Development of a Formula SAE Body 100% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.
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.

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Abstract

The team will develop the exoskeleton body structure and its respective ground effects for the Florida International University Formula SAE segment, 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, wind drag resistance, functionality and aesthetics.

The following project is divided into three phases, design (or modeling), analysis and manufacturing. First, on the design stage, a rough hand sketch of the vehicle will be made. Then, a mock-up of the vehicle body and diffuser will be modeled in SolidWorks. Subsequently, several iterations of shapes and sizes will be modeled. Finally, a design is going to be chosen based on the results of phase two, and the final optimization needs to be performed. For phase two, analysis, several body designs are going to be initially tested using SolidWorks as the preferred CAD software due to the convenience of easy availability. Both Finite Elements Analysis (FEA) and Computational Fluid Dynamics (CFD) simulations will be performed to ensure the best performance of the final design chosen based on some previously set goals. For the third stage, manufacturing, first several molds are going to be machined in sections due to the apparatus limitations on ISO-C1, two pound density foam using a CNC routing machine, then sanded, glued and assembled together and then prepared in order to lay the carbon fiber. The preparation consists on doing an initial coat of orange tooling to harden and show imperfections on the molds. Later, the molds will be repaired and leveled with lightweight putty on critical areas following several coats of the tooling gelcoat to harden the gelcoat and left to dry for 24 hours. Later, after sanding the grooves left by the spraying of tooling gelcoat, several coats of sealer, polishing compound, and other release agents will be used to ensure a smooth mold, which translates to a smooth and nice looking part. Subsequently, a HI-UV clear gelcoat is going to be sprayed for shininess and left to dry; the carbon fiber will then be laid onto the molds and saturated with Vinylester resin, the layers will then be removed to reveal the final product. Finally after carefully choosing an optimal design and after the completion of its manufacturing, the physical body will be tested in the FIU WOW wind tunnel.
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 that was built. It was a last minute design and manufacturing mainly because of the lack of human power and knowledge on the matter. 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 much-improved body for the FIU Formula SAE 2012-2013 prototype.

Figure 1: 2011-2012 FIU-FSAE Prototype

The principal limitation will be 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 measures taken 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 a proper body design. By approaching this task as a Senior Design Project, it would allow for a better and more in-depth analysis of the matter 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 [11]. 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 [11]

<table>
<thead>
<tr>
<th>Type of Event</th>
<th>Category</th>
<th>Points</th>
</tr>
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<tbody>
<tr>
<td>Static Events</td>
<td>Presentation</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Engineering Design</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Cost Analysis</td>
<td>100</td>
</tr>
<tr>
<td>Dynamic Events</td>
<td>Acceleration</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Skid-Pad</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Autocross</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Fuel Economy</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Endurance</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td><strong>Total Points</strong></td>
<td><strong>1,000</strong></td>
</tr>
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</table>

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 and its respective ground effects 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 aesthetics. 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 have 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 coefficient 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 Alternative Designs: Platform

3.2.1 Design Alternate I

The team's first 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 full body monocoque body that would eliminate the use of a frame. This of course would eliminate weight and would increase the overall rigidity of vehicle.

![Design Alternative 1](image)

Figure 3: Design Alternative 1

3.2.2 Design Alternate II

The second design path is to build a hybrid monocoque. 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’ space frame design of choice, plus, it’s still a very costly solution.
3.2.3 Design Alternate III

Our third option was not much of a consideration as the only reason we would resort to doing a space frame half-body prototype lays in our budget. This is very unlikely since a budget cut would most likely affect our manufacturing procedure rather than the proposed design. Nonetheless, we must consider even the most unlikely situations so that we are not caught off guard if these were to happen.
3.3 Alternative Designs: Materials

Following the same idea explained on the overview of this section, our main goal is performance and aesthetics of the vehicle to increase the scores given by the competition judges. Therefore, as per our research there are three main types of materials used in teams all from around the world. Aluminum, Fiberglass and Carbon fiber; all of these materials have their pros and cons as per their properties and we didn’t want to get to much into detail with these because it really depends on the team goals and ease of availability. Aluminum was almost immediately discarded, because of how hard it is to shape around an aerodynamic design. If we were to choose this material, we’ll have to go with a more simple design with flat panels shaping the body. 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 fracturing failure, plus it was used on last year’s prototype and it didn’t present the expected characteristics. Therefore, the material of choice will be carbon fiber due to its low density, durability, strength and aesthetics.

3.4 Feasibility Assessment

Some of these alternatives are very feasible. Design alternate III is very simple and could 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 studied shape, and the material of usage is going to be carbon fiber. Design alternate II and I are the least feasible of all three designs. The main reason these design concepts are 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, these designs were 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.
3.5 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 shows the first iteration of the proposed design.

![Figure 6: Proposed Design](image)
4. Engineering Design and Analysis

4.1 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.

4.2 Body Analysis

When designing the body of a racecar, the two main purposes for the geometry of the body are to slice through air as efficient as possible and to channel airstreams to desired locations to produce downforce. When we apply this force in specific locations of the car, we can increase grip on the tires, thus improving performance.

The Bernoulli Principle can further explain the previously mentioned force. As seen in racecar aerodynamics, this principle explains that a fluid flowing around an object can experience changes in pressure. This is due to the fact that a slowing moving fluid will create more pressure than a faster moving object. By controlling the shape of the object, this change of pressure can force the body to a desired 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, \( \rho \) is the density, and \( v \) is the velocity. This formula shows that higher velocities and tighter curvatures create larger pressure differentials.

