frac{J}{Kg.K}$
Thermal conductivity	$51.9 \frac{W}{m.K}$	$130 \frac{W}{m.K}$	$42.7 \frac{W}{m.K}$
Tensile strength	384Mpa	503Mpa	561Mpa
Yield strength	165Mpa	445Mpa	361Mpa
Elongation	32%	11%	28%
Hardness	137HB	150HB	197HB

From the table, Aluminium 7075-T6 has the advantages over the other material in term of density where it has low density. This will lead to an advantage in term of weight for the chassis that will be fabricated. In term of strength Aluminium is stronger compare to other two materials followed by SAE 4130 and SAE 1020. But the drawback of Aluminium is fatigue [1]. This can be proved from the figure 2-12. It shows that Aluminium does not posses endurance limit where it fall whilst steel posses such properties where it can sustain even at higher cycle.

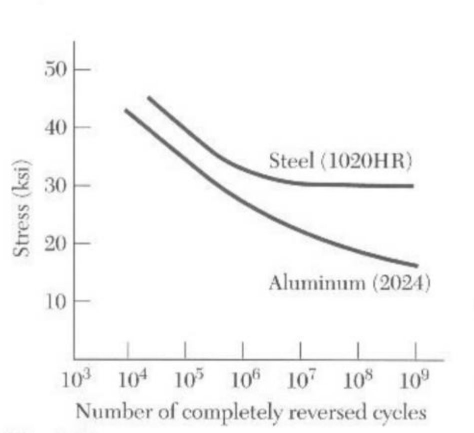


Figure 2-12: Stress – Loading Cycles Curves (Beer,Johnston&DeWolf)

2.5.3. Economic consideration

Economic factor is one of the crucial elements in every project. In FSAE, each team must be able to design a whole car within the budget which is USD25000. Thus, proper material selection will lead to cost saving and enable the project to run within the budget. Economic considerations involve the cost for raw material, quantity of the raw material required and fabric ability which include formability and weld ability.

In term of cost, SAE1020 is a lot cheaper compare to 7075-T6 and SAE 4130 but still in term of the strength SAE 4130 and 7075-T6 out number the SAE1020. This will be the advantages for the material to be selected. For the quantity, number of the steel tubing required is depending on the design of the chassis plus fifteen percent extra tubing in case any error occur during the fabrication of the chassis. This factor needs to be considered as it will affect the overall budget.

Another factor to consider is the formability and weldability of these materials. The material should be easy to bend and to be welded. SAE1020 and SAE 4130 posses both of the element but Aluminium 7075-T6 required special skills and setting to weld them.

2.5.4. Material selection

Based on the several factors discussed earlier and also from the study, the most common material used by other university in the FSAE competition is the Alloy steel. To be more specific, it is the SAE 4130 carbon steel or best known of the family chromoly steels.

Alloy steel is identified by a four digit number. The first two digit numbers indicate the major alloying element. As for SAE 4130, the 41XX represent that this type of alloy consist of 0.50%, 0.80% or 0.95% Chromium plus 0.25% Molybdenum. The exact composition for SAE 4130 is Carbon 0.30%, Manganese 0.5%, Molybdenum 0.2% and Chromium 1.0% [13].The advantages of using this material compare to SAE1020 is the strength of the chassis that will be built using this material even though the weight will be slightly the same.

The other material that will be considered to be used for the construction of the chassis is the Aluminium. Since the chassis must be lightweight, combination of Aluminium with 4130 carbon steel can produce such chassis. The construction of the chassis that required the usage of Aluminium as the material will be shown in the result and discussion part.

According to the findings and research, the strongest Aluminium family that suit for this application is the Aluminium 7075-T6. Aluminium is selected because of its characteristic, which is very high strength material used for highly stressed structural parts [5]. Compositions for Aluminium 7075-T6 are consist of Aluminium 87.1-91.4%, Chromium 0.18%-0.28%, Copper 1.2-2%, Ferrum maximum of 0.5%, Magnesium 2.1-2.9%, Manganese 0.3%, Silicon 0.4%, Titanium 0.2%, and Zinc 5.1-6.1% [5].

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1. PROJECT FLOW CHART

Figure 3-1 gives the overview of the suggested project flow chart for the first semester (FYP1). Project started with identifying the problems and also the objectives of the project. The next step is to determine the target specification whilst completing the literature review. Once finished, the author has to come out with several chassis design with different approaches in order to achieve the target specification which has been decided earlier. Decision matrix method will be used to decide which design will be selected and this will lead to a finalization of target specification. Once the target specification is firm, analytical calculation will be used to determine the estimated parts and component size. The design and analysis task will be done after all the information is obtain. If the design meets the specification target, the process will be continued by the critical design review where the final design of the chassis will be evaluated.

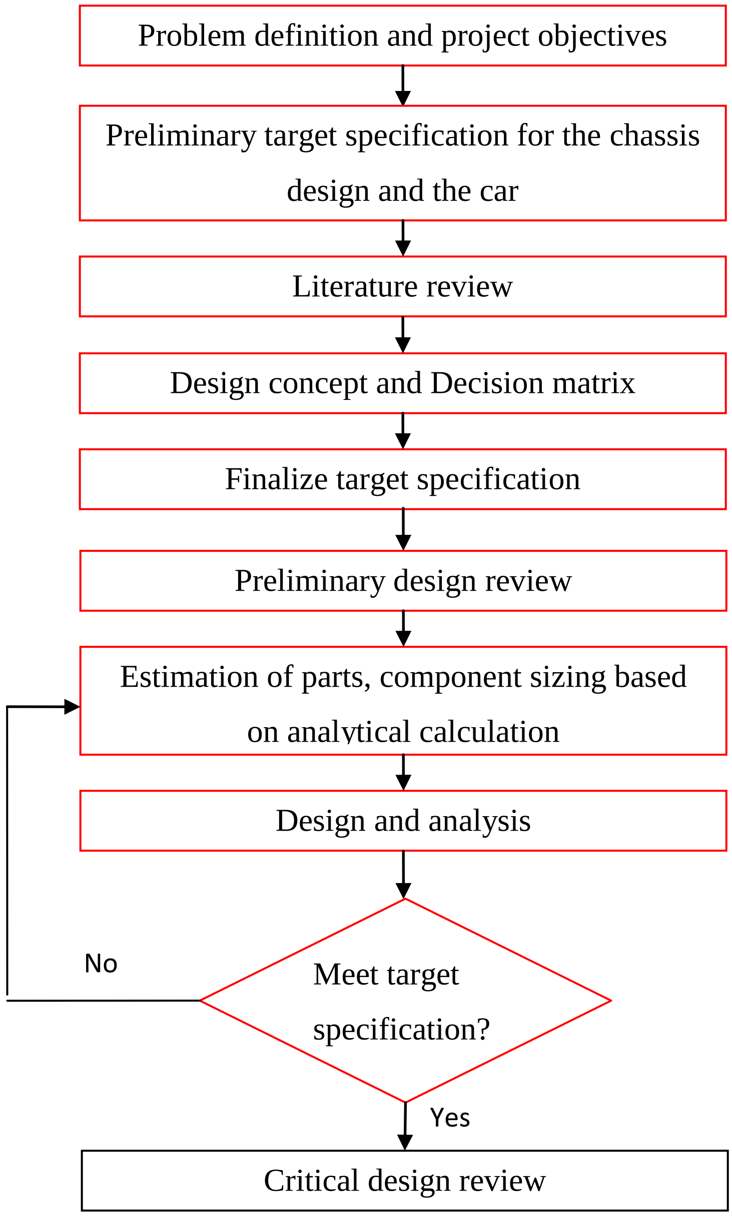


Figure 3-1: Proposed project flow chart for first semester (FYP1)

