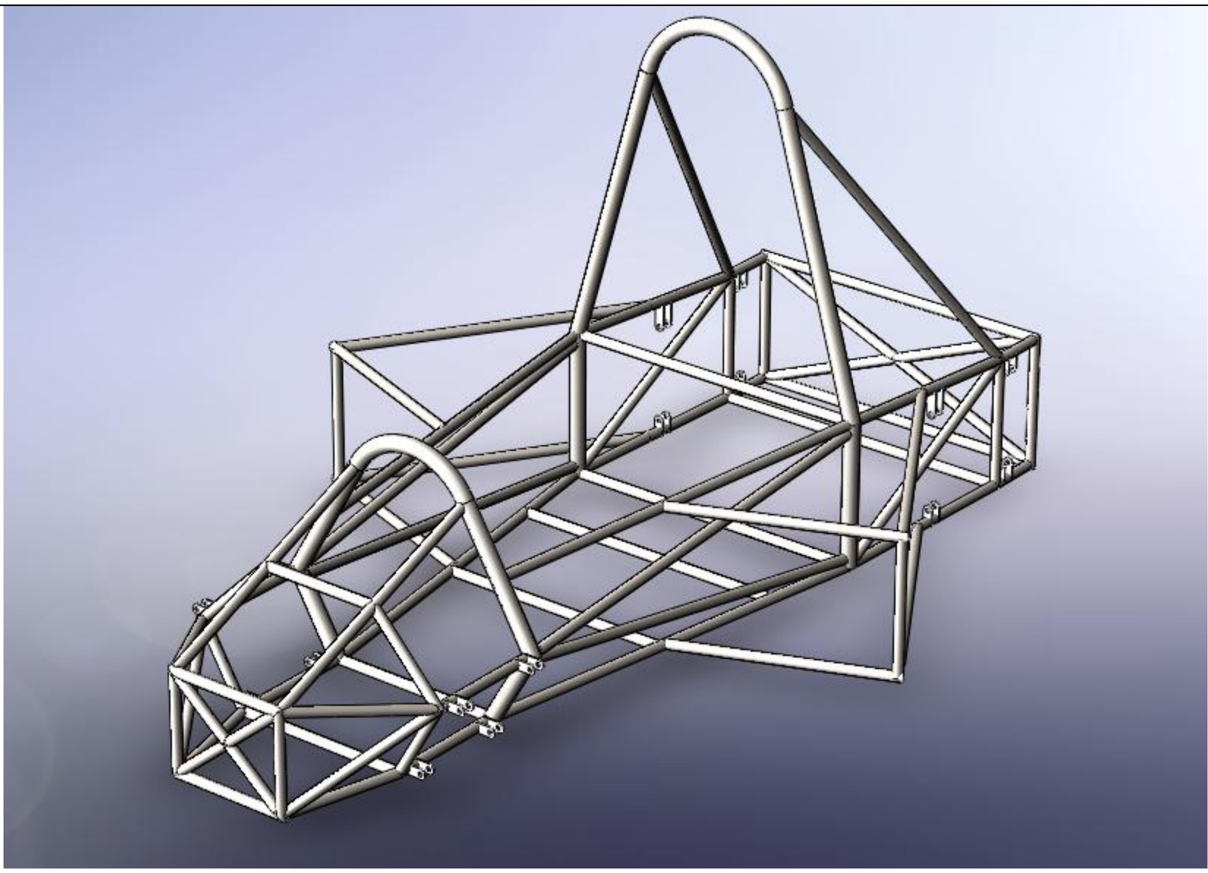
CHASSIS



Chassis Design Considerations

Design of the 2011 BHR Formula SAE race car began with the frame. There are several factors that must be considered when designing the frame.

- Stiffness

Normally, a race car chassis should be as stiff as possible to withstand torsion. This is to facilitate easier suspension tuning. When determining the handling qualities of a race car, one of the most effective methods of adjusting the amount of over-steer and under-steer is the adjustment of roll stiffness, front-to-rear. By increasing front roll stiffness while decreasing rear roll stiffness, both rear tires are more equally weighted than the front tires. The force on the outside front tire quickly overwhelms the traction available to it, and the car under-steers. Conversely, with a large amount of rear roll stiffness and a small amount of front roll stiffness, the inside rear tire is lifted during a turn, the amount of available rear traction is reduced, and the car over-steers. By tuning the stiffness of the anti-roll bars, it is possible to affect the balance of the car. However, torsional flex in the frame adds another spring to this two-spring system. This makes tuning much more difficult, and in extreme cases, impossible. Some torsional compliance in the frame is actually desirable with this year's suspension design.

- Weight

As discussed earlier, wherever possible, weight should be minimized. All tubing sizes not dictated by the rules were chosen to be as light as possible while remaining structurally sound and suitably stiff. Just as important as weight, is mass moment of inertia. A car with a lower mass moment of inertia will be able to turn more quickly. In order to reduce mass moment of inertia, all weight on the chassis is pushed as far as possible towards the centre of the vehicle.

- Fitment and Packaging

Possibly the most difficult criterion to satisfy is fitment. This criterion determines the functionality of the chassis. The chassis must accommodate the driver, as well as the engine, suspension components, and templates while remaining as light and small as possible. While a problem with structural integrity or stiffness can usually be solved by simply varying the wall thickness or diameter of a tube, the challenge of fitting all components into the smallest space possible rarely has clear or straightforward solutions. Multiple iterations and brainstorming sessions are usually required for fitment problems.

Chassis Construction Methods

The team had several choices for construction methods for the frame:

- Tubular space-frame

The most common frame type, the tubular space-frame, is a structure composed of many small, usually round tubes bent to shape and welded together. Tubular space-frames do not require specialized machinery or equipment for manufacture, and they are inexpensive and can be constructed from a wide variety of readily available materials. The Formula SAE rules dictate many of the tubing sizes for a steel tubular space-frame, and construction of any other type of chassis requires proof that the alternate structure is as strong or stronger than a similar tubular space-frame structure.

- Metal Monocoque

A monocoque chassis is a structure that constitutes both the frame and the body. By combining these two critical components into one piece, it is sometimes possible to build a light car. In a metal monocoque design, the chassis and body are fabricated from aluminium or steel sheet, welded or riveted together.

- Composite Monocoque

Composite monocoque frames are usually among the lightest. The strength to weight and stiffness to weight ratios of carbon fibre and similar composite materials are generally much higher than those of steel or aluminium, and the non-uniform nature of a moulded frame allows for a great deal of optimization. However, composite monocoque usually requires a unique mould for production, and a design change generally requires a new mould to be made. Composite monocoque is rarely easily repairable, and the materials required for their construction are expensive and often difficult to work with.

Chassis Material Considerations

The 2011 BHR team decided to use a tubular space-frame due to cost, ease of construction, and facilities available. Additionally, no extra analysis is required for Structural Equivalency Forms, which affords the team extra time for further analysis and testing. Because the chassis is a tubular space-frame design, the materials used in its construction were limited to readily available, easily weldable materials. In the interest of simplicity, it was decided that all tube members would be made from the same type of material. The following materials were considered:

- Steel

The most common material for tubular space-frames, steel retains its strength and ductility after welding. It is inexpensive, easy to find, and easy to cut and grind. The Formula SAE rules dictate tubing sizes for steel, and the use of any other material requires the completion of a structural equivalency form.41.

- Aluminium

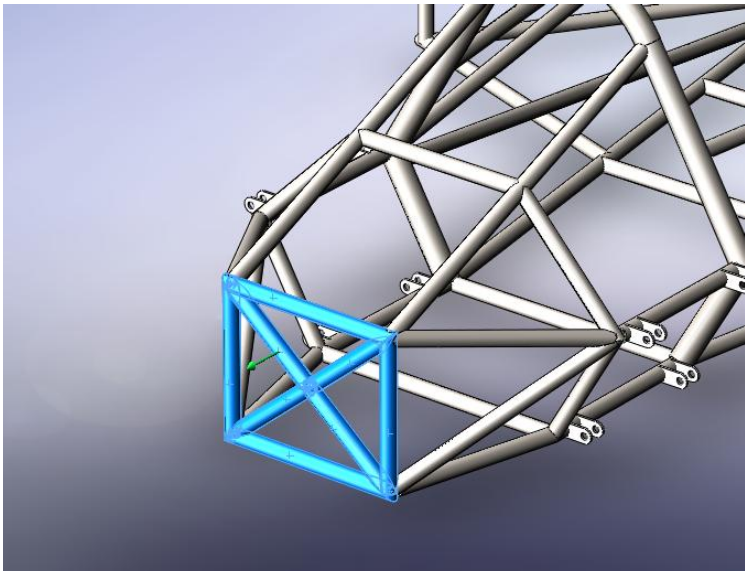
Aluminium, while not as strong as steel, is lighter. Its stiffness is roughly one third that of steel; however, so is its weight. It can be welded with common TIG and MIG processes; however, it loses significant strength unless heat treated. When used on a tubular space-frame chassis, it must be accompanied by a structural equivalency form. Additionally, the main and front hoops must be made from steel.

