Dartmouth Formula Racing 2016-17 Chassis Design
Advised by Professor Van Citters and Raina White

Engs 87- Final Report

By Erik Loscalzo

Suspension Design by Martin Anguita
Suspension Statics by Carter Noordsij
Driver Ergonomics by Edward Cornew

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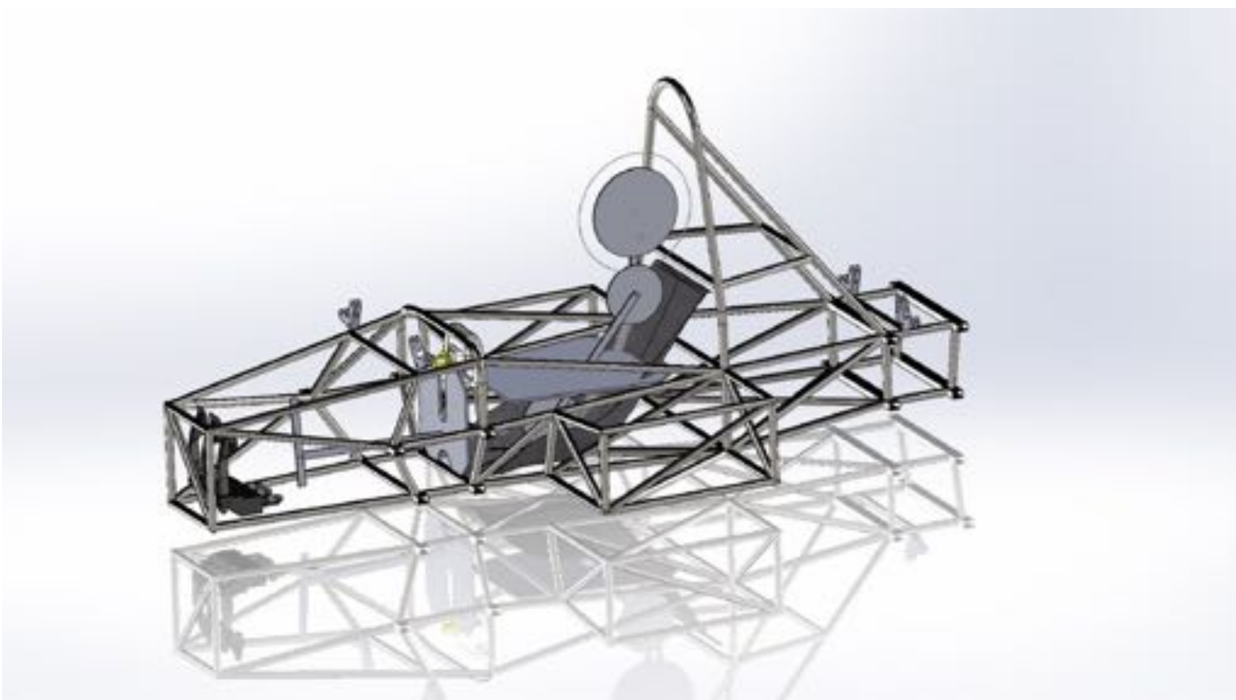
Project Objective

The goal of this project was to design a new chassis for the Dartmouth Formula Racing Team. The current chassis did not pass mechanical inspection in the 2015/16 competition due to its small cockpit size and packaging issues. Additionally, the current chassis has an unwanted weight distribution. Making the chassis rules compliant was the most important aspect of the project. Of secondary importance was designing for the best performance possible with our current components.

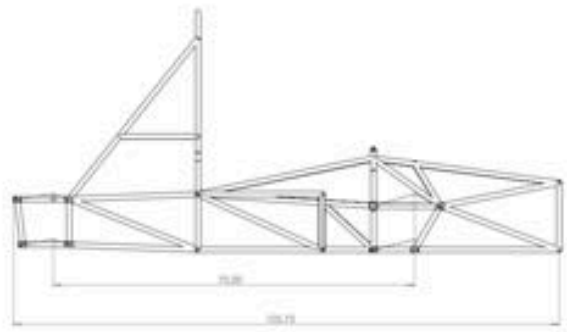
The chassis is the main structural part of the car which protects the driver and holds all the components of the car. Since the chassis interfaces with many components on the car, you need to plan carefully so that everything will fit properly. One of the main defining features of the chassis is the suspension points. I worked closely with Martin Anguita to define suspension points that would allow for adequate space for the driver and drive components and have the optimal performance within those requirements. Also, I made sure that all the major parts, like the drivetrain components, fit in the back of the car with adequate space to work. This was critical to making a car that would be reliable and easy to fix. I worked with Carter Noordsij to perform a stress analysis on the chassis to simulate the forces the chassis would experience during cornering and braking. Our current car is also difficult to exit due to the low dash board. In order to make sure that the driver would be comfortable and be able to exit the car easily, I worked with Edward Cornew to develop an ergonomic cockpit for the driver.

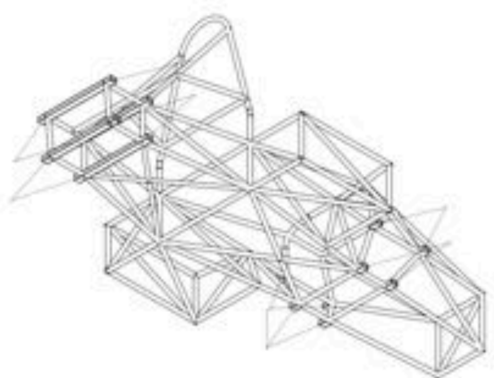
Final Design

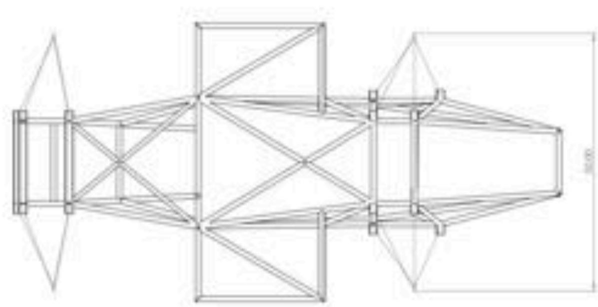
Throughout the 10 week term I worked towards designing a chassis for the 2017 Formula Hybrid Competition. Every week I performed design iterations after our weekly meeting with Professor Van Citters and Raina White. In this rendering below the chassis is shown with three templates: Percy the competition person template, the cockpit opening template and the vertical template. I also included the pedal package, steering wheel and seat to show the driver ergonomics. The suspension point tabs are also pictured on the chassis along with the rockers for the pushrods. The end result from all of the chassis design iterations is shown below:



The final chassis has a wheel base of 70 inches and a track width of 56 inches. These were design requirements that Martin and I worked towards after looking into the design for the ideal performance. We then made realistic specifications that worked with our current components. The overall length of the chassis is 105.75 inches and the width (including battery boxes) is 53 inches. The chassis drawing can be seen below:







<u>Performance Targets</u>

Total Weight:

Our goal was to design the lightest chassis possible by eliminating unnecessary members. Currently this new chassis design weighs 91.7lbs and the old chassis weighs 93.7lb. The current design is not finished and additional members still need to be added for mounting the motor. Therefore, the weight will go up. I expect the final weight of the car to be very similar in weight to the old chassis even though we added 10 inches to the wheel base!