4.3 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 7: Air Flow](image)

### 4.4 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 8: Ground Effects](image)

Following these principles, figure 9 shows an isometric view of our first iteration conceptual design of the diffuser, which will be located on the bottom of the vehicle. More details about the design approaches used for this part will be explained later on.

![Figure 9: First Iteration Diffuser Design, Isometric View](image)
Figure 10 shows the bottom view of the diffuser conceptual design.

Figure 10: First Iteration Diffuser Design, Bottom View

4.5 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 \( \delta \) 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 11: Structural Design](image)

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. Even though the design of the space frame is out of the scope of our project, we consider necessary and pertinent information anything related to it.
4.6 Cost Analysis

The first step towards producing a carbon fiber body and diffuser is to create a mold for it. The team decided that using foam and a 3-D CNC routing machine would produce the best mold needed for this project. After the first mold is created it is brushed with wood glue and then sprayed with orange tooling gelcoat. This will make a smooth surface where the carbon fiber, resin and hardener will be laid but not before using several mold release agents on the surface. 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>
<thead>
<tr>
<th>Extra Expenses</th>
<th>Amount of Resources</th>
<th>Cost per Resource</th>
<th>Cost Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man Hours</td>
<td>180 Hrs.</td>
<td>$45</td>
<td>$8,100</td>
</tr>
<tr>
<td>Air Compressor</td>
<td>1</td>
<td>$250</td>
<td>$250</td>
</tr>
<tr>
<td>3-D CNC Router</td>
<td>1</td>
<td>$2,500</td>
<td>$2,500</td>
</tr>
<tr>
<td>Hand Tools</td>
<td>1</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Professional</td>
<td>4 Hrs.</td>
<td>$80</td>
<td>$320</td>
</tr>
<tr>
<td>Consulting</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 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 3: Current Hours Spent

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Human Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Javier Gutierrez</td>
<td>77</td>
</tr>
<tr>
<td>Angel Nuñez</td>
<td>60</td>
</tr>
<tr>
<td>Diego Quintero</td>
<td>78</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>215</strong></td>
</tr>
</tbody>
</table>

Table 4 shown above illustrates the current human hours spent on this project.
5. Prototype Construction

5.1 Description of Prototype

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

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.
5.3 Cost Acknowledgements

After hard work and countless hours of communicating over the phone with many companies, we were able to considerably lower our manufacturing cost. Dyplast Products, a polymer foam manufacturer, was kind enough to provide us with all the foam that we needed for our molds. This foam was the material used by the CNC router that the FIU architecture department very kindly and diligently allowed us to work with. As far the composites go, we were not able to get sponsored for them. We did fight hard to get the best prices and student discounts wherever possible, this was able to save us about 40% off all materials cost. The help and insight that our engineering professors as well as professors from other faculties provided us with is not measureable. We really could not have done it without them.

5.4 Revised Cost Analysis

After immense research and countless hours in meetings with field professionals, as well as several donations received from sponsors and all the support from FIU faculty members. We were able to cut the original budget in almost 70% without sacrificing the performance or appearance of the final product. The following table shows the details of the cost of every material used for the construction of the prototype.
### Table 5: Final Cost Analysis

<table>
<thead>
<tr>
<th>Item #</th>
<th>Item</th>
<th>Qty</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>134505</td>
<td>1-1/2 - 50 - 1.28 lb x 99</td>
<td>1</td>
<td>$126.72</td>
<td>$126.72</td>
</tr>
<tr>
<td>125646</td>
<td>1708 - 50 - 1.83 lb x 100</td>
<td>1</td>
<td>$183.00</td>
<td>$183.00</td>
</tr>
<tr>
<td>133373</td>
<td>ISO Resin (gal.)</td>
<td>3</td>
<td>$26.00</td>
<td>$78.00</td>
</tr>
<tr>
<td>126150</td>
<td>Orange Tooling (gal.)</td>
<td>2</td>
<td>$44.00</td>
<td>$88.00</td>
</tr>
<tr>
<td>123984</td>
<td>Mek Catalyst (gal.)</td>
<td>1</td>
<td>$28.50</td>
<td>$28.50</td>
</tr>
<tr>
<td>130718</td>
<td>Carbon Fiber (yd.)</td>
<td>15</td>
<td>$30.00</td>
<td>$450.00</td>
</tr>
<tr>
<td>128848</td>
<td>Vinylester Polyester (gal.)</td>
<td>2</td>
<td>$36.00</td>
<td>$72.00</td>
</tr>
<tr>
<td>125979</td>
<td>Gel Coat (gal.)</td>
<td>1</td>
<td>$37.00</td>
<td>$37.00</td>
</tr>
<tr>
<td>128692</td>
<td>TR-104 Paste Wax</td>
<td>1</td>
<td>$12.50</td>
<td>$12.50</td>
</tr>
<tr>
<td>123942</td>
<td>TR-905 Mold Prep. Cleaner QT</td>
<td>1</td>
<td>$12.00</td>
<td>$12.00</td>
</tr>
<tr>
<td>123929</td>
<td>TR-301 Mold Sealer</td>
<td>1</td>
<td>$15.50</td>
<td>$15.50</td>
</tr>
<tr>
<td>129246</td>
<td>Box Chip Brushes 2&quot;</td>
<td>2</td>
<td>$8.50</td>
<td>$17.00</td>
</tr>
<tr>
<td>129703</td>
<td>Laminating Roller 1/2&quot; X 6&quot;</td>
<td>3</td>
<td>$10.00</td>
<td>$30.00</td>
</tr>
<tr>
<td>133377</td>
<td>9&quot; Naps</td>
<td>1</td>
<td>$5.99</td>
<td>$5.99</td>
</tr>
<tr>
<td>129209</td>
<td>4&quot;Naps</td>
<td>1</td>
<td>$1.73</td>
<td>$1.73</td>
</tr>
<tr>
<td>129427</td>
<td>4&quot; Frame</td>
<td>1</td>
<td>$1.10</td>
<td>$1.10</td>
</tr>
<tr>
<td>129429</td>
<td>9&quot; Frame</td>
<td>1</td>
<td>$1.10</td>
<td>$1.10</td>
</tr>
<tr>
<td>129133</td>
<td>Acetone (gal.)</td>
<td>1</td>
<td>$15.99</td>
<td>$15.99</td>
</tr>
<tr>
<td>128903</td>
<td>L Gloves, Powdered (100ct)</td>
<td>1</td>
<td>$5.99</td>
<td>$5.99</td>
</tr>
<tr>
<td>129003</td>
<td>Respirator</td>
<td>6</td>
<td>$0.30</td>
<td>$1.80</td>
</tr>
<tr>
<td>129539</td>
<td>2&quot; Tape</td>
<td>3</td>
<td>$3.64</td>
<td>$10.92</td>
</tr>
<tr>
<td>129957</td>
<td>Shears, 10&quot; Trimmer</td>
<td>1</td>
<td>$35.00</td>
<td>$35.00</td>
</tr>
</tbody>
</table>