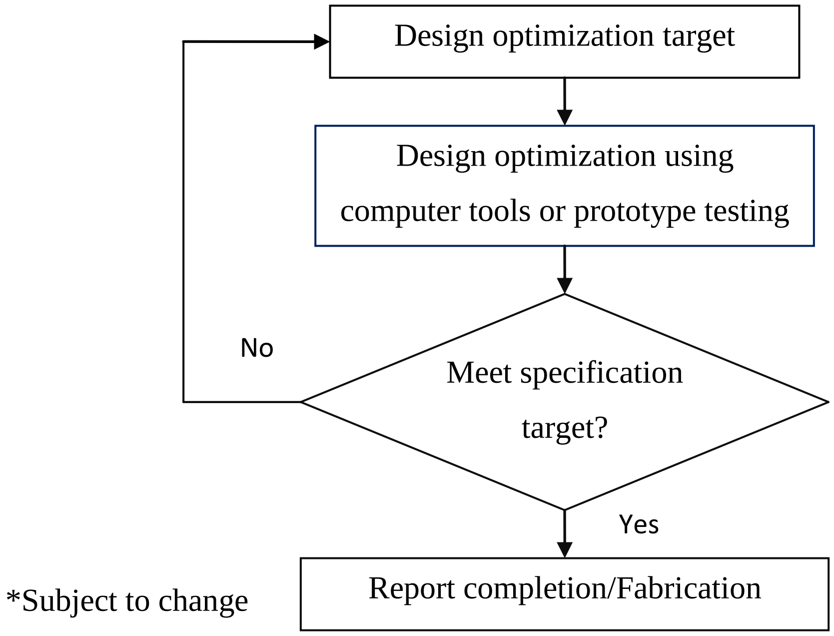


Figure 3-2: Proposed project flow chart for second semester (FYP2)*

Figure 3-2 shows the proposed project flow chart for the second semester (FYP2). The finalized design will undergo several design changes in order to achieve the optimize design. This will include the fabrication method and also refinement of the costing. The method that will be used is either by using computer tools or prototype testing. If the modification done to the design achieved the specific target; and if time permit, fabrication work will take place and also the completion of the final report. Gantt chart for the overall project is available in the appendices section.

3.2. TOOLS and EQUIPTMENT

The tools required to complete this project such as:-

3.2.1. Engineering software such as CATIA V5 and ANSYS
3.2.2. Adams car

3.3. DECISION MATRIX

In order to decide which design is feasible for this project, decision matrix is used. Each and every factor that will contribute to selection of the design approach will be listed and will be given score accordingly. This step is essential to determine the best design approach that will be considered for the project.

Each design approach will be assigned to a number such as:-

3.3.1. Space frame chassis with four cylinder engine will be assigned as Design Approach 1 (DA1).

3.3.2. Space frame chassis with single cylinder engine is known as Design Approach 2 (DA2).

3.3.3. Full carbon fibre monocoque with single cylinder or four cylinder engine will be assigned as Design Approach 3 (DA3).

The factor that will be use to evaluate the Design Approaches are: -

3.3.3.1. Low production cost

3.3.3.2. Ease of maintenance

3.3.3.3. Ease of manufacturing

3.3.3.4. Reliability

3.3.3.5. Performance

The score given is in the range of one (1) to ten (10). 1 represents the least and 10 are the highest mark. Total mark is 50.

Table 3: Decision matrix

	DA1	**DA2**	**DA3**
Production cost	7	9	3
Maintenance	5	5	7
Ease of manufacturing	5	6	4
Reliability	6	6	7
Performance	7	6	8
TOTAL	30	32	29

If these three design approaches were analysed in term of production cost, DA2 is the ideal design approach to select. It is because in order to fabricate the chassis the tool required is much more simple compare to DA3. Between DA2 and DA1, DA2 required less production cost because less no of part need to be fabricated compare to DA1.

As for ease of maintenance, DA3 scored highest mark because for instance, the carbon fibre monocoque chassis is easy to reconstruct if accident happened. It just required changing the affected section meanwhile with space frame chassis it is almost impossible to change the frame member that is affected. In term of manufacturing, DA2 score the highest mark. It is because to fabricate a car with single cylinder engine with space frame is less hassle compare to four cylinders engine or even worst if the chassis is carbon fibre monocoque. It is because carbon fibre monocoque required special skill and also special equipment to fabricate the chassis.

For reliability, all three design approaches is reliable. But DA3 scores higher simply because carbon fibre chassis is very strong and also rigid. For DA2 and DA1, space frame chassis is strong and also rigid but many factors can influence the strength and rigidity of the chassis such as the quality of the welded member and also proper heat treatment. Finally, all of the design approaches were evaluated base on its performance. Clearly that DA3 has more advantages due to weight saving characteristic that carbon fibre monocoque offers. From the analysis, DA2 has scored the highest mark and will be considered as the design approaches for this project.

CHAPTER 4
RESULT AND DUSCUSSION

As for preliminary design for part 1 (FYP1), 3 designs will be used to compare to the other previous design. This is to differentiate the design that the author has come out with and the previous design in term of the weight of the chassis and the deflection of the frame when subjected to several loads. To validate the design, for part 1 (FYP1) the analysis function in CATIA will be used. Even though the result is not as accurate as analysis is done using ASYS, but the result is still acceptable.

4.1. Part 1 result and discussion

4.1.1. Design

The previous design will be used to compare with author's design. Previous design is indicated by SF-01 and SF-02 while author's design is indicated by SF03_01, SF03_02 and SF03_03. These chassis will be compared in term of the weight; Von misses stress, and translational displacement of each design in the analysis section. Refer appendix 5 for the translational deflection and von misses stress of the chassis.

4.1.1.1. SF-01

This is the first design of chassis for UTP FSAE car. The design is over weight and too big. In addition to that, there is no ergonomic study conducted during the designing process of the chassis. As a result, driver feels not comfortable when sitting in side the car. Refer appendix 6-1 for the design and properties of the chassis.

4.1.1.2. SF-02

This is the second design of UTP FSAE chassis. As what can be seen, it has undergone a lot of improvement in term of the design, ergonomic and also the weight of the chassis. Refer appendix 6-2 for the design and properties of the chassis.

4.1.1.3. SF-03_01

This is the first proposed design by the author. To fulfil the objective of the project, the chassis must have lighter weight but for this design the weight is a bit heavier from the previous design. If this design is selected, some weight can be removed especially at the rear bulk head part. The manufacturing processes involved are also being taken into consideration. This will ensure that the fabrication process will go smoothly and according to the plan. From this design, the difference is at the rear bulk head construction. It differs from the previous design where in this design, the author decided to use Aluminium plate as the construction. The purpose is to ease the assembly process where the plate provides a space for suspension to be mounted. But the design is not in detail since this is only for the preliminary design purposes.

From the pass experience, the problem occurs when to determine the mounting of the suspension where during the design process, the previous designers have not taken this matter into their consideration. By reducing the weight of the chassis without compromising the ergonomic need, this design can assist to achieve the objectives of this project. Refer appendix 5-3 for the design and properties of the chassis.