For ease of construction, the chassis is made from steel. In order to determine the type of steel to be used, further analysis is necessary. In the interest of safety, the Formula SAE rules dictate most of the tubing sizes used. The chassis can be broken up into three plane structures and two tubular sections that connect them. Starting from the front of the chassis and working back, these sections are:

- Front Bulkhead

The front bulkhead, as defined by the FSAE rules, is “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”. The front bulkhead is to be made from 1.0 inch diameter 0.065 inch wall thickness steel. On the 2011 car, the front bulkhead is simply a rectangular structure which is 250mm tall by 300mm wide, measured at the tubing centreline.

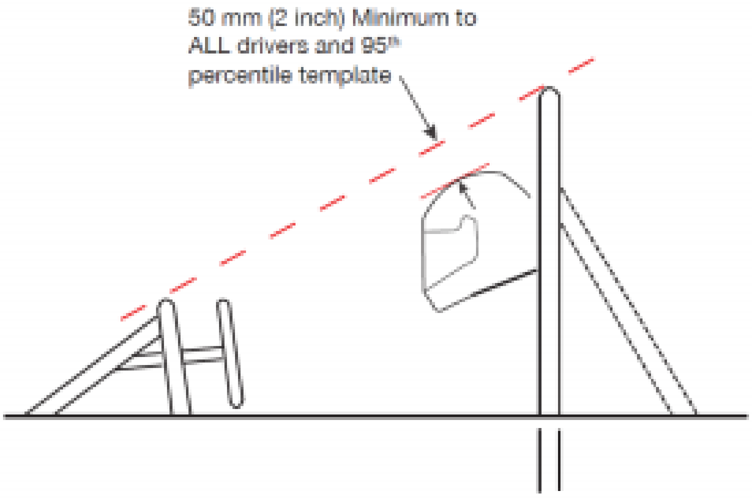
The joints are mitred at 45 degrees for easy welding. The size and shape of the front bulkhead are determined by ease of construction and in order to give the driver ample foot room.



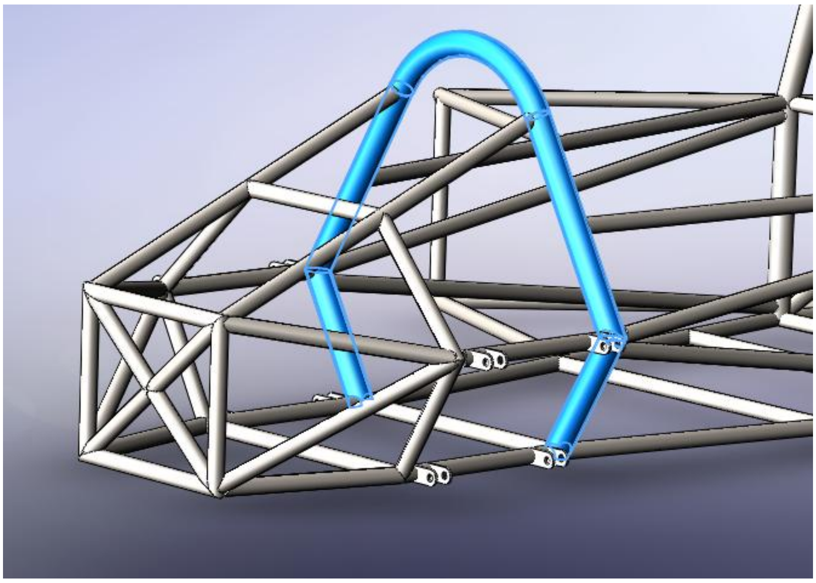
Front bulkhead on chassis

- Front Roll Hoop

According to the FSAE Rules, the front roll hoop is “a roll bar located above the driver’s legs, in proximity to the steering wheel.” The front roll hoop is to be made from 40mm diameter 0.095 inch wall thickness steel. It must be tall enough to allow drivers to fit into the chassis while passing the “2-inch rule,” which states that a line drawn from the top of the main hoop to the top of the front hoop must be at least 2 inches from the top of any seated driver’s helmet.



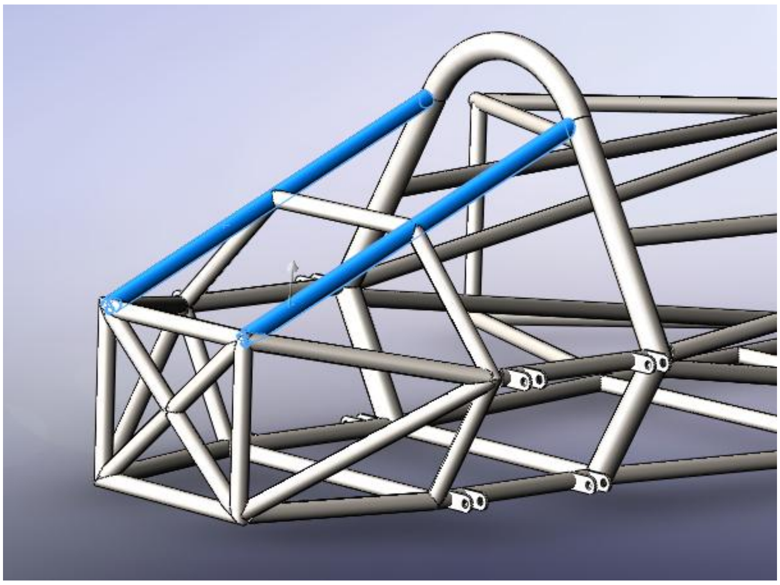
"2 inch rule" for helmet clearance



Front roll hoop

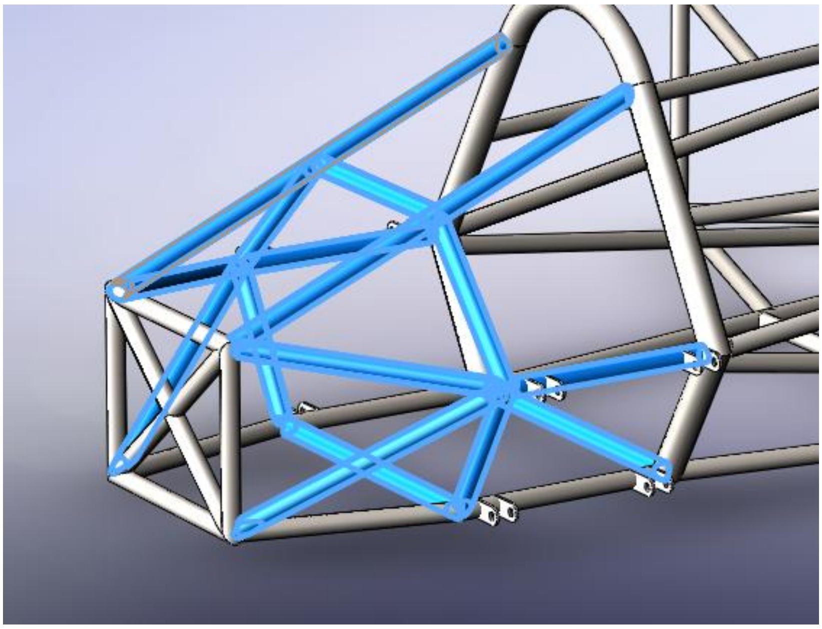
- Front Bulkhead Support System and Front Hoop Supports

This is the structure which connects the front hoop and front bulkhead. The rules state that the front bulkhead support system must be made from 1.0 inch diameter 0.049 inch wall thickness steel tubing properly triangulated node-to-node (no tubes in bending). Additionally, the front hoop must be supported by front hoop supports, integrated securely into the rest of the structure. These tubing members are shown and must also support the front suspension attachment points, as well as shock attachments. They must also be placed to accommodate feet of the driver along with the pedal assemblies and steering rack.



Front hoop support

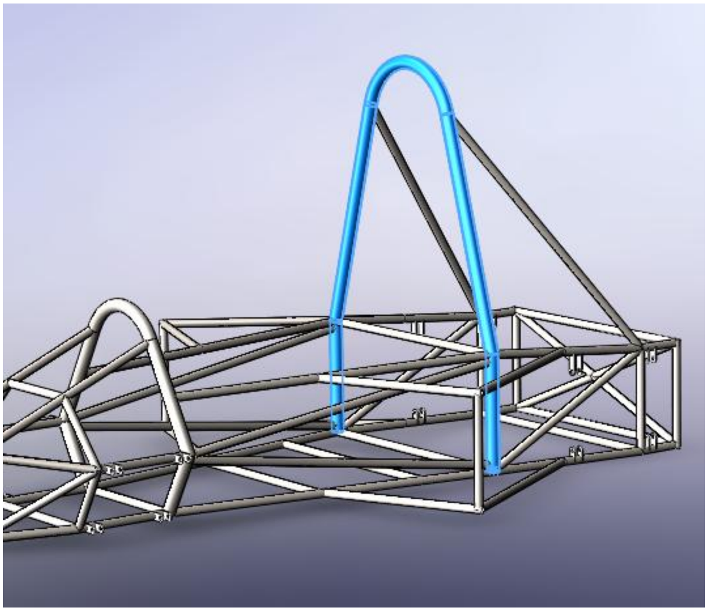
The bulkhead support system was made by incorporating the front suspension box in a support structure that supports the front hoop support, bulkhead and triangulated with the base rod. This approach is somewhat link extensive. However, it allows all forces to be fully resolved without putting any frame members in bending. Additionally, it easily contains the driver's legs and feet in all situations, and allows for easier mounting of the brake pedal and other hardware.