**Total: $1,229.84**
6. Simulations and Evaluation

6.1 Overview

Testing for this design will first take place in the preferred CAD program for the team’s senior design project, SolidWorks. 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 speeds and with different ground effect components and accessories (Spoiler, Diffuser, 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.
6.2 Finite Element Analysis (FEA)

Since the development of the frame of the vehicle is out of the scope of our project, FEA will not be a major factor for our design. Nonetheless, the team wanted to leave this report as a handbook for future FIU-SAE teams. Therefore, we approached the task of designing a monocoque and do the respective simulations that can be later on used as reference for future projects. Illustrated in the figures below are the results from the Finite Element Analysis testing on the second iteration of the proposed body design. NOTE: the space frame underneath the body is not included in test. It'll be treated as a monocoque design. The entire rear face of the body is held rigid during all tests. The simulated loads are placed on the front suspension points on either side of the chassis. Predicting a total weight of 590lbs, the following reacting forces were obtained for a 40:60 weight distribution ratio vehicle:

<table>
<thead>
<tr>
<th>Fixture</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-1 &lt;Hybrid_Monocoque&gt; on 1 Face(s) fixed.</td>
<td></td>
</tr>
<tr>
<td>Force-1 &lt;Hybrid_Monocoque&gt; on 4 Face(s) apply force 2100 N normal to reference plane with respect to selected reference Top Plane using uniform distribution</td>
<td></td>
</tr>
<tr>
<td>Force-2 &lt;Hybrid_Monocoque&gt; on 4 Face(s) apply force 2100 N normal to reference plane with respect to selected reference Top Plane using uniform distribution</td>
<td></td>
</tr>
</tbody>
</table>

Figure 13: Load and Restrains

For the thickness use of 1/4in a total mass of 53.0kg was found for the proposed body design. Figure 14 shows the results found:

<table>
<thead>
<tr>
<th>No.</th>
<th>Body Name</th>
<th>Material</th>
<th>Mass</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SolidBody 1(Cut-Extrude8)</td>
<td>Custom Carbon Fiber</td>
<td>52.9981 kg</td>
<td>0.0264992 m³</td>
</tr>
</tbody>
</table>

Figure 14: Body Material Properties

Figure 15 exemplifies the material properties for the proposed carbon fiber body based on online research of previous Formula SAE teams:
Figure 15: Material Properties

The information for the mesh used in the analysis is tabulated on figure 16:

<table>
<thead>
<tr>
<th>Property Name</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>3e+11</td>
<td>Nm/deg</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.3</td>
<td>NA</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>5e+09</td>
<td>Nm/deg</td>
</tr>
<tr>
<td>Mass density</td>
<td>2000</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>1.6e+09</td>
<td>Nm/2</td>
</tr>
<tr>
<td>Yield strength</td>
<td>1.3e+09</td>
<td>Nm/2</td>
</tr>
</tbody>
</table>

Figure 16: Mesh Information

The analysis done yields a structural rigidity of 17,325 Nm/deg. The calculation for this value is shown in figure 17:

\[
K_T = \frac{T}{\varphi} = \frac{FB}{(\varphi_d + \varphi_p)} = 17,325 \text{ Nm/deg.}
\]

\[
\begin{align*}
F & = 2100 \text{ N} \\
B & = 0.3 \text{ m} \\
\varphi_d & = \tan^{-1}\left(\frac{v_d}{B/2}\right) \\
\varphi_p & = \tan^{-1}\left(\frac{v_p}{B/2}\right) \\
\end{align*}
\]

\[v_d = 4.76 \times 10^{-5} \text{ m}
\]

Figure 17: Structural Rigidity
Figure 18: Body Displacement

Figure 19: Von Misses Stress
The maximum displacement found in our design of value $4.76 \times 10^{-5}$ m as shown in figure 20, was used for the calculation of the structural rigidity shown in figure 17. After the analysis, the lowest factor of safety (FOS) found in the proposed design was of 94.7. Surpassing enormously the team goal for a factor of safety of 2.

