University of Southern Queensland

Faculty of Engineering and Surveying

Chassis Development for the Formula SAE Racer

A dissertation submitted by

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Towards the degree of

Bachelor of Mechanical Engineering

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Abstract

The dissertation that follows consists of the method, design, testing and construction of the Formula SAE (FSAE) chassis for the USQ Motorsport entry into the 2006 competition.

The chassis design was limited early in the process to designing a space frame chassis that used cold drawn mild steel tube 350LO as the material. It was limited to the space frame because of previous research into the topic and the material was supplied by a sponsor.

The main areas that are considered in this report of the design are as follows:

1. The size and shape of all the other components.
2. Improvements on the previous years design in areas of:
    a. Weight.
    b. General and specific size.
    c. Strength.
    d. Driver comfort.
    e. General aesthetics of the car.
3. General feedback from previous year's team.

A skeleton model created in Pro-engineer was the method used to model the chassis in the design stages. The skeleton model set up the geometry of the design and from this all other components could be generated off it to produce a final model of the entire chassis. Ansys was used as the analysis program using an input file method.

Many different processes were used in the construction of the chassis however the most advantageous part of the process was the initial construction of a 'construction bed' which provided much greater comfort and accessibility to the welds throughout the construction process.

Overall a chassis was designed and constructed that in theory met all specified goals, provided good room for all the required components to be fitted and was aesthetically pleasing to the eye.

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Certification

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except were specifically stated.

Jared Armstead

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Signature

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Date

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To my supervisor Mr Chris Snook for his guidance throughout the project and dissertation, also for creating the opportunity for me to undertake this project gaining valuable experience in the motorsport area and design.

To my fellow USQ Motorsport team mates who have provided me with their opinions on some aspects of the design throughout the process that which has proved very valuable on a number of occasions.

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1. Chapter 1 Introduction

The following report covers all of the information regarding the process followed to ‘To design, develop and build a rigid, lightweight chassis for the 2006 model USQ FSAE race car’ which is the aim of this project. The areas that were required to achieve this are detailed below:

1. Study the FSAE Rules to determine guidelines in accordance to Safety and Design requirements.
2. Access the effectiveness of the 2005 model car and specify areas of improvement.
3. Create a design/layout of the chassis through talks with relevant team members.
4. Specify materials to be used
5. Analyse using FEA software the design in regards to deflection and torsional stiffness.
6. Determine if design is suitable or make changes as found in step 5.
7. Create a manufacture guideline for the chassis and liaise with workshop staff and fellow teams members on the construction of the chassis.
8. Develop a physical torsional rigidity test rig for the chassis.

   If time and resources permit:

9. Assist in team management and sponsorship activities
10. Assist in manufacture and testing of the car.

Also in the conclusion of the report talks about what could be done in the future to add to the project that either wasn’t investigated or time didn’t permit for it to be done as part of this particular study.

2. Chapter 2 Literature Review and Background

2.1.Literature

2.1.1.Competition Rules

Adhering to the rules that govern the chassis for the competition is a pivotal part of the research. If one small sub-section rule isn't followed the chassis will disqualify the whole car from the competition.

Within the competition rules fifteen A4 pages are solely for the chassis, when attempting to insure all the rules are meet, it is easy to miss small details when the rules are set out in this form. So to simplify this process a summary of the rules was created and broken down into all individual areas of the chassis layout. These areas were, Main Hoop, Front Hoop, Bulkhead, Main Hoop Bracing, Front Hoop Bracing, Bulkhead Support, Other Bracing and Side Impact Members.

The summarised version of the rules can be found in Appendix 1. Along with this summary of the rules come some diagrams that relate to the safety aspects of the car. These are shown as follows:

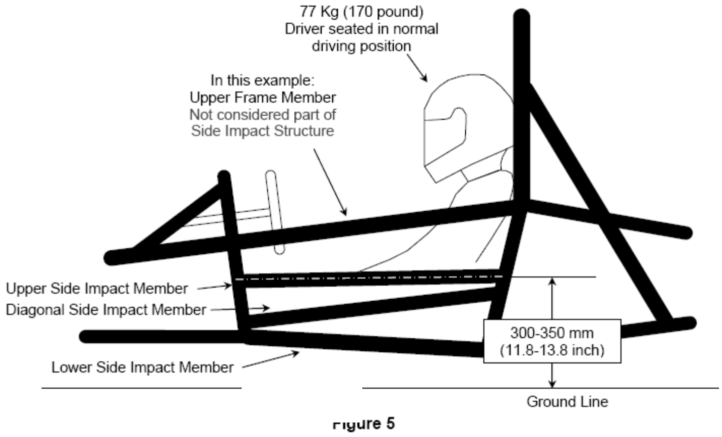


Figure 1: Illustration of the side impact member's location.

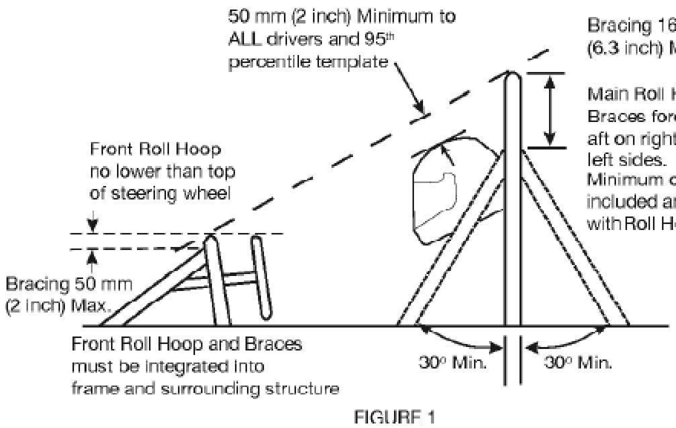


Figure 2: Illustration of the clearance required above the drivers head.

A two dimensional template used to represent the 95th percentile male is made to the following dimensions:

- A circle of diameter 200 mm (7.87 inch) will represent the hips and buttocks.
- A circle of diameter 200 mm (7.87 inch) will represent the shoulder/cervical region.
- A circle of diameter 300 mm (11.81 inch) will represent the head (with helmet).
- A straight line measuring 490 mm (19.29 inch) will connect the centers of the two 200 mm circles.
- A straight line measuring 280 mm (11.02 inch) will connect the centers of the upper 200 mm circle and the 300 mm head circle.

Figure 3: 95th percentile male dimensions as depicted in the 2006 rules.

2.1.2. Past Dissertations

These are an important tool into the development of each proceeding year's chassis. If each year no knowledge was passed on to the following year then the chassis wouldn't improve over time.

When past dissertations can be read and studied then the research of the previous person isn't lost. For example with this years chassis it was concluded early in the project that it would be of a space frame nature as the research of last year showed this was by far the most efficient style of chassis. Hence more research and development was devoted to improving this style of chassis rather than to deciding of what style of chassis to use.

2.2. Background

2.2.1. Competition

The Australasian component of the FSAE competition has been run for quite a few years; however the University of Southern Queensland and USQ Motorsport have only been a part of this competition for 2 years previous to this one. So as a University USQ is a new comer to the competition and is still developing techniques and designs that will allow USQ to become a competitive team.

The competition allows students to apply their knowledge gained in the classroom to a real life problem/application. "The Formula SAE competition (formed in USA) is for SAE student members to conceive, design, fabricate, and compete with small formula-style racing cars. The restrictions on the car frame and engine are limited so that the knowledge, creativity, and imagination of the student are challenged." (Formula SAE website).

The competition is a wonderful tool in producing high quality engineers and exposing them to the industry.

2.2.2.Car

The car involved in this competition is a formula style open wheeler car. It has various rules restricting engine size, overall dimensions, component technology and appearance. The car has to perform both in dynamic and static events including skid pan, acceleration, presentation just to name a few. Pictured below is last year's car on track in the competition.

Figure 4: Last year's car in action on the track

2.2.3.Chassis

2.2.3.1. SAE chassis

In terms of the FSAE the chassis isn't defined as "the frame, wheels, and machinery of a motor vehicle, on which the body is supported" (Reference 2), but as the frame component itself.

The chassis in USQ Motorsports previous two endeavours in the competition has been of a space frame design show in Figure 5 below.

Figure 5: The chassis used in USQ Motorsports previous two cars

The chassis consists of four main defining sections, the Main Hoop, the Front Hoop, the Bulkhead and the Rear Box Section.

All of these components help define the overall size and shape of the chassis and are governed in some areas by the competition rules. However other components such as the suspension, engine, driver and smaller components of the car affect its final shape and dimensions.

2.2.3.2. History of the chassis and automobile

Throughout history many inventors and pioneers of the chassis and automobile have laid claim to being the first to design a particular component or introduce a new concept. In truth "It is estimated that over 100,000 patents created the modern automobile," (Reference 1) having said this there is recorded developments in history linking particular improvements and concepts to individuals.

The very first "self-propelled road vehicle," (Reference 1) was designed in 1769 and was powered by steam with a top speed of two and a half miles per hour, pictured below:

Figure 6: The first recorded “self-propelled road vehicle” (Reference 1)

The chassis in this case consisted of a very simple and uncomplicated single bar off which everything else was located.

The biggest effect on the development of automotive chassis was perhaps the invention of the modern day gasoline engine by Gottlieb Daimler, patented in 1887. With this came the need for a stronger chassis that could handle the loads applied to it.

In 1908 Henry Ford produced the first mass-produced motor vehicle the now famous model T; in 1913 he developed an assembly line that now allowed him to produce a model T every “ninety three minutes” (Reference 1).

The model T had a platform style of chassis. In the picture directly below it is shown that as the definition of a chassis previously mentioned describes the chassis of an automobile is made up of all the components in which the body attaches too.

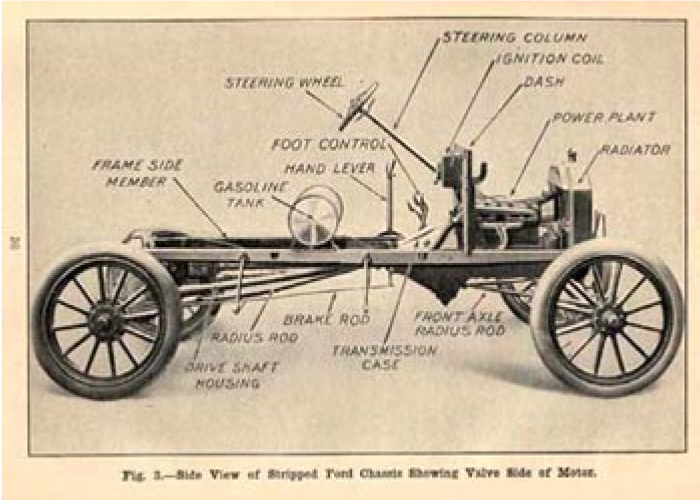


Figure 7: Model T Ford in its basic commodity as a chassis with all components included. (Reference 1)

The overall make up of the model T was much more glorified than it was in its basic chassis form.

Figure 8: Shows the model T in its glorified form (Reference 1)

3. Chapter 3 Methodology

The methodology used throughout the design process describes how all the information was gathered to be able to create a final design, it also covers the methods that are used in the design process to model and test the chassis.

3.1. Analysis of last year's chassis

This part of the methodology was greatly attributed to attempting to improve USQ Motorsports entry year by year to the FSAE competition. It consisted of measuring dimensions off last years car, analysing the construction methods, tubing and overall design of the chassis, and finally altering any of the observations in this years design.

There were quite a few areas of the previous year's design that no longer met the new competition rules both in general construction and driver safety areas, these parts weren't analysed as it was irrelevant information to this year's process. The most beneficial information that was gained was from the measuring of the basic dimensions of the car. From this information it could easily be determined during the proceeding design process if a designed dimension was realistic or not.

3.2. Consultations

There are many different types of consultations involved in the design of the chassis. These are outlined below:

3.2.1. Team Members

This is perhaps the most important consultation that needs to be made as the other team members are the ones that are designing the other components of the car.

The chassis becomes a lot more robust and neat if all the other components mount points and dimensions are included in the initial design rather than added on at the end. There are advantages in the final construction of the car if these components are included in the design stage.

3.2.2. Supervisor

Chris Snook has been a valuable tool in the design process and Finite Element Analysis (FEA) development for the chassis. By understanding what went into the design of the chassis in previous years his input allowed the process to flow smoothly without investigating areas that weren't beneficial to the final project.

3.2.3. Workshop Staff

Throughout the process of design workshop staff needed to be consulted to incorporate their chosen construction methods into the design. This creates a workable design that can easily be constructed. Their input also shortened the construction process greatly when it came to that stage of the process.

3.3. Modelling

The modelling side of this project consisted of modelling the final design so it could be added to the model of the complete car, also to produce construction drawings from, and further to check that the design matched up with other components and satisfied the rules of the competition.

The program chosen to model the chassis was Pro-Engineer as it was readily available and some knowledge of the program already existed. Within this program there is many different ways to model the same object. Early in the process a simple model with minimal members was modelled in many different ways to determine the time frame to model it and the easiest ways in which to do so.

From this process it was determined that the best way in which to model the chassis was using a skeleton model method. This involves starting with a new assembly model and within the assembly creating what is called a skeleton model. Within this skeleton model every node and plane is defined for the entire model. Once this has been done each component is created and referenced to the nodes defined in the skeleton model.

By modelling the chassis in this way the entire model can be altered just by changing the skeleton model nodes. This allows for minor changes to the dimensions and shape of the final design model to be altered within minutes of making the changes.

3.4. Analysing

This is an important part in the approval of the chassis design so it can be constructed. It is done in two areas, firstly the theoretical stage to allow the construction to go ahead and secondly the physical/practical stage once the chassis has been constructed.

3.4.1. Theoretical – FEA software

As for the modelling side of the project there is many different ways in which to analyse the model using FEA software. Because of its use throughout the duration of the mechanical engineering course, Ansys was the chosen software program in which to perform this analysis.

There are three different methods that were known from experience and needed to be explored:

The first method being to input the model from pro-engineer as an iges file and then load and solve the analysis in Ansys. This method is successful in saving time but makes it difficult as every time the geometry is changed the model needs to be inputted again with meshes and loads applied.

The second method which wasn't considered for any great length of time due to the duration of performing the analysis was creating the geometry in Ansys along with the meshing and loading. This is a timely process and isn't very viable given the time constraints.

The third option was brought to attention by Chris Snook, this was to write an input file in any common text program such as notebook as an example or in an m-file in Matlab and inputting it into Ansys. By doing this the code for plotting the geometry, meshing, loading and solving the model never needs to be altered for each analysis (except where the loading conditions are altered which is a simple code change). All that needs to be changed when a point on the chassis changes is the geometry input. Once this code has been refined and the geometry decided on all that needs to be done to perform the analysis in Ansys is to input the file into the program. This is done by simply going to the File bar in Ansys and clicking on 'read input from', then selecting whatever the name of the word document is called.

The third method of writing a code and inputting it into Ansys to solve was the selected method for use in this project. It allowed the process of changing geometry and re-analysing the model to be done within a few minutes not hours or even days as in the other methods, the longest time involved in this method was setting up the base code which was minimal once again.

3.4.2. Physical/Practical – Physical test rig

The physical test rig was decided on through the knowledge of how the chassis is loaded when operating as the frame for the race car. Other teams in the competitions methods were looked into briefly and it appeared that the method that was assumed to be the most efficient was the way other teams had done their torsional stiffness testing of the chassis.

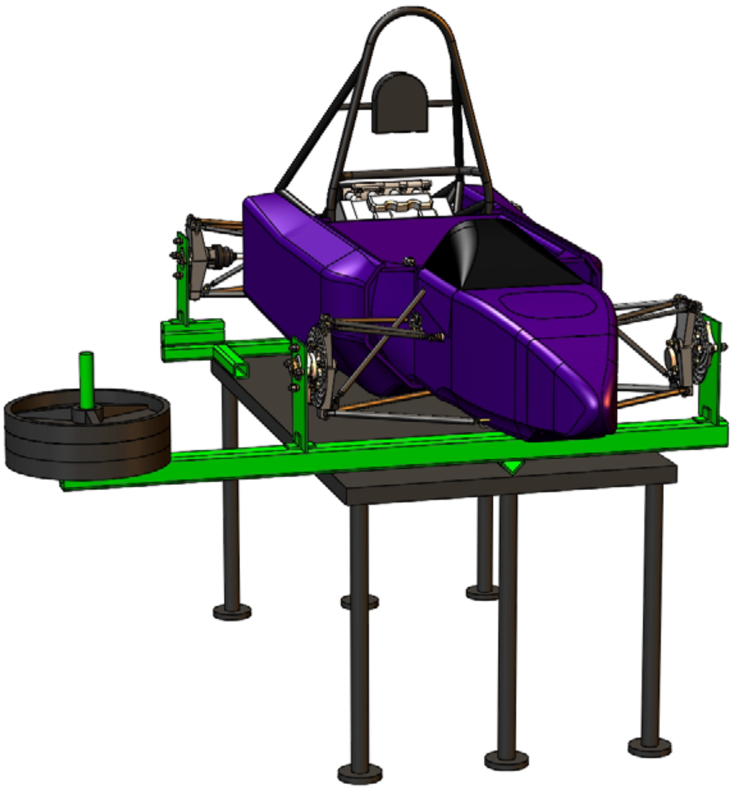


Figure 9: Another team's test rig for physically testing the chassis's torsional stiffness.

Overall the test rig that was designed was similar to the one above with subtle changes to suit the way in which was chosen to test the chassis and improve the loading and holding methods.

4. Chapter 4 Design

This chapter will cover the design process that was undertaken to create a final design and how the methodology applies to this process. It will provide information on the initial aims set out for the project, the requirements to achieve these aim, the process that was followed, the dimensions of the final design and what created that dimension and a final check on the compliance of this design to the rules.

4.1. Aims

The first step in the design process was to set down some basic aims that needed to be achieved to create the final design.

As the aim of the project stated; 'To design, develop and build a rigid, lightweight chassis for the 2006 model USQ FSAE race car' the main aims were in terms of size, weight and strength but also there were miscellaneous aims that related to driver comfort and the overall aesthetics of the can. These aims were set at values determined from previous projects and from feedback from team members in last years endeavour.

4.1.1. Size

This area of the aims limited particular areas of the chassis in size. The main areas that these sizes were determined from were so the chassis abided by the competition rules and feedback from last years team members.

The wheel base was aimed at 1600mm, 150 less than last year's car to allow better manoeuvrability around the tight track.

The overall length from the main role hoop to the front bulkhead of the car was aimed to be reduced from the previous years length of

1400mm to 1300mm as there was 100mm of wasted space in front of the pedal box in last years car.

4.1.2. Strength

The main component of strength that was aimed at was the torsional rigidity; this was set in previous years at 300N.m/degree and was aimed at greater or equal to this value

4.1.3. Weight

Once again weight was a large factor in the campaign last year that was determined as a cause of hindrance to the performance of the car.