Weight Distribution:

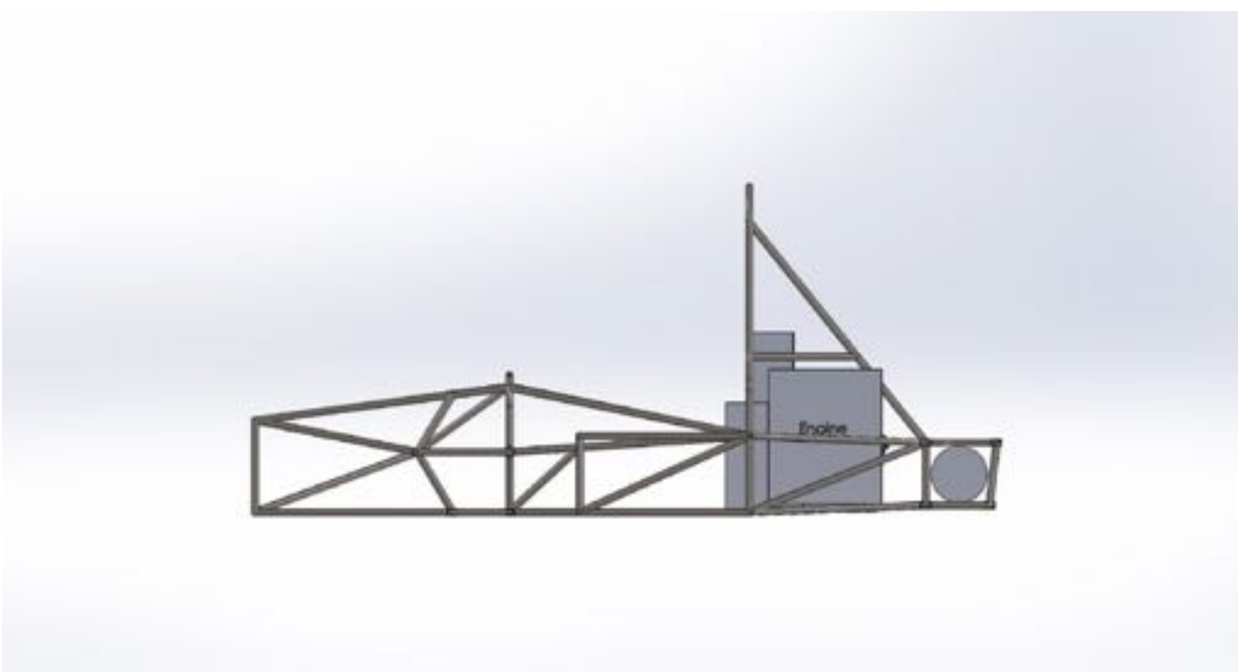
Currently the car has a 55/45 (front/back) weight distribution and our goal for the new chassis is to bring it closer to 40/60 (front/back). With the chassis extension, approximately 8 of the 10 inches went into moving the front wheels forward, leaving the rear components in a similar position. Additionally, the battery packs were mounted as far back as possible to help reach our goal of a 40/60 weight distribution. Another concern was the CG height so we placed the heavy components as low as possible to reduce the CG height. Another problem we have in this car is that the weight of the car is not symmetric. Major adjustments in the suspension are required to get the side to side weight distribution to 50/50. This offset is mostly caused by the motor being offset to the driver's left. To fix this, it would make a lot of sense to mount the motor in the center of the car and put the pre-charge box in its current location. This would also reduce the length of the drive shaft in the coupling. I think this was a major mistake in the current packaging of the car because of the added complexity it added to the drivetrain coupling and the side effect of the offset weight in the back of the car.

Design Requirements

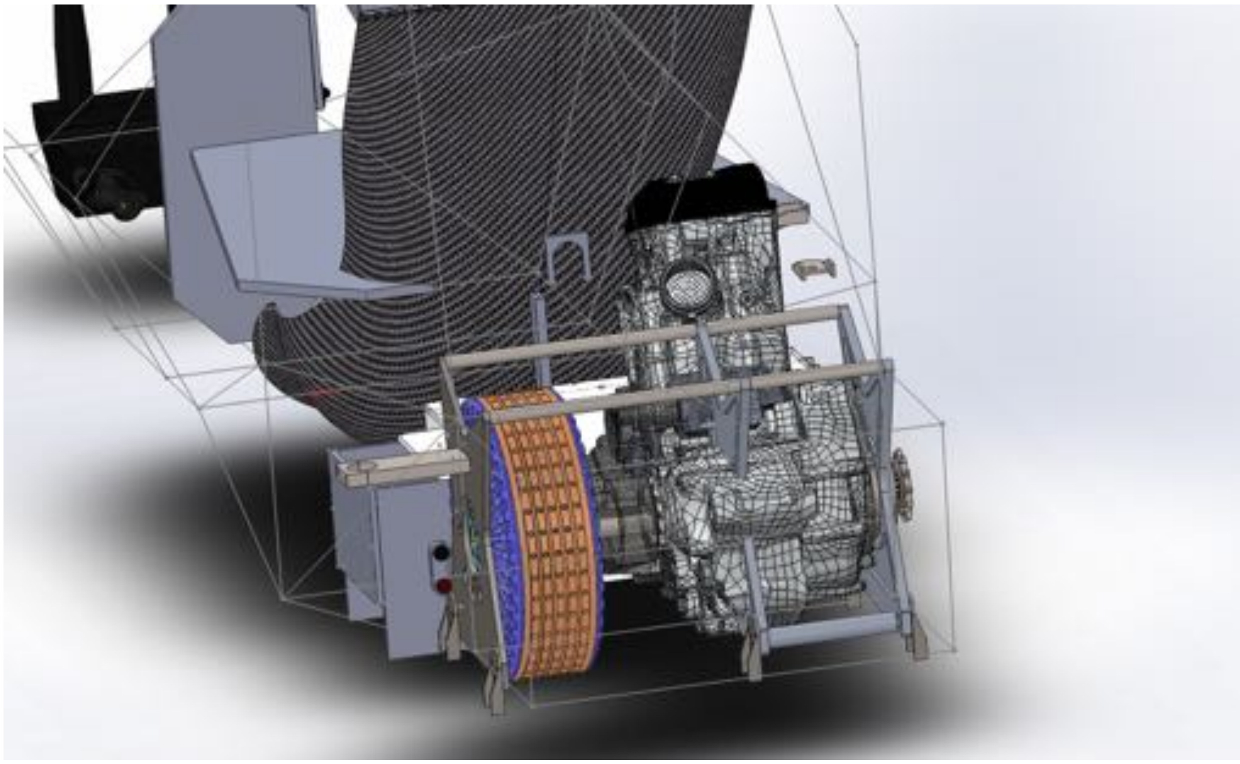
Component Space:

After discussion with the team at our weekly meeting, we concluded that it would be best to increase the back of the car by approximately 25% volume. This, along with the saved space from the new drive train design, will allow us to have a lot more room. If we decide to keep the current drive train, this design should accommodate that. I talked with Martin and we decided to move the rear suspension points back 10 inches to make more space in the back of the car. This makes the new chassis 10 inches longer than the old chassis. It allows for more space for components and it makes it easier to pass inspection.

To figure out how much space was needed in the rear of the car, I made block models of our current components of the car in CAD. I placed these boxes in the chassis and arranged them so that they would fit and so that everything could be easily accessible. The battery cages were designed for our current battery packs, but the actual battery packs are not pictured below. The rendering below shows the block components placed inside the rear of the new chassis. A major design difference in the packaging is that the differential is now placed within the chassis for performance reasons.



The next rendering shows my proposed drivetrain design between the electric motor and the IC motor. This design eliminates a drive shaft and shortens the main drive shaft. Below you can see the electric motor on the left and the IC motor on the right. In the middle on the drive shaft there is an alignment coupling and drive sprocket.



Steering Angle:

The wheels must be able to turn at least 11.3 degrees to get around the tightest turn on autocross which is 9 meters. A major reason we made the wheel base as short as possible is because it is easier to turn if the wheelbase is shorter. A shorter wheelbase means the wheels don't have to turn as much. Not having to turn as much means a lower steering angle, which is better because there is less force on the road-tire contact, therefore making the car less likely to slip.

Rules Compliance:

In order to make this design as light as possible I tried to use the fewest members possible while still having all the required members defined in the rules. I went through all of the Formula Hybrid rules to figure out which rules would create design requirements for the chassis. Attached in Appendix 1 is the list of rules that I used as design requirements for the chassis. During the design review, Professor Van Citters helped me perform a mock mechanical inspection in CAD. I feel very confident that this chassis will pass mechanical inspection which is the main goal of this chassis revision.

Suspension Points:

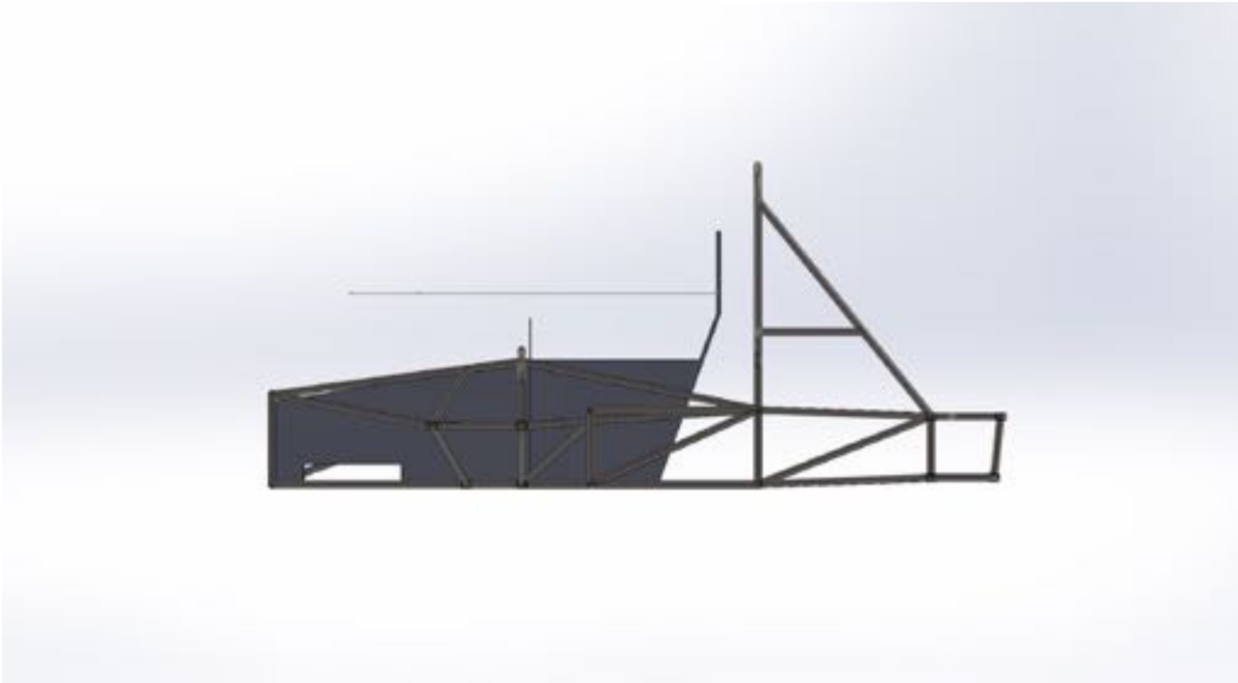
I worked with Martin to integrate the suspension points he defined into the chassis. This took a lot of collaboration because the perfect suspension point locations were not in ideal locations for minimizing the structural members on the chassis. This required many iterations to achieve optimal performance in the suspension and not add additional members to the chassis. Once we agreed on locations for all the points, I had to make sure that the chassis had proper triangulation to support the suspension points.