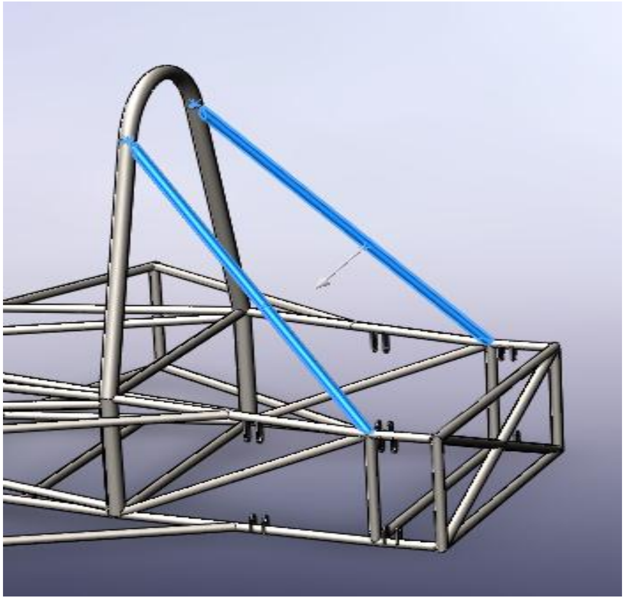
Front bulkhead support system

- Main Hoop, Main Hoop Bracing, Shoulder Harness Mounting Bar

The main hoop is “a roll bar located alongside or just behind the driver’s torso.” The main hoop is to be constructed from 1.0 inch diameter 0.095 inch wall thickness steel, the same material as the front hoop. It is constructed from a single piece, bent to shape. There are five bends, which are all coplanar, facilitating easy manufacturing. The shape of the main hoop is designed to accommodate the templates when attached to the main hoop braces, as well as the side impact members. The main hoop height dimension is only tall enough to facilitate passing the 2-inch rule. The main hoop braces are 40mm diameter 0.065 inch wall thickness tubing.
The main hoop braces can be routed towards the front or back of the chassis, but they must be securely integrated into the primary structure. In most cars, the braces are routed rearwards. If the braces are routed rearwards, they are usually attached to the rear suspension pick-ups in some way, increasing the torsional rigidity of the chassis.



Main hoop

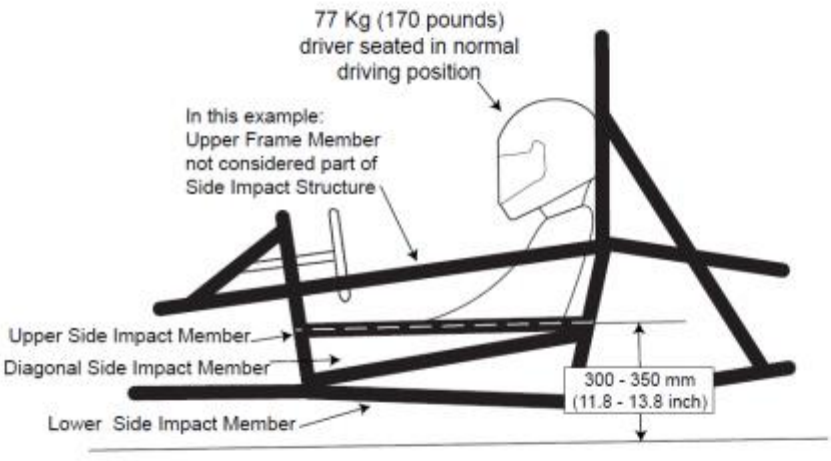


Main hoop bracing

The shoulder mounting bar is made from 1.0 inch diameter 0.065 inch wall thickness tubing, placed at shoulder height.

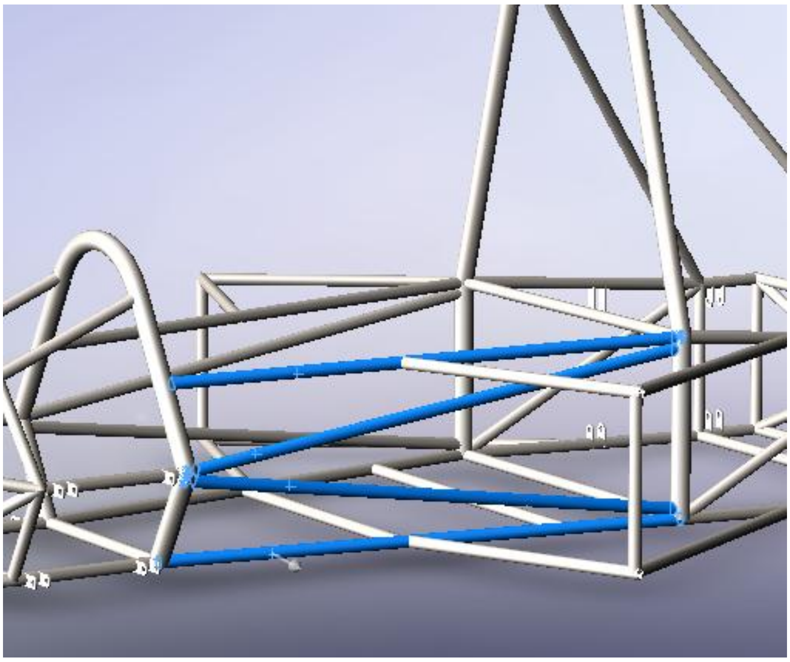
- Side Impact Structure and Side Pods

According to the rules, the driver must be protected by a side impact structure, composed of at least three tubes. There must be one upper side impact member, one lower side impact member, and one diagonal side impact member. The diagonal member can be more than one tube if it is properly triangulated, and the lower and upper side impact members can be the upper and lower frame rails if they satisfy the tubing requirements.



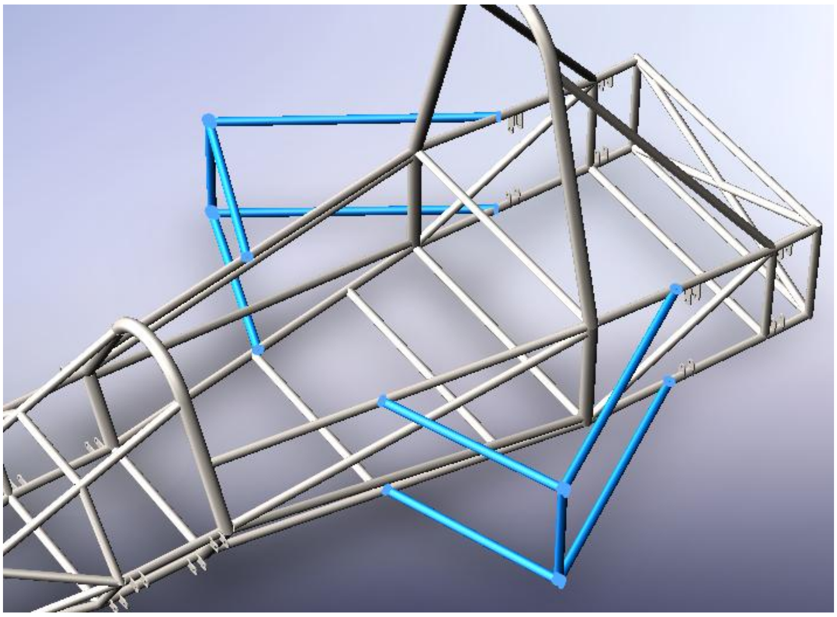
Side impact members

The team choose to provide a four member side impact structure with the lower side impact structure being the lower rail of the chassis. The upper impact structure is connected horizontally between front and main hoop. The other two members form the triangulation.



Side impact structure

Important to note is that side pod structure for the radiator are present in our design, therefor it also constitute as side impact structure. A triangular planar structure is taken to make the design simple and rigid.