4.1.1.4. SF-03_02

This is the second proposed design by the author. The construction of this chassis is a lot like the same with the first one but notice the different is at the rear bulk head construction. Instead of using Aluminium plate, the construction of the rear bulk head utilised the square shape tubing. The reason is to provide a flat surface to enable the suspension mounting (cleavage) and plate to hold the differential to be mounted at the rear bulk head. The manufacturing process for this design is also a lot easier compare to SF-03_01 where no machining required. Even though it looks simple, but this design can provide a lot of weight saving features besides saving the cost to manufacturer the chassis compare to SF-03_01. Refer appendix 6-4 the design and properties of the chassis.

4.1.1.5. SF-03_03

Third design proposed by the author is completely different design from the previous design. It looks a bit complicated to build but if this design is to be considered, it can provide a stronger and stiffer chassis. The disadvantages of this design is it is a bit heavier compare to SF-03_02 but two kilograms lighter compare to SF-03_01. Similar to SF-03_01 the rear bulk head is fabricated using Aluminium plate as it will provide convenience during the assembly process especially to mount the suspension at the rear bulk head. Refer appendix 6-5 for the design and properties of the chassis.

4.1.2. Power-to-weight calculation

One of the objectives of this project is to achieve an optimum power-to-mass ratio. In order for a car to possess a good power-to-mass ratio, the car should have the ideal overall weight so that the power produced from the engine will able to move the car without any problems. One of the factors that contribute the overall weight of the car is the chassis itself. The advantages of a car having a good power-to-weight ratio is the car will able to accelerate faster.

To calculate the power-to-weight ratio, the following governing equation is used:-

$$Power - to - weight\ ratio = \frac{power}{weight} \quad (5)$$

4.1.2.1.Calculation for SF02

As for SF02 car, the engine used is the CBR f4i with the capacity of 600cc. The maximum power for the engine is 81kW@12 500rpm and maximum torque is 65Nm@10 500rpm. But the power will no be delivered totally since there is a 20mm restrictor that restrict the amount of air for the combustion. Since they are no dyno testing conducted for UTP FSAE engine with 20mm restrictor, data from other university is used. From the research the amount of power left is about 75 to 76 Hp (55.927 490 25 to 56.673 190 12 kilowatt) [16]. So for the total power output is assumed to be 56.67kW.

For the total weight, the chassis, engine, bodywork and peripheral is the main component that counted. Table 4 shows the weight for each component:-

Table 4 Components weight for SF02 car

Chassis	29.531kg
Engine	59kg
Bodywork	35kg
Peripherals	140kg
Total	263.531 kg

Thus the power-to-weight ratio for SF02 is **215.04 W/kg.**

4.1.2.2. Calculation for SF03_02

From the previous calculation it shows that SF02 has a good power-to-weight ratio; where the bigger the ratio is the better the car can accelerate faster on a straight line. For SF03_02 the engine that will be used is assumed to be a single cylinder engine from Yamaha which is the Yamaha WR450F with engine capacity of 450cc. the maximum power the engine can deliver is 42.3kW@9000 rpm and maximum torque of 49Nm @ 7000 rpm [17]. The rules stated that a 20mm restrictor must be installed to limit the amount of power, therefore the power left after the engine is installed with the 20mm restrictor is 41.013 492 85 kilowatt [17]. For total weight, table 5 shows each of the component weight.

Table 5 Components weight for SF03_02 car

Chassis	23.936kg
Engine	29kg
Bodywork	30kg
Peripherals	100kg
Total	182.936 kg

Therefore from the data the power-to-weight ratio is **224.195 W/kg**

As what can be observed from the calculation, it shows that the SF03_02 has slightly better power-to-weight ratio. Which mean the car will able to accelerate faster in straight line. Even though the engine used has less capacity compare to CBR engine in SF02, the car still able to accelerate faster due to less amount of overall weight of the car.

What is important for FSAE car is low end torque available, so with proper ratios it can prove that acceleration performance is as good given the short straight away section of FSAE track. This is what SF03_02 trying to prove. In addition to this, the sacrifice of using less power engine is worth it because handling is much more improved due to lower overall weight, thus lower turning movement considering many tight corners in FSAE track. Car that has engine with high top speed like the Honda CBR engine will not able to achieve it highest speed due to condition of the track, therefore it is better to concentrate to engine that can give an instant power to accelerate faster like the Yamaha WR450F.

4.1.3. Analysis

For the first part (FYP 1), the analysis to validate the design will be conducted using generative structural analysis function in CATIA. As mentioned earlier, even though the result is not as accurate as analysis using ANSYS, but the result is acceptable and can be used to compare each of the design in term of von misses stresses and the translational deflection. Table 6 tabulate the result of the analysis where the values represent the maximum translational deflection each design when subjected 100N to 1000N of forces (load). Note that this analysis is just for the purpose of comparing each design capability to sustain such loads subjected to the frame. Once the final design is decided, an accurate analysis will be conducted using ANSYS during the second part (FYP 2) of the project. The figure of the displacement and von misses stress of each chassis are available in the appendices section.

Table 6 Maximum translational deflection of each design

Load (N)	SF01 deflection (mm)	SF-02 deflection (mm)	SF03_01 deflection (mm)	SF03_02 deflection (mm)	SF03_03 deflection (mm)
100	1.30	0.6	0.466	0.361	0.392
200	2.59	1.2	0.933	0.721	0.785
300	3.89	1.8	1.400	1.080	1.180
400	5.18	2.4	1.870	1.440	1.570
500	6.48	3.0	2.330	1.800	1.960
600	7.78	3.6	2.800	2.160	2.350
700	9.07	4.2	3.260	2.520	2.750
800	10.4	4.8	3.730	2.880	3.140
900	11.7	5.4	4.200	3.240	3.530
1000	13.0	6.0	4.660	3.610	3.920

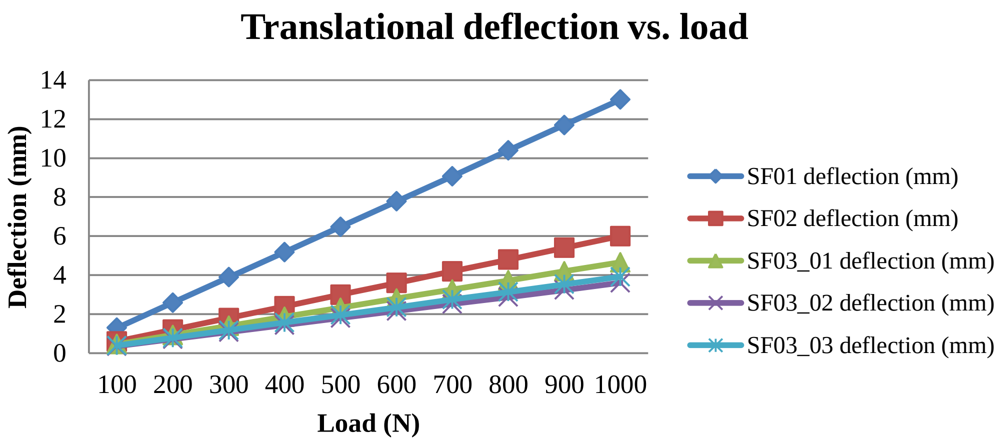


Figure 4-1 Translational deflection vs. load

4.1.4. Discussion

The result obtained from the analysis show that the first chassis design (SF-01) is not stiff enough because it can deflect until 13mm which quite a high value. This is not favourable for a car because it can lead to poor handling of the car. As for the second design (SF-02), there has been major improvement in term of the stiffness of the chassis. The design manages to reduce more than 50% of deflection thus make it stiffer compare to the first design.

