EML 4551 Senior Design Project

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BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Development of a Formula SAE Body 25% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4551. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Fall 2012

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Javier Gutierrez, Angel Nuñez, and Diego Quintero and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

Javier Gutierrez	Angel Nuñez	Diego Quintero
Team Leader	Team Member	Team Member

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Abstract

A body for the Florida International University (FIU), Formula SAE team latest prototype with the proper studies and analysis will be developed, taking into account several factors to present an optimum body model as a final result. These factors include, but are not limited to, weight, cost, drag resistance, functionality and esthetics.

The following project is divided into three phases, *design* (or modeling), *analysis* and *manufacture*. First, on the *design* stage, a rough hand sketch of the vehicle will be made. Then, a mock-up of the vehicle body will be modeled in SolidWorks. Subsequently, several iterations of shapes and sizes are going to be modeled. Finally, a design will be chosen and the final optimization will be performed. For phase two, *testing*, initially the body design will be tested using CAD software. Afterwards, several shapes and profiles will be analyzed. Finally, the physical body will be tested in a wind tunnel. For the third stage, *manufacture*, first a mold needs to be assembled and prepared in order to lay the fiber without adhesion. The carbon fiber is then laid onto the mold and saturated with resin. Later, un-adhesive paper is then placed on top of the fiber to prevent adhesion to adjacent layers. Afterwards, a plastic bag is placed over the whole part and air sealed through a vacuum to avoid air pockets in the product. Finally, it is left to dry and the layers are then removed to reveal the final product.

1. Introduction

1.1 Problem Statement

The Florida International University Formula SAE (FSAE) team wanted to build their second prototype vehicle for the 2013 FSAE competition. Due to the complexity of this project, several sub-teams are needed in order to develop a competitive car. Each of these sub-teams will take full responsibility of each system of the vehicle (i.e. Engine, Drivetrain, Brakes, Suspension, Electrical, Body and Frame). One of the biggest defects of last year's car, shown in Figure 1, was the body built. It was a last minute design and manufacture because of the lack of human power. Also, no analyses were done respecting the study of aerodynamics and poor attention was given to weight, functionality and esthetics. Therefore, the scope of this project will be the development of a body for FIU, Formula SAE 2012-2013 prototype.

Figure 1: 2011-2012 FIU-FSAE Prototype

The principal limitation will be in time since the vehicle will be participating in the Collegiate Design Series: Formula SAE competition to be held in Brooklyn, Michigan on May 8th, 2013. Therefore, the vehicle has to be completely finished several weeks before the competition date for overall testing. Another important factor to take into consideration, as a limitation, is funding. Mainly, personal out-of-pocket expenses will be minimized. Some of the actions to be measured to support this objective include the development of a sponsorship proposal to approach companies. Some of the benefits for companies include: exposure, since the vehicle will be competing in a national event; tax deduction, since FIU-SAE is a non-profit organization with a Tax-ID number; and, the fact that they will be supporting future engineers with great passion for the automotive industry. Another source of income will be to attend several fundraising events hosted by FIU-SAE.

1.2 Motivation

Based on the results of last year's competition, one of the major proposed improvements for the upcoming prototype was body design. By approaching this task as a Senior Design Project, it would allow for better and more in-depth analysis that would yield an optimal design. Our team decided to tackle this project as it involves various advanced concepts from different fields of engineering, such as: Fluid Dynamics, Structural Analysis, Mechanics of Materials and Computer Aided Design.

1.3 Literature Survey

In order to develop a highly competitive body for a Formula SAE application, first, the 2012 competition winner vehicle needs to be examined. The Oregon State university team has won several competitions in the past few years, therefore, is a great candidate to be analyzed.

Figure 2: GPR 2011-2012 Vehicle

Before analyzing its body, a brief explanation about GFR will be provided. “Global Formula Racing is the first innovative global collaboration of its kind in the history of both the US-based Formula SAE and EU-based Formula Student programs. The former BA Racing Team from the Duale Hochschule Baden-Württemberg-Ravensburg (DHBW-R), Germany, and the Beaver Racing Team from Oregon State University (OSU) have combined forces to compete as a single entity. The two universities share physical and intellectual resources to create a highly competitive vehicle worthy of international reputation.” [9]

The GFR team uses a carbon fiber monocoque as its frame and body. The body also provides a structural rigidity to mount the rest of the systems of the car. This solutions yield to a tremendous amount of weight savings, but its application is very expensive and requires a lot of human resources. Due to the complexity of this application and the limited budget of the FIU-SAE team, the scope of our project will be limited to developing of a carbon fiber body. More details about this will be explained further in this report.

Several concepts need to be explained before further elaboration on the chosen design project. First of all, Society of Automotive Engineers (SAE) International is a global association of more than 128,000 members worldwide. SAE provides a standard in the aerospace, automotive and commercial-vehicle industries [10]. Moreover, SAE hosts various student competitions: Baja, Formula, Super Mileage, among others. Secondly, Formula SAE (FSAE) is a project approached mainly by engineering students in which they have to develop an open wheel, open cockpit small Formula-style racecar. This racecar, is to be evaluated for its potential as a production item in an international competition with over 120 Universities from around the world participating. Students have to research, design, manufacture, test, develop, and manage production of their school’s prototype. This competition is divided into two main type of events, Statics and Dynamics. Each of these events has several categories of different evaluation weighs. The details are provided in Table 1, as shown below:

Table 1: Competition Events [10]

Type of Event	Category	Points
Static Events	Presentation	75
	Engineering Design	150
	Cost Analysis	100
Dynamic Events	Acceleration	75
	Skid-Pad	50
	Autocross	150
	Fuel Economy	100
	Endurance	300
	Total Points	**1,000**

Lastly, FIU-SAE is a group of diverse people with a strong passion for the automotive industry and is mainly composed by engineering students that represent the Florida International University Chapter of the Society of Automotive Engineers worldwide. With their second prototype ever built, FIU-SAE is striving to compete and thrive in the 2013 Formula SAE competition. The main purpose of this organization, is to further develop the engineering concepts learned in class, and provide a hands-on experience with an actual object to successfully develop integral engineers for the future.

2. Project Formulation

2.1 Project Objectives

To develop a body for the new prototype with the proper studies and analysis, taking into account several factors to present an optimum body model as a final result. These factors include, but are not limited to, weight, cost, drag resistance, functionality and esthetics. The expected product is to be appealing to the eye and it will increase the performance of the vehicle. Additional objectives include being able to accommodate the budget while maintaining a highly competitive level to perform well in the competition. Furthermore, other objectives relates to improvements of past designed bodies. The first generation of the FIU Formula car was made from fiberglass and its surface was not very smooth. The new design will reduce the weight of the prototype and as well as the air drag, taking into consideration the ground effects desired to be implemented in the vehicle as a crucial factor. Moreover, the new body will be easier to dismantle reducing the service time.

Another fundamental objective will be participating in the 2013 Formula SAE competition to be held in Michigan in June 2013. Therefore, not only will this project has to satisfy the class requirements but also it has to follow and satisfy all of the rules set forth by SAE International.

3. Design Alternatives

3.1 Overview of Conceptual Designs Developed

The designs that have been considered are thought to tackle the team's main concerns, which are wind drag and weight reduction in order to improve overall vehicle performance. Also, we would like to incorporate some visual attraction with a light but aerodynamic body design. This will give the vehicle a greater opportunity to score higher with the judges in the upcoming competitions

3.2 Design Alternate I

The first design path was to go simple and practical. The team discussed how this might affect the judges' outlook on the design complexity but after further research we discovered that it has been shown that complex is not always better. After extensive consideration we decided that it was more beneficial to the FIU Formula SAE team for us to design a single piece body that would be an exoskeleton to the teams frame design of choice.

Figure 3: Design Alternative 1

3.3 Design Alternate II

Our second alternative has a more costly direction and would be an ideal design if the extensive funds were available to the team. The design consists of a monocoque body that would eliminate the use of a frame. This of course would eliminate weight and would increase the overall rigidity of vehicle.

Figure 4: Design Alternative 2

3.4 Design Alternate III

Our third option was not much of a consideration as the only reason we would resort to using fiberglass rather than carbon fiber would be a disruption in our budget. This is very unlikely since a budget cut would most likely affect our design procedure rather than our materials. Nonetheless, we must consider even the most unlikely situations so that we are not caught off guard if these were to happen. Fiberglass, although it is much less costly than carbon fiber, it is a heavier, harder to work, and even dangerous material due to its very explosive failure of fracturing.