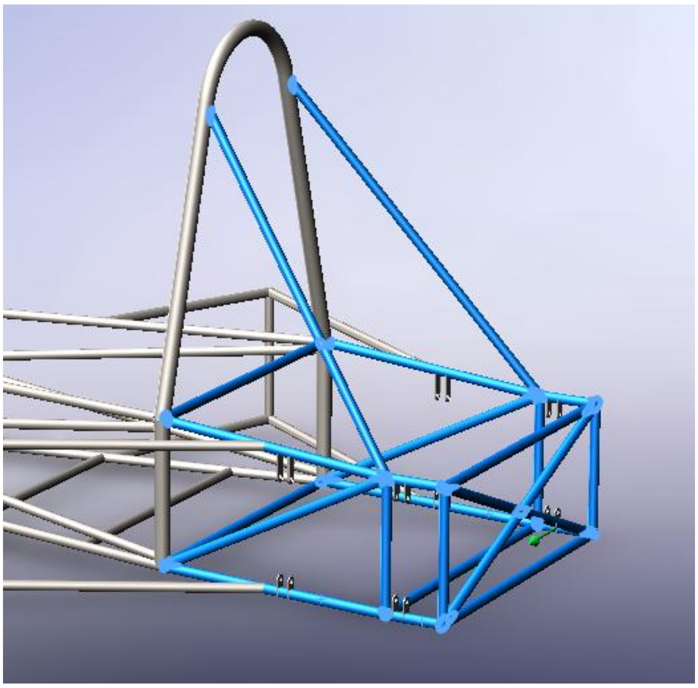


Side pod structure

- Rear Suspension and Engine Housing

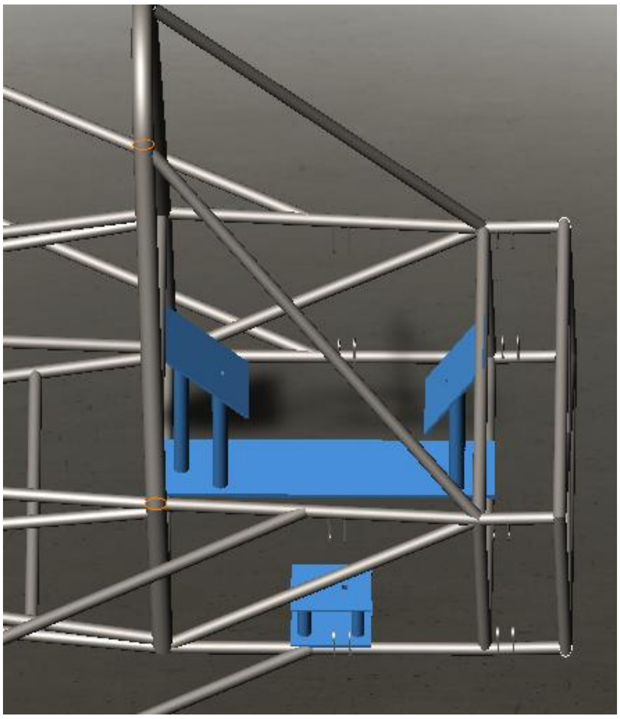
The rear of the chassis is composed of the rear bulkhead and the engine housing. The housing is designed according to the engine size and possibility of a very rigid and stable engine mount. The rear suspensions bracing is provided on the engine housing members. Proper triangulation is done to transfer the load to the main base rail of the chassis.

The engine housing members are designed so, that it should take all the engine load both static and dynamic. This imposes a requirement for the housing to be rigid and accommodate engine fully.



Engine housing

The engine mount is designed according to the mount points available on the engine. The three point mounting is the best way of mounting the engine as it keeps the engine stable in all three planes and reduces torsion on the chassis members supporting the engine mounts.



Engine mounting

- Other Members

The other members for connecting the base rails and seat support are made from the same 1 inch pipe.

STRUCTURAL ANALYSIS

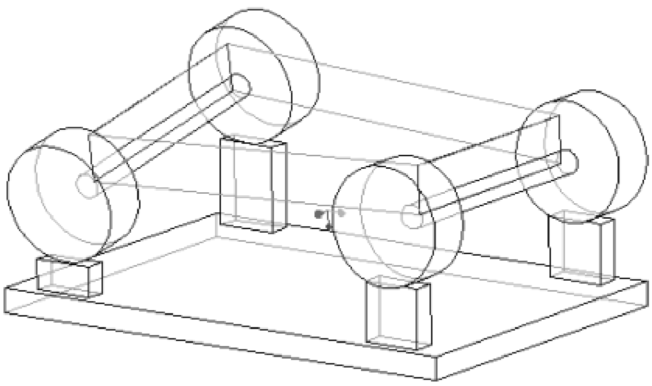
First we must understand the dynamics of a car and the different types of loading onto the chassis. A thorough understanding of the same will make it possible to answer some most crucial questions while designing a chassis.
Some key questions are: What is the best way to transfer the loads through the structure? What are the deformation modes of the structure? How stiff should the frame be in each of the deformation modes? How does the frame stiffness affect the dynamic response of the car?

Vehicle Loading

The first step to designing a vehicle frame, or any structure, is to understand the different loads acting on the structure. The main deformation modes for an automotive chassis are given in [8] as:

1. Longitudinal Torsion
2. Vertical Bending
3. Lateral Bending
4. Horizontal Lozenging

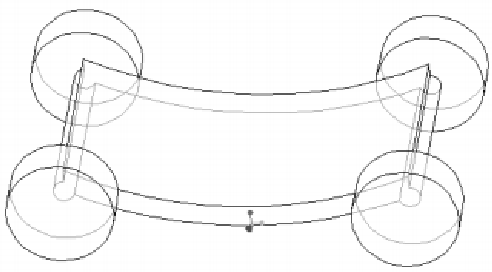
1. Longitudinal Torsion



Longitudinal Torsion Deformation Mode

Torsion loads result from applied loads acting on one or two oppositely opposed corners of the car. The frame can be thought of as a torsion spring connecting the two ends where the suspension loads act. Torsional loading and the accompanying deformation of the frame and suspension parts can affect the handling and performance of the car. The resistance to torsional deformation is often quoted as stiffness in foot-pounds per degree. This is generally thought to be the primary determinant of frame performance for a FSAE race car.

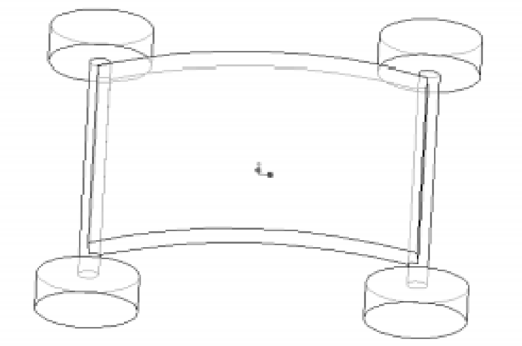
2. Vertical Bending



Vertical Bending Deformation Mode

The weight of the driver and components mounted to the frame, such as the engine and other parts, are carried in bending through the car frame. The reactions are taken up at the axles. Vertical accelerations can raise or lower the magnitude of these forces.

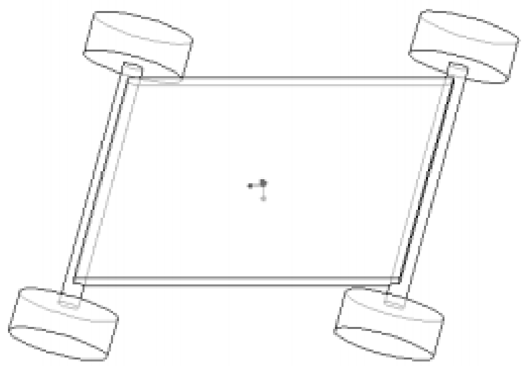
3. Lateral Bending



Lateral Bending Deformation Mode

Lateral bending loads are induced in the frame for various reasons, such as road camber, side wind loads and centrifugal forces caused by cornering. The sideways forces will act along the length of the car and will be resisted at the tires. This causes a lateral load and resultant bending.