As far as this concerned the chassis the weight of the previous year's chassis was around about fifty kilograms, the chassis that was designed but not included in the car last year was thirty eight kilograms, so an aimed weight for this year's campaign was thirty five kilograms of lighter.

4.1.4. Miscellaneous

In this area of the aims the governing factor that caused these to be set was the driver's ability to fit in the car in a comfortable position and be able to access all the areas required whilst driving without any difficulty, and were determined from complaints notices whilst driving last year's car.

The first of these was to create a front role hoop that allowed the drivers knees clearance when sitting in the car.

Next was to narrow the front role hoop so more on track visibility was possible.

To create a dash that was able to be seen by the driver in the racing position.

To have the cockpit area built in a way that provided greater protection to the driver elbows and arms and prevented them from sitting outside the confines of the chassis whilst driving.

One that doesn't relate to driver comfort but more mechanic comfort is to design the chassis in such a way that the engine can be bought in and removed from the bottom of the engine bay area.

4.2.Requirements

Certain inputs outside my research boundaries and aims needed to be ascertained to create a final design that was satisfactory to include in the race car. These included such things as:

- ◊ The dimensions of all components of the race car that were being designed by other team members and needed to be included within the chassis dimensions.
- ◊ What types of materials and chassis styles were available to be looked at relating to the teams ability to source the materials and construct the chassis.

4.3.Process

Throughout the duration of the project a process was followed to produce a final design for testing and construction. One the aims were set and the requirements were defined this involved several steps outlined below.

1. Set that the chassis design was going to be of a space frame type due to past research by other designers into the topic. In studies by Anthony O'Neill the space frame chassis was found to be the most suited to this application because of the following reasons, "1. The safety regulations require considerable amount of steel tubing, 2. Simplicity of design and manufacture, 3. Light weight, 4. Potential strength and torsional rigidity, 5. Suitable for small production runs, 6. Very suitable for the construction of a 'one off' prototype, 7. Prototype can be easily modified as required, 8. Prototype can be manufactured and modified very cheaply, 9. Can be built in any small workshop," (Reference Anthony O'Neill's 2005 dissertation). So this was the chosen style of chassis for this year's campaign.

2. Analyse the previous year's chassis to gain knowledge of the basic dimensions of the car. See section 3.1 for more information regarding this step.

3. Research the rules of the competition and summarise them into each area of the chassis, (this can be seen in Appendix A). See section 2.1.1 for more information into the process involved in this step.

4. Develop modelling techniques that allow the process to be simple and modified easily. See section 3.3 for more information on this step.

5. Liaise with team members, supervisor and workshop staff on their opinions and any inputs they have. See section 3.2.1 for more information on this step.

6. Gain dimensions of components that relate to the chassis from each components relevant designer. This step in the process involved sitting down with all other designers separately and gaining the information regarding their components and where and how they were related to the chassis design.

7. Create a design that is feasible and incorporates all of the above areas. This involved modelling for the first time a design that incorporated all the known dimensions of other components, along with abiding by the competition rules and incorporating the driver comfort side of the design into one model that could me manipulated as further information was gained and other components changed.

8. Allow time for the other components to be altered. This is to allow for any changes that might occur during the design process of the other components and to the possibility of new considerations that weren't originally included in the design.

9. Create drawings of the chassis design for fellow team mates to look at and analyse. This is mainly a communication check that is required in case in the design a dimension that was included in the design wasn't what was required for a particular component or other part of the car.

10. Analyse any feedback from the other team mates and make changes to the design accordingly. Include any required changes from step 9 into the design and make the relative changes in the model.

11. Continue steps 7-10 till a final design that incorporates as much as possible is found. Once this step is done a final design is reached and the analysis and construction areas of the project can be done.

12. Define materials to be used in the construction of the chassis, in this case defined by the availability of a sponsor for the material and selected dimensioned tubes were selected from that sponsor list that met the competition rules and specifications regarding this area. The material that was selected is a cold drawn mild steel tube 350LO and the dimensions of this tube are outlined in section 4.4.

4.4.Dimensions of final chassis design

Each component was designed to incorporate many different areas of the car and competition rules. Each dimension originated from either a requirement of the rules, feedback from last years car, other components dimensions and general car aesthetics. The following passage outlines each components dimension in detail and exactly how that dimension came about.

4.4.1. Overall Chassis

The main dimensions that affected the overall size of the car were the wheelbase dimension, the required size for the passenger cell. This can be seen on the top view diagram below:

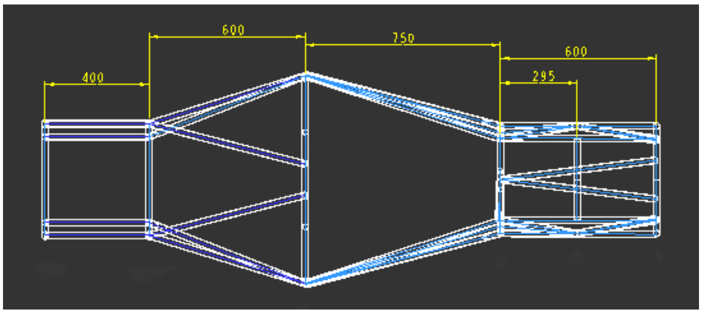


Figure 10: Top view of the modelled chassis.

The following two diagrams outline the front and side view of the final modelled chassis, the dimensions and shapes shown in these diagrams a justified for each individual component in the following sections.

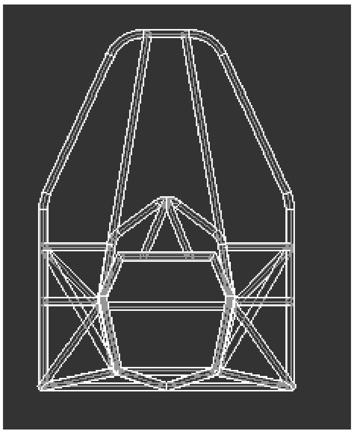


Figure11: Front view of the final modelled chassis

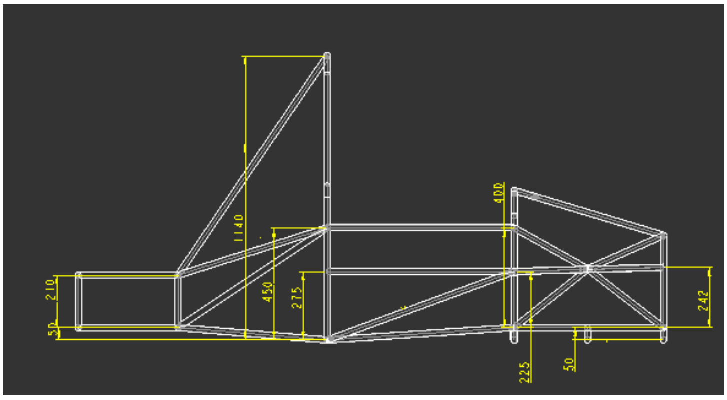


Figure12: Side view of the final modelled chassis.

The raised front section that can be seen in Figure 12 is designed to allow better air flow underneath the car and also to position the driver's legs higher than normal to allow for better comfort whilst driving.

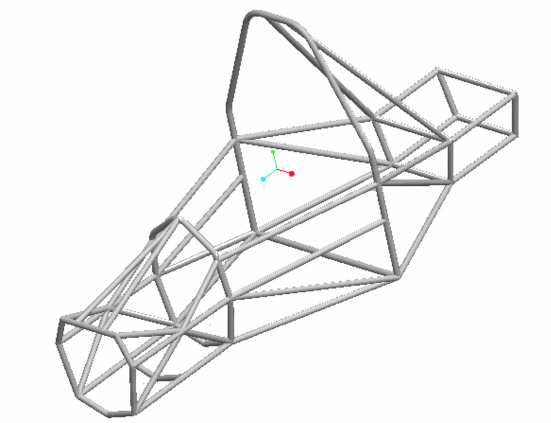


Figure 13: The 3D model of the final design of the chassis

4.4.2. Role Hoops

The role hoops sizes were affected predominately by the competition rules, the required passenger cell size and the visibility over the front hoop. The affects are outlined in greater detail and for the relevant hoop below.

4.4.2.1. Main Hoop

This component was the basis of the initial design, having been through many different changes its final design was as follows.

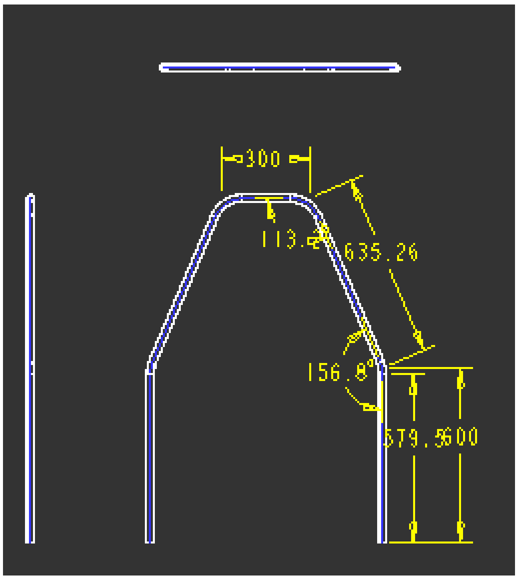


Figure 14: Final design for the main role hoop

The main competition rule that affected the main hoops dimension was rule number 3.3.4. This relates to having a clearance when a straight line is drawn from the top of the main hoop to the top of the front hoop of 50.8mm from the driver's helmet.

Other than this requirement the rest of the main hoops dimensions were attained from the passenger cell and engine bay size requirement. The width at the bottom was to allow clearance around the seat, the driver's shoulders and to allow the engine to be inserted to the final car via the bottom once the bars are linked to the rear box section. The top width is to allow for clearance around the helmet. The bend in the upwards member was to link these two widths and its height location was to allow for the shoulder brace explained later.

4.4.2.2. Front Hoop

The front hoop is the most complex of all the components that make up the chassis. It is the link between the front of the car and the rear of the car and hence has many influencing factors in its design. The final dimensions of the front hoop are shown below:

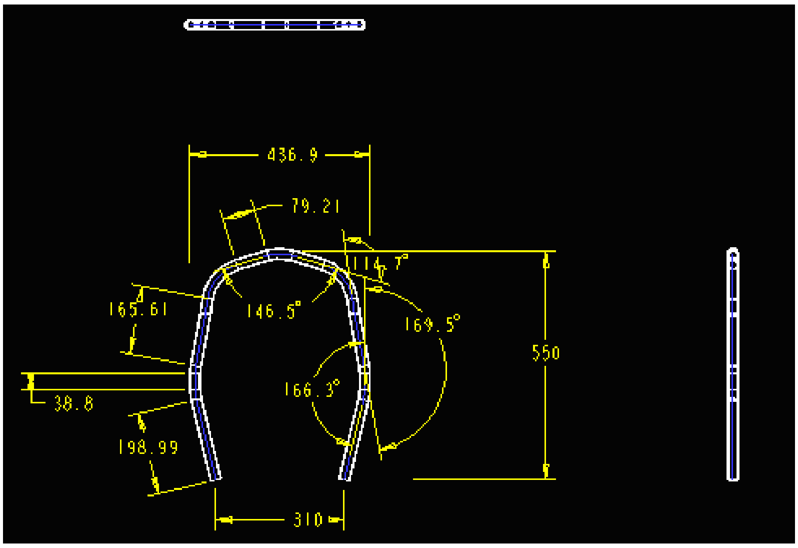


Figure 15: The most complex component the front hoops final design.

The first influencing factor on the front hoop was rule number 3.3.4 which required it to be of a certain height for clearance over the drivers head. However in doing this the height had to stay low enough that when in the racing position the driver had good vision over the front of the car. One more rule indirectly relates to the design and that is rule number 3.3.4 Figure 1, which requires the steering wheel to be below and covered by the front hoop when looking at it from the frontal direction. This is why the front hoop doesn't shape to a point at the top.

Following this the next factor was the required chassis width for the suspension points, the affected dimensions were the lower dimension of 310mm and the slope from that point to the width at 410mm at a height of 225mm, this height also adhered to rule number 3.3.8.1(a) which relates to the side impact members height. The width at the bottom also had to be such that the bottom member linking it to the main hoop was such that that seat could still be located.

After here it was down to driver size requirement which is why the front hoop is kept wide until its top height. This is to allow for the taller drivers legs to fit through the hoop with clearance for both safety reasons and comfort reasons.

4.4.3. Bulkhead

The front bulkhead dimensions were predominately affected by two things, the visibility over the front nose and the positioning of the suspension points.

The height was lowered from last year's car to allow for greater visibility and greater slope on the nose cone section. The width and bend point (the point where the bend occurs in upwards member) was affected by the width and height required for the suspension points, these being 310mm at the bottom and 410 at the bend point. The height of the bend point was located to gain sufficient slope from the front hoop through the front suspension arm point to the bulkhead attachment.

The length between the front hoop and the bulkhead was defined by rule 3.3.6.1(c) which related to the bulkhead being positioned such that the drivers feet where located behind it when the pedal were completely suppressed and in the forwards most position.

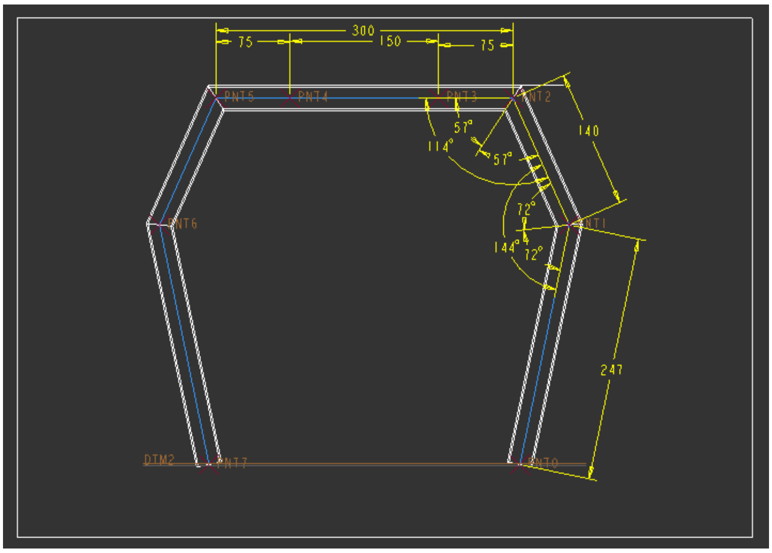


Figure 16: Shows the dimensions of the front bulkhead section

4.4.4. Side Impact Members

The main influence on this component of the chassis was rule section 3.3.8. This rule required that there are three side impact members, one lower which connects the bottom of the main hoop to the bottom of the front hoop, one upper which links the front hoop to the main hoop at a height between 300mm and 350mm from the ground when a 77kg driver is seated in the car and one diagonal which links the front hoop and main hoop and also the upper and lower bars.

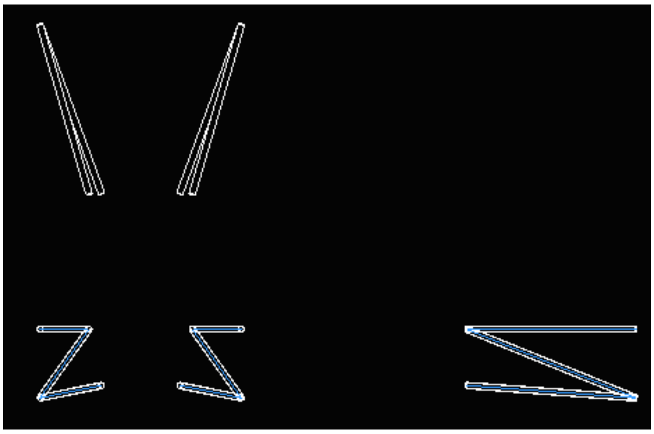


Figure 17: Side Impact members of the final design

4.4.5. Front Supports

There are two different areas that make up this full component area; the first is the top middle and bottom bars pictured below:

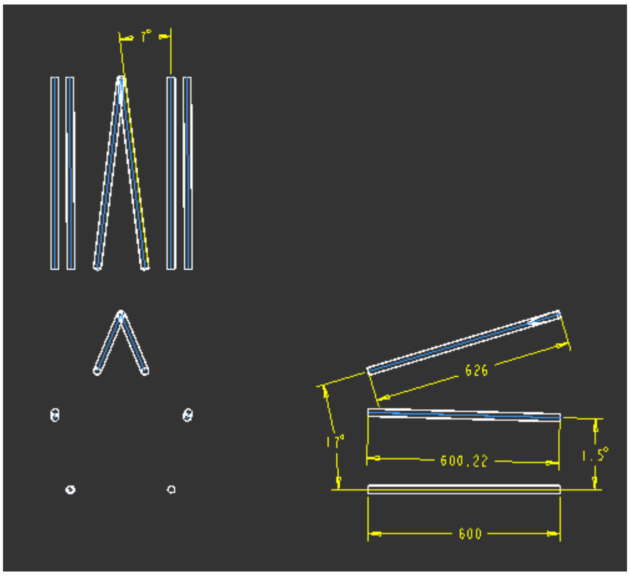


Figure 18: The main members that make up the front support component off the final design.

The main influence on these bars is rule 3.3.6.2(a) which states that the bulkhead is supported on both sides by a member that attaches to the bulkhead less than 50.8mm from its top and extends to the front hoop. The middle member locates the attachment to the chassis for the upper suspension arm. The lower member locates the attachment point for the lower suspension arm and completes the section.

The next area is the diagonal members; these are located as follows and complete the front supports component.

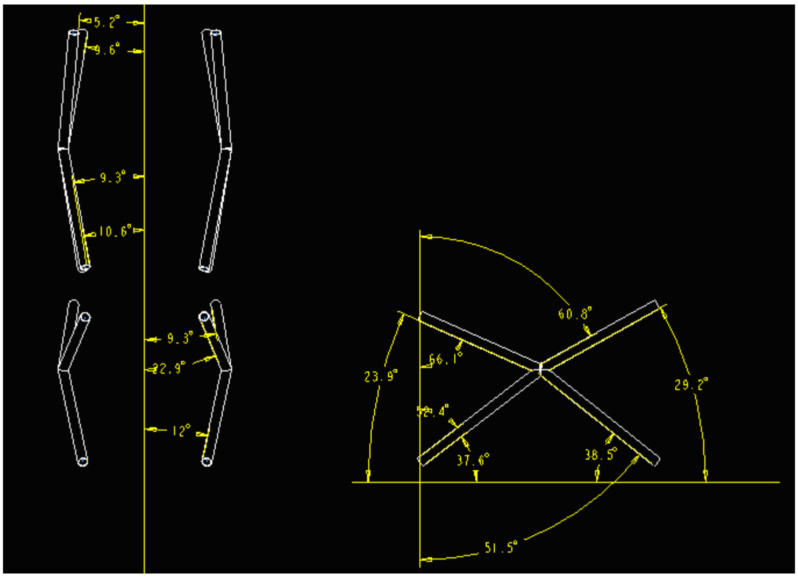


Figure19: The diagonal members that add to the main members above to make up the front supports component of the final design.