Figure 5: Design Alternative 3

3.5 Feasibility Assessment

Some of these alternatives are very feasible. Design alternate III and I are very simple and implements the usage of cheaper materials for its fabrication. Due to the fact that the problem was approached as a mean for the senior design class, an extra level of complexity is going to be applied. The proposed design will be of a simple yet properly study shape, and the material of usage is going to be carbon fiber. Design alternate II is the least feasible of all three designs. The main reason why this design concept is not going to be applied is due to the fact that SAE-FIU has a limited budget. The development of a monocoque structure for this application will cost approximately $10,000-$15,000 and last year's budget for the whole prototype was around $10,000. Therefore, this design was immediately disregarded. The proposed design will bring that balance of cost-effectiveness to the table. The feasibility for this design is high, but since again the team dealing with a limited budget, for last-resort a change in material selection from carbon fiber to fiber glass or any other type of material might be the case.

3.6 Proposed Design

Our proposed design is going to involve creating sectional carbon fiber parts that will come together to create a formula body that would cover about 80% of the vehicle. This design will allow easier access to key mechanical components and will make it easier to configure different aerodynamic packages that we will add to the main body. It will also allow for other additions like that of our fellow senior design students that are creating the adjustable spoiler for this vehicle.

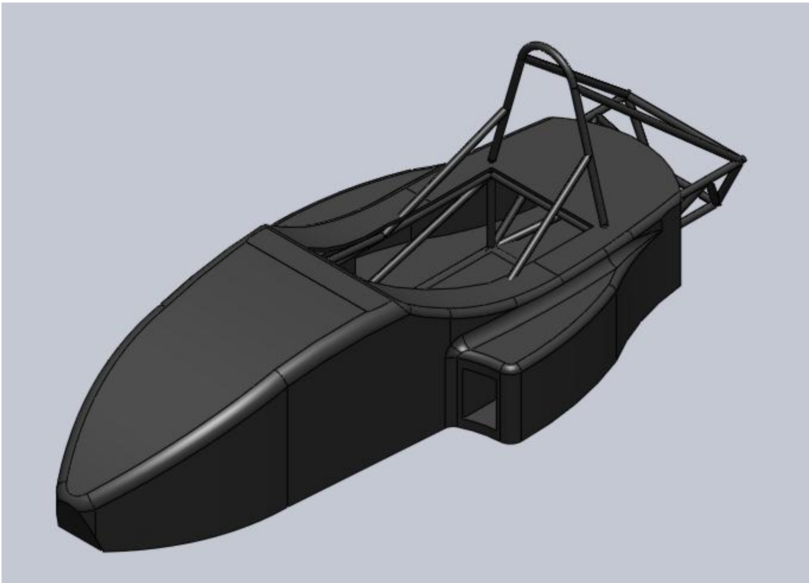

Figure 6: Proposed Design

4. Project Management

4.1 Overview

Since several deliverables have to be turned in during the fall and spring semesters, a key factor for this project will be planning and organization. Also, if the goals and objective set forth for this project wants to be accomplished all the requirements from the senior design class and SAE rules have to be successfully reached in a timely manner. For all of these reasons a timeline, a breakdown of work into tasks and a breakdown of responsibilities were developed.

4.2 Breakdown of Work into Specific Tasks

The Gantt chart shown in Figure 7 aids to act as an organizational tool for the team to have strict deadlines in order to improve the overall organization of the project. The report submissions for the Fall 2012 semester have been included since they represent important milestones that the team needs to accomplish. As the semester develops and the dates for presentations and partial reports for the Spring 2013 semester becomes known, an update to the Gantt chart needs to be made. Also, the beginning of the project is more research-oriented with a strong focus on literature survey. As the project develops, it becomes more of an engineering project and the design of all of the components, as well as testing and manufacture becomes the first priority. Finally a final report will be rendered and the vehicle will go to competition.

4.3 Organization of Work and Timeline

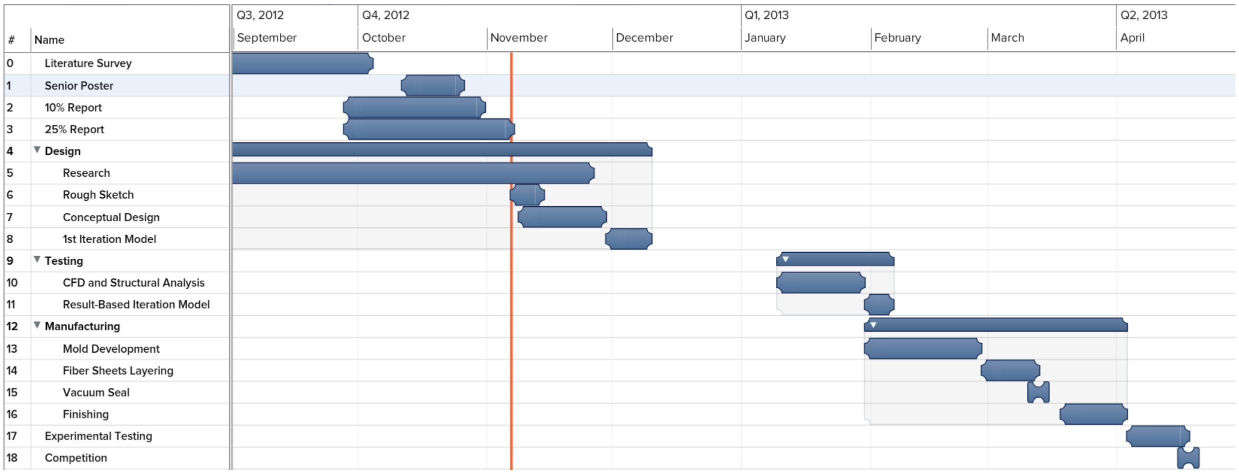

Figure 7: Gantt chart

August-September

- Create a project budget and cost analysis for the total design cost
- Put together a sponsorship proposal that will allow the team to approach multiple companies that will help us monetarily and conceptually.
- Initial designs are analyzed and design elimination begins.

October-November

- Budget is organized and design parameters are prioritized.
- Final design path is chosen and background design begins.
- Conceptual design is put together and theoretically tested.

December-January

- Physical construction of multiple body designs begins.
- Budget is analyzed and finalized.
- Fitting and configuration of complementary equipment is discussed for possible execution soon after.

February-March

- Final design is chosen and constructed.
- Testing, testing and more testing…
- Painting and cosmetic touches are added.

April-May

- Paperwork is put together and refined.
- Presentation and public speaking skills are reviewed in order to prepare for board presentation.
- FSAE competition begins and the car is put to the test against other schools.

4.4 Breakdown of Responsibilities

In order to efficiently achieve the goals and milestones set, the breakdown of responsibilities was done in such a way that relates to the strengths of each team member. Javier Gutierrez will take responsibility of the designing stage, Angel Nuñez of the Manufacture stage and Diego Quintero the analysis stage. Having this distribution as such, it doesn't mean that each team member will do that specific section on its entirety by themselves, It means that the person will have the responsibility to act as a team leader for that section and assign other members their required workload. That way it can be assured that all team members gain the same knowledge and experience. The reports and presentations will be done in conjunction.

Table 2: Breakdown of Responsibilities

Team Member	Design	Manufacture	Analysis	Reports	Presentations
Javier Gutierrez	*			*	*
Angel Nuñez		*		*	*
Diego Quintero			*	*	*

5. Engineering Design and Analysis

5.1 Analytical Analysis

As a design was selected, the body was divided into different sub-components for a more in-depth approach. These features can be categorized separately as they are governed by different physical principles. The three main components on the racecar are: Body, Side Pods and Ground Effects.

5.1.1 Body Analysis

In racecar engineering, the main two reasons for the particular shape of the body is slice through the air to reduce resistance and to channel the air and create downforce in specific areas. When used correctly, downforce can directly increase the grip of the tires by applying a vertical force.

The Bernoulli Principle can explain the main effect during downforce. This states that a fluid flows around an object at different speeds. The slower moving fluid will create more pressure than the faster moving fluid on an object. The object will then be forced toward the faster moving fluid. These same methods are used in airplane wings to create lift, by creating a pressure drop in the opposite direction. The direct relationship between curved streamlines and pressure differences was derived by Leonard Euler, which states [5]:

$$\frac{dp}{dR} = \rho \frac{v^2}{R}$$

where R is the radius of curvature, p is the pressure, ρ is the density, and v is the velocity. This formula shows that higher velocities and tighter curvatures create larger pressure differentials.

The design of a racecar's body is designed with this principle in mind. This characteristic is mostly used by wings or airfoils, which are usually placed above the wheels to increase grip.