All of the chassis designed by the author posses quite a good stiffness characteristic. As what can be observed from the analysis result, the average reduction of all the chassis is more than 50% compare to the second design (SF-02). This indicates that the chassis are stiffer compare to the previous design. Another factor that contributes such result is the chassis is modelled properly in CATIA. The previous two designs were not properly design as in all the frame members are not properly connected to each other. For instance, the following figure shows the kind of error occur in the design. The figure show the rear bulk head of SF-02 where it was not design properly. There should not be any excess tube at a point where numbers of tubing meet together. This kind of error can cause difficulties when it comes to mesh the chassis thus producing inaccurate result.

Figure 4-2 improper chassis design

4.1.5. Part 1 result and discussion conclusion

Base on the design and the result of the analysis, the design that fulfils the entire requirement to build a strong chassis, lightweight, and economically feasible to be built is the second design (SF-03_02). With the overall chassis weight of 23.936 kg, and from the analysis, it shows that this design is the stiffer compare to other design it will be the advantages for the future UTP FSAE car if the car utilise this design as the frame for the car. With such characteristics, it is hope that this chassis can provide better handling of the car, and a balance power to-mass ratio of the car.

In the second part (FYP 2), this design will be the base for further improvements. The design will be evaluated further by using ANSYS and ADAMS CAR to obtain a more accurate analysis results.

4.2. Part 2 result and discussion

As being proposed, second part of this project will involve improvement and design optimization of the designed chassis that has been selected. For the second part, ANSYS is use to perform the structural analysis on the selected chassis. by using ANSYS, more accurate result can be obtain.

From the previous result, it shows that the selected chassis design which is SF03_02 has the least torsional deflection when it is subjected to several magnitude of load. For the second part, the chassis will be analysed by using ANSYS with the same configuration as what being used when analysing using CATIA. Figure 4-3 shows the boundary condition used when analysing using ANSYS.

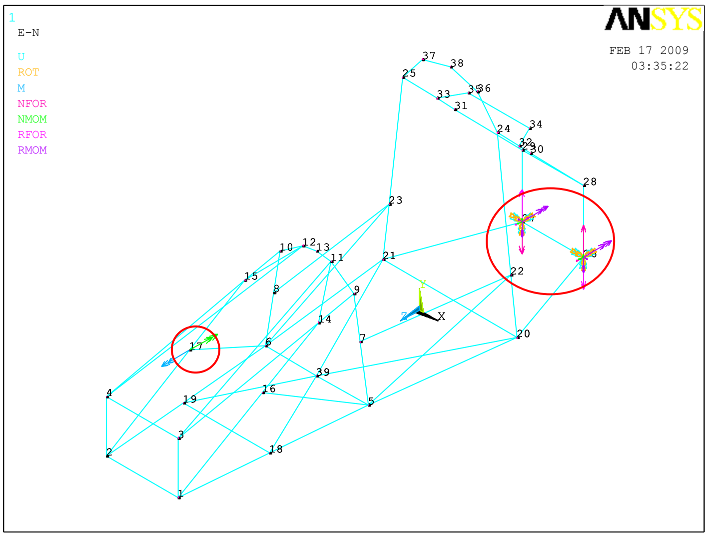


Figure 4-3 Boundary condition

The figure shows the bottom part of the rear bulkhead is constrained so that it will not move and a moment is applied at the right side of the suspension arm mounting. The model used is the wire frame model because it is easier to model the wire frame in ANSYS.

4.2.1. Analysis result (ANSYS)

Before any improvement and modification is done to the model, the analysis result obtain by using CATIA is used to compared with the analysis result using ANSYS. There are significant different in terms of the result obtain. ANSYS result seem to give less torsional deflection compare to the result obtain from CATIA. As mentioned earlier, ANSYS could provide an accurate and better result. The following table shows the comparison of analysis conducted by using ANSYS and CATIA.

Table 7 Translational deflection comparison

Force (N)	Translational deflection (mm) ANSYS	Translational deflection (mm) CATIA
100	0.2682	0.361
200	0.5366	0.721
300	0.8049	1.080
400	1.073	1.440
500	1.341	1.800
600	1.61	2.160
700	1.878	2.520
800	2.146	2.880
900	2.415	3.240
1000	2.683	3.610

The other important result that can be obtained is the torsional stiffness of the chassis. In order to get the torsional stiffness, the following analysis setup is use.

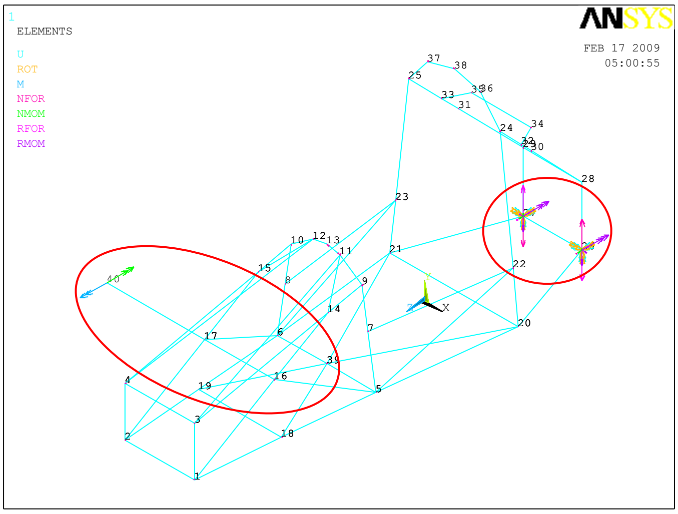


Figure 4-4 Torsional stiffness analysis set up

The figure shows the bottom part of the rear bulkhead is constrain and one extended element is modelled from the left suspension arm mounting, right suspension arm mounting and at the end of the element, there is a torque applied. The amount of the torsional stiffness of the chassis can be obtained with the following formula:-

$$\frac{Torque}{57°} x \frac{Spread\ distance}{Deflection}$$

Basically, the method to find a torsional stiffness for a chassis is by finding the average of the torsional stiffness at every selected point. For this project, there will be five nodes (node 4, node 16, node 8, node 23 and node 33) to be selected to calculate the torsional stiffness as shown in the following figure:-

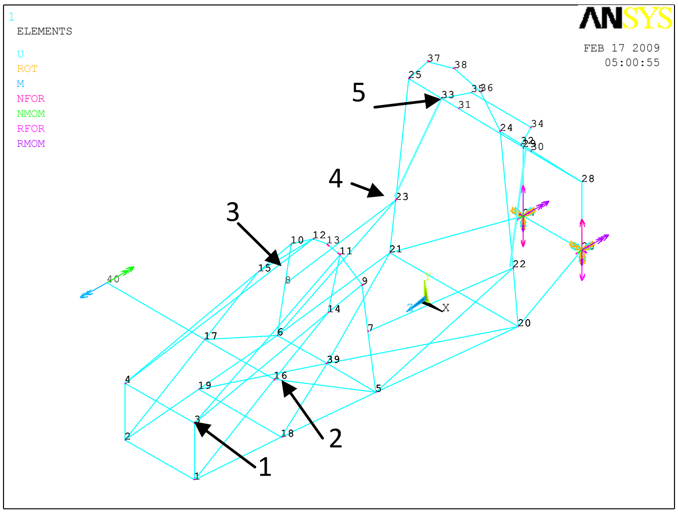


Figure 4-5 Five nodes selected to calculate the torsional stiffness

The amount of torque being applied is 5 980 764Nmm. This is corresponding to the amount of forces when this car hit a bump. With total weight of approximately 200kg and g forces of 4.5g [1] the resulting force is 8829N. The spread distance is 500mm. Table 8 summarized the amount of deflection which is obtained from the analysis and the value for torsional stiffness.