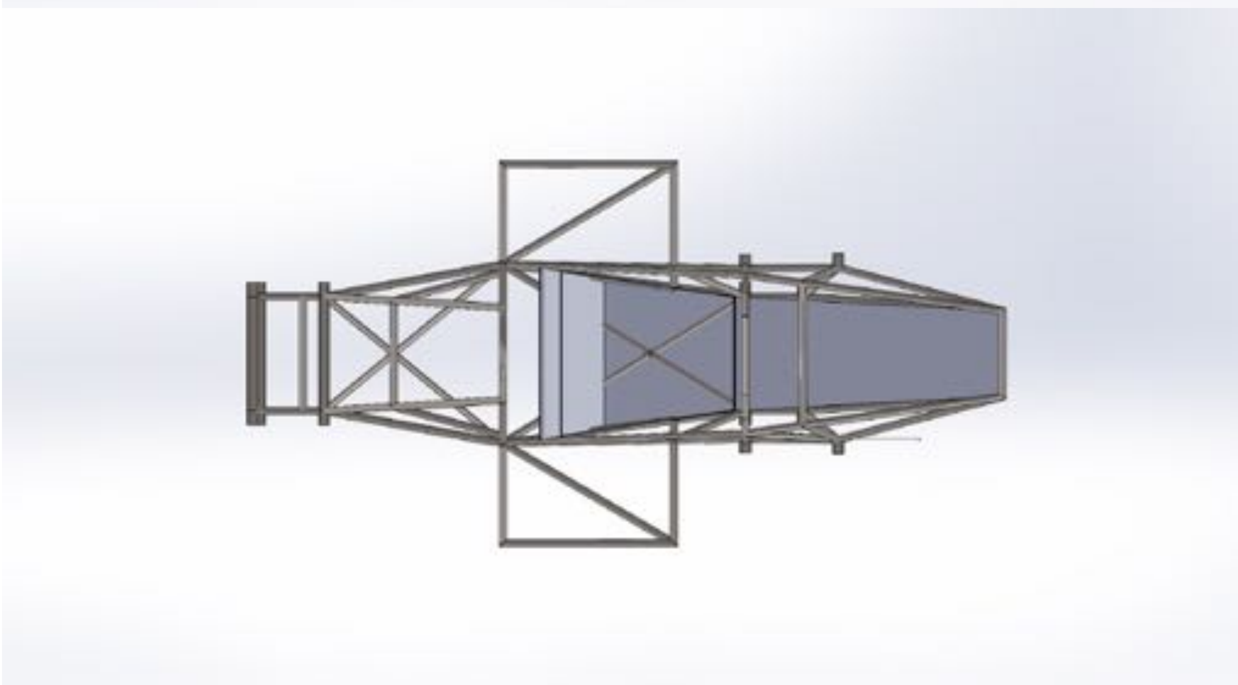
Rocker and Shock Mounts:

In order to position the rockers, I had to figure out the location of the uprights. I positioned the rockers at the proper height so that they could be supported by the chassis. Then, I gave these values to Martin to perform the calculations on the proper size of the rocker and spring angle. Below is a rendering of the chassis with the rocker mounts:

Driver Cockpit:

I worked with Ed to make a driver cockpit that was both comfortable and rules compliant. This included making sure that the driver had good visibility and that the steering wheel was ergonomically placed. As seen in the diagram below, you can see the driver cockpit envelope designed by Edward placed in the final chassis design. The chassis design gives the driver extra space allowing the car to fit drivers above the 95th percentile for height. (Currently we have a few members on the team who are taller than the 95th percentile.) The extra space also allows the templates to pass through the chassis without hitting wires.