5.1.2 Side Pod Analysis

The air that passed through the nose is then guided to the side of the car by the splitter located just in front of the side pods. The design of side pod can smoothen out the airflow that has been disturbed by front wheels. It separates the flow into two parts; one is directed into the side pod and other is diverted outside. The air passes through the smooth surface of side pod with minimum drag force. It acts to block the airflow from hitting the rear wheels. The direct hit of air on the wheels may create turbulent which disturbs the whole airflow dynamics on the real part of car. The design makes the air to flows in steadier ways. Besides, the installation of side pods increases the safety of the car, it is able to stabilize the whole body of car and protects driver from side collisions. Air directed into the side pod is also used to cool the engine; it acts like a radiator intake. This design is essential to enhance the performance of engine and protect it from overheating [5].

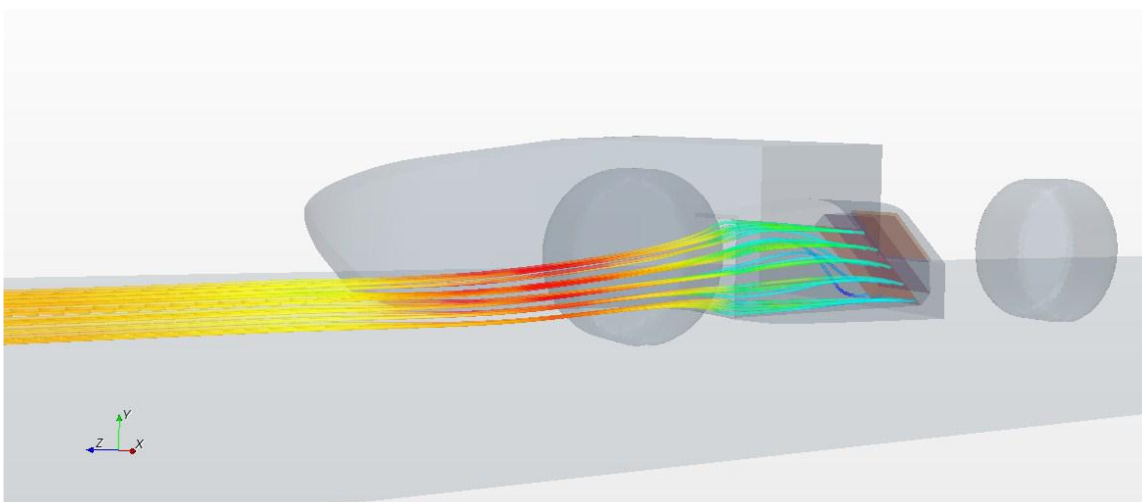

Figure 8: Air Flow

5.1.3 Ground Effect Analysis

The term "ground effects" was first introduced in Formula 1 racing. Engineers needed to figure it out a way to make the vehicle go faster without modifying the power of the engine due to rules restrictions [3].

The ground effects general concept is relatively simple. Formula 1 engineers wanted to obtain a low-pressure area beneath the car that when combined with the high pressure above it, would create an amazing force pushing the car downwards. An under body diffuser, was the proposed solution, acting as inverted airfoils, allowed the air that entered the car's underbody to accelerate through a narrow mid-section between the car and the ground, therefore creating a low-pressure section. However, this previously discussed design was not able to produce the desired ground effects therefore sealing its underside section. While initially built out of brushes or plastic, the best solution was to create some skirts running from the side of the body to maintain this pressure drop under the floor and that way the ground effects will be maximized [3].

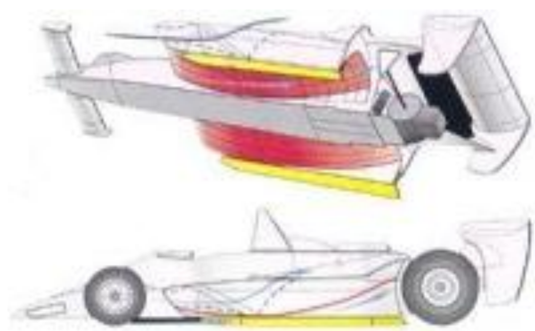

Figure 9: Ground Effects

5.2 Structural Design

Prior to designing the body of the car, one has to understand the forces exerted on in for optimal structural integrity. Racecars are subjected to extreme forces due to high cornering, acceleration and drag. Taking into consideration forces like longitudinal torsion, vertical bending, lateral bending and horizontal lozenging, is crucial since these forces will directly affect the performance of the racecar.

The primary value that determines the performance of a racecar's frame is stiffness. When forces are being applied in opposite corners of the vehicle, the frame is subjected to torsional loads. Racecar frames can deform when subjected to these torsional loads, directly affecting the handling and performance of the car. Stiffness can be described as the resistance of the frame to these torsional forces. Stiffness is usually measured in foot-pounds per degree, and in a single degree of freedom follows the following governing equation [5]:

$$k = \frac{F}{\delta}$$

Where F is the force applied to the particular body and δ is the displacement produced by the force.

Other forces considered such as lateral and vertical bending follow the same principles. Vertical bending on the frame is usually produced by the weight of the driver and other components such as the engine, transmission, etc. In the case of lateral bending, it usually occurs when the vehicle is subjected to forces due to cornering. Other factors that create lateral bending are road camber and side wind loads. All these factors have to be considered during the preliminary design stages of the frame, as torsion stiffness is generally very important, as total cornering traction is a function of lateral weight transfer.

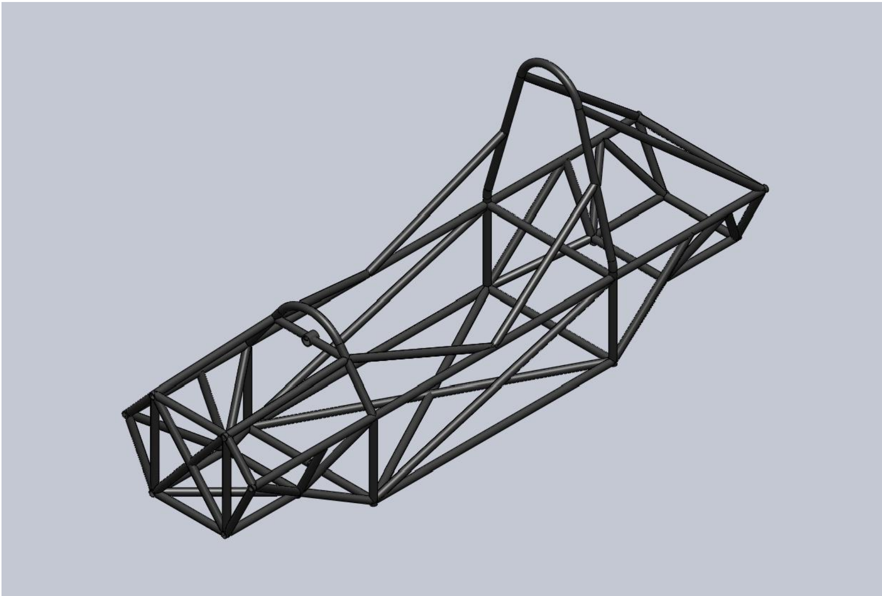

Figure 10: Structural Design

The figure above shows the tubular space frame designed for the FSAE body. This design had to comply with rigorous safety and performance rules stated by SAE. Factors such as cockpit clearance, overall length and height, and driver dimensions, had to be considered on top of the torsional loads previously discussed.

5.3 Cost Analysis

The first step towards producing a carbon fiber body is to create a mold for it. The team decided that using foam and a 3-D printer would produce the best mold needed for this project. After the first mold is created it is topped with a RTV rubber compound. This will make a smooth surface where the carbon fiber, resin and hardener will be laid but not before using a mold release agent on the surface. The next set of materials used includes a perforated release film that is used to pick up any extra resin left over, with conjunction with a Nylon bagging film. This film is sealed with sealing tape and then air vacuumed to allow the resin to cure. A smoothing wax is then applied to the raw product and with some slight sanding and waxing there will be a glossy and glamorous look that carbon fiber produces. There are some costs that need to be accounted for the sake of engineering budgeting but will not be accounted for in our student budget. Some of these cost include the man-hours used for the project, the machinery used will have to be appraised, professional advising and consultation expenses. The following chart will show this cost analysis in more depth.

Table 3: Cost Analysis [7]

Extra Expenses	Amount of Resources	Cost per Resource	Cost Predictions
Man Hours	180 Hrs.	$45	$8,100
Air Compressor	1	$250	$250
3-D printer	1	$2,500	$2,500
Hand Tools	1	$200	$200
Proffesional Consulting	4 Hrs.	$80	$320
		Total Extra Expense	**$11,370**

Table 3 shown above illustrates the extensive extra expensive this project would obscure if we didn't have access to the machinery and Professors of FIU.