These diagonal members are added to the main members in the front support component to adhere to rule 3.3.6.2(b) that requires the front section between the bulkhead and the front hoop to be triangulated.

These members also support the upper front suspension point which is located at the intersection of all the members. They are designed in such a way that if a frontal impact was applied the transfer through these members would transfer throughout the chassis.

4.4.6. Engine Bay

The engine bay is perhaps the simplest area to design, the main contributing factors to the design are rule number 3.3.5.1 which relates to the bracing of the main hoop and the area required to fit the engine and working components within it. The final design is shown below:

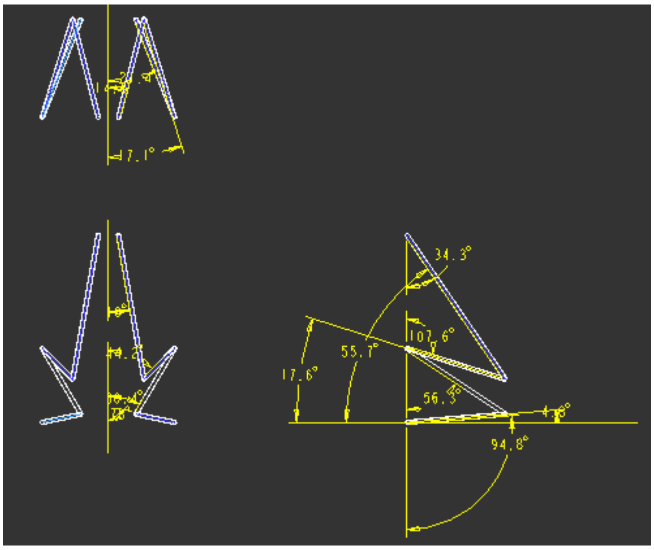


Figure 20: The final design of the engine bay component of the chassis

Rule number 3.3.5.1 relates to the angle in which the main hoop must be supported and where it must be supported. The braces must be straight with no bends, be attached within 160mm of the top of the main hoop and have a minimum of 30 degrees between them and the main hoop. In this design they are attached directly to the top of the main hoop and have an angle of 34 degrees between them and the main hoop. These braces are the uppermost members shown in Figure 20.

The three lowest members shown in Figure 20 make up the rest of the engine bay area. These have no direct rules related to them however have many things that need to be considered in their design. The most predominant factor that created the dimensions for the final design was the size of the engine to be used in the car. When taking a direct line from the bottom of the main hoop to the bottom of the rear box area the outermost dimensions of the engine must be clear of the members. The estimated clearances on either side of the outermost extremes of the engine were determined to be 6mm.

4.4.7. Rear Box

This section involves the inclusion of the rear suspension mounts, the drive train area and the inclusion of the rear jacking point. The dimensions of the final design are shown below:

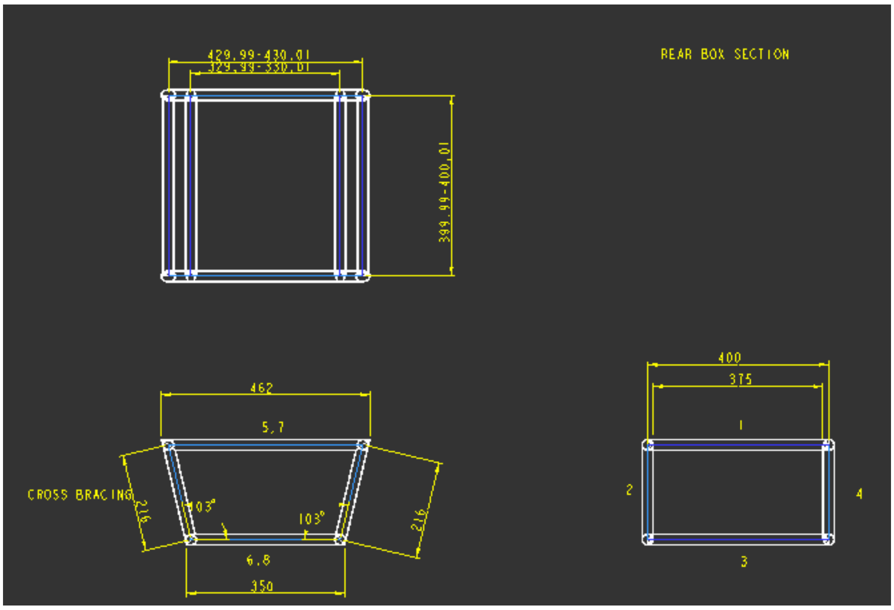


Figure 21: The dimensions of the rear box component of the final design.

The dimensions of the bottom 350mm and top 462mm of the box section were to allow for the required width of the rear suspension, and the height of such was for the bottom 110mm off the ground and 320mm off the ground for the top. The total length of the component was not defined by the suspension as it could be manipulated accordingly. This length was required to accommodate the drive line sprocket and the rear disk brake. The actual length of 400mm gives plenty of clearance for the two disks. The position of the sprocket clears the bottom outside tube by approximately 5mm.

4.4.8. Other Bars

These bars are the extras that make up the cross bracing within the chassis. They are required to provide greater strength to the chassis and to complete the design. The dimensions in the final design are shown below:

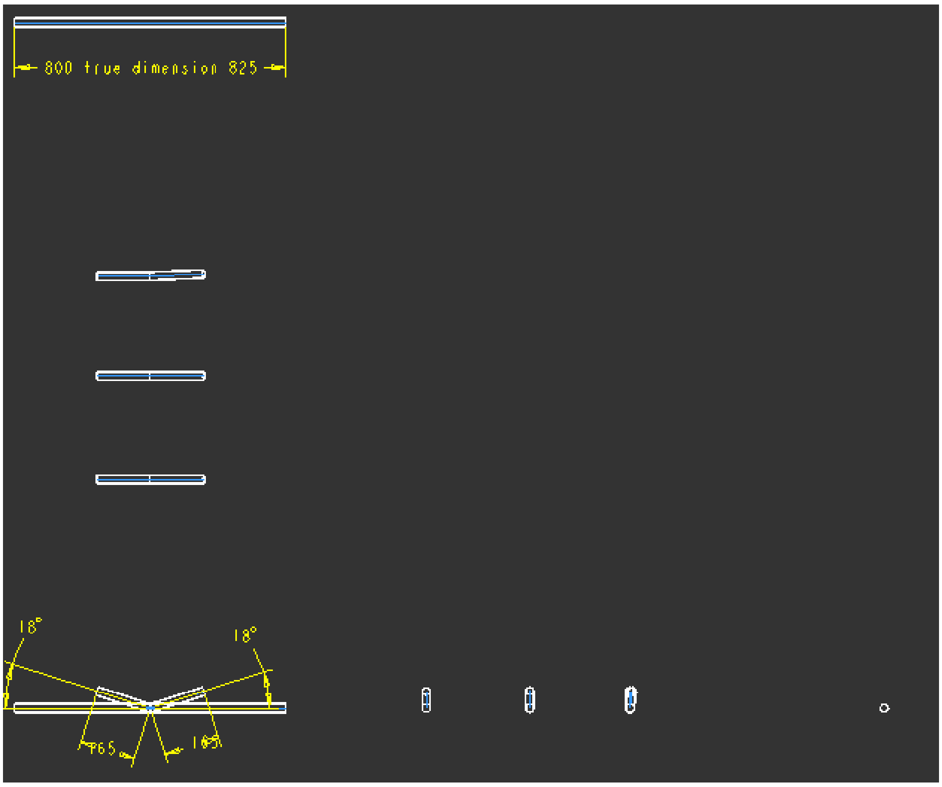


Figure22: Shows the dimensions of the cross bars in the final design.

The angle of 18 degrees that can be seen in Figure 22 was included in the design to allow for more room to include the springs steering column and master cylinders that are located in the front section of the car.

4.4.9. Seat Location Members

These members are located within the passenger cell area of the car between the front hoop and the main hoop and within the boundaries of the lower side impact members. They were not included in the model stage of the design because the seat was not available at that stage of the design and hence attachment points couldn't be measured. They will be added to the physical chassis once the seat has been attained.

4.4.10. Harness Bracing

This part of the chassis is an important one as it is the main restraint for the driver in the event of an accident. They are to be designed once the seat location members have been included in the physical chassis. There are three main areas of the harness bracing, the lap attachment which is to the side of and behind the seat, the crutch strap which is located below the seat between where the driver's legs will be located and the shoulder attachment point located behind the seat at the level of the drivers shoulder. Rule number 3.4.1 relates to the positioning of these harness attachment points relative to the driver and seat.

4.5. Compliance to Rules

One final check needed to be performed on the complete final design after it had been checked by all other areas and that was too the rules. The main rule that hadn't been checked previously within individual components was rule number 3.3.4, clearance of 50.8 mm between the driver helmet and a straight line between the tops of the role hoops.

Below is the way in which the rule was checked within the model. The 'dummy' as it was appropriately named is created in accordance with the rule and is represented as follows; the bottom red circle of 200mm diameter represents the hips and buttocks, the top red circle also of 200mm diameter represents the shoulders, the line parallel to the seat between these two circles of 490mm represents the torso, the blue circle of 300mm diameter represents the head with a helmet on and the blue line between the top red circle and the blue circle represents the neck region. It was found that there was approximately 60mm of clearance therefore the chassis complied with this rule. Further checking of this rule is necessary once the physical chassis has been constructed and the seat positioned.

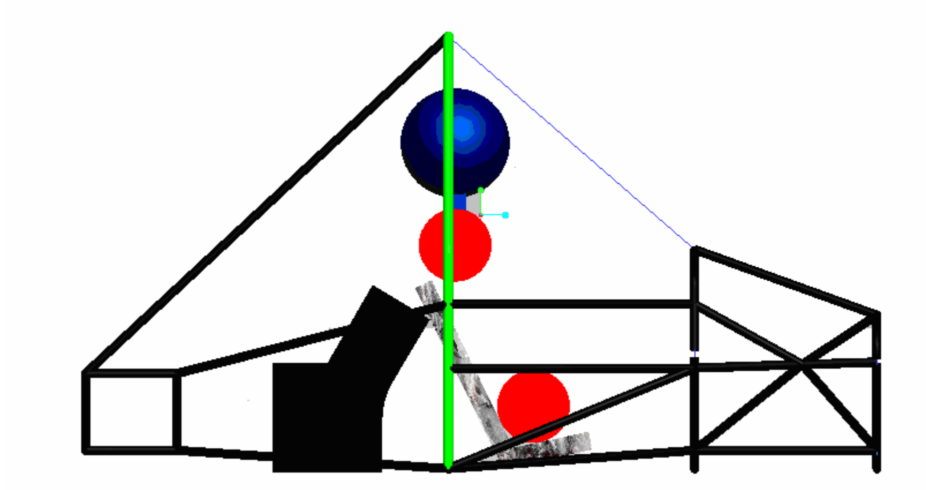


Figure 23: The test dummy modelled to test for clearance from role hoops

The next part was to add on to the given ‘dummy’, done to check that the chassis had been designed in such a way that was practical for the application. Some measurements were taken of team mates to find an average leg size and this was modelled onto the dummy to see how well the legs and feet would fit into the front of the chassis; this can be seen in Figure 24 below.

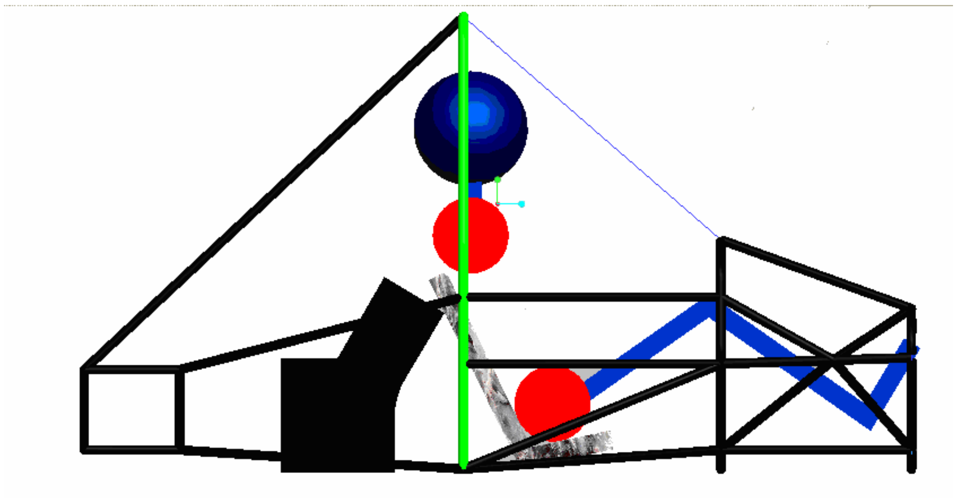


Figure 24: Added legs onto test dummy to check for clearance

5. Chapter 5 Testing – Finite Element Analysis (FEA)

5.1. Script File

It was decided that the writing of a script file was the most appropriate method of analysing the chassis in FEA, see section 3.4.1 for reasoning behind this decision.

This method involved the creation of a word file that included all the Ansys commands to when inputted into Ansys define the material properties, the geometry, the mesh density, and the loading conditions and then solve for a solution. This is done using many different commands each having an important role in the overall formation of the code. Initially the tube dimensions, Young's modulus and density are set up for each type of tube by the code shown in Figure 25.

```
!* Roll hoop info
R_Outer = 26.9
R_Wall = 2.3
R_E = 200e3
R_Dens = 7.8e-9
R_u = 0.3
```

Figure 25: Code that defines material properties

Following this the element length is set to 50mm. This length was determined to be accurate enough for the analysis required.

```
ELENGTH = 50
```

Figure 26: Code defining the mesh element length

Then the material properties set previously are assigned to a particular tube type, (roll hoops, other tube and wishbone tubes). Pipe one is assigned as the role hoops tube, pipe two is assigned as the other components tube and pipe three is assigned as the wishbone and test bar tube. Below is the code for pipe one.

```
ET,1,PIPE16
KEYOPT,1,6,1                !* Include stress and member forces in output
R,1,R_Outer,R_Wall, , , , ,

MP,EX,1,R_E
MP,PRXY,1,R_u
MP,DENS,1,R_Dens
```

Figure 27: Code assigning the material properties to a particular tube type

Now in millimetres the x, y and z components of each node within the chassis are defined as keypoints. Where the x component is in the width of the chassis direction, the y component is in the height of the chassis direction and the z component is in the length of the chassis direction. The centre reference of the chassis was set to the middle of the centre of the tube located at the bottom of the main hoop. Shown below is the code to set up the keypoints of the main hoop.

```
!* Main Hoop Points

K,1,    0,      0,      0
K,2,    400,    0,      0
K,3,    400,    275,    0
K,4,    400,    450,    0
K,5,    400,    600,    0
K,6,    150,    1140,   0
K,7,    60,     1140,   0
K,8,    0,      1140,   0
K,9,    -60     ,1140,  0
K,10,   -150    ,1140,  0
K,11,   -400    ,600,   0
K,12,   -400    ,450,   0
K,13,   -400    ,275,   0
K,14,   -400    ,0,     0
```

Figure 28: Code defining the main hoop keypoints.

These keypoints are then linked to create each component of the chassis. Each link between keypoints is labelled with a line number relative to when they were created in the code. The code is simply L,a,b which is line between keypoint a and b. The code to create the main hoop geometry is shown below.

```
!*Main Hoop


L,2,3   !*Line 1
L,3,4   !*Line 2
L,4,5   !*Line 3
L,5,6   !*Line 4
L,6,7   !*Line 5
L,7,8   !*Line 6
L,8,9   !*Line 7
L,9,10  !*Line 8
L,10,11         !*Line 9
L,11,12         !*Line 10
L,12,13         !*Line 11
L,13,14         !*Line 12
```

Figure 29: Code linking the main hoop keypoints to create its geometry

On the main hoop these lines are also filleted to create the bends in the shape of the hoop. This is done by using the LFILLT command as follows LFILLT,c,d,120 which relates to a fillet between line c and d with a radius of 120mm.

```
LFILLT,3,4,120      !*Line 13
LFILLT,4,5,120      !*Line 14
LFILLT,8,9,120      !*Line 15
LFILLT,9,10,120     !*Line 16
```

Figure 30: Code creating fillets between lines on the main hoop

The next stage in the code is to assign each tube type to a particular part of the geometry relative to what tube creates that part of the chassis and to initial mesh the geometry. This stage directly follows the code that defines the geometry so therefore once the main hoop and the front hoops geometries are defined they are assigned to the role hoops tube and meshed. This step is repeated following the rest of the components geometry being created but using the other tube type. The following code is meshing and assigning material properties to the role hoops.

```
!*************************************************************
********************************
!* Set attributes for all subsequently created lines to be set number one,
!*eg Roll Hoops
LATT,1,1,1,0, , ,
!*LESIZE,ALL,ELENGTH, , , ,1, , ,1, !* Try to mesh all selected lines to be
ELENGTH long
LMESH,ALL                !* Mesh all lines, can use NAME instead of
ALL
EPLOT
!*************************************************************
```

Figure 31: Code assigning the tube type with its associated material properties to the geometry relative to them.

The final step is to plot all of the geometry and set it to display in isometric view and fit it to the screen.

```
/VIEW, 1 ,1,1,1 !* Isometric view
/SHRINK,0
/ESHAPE,1
/EFACET,1
/RATIO,1,1,1
/CFORMAT,32,0
/REPLOT
```

Figure 32: Code finalising the model and plotting it in full.

Initially a 'base code' file was set up that defined the material properties and geometry of only the chassis. The code that was written can be seen in Appendix D. When this code was inputted into Ansys it produced what is shown in Figure 33. The blue section represents the role hoops and hence the hoop tubing material and the purple represents the other tubing on all other components.

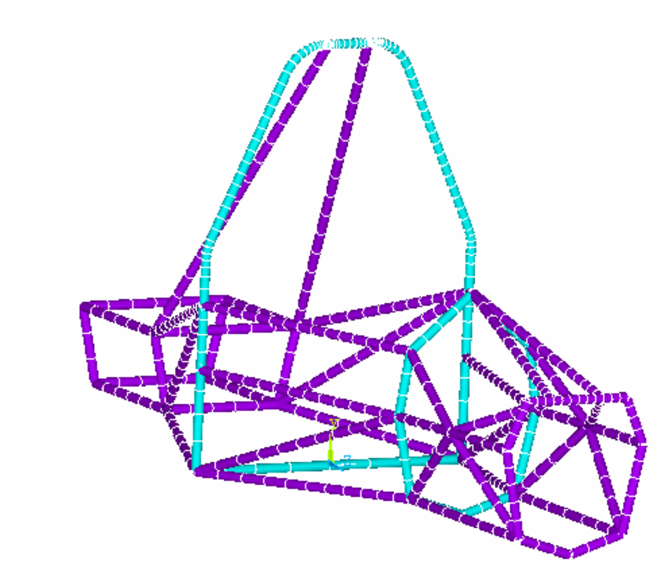


Figure 33: The chassis geometry as defined by the base code script file in Ansys.