4. Horizontal Lozenging

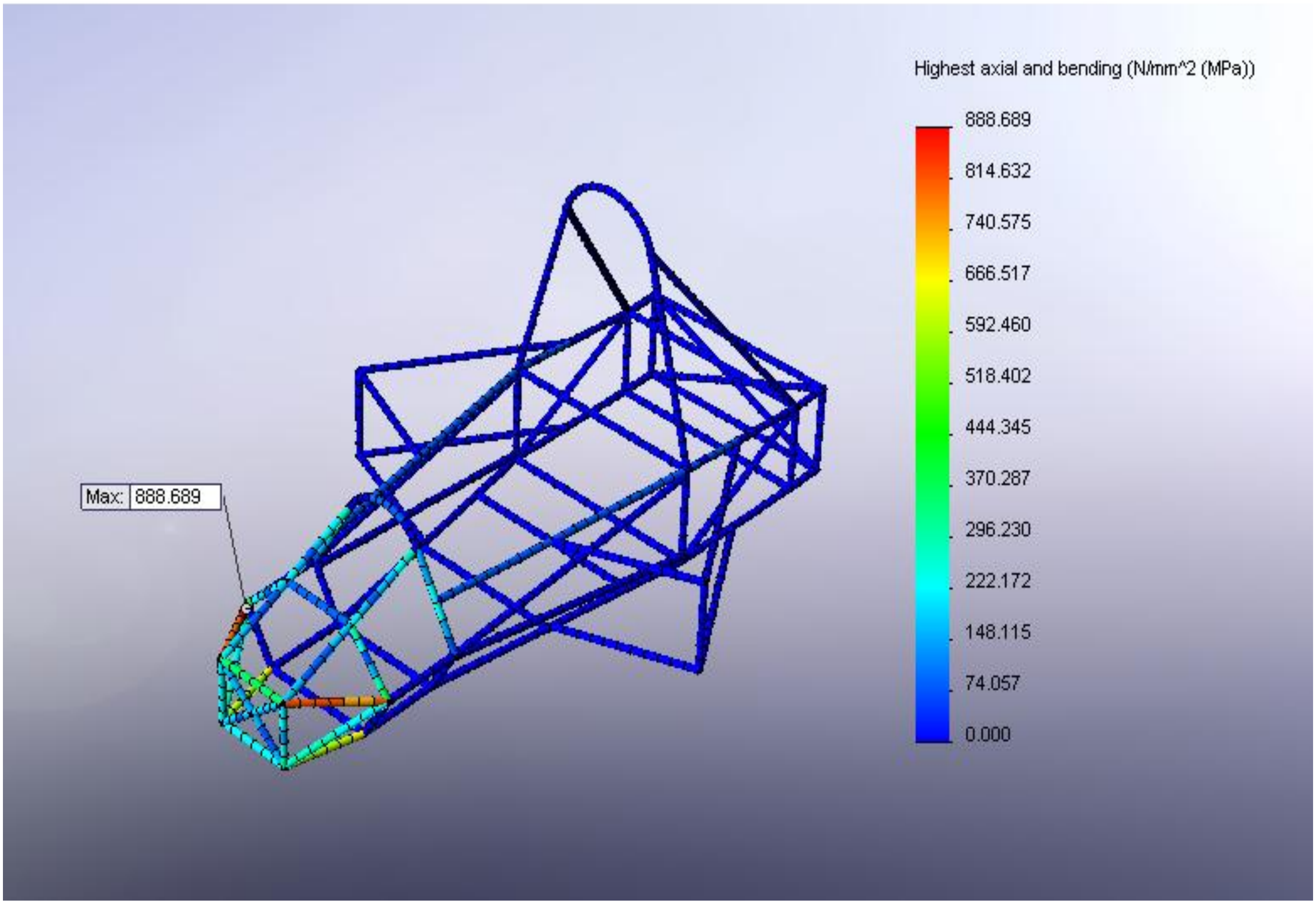


Horizontal Lozenging Deformation Mode

Forward and backward forces applied at opposite wheels cause this deformation. These forces may be caused by vertical variations in the pavement or the reaction from the road driving the car forward. These forces tend to distort the frame into a parallelogram shape as shown in the figure.

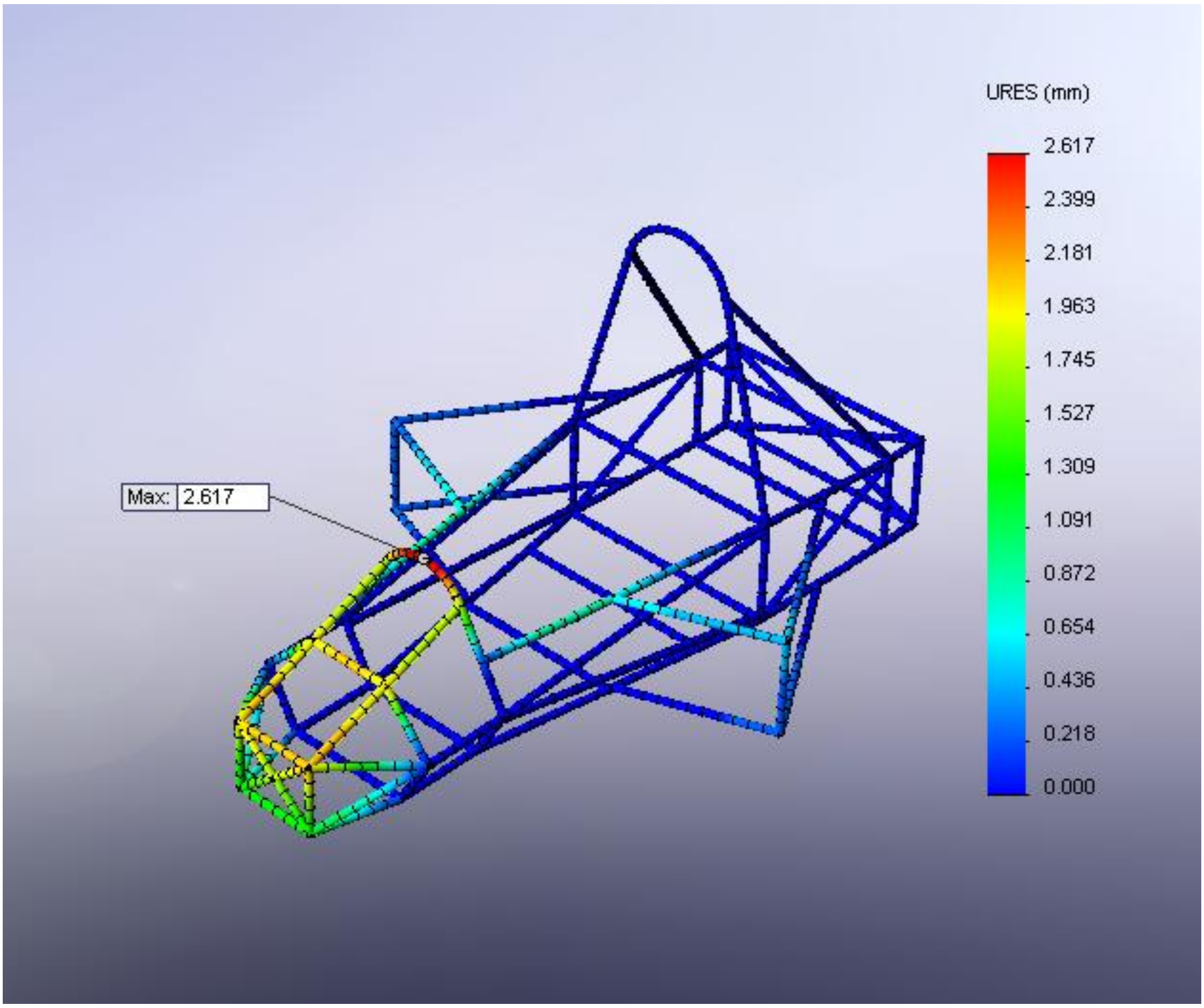
It is generally thought that if torsional and vertical bending stiffness are satisfactory then the structure will generally be satisfactory. Torsional stiffness is generally the most important as the total cornering traction is a function of lateral weight transfer.

CosmosWorks was used to validate the structural integrity of the frame. The beam mesh technique was used for analysis. In a beam mesh, all structural members of a tubular structure are approximated as a series of small beams, rather than a mesh of triangles or tetrahedrons. This is much less processor-intensive and much faster than a solid mesh or shell mesh, though obviously not suited for parts that are not composed of beam-like elements (for example, a machined part could be analysed with solid mesh, a sheet metal part could be analysed with a shell mesh, and a tubular space-frame such as this one could be analysed with a beam mesh). It is important to note, however, that a beam mesh is incapable of analysing the effects of welding on tube.



Front impact testing at 400000 N (max axial and bending stress)

For the basic front impact test we fix all the suspension pick-up points and the load is applied on the front bulk head. Here 100000 N on each corner node of the bulk head. This sum up to the total value of 400000 N static load at front bulk head nodes. As the study is static therefore the load for the impact is taken so high, as in reality an impact is an impulse and can be high. A simple real world scenario can be had on collision at full speed. The impulse can easily be calculated using equation of motion as mass of (vehicle + driver)*(top speed) which is approximately 10000 N. Thus from analysis we see that the structure is sound.