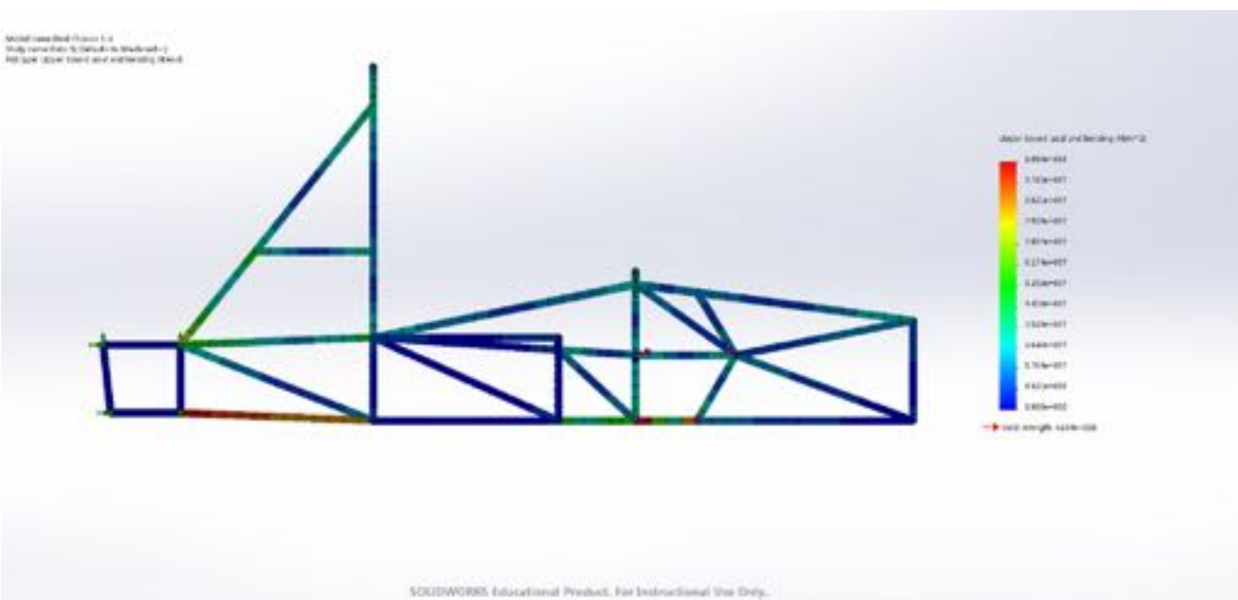


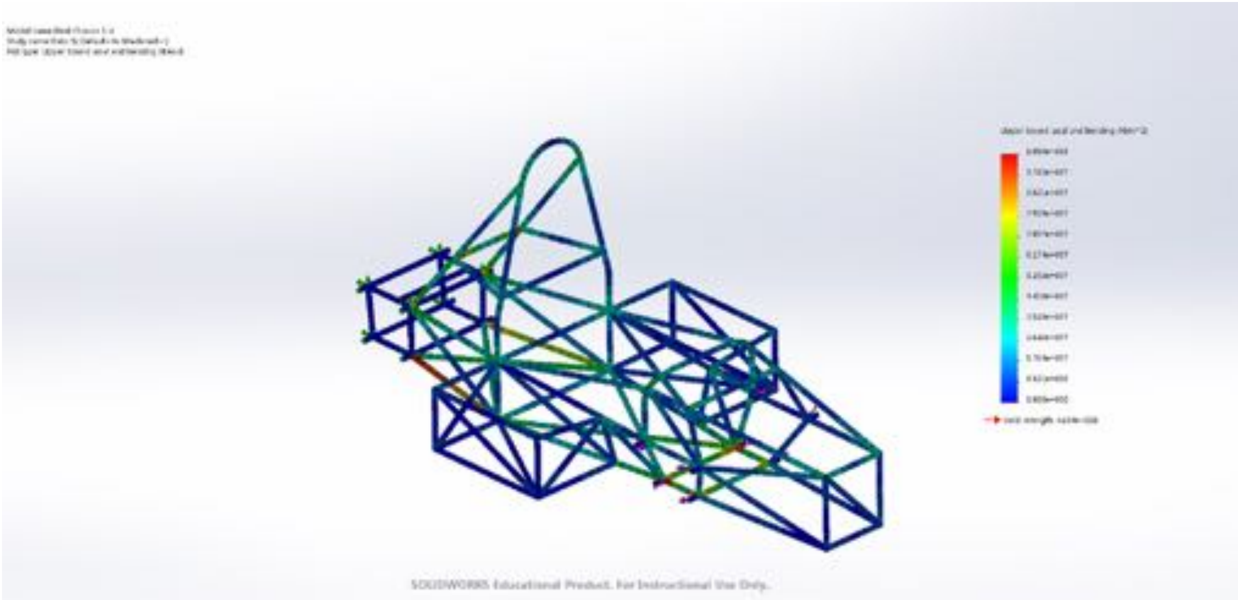
Static Simulation

One of the main purposes of the chassis is to be able to support the forces on the suspension system during driving conditions. To verify that the chassis could handle the forces during driving conditions, Carter and I modeled the forces on the chassis during 1G braking and 1G turning. (We left out bump because all of this force went into the push rod.) This gave us our best guess of a worst case driving scenario which should give us the highest forces on the suspension points. Then, I applied these forces that Carter calculated to the suspension points on the chassis in SolidWorks Simulation. I used a curvature mesh to model the bent pipes and increased the mesh resolution in areas of high stress. After the first stress simulation, I added cross bracing under the driver cockpit and in the engine compartment. This greatly reduced the peak stress. Currently our safety factor is 2.4x. It is good to have a high safety factor because the welded joints might not be as strong as Solidworks predicts.

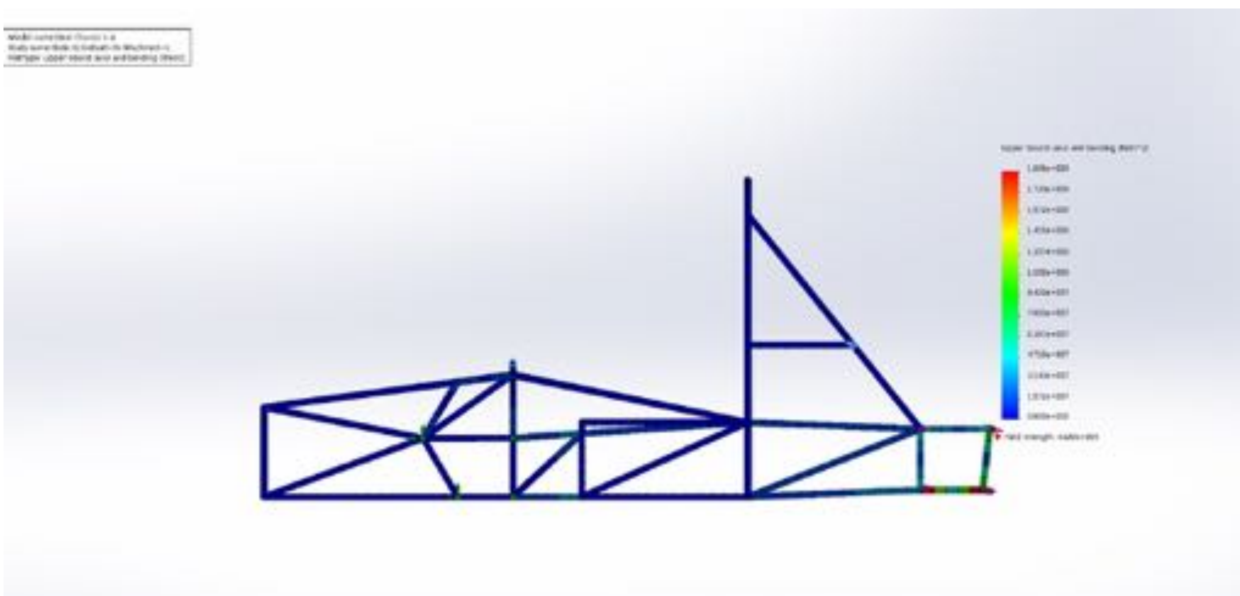
I simulated the chassis under two loading conditions to simulate the worst case loads. I found that the most common way to simulate chassis is to fix the front set of suspension points (8 points) and then to apply the forces to the rear points. You can then switch, fixing the rear set of points and applying the forces to the front points. In the following four pictures you can see the results from the simulation.

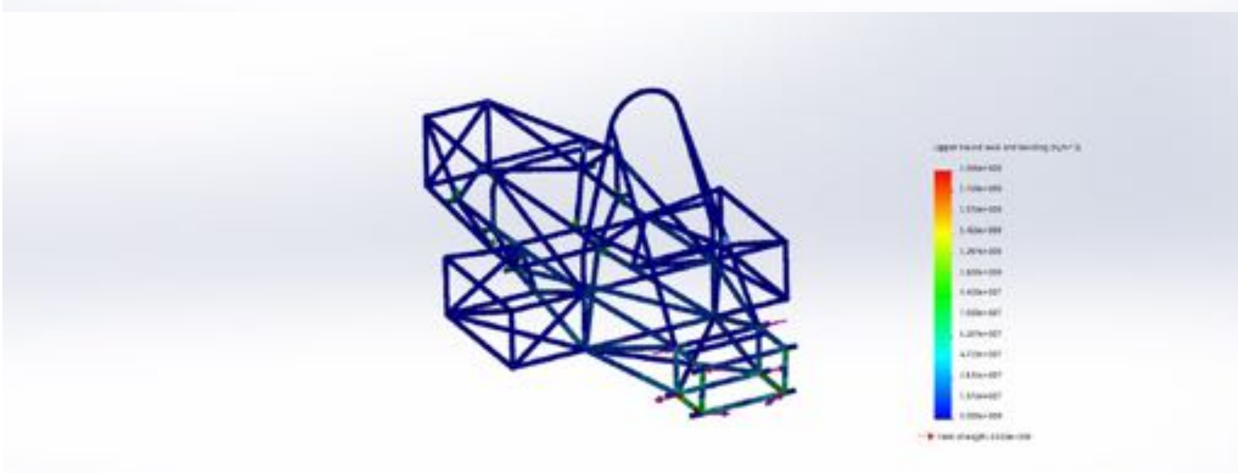
Right Turn: Rear points fixed, forces applied to front points:





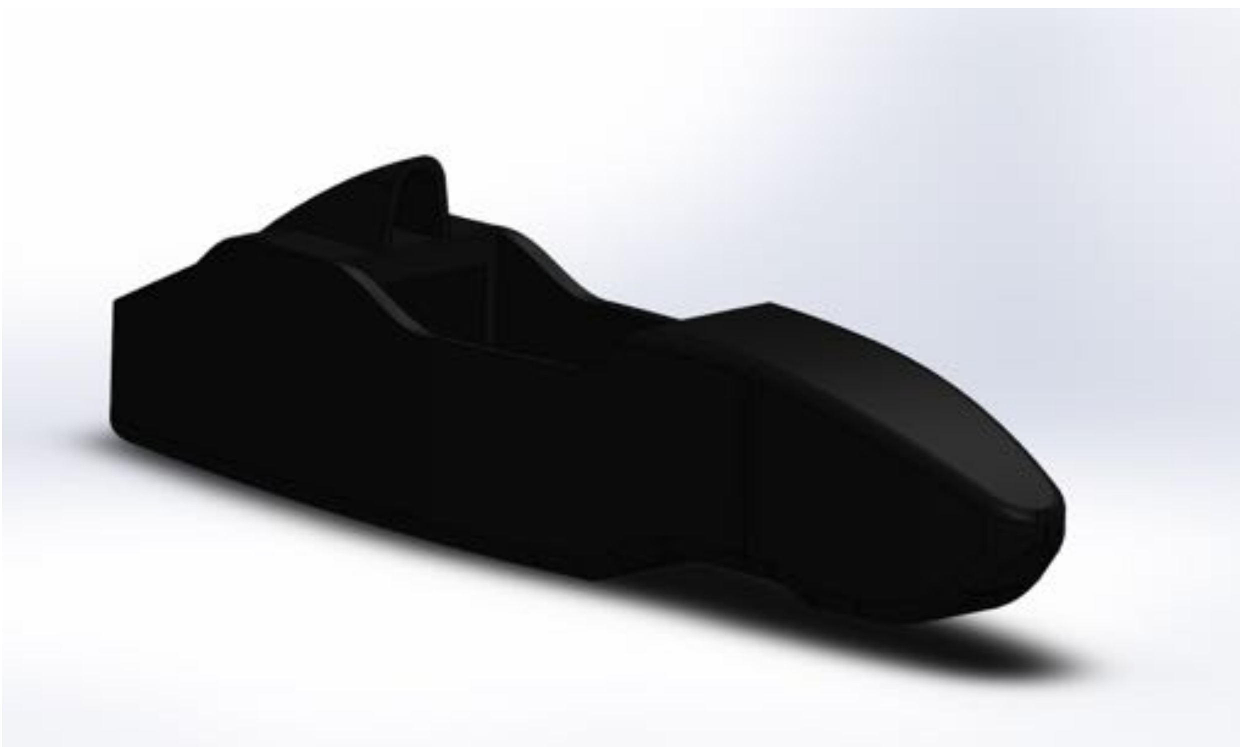
Right Turn: Front points fixed, forces applied to rear points