Table 8 Deflection and Torsional stiffness for each node

Nodes	Deflection (mm)	Torsional stiffness (Nmm/deg)
3	65.642	799226.7467
16	36.231	1448009.774
8	70.896	739997.2087
23	34.144	1536517.166
33	37.313	1406020.478

From the calculated value, to average torsional stiffness for the designed chassis is 1185954.275 Nmm/degree or 1185.95Nm/degree. This amount shows that the value is around the acceptable values which are around 1000 Nm/degree until 2900Nm/degree. These values are based on the literature review that has been conducted in the early stage of this project.

4.2.2. Analysis result (ADAMS Car)

The analysis with ANSYS shows that the design chassis has less amount of torsional deflection as compared to analysis conducted using CATIA. But both analyses are only meant for structural analysis. In order for the design chassis to be fully functional, the dynamic analysis must be conducted. ADAMS Car is used to verify that the design chassis is reliable and also suitable to be fabricated. The analysis that the author conduct by using ADAMS is only to verify the functionality of the hard points at the chassis for the suspension design. The result may not be smooth because the suspension template used is the standard template as it is not the scope of the project to consider the suspension setting for the analysis.

The type of analysis that is conducted is the simplest analysis which is the single lane change. In this analysis, the fully assembly car is set so that the car will change lane while travelling at initial set speed. All the subsystems were assembled together as for examples the chassis, suspension, steering, tyre, brake, and engine. For this analysis, two type of configuration is analysed. The model from SF02 was also used for the comparison of the result. The first configuration is the as shown in the picture below.

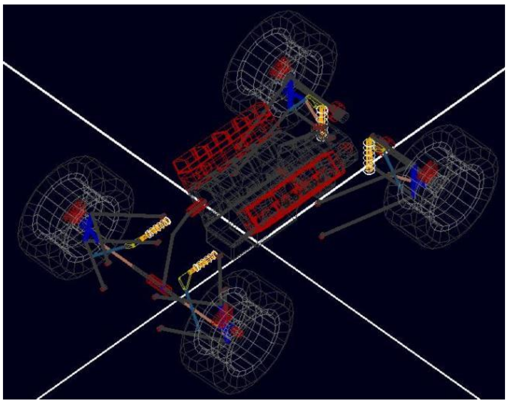


Figure 4-6 First configurations

As what can be observed from the picture above, the car is assembled so that it can be analysed with the single lane change analysis. As in CATIA model, figure 4-7 shows the suspension setup in the model. If this configuration is considered, additional mounting is required to be modelled as the original design of the chassis does not have the mounting.

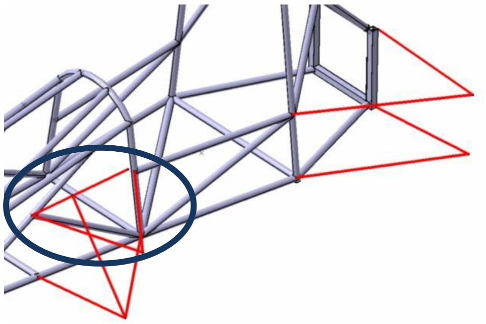


Figure 4-7 Suspension configurations in CATIA model

The following figure shows the second configuration used for the analysis.

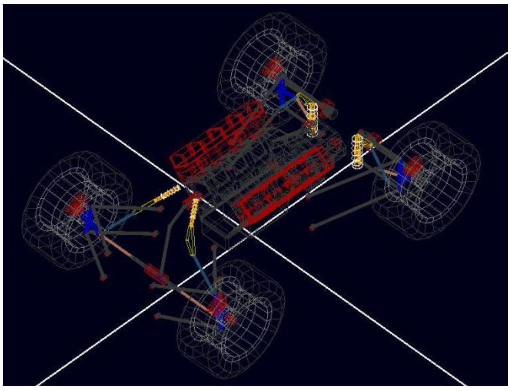


Figure 4-8 Second configurations

For CATIA model, the suspension set up is shown in the following figure.

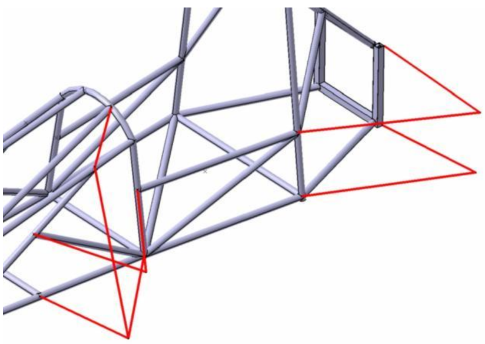


Figure 4-9 Suspension set up in CATIA

Unlike the first configuration, there are no requirements to add extra mounting for the suspension system to be adapted to the chassis. This will also contribute the weight saving features for the chassis. In addition, less fabrication works is required and less material will be consumed. Figure 4-10 below shows the car assembly in ADAMS for SF02 model. This model has the complete subsystems such as the suspension and the engine. As mentioned earlier, this model is used to compare the result obtained from the analysis.

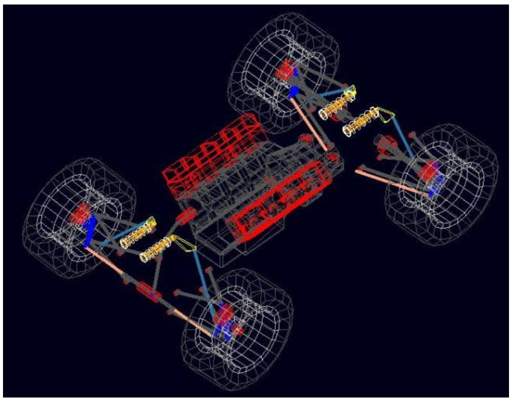


Figure 4-10 SF02 assembly in ADAMS Car

The entire model is analysed and giving the expected result. But the curve produced by the first and second configuration analysis is not as smooth as the result produced by the SF02 model. As mentioned earlier, the purpose of this analysis is just to verify that the design chassis has the suitable mounting points for the suspension system. Based on this analysis, the best configuration that gives the acceptable result will be chosen. Figure 4-11 below shows the results that are obtained from the analysis.