This geometry that was set up in the base code isn't completely representative of the actual geometry of the chassis, the front hoops bends were difficult to define in the code therefore the bends have been left out to minimise the difficulty of the code. This minimal difference in the geometry will only affect the results marginally.

Once this geometry base code is set up further code can be added to it to model the suspension and load the chassis. Each loading code produced results of some sort these can be seen in section 5.2 following.

The first code added was to determine the chassis's bending capabilities. This code can be seen in Appendix E. This code represented a static loading of the chassis. By constraining the lower suspension points both front and back by the DK,e,ALL,0 and replacing the e with all the required keypoints they become constrained in all degrees of freedom. Then loading all of the weight of the car through that approximate centre of the car located at the bottom of the main hoop using the code FK,f,FY,-2500 where f is the loaded keypoint and FY specifies the direction of the load and -2500 is the load applied. The load of 2500N was derived using estimated weight of the car is 400kg and by adding a 1.25 factor to allow for extra unknown weights the total force on the chassis is 5000N assuming that the weight distribution side to side of the car is even 2500N is applied to each side of the bottom of the main hoop. These load applications and applied constraints are sufficient to gain satisfactory results allowing the chassis to be constructed, however they are only as close as possible but by no means an accurate representation of the actual conditions the chassis would be exposed to. The code that performs this loading is as follows.

```
!********Apply Forces
!*Constrain Lower Suspension Points Front
and Back
DK,37,ALL,0
DK,32,ALL,0
DK,35,ALL,0
DK,39,ALL,0

DK,16,ALL,0
DK,43,ALL,0
DK,22,ALL,0
DK,42,ALL,0

!*Apply Force of Car Down on Centre
Position 400kg car with factor of safety of 1.25
gives 5000N applied static load
FK,2,FY,-2500
FK,14,FY,-2500
```

Figure 34: Code that loads and constrains points on the chassis.

The next add on to perform the solution and gain results from the input file is as follows, the comments beside each line of code explain their purpose.

```
FINISH
!* ************* Enter the solver
/SOL
SOLVE
FINISH                    !* Leave the solver

/POST1                    !* Enter the postprocessor
PLDISP,2                  !* plot displaced shape of chassis

/EFACET,1
PLNSOL, S,EQV, 0,1.0    !* Plot nodal solution of SEQV (Von
Mises)
PRRSOL,                    !* Print all reaction forces and moments
```

Figure 35: Code which enters the solver and solves for results in Ansys

The code contained in Figures 34 and 35 when added to the base code and further inputted into Ansys produced the following model.

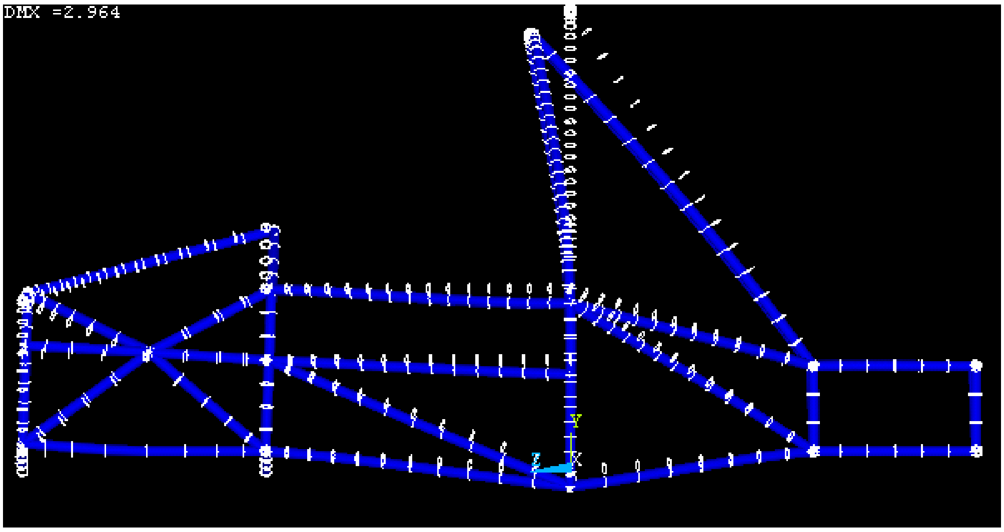


Figure 36: The chassis deflection when statically loaded.

The next step in the loading process involves testing for the torsional stiffness of the chassis. To do this firstly the wishbone geometry must be created. This needs to be done to accurately test the chassis in a way representative of how it is loaded in its application. The wishbone geometry is set up in a similar way to the chassis geometry, it is created using a stronger material to minimise the errors due to bending/flexing of the wishbones. The code that defines the geometry of the wishbones can be seen in Appendix F and is added to the base code after the tube types is assigned to all components other than the hoops and before the final plot is done. When this code was added it produced the following, as with the base code the blue and the purple represent the two different types of tubing and the red now represents the wishbone tubing and outlines the new geometry of the wishbones.

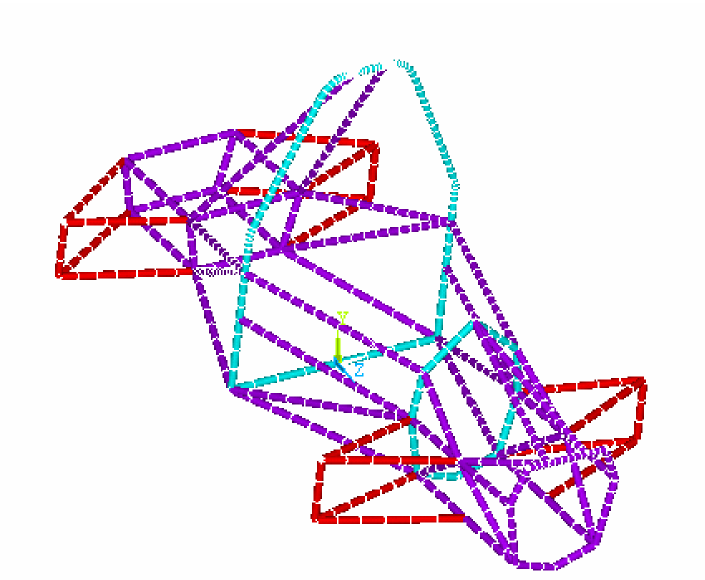


Figure 37: The result of the base code plus wishbones when inputted into Ansys.

The wishbone geometry is only representative of the actual wishbone geometry however is positioned with the actual track (width from side to side) of the car. The geometry defined is sufficient to correctly analyse the chassis for its torsional stiffness.

Now the wishbones need to be loaded in such a way that best represents the way in which the chassis will twist in a its application. To do this a ‘test bar needs to be created within the geometry which links the two front wishbones together in a way that they will move as one and extend out one side a metre from the centre of the chassis. This is so the loading is located at a set distance from the rotation point of the chassis. The test bar added to the code produces the following geometry in Ansys.

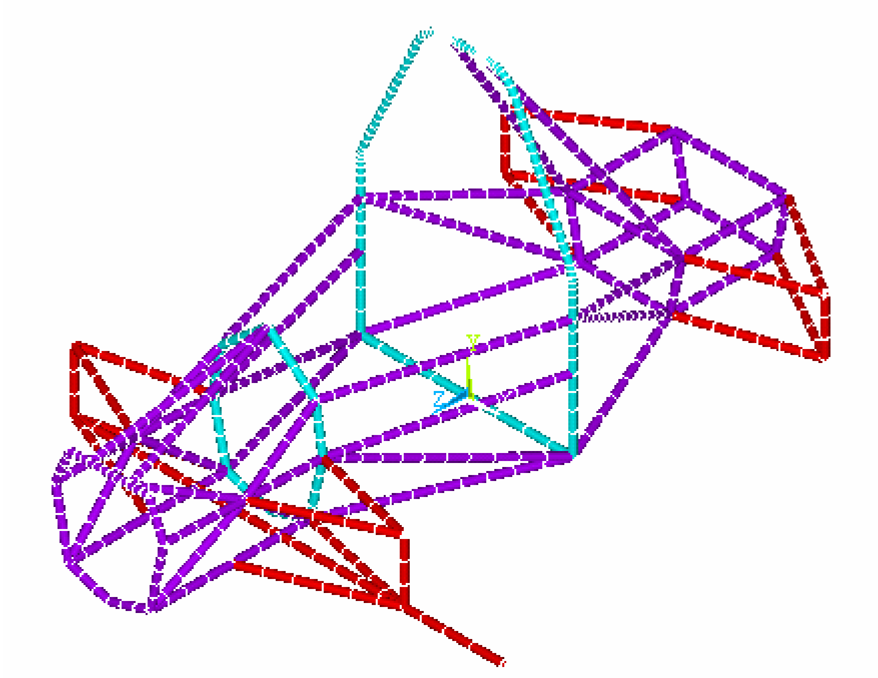


Figure 38: The added on test bar for loading to test for torsional stiffness

Now to load the chassis, this is done using the same code as seen in Figure 34 and solved by the same code in Figure 35. Firstly the rear outer wishbone points are constrained so the rear of the car is held. The other points to be constrained are the lowest points on both the front hoop and the bulkhead to create a point of rotation. Then a load is applied to the end of the 'test bar' to create the moment around the rotation points.

Once this is done the deflection can be found at points on the chassis and the moment is known from where and how much the load applied is so the torsional stiffness can be found. The, add on code that does this can be found in Appendix G. Figure 39 shows the diagram created when this file is inputted into Ansys, it can be seen that the chassis is twisting in a way similar to that expected on the race track.

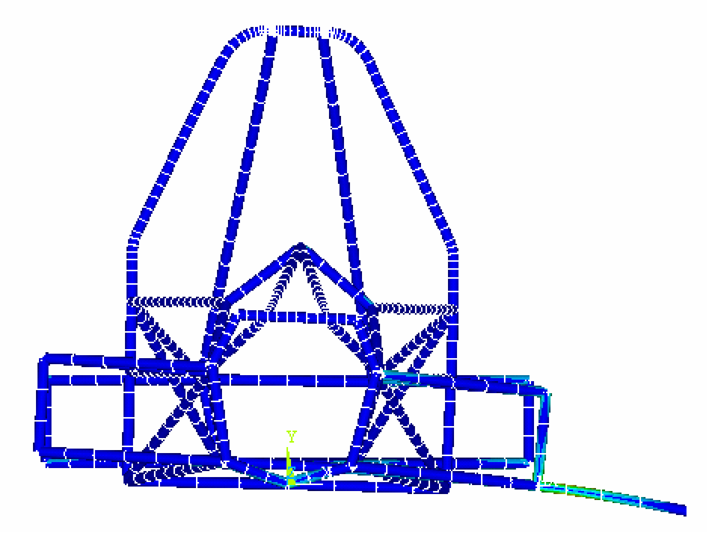


Figure 39: Torsional testing model of the chassis

5.2.Results

The results are separated into two parts, firstly the static loading of the chassis and then the torsional stiffness testing of the chassis.

5.2.1. Static loading

The static loading of the chassis provided the knowledge that the chassis could indeed hold the loads imposed upon it in its static form.

Figure 40: The Ansys window when the static load code was inputted

When the chassis was loaded representative of it static loading the maximum deflection was only 2.964mm and the maximum stress was only 68.217 MPa which occurred at the point where the shoulder brace attached to the main hoop which was adequately supported.

Therefore the chassis in terms of static loading is designed to a satisfactory standard.

5.2.2. Torsional Stiffness

The torsional stiffness of the chassis is an important part in its design; if it is inadequate the chassis will flex and affect the suspension performance.

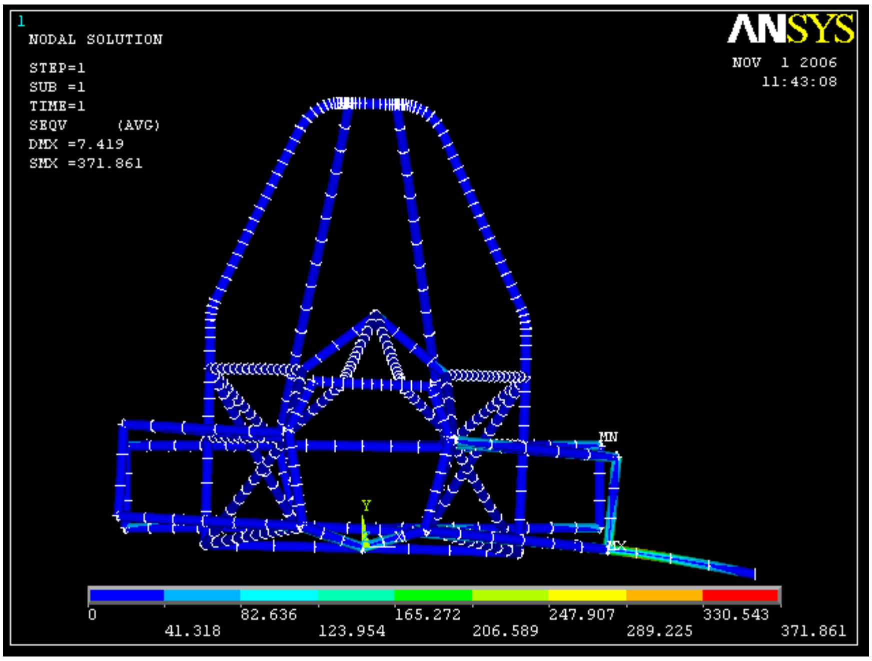


Figure 41: The Ansys window for when torsional stiffness code was inputted

The results of loading the chassis in a similar way to that which it would be on the race track determined that the maximum deflection which occurred at the end of the test bar was 7.419mm with a maximum stress of 371.861 MPa occurring outside the chassis geometry and in the wishbones. The chassis appeared to have minimal stress transferred throughout the members.

From these results gained a final torsional stiffness for the chassis can be found, by knowing that torsional stiffness is portrayed in N.m / degree. The load and distance at which it was applied is known to be 1000N at one metre in distance, therefore the moment on the chassis is 1kN.m. From the known deflection over the distance it is located the angle was found to be 7.419 x 10^-3. Using these values the torsional stiffness of the chassis is 134.8kN.m/degree.

The results gained for the static loading of the chassis were quite appropriate and could be used as a guide on the strength of the chassis however the torsional stiffness results were inconclusive as they were much greater than predicted or aimed at.

Further work is required to refine the torsional stiffness code and gain results appropriate to the situation.

6. Chapter 6 Construction

6.1. Pipe Lengths

Overall in the chassis there are seven components that are one offs and nineteen components that have two members the same dimensions symmetrical on each side of the chassis. To allow for a quicker and more productive construction process each of these components was given a number and set out into a list of pipe lengths. Within this table each component had a drawing associated with it as can be seen in section 4.4 and a length of pipe it required to be constructed. In Appendix H is the table created that lists all the pipes and their lengths.

Once this table was formulated the theoretical work is completed and it is time to move onto the construction of the chassis.

6.2. Construction Bed

To make the construction process simple and uncomplicated a construction bed was designed. It was built at a height of 700mm from the ground and to a top dimension that would surround the entire chassis. The legs were on wheels to allow for easy transportation between the welding bay and the workspace/storage space. The bed was designed in a way that would allow it to be dismantled into smaller components for travel to the competition to be used as a work/display bench.

On the working top of the construction bed were various clamps set up to hold the main components of the chassis in place throughout the construction process.

6.3.Process

The construction of the chassis predominately took place in the Z4 workshop located to the north of engineering block. The first step was the only outsourced work required in the process, and it was to have the main and front hoops mandrel bent into shape; the workshop doesn't have the facilities to do this on premises.

The first in house part of the process consisted of cutting the pipes according to the table seen in Appendix H. The pipes once cut were bundled together in a convenient place to be added to the chassis one by one.

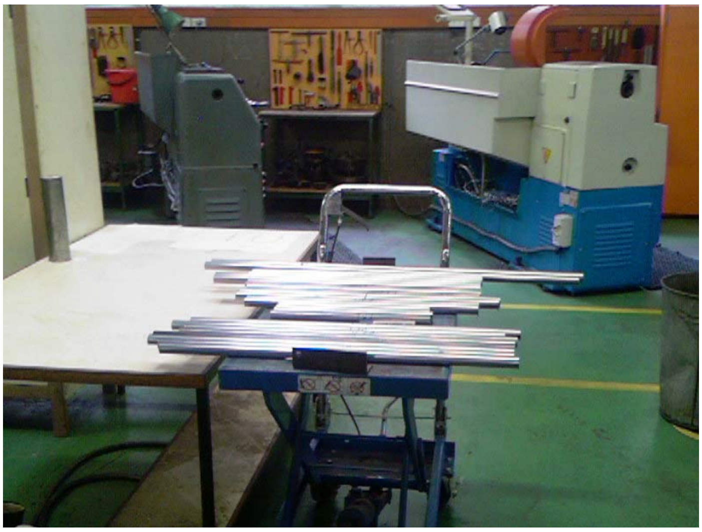


Figure 42: All of the pipes cut to length waiting to be added to the chassis throughout construction.

Once these pipes were cut to size the next step was to position the main components, these being the main hoop, the front hoop, the rear box section and the bulkhead to the construction bed in their final positions. Whilst the main and front hoops were being positioned the cut pipes for the bulkhead and the rear box section were welded together so these main components could be added to the construction bed along with the hoops.

Figure 43: The main components positioned on the construction bed

Now all of the cut pipes need to be roughly notched (core the ends of the pipes so they fit onto the relative weld points) one by one and added to the main components already on the construction bed. The first pipes added were the main front supports.

Figure 44: First pipes to be added to the main components the front supports.

Now the spider members (remaining diagonal front support members) as they were appropriately labelled, were added to the front section of the chassis.

This process required a lot of extra grinding after the initial notching to create a neat fit onto the bar.

Figure 45: Spider added to the frontal area of the chassis.

Having completed the frontal supports the next step moved onto the passenger cell construction. It involved firstly positioning the shoulder support and the upper side impact member followed by the lower and then diagonal side impact members.

Figure 46: Passenger cell construction

Now the engine bay was welded together and a completed chassis was ready for further checks that the design was sufficient in all areas of the dimensions and construction. The seat was roughly positioned along with the engine to ensure those major parts of the final car fitted into the chassis.

Figure 47: The final design fully constructed with the engine and seat in position to check the design was suitable

The construction process took a period of two weeks over the semester break to complete start to finish, once all the information was available. This period will always be required when constructing the chassis as it is a long and demanding process. Also the workshop staff were completely devoted to the project over the construction period, without this dedication to the project a greater amount of time would need to be set aside to complete the chassis.