Since the designed body and components will be later on attached to the frame designed by the chassis manager of the FIU-SAE team, we considered revising their structural analysis on the frame and considered its torsional rigidity and displacement distortion with the applied loads to observe where the probable areas that we could mount the body on could be located.
After observing both of these figures and hosting several meetings with different FIU-SAE technical managers, we were able to obtain around 15 possible points or areas that we could mount both the body with sidepods and the diffuser to the frame without interfering with any other system on the car and placing the designed body as tight as possible to the frame to avoid any undesired movement.

### 6.3 Computational Fluid Dynamics (CFD)

The following simulation will be the most important to ensure the maximum performance of the vehicle and it’ll be validated after a physical evaluation of the actual vehicle on a wind tunnel. Illustrated in the figures below are the results from the Computational Fluid Dynamics testing on the proposed body design. NOTE: the Space frame underneath the body is not included in the test for simplicity. After the FIU-SAE team finalizes a fully functional assembly of all the components of the car, we can proceed to do a CFD analysis of the entire vehicle.

For this analysis air was selected as the fluid of choice since the car will be exposed to the environment, and all the calculations are based on the vehicle reaching a maximum velocity of 40mph or 17.88m/s as shown in figure 23. The calculation of the drag coefficient...
shown in figure 27 is based on a frontal reference area of 732.87 in^2 as found in the proposed design.

Figure 23: Fluid Conditions

Figure 24: Pressure Analysis
Figure 25: Temperature Analysis

Figure 26: Velocity Analysis
As shown in figure 27, a drag coefficient value of 0.32 was found in the proposed design using a drag force of 31.16N as obtained in analysis done and shown tabulated in table 5.

**Table 6: Drag Force**

<table>
<thead>
<tr>
<th>Goal Name</th>
<th>Unit</th>
<th>Value</th>
<th>Averaged Value</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Progress %</th>
<th>Use in Convergence</th>
<th>Delta</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>GG Y - Component of Frc</td>
<td>N</td>
<td>41.25942264</td>
<td>39.0625409</td>
<td>39.0533957</td>
<td>41.25042264</td>
<td>100</td>
<td>Yes</td>
<td>2.230988025</td>
<td>5.591931428</td>
</tr>
<tr>
<td>GG Z - Component of Frc</td>
<td>N</td>
<td>-31.32938116</td>
<td>-34.33863681</td>
<td>-34.33863681</td>
<td>-31.016252</td>
<td>100</td>
<td>Yes</td>
<td>12.60684027</td>
<td>14.12203106</td>
</tr>
</tbody>
</table>

The next section to be analyzed is the Ground Effects of the vehicles, mainly composed by a diffuser. The idea behind implemented a diffuser in a racecar, as mentioned before, is to increase downforce to provide the vehicle with more traction. Therefore, increasing its overall performance.
There are several recommendations that one should follow when designing a diffuser according to our research. The main idea is to divide these components into two sections. The front section will be designed with the purpose of the airflow to travel from large to small cross-sectional area to increase its velocity avoiding flow separation. On the second or rear section, it’ll be design with the opposite purpose. The airflow will travel from small to large cross-sectional area to decrease the airflow velocity and create a low-pressure zone below the car, which would yield a generation of downforce. Also, vortex generators at the very end of the diffuser will aid with this resolution of creating a low-pressure area. Then, the goal would be to get the airflow velocity at the very end of the diffuser to match or be more or less of a value near the initial or inlet velocity [10].

As shown in figure 29, air will enter through the right side (Front section of the vehicle) and it will exit through the left side. As well as the previous CFD analysis, air speed was assumed to be at 40mph, which approximately represent the top speed that the vehicle will get at the track. To further bring a realistic element into this calculation, a floor was placed at 1-inch bellow the diffuser, which is the minimum ground clearance permitted by the Formula SAE rules [11].
It can be appreciated on figure 30, that the design chosen follows the principles recommended by the Race Car Vehicles dynamics book [10] in which the air enters at a certain speed, in this case 40mph and as the cross-sectional area reduces in size the airflow speed increases up to a maximum value of more than 100mph, then as the cross-sectional area increases the airflow speed reduces to a value close to the inlet speed which is desired as explained before. Figure 31 shows how the vortex generators cause turbulence in the flow with a careful and thoughtful design to avoid airflow separation, which aid to create that low-pressure area underneath the vehicle, which will have a direct impact on the vehicle’s performance, by creating downforce.
6.4 Improvements of Design

6.4.1 Body Designs

The body was re-designed several times based mostly on aesthetics and the FIU-SAE team needs for the body to cover completely their frame design. The following pictures show the progress of this iterative design:

![Figure 32: First Iteration Body Design](image)