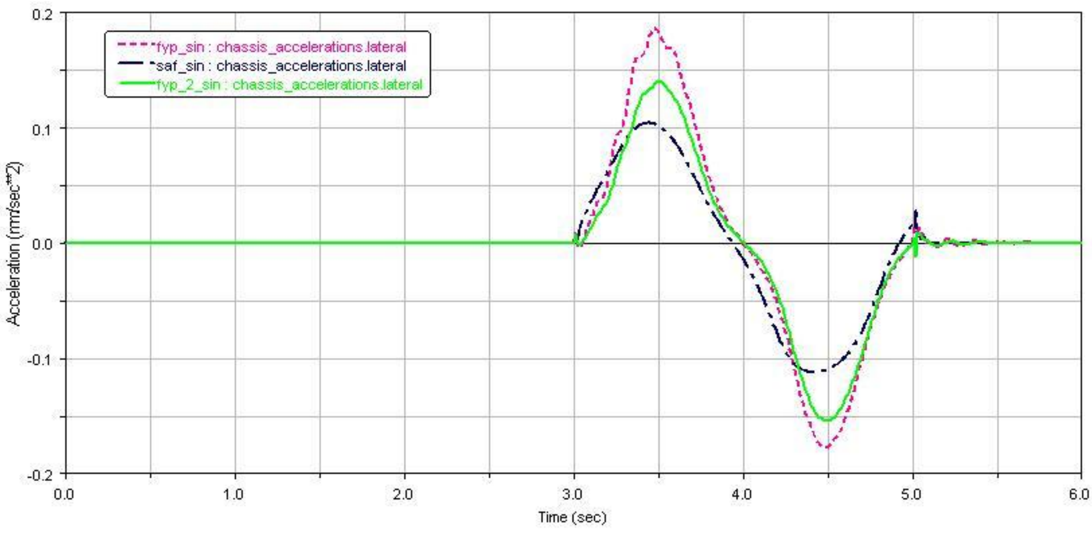


Figure 4-11 Graph lateral chassis acceleration vs. time for all the car assembly

From the graph above, the green line represent the results produced by the second configurations, the pink dotted line represent the result obtain from the first configuration and the blue dotted line represent the result produced by the SF02 model. The curve that the SF02 model produced is much smoother as compare to the other two curves. As said, SF02 model has the complete subsystem assembly in which help to produce such result. But for the other two configurations, the result is not as smooth as the SF02 model because of some inadequate parameters that have been used in order to execute the analysis.

The factors that contribute for such results are; first is the configuration or geometry setup for the suspension that is used in the first and second configuration. The standard suspension template is used and adapted to the hard points that are available at the chassis. No further fine tuning was done to the set up because it is not the scope of this project. Second is the engine data used was not the single cylinder engine data since there are no available data for this engine. Therefore the engine used in the assembly is the four cylinder engine. The mounting of this engine is also being assumed since there are no actual data available.

Even tough the result obtained is not as smooth as SF02 result, but with the design mounting points for the suspension at the first and second configuration, it is able to produce much more straight line result compare to SF02 model. This means that the design chassis is able to move in straight line. Figure 4-12 below shows the result at the beginning of the analysis where the car moving in straight position.

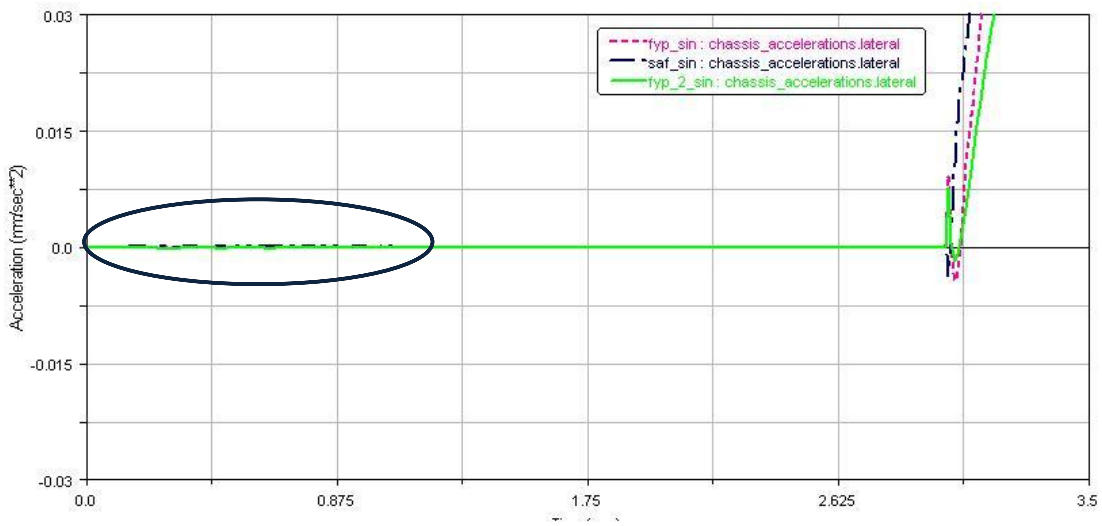


Figure 4-12 Straight line result

Similar when the car reacts after changing the line. The design chassis is able to reduce the lateral acceleration of the chassis. But it is slightly not very stable in the end maybe because of inappropriate suspension setting.

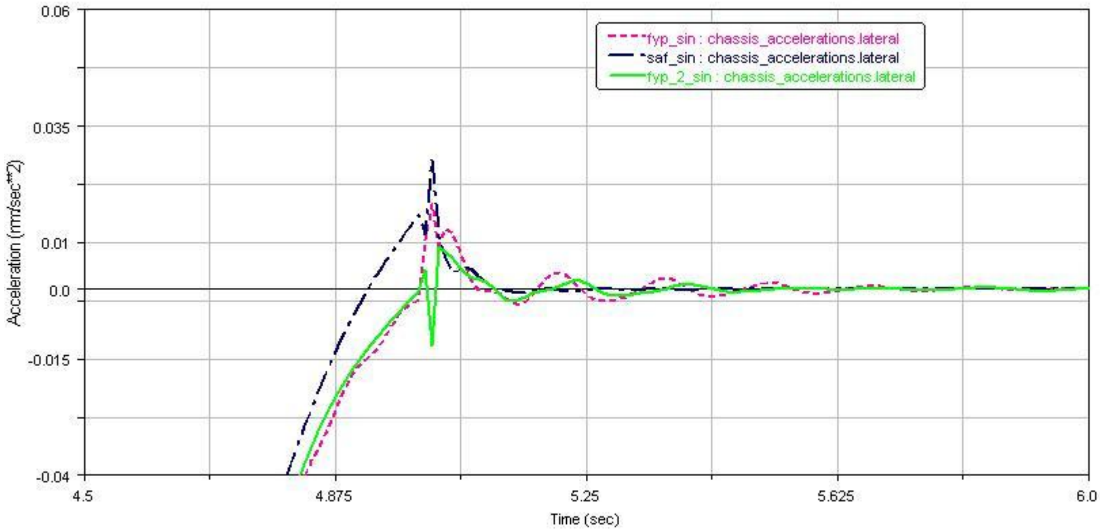


Figure 4-13 Result produced after the car changing line

4.3. Fabrication processes

Even though UTP FSAE team has managed to build the first car, but the result is not satisfactory since the car causes several problems. These problems arose due to improper fabrication methods that have been implemented during completing the car. Based on the author experience, improper jig construction, imperfection during profiling and cutting process, and error during the welding process are the major contributor to the problems. Thus, in this project, the author would like to suggest several approaches that may be considered in order to overcome the mentioned problems. The following figure summarizes the fabrication processes that are suitable for small scale production.