Table 4: Current Hours Spent

Team Member	**Human Hours**
Javier Gutierrez	15
Angel Nuñez	14
Diego Quintero	16
Total	**45**

Table 4 shown above illustrates the current human hours spent on this project

6. Prototype Construction

6.1 Description of Prototype

This final prototype consists in of a low weight high strength exoskeleton body for the FSAE team at the Florida International University. The design also has to be pleasing to the eye since it will be judged in competition by a group of engineers from all over the world. For these reasons we decided to take the path of carbon fiber composite, rather than using fiberglass or even aluminum which will increase weight and compromise strength. The research has shown than unlike earlier days, the carbon fiber composite is much more affordable now, and the curing process is close to that of fiberglass. First we will need to create a mold for the body, in our case with the complexity that a cockpit brings we will have to mold two halves and later join them together. The a series of curing processes explained in other sections will take place using carbon fiber sheets and curing them with epoxy resin. The next step will be to cut off excess material and wax the surface to get a shinny, eye appealing final shell. The hinges and frame connection point are then installed onto the body as well as any additional parts such as side pods, spoilers and other elements of that nature. Finally the body will be painted to the FSAE teams' specifications and connected to their vehicles frame.

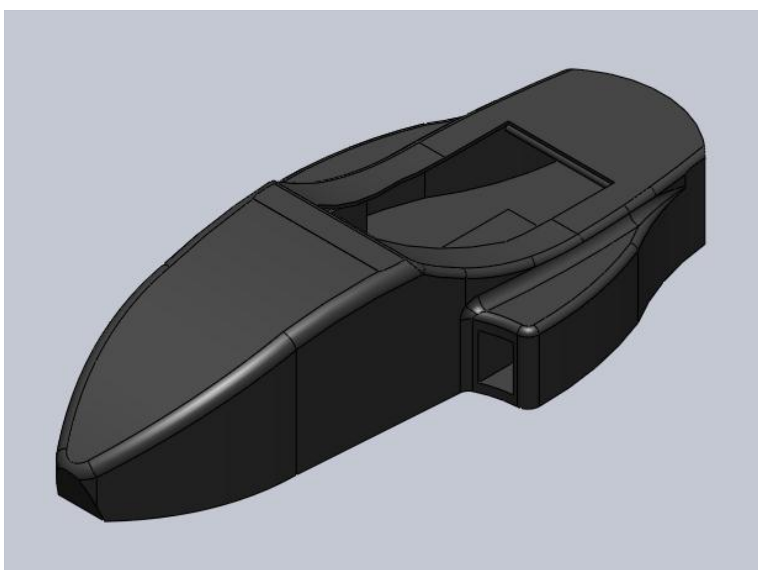

Figure 11: Prototype

6.2 Prototype Cost Analysis

The prototype materials mentioned below have been budgeted in order to create an accurate sponsorship proposal. Although the man power, machinery and professional consulting is provided by the team and professors of Florida International University a detailed budget had to be formatted since our budget as student is reasonably low. A very effective budgeting building procedure had to be placed in order to create a low cost high quality product. As the following chart explains;

Table 5: Prototype Cost Analysis [6]

Materials Used	Unit sold in	Cost per Unit	Quantity	Total Price
Carbon Fiber Sheets	50 in X 1yd	$39.60 per Yd	32 yds	$1,267.20
Epoxy Resin	gallons	$40.2 per gal	10 gal	$402
Polimer Resin	gallons	$40.2 per gal	10 gal	$402
Composite Hardener	gallons	$40.2 per gal	6.6 gal	$265.36
Polyurethane RTV mold rubber	gallons	$40.3 per gal	10 gal	$430
PVA #10 Mold Release	gallons	$15 per gal	6 gal	$90
Nylon Bagging Film	50 in X 1yd	$4.70 per yd	32 yds	$150
Perforated Release Film	50 in X 1yd	$5.60 per yd	32 yds	$179.20
Sealant Tape	rolls	$6.50 per roll	8 rolls	$52
Al. Vacuum Bag Connector	unit	$29.99 per unit	6 units	$180
Styrene	gallons	$20 per gal	4 gal	$80
Mixing Container Kit	unit	$45 per kit	2 kits	$90
Application Brush Kit	unit	$28 per kit	2 kits	$56
Application Rollers	Unit	$3 per unit	15 units	$45
Utherane Foam	kit	$264 per kit	1 kit	$264
3-D Printing	hourly	$80	12 hrs	$960
			Total Budget	**$4,912.70**

As shown above, the investment of the project will be much more if the extra expenses were added to the budget shared by this student team.

7. Testing and Evaluation

7.1 Overview

Testing for this design will first take place in CAD programs such as SolidWorks, Ansys, etc. There will be major testing components that will be looked at, taking aerodynamic design testing as our priority since the body will have a frame underneath and strength testing is not as crucial. Through the SolidWorks FlowExpress feature will be able to simulate the aerodynamic features of the vehicle at different speed and with different ground effect components and accessories (Spoiler, ground tunnels, side pods, etc.). Our final and most important design testing will come from an actual wind tunnel machine. The physical vehicle will be placed inside this machine and tested a velocity much higher than the assumed maximum speed of the vehicle to ensure durability and performance. Before and after every test run there will be a visual inspection of all the components of the vehicle to check for any signs of structural failure.

8. Conclusion

8.1 Conclusion and Discussion

The overall design process has been closely discussed and the team has concluded that as long as we stay on task with our timeline we will be able to construct a field-leading product. This body is expected to boost the chances for this university's chances of doing great in the competition. Our biggest task will be to exercise the molding techniques needed to create quality caliber carbon fiber construction. With the right mindset and determination this team is looking to challenge itself but more importantly we are looking to challenge the competition but like everything worth doing it will not come without hard work and discipline on our part.

Figure 12: Desired Design

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10. Appendices

Appendix A. Formula SAE Body Rule Book

FORMULA SAE SAE International

ARTICLE 2: GENERAL DESIGN REQUIREMENTS

T2.1 Vehicle Configuration

The vehicle must be open-wheeled and open-cockpit (a formula style body) with four (4) wheels that are not in a straight line.

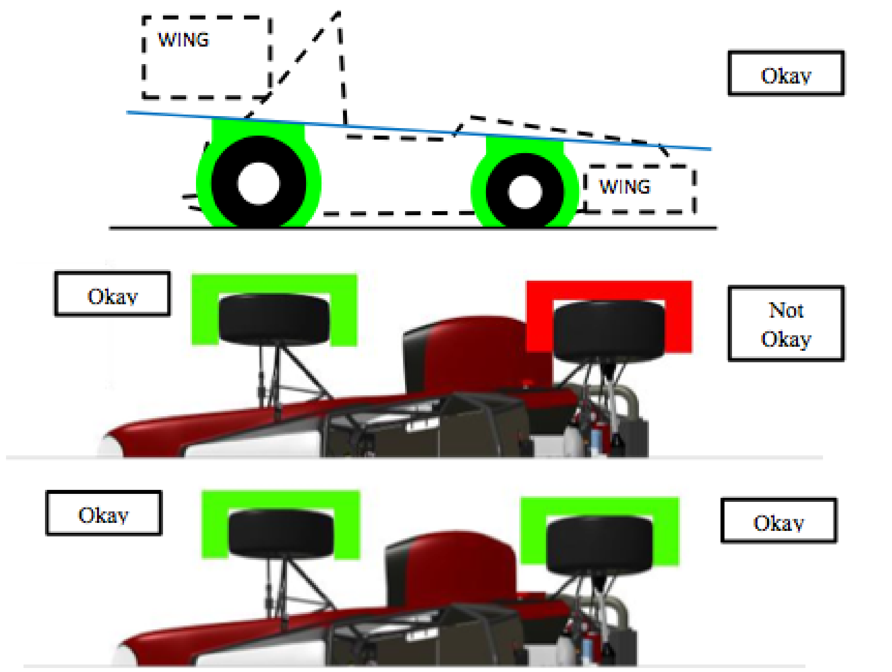
Definition of "Open Wheel" – Open Wheel vehicles must satisfy all of the following criteria:

1) *The top 180 degrees of the wheels/tires must be unobstructed when viewed 68.6mm (2.7 inches) above the plane formed by the tops of the front and rear tires.*

2) *The wheels/tires must be unobstructed when viewed from the side.*

3) *No part of the vehicle may enter a keep-out-zone defined as a circle 68.6mm (2.7 inches) larger radially than the outside diameter of the tire with the tires steered straight ahead with a 77kg (170 pound) driver seated in the normal driving position. The inner sidewall of the tire (vehicle side) is not included in this assessment. See the figure below.*

Note: The dry tires will be used for all inspections. For technical inspection the keep-out-zone may be inspected by use of a tennis ball fastened to the end of a stick. The ball will have the 68.6mm (2.7 inches) diameter and must be able to be freely moved around the outside of the tire without contacting any portion of the car other than the tire.