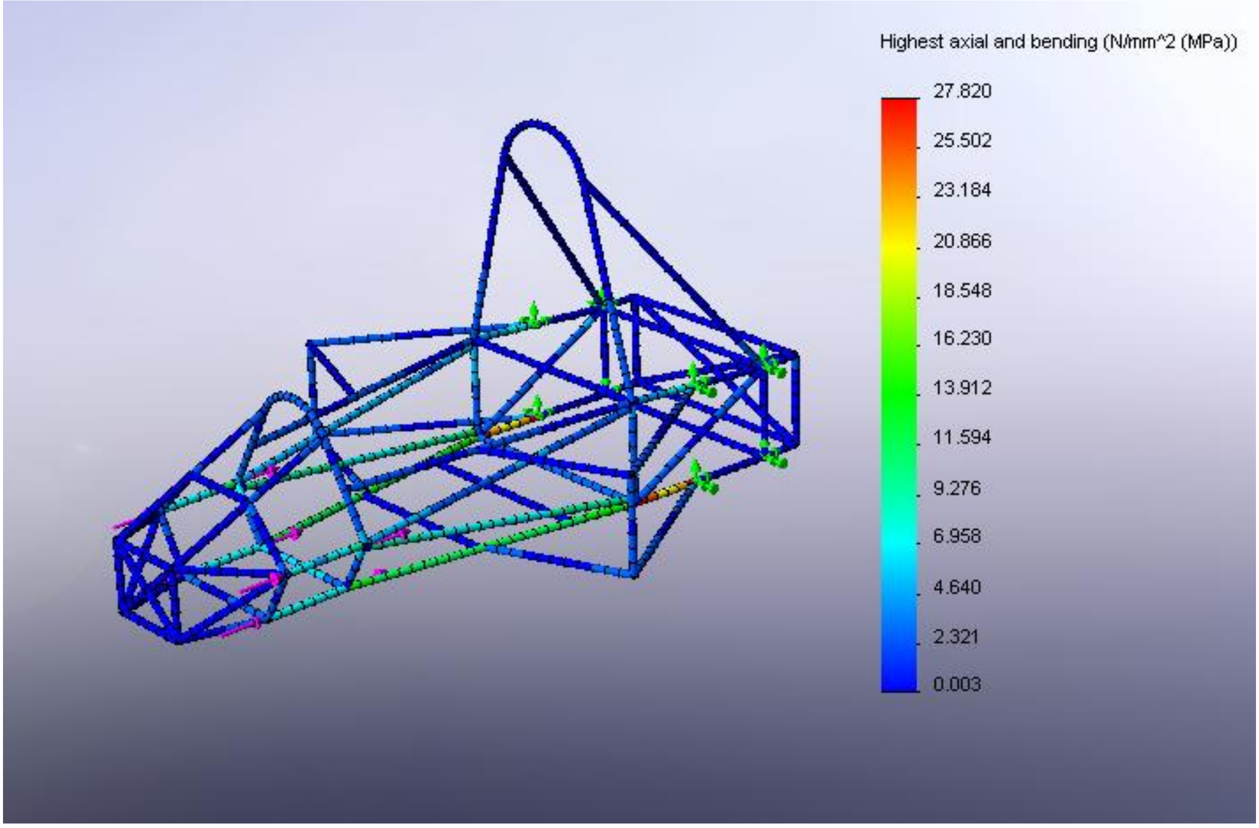


Front impact testing at 400000 N (max. displacement)

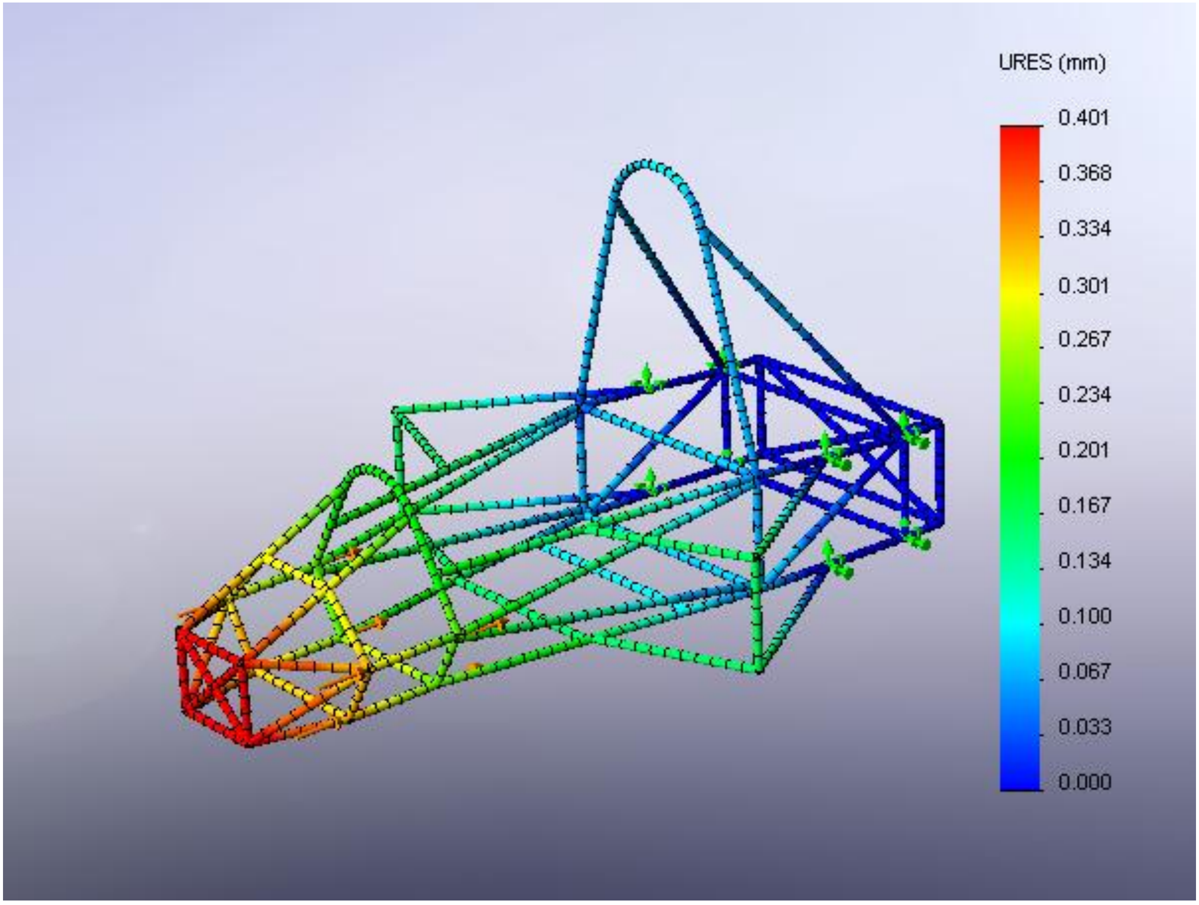
For breaking analysis, the rear suspension pick-up nodes were fixed while loads were applied to front suspension nodes. Forces are found at the tires of the chassis through simple Newtonian mechanics using $F = Ma$. For this, 2 g of longitudinal acceleration (braking) and 1.5 g of lateral acceleration (cornering) were used to find forces, and a vehicle weight of 300 Kg was used.

For maximum braking, the resulting maximum axial stress on the chassis is 27.820 MPa. This is very low when compared to the yield strength of even mild steel; however, this is an idealized, static situation. Additionally, this is during braking only, and does not take into account effects from the weight of the vehicle, or the vehicle hitting a bump during braking. Additionally, the tubing sizes used are mostly dictated by the rules, so significant weight savings are not possible without resorting to very thin tubing, which is very difficult to weld to the thicker tubing used on the front hoop. The real value in using CosmosWorks is in finding the deflections of the chassis points.

Using the same study, deflections can also be displayed. In this case of braking, the maximum deflection amount occurs at the upper front suspension attachment nodes. The deflection in this case is approximately 0.401 mm, which, although probably negligible in suspension geometry changes, is accounted for calculations. The chassis is more than capable of withstanding any and all loads encountered during normal driving. However, it cannot be made lighter because of the rules and manufacturability.



Stress analysis on hard breaking



Displacement analysis on hard breaking

One of the most important FEA studies done with this car is the torsional rigidity study. It is deciding factor for a chassis in a FASE race car. The frame is fixed at the rear with opposite vertical forces (one up one down) going through the front suspension pick up points. This will yield the torsional spring rate k of the chassis when calculations are performed using the equation:

$$k = \frac{T}{\theta}$$

Where T is the torque applied to the pick-up points and θ is the angle that the rear of the chassis makes with respect to the front of the chassis. The plot is shown in Figure showing stress. In this case, the maximum stress is 147.597 MPa in a worst-case scenario, when a minimum FOS of 2.4 is considered. The stiffness coefficient K is found out to be 3437 Nm/deg at 2.4 FOS and 3020 Nm/deg at 8.1 FOS. These values are approximate as the restraint conditions used for the analysis do not follow the real scenario correctly. But this value of stiffness coefficient along with maximum stress and displacement give a pretty good idea of the type of material to be chosen.

It should be noted that AISI 1020 was selected for the analysis as this chassis is expected to have high deflections, which imply high stresses. If the chassis were designed for low deflections and high stiffness, mild steel would probably be appropriate, as the elastic modulus of mild steel is almost identical to that of carbon steel, even though their yield and tensile strengths are higher.