Overall the final constructed chassis was a success, with only minimal parts outside a two millimetre tolerance. The welding was completed by predominantly Chris Galligan (workshop manager) with Bart Smith (motorsport team manager) helping out with some of the smaller areas. The cutting and notching was performed by Jared Armstead with some help from Scott Coombes (motorsport team member). The final constructed weight was around 35kg so the weight aim was met.

Recommendations for future endeavours in constructing the chassis would be to definitely use the construction bed, and work off the main components clamped in place.

7. Chapter 7 Testing – Physical

The physical testing of the chassis is an important part in the analysis of its actual strength, and to justify what was found in the FEA testing. To do this analysis as accurately as possible a test rig must first be designed that will simulate how the chassis will be loaded in its actual application.

7.1. Test Rig

The main test that needs to be carried out is to determine the torsional stiffness of the chassis. To do this the chassis needs to be twisted in some way respective to the way it would be when racing. To achieve this, the chassis must be held at one end and loaded in a way that creates moment around the other end.

The way in which the test rig will do this is simple, once the chassis has had the wishbones, uprights and hubs attached to it all that needs to be done is replace the shocks with a single strong piece of metal (this holds the suspension firm and prevents it from some of the load away from the chassis). Now the test rig is a basic box sectioned with brackets at one end that bolt straight onto the hubs as if they were the wheels. The other end of the test rig will be the loading and rotation end, it will consist of attachment points representative of the wheels attached to a beam that pivots on a central point and extends one metre from the pivot point on one side. A rough drawing of what the test rig will look like can be seen in Figure 48.

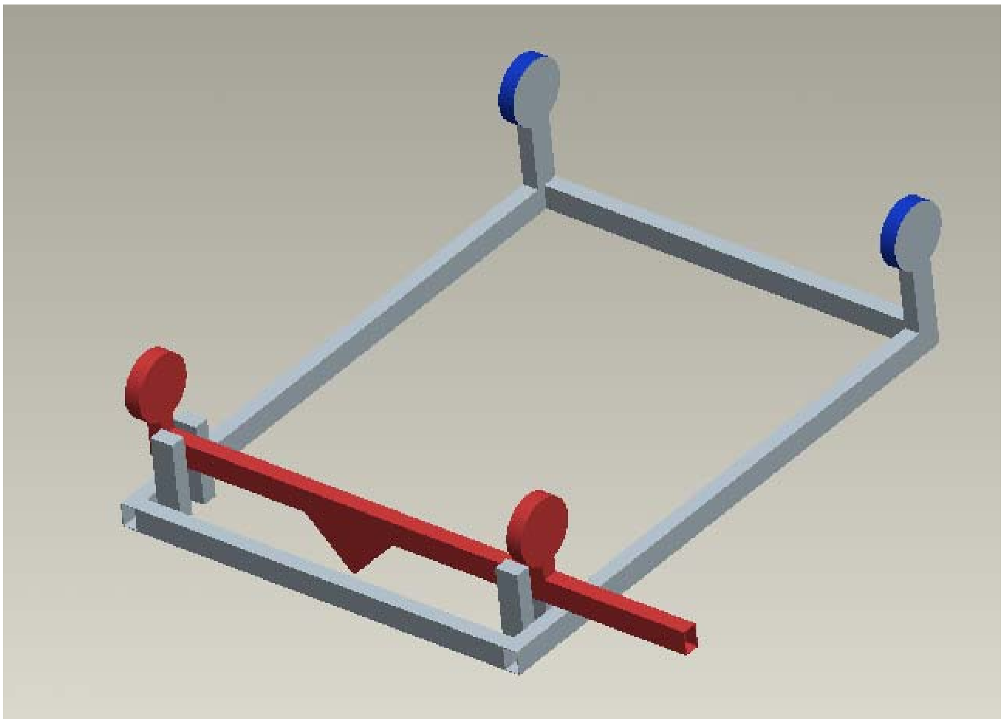


Figure 48: Rough model of the design test rig for torsional stiffness

7.2.Process

The process for testing the chassis using the test rig designed is very simple. The chassis needs first to be bolted into place by bolting the hubs of the chassis through the test rig as if the test rig was the wheels. Once this is done the end of the red bar in the diagram is loaded to a specified value. Because it is exactly a metre from the rotation point whatever the load that is applied is, is the value of the applied moment. From this device an angle of twist can be gained and hence a final result in N.m/degree can be found.

7.3.Results

Due to time constraints the experiment wasn't performed and hence no results were gained. This process will be done at a later date and any results gained will be recorded for future development.

Chapter 8 Conclusions

Overall the final design of the chassis reached all the aims that were set out to achieve. It meets all of the competitions rules and incorporates the necessary components of the car into it.

The final weight was approximately 35kgs, the final wheel base was 1610mm in length, 100mm was removed from the front area of the car, the goal of 300N.m/degree was met however not fully justified, all of the miscellaneous goals were met including the drivers knees has clearance and visibility is good over the top of the front hoop, the engine is able to be installed and removed from the lower of the engine bay region and the drivers cockpit area provides better protection and comfort.

The final chassis allowed all components relevant clearance and met all the attachment points perfectly, the construction was done to plus or minus two millimetres over the entire chassis relative to the model dimensions which shows that the construction bed and methods used were accurate and very good in their application. It can be seen below with the engine seat and driver positioned appropriately.

Figure 49: The final completed chassis

To add to the conclusion of the work that was done to complete the final design and this project a look at what more could have been done if time permitted.

The code that was created had minimal errors in the geometry, the front hoop bends mainly. Although it didn't have too greater affect on the final outcome of results it would be good to refine the code so the geometry was 100 percent accurate. Also once this code was completed a greater analysis of each component to find out the critical members and eliminate ones that don't carry loads.

The torsional stiffness testing in the code wasn't conclusive with what was expected so further research into this would be required.

The physical testing need to be completed and results gained from the test rig analysis, this will give some indication of the chassis ability to withstand torsional loading.

The geometry that the chassis was designed around is finalised and correct at the time of construction by the relevant component design teams. Some very large errors were found at a stage of no return in terms of chassis construction on this year's model.

A new model needs to be done with all the added seat attachment points and harness attachment points to fully analyse how the chassis will behave under certain loading conditions.

Appendix A - Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

For: **Jared Kenneth Armstead**

Topic: Chassis development for the Formula SAE-A Racer

Supervisor: Chris Snook

Project Aim: To design, develop and build a rigid, lightweight chassis for the 2006 model USQ FSAE race car.

Program: **Issue A: 21st March 2006**

11. Study the FSAE Rules to determine guidelines in accordance to Safety and Design requirements.

12. Access the effectiveness of the 2005 model car and specify areas of improvement.

13. Create a design/layout of the chassis through talks with relevant team members.

14. Specify materials to be used

15. Analyse using FEA software the design in regards to deflection and torsional stiffness.

16. Determine if design is suitable or make changes as found in step 5.

17. Create a manufacture guideline for the chassis and liaise with workshop staff and fellow teams members on the construction of the chassis.

18. Develop a physical torsional rigidity test rig for the chassis.

If time and resources permit:

19. Assist in team management and sponsorship activities

20. Assist in manufacture and testing of the car.

Agreed ________________________ (student) ________________________ (supervisor)

Dated: __/__/2006

Appendix 1 - The created summary of the 2006 competition rules

Component specific summary of FSAE rules relating to the chassis

Main Hoop

Definition: a roll bar located alongside or just behind the drivers torso.

Material: Round, mild or alloy steel tubing (min.1% carbon)

Dimensions of Tube: 25mm Diameter by 2.5mm thickness

Construction:

Must be constructed of a single piece of uncut, continuous closed section steel tubing.

It must extend from the lowest frame member on one side of the frame, up, over and down to the lowest frame member on the other side.

In the side view of the vehicle the portion of the main roll hoop that lies above its attachment point to the major structure of the frame just be within 10 degrees of the vertical.

380 mm at least at the bottom side to side.

Front Hoop

Definition: A fool bar located above the drivers legs, in the proximity to the steering wheel.

Material: Round, Mild or Alloy steel tubing (min 0.15 carbon)

Dimensions of Tube: 25mm Diameter by 2.5mm Thickness

Construction

Must be constructed of closed section metal tubing

It must extend from the lowest frame member on one side of the frame up, over and down to the lowest frame member on the other side.

The top most surface of the front hoop must be no lower than the top of the steering wheel in any angular position

In side view no part of the front hoop can be inclined at more than 20 degrees from the vertical.

Bulkhead

Definition: A planer structure that defines the forward plane of the major structure of the frame and functions to provide protection for the driver's feet.

Dimensions of Tube: 25mm Diameter by 1.75mm Thickness or 25.4mm Diameter by 1.6mm Thickness.

Construction

Must be constructed of closed section steel tubing.

Forward of all non-crushable items e.g. batteries, master cylinders.

Must be located such that the soles of the drivers feet, when touching but not applying the pedals, are rearward of the bulkhead plane. Pedals must be in the forward most position.

Main Hoop Bracing

Material: Closed section steel tubing

Dimensions of Tube: 25mm Diameter by 1.75mm Thickness of 25.4mm Diameter by 1.6mm Thickness.

Construction

Main hoop must be supported by two braces extended in the forward or rearward direction on both the left and right sides. In the side view the main hoop and braces must not lye in the same vertical plane. If the main hoop leans forward then the braces must extend forward, if the braces lean backwards then the braces must extend rearwards.

Must be attached as near as possible to the main hoop but no more than 160mm below the top most surface of the main hoop.

Then angle between the main hoop and the braces must be at least 30 degrees.

The braces must be straight (not bent in anyway)

Must be capable of transmitting all loads applied to them.

Front Hoop Bracing

Dimensions of Tubes: 25mm Diameter by 1.75mm Thickness of 25.4mm Diameter by 1.6mm Thickness.

Construction:

Must be 2 braces extending forwards on each side.

Must protect the driver legs, extend to the structure in front of the drivers legs.

The front braces must be attached as near as possible to the top of the front hoop but no more than 50.8mm from the top most surface of the hoop.

Bulkhead Support

Material: Must be constructed of closed section steel tubing.

Dimensions of Tube: 25mm Diameter by 1.25mm Thickness.

Construction:

Must be securely integrated into the frame

As a minimum the front bulkhead must be supported on each side to the front hoop by frame members at the top (50.8mm or less) and the bottom.

The support must have node-node triangulation, at least one diagonal brace.

Other Bracing:

Where other braces are not welded they must be securely attached to the frame using 8mm grade 8.8 (5/16in Grade 5) bolts and 2mm thick mounting plates.

Side Impact Members

Dimensions of Tube: 25mm Dimensions by 1.75mm Thickness or 25.4mm Diameter by 1.6mm Thickness

Construction:

Three tubular members each side of the driver

Upper side impact member must connect the main hoop and front hoop at a height between 300mm and 350mm above the ground with a 77kg driver in the seat.

May be the upper most side member.

Lower side impact member just connect between the bottom of the main hoop and the bottom of the front hoop. Is the lower rail/frame member.

Diagonal side impact member must connect the upper and lower side impact members forward of the main hoop and rearward of the front hoop.

Appendix 2 - The 2006 competition rules

3.2.6 Jacking Points

A jacking point, which is capable of supporting the car's weight and of engaging the organizers' "quick jacks", must be provided at the rear of the car.

The jacking point is required to be:

(A) Oriented horizontally and perpendicular to the centerline of the car

(B) Made from round, 25.4 mm (1.0 inch) O.D. aluminium or steel tube

(C) A minimum of 300 mm (11.8 inches) long

(D) Exposed around the lower 180 degrees of its circumference over a minimum length of 280 mm (11 in)

The height of the tube is required to be such that:

(A) There is a minimum of 75 mm (3 in) clearance from the bottom of the tube to the ground measured at tech inspection,

(B) With the bottom of the tube 200 mm (7.9 in) above ground, the wheels do not touch the ground when they are in full rebound.

3.3 Structural Requirements

Among other requirements, the vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system and Impact Attenuator, and side impact structures.

3.3.1 Definitions

The following definitions apply throughout the Rules document:

(A) Main Hoop - A roll bar located alongside or just behind the driver's torso.

(B) Front Hoop - A roll bar located above the driver's legs, in proximity to the steering wheel.

(C) Frame Member - A minimum representative single piece of uncut, continuous tubing.

(D) Frame - The "Frame" is the fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single welded structure, multiple welded structures or a combination of composite and welded structures.

(E) Primary Structure – The Primary Structure is comprised of the following Frame components: 1) Main Hoop, 2) Front Hoop, 3) Roll Hoop Braces, 4) Side Impact Structure, 5) Front Bulkhead, 6) Front Bulkhead Support System and 7) all Frame Members, guides and supports that transfer load from the Driver's Restraint System into items 1 through 6.

(F) Major Structure of the Frame – The portion of the Frame that lies within the envelope defined by the Primary Structure. The upper ortion of the Main Hoop and the Main Hoop braces are not included in defining this envelope.

(G) Front Bulkhead – A planar structure that defines the forward plane of the Major Structure of the Frame and functions to provide protection for the driver's feet.

(H) Impact Attenuator – A deformable, energy absorbing device located forward of the Front Bulkhead.

3.3.2 Structural Equivalency

The use of alternative materials or tubing sizes to those specified in Section 3.3.3.1 - Baseline Steel Material, is allowed, provided they have been judged by a technical review to have equal or superior properties to those specified in Section
3.3.3.1. Approval of alternative material or tubing sizes will be based upon the engineering judgment and experience of the chief technical inspector or his appointee.

The technical review is initiated by completing the "Structural Equivalency Form" using the format given in Appendix A-1. The form must be submitted no later than the date given in the "Action Deadlines" located in the Appendix.

3.3.3 Minimum Material Requirements

3.3.3.1 Baseline Steel Material

The Primary Structure of the car must be constructed of:

Either: Round, mild or alloy, steel tubing (minimum 0.1% carbon) of the minimum dimensions specified in the following table,

Or: Approved alternatives per Section 3.3.3.2

ITEM or APPLICATION	OUTSIDE DIAMETER x WALL THICKNESS
Main & Front Hoops	1.0 inch (25.4 mm) x 0.095 inch (2.4 mm) or 25.0 mm x 2.50 mm metric
Side Impact Structure, Front Bulkhead, Roll Hoop Bracing & Driver's Restraint Harness Attachment	1.0 inch (25.4 mm) x 0.065 inch (1.65 mm) or 25.0 mm x 1.75 mm metric or 25.4 mm x 1.60 mm metric
Front Bulkhead Support	1.0 inch (25.4 mm) x 0.049 inch (1.25 mm) or 25.4 mm x 1.25 mm metric

Note: The use of alloy steel does not allow the wall thickness to be thinner than that used for mild steel.

3.3.3.2 Alternative Tubing and Material

3.3.3.2.1 General

Alternative tubing geometry and/or materials may be used. However, if a team chooses to use alternative tubing and/or materials:

(A) The material must have equivalent (or greater) Buckling Modulus EI (where, E = modulus of Elasticity, and I = area moment of inertia about the weakest axis)

(B) Tubing cannot be of thinner wall thickness than listed in 3.3.3.2.2 or

3.3.3.2.3.

(C) A "Structural Equivalency Form" must be submitted per Section 3.3.2. The teams must submit calculations for the material they have chosen, demonstrating equivalence to the minimum requirements found in Section 3.3.3.1 for yield and ultimate strengths in bending, buckling and tension, for buckling modulus and for energy dissipation. The main roll hoop and main roll hoop bracing must be made from steel, i.e. the use of aluminium or titanium tubing or composites are prohibited for these components.

3.3.3.2.2 Steel Tubing Requirements

Minimum Wall Thickness Allowed:

MATERIAL & APPLICATION	MINIMUM WALL THICKNESS
Steel Tubing for Front and Main Roll Hoops	2.1 mm (0.083 inch)
Steel Tubing for Roll Hoop Bracing, Front Bulkhead & Driver's Harness Attachment	1.65mm (0.065 inch)
Steel Tubing for Side Impact Structure & Front Bulkhead Support	1.25 mm (0.049 inch)

Note: To maintain EI with a thinner wall thickness than specified in 3.3.3.1, the outside diameter MUST be increased.
Note: All steel is treated equally - there is no allowance for alloy steel tubing, e.g. SAE 4130, to have a thinner wall thickness than that used with mild steel.

3.3.3.2.3 Aluminium Tubing Requirements
Minimum Wall Thickness:

MATERIAL & APPLICATION	MINIMUM WALL THICKNESS
Aluminum Tubing	3.175 mm (0.125 inch)

The equivalent yield strength must be considered in the "as-welded" condition, (Reference: WELDING ALUMINUM (latest Edition) by the Aluminium Association, or THE WELDING HANDBOOK, Vol . 4, 7th Ed., by The American Welding Society), unless the team demonstrates and shows proof that the frame has been properly solution heat treated and artificially aged.

Should aluminium tubing be solution heat-treated and age hardened to increase its strength after welding, the team must supply sufficient documentation as to how the process was performed? This includes, but is not limited to, the heat-treating facility used, the process applied, and the fixturing used.

3.3.3.2.4 Composite Materials

If any composite or other material is used, the team must present documentation of material type, e.g. purchase receipt, shipping document or letter of donation, and of the material properties. Details of the composite lay-up technique as well as the structural material used (cloth type, weight, resin type, number of layers, core material, and skin material if metal) must also be submitted. The team must submit calculations demonstrating equivalence of their composite structure to one of similar geometry made to the minimum requirements found in Section 3.3.3.1. Equivalency calculations must be submitted for energy dissipation, yield and ultimate strengths in bending, buckling, and tension. Submit the completed “Structural Equivalency Form” per Section 3.3.2.

Composite materials are not allowed for the main hoop or the front hoop.

3.3.4 Roll Hoops

The driver’s head and hands must not contact the ground in any rollover attitude. The Frame must include both a Main Hoop and a Front Hoop as shown in Figure 1.

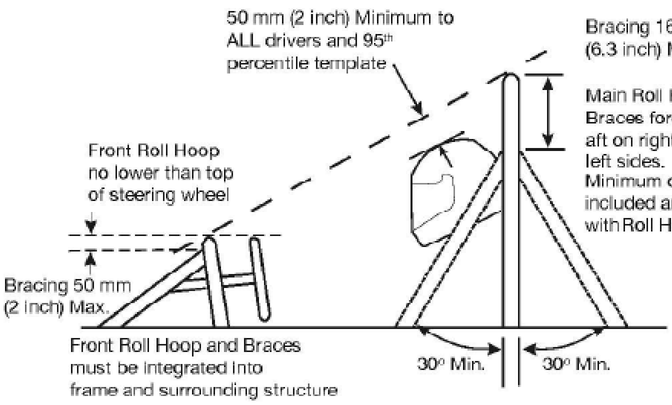


FIGURE 1

3.3.4.1 Main and Front Hoops – General Requirements

(A) When seated normally and restrained by the Driver’s Restraint System, a straight line drawn from the top of the main hoop to the top of the front hoop must clear by 50.8 mm

(2 inches) the helmet of all the team's drivers and the helmet of a 95th percentile male (anthropometrical data).