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 2013 Formula SAE Rules

T2.2 Bodywork
There must be no openings through the bodywork into the driver compartment from the front of the vehicle back to the roll bar main hoop or firewall other than that required for the cockpit opening. Minimal openings around the front suspension components are allowed.

T2.3 Wheelbase
The car must have a wheelbase of at least 1525 mm (60 inches). The wheelbase is measured from the center of ground contact of the front and rear tires with the wheels pointed straight ahead.

T2.4 Vehicle Track
The smaller track of the vehicle (front or rear) must be no less than 75% of the larger track.

T2.5 Visible Access
All items on the Inspection Form must be clearly visible to the technical inspectors without using instruments such as endoscopes or mirrors. Visible access can be provided by removing body panels or by providing removable access panels.

ARTICLE 3: DRIVER'S CELL

T3.1 Vehicle Structure - 2 Options
Teams may, at their option, design their vehicle to comply with either of two (2) separate, but related, sets of requirements and restrictions. Specifically, teams may elect to comply with **either**:

(1) Part T Article 3 "Drivers Cell" as defined below **or**
(2) Part AF "Alternate Frame Rules" as found in Appendix AF and the FSAE website.

T3.1.1 Notice Requirement – Teams planning to use the Part AF "Alternate Frame Rules" must notify the Rules committee of their intent by the date posted on the SAE Website. The instructions for notification appear in Part AF. The Rules Committee will review the submission and notify the team if the request is granted. Part AF has significant analytical requirements and as it is still in development this application process will insure that the Committee can handle the workload and give teams the support they may require to show certification as well as insure the teams have the technical capability to analyze their design and prove compliance with the AF Rules.

T3.1.2 Alternate Frame Rules use requires the submission of the "Structural Requirements Certification Form (SRCF)" which **supersedes** the "Structural Equivalency Spreadsheet".

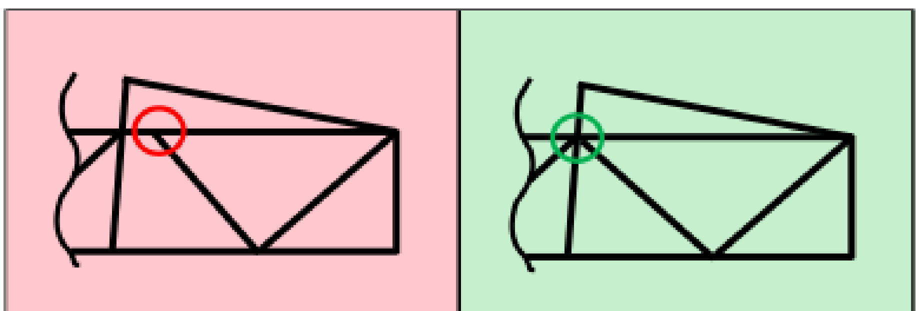
Teams submitting a Structural Requirements Certification Form (SRCF) **do not** have to submit a Structural Equivalency Spreadsheet (SES).

T3.2 General 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.

T3.3 Definitions
The following definitions apply throughout the Rules document:

- Main Hoop - A roll bar located alongside or just behind the driver's torso.
- Front Hoop - A roll bar located above the driver's legs, in proximity to the steering wheel.
- Roll Hoops – Both the Front Hoop and the Main Hoop are classified as "Roll Hoops"

- Roll Hoop Bracing Supports – The structure from the lower end of the Roll Hoop Bracing back to the Roll Hoop(s).
- Frame Member - A minimum representative single piece of uncut, continuous tubing.
- 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.
- Primary Structure – The Primary Structure is comprised of the following Frame components: 1) Main Hoop, 2) Front Hoop, 3) Roll Hoop Braces and Supports, 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.
- Major Structure of the Frame – The portion of the Frame that lies within the envelope defined by the Primary Structure. The upper portion of the Main Hoop and the Main Hoop *Bracing* are not included in defining this envelope.
- 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.
- Impact Attenuator – A deformable, energy absorbing device located forward of the Front Bulkhead.
- Side Impact Zone – The area of the side of the car extending from the top of the floor to 350 mm (13.8 inches) above the ground and from the Front Hoop back to the Main Hoop.
- Node-to-node triangulation – An arrangement of frame members projected onto a plane, where a co-planar load applied in any direction, at any node, results in only tensile or compressive forces in the frame members. This is also what is meant by "properly triangulated".



Not OK	Properly Triangulated

T3.4 Minimum Material Requirements

T3.4.1 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 Rules T3.4, T3.5, T3.6 and T3.7.

ITEM or APPLICATION	OUTSIDE *DIMENSION* X WALL THICKNESS
Main & Front Hoops, Shoulder Harness Mounting Bar	Round 1.0 inch (25.4 mm) x 0.095 inch (2.4 mm) or Round 25.0 mm x 2.50 mm metric
Side Impact Structure, Front Bulkhead, Roll Hoop Bracing, Driver's Restraint Harness Attachment (except as noted above) EV: Accumulator Protection Structure	Round 1.0 inch (25.4 mm) x 0.065 inch (1.65 mm) or Round 25.0 mm x 1.75 mm metric or Round 25.4 mm x 1.60 mm metric or Square 1.00 inch x 1.00 inch x 0.049 inch or Square 25.0 mm x 25.0 mm x 1.25 mm metric or Square 26.0 mm x 26.0 mm x 1.2 mm metric
Front Bulkhead Support, Main Hoop Bracing Supports EV: Tractive System Components	Round 1.0 inch (25.4 mm) x 0.049 inch (1.25 mm) or Round 25.0 mm x 1.5 mm metric or Round 26.0 mm x 1.2 mm metric

Note 1: The use of alloy steel does not allow the wall thickness to be thinner than that used for mild steel.

Note 2: For a specific application:
- Using tubing of the specified outside diameter but with greater wall thickness,
- **Or** of the specified wall thickness and a greater outside diameter,
- **Or** replacing round tubing with square tubing of the same or larger size to those listed above,

Are NOT rules deviation requiring approval.

Note 3: Except for inspection holes, any holes drilled in any regulated tubing require the submission of an SES.

Note 4: Baseline steel properties used for calculations to be submitted in an SES may not be lower than the following:

Bending and buckling strength calculations:
Young's Modulus (E) = 200 GPa (29,000 ksi)
Yield Strength (Sy) = 305 MPa (44.2 ksi)
Ultimate Strength (Su) = 365 MPa (52.9 ksi)

Welded monocoque attachment points or welded tube joint calculations:
Yield Strength (Sy) = 180 MPa (26ksi)
Ultimate Strength (Su) = 300 MPa (43.5 ksi)

Where welded tubing reinforcements are required (e.g. inserts for bolt holes or material to support suspension cutouts) the tubing **must** retain the baseline cold rolled strength while using the welded strength for the additional reinforcement material.

T3.5 Alternative Tubing and Material - General

T3.5.1 Alternative tubing geometry and/or materials may be used except that the Main Roll Hoop and Main Roll Hoop Bracing must be made from steel, i.e. the use of aluminum or titanium tubing or composites for these components is prohibited.

T3.5.2 Titanium or magnesium on which welding has been utilized may not be used for any part of the Primary Structure. This includes the attachment of brackets to the tubing or the attachment of the tubing to other components.

T3.5.3 If a team chooses to use alternative tubing and/or materials they must submit a "Structural Equivalency Spreadsheet" per Rule T3.9. The teams must submit calculations for the material they have chosen, demonstrating equivalence to the minimum requirements found in Section T3.4.1 for yield and ultimate strengths in bending, buckling and tension, for buckling modulus and for energy dissipation. (The Buckling Modulus is defined as EI, where, E = modulus of Elasticity, and I = area moment of inertia about the weakest axis.)

T3.5.4 Tubing cannot be of thinner wall thickness than listed in T3.6 or T3.7.

T3.5.5 If a bent tube is used anywhere in the primary structure, other than the front and main roll hoops, an additional tube must be attached to support it. The attachment point must be the position along the tube where it deviates farthest from a straight line connecting both ends. The support tube must have the same diameter and thickness as the bent tube. The support tube must terminate at a node of the chassis.

T3.5.6 Any chassis design that is a hybrid of the baseline and monocoque rules, must meet all relevant rules requirements, e.g. a sandwich panel side impact structure in a tube frame chassis must meet the requirements of rules T3.28, T3.29, T3.30, T3.31 and T3.34.

Note: It is allowable for the properties of tubes and laminates to be combined to prove equivalence. E.g. in a side-impact structure consisting of one tube as per T3.4 and a laminate panel, the panel only needs to be equivalent to two side-impact tubes.