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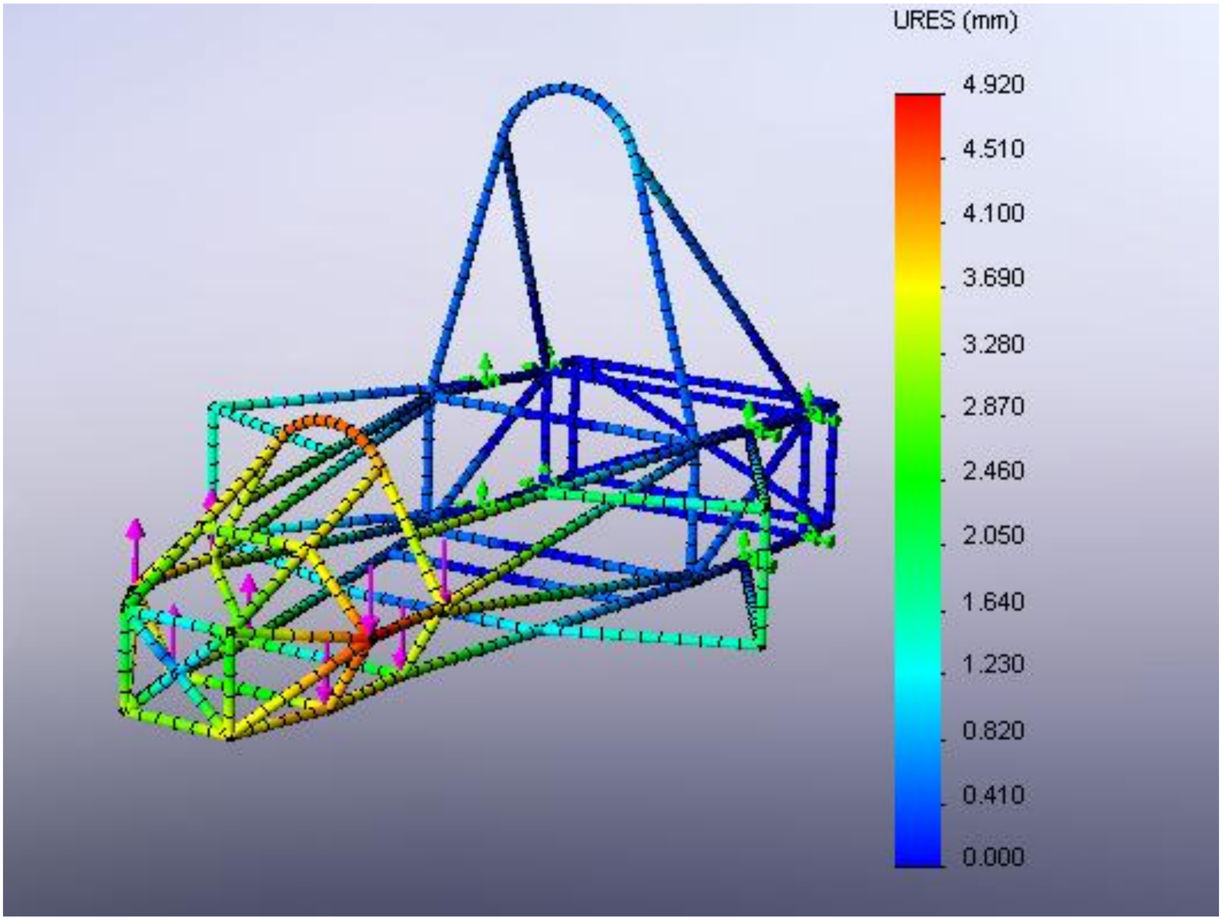
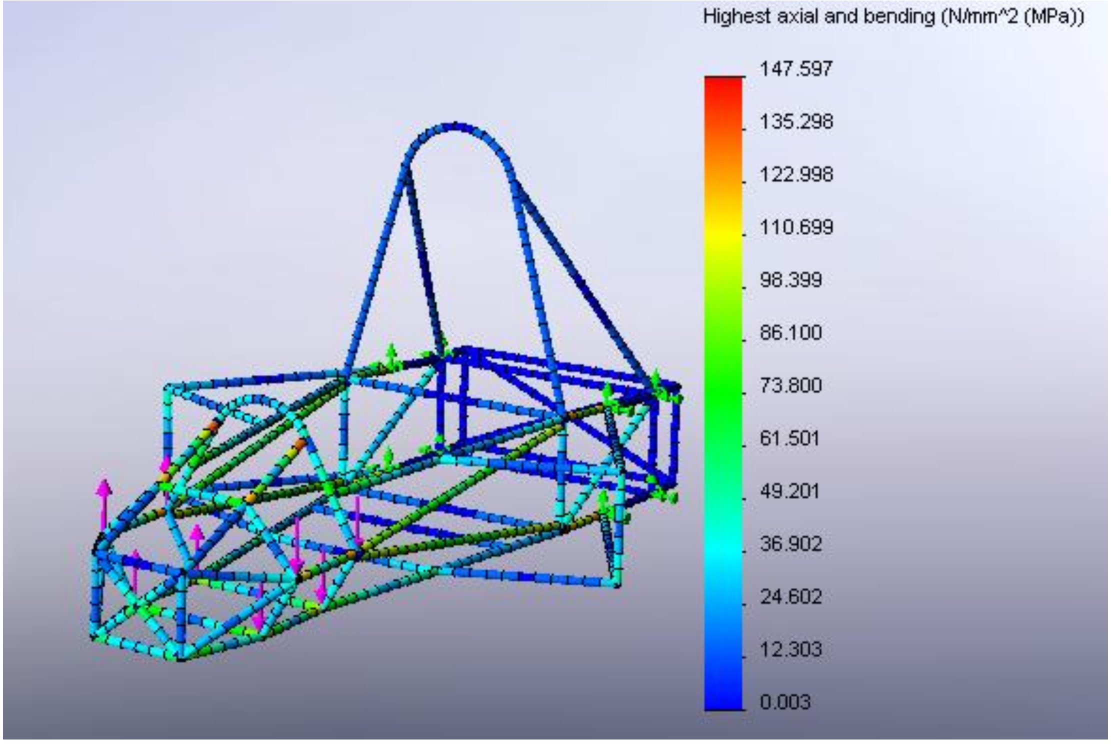
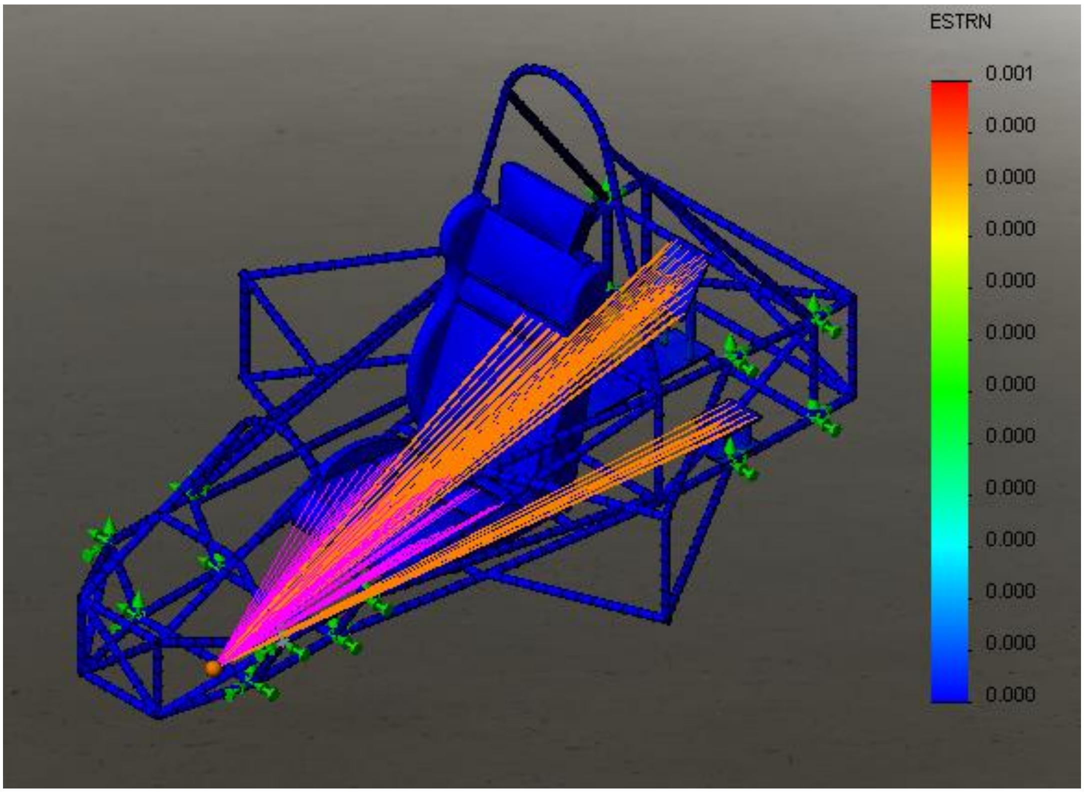