![Figure 33: Second Iteration Body Design](image)
6.4.2 Diffuser Designs

The original diffuser design was modified numerous times to ensure maximum performance of the part and the lowest cost of manufacturing. Also, since the diffuser directly affects the clearance of the vehicle with respect to the ground, per SAE rules the prototype has to be able to travel one inch up and down with respect to the neutral position of the car. Consequently, later on in the semester the suspension team had to re-design its original shocks layout and positioning, the diffuser had to be modified accordingly to allow proper suspension travel. After performing several CFD analyses on various iterations of conceptual designs, as shown in the next pictures:

Figure 34: Third and Final Iteration Body Design
Velocity:

Figure 35: Velocity, First Iteration Model

Figure 36: Velocity, Second Iteration Model
Figure 37: Velocity, Third Iteration Model

Figure 38: Velocity, Fourth Iteration Model
Figure 39: Velocity, Fifth and Final Iteration Model

Pressure:

Figure 40: Pressure, First Iteration Model
Figure 41: Pressure, Second Iteration Model

Figure 42: Pressure, Third Iteration Model
Figure 43: Pressure, Fourth Iteration Model

Figure 44: Pressure, Fifth and Final Iteration Model
Even tough the modification of the diffuser to allow proper suspension travel, originally affected negatively the performance of this part. It was re-design with the goal of reducing the pressure at the bottom of the vehicle and to have an exit velocity with a value similar to the inlet velocity. As it can be appreciated on both fifth iteration model for the pressure and velocity CFD analysis, both of these goals were successfully achieved and the performance of the part was even improved. An isometric view of the final product can be appreciated in the next figure:

![Figure 45: Final Diffuser Rendering](image)

The final vehicle after manufacturing will utilize both of this design and several other components that the FIU-SAE team is currently in the process of manufacturing. The following pictures exemplify a rendering of what the final product will look like.
Figure 46: 2013 FIU-SAE Prototype, Final Rendering
7. Manufacturing

7.1 Process Overview

After completing the design and analysis stages, the following step is manufacturing. The development of composite materials is an extensive process with a multiple number of steps and considerations. In general, the process is usually the same but depending on the application certain variables change. The entire manufacturing process is divided into four main sections: Mold Creation, Mold Preparation, Release and Finish, and Juncture and Attachment.

7.2 Mold Creation

Mold Creation is the first step into the manufacturing process. This step is one of the most important because it will directly affect the amount of time that you are going to spend on the remaining steps. Various considerations have to be taken into account to determine the best way to create a mold. Factors such as design, size, manufacturing limitations and time will lead to the optimal mold type.

The first consideration is to create either a male or female mold. The selection between the two will be determined on the finish and shapes within the parts. When creating composites from a mold, the surface with the smoother is the one in direct contact with the mold. In certain cases this factor can be disregarded if the parts are going to be painted or covered by other components. Since our project is focusing in aerodynamics and the aesthetics of the vehicle, we need to achieve the smoothest surface possible. With this in mind; the best mold type would be a female mold, which would yield the smoothest surface on the outside of the racecar.

7.2.1 Material Selection

The second consideration that has to be analyzed is material selection. The mold is basically a vessel from where the finish part will be released. There are a number of different materials that can be used to create this vessel, but some have more advantages than others based on the application. Materials such as fiberglass, wood and foam are commonly used in the industry to construct composite molds.
Fiberglass is generally used when the part needs to be duplicated from an existing part. By laying fiberglass onto the original part, an exact negative can be created and later used as the mold. A disadvantage of this material selection is that once it is created, it can no longer be modified. Furthermore, creating a fiberglass mold requires more resources and manufacturing time. In contrast, wood is inexpensive and easier to manufacture. The disadvantage with this material is that most of the manufacturing would be handmade which would defeat the purpose of the aerodynamics-based design.

In our particular case, the first variable that leads us to the optimal mold material is the type of composite in use. Since we are using carbon fiber as our composite, and we want the finish product to expose the composite weave, a material that provides the smoothest surfaces needs to be selected. In addition, the mold has to be able to be modified by hand when alterations are needed. With these two factors in mind, we can clearly determine that the optimal material for our mold would be foam. Another factor that determined the mold material was the tools used to create the surfaces. We used a CNC router, which commonly mills through the type of foam selected.
7.2.1.1  Foam Characteristics

As foam was selected as our mold material of choice, we now had to determine the specifics of the material. This type of material has a wide range of different properties and uses for a number of applications. In our particular case, we needed a specific type of foam that is easy to mill and sand, but maintains structural rigidity. After consulting with an expert in the field, we determined that ISO-C1/2.0 Polyisocyanurate Insulation from Dyplast Products was our best selection. This 2.0 lb/ft³ material is easy to handle, relatively light, and structurally sound. The following figure shows more in-depth properties of ISO-C1.
Another advantage of this specific material is wide range of sizing options. ISO-C1 is created on large blocks that can be later hot-wired to the customer's specifications. In our specific case, we were able to get 48” x 36” x 8 blocks of foam.

7.2.2 Body Sectioning

Now that the material and mold type have been selected, the body design has to be adjusted to comply with the previous selections. As mentioned before, since we are using a CNC router to mill the molds, we have to take into consideration the limitations from this machine. Based on these factors, we can continue to section the entire body into separate sub-sections.