T3.6 Alternative Steel Tubing

Minimum Wall Thickness Allowed:

MATERIAL & APPLICATION	MINIMUM WALL THICKNESS
Steel Tubing for Front and Main Roll Hoops, and Shoulder Harness Mounting Bar	2.0 mm (0.079 inch)
Steel Tubing for Roll Hoop Bracing, Roll Hoop Bracing Supports, Side Impact Structure, Front Bulkhead, Front Bulkhead Support, Driver's Harness Attachment (except as noted above), Protection of HV accumulators, and protection of HV tractive systems	1.2 mm (0.047 inch)

Note 1: 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.

Note 2: To maintain EI with a thinner wall thickness than specified in T3.4.1, the outside diameter MUST be increased.

Note 3: To maintain the equivalent yield and ultimate tensile strength the same cross-sectional area of steel as the baseline tubing specified in T3.4.1 **MUST** be maintained.

T3.7 Aluminum Tubing Requirements

T3.7.1 Minimum Wall Thickness: Aluminum Tubing 3.0 mm (0.118 inch)

T3.7.2 The equivalent yield strength must be considered in the "as-welded" condition, (Reference: WELDING ALUMINUM (latest Edition) by the Aluminum Association, or THE WELDING HANDBOOK, Volume 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.

T3.7.3 Should aluminum 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.

T3.8 Composite Materials

T3.8.1 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, and 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 T3.4.1. Equivalency calculations must be submitted for energy dissipation, yield and ultimate strengths in bending, buckling, and tension. Submit the completed "Structural Equivalency Spreadsheet" per Section T3.9.

T3.8.2 Composite materials are not allowed for the Main Hoop or the Front Hoop.

T3.9 Structural Documentation – SES or SRCF Submission

All equivalency calculations must prove equivalency relative to steel grade SAE/AISI 1010.

T3.9.1 All teams MUST submit either a STRUCTURAL EQUIVALENCY SPREADSHEET (SES) or a STRUCTURAL REQUIREMENTS CERTIFICATION FORM (SCRF).

Teams complying with the Part T Article 3 "Drivers Cell" rules MUST submit a Structural Equivalence Spreadsheet (SES), even if they are NOT planning to use alternative materials or tubing sizes to those specified in T3.4.1 Baseline Steel Materials.

Teams following the Part AF "Alternate Frame Rules" MUST submit a Structural Requirements Certification Form (SRCF). See Rule AF2.

T3.9.2 The use of alternative materials or tubing sizes to those specified in T3.4.1 "Baseline Steel Material," is allowed, provided they have been judged by a technical review to have equal or superior properties to those specified in T3.4.1.

T3.9.3 Approval of alternative material or tubing sizes will be based upon the engineering judgment and experience of the chief technical inspector or his appointee.

T3.9.4 The technical review is initiated by completing the "Structural Equivalency Spreadsheet" (SES) using the format given in Appendix T-1.

T3.9.5 Structural Equivalency Spreadsheet – Submission

a. Address – SESs must be submitted to the officials at the competition you are entering at the address shown in the Appendix or indicated on the competition website.

b. Due Date – SESs must be submitted no later than the date indicated on the competition website. Teams that submit their Structural Equivalency Spreadsheet after the due date for the competition will be penalized 10 points per day up to a maximum of 50 points, which will be taken off the team's Total Score.

c. Acknowledgement – North America competitions – SESs submitted for vehicles entered into competitions held in North America will be acknowledged automatically by the fsaeonline website.

Do Not Resubmit SES's unless instructed to do so.

T3.9.6 Vehicles completed under an approved SES must be fabricated in accordance with the materials and processes described in the SES.

T3.9.7 Teams must bring a copy of the approved SES with them to Technical Inspection.

Comment - The resubmission of an SES that was written and submitted for a competition in a previous year is strongly discouraged. Each team is expected to perform their own tests and to submit SESs based on their original work. Understanding the engineering that justifies the equivalency is essential to discussing your work with the officials.

T3.10 Main and Front Roll Hoops – General Requirements

T3.10.1 The driver's head and hands must not contact the ground in any rollover attitude.

T3.10.2 The Frame must include both a Main Hoop and a Front Hoop as shown in Figure 1.

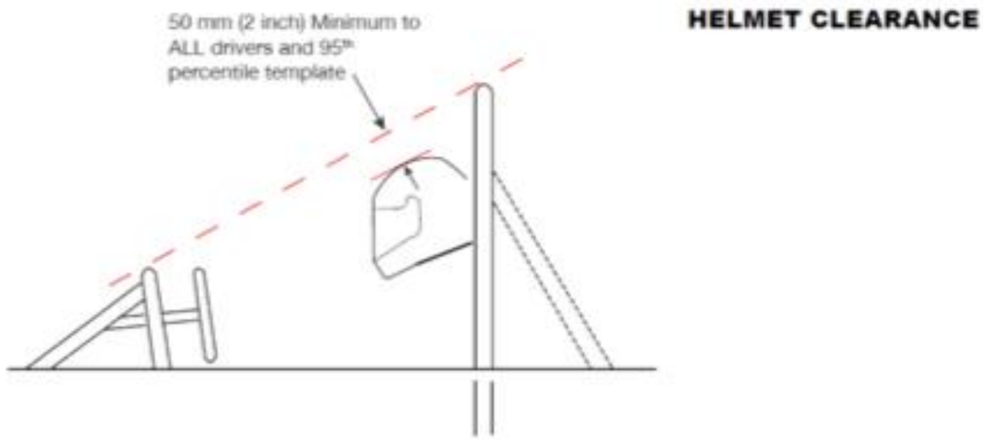


FIGURE 1a

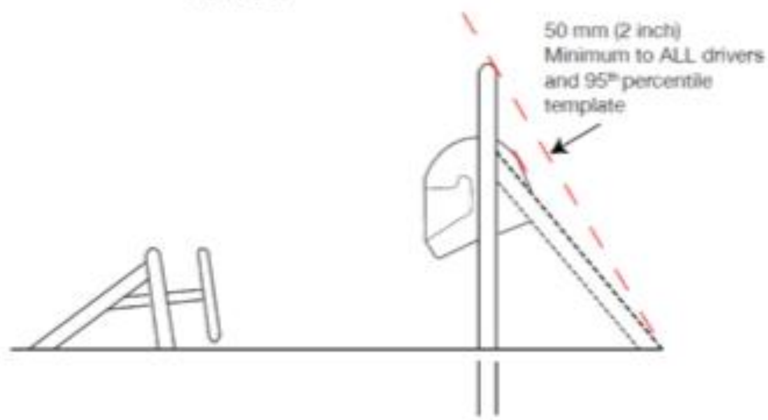


FIGURE 1b

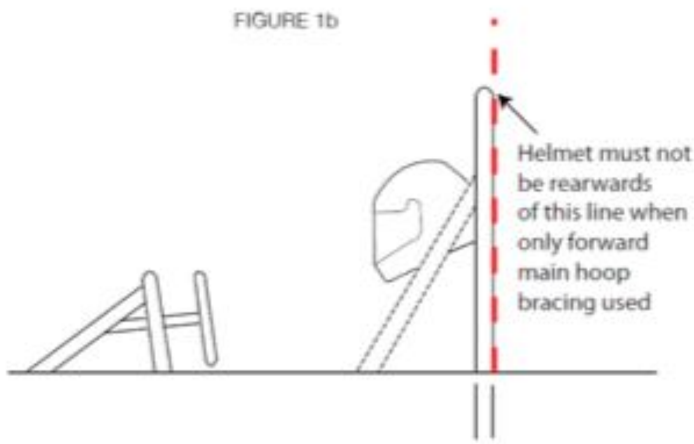


FIGURE 1c

T3.10.3 When seated normally and restrained by the Driver's Restraint System, the helmet of a 95th percentile male (anthropometrical data) and all of the team's drivers must:

a. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the top of the front hoop. (Figure 1a)
b. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing if the bracing extends rearwards. (Figure 1b)
c. Be no further rearwards than the rear surface of the main hoop if the main hoop bracing extends forwards. (Figure 1c)

95th Percentile Male Template Dimensions

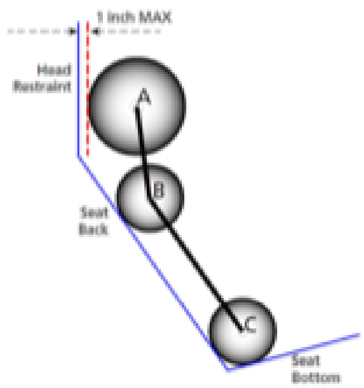
A two dimensional template used to represent the 95th percentile male is made to the following dimensions:

- 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.

T3.10.4 The 95th percentile male template will be positioned as follows: (See Figure 2.)

- The seat will be adjusted to the rearmost position,
- The pedals will be placed in the most forward position.
- *The bottom 200 mm circle will be placed on the seat bottom such that the distance between the center of this circle and the rearmost face of the pedals is no less than 915 mm (36 inches).*
- The middle 200 mm circle, representing the shoulders, will be positioned on the seat back.
- The upper 300 mm circle will be positioned no more than 25.4 mm (1 inch) away from the head restraint (i.e. where the driver's helmet would normally be located while driving).