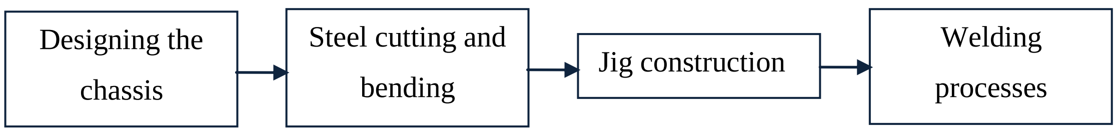


Figure 4-14 Fabrication processes

4.3.1. Designing the chassis

This step has been discussed earlier in the previous section. With proper design methodology, a proper chassis can be constructed in order to achieve the target design of the chassis. As for this project, the target specifications for the chassis are overall weight of the chassis less then 30kg, the exact weight as refer to the CATIA model is 23.936kg.

4.3.2. Steel cutting and bending

In order to weld all the frame members, the steel that need to be connected must be cut either straight or curved depend on the design of the chassis. Usually the straight cutting process just utilised the abrasive cut-off saw machine. The heat affected zone due to the cutting using this machine is negligible if compared to heat affected zone due to welding [1]. Figure 4-15 shows the example of the abrasive cut-off saw machine used.

Figure 4-15 Abrasive cut-off saw machine

For the curved cutting, usually UTP FSAE team use the skills of the team members to get the desired profile of the curves. Sometimes the result will not be good due to the inconsistency during the cutting process. Because of the inconsistency, there are some gaps produced between the mating steel tubes where it will affect the welding process as a result more fillers needed to cover the gap during the welding process. If the gap is too big to cover with the filler, new steel is required which mean some wastage is done. This process is also a time consuming process where trial and error is used to get the desired profile. The machine used is the grinding angle machine. Figure 4-16 shows example of the grinding machine used.

Figure 4-16 Angle grinders

To make this process more efficient and less time consuming another method is suggested which is utilising the *pipe notcher*. It is not a newly invented machine but utilised the hole saw blades that is commercially available couple with the pipe notcher which is also commercially available. Due to its flexibility to cut rectangular hollow section (RHS), square hollow sections (SHS) as well as round tube it is beneficial to invest on this equipment since it helps to reduce the time to profile and reduce the wastage due to human error. It is capable to cut the holes at any angle up to 50^o. By using this machine a typical hole took about 30 seconds to cut [1]. Figure 4-17 shows example of pipe notcher that is commercially available in the market.

Figure 4-17 Typical pipe notcher (Anthony M O'Neill, 2005)

Bending process is only applied to the front roll hoop and also the main roll hoop. Previously UTP FSAE team has to outsource to bend the pipe since UTP does not have the appropriate facilities to bend the tubing. The manual tube banding that is available in the laboratory is not capable to bend the pipe to the desired angle. This is because the SAE4130 tube is to stiff to be bended manually. It required external force that able to bend it like the hydraulic pipe bender. But the machine is too expensive to buy, but according to University of Southern Queensland FSAE team, they managed to bend the pipe without any crimping or any other form of distress in house by using the Bramley pipe bender [1]. So if this machine is economically feasible for the project, it is preferable that UTP FSAE invest some amount of money to buy this machine because it can also be used in the future. Figure 4-18 shows the pipe bender used by the Southern Queensland FSAE team.

Figure 4-18 Bramley pipe benders

4.3.3. Jig construction for chassis fabrication

In order to fabricate a proper chassis what is important is a proper jig. Jig can be defined as a device that guides tools and holds materials or parts securely. From the previous experienced, UTP FSAE team does not have a proper jig that can support all the frames. The method used is by using wood about 1cm thick, screw, L plate and steel holder (eight figure steel plate). The steel tubes that need to be welded are placed on the wood and it is positioned to the desired dimension base on the CATIA model. Figure 4-19 illustrates the jig construction that is used by UTP FSAE team.

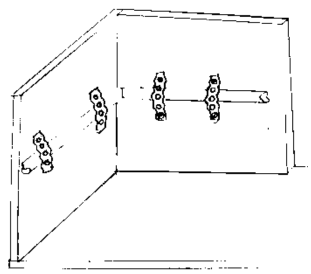


Figure 4-19 Jig construction for previous chassis fabrication

Due to the lack of proper jig construction, some imperfection occurred to the fabricated chassis as for instance the base of the chassis tend to flex and the crucial area which is the suspension mounting are not exactly straight. This will not only affect the strength of the chassis but will also affect the overall performance of the car. Therefore in order to overcome this problem a proper jig must be fabricated. The following figure shows the suggested CATIA model of a jig.

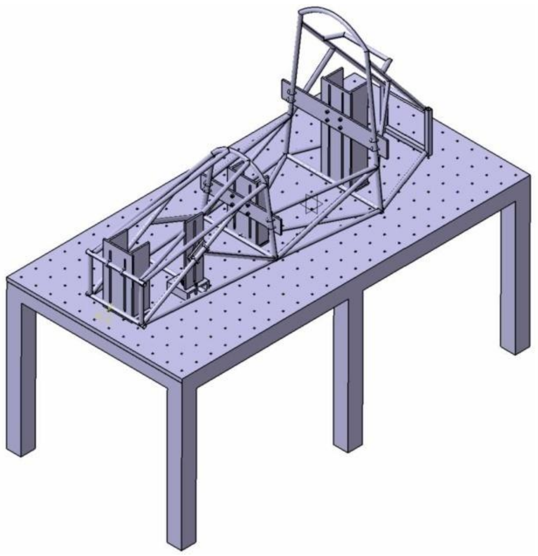


Figure 4-20 Suggested jig construction

The figure above showed a proper jig construction for chassis fabrication. The welding table is made from steel with the length of 2400mm and width of 1200mm. the surface of the table is drilled with equally spaced tapped holes. The hole diameter is 10mm with the spacing of 100mm. The purpose of these hole is to enable the frame holder (refer figure 4-21) as well as the chassis to be properly mounted on the table. This is to avoid the chassis from moving during the welding process.

It is crucial that the frame members are positioned at the correct location before it is welded. This is to ensure there will be no misalignment after the welding process completed. To avoid this problem, the frame support can be used. It is made from steel plate that is cut and welded to form a rectangular shape. It also has slots that enable another steel plate so slide so that it can hold the frame at the desired location. The frame is bolted to the table by using the hexagonal socket heat bolt with the diameter size of 10mm. Meanwhile, for the frame, it will be tighten up by using the 'U' shape bracket which is commercially available in the market. The following figure shows the construction of the support.

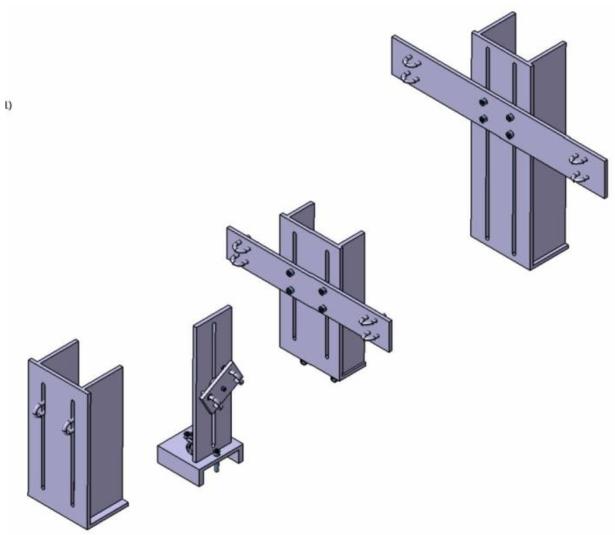


Figure 4-21 Steel tubing holders

The idea to fabricate the whole jig construction may involve a lot amount of money. But the advantages are it can be used for a longer period of time. The only parts that need to be re-fabricated are the steel plates that use to hold the frame. Which mean, there are no need to build new jig for a new chassis compared to if the jig is constructed using wood just like what UTP FSAE team usually practise. Furthermore, by using this method, it is confirmed that the welded chassis will not flex since all the members are hold properly and tightly before they are welded. Several universities have practised this method and it found that the result is satisfactory.