> A two dimensional template used to represent the 95th percentile male is made to the following dimensions:
>
> - A circle of diameter 200 mm (7.87 inch) will represent the hips and buttocks.
> - A circle of diameter 200 mm (7.87 inch) will represent the shoulder/cervical region.
> - A circle of diameter 300 mm (11.81 inch) will represent the head (with helmet).
> - A straight line measuring 490 mm (19.29 inch) will connect the centers of the two 200 mm circles.
> - A straight line measuring 280 mm (11.02 inch) will connect the centers of the upper 200 mm circle and the 300 mm head circle.

.

With the seat adjusted to the rearmost position, the bottom 200 mm circle will be placed in the seat, and the middle 200 mm circle, representing the shoulders, will be positioned on the seat back. The upper 300 mm circle will be positioned up to 25.4mm (1 inch) away from the head restraint (i.e. where the driver's helmet would normally be located while driving).

(B) The minimum radius of any bend, measured at the tube centerline, must be at least three times the tube outside diameter. Bends must be smooth and continuous with no evidence of crimping or wall failure.

(C) The Main Hoop and Front Hoop must be securely integrated into the Primary Structure using gussets and/or tube triangulation.

3.3.4.2 Main Hoop

(A) The Main Hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing per Section 3.3.3.

(B) The use of aluminum alloys, titanium alloys or composite materials for the Main Hoop is prohibited.

(C) The Main Hoop must extend from the lowest Frame Member on one side of the Frame, up, over and down the lowest Frame Member on the other side of the Frame.

(D) In the side view of the vehicle, the portion of the Main Roll Hoop that lies above its attachment point to the Major Structure of the Frame must be within 10 degrees of the vertical.

(E) In the front view of the vehicle, the vertical members of the Main Hoop must be at least 380 mm (15 inch) apart (inside dimension) at the location where the Main Hoop is attached to the Major Structure of the Frame.

(F) On vehicles where the Primary Structure is not made from steel tubes, the Main Hoop must be continuous and extend down to the bottom of the Frame. The Main Hoop must be securely attached to the monocoque structure using 8 mm Grade 8.8 (5/16 in Grade 5) bolts. Mounting plates welded to the Roll Hoop shall be at least 2.0 mm (0.080 inch) thick steel. Steel backup plates of equal thickness must be installed on the opposing side of the monocoque structure such that there is no evidence of crushing of the core. The attachment of the Main Hoop to the monocoque structure requires an approved Structural Equivalency Form per Section 3.3.2. The form must demonstrate that the design is equivalent to a welded Frame and must include justification for the number and placement of the bolts.

3.3.4.3 Front Hoop

(A) The Front Hoop must be constructed of closed section metal tubing per Section 3.3.3.

(B) The use of composite materials is prohibited for the Front Hoop.

(C) The Front Hoop must extend from the lowest Frame Member on one side of the Frame, up, over and down to the lowest Frame Member on the other side of the Frame. With proper gusseting and/or triangulation, it is permissible to fabricate the Front Hoop from more than one piece of tubing.

(D) The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position.

(E) In side view, no part of the Front Hoop can be inclined at more than twenty (20) degrees from the vertical.

3.3.5 Roll Hoop Bracing

3.3.5.1 Main Hoop Bracing

(A) Main Hoop braces must be constructed of closed section steel tubing per Section 3.3.3.

(B) The use of aluminium alloys, titanium alloys or composite materials is prohibited for the Main Hoop braces.

(C) The Main Hoop must be supported by two braces extending in the forward or rearward direction on both the left and right sides of the Main Hoop. In the side view of the Frame, the Main Hoop and the Main Hoop braces must not lie on the same side of the vertical line through the top of the Main Hoop, i.e. if the Main Hoop leans forward, the braces must be forward of the Main Hoop, and if the Main Hoop leans rearward, the braces must be rearward of the Main Hoop.

(D) The Main Hoop braces must be attached as near as possible to the top of the Main Hoop but not more than 160 mm (6.3 in) below the top-most surface of the Main Hoop. The included angle formed by the Main Hoop and the Main Hoop braces must be at least 30 degrees.

(E) The Main Hoop braces must be straight, i.e. without any bends.

(F) The attachment of the main hoop braces must not compromise the function of the bracing, i.e. the attachment method and supporting structure must be capable of transmitting all loads applied to them by the bracing without failing.

3.3.5.2 Front Hoop Bracing

(A) Front Hoop braces must be constructed of material per Section 3.3.3.

(B) The Front Hoop must be supported by two braces extending in the forward direction on both the left and right sides of the Front Hoop.

(C) The Front Hoop braces must be constructed such that they protect the driver's legs and should extend to the structure in front of the driver's feet.

(D) The Front Hoop braces must be attached as near as possible to the top of the Front Hoop but not more than 50.8 mm (2 in) below the top-most surface of the Front Hoop.

(E) Monocoque construction used as Front Hoop bracing requires an approved Structural Equivalency Form per Section 3.3.2.

3.3.5.3 Other Bracing Requirements

(A) Where the braces are not welded to steel Frame Members, the braces must be securely attached to the Frame using 8 mm

Grade 8.8 (5/16 in Grade 5), or stronger, bolts. Mounting plates welded to the Roll Hoop braces must be at least 2.0 mm (0.080 in) thick steel.

(B) Where Main Hoop braces are attached to a monocoque structure, backup plates, equivalent to the mounting plates, must be installed on the opposing side of the monocoque structure such that there is no evidence of crushing of the core. The attachment of the Main Hoop braces to the monocoque structure requires an approved Structural Equivalency Form per Section 3.3.2. The form must demonstrate that the design is equivalent to a welded frame and must include justification for the number and placement of the bolts.

3.3.5.4 Other Side Tube Requirements

If there is a roll hoop brace or other frame tube alongside the driver, at the height of the neck of any of the team's drivers, a metal tube or piece of sheet metal must be firmly attached to the Frame to prevent the drivers' shoulders from passing under the roll hoop brace or frame tube, and his/her neck contacting this brace or tube.

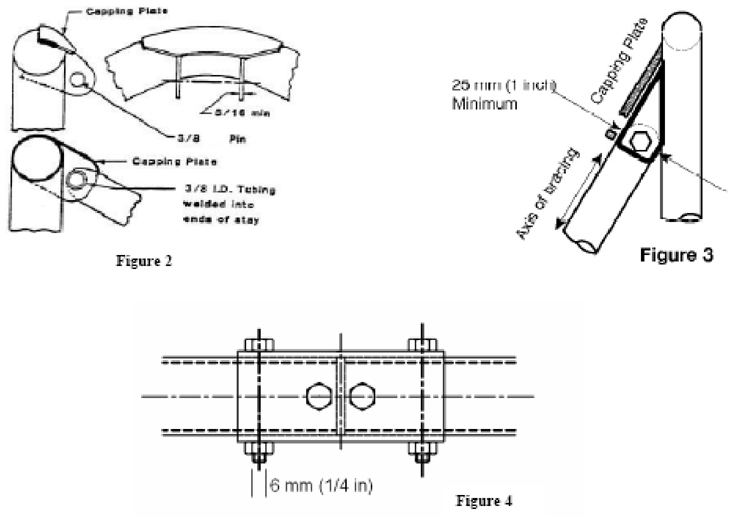
3.3.5.5 Removable Roll Hoop Bracing

(A) Roll Hoop bracing may be removable. Any non-permanent joint must be either a double-lug joint as shown in Figures 2 and 3, or a sleeved butt joint as shown in Figure 4. The threaded fasteners used to secure non-permanent joints are considered critical fasteners and must comply with paragraph 3.7.2.2. No spherical rod ends are allowed.

(B) For double-lug joints, each lug must be at least 4.5 mm (0.177 in) thick steel, measure 25 mm (1.0 in) minimum perpendicular to the axis of the bracing and be as short as practical along the axis of the bracing. All double-lug joints, whether fitted at the top or bottom of the tube, must include a capping arrangement (Figures 2 & 3). The pin or bolt must be 10 mm Grade 9.8 (3/8 in Grade 8) minimum.

The attachment holes in the lugs and in the attached bracing must be a close fit with the pin or bolt.

(C) For sleeved butt joints, the sleeve must have a minimum length of 76 mm (3 inch), 38 mm (1.5 inch) either side of the joint, and be a close-fit around the base tubes. The wall thickness of the sleeve must be at least that of the base tubes. The bolts must be 6 mm Grade 9.8 (1/4 inch Grade 8) minimum. The holes in the sleeves and tubes must be a close-fit with the bolts.



REMOVABLE ROLL BAR BRACES ATTACHMENT DETAILS (FIGURES 2, 3 & 4)

3.3.6 Frontal Impact Structure

The driver’s feet must be completely contained within the Major Structure of the Frame. While the driver’s feet are touching the pedals, no part of the driver’s feet can extend above and/or outside of the Major Structure of the Frame. Forward of the Front Bulkhead must be an energy-absorbing Impact Attenuator.

3.3.6.1 Bulkhead

(A) The Front Bulkhead must be constructed of closed section tubing per Section 3.3.3.

(B) The Front Bulkhead must be located forward of all non-crushable objects, e.g. batteries, master cylinders.

(C) The Front Bulkhead must be located such that the soles of the driver's feet, when touching but not applying the pedals, are rearward of the bulkhead plane. (This plane it defined by the forward-most surface of the tubing.) Adjustable pedals must be in the forward most position.

(D) Monocoque construction requires an approved Structural Equivalency Form, per Section 3.3.2. The form must demonstrate that the design is equivalent to a welded Frame in terms of energy dissipation, yield and ultimate strengths in bending, buckling and tension.

3.3.6.2 Front Bulkhead Support

The Front Bulkhead must be securely integrated into the Frame.

(A) As a minimum, the Front Bulkhead must be supported on each side of the vehicle back to the Front Roll Hoop by Frame Members at the top (within 50.8 mm (2 inches) of its top-most surface), and at the bottom.

(B) The Support must have node-to-node triangulation with at least one diagonal brace per side.

(C) All tubes of the Front Bulkhead Support must be constructed of closed section tubing per Section 3.3.3.

(D) Monocoque construction requires an approved Structural Equivalency Form, per Section 3.3.2. The form must demonstrate that the design is equivalent to a welded Frame in terms of energy dissipation, yield and ultimate strengths in bending, buckling and tension.

3.3.6.3 Impact Attenuator

(A) The Impact Attenuator must be installed forward of the Front Bulkhead.

(B) The Impact Attenuator must be at least 150 mm (5.9 in) long, with its length oriented along the fore/aft axis of the Frame.

(C) The Impact Attenuator must be at least 100 mm (3.9 in) high and 200 mm (7.8 in) wide for a minimum distance of 150 mm (5.9 in) forward of the Front Bulkhead.

(D) The Impact Attenuator must be attached securely and directly to the Front Bulkhead such that it cannot penetrate the Front Bulkhead in the event of an impact. The use of adhesive tape and/or Dzus type fasteners is prohibited. The Impact Attenuator shall not be attached to the vehicle by being part of non-structural bodywork. The attachment of the Impact Attenuator must be constructed to provide an adequate load path for transverse and vertical loads, in the event of off-center and off-axis impacts.

3.3.6.4 Impact Attenuator Data Requirement

The team must submit calculations and/or test data to show that their Impact Attenuator, when mounted on the front of a vehicle with a total mass of 300 kgs (661 lbs) and run into a solid, non-yielding impact barrier with a velocity of impact of 7.0 metres/second (23.0 ft/sec), would give an average deceleration of the vehicle not to exceed 20 g. The calculations and/or test data must be submitted electronically in

Adobe Acrobat ® format (*.pdf file) to the address and by the date provided in the Appendix.

3.3.6.5 Non-Crushable Objects

All non-crushable objects (e.g. batteries, master cylinders) must be rearward of the bulkhead. No non-crushable objects are allowed in the impact attenuator zone.

3.3.7 Front Bodywork

Sharp edges on the forward facing bodywork or other protruding components are prohibited. All forward facing edges on the bodywork that could impact people, e.g. the nose, must have forward facing radii of at least 38 mm (1.5 inches). This minimum radius must extend to at least 45 degrees relative to the forward direction, along the top, sides and bottom of all affected edges.

3.3.8 Side Impact Structure

The Side Impact Structure must meet the requirements listed below.

3.3.8.1 Tube Frames

The Side Impact Structure must be comprised of at least three (3) tubular members located on each side of the driver while seated in the normal driving position, as shown in Figure 5. The three (3) required tubular members must be constructed of material per Section 3.3.3. The locations for the three (3) required tubular members are as follows:

(A) The upper Side Impact Structural member must connect the Main Hoop and the Front Hoop at a height between 300 mm (11.8 inch) and 350 mm (13.8 inch) above the ground with a 77kg (170 pound) driver seated in the normal driving position. The upper frame rail may be used as this member if it meets the height, diameter and thickness requirements.

(B) The lower Side Impact Structural member must connect the bottom of the Main Hoop and the bottom of the Front Hoop. The lower frame rail/frame member may be this member if it meets the diameter and wall thickness requirements.

(C) The diagonal Side Impact Structural member must connect the upper and lower Side Impact Structural members forward of the Main Hoop and rearward of the Front Hoop. With proper gusseting and/or triangulation, it is permissible to fabricate the Side Impact Structural members from more than one piece of tubing. Alternative geometry that does not comply with the minimum requirements given above requires an approved Structural Equivalency Form per Section 3.3.2.

3.3.8.2 Composite Monocoque

The section properties of the sides of the vehicle must reflect impact considerations. Non-structural bodies or skins alone are not adequate. Teams building composite monocoque bodies must submit the "Structural Equivalency Form" per Section 3.3.2. Submitted information should include: material type(s), cloth weights, resin type, fibre orientation, number or layers, core material, and lay-up technique.

3.3.8.3 Metal Monocoque

These structures must meet the same requirements as tube frames and composite monocoque. Teams building metal monocoque bodies must submit the "Structural Equivalency Form" per Section 3.3.2

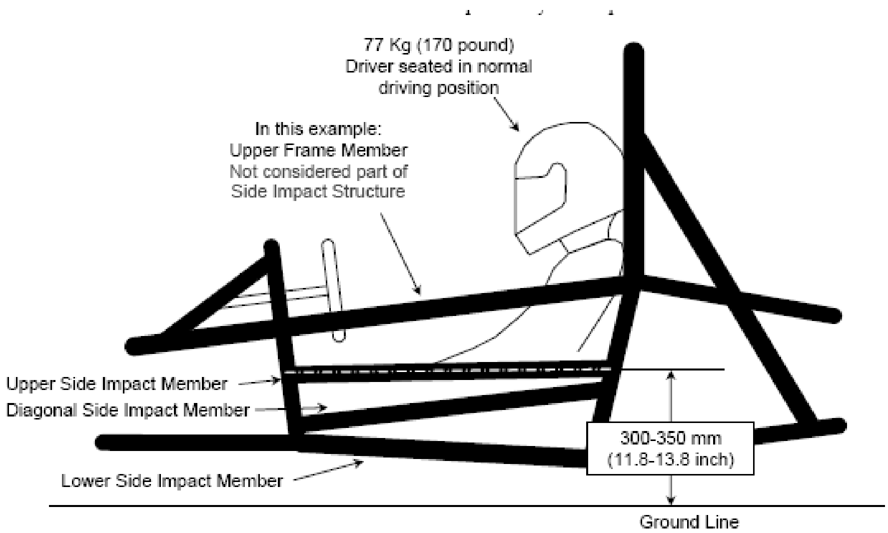

77 Kg (170 pound)
Driver seated in normal
driving position
In this example:
Upper Frame Member
Not considered part of
Side Impact Structure
Upper Side Impact Member
Diagonal Side Impact Member
Lower Side Impact Member
300-350 mm
(11.8-13.8 inch)
Ground Line

Figure 5

Appendix D - Base input code for Ansys

```
!* Input file to create geometry for 2006 chassis
!* Version : Final
!*
!* Created by : Chris Snook/ Jared Armstead
!* Date : 28 October 2006
!*
!* Geometry approved by: Jared Armstead

FINI
/CLEAR
/PREP7



!*
*********************************************************************
*
!* User input goes here ***************************************************
!* Length = mm
!* Force = N
!* Mass = tonne
!* Density = tonne/mm^3
!* Stress,Pressure = N/mm^2 aka MPa

!* Roll hoop info
R_Outer = 26.9
R_Wall = 2.3
R_E = 200e3
R_Dens = 7.8e-9
R_u = 0.3

!* Other tube info
O_Outer = 25.4
```

```
O_Wall = 1.6
O_E = 200e3
O_Dens = 7.8e-9
O_u = 0.3

!*Wishbone tube info
W_Outer = 19
W_Wall = 1.2
W_E = 1000e3
W_Dens = 7.9e-9
W_u = 0.3

ELENGTH = 50      !* Typical element length
!*
*******************************************************************
**

!* Now define the two tube types

ET,1,PIPE16
KEYOPT,1,6,1             !* Include stress and member forces in output
R,1,R_Outer,R_Wall, , , , ,

MP,EX,1,R_E
MP,PRXY,1,R_u
MP,DENS,1,R_Dens

ET,2,PIPE16
KEYOPT,2,6,1             !* Include stress and member forces in output
R,2,O_Outer,O_Wall, , , , ,

MP,EX,2,O_E
MP,PRXY,2,O_u
MP,DENS,2,O_Dens
```

```
ET,3,PIPE16
KEYOPT,3,6,1          !* Include stress and member forces in output
R,3,W_Outer,W_Wall, , , , ,

MP,EX,3,W_E
MP,PRXY,3,W_u
MP,DENS,3,W_Dens


!* Define keypoints for main geometry
!* Point 0,0,0 is at centre of lower reference tube
!* user input required for keypoint locations and for connectivity


!*    x     y     z

!* Main Hoop Points

K,1,  0,    0,    0          !* Centre reference of car
K,2,  400,  0,    0
K,3,  400,  275,  0
K,4,  400,  450,  0
K,5,  400,  600,  0
K,6,  150,  1140, 0
K,7,  60,   1140, 0
K,8,  0,    1140, 0
K,9,  -60   ,1140, 0
K,10, -150  ,1140, 0
K,11, -400  ,600, 0
K,12, -400  ,450, 0
K,13, -400  ,275, 0
K,14, -400  ,0,   0
```

!*Front Hoop Points

K,15,	0,	0,	750
K,16,	157,	50,	750
K,17,	207,	275,	750
K,18,	180,	450,	750
K,19,	0,	600,	750
K,20,	-180	,450,	750
K,21,	-207	,275,	750
K,22,	-157	,50,	750