"Percy" – 95th Percentile Male with Helmet



Circle A = Head with helmet – 300 mm diameter
Circle B = Shoulders – 200 mm diameter
Circle C = Hips and buttocks – 200 mm diameter

Line A-B = 280 mm from centerpoint to centerpoint
Line B-C = 490 mm from centerpoint to centerpoint

FIGURE 2

T3.10.5 If the requirements of T3.10.4 are not met with the 95th percentile male template, the car will NOT receive a Technical Inspection Sticker and will not be allowed to compete in the dynamic events.

T3.10.6 Drivers who do not meet the helmet clearance requirements of T3.10.3 will not be allowed to drive in the competition.

T3.10.7 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.

T3.10.8 The Main Hoop and Front Hoop must be securely integrated into the Primary Structure using gussets and/or tube triangulation.

T3.11 Main Hoop

T3.11.1 The Main Hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing per Rule T3.4.1.

T3.11.2 The use of aluminum alloys, titanium alloys or composite materials for the Main Hoop is prohibited.

T3.11.3 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.

T3.11.4 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 ten degrees (10°) of the vertical.

T3.11.5 In the side view of the vehicle, any bends in the Main Roll Hoop above its attachment point to the Major Structure of the Frame must be braced to a node of the Main Hoop Bracing Support structure with tubing meeting the requirements of Roll Hoop Bracing as per Rule T3.4.1.

T3.11.6 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.

T3.12 Front Hoop

T3.12.1 The Front Hoop must be constructed of closed section metal tubing per Rule T3.4.1.

T3.12.2 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.

T3.12.3 With proper gusseting and/or triangulation, it is permissible to fabricate the Front Hoop from more than one piece of tubing.

T3.12.4 The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position.

T3.12.5 The Front Hoop must be no more than 250 mms (9.8 inches) forward of the steering wheel. This distance shall be measured horizontally, on the vehicle centerline, from the rear surface of the Front Hoop to the forward most surface of the steering wheel rim with the steering in the straight-ahead position.

T3.12.6 In side view, no part of the Front Hoop can be inclined at more than twenty degrees (20°) from the vertical.

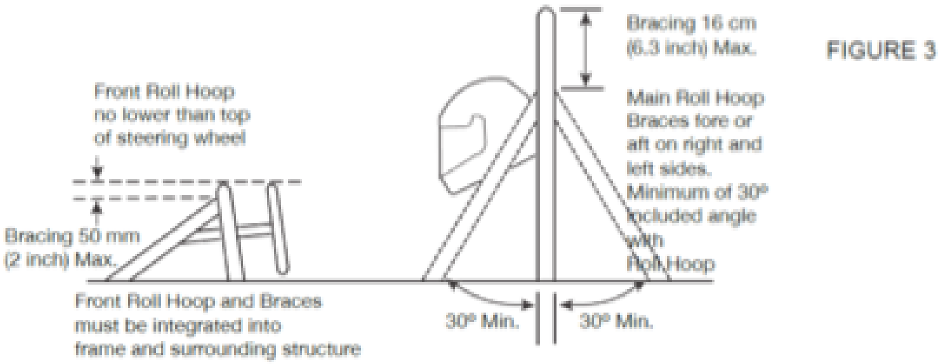
T3.13 Main Hoop Bracing

T3.13.1 Main Hoop braces must be constructed of closed section steel tubing per Rule T3.4.1.

T3.13.2 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.

T3.13.3 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.

T3.13.4 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 thirty degrees (30°). See Figure 3.



T3.13.5 The Main Hoop braces must be straight, i.e. without any bends.

T3.13.6 The attachment of the Main Hoop braces must be capable of transmitting all loads from the Main Hoop into the Major Structure of the Frame without failing. From the lower end of the braces there must be a properly triangulated structure back to the lowest part of the Main Hoop and the node at which the upper side impact tube meets the Main Hoop. This structure must meet the minimum requirements for Main Hoop Bracing Supports (see Rule T3.4) or an SES approved alternative. Bracing loads must not be fed solely into the engine, transmission or differential, or through suspension components.

T3.13.7 If any item which is outside the envelope of the Primary Structure is attached to the Main Hoop braces, then additional bracing must be added to prevent bending loads in the braces in any rollover attitude.

T3.14 Front Hoop Bracing

T3.14.1 Front Hoop braces must be constructed of material per Rule T3.4.1.

T3.14.2 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.

T3.14.3 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.

T3.14.4 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. See Figure 3.

T3.14.5 If the Front Hoop leans rearwards by more than ten degrees (10°) from the vertical, it must be supported by additional bracing to the rear. This bracing must be constructed of material per Rule T3.4.1.

T3.15 Other Bracing Requirements

Where the braces are not welded to steel Frame Members, the braces must be securely attached to the Frame using 8 mm Metric Grade 8.8 (5/16 in SAE 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.

T3.16 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.

T3.17 Mechanically Attached Roll Hoop Bracing

T3.17.1 Roll Hoop bracing may be mechanically attached.

T3.17.2 Any non-permanent joint at either end must be either a double-lug joint as shown in Figures 4 and 5, or a sleeved butt joint as shown in Figure 6.

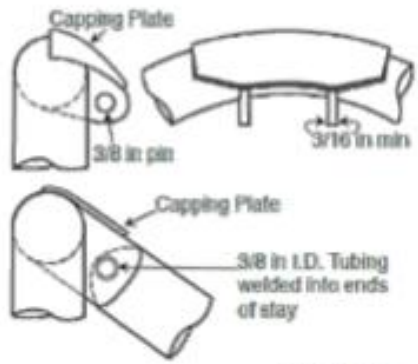


FIGURE 4

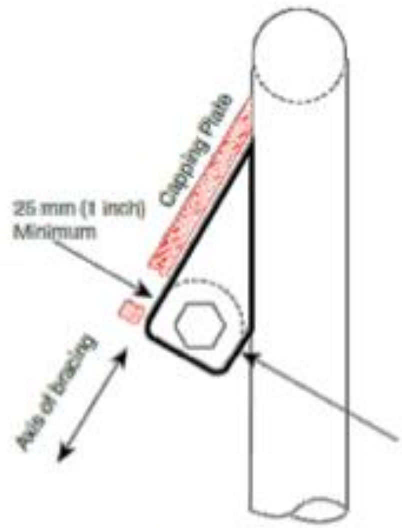


FIGURE 5

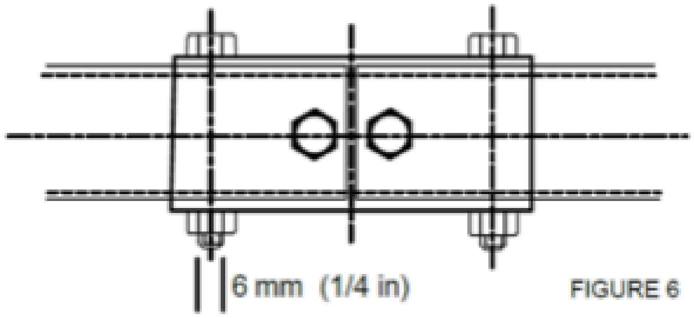


FIGURE 6

T3.17.3 The threaded fasteners used to secure non-permanent joints are considered critical fasteners and must comply with ARTICLE 11:.

T3.17.4 No spherical rod ends are allowed.

T3.17.5 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.

T3.17.6 All double-lug joints, whether fitted at the top or bottom of the tube, must include a capping arrangement (Figures 4 & 5).

T3.17.7 In a double-lug joint the pin or bolt must be 10 mm Metric Grade 9.8 (3/8 in. SAE Grade 8) minimum. The attachment holes in the lugs and in the attached bracing must be a close fit with the pin or bolt.

T3.17.8 For sleeved butt joints (Figure 6), 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 Metric Grade 9.8 (1/4 inch SAE Grade 8) minimum. The holes in the sleeves and tubes must be a close-fit with the bolts.

T3.18 Frontal Impact Structure

T3.18.1 The driver's feet *and legs* must be completely contained within the Major Structure of the Frame. While the driver's feet are touching the pedals, in side and front views no part of the driver's feet *or legs* can extend above or outside of the Major Structure of the Frame.

T3.18.2 Forward of the Front Bulkhead must be an energy-absorbing Impact Attenuator.

T3.19 Bulkhead

T3.19.1 The Front Bulkhead must be constructed of closed section tubing per Rule T3.4.1.

T3.19.2 Except as allowed by T3.19.3, The Front Bulkhead must be located forward of all non-crushable objects, e.g. batteries, master cylinders, hydraulic reservoirs.