7.2.2.1 CNC Router Limitations

After analyzing the advantages and disadvantages of using a CNC Router, we opted to use the Techno LC Series 4896 provided by the FIU School of Architecture. With this machine we would be able to accurately mill our designs into the foam mold. The first
limitation that we encountered with this particular CNC Router was the dimensions of the loading bed. These values dictate the maximum possible length and width of the material used for the mold. After measuring these dimension, we determined that the mold could not be any longer than 8 ft. and wider than 50 in. Another limitation that we encountered was the maximum depth that the router can mill. As shown in figure 48, the router bit could only mill 4 in. deep per mold. In addition, another limitation on the machine is the inability to mill in three dimensions. By only being able to mill vertically, faces with negative curvatures would not be able to be recreated. After taking into account all these limitations, proper sectioning of the entire body was achieved.

![Techno CNC Router](image)

Figure 48: Techno CNC

### 7.2.2.2 Sectioning of Body

Since the model was originally sectioned for serviceability reasons, we continued with further sectioning to comply with the CNC router limitations.

Taking the ‘Nose’ sub-section as an example, we can further demonstrate how the sectioning was applied. Splitting the nose through the middle was the first sectioning that was implemented. If we were to use a single mold for this section, we would not be able to lay the composite fibers for the top section of the nose. By sectioning the part in two, we would be able to place the molds horizontally and lay the composite fibers from above. At this stage the sections still did not comply with the CNC limitations, which meant that further sectioning had to be applied.
7.2.3 Conversion to MasterCam

Our body prototype was originally created in SolidWorks using surface modeling. All these files have to be converted into a language that the CNC router can understand. Generally, CNC routers follow a set a computational coordinates in order to create the shapes and curvatures desired. For this reason, we have to be able to convert our surface models into a language that the CNC router can understand. We initially converted the files to ‘iges’ format, to be able to open them in Rhino 3D. In this software we are able to create a model of the female mold, by removing the model’s surface from rendered mold. Now that we have the surfaces that we want to be created on the mold, we can now convert the entire file to G-Code. By importing the file to MasterCam, this software can analyze the surfaces and automatically create the coordinate system that the CNC router is going to use.
7.2.4 CNC Milling

After the proper language and files were created, we imported them to the CNC router. Then the foam block was placed in the loading bed and locked into place. This particular model of CNC has an integrated vacuum system that suctions the block against the bed, keeping it in place during the entire process. Depending on the size of the mold, the milling process would take between 30 – 50 minutes. Even though this process is automated, constant supervision of the machine was required. As the bit mills through the foam block, the residual dust starts collecting around the bit and other moving parts which can cause jams and errors. To prevent this from happening, we constantly vacuumed around the bit and other moving parts. After completing all the separate molds, a total of 21 hours were spent during the entire milling process.
7.2.5 Attachment of Molds

Once all the parts are milled, the following step is to join all the different sections into the main components of the body. Two different factors have to be taken into account during the attachment: optimal accuracy and mold structural integrity. Each component mold has to be attached as accurately as possible to be able to continue the surface curves from one section to the other. If this is not done correctly, the aerodynamic properties created during the design process can be lost. As far as mold structural integrity, the final mold has to be able to be handled and transported to different locations while maintaining the curvatures intact. With these two factors in mind, we decided to attach each section with rods and Liquid Nails. The rods would help keep the entire structure stable, while Liquid Nails is the preferred adhesive for foams and insulation.
7.3 Mold Preparation

Mold preparation is the second and most important step during the manufacturing process of composites. This step will directly affect the final quality of the part and the difficulty of part release. Mold preparation mainly consists of a large number of small steps that will repair the mold surface for optimal performance.

7.3.1 Material Selection

Similarly to the Mold Creation step, material selection is very crucial during Mold Preparation. Selecting the correct compounds will and amounts will ensure the desired finish. Most of the materials selected for this project were polymer gelcoats and resins processed with MEK-P hardeners.

7.3.2 Initial Sanding and Repairs

Before starting to apply the materials mentioned above, the foam mold has to be prepped. As the molds were milled, the router left a number of grooves between each pass of the bit. These grooves have to be manually sanded down to be able to maintain the curvatures of the surfaces. Since the foam material selected has a density of 2.0 lb/ft³, the sanding process is relatively easy. This process also had to be made after attaching the mold sections to ensure continuance of the curves within the surfaces.

Figure 53: Nose With Gaps Repaired
In addition, we were able to make initial repairs on areas where the CNC router did not reach. As mentioned during the CNC Limitations, the router is not able to mill negative curvatures. We encountered some of these issues with a small number of our foam molds. The router incorrectly interpreted these negative curves by creating gaps and cracks and the end of each surface. Filling the gaps with lightweight bonding putty initially repaired these undesired gaps. This compound was selected due to its properties after drying. Bonding putty is easy to handle and optimal for sanding after it is applied.

### 7.3.3 Initial Compound Layering

After the mold was sanded and the gaps were repaired, we had to begin layering the different compounds to prepare the mold. The first material that we used was wood glue. We applied this material to be able to cover the pores within the foam. Two layers of wood glue were applied to ensure even coverage throughout the part. A waiting time of 30-40 minutes between each layer had to be applied.

![Wood Glue Brushing](image)

**Figure 54: Wood Glue Brushing**

After the wood glue was fully dried, we continued the layering process by applying tooling gelcoat. This type of polyester gelcoat, also known as orange tooling, would create a thin hardened layer of plastic once it is cured. To make this chemical reaction, the gelcoat
has to be mixed with a hardener or catalyst. When polyester gelcoats and resins are use, an MEK-P catalyst has to be used to initiate the chemical reaction. In this case, we needed to mix 2% of MEK-P by vol of the amount of gelcoat used. This hardener raises the temperature of the gelcoat to up to 120 F to begin the hardening stage. This process takes from 10-12 hours to fully cure. Once the gelcoat is completely dry, we can further repair the remaining gaps and pores that are still present on the surface. After the bonding compound is applied again, the entire surface has to be sanded once more.