!*Bulkhead Points

K,23,	0,	0,	1350
K,24,	155,	50,	1350
K,25,	205,	292,	1350
K,26,	150,	420,	1350
K,27,	75,	420,	1350
K,28,	-75	,420,	1350
K,29,	-150	,420,	1350
K,30,	-205	,292,	1350
K,31,	-155	,50,	1350

!*Front of Rear Box

K,32,	168,	50,	-600
K,33,	215,	260,-600	
K,34,	-215	,260,	-600
K,35,	-168	,50,	-600

!*Back of Rear Box

K,36,	168,	50,	-1000
K,37,	215,	260,	-1000

```
K,38,   -215    ,260,    -1000
K,39,   -168    ,50,     -1000

!*Front Suspension Mount

K,40,   207,    285,     1045
K,41,   -207    ,285,    1045
K,42,   -157    ,50,     1045
K,43,   157,    50,      1045
K,44,   0,      0,       1045

!*Rear Wishbone Points

K,45, 605,260,-750
K,46, -605,260,-750
K,47, 605,50,-750
K,48, -605,50,-750

!*Front Wishbone Points

K,49,625,285,860
K,50,-625,285,860
K,51,625,50,860
K,52,-625,50,860


!***********************************************************************
******
!* Now create the geometry by joining the keypoints to form the relative components.

!*Join lines to create Hoops

!*Main Hoop
```

```
L,2,3	!*Line 1
L,3,4	!*Line 2
L,4,5	!*Line 3
L,5,6	!*Line 4
L,6,7	!*Line 5
L,7,8	!*Line 6
L,8,9	!*Line 7
L,9,10	!*Line 8
L,10,11		!*Line 9
L,11,12		!*Line 10
L,12,13		!*Line 11
L,13,14		!*Line 12
LFILLT,3,4,120		!*Line 13
LFILLT,4,5,120		!*Line 14
LFILLT,8,9,120		!*Line 15
LFILLT,9,10,120		!*Line 16

!*Front Hoop

L,15,16		!*Line 17
L,16,17		!*Line 18
L,17,18		!*Line 19
L,18,19		!*Line 20
L,19,20		!*Line 21
L,20,21		!*Line 22
L,21,22 !*Line 23
L,22,15 !*Line 24

L,2,1	!*Line 25
L,1,14	!*Line 26

!*********************************************************************
***************************
!* Set attributes for all subsequently created lines to be set number one,
```

```
!*eg Roll Hoops
LATT,1,1,1,0, , ,
!*LESIZE,ALL,ELENGTH, , , ,1, , ,1,          !* Try to mesh all selected lines to be
ELENGTH long
LMESH,ALL                          !* Mesh all lines, can use NAME instead of ALL
EPLOT
!******************************************************************
**************************

!*Bulkhead

L,23,24         !*Line 27
L,24,25         !*Line 28
L,25,26         !*Line 29
L,26,27         !*Line 30
L,27,28         !*Line 31
L,28,29         !*Line 32
L,29,30         !*Line 33
L,30,31         !*Line 34
L,31,23         !*Line 35

!*Front of Rear Box

L,32,33         !*Line 36
L,33,34 !*Line 37
L,34,35         !*Line 38
L,35,32 !*Line 39

!*Back of Rear Box

L,36,37         !*Line 41
L,37,38         !*Line 42
L,38,39         !*Line 43
L,39,36         !*Line 44
```

```
!* Complete Rear Box

L,32,36		!*Line 45
L,33,37		!*Line 46
L,34,38		!*Line 47
L,35,39		!*Line 48

!*Main Hoop Braces

L,33,4	!*Line 49
L,34,12		!*Line 50
L,33,7	!*Line 51
L,34,9	!*Line 52

!* Engine Bay

L,32,2	!*Line 53
L,35,14		!*Line 54
L,32,4	!*Line 55
L,35,12		!*Line 56

!*Side Impact

L,2,16	!*Line 57
L,14,22		!*Line 58
L,3,17	!*Line 59
L,13,21		!*Line 60
L,2,17	!*Line 61
L,14,21		!*Line 62

!*Shoulder Brace

L,4,18	!*Line 63
```

```
L,12,20         !*Line 64

!*Front Braces

L,16,43         !*Line 65
L,43,24         !*Line 66
L,17,40         !*Line 67
L,40,25         !*Line 68

L,21,41         !*Line 69
L,41,30         !*Line 70
L,22,42         !*Line 71
L,42,31         !*Line 72

L,19,27         !*Line 73
L,19,28         !*Line 74

L,27,40         !*Line 75
L,28,41         !*Line 76
L,40,18         !*Line 77
L,41,20         !*Line 78

!* Cross Bracing

L,16,40         !*Line 79
L,40,24         !*Line 80
L,22,41         !*Line 81
L,41,31         !*Line 82

!*******************************************************************
***************************
!* Set attributes for all subsequently created lines to be set number one,
eg Roll Hoops
LATT,2,1,1,0, , ,
```

```
!*LESIZE,ALL,ELENGTH, , , ,1, , ,1,          !* Try to mesh all selected lines to be ELENGTH long
LMESH,ALL                        !* Mesh all lines, can use NAME instead of ALL
EPLOT
!**********************************************************************
****************************

/VIEW, 1 ,1,1,1 !* Isometric view
/SHRINK,0
/ESHAPE,1
/EFACET,1
/RATIO,1,1,1
/CFORMAT,32,0
/REPLOT
```

Appendix E - Add on code for static loading of the chassis

```
!********Apply Forces
!*Constrain Lower Suspension Points Front and Back
DK,37,ALL,0
DK,32,ALL,0
DK,35,ALL,0
DK,39,ALL,0

DK,16,ALL,0
DK,43,ALL,0
DK,22,ALL,0
DK,42,ALL,0

!*Apply Force of Car Down on Centre Position 400kg car with factor of safety of 1.25 gives 5000N applied static load
FK,2,FY,-2500
FK,14,FY,-2500



FINISH
!* ************* Enter the solver
/SOL
SOLVE
FINISH                  !* Leave the solver

/POST1                  !* Enter the postprocessor
PLDISP,2                 !* plot displaced
!***
!*
/EFACET,1
PLNSOL, S,EQV, 0,1.0        !* Plot nodal solution of SEQV (Von Mises)
PRRSOL,                          !* Print all reaction forces and moments
```

Appendix F - Wishbone and test bar add on code

```
!* Wishbones and Test Bar

L,37,45
L,33,45
L,45,47
L,36,47
L,32,47

L,38,46
L,34,46
L,46,48
L,35,48
L,39,48

L,17,49
L,40,49
L,49,51
L,16,51
L,43,51

L,21,50
L,41,50
L,50,52
L,22,52
L,42,52

!*******************************************************************
***************************
!* Set attributes for all subsequently created lines to be set number one,
eg Roll Hoops
LATT,3,1,1,0, , ,
```

```
!*LESIZE,ALL,ELENGTH, , , ,1, , ,1,         !* Try to mesh all selected lines to be ELENGTH long
LMESH,ALL                    !* Mesh all lines, can use NAME instead of ALL
EPLOT
```

!**

Appendix G - Add on code for the torsional loading of the chassis

```
!********Apply Forces

!*Constrain rear wishbone points and rotation points at bottom of bulkhead and front hoop
DK,47,ALL,0
DK,45,ALL,0
DK,46,ALL,0
DK,48,ALL,0
DK,23,ALL,0
DK,15,ALL,0

!*Apply Force at end of test bar.
FK,53,FY,-1000


FINISH
!* ************* Enter the solver
/SOL
SOLVE
FINISH                  !* Leave the solver

/POST1                  !* Enter the postprocessor
PLDISP,2                 !* plot displaced
!***
!*
/EFACET,1
PLNSOL, S,EQV, 0,1.0          !* Plot nodal solution of SEQV (Von Mises)
!***
PRRSOL,                          !* Print all reaction forces and moments
```

Appendix H - List of pipe lengths for use in construction process

List of Pipes				
Area	**Number**	**Size of Pipe**	**Quantity**	**Length**
Rear Box	1	25.4*1.6	2	410
	2	25.4*1.6	2	220
	3	25.4*1.6	2	410
	4	25.4*1.6	2	220
Engine Bay	1	25.4*1.6	2	1085
	2	25.4*1.6	2	665
	3	25.4*1.6	2	770
	4	25.4*1.6	2	655
Passenger				
Cell	1	25.4*1.6	2	790
	2	25.4*1.6	2	785
	3	25.4*1.6	2	830
	4	25.4*1.6	2	800
Front Braces	1	25.4*1.6	2	640
	2	25.4*1.6	2	350
	3	25.4*1.6	2	370
	4	25.4*1.6	2	610
	5	25.4*1.6	2	390
	6	25.4*1.6	2	400
	7	25.4*1.6	2	610
Cross Braces	1	25.4*1.6	1	2*175
	2	25.4*1.6	1	2*175
	3	26.9*2.3	1	2*175
	4	26.9*2.3	1	835
	5	25.4*1.6	1	425
	6	25.4*1.6	1	360
	7	25.4*1.6	1	425
	8	25.4*1.6	1	360

Appendix I - Design Report for the USQ motorsport 2006 model FSAE race car.

FSAE-A
DESIGN REPORT 2006

This document provides an overview of the design criteria, and characteristics for the University of Southern Queensland's Formula SAE-A race car.

General Overview of Design

USQ Motorsport's prototype FSAE 2006 racer (model designate FT2) is near completion and is currently undergoing final testing.
Model FT2 is a mid engined steel tube frame single seat , open wheel car with fiberglass bodywork, using a Yamaha 4ND four cylinder in line liquid cooled motorcycle engine with integral six speed gearbox.
While essentially conventional, the design includes a number of technical features intended to enhance its' ability to meet the following expectations of the market.

1. Reliability: A market analysis indicates that the owners of this type of car will expect to spend time on the track and not to have their enjoyment of the sport compromised by expensive or time consuming repairs or high rates of component failure. Racing cars will, at times come off the circuit, or be damaged by handling, therefore engineering effort has been directed at designing to withstand undesirable events, not merely meet the design loads arising from performance based predictions.

2. Ease of Maintenance: Items requiring frequent servicing, or having a short service life can be removed or replaced without the use of special tools. Access is provided to most items without the necessity to remove more than the external body panels. The engine / gearbox assembly is removed from below the car. Removal and refit of the engine / gearbox assembly can be performed without disturbing the suspension or rear axle assembly. FT2 uses a number of commercial or aftermarket motorcycle components in areas where short service life or component changes to alter specification are desired. The multiple source of supply provides both a wide range of products around the basic specification with strong competition to ensure pricing remains reasonable over the production life of the product.

3. Value for Money: By utilising cheap and readily available components wherever possible the overall cost of the car has been kept to a minimum. Specific parts are manufactured from common engineering materials, and can be produced in any type of general engineering workshop. Upgradeability is catered for in the electrical, suspension and engine systems.

Chassis Design

The chassis is comprised of a tubular C350LO mild steel space frame. This material was specified for its low cost, ease of manufacture and that it can be easily repaired using standard welding techniques. Heat treatment does not need to be applied to any welded structural or suspension element of the FT2.

The space frame was designed from anthropometric data for 95th percentile male, including leg lengths. The driver safety cell incorporates a number of specific features, including shoulder level side rails, full height main roll hoop bracing and an ADR approved seat with integral head restraint. The steering wheel is non contactable under a 30g forward impact.

Full-scale mock-ups were used for verification of ergonomic dimensions of the key passenger compartment elements, and Pro/Engineer wildfire solid modelling software, was used for subsequent design, packaging and assembly work.

Chassis strength and rigidity has been analysed using non-destructive testing and finite element analysis (FEA) using the ANSYS package. The non-destructive testing consisted of torsional tests, with the complete frame clamped and loaded in a purpose built test rig. The results of these tests were used to maintain strength and rigidity requirements whilst reducing gross weight.

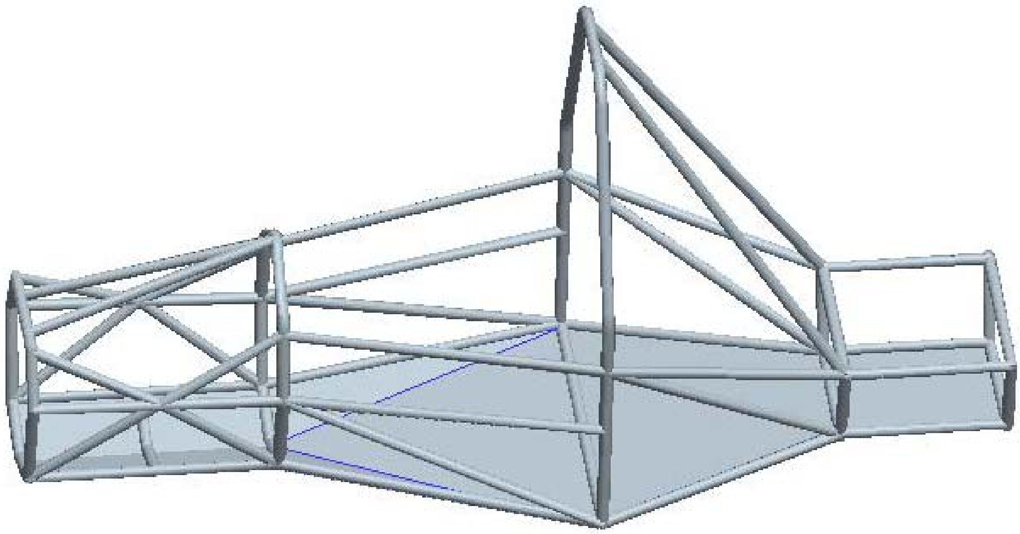


Figure 1. FT2 chassis

Braking System

The braking system is a dual circuit type, incorporating non-assisted dual hydraulic master cylinders and a mechanical brake bias adjustment to accurately control the front to rear hydraulic ratio. The pedal box has a 4:1 mechanical ratio and is adjustable to provide a range of movement of 100mm to ensure correct fitment for drivers up to the 95^{th} percentile.

Front brakes are mounted inboard of the front uprights and consist of a cross-drilled custom made steel rotor and "Wilwood Billet Dynalite Single" callipers acting on each of the front wheels. Mounting the callipers inboard has allowed the suspension design to obtain a small scrub radius and accommodate a wide range of wheel sizes and offsets. Front discs are 9mm thick to provide adequate heat dissipation under prolonged braking.

A single steel rotor and calliper acts on the rear axle, of which are production items supplied by Yamaha. The use of a rear spool has enabled the simplicity of one rear brake, along with associated weight savings.

A pedal effort of 370N (under maximum braking at 1.2g, with a pad coefficient of 0.5) is achieved with a 14kN clamping force on the front brakes, and 5kN on the rear brakes. The overall pedal gearing has been chosen to provide the driver with a perception of good braking response, without undue risk of inadvertent brake lockup. A brake pad friction of 0.5 is in the mid range of available competition products currently available, giving scope to tune the braking response by component changes without the need to modify or disturb the mechanical or hydraulic components of the braking system.

Engine and Drivetrain

The engine utilises a fully sequential fuel injection system, controlled by an Adaptronic™ ECU. Ignition mapping is also carried out by the ECU. This system was chosen for it's adaptability, ease of tuning, product support, and cost. Generic Bosch ™ sensors are used throughout, as they are readily available, and inexpensive. The intake system is a common plenum with individual tuned runners to each cylinder, designed to provide maximum torque at 8250rpm. In order to provide a compact, aesthetically pleasing intake system, the restrictor is neatly tucked away inside the plenum chamber. The chamber volume is 1739cc and is designed to sufficiently slow the incoming air from the restrictor, and to dampen out the velocity pulses caused by the induction process. The throttle body is bolted onto the side of the plenum chamber, neatly within the confines of the engine compartment

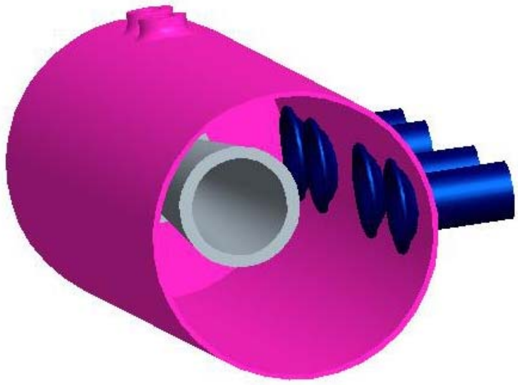


Figure 2 Plenum chamber with integral restrictor

Power transmission from motor to the rear axle is by single row roller chain. Weight, ease of installation and maintenance led to this being the most suitable option. It is an off the shelf part so replacement and sourcing is simple. The spool rear axle arrangement was decided upon for weight, simplicity and cost without undue penalty in performance. From experience, empirical evidence and quantitative testing a spool arrangement has proven successful. This produces competitive results provided the dynamic characteristics are catered for in the chassis design, and wheel alignment specifications.

Tripod type constant velocity joints were used on both the inner and outer joints. They are off the shelf items, which are readily obtainable and cost effective. The main centre axle is constructed from 4130 hollow bar. Material was selected for manufacturability, ready supply and cost.

Sprockets are off the shelf commercially available aftermarket motorcycle products. These components will naturally wear in service, and can be easily sourced. In addition, the owner has the option to change the final drive ratio as required for certain race tracks.

Steering System

The non assisted rack and pinion steering is fitted on the base of the chassis, acting on the front wheels through tie rods and tie rod ends. The decision to mount on the base was to reduce weight through elimination of rocker arms, keep the centre of gravity low to the ground, and to prevent twisting of the chassis when a steering moment is applied. Mounting the steering rack on the base also removes the risk of injuring the occupant's legs in the event of a collision.

Lock to lock, the steering wheel moves through 190º and provides 68mm total rack travel. Turn radius at full lock is 3.1m. 100 % Ackerman geometry is used to improve low speed manoeuvring, which is non-adjustable. The steering wheel is mounted on a quick release hub designed to accept the addition of gear selector and clutch "paddle" actuators. The steering column is non adjustable.

Toe in adjustment is provided by left and right hand threaded rod ends. There is no adjustment for Ackermann.

Suspension System

Unequal length, non-parallel double wishbone suspension is fitted front and rear. The suspension geometry provides the same camber rate front and rear in order to maintain a constant handling balance. There is no anti-dive or anti-squat geometry included into this design. Static roll centre height is 51mm below ground level with a range of 3mm

Pull rod suspension is used at the front, acting via a rocker arm, with no anti-roll bar. Front suspension units are coil over shocks, mounted inboard acting at the centre part of the chassis. These have adjustment for spring preload, rebound and compression.
Push rod suspension is used at the rear acting via a rocker arm, with an anti-roll bar. Rear suspension units are coil over shocks, with adjustment for rebound and spring pre-load.

Suspension uprights have undergone substantial FEA analysis to reduce weight whilst meeting packaging, strength, and stiffness requirements.

There are no driver accessible adjustments for the suspension, however all other adjustments are easily performed with the car stationary.