T3.19.3 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 is defined by the forward-most surface of the tubing.) Adjustable pedals must be in the forward most position.

T3.20 Front Bulkhead Support

T3.20.1 The Front Bulkhead must be securely integrated into the Frame.

T3.20.2 The Front Bulkhead must be supported back to the Front Roll Hoop by a minimum of three (3) Frame Members on each side of the vehicle with one at the top (within 50.8 mm (2 inches) of its top-most surface), one (1) at the bottom, and one (1) as a diagonal brace to provide triangulation.

T3.20.3 The triangulation must be node-to-node, with triangles being formed by the Front Bulkhead, the diagonal and one of the other two required Front Bulkhead Support Frame Members.

T3.20.4 All the Frame Members of the Front Bulkhead Support system listed above must be constructed of closed section tubing per Section T3.4.1.

T3.21 Impact Attenuator

T3.21.1 The Impact Attenuator must be:

a. Installed forward of the Front Bulkhead.
b. At least 200 mm (7.8 in) long, with its length oriented along the fore/aft axis of the Frame.
c. At least 100 mm (3.9 in) high and 200 mm (7.8 in) wide for a minimum distance of 200 mm (7.8 in) forward of the Front Bulkhead.
d. Such that it cannot penetrate the Front Bulkhead in the event of an impact.
e. Attached securely and directly to the Front Bulkhead and not by being part of non-structural bodywork.

T3.21.2 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.

T3.21.3 The attachment of the Impact Attenuator to a monocoque structure requires an approved "Structural Equivalency Spreadsheet" per Article T3.9 that shows equivalency to a minimum of four (4) 8 mm Grade 8.8 (5/16 inch Grade 5) bolts.

T3.21.4 On all cars, a 1.5 mm (0.060 in) solid steel or 4.0 mm (0.157 in) solid aluminum "anti-intrusion plate" must be integrated into the Impact Attenuator. If the IA plate is bolted to the Front Bulkhead, it must be the same size as the outside dimensions of the Front Bulkhead. If it is welded to the Front Bulkhead, it must extend at least to the centerline of the Front Bulkhead tubing.

T3.21.5 If the anti-intrusion plate is not integral with the frame, i.e. welded, a minimum of four (4) 8 mm Metric Grade 8.8 (5/16 inch SAE Grade 5) bolts must attach the Impact Attenuator to the Front Bulkhead.

T3.21.6 Alternative designs of the anti-intrusion plate required by T3.21.4 that do not comply with the minimum specifications given above require an approved "Structural Equivalency Spreadsheet" per Article T3.9. Equivalency must also be proven for perimeter shear strength of the proposed design.

T3.22 Impact Attenuator Data Requirement

T3.22.1 The team must submit 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 meters/second (23.0 ft/sec), would give an average deceleration of the vehicle not to exceed 20 g's, with a peak deceleration less than or equal to 40 g's. Total energy absorbed must meet or exceed 7350 Joules.

Note: These are the attenuator functional requirements not test requirements. Quasi-static testing is allowed.

T3.22.2 When using acceleration data, the average deceleration must be calculated based on the raw data. The peak deceleration can be assessed based on the raw data, and if peaks above the 40g limit are apparent in the data, it can then be filtered with a Channel Filter Class (CFC) 60 (100 Hz) filter per SAE Recommended Practice J211 "Instrumentation for Impact Test", or a 100 Hz, 3rd order, lowpass Butterworth (-3dB at 100 Hz) filter.

T3.22.3 A schematic of the test method must be supplied along with photos of the attenuator before and after testing.

T3.22.4 The test piece must be presented at technical inspection for comparison to the photographs and the attenuator fitted to the vehicle.

T3.22.5 The test data and calculations must be submitted electronically in Adobe Acrobat ® format (*.pdf file) to the address and by the date provided in the Action Deadlines provided on the relevant competition website. This material must be a single file (text, drawings, data or whatever you are including).

T3.22.6 The Impact Attenuator Data must be named as follows: carnumber_schoolname_competition code_IAD.pdf using the assigned car number, the complete school name and competition code [Example: 087_University of SAE_FSAEM_IAD.pdf]

Competition Codes are listed in Rule A.2.6

T3.22.7 Teams that submit their Impact Attenuator Data Report after the due date will be penalized 10 points per day up to a maximum of 50 points, which will be taken off the team's Total Score.

T3.22.8 Impact Attenuator Reports will be evaluated by the organizers and the evaluations will be passed to the Design Event Captain for consideration in that event.

T3.22.9 During the test, the attenuator must be attached to the anti-intrusion plate using the intended vehicle attachment method. The anti-intrusion plate must be spaced at least 50 mm (2 inches) from any rigid surface. No part of the anti-intrusion plate may permanently deflect more than 25.4 mm (1 inch) beyond the position of the anti-intrusion plate before the test.

Note: The 25.4 mm (1 inch) spacing represents the front bulkhead support and insures that the plate does not intrude excessively into the cockpit

T3.22.10 Dynamic testing (sled, pendulum, drop tower, etc.) of the impact attenuator may only be done at a dedicated test facility. The test facility may be part of the University but must be be supervised by professional staff or University faculty. Teams are not allowed to construct their own dynamic test apparatus. Quasi-static testing may be performed by teams using their universities facilities/equipment, but teams are advised to exercise due care when performing all tests.

T3.22.11 Standard Attenuator – An officially approved impact attenuator can be found at http://www.fsaeonline.com.
Teams may choose to use that style of impact attenuator and need not submit test data with their IAD Report. The other requirements of the IAD Report must still be submitted including, but not limited to, photos of the team's actual attenuator with evidence that it meets the design criteria given on the website.

T3.23 Non-Crushable Objects

T3.23.1 Except as allowed by T3.23.2, all non-crushable objects (e.g. batteries, master cylinders, hydraulic reservoirs) must be rearward of the bulkhead. No non-crushable objects are allowed in the impact attenuator zone.

T3.23.2 The front wing and wing supports may be forward of the Front Bulkhead, but may NOT be located in or pass through the Impact Attenuator. If the wing supports are in front of the Front Bulkhead, the supports must be included in the test of the Impact Attenuator for T3.22.

T3.24 Front Bodywork

T3.24.1 Sharp edges on the forward facing bodywork or other protruding components are prohibited.

T3.24.2 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 forty-five degrees (45°) relative to the forward direction, along the top, sides and bottom of all affected edges.

T3.25 Side Impact Structure for Tube Frame Cars

The Side Impact Structure must meet the requirements listed below.

T3.25.1 The Side Impact Structure for tube frame cars 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 7.

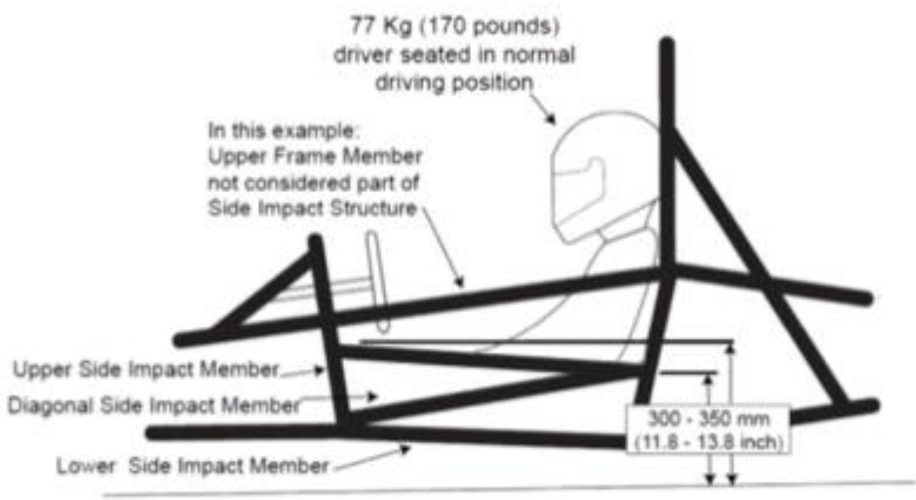


FIGURE 7

T3.25.2 The three (3) required tubular members must be constructed of material per Section T3.4.

T3.25.3 The locations for the three (3) required tubular members are as follows:

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

- 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.
- 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.

T3.25.4 With proper gusseting and/or triangulation, it is permissible to fabricate the Side Impact Structural members from more than one piece of tubing.

T3.25.5 Alternative geometry that does not comply with the minimum requirements given above requires an approved "Structural Equivalency Spreadsheet" per Rule T3.9.

T3.26 Inspection Holes

T3.26.1 The Technical Inspectors may check the compliance of all tubes. This may be done by the use of ultra-sonic testing or by the drilling of inspection holes at the inspector's request.