![Figure 55: First Orange Tooling Gelcoat Layer](image)

7.3.4 Second Compound Layering

The second compound layering begins after all the surfaces on the mold are completely cured and sealed. During this stage, we apply more compounds with the goal to improve the final finish of the surface. We begin by adding 3-4 more layers of orange tooling to ensure a hardened surface. This amount of layers also allow for extensive sanding to maintain a smooth finish. Once these layers are cured and sanded, we continue
by polishing the surfaces. We started by applying two layers of sealer to make sure that all the pores are coated. Once the sealer is cured, we continue by adding a layer of polish compound. This would start adding shine and creating a smooth surface.

![Figure 56: Tooling Gelcoat After Sanding](image)

Now that the surface is smooth, we started adding compounds that would facilitate the release of the part. We started by applying five layers of wax to the surface. We had to wait 30 mins between each layer to allow the wax to settle. Once all the layers have been applied, we continue by adding a mold release agent. We opted to use PVA as it would ensure a smooth release without sacrificing surface finish. This release agent dries generally quickly and is the final stage of the mold preparation step.
7.4 Carbon Fiber Laying

The following step after prepping the mold was start laying the carbon fiber inside the mold. In our case, we decided to use three layers of carbon fiber to keep a rigid body. The process begins by spraying a polyester clear coat on the mold and letting it dry until tacky.
Once the mold was ready, we started laying the first layer of carbon fiber and pressing it into place. By placing it while the clear coat is tacky, the carbon fiber will slightly adhere to the mold. Once the sheet was on the desired position we continued by applied the first layer of polyester resin. Similarly to the orange tooling, this resin has to be prepared by using the MEK-P catalyst. We used a brush to apply the resin, which helps to reduce air pockets on the surface. This step is later on repeated for each of the following carbon fiber layers. This process takes 24 hours to fully cure.
7.5 **Release and Finish**

One of the final steps of the process is the release and finish of the carbon fiber part. Once the part was fully cured within the mold, we continued by carefully removing it. The best way to release the part from the mold is by shooting compressed air between the part and the mold. Afterwards, we can carefully start pulling the part from it. At this stage, the part should come out shiny and smooth with a small out or residual PVA on top. This can be easily removed by wiping it with a dry cloth.
Since the carbon fiber was laid with oversized dimensions we needed to trim the edges. The best tool to accomplish this is an electric grinder. Once all the edges were trimmed, we smoothed off the edges with a sander. In case of surface errors, can further polish the surface to ensure a great finish.

Figure 60: Unmolding of Part

Figure 61: Carbon Fiber Final Part
7.6 Juncture and Attachment

Certain parts of the body were created separately due to manufacturing restraints. Once the parts were completed, we continued by attaching the parts into main components. To accomplish this, we created tabs around the areas that were going to be merged. The tabs would later be glued with epoxy and carbon tap, and finally sanded and polished.

After all the junctures were created and all the separate parts were finished, the final step was to attach the body to the frame of the racecar. We installed tabs around the frame on specific locations to keep the body in place. Since this body has to be able to be removed due to serviceability reason, quarter-turn fasteners were added to the body for quick release. Finally, a detailed check-up of all components was performed and process was finalized.

7.7 Design Considerations

After various iterations a final model was designed with the manufacturing process in mind. As the design process was restarted, various components and measurements had to be revised due to changes on the frame of the racecar. Since the engine's intake system was modified, the overall frame had to be extended to fit the new modifications. These changes had to be taken into consideration when the final body model was designed. This iteration was divided into three different sections for better analysis and ease of assembly: Body, sidepods and ground effects.

The first section known as body, consist of the main portion of the model that covers the cockpit and routes the airflow into the sidepods. Taking a more in-depth look at this section, we further divided the model into different sub-sections: Nose, sub-body and engine cover as shown in figure 62. The main factor that dictated the location of these divisions was serviceability. The team has to be able to access the engine and suspension
components with ease during the course of the race, and reducing body removal time is crucial to do modifications efficiently.

![Figure 62: Body Sub-Sections](image)

As mentioned before, a secondary factor that affected the division process was manufacturing. Since these components are going to be constructed with the use of molds, certain constrains have to be taken into consideration. Certain shapes and curves cannot be done using a single mold, so the design has to be further divided. An example of this issue can be seen with nose sub-section. If we were to use a single mold for this section, we would not be able to lay the composite fibers for the top section of the nose. To prevent this problem, it was decided to divide the nose into two identical molds, which would later be bonded together.

This method produces another manufacturing concern: How to properly bond to composite parts together. We started to tackle this issue during the design process. As we split the CAD model into their respective sections, we added tabs to the edges of each part that would later fit onto each other. Afterwards, adhesive elements are added to these sections to bond the pieces into one. Same design considerations were applied to the sidepods and the diffuser in order to facilitate their manufacturing process.
7.8 Safety Considerations

Dealing with chemicals and hazardous materials is very dangerous, not to mention spending hours at a time inside machine shops and workshops. The most safety procedures were followed. At all times when dealing with high-density foam goggles and respirator mask were used. The particles released by the foam are minimal in size and can be easily inhaled without the proper care. In addition while using chemicals like epoxy resin and gel coats gloves had to be used in order to protect our hands from harmful chemical reactions. These chemicals were never used near any open flames and never left out in the sun were they could over heat and possibly ignite. Finally, as a team we proud ourselves as strict followers of safety regulations in all labs and machine shops that we worked in, and our zero incident project manufacturing reflects our dedication to safety.
8. Project Management

8.1 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.