4.3.4. Welding processes

The most crucial process to fabricate the chassis is the welding process. One of the factors that determine the strength of the chassis is the quality of the welded frame. Therefore a proper selection of welding type is important. Basically, welding can be classified into 2 major categories which are fusion welding and solid state welding [15]. The disadvantage of solid state welding is the welding process requires pressure or heat and pressure which make this welding is not suitable for notched tubing.

By definition, fusion welding is a welding process that melts two parts that are going to be joined. In addition to normal process, a filler material is also used. There are a few types of fusion welding:-

4.3.4.1. Arc welding – consumables and non-consumables electrodes
4.3.4.2. Resistance welding
4.3.4.3. Oxyfuel gas welding
4.3.4.4. Others - electron & laser beam, electroslag & thermite

Oxyfuel gas welding tends to overheat the tubes. Since the thickness of the tubes used is only 1.64mm, the possibility for the tubes to melt faster is higher. Therefore, it is not recommended to use the oxyfuel gas welding. Electron & laser beam welding and resistance welding are for specialised application. The result of the welding will be very good but to incorporate this project with this type of welding is not worth it. The cost for the welding will be too expensive. The only option left is the arc welding. There are two types of arc welding which are the consumables electrodes and non-consumables electrode. The consumables consist of the shielded metal arc welding (SMAW) or stick weld and gas metal arc welding (GMAW) or metal inert gas (MIG) welding. Figure 4-22 and 4-23 show the welding process respectively. Gas tungsten arc welding (GTAW) or tungsten inert gas (TIG) is the examples of the non-consumables electrodes method. Figure 4-24 shows the TIG welding process.

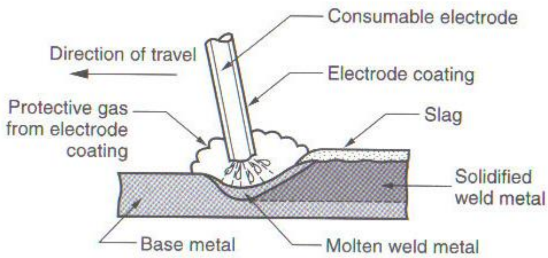


Figure 4-22 SMAW or Stick welding (Groover, 2002)

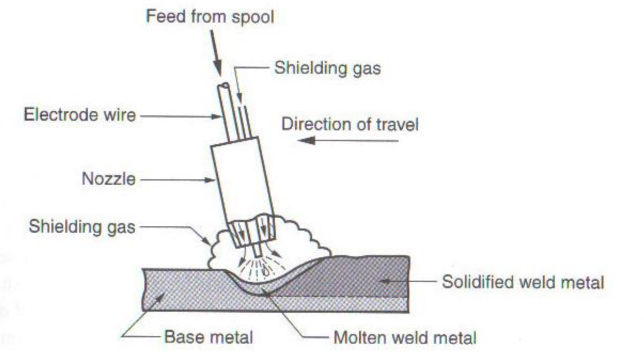


Figure 4-23 GMAW or MIG welding (Groover, 2002)

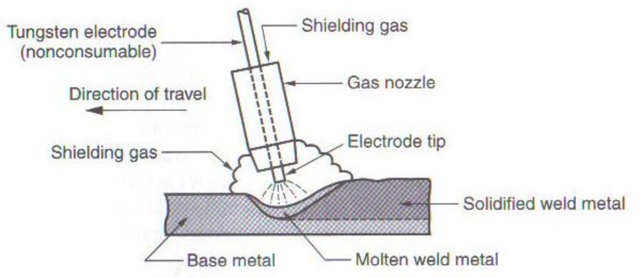


Figure 4-24 GTAW or TIG welding (Groover, 2002)

The welder seldom chooses the consumables arc welding since it requires manual removal of the protective slug. In addition, the welding quality is only at moderate level. Although the equipment setup cost for non-consumables welding is high, the result that this type of welding produced is quite pleasing. The cleanness of the welding is good furthermore it is slug free which mean the overall welding process time can be shorten compare to stick weld. Moreover, TIG welding has an added value which is the ability to weld with or without the filler depending on the job. Additionally, TIG welding produced higher quality spatter free weld, and suitable to weld various steel alloy and also aluminium. As a consequence, GTAW or TIG welding is suggested for the welding process for this project.

CHAPTER 5

CONCLUSION

By understanding the factor that influences the strength of the chassis, it helps to decide the design of the chassis that will provide high strength and better handling. Decision matrix has provided a method to decide which design approach that is more feasible and realistic for this project. Proper material selection will help to build a strong and reliable chassis construction. Therefore SAE 4130 chromoly alloy is chosen for the construction. The analysis result shows that the designed chassis is stiffer compare to the other plus it is economically feasible for this project. The design simplified the manufacturing processes and the design provided an easy assembly process when it comes to assemble the car later.

The design chassis has been further analysed with ANSYS and ADAMS Car. These analyses are crucial since it determined the functionality and reliability of the design chassis. The chassis that has been design has incorporated the suspension geometry and it has been verified by an analysis using ADAMS Car.

The manufacturing processes that have been suggested are intended to improve the previous process that being practised for quite some time. It is also aimed to increase the quality as well as the efficiency of the manufacturing processes required to fabricate the chassis.

As for the conclusion, this project has successfully fulfilled its objectives where the designed chassis has being improved in term of the design as well as the analysis; furthermore the manufacturing processes that are required to fabricate the chassis are also discussed in this report.

CHAPTER 6

RECOMMENDATION

There a few improvements that can be done if there are any similar project in the future. First, in term of design, it is better to incorporate the suspension geometry during the designing phase. The suspension mounting should be design properly as it plays a major role in determining a good dynamic of a car and also the handling of the car.

It is suggested that, during the design phase, analysis using ADAMS Car is performed concurrently. This is to validate the functionality of the suspension mounting that has been design. There is also a few more analysis that can be conducted in ADAMS Car instead of single lane change for instance steep steer analysis, constant radius cornering, straight line acceleration and also breaking. These analyses can be performed to further validate the reliability of the chassis and also to produce a good quality chassis before it can be fabricated.

Other than the suspension mounting, another factors than should be taken into consideration when designing the chassis is the center of gravity (CG). CG will affect the car’s handling, thus it is essential to determine the best possible position for the CG (as lower as possible). ADAMS Car has the capability to find the required CG in the designed chassis.

As for analysis using ANSYS, it is best if the analysis of 3D solid model can be conducted as an alternative to wire frame model. The result produced is expected to be more accurate than the wire frame model. Finally, it is an advantage if a prototype model or mock up model of the design chassis can be fabricated. The model can undergo a physical testing to validate its strength as well as its reliability.