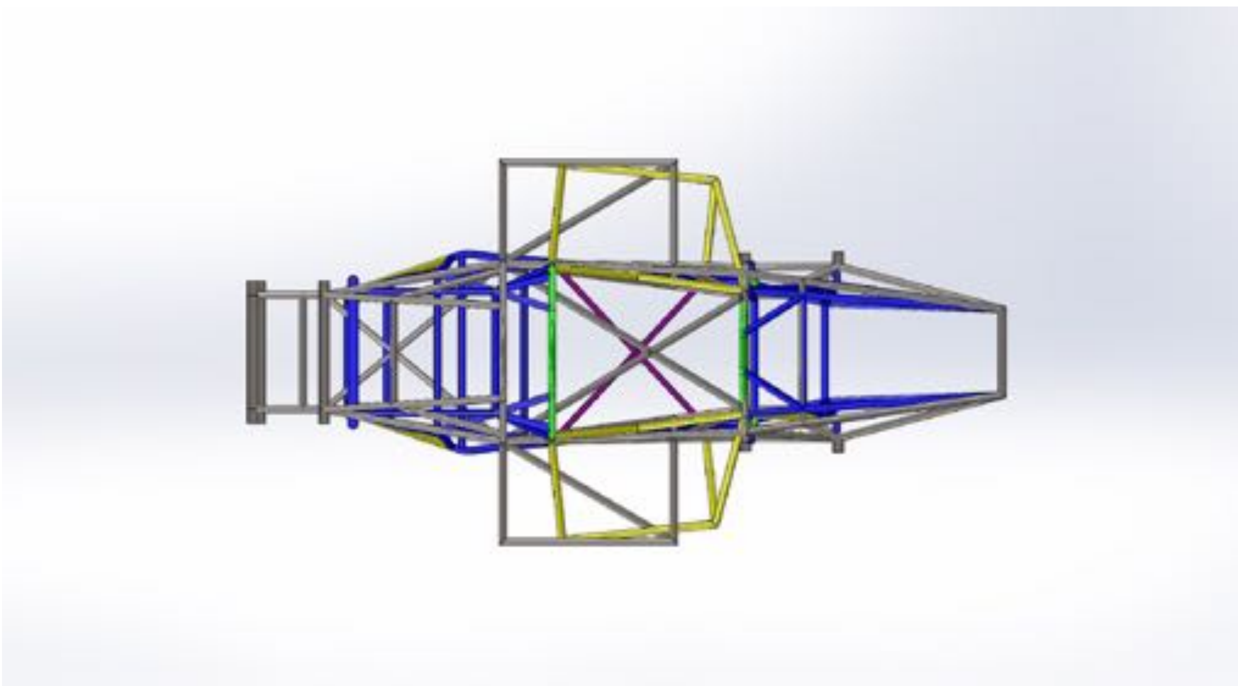
Carbon Fiber Monocoque Chassis

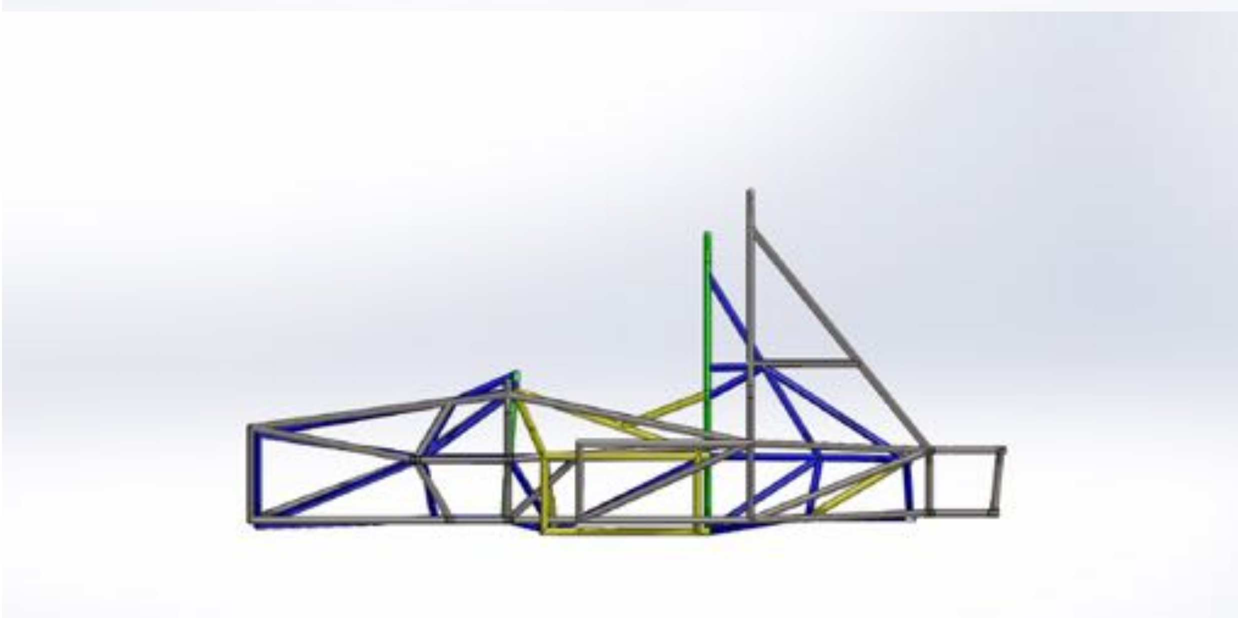
I have been working with Custom Composites to lay the groundwork for the 89/90 project that was submitted for 16F/17W. This chassis is part of a 2-year project to create a 4 hub motor car with a centralized battery pack. I believe that the monocoque chassis will become more common on cars in the near future so it is important for students at Thayer to get exposure to this new technology.



Current Design Comparison

It is interesting to compare the old chassis (colored pipes) to the new chassis that we designed. You can tell from the comparison below that the new chassis design is much larger than the old design in length, width and height. This hopefully will allow the chassis to pass through the inspection easily.





Steps to a Completed Design

Although this chassis has an integrated suspension design, driver ergonomics and space allocated to components, it does not have all the necessary members for mounting the components (like the engine and battery packs). These components may change and the design for the drivetrain will be another independent project next semester. The rear of the chassis may also need additional reinforcement to handle the torque of the motors. A complete stress analysis is required once the drivetrain has been completed. Also, if the current battery packs are reused, the mounting system should be changed because presently they are very hard to open. The dashboard and steering rack system should also be designed before ordering the chassis to ensure that the steering column can make the bend and that the steering wheel fits below the dashboard.

Conclusion

By the end of this course I felt that I had made significant progress towards a finalized chassis design. The chassis project involved a lot of collaboration between many members of our team and I feel I was able to incorporate everyone's work together into a finalized design. I would also like to thank Professor Van Citters and Raina White for taking the time to meet with all of us every week to give us feedback on our designs. I feel like the course was very organized and going through as a group kept the project very structured. All of the CAD files referred to in this document can be found in the Thayer FS Folder- **Common:\dfr\2017 DFR\CAD\Chassis.** I am looking forward to the Formula Hybrid 2016-17 season!

Appendix 1
Formula Hybrid Rules Design Criteria

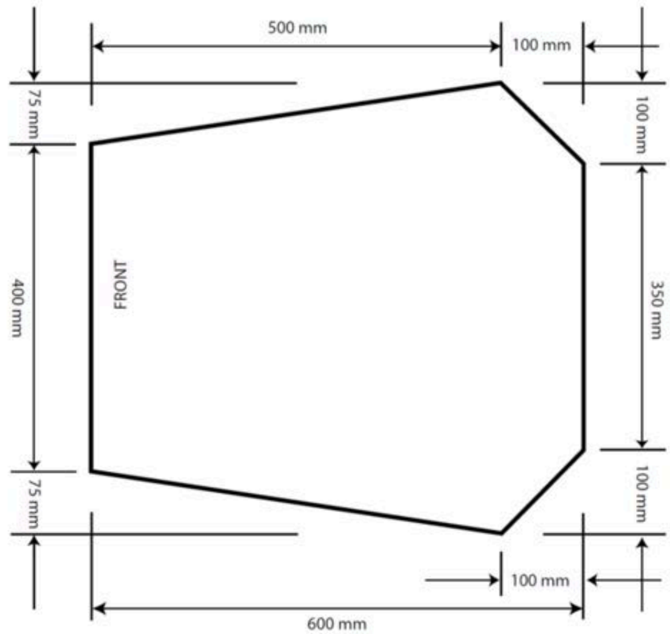
Rule #	Description
T2.1.2	Definition of "Open Wheel" – Open Wheel vehicles must satisfy all of the following criteria: (a) The top 180 degrees of the wheels/tires must be unobstructed when viewed from vertically above the wheel (b) The wheels/tires must be unobstructed when viewed from the side. (c) No part of the vehicle may enter a keep-out-zone defined by two lines extending vertically from positions 75 mm in front of and 75 mm behind the outer diameter of the front and rear tires in side view elevation of the vehicle with the tires steered straight ahead. This keep-out zone will extend laterally from the outside plane of the wheel/tire to the inboard plane of the wheel/tire.
T2.3	Wheelbase The car must have a wheelbase of at least 1525 mm. The wheelbase is measured from the center of ground contact of the front and rear tires with the wheels pointed straight ahead.
T3.1.1	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.
T3.2	The following definitions apply throughout the Rules document: Main Hoop - A roll bar located alongside or just behind the driver's torso. (b) Front Hoop - A roll bar located above the driver's legs, in proximity to the steering wheel. (c) Roll Hoops – Both the Front Hoop and the Main Hoop are classified as "Roll Hoops" (d) Roll Hoop Bracing Supports – The structure from the lower end of the Roll Hoop Bracing back to the Roll Hoop(s). (e) Frame Member - A minimum representative single piece of uncut, continuous tubing. (f) 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. (g) Primary Structure – The Primary Structure is comprised of the following Frame components (i) Main Hoop (ii) Front Hoop (iii) Roll Hoop Braces and Supports (iv) Side Impact Structure (v) Front Bulkhead (vi) Front Bulkhead Support System (h) 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. (i) 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. (j) Impact Attenuator – A deformable, energy absorbing device located forward of the Front Bulkhead. (k) Side Impact Zone – The area of the side of the car extending from the top of the floor to 350 mm above the ground and from the Front Hoop back to the Main Hoop. (l) 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".
T3.3.1	Baseline Steel Material The Primary Structure of the car must be constructed of: Either: Round, mild or alloy, steel tubing (minimum 0.1% carbon) of the minimum