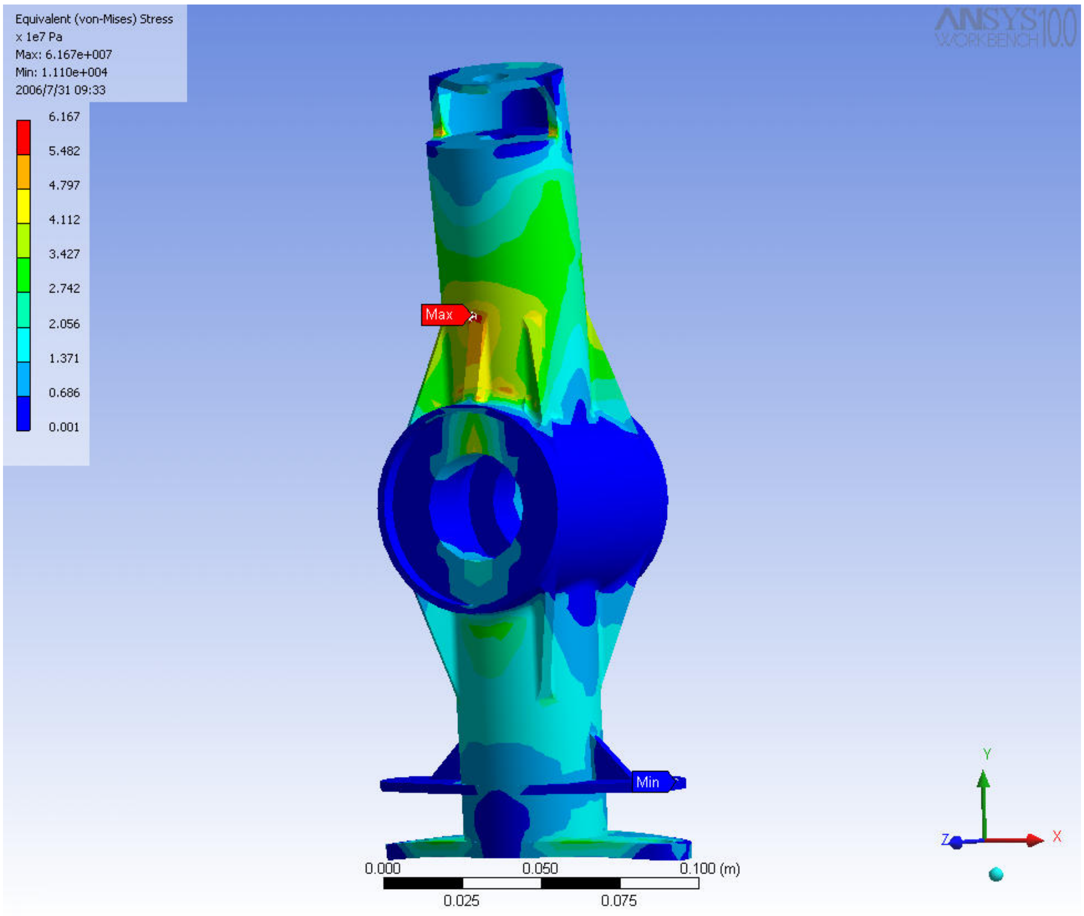
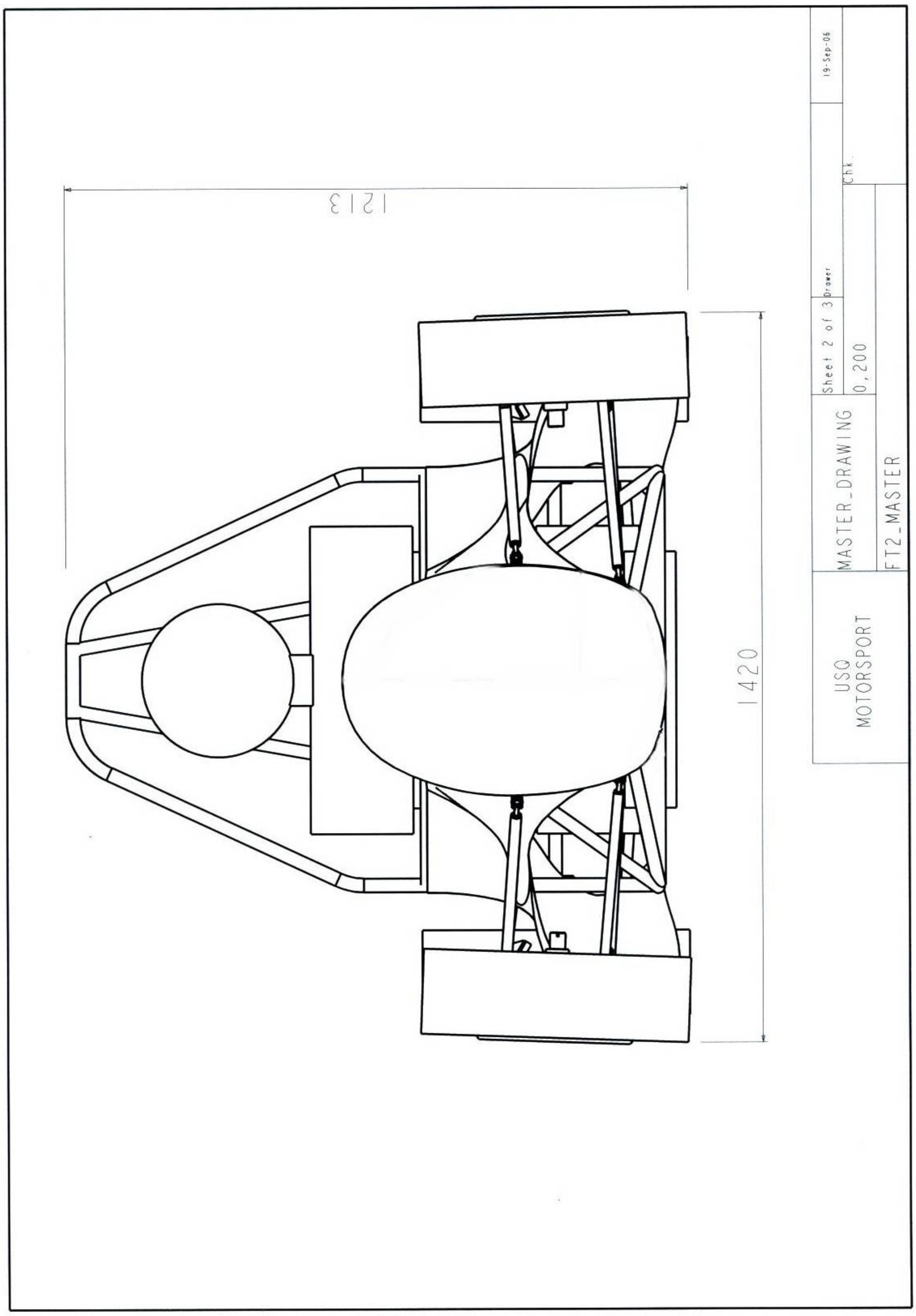
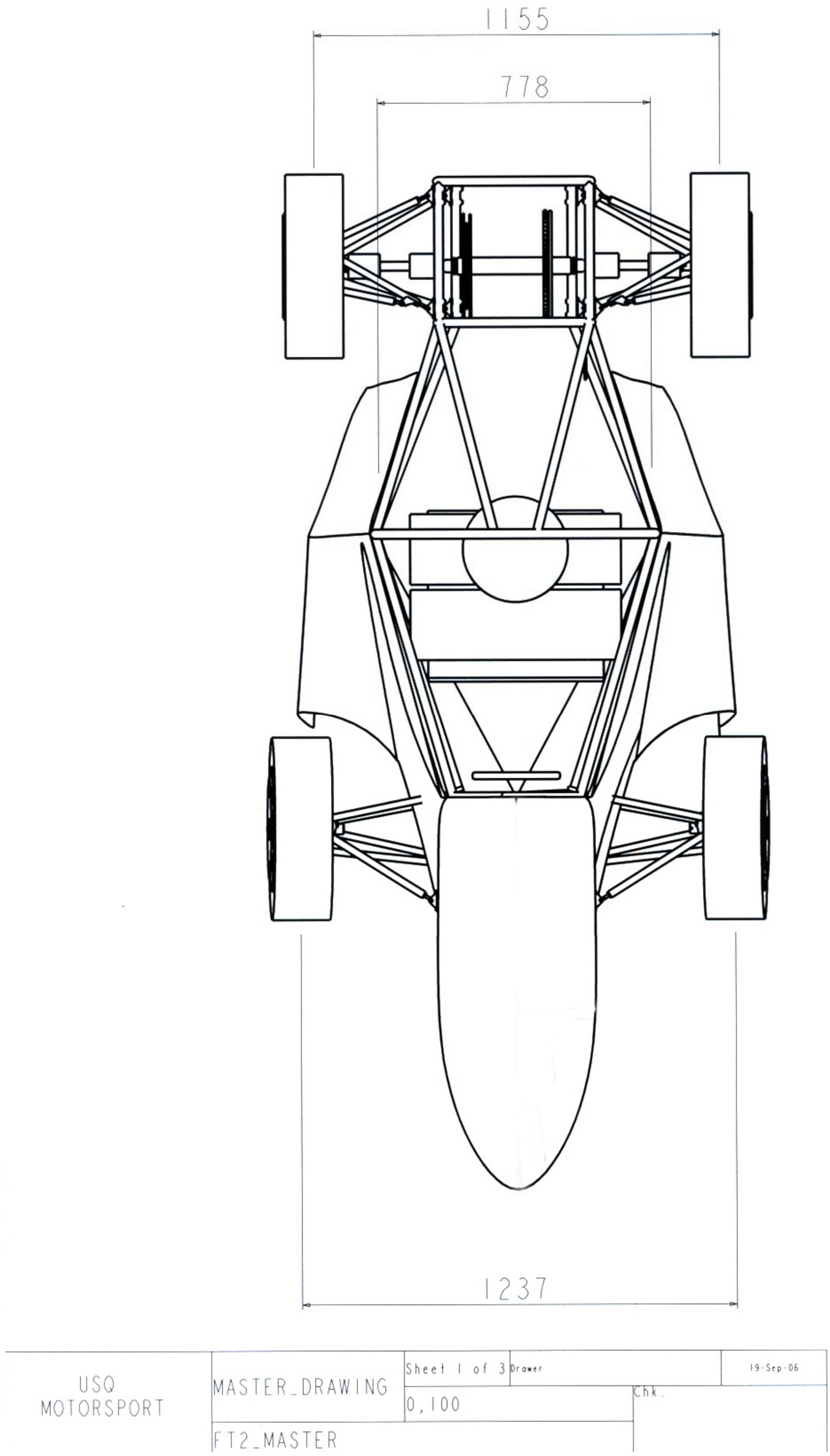


Figure 3. Left-hand rear upright


1213
1420
USQ
MOTORSPORT
MASTER_DRAWING
FT2_MASTER
Sheet 2 of 3
Drawer
0,200
Chk
19-Sep-06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778
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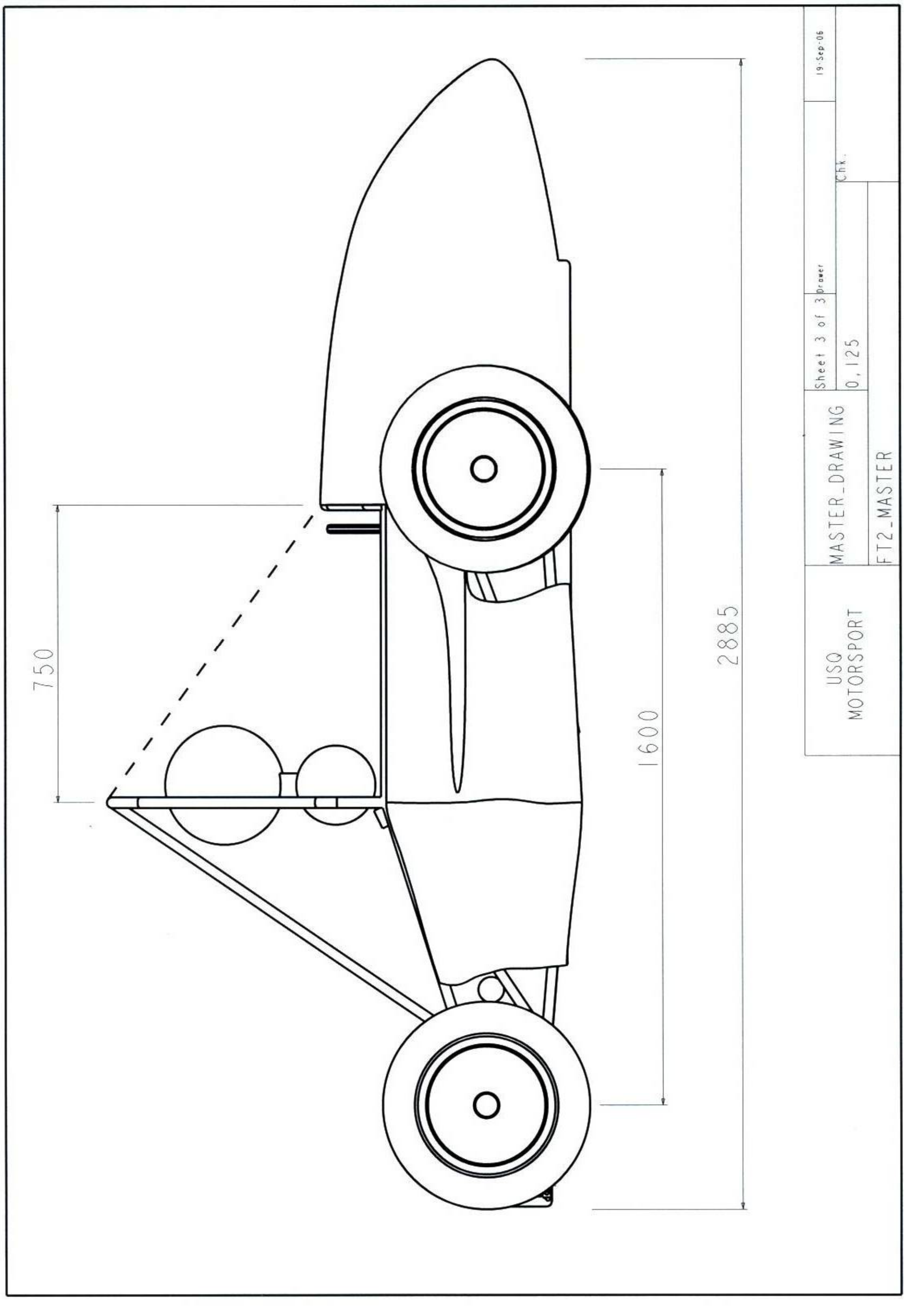
MASTER_DRAWING
Sheet 1 of 3
Drawer
19-Sep-06
0,100
Chk.
FT2_MASTER


750
1600
2885
USQ
MOTORSPORT
MASTER_DRAWING
FT2_MASTER
Sheet 3 of 3
Drawer
0,125
Chk.
19-Sep-06

USQ Motorsport: Evolutionary Process

The overall aims of USQ Motorsport is to develop it's race car by evolving technologies from year to year, and in line with market expectations. Such technologies are researched thoroughly, then to be implemented for the following model. Considerable testing is carried out prior to pre-production release to ensure, reliability, safety, and driveability.

FT2 represents the 3rd evolution car for USQ Motorsport. The major improvements over previous models include:

1. Lighter chassis.
2. Implementation of fuel injection, and ECU control.
3. Integral restrictor in plenum chamber.
4. Inboard callipers on front brakes.
5. Side pods to allow for fitment of radiators and oil coolers.
6. Cockpit manufactured to ensure fitment for wide range of customers.
7. Full in-house database for document and parts control.

Technologies are currently being developed that will be incorporated into the next model, due for release in 2007. These include:

1. Casting of components to greatly reduce weight.
2. Active differential.
3. Use of alternative materials to increase stiffness and reduce weight.
4. Electronic gearshift.
5. Traction control.

Appendix J: Cost Report tables for the chassis

Component	Description/ Model # or Part #	Purchased or Manuf'd (P or M)	Quantity	What You Paid/ Representative Process*	Retail Cost Each	Unit of Measure	Supplier's Name and Phone Number	Total Retail Cost	Reference Pages of Cost Report for Detail on Process	Reference Pages for Receipts	Requires Manufacturing Process to be written
Pedals		m	1	0	131.68	Assembly	USQ motorsport Ph 07 46312717	131.68	59		Detailed Process to be Written
Shifter		m	1	0	70.12	Assembly	USQ motorsport Ph 07 46312717	70.12	59		Detailed Process to be Written
Thottle Controls	Part of Pedal Box			0				0.00			
Frame / Frame Tubes		m	1	0	38.56	each	USQ motorsport Ph 07 46312717	**38.56**	60		Detailed Process to be Written
Tube Cuts / Bends		m	1	366	424.41	total	USQ motorsport Ph 07 46312717	**424.41**	60		Detailed Process to be Written
Tube End Preps		m	1	0	118.59	each	USQ motorsport Ph 07 46312717	**118.59**	60		Detailed Process to be Written
Body Material		m	1	0	708.81	Assembly	USQ motorsport Ph 07 46312717	708.81	61		Detailed Process to be Written
Body Processing		m	1	0	586.25		USQ motorsport Ph 07 46312717	586.25	61		Detailed Process to be Written
Body Attachments	see fasteners page	p	0	0	-			0.00			

Mounts Integral to Frame		m	1	0	465.67	each	USQ motorsport Ph 07 46312717	465.67	62		Detailed Process to be Written
Floor Pan		m	1	0	111.05	Assembly	USQ motorsport Ph 07 46312717	111.05	62		Detailed Process to be Written
Clutch		part of shifter		0				0.00			
Aerodynamic Wing (if used)		n/a		0				0.00			
Shifter Cable / Linkage		m	1	0	94.92	Assembly	USQ motorsport Ph 07 46312717	94.92	63		Detailed Process to be Written
Final Assembly			180	0	0.77	min		138.60	63		
Welding		m	160	0	1.50		USQ motorsport Ph 07 46312717	239.53	63		Detailed Process to be Written
Fasteners		p	84	0		each		10.92	64		
Sub-Total								3139.11			
Fixturing & Jig Time	Labor and Set-up time for welding		240	0	0.77	min		**184.80**			
Assembly Cost	Labor to Asssemble to vehicle		180	0	0.77	min		**138.60**			
Area Total								3462.51			

The total cost of the chassis is the total of the bolded sections above which is equal to approximately $905.

References

Reference 1: http://inventors.about.com/library/weekly/aacarssteama.htm

Reference 2 http://dictionary.reference.com/browse/chassis

Reference 3: http://fsae.com/eve/forums/a/tpc/f/442600868/m/89010136711