8.2 Breakdown of Work into Specific Tasks

The Gantt chart shown in Figure 64 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.
8.3 Organization of Work and Timeline

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.

8.4 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 manufacturing 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 8: Breakdown of Responsibilities

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Design</th>
<th>Manufacture</th>
<th>Analysis</th>
<th>Reports</th>
<th>Presentations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Javier Gutierrez</td>
<td>Body, Side Pods</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Angel Nuñez</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diego Quintero</td>
<td>Diffuser</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>
9. Conclusion

9.1 Conclusion and Discussion

In the previous figures it may be seen that the proposed body design has met and surpassed the goals of this project in terms of safety, torsional rigidity, weight, and coefficient of drag. For the researched material properties, a mass of 53.0 kg was found in the proposed carbon fiber body design. Which, compared to the 30kg weight that was set at the beginning of the past semester (fall 2012) is almost twice as much, meaning that a third iteration analysis could be made in future papers using thinner thickness in the model. Moreover, the same applies for the structural rigidity found of value 17,325 Nm/deg. that compared with the value of the goal set of 3,000 Nm/deg. surpasses this value tremendously. Also, the factor of safety found with this analyses is 94.7, confirming that a thinner thickness can be used for the actual body. However, as some components and the A-Spaced frame underneath the body of the vehicle were not included in these analyses the true values for torsional rigidity (in this context referred to as “chassis loading” when loads travel through the suspension) and coefficient of drag are not accurate to real world values.

The drag coefficient found for this design is 0.32 that compared to the goal value of 0.73 is almost half, but by adding a spoiler to the vehicle this drag coefficient can be increased with the purpose of generating more downforce.

9.2 Recommendations and future work

As stated above, a thinner thickness can be used for future models to decrease overall weight and increase the performance of the vehicle. Also, other programs such as Ansys can be used to further corroborate the results. Moreover, the values gained from the FEA and CFD testing does not reflect errors, which may be made during manufacturing which may compromise the strength of the structure. Real-world testing is necessary prior to implementation of this design to ensure performance and more importantly, its safety.

One of the biggest gains of the completion of this project is the knowledge that future FIU students will gain from our experience. Since this project was developed for the FIU
SAE team, future members will be able to see our process, design considerations, and further optimize our designs. At this point we can compare this year’s design, with the previous year’s aerodynamics package and see the improvements. In the same fashion, we can expect the same amount of improvement for future prototypes. The next step to improve the current design is to further optimize the design by making it lighter while gaining positive downforce. To accomplish this, the racecar prototype can be converted into a hybrid-monocoque design, which would yield a lighter vehicle. Also, since the frame of the car restricted most of the curves on the body, developing a sleeker and more efficient frame design is critical for further performance enhancement. Other aspects to take into consideration are the restrictions caused by the manufacturing process. During our process, even though we took the manufacturing process into consideration, unforeseen problems and new restrictions arose. One example of these new restrictions was the issues caused when milling the molds with CNC machine. As each mold was milled, we noticed that the machine had difficulties interpreting negative curvatures for each piece of the body. After noticing these mistakes, the molds had to be manually repaired. Now that we fully understand how the CNC machine operates, we can improve or design and mold creation to avoid these errors.
10. References


11. Appendices
Appendix A. Technical Drawings
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Figure 66: Body – Left Wall
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Figure 68: Body – Nose LC
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Figure 70: Body – Nose RC
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Figure 80: Body – Sidpod Right - Side
Figure 81: Body – Sidepod Right - Top
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 stick 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.
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”.

![Diagram of Not OK and Properly Triangulated structures]
### 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.

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

**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:

<table>
<thead>
<tr>
<th>MATERIAL &amp; APPLICATION</th>
<th>MINIMUM WALL THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Tubing for Front and Main Roll Hoops, and Shoulder Harness Mounting Bar</td>
<td>2.0 mm (0.079 inch)</td>
</tr>
<tr>
<td>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</td>
<td>1.2 mm (0.047 inch)</td>
</tr>
</tbody>
</table>

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/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 fiaso online 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 (anthropometric 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 (35.6 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](image1)

![Figure 5](image2)
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: UMN_School_of_Engineering_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.fsaonline.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](image)

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.
Appendix C. Quotes

Quote

Company: Fiberglass Coating

Date: 03/13/2013

Main Contact:
Angel Nunez
Anune024@fiu.edu
(786) 953-0365

Secondary Contact(s):
Javier Gutierrez  Diego Quintero
jguti032@fiu.edu  dquin024@fiu.edu
(786) 423-8148  (786) 877-5916

Table 9: Fiberglass Coating Quote

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<th>Item #</th>
<th>Item</th>
<th>Qty</th>
<th>Unit Price</th>
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<td>Laminating Roller 1/2&quot; X 6&quot;</td>
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TOTAL: $1,229.84
Appendix D. Apparatus

Figure 82: Techno CNC LC4896 Series