	dimensions specified in Table 5. Or: Approved alternatives per Rules T3.3, T3.4, T3.5 and T3.6. Bending and buckling strength calculations: See Rules
T3.4.4	To be considered as a structural tube in the SES Submission (T3.8) tubing cannot have an outside dimension less than 25 mm or a wall thickness less than that listed in T3.5 or T3.6.
T3.4.5	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.
T3.4.6	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 T3.27, T3.28, T3.29, T3.30 and T3.33 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 T3.3 and a laminate panel, the panel only needs to be equivalent to two side-impact tubes.
T3.9	Main and Front Roll Hoops – General Requirements T3.9.1 The driver's head and hands must not contact the ground in any rollover attitude. T3.9.2 The Frame must include both a Main Hoop and a Front Hoop as shown in Figure 4. T3.9.3 When seated normally and restrained by the Driver's Restraint System, the helmet of a 95th percentile male (anthropometrical data; See Table 7 and Figure 5) and all of the team's drivers must: (a) Be a minimum of 50.8 mm from the straight line drawn from the top of the main hoop to the top of the front hoop. (Figure 4a) (b) Be a minimum of 50.8 mm 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 4b) (c) Be no further rearwards than the rear surface of the main hoop if the main hoop bracing extends forwards. (Figure 4c) T3.9.4 The 95th percentile male template (Percy) will be positioned as follows: (See Figure 6) (a) The seat will be adjusted to the rearmost position, (b) The pedals will be placed in the most forward position. (c) 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. (d) The middle 200 mm circle, representing the shoulders, will be positioned on the seat back. (e) The upper 300 mm circle will be positioned no more than 25.4 mm away from the head restraint (i.e. where the driver's helmet would normally be located while driving). T3.9.5 Drivers who do not meet the helmet clearance requirements of T3.9.3 will not be allowed to drive in the competition. T3.9.6 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. T3.9.7 The Main Hoop and Front Hoop must be securely integrated into the Primary Structure using gussets and/or tube triangulation.
T3.10	Main Hoop T3.10.1 The Main Hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing per Rule **T3.3.1** T3.10.2 The use of aluminum alloys, titanium alloys or composite materials for the Main Hoop is prohibited. T3.10.3 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.

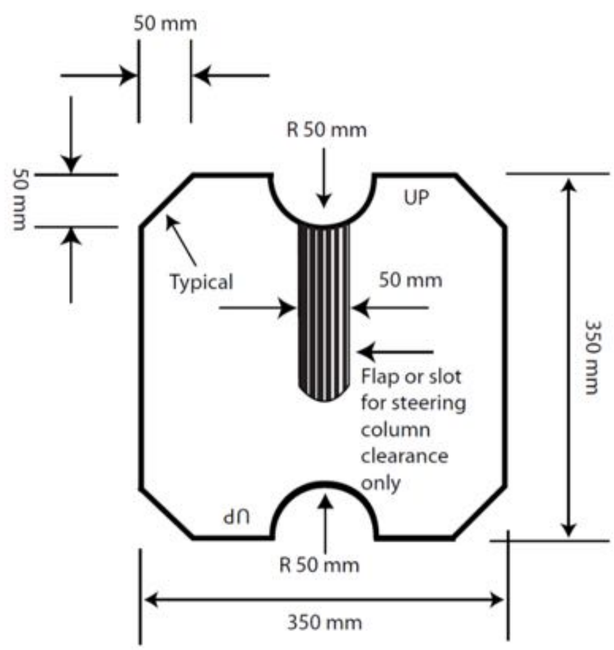
	T3.10.4 In the side view of the vehicle, the portion of the Main Roll Hoop that lies above its attachment point to the Major Structure of the Frame must be within ten degrees (10°) of the vertical. T3.10.5 In the side view of the vehicle, any bends in the Main Roll Hoop above its attachment point to 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 **T3.3.1** T3.10.6 In the front view of the vehicle, the vertical members of the Main Hoop must be at least 380 mm apart (inside dimension) at the location where the Main Hoop is attached to the Major Structure of the Frame.
T3.11	Front Hoop T3.11.1 The Front Hoop must be constructed of closed section metal tubing per Rule **T3.3.1**. T3.11.2 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. T3.11.3 With proper gusseting and/or triangulation, it is permissible to fabricate the Front Hoop from more than one piece of tubing. T3.11.4 The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position. T3.11.5 The Front Hoop must be no more than 250 mm 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. T3.11.6 In side view, no part of the Front Hoop can be inclined at more than twenty degrees (20°) from the vertical.
T3.12	Main Hoop Bracing T3.12.1 Main Hoop braces must be constructed of closed section steel tubing. T3.12.2 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. T3.12.3 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. T3.12.4 The Main Hoop braces must be attached as near as possible to the top of the Main Hoop but not more than 160 mm 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 7
T3.13	Front Hoop Bracing T3.13.1 Front Hoop braces must be constructed of material per Rule **T3.3.1**. T3.13.2 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. T3.13.3 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. T3.13.4 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 below the top-most surface of the Front Hoop. See: **Figure 7** T3.13.5 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 **T3.3.1**.

T3.15	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	Frontal Impact Structure T3.17.1 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. T3.17.2 Forward of the Front Bulkhead must be an energy-absorbing Impact Attenuator.
T3.19	Front Bulkhead Support T3.19.1 The Front Bulkhead must be securely integrated into the Frame. T3.19.2 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 of its top-most surface), one (1) at the bottom, and one (1) as a diagonal brace to provide triangulation. T3.19.3 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. T3.19.4 All the Frame Members of the Front Bulkhead Support system listed above must be constructed of closed section tubing per Section T3.3.1.
T3.24	Side Impact Structure for Tube Frame Cars The Side Impact Structure must meet the requirements listed below. T3.24.1 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 11. T3.24.2 The three (3) required tubular members must be constructed of material per Section T3.3. T3.24.3 The locations for the three (3) required tubular members are as follows: (a) The upper Side Impact Structural member must connect the Main Hoop and the Front Hoop. With a 77 kg driver seated in the normal driving position all of the member must be at a height between 300 mm and 350 mm above the ground. The upper frame rail may be used as this member if it meets the height, diameter and thickness requirements. (b) The lower Side Impact Structural member must connect the bottom of the Main Hoop and the bottom of the Front Hoop. The lower frame rail/frame member may be this member if it meets the diameter and wall thickness requirements. (c) The diagonal Side Impact Structural member must connect the upper and lower Side Impact Structural members forward of the Main Hoop and rearward of the Front Hoop. T3.24.4 With proper gusseting and/or triangulation, it is permissible to fabricate the Side Impact Structural members from more than one piece of tubing. T3.24.5 Alternative geometry that does not comply with the minimum requirements given above requires an approved "Structural Equivalency Spreadsheet" per Rule T3.8.

T4.1 Cockpit Opening Template:



T4.2 Cockpit Internal Cross Section:



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