Torsional analysis (displacement

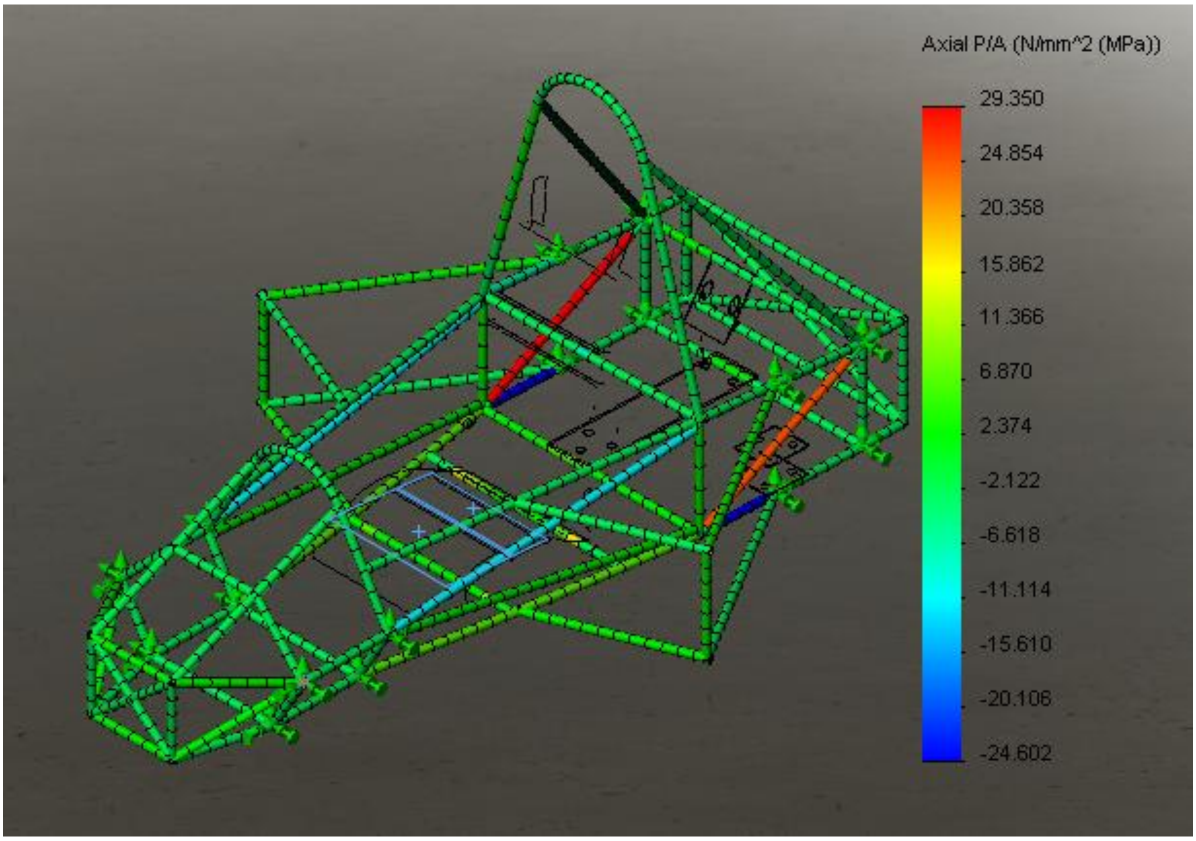


Torsional analysis (maximum stress)

Another aspect that is to be analysed is the vertical bending of the chassis under the weight of driver, engine and other components. This analysis should be carried out at the axels to get the correct value for the bending. Including the suspension in the analysis complicates the analysis. Thus, we can make the similar assumption as done for previous analysis, that the effect for different loading can be approximated to the suspension pick up points. For this analysis the front and rear pick up points are fixed and the static load of driver and engine is applied to their respective support members. It is very important to carry out the analysis with gravity defined so that the chassis weight is also included in the calculation.



Vertical bending analysis-strain (under uniformly distributed mass)



Vertical bending-stress

The maximum stress for vertical bending was found out to be 29.350 MPa, with maximum strain as 0.001 which is a very low value. The chassis is perfectly taking the major loads under static conditions.

Alternative Frame Analysis: Modal Analysis

One of the primary requirements for structure analysis is to check high stiffness to weight ratio for the chassis. This figure is very useful for designing the chassis, and dictates a design that both maximizes stiffness and reduces weight. High stiffness improves the responsiveness of the vehicle and allows for more driver feedback, and lighter weight improves handling and overall performance. Thus, a high stiffness to weight ratio indicates that the frame will perform well.

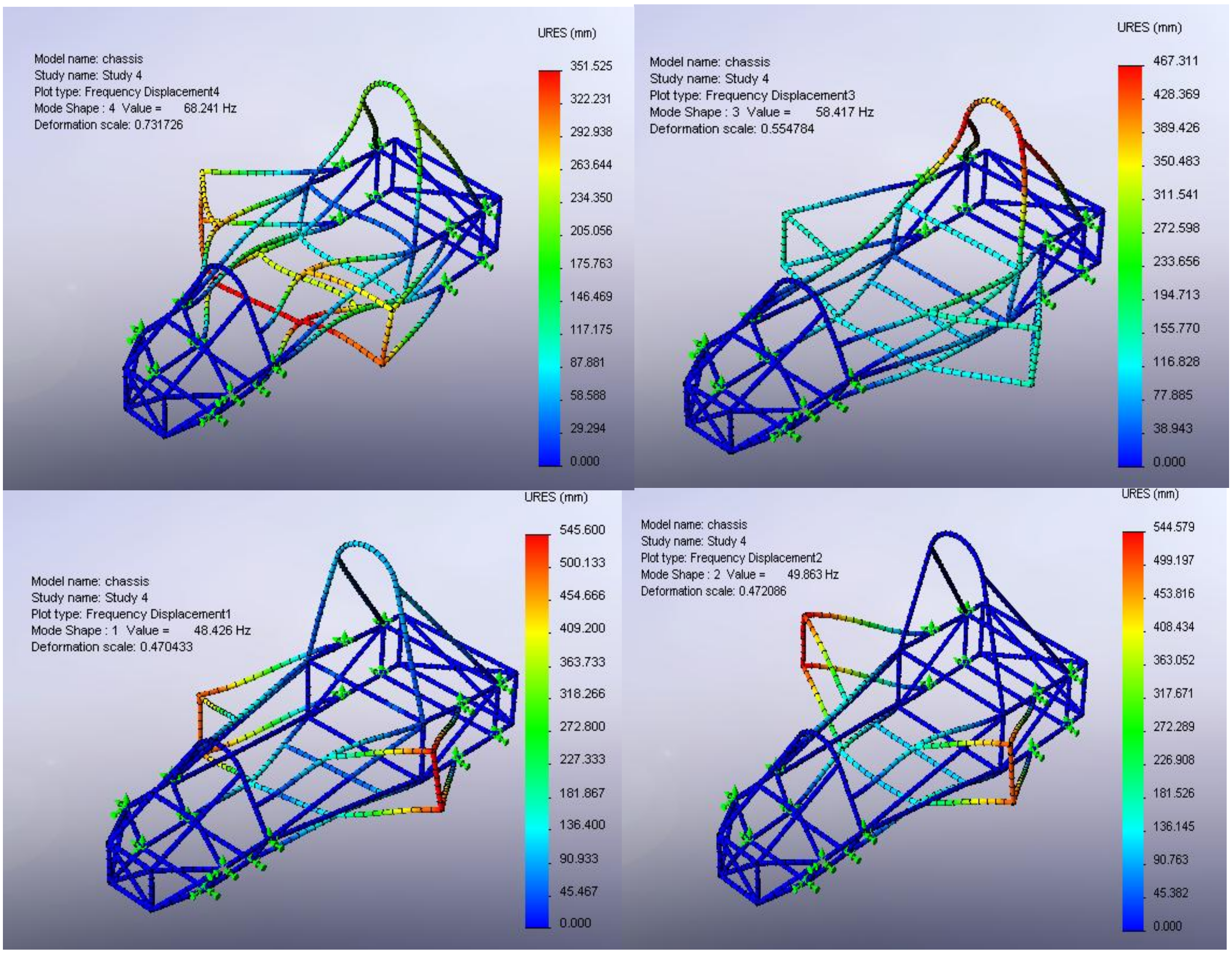
The conventional method for evaluating the stiffness to weight ratio is to both measure the weight of the bare frame, and calculate the stiffness, either in flexure or torsion. The ratio of these two numbers will then give the stiffness to weight ratio. A second method also exists to determine the stiffness to weight ratio using analysis of the response of the frame under vibration. When perturbed, any solid body will vibrate at a certain frequency, known as its natural frequency. The natural frequency is defined as follows:

$$\omega_n = \sqrt{\frac{k}{m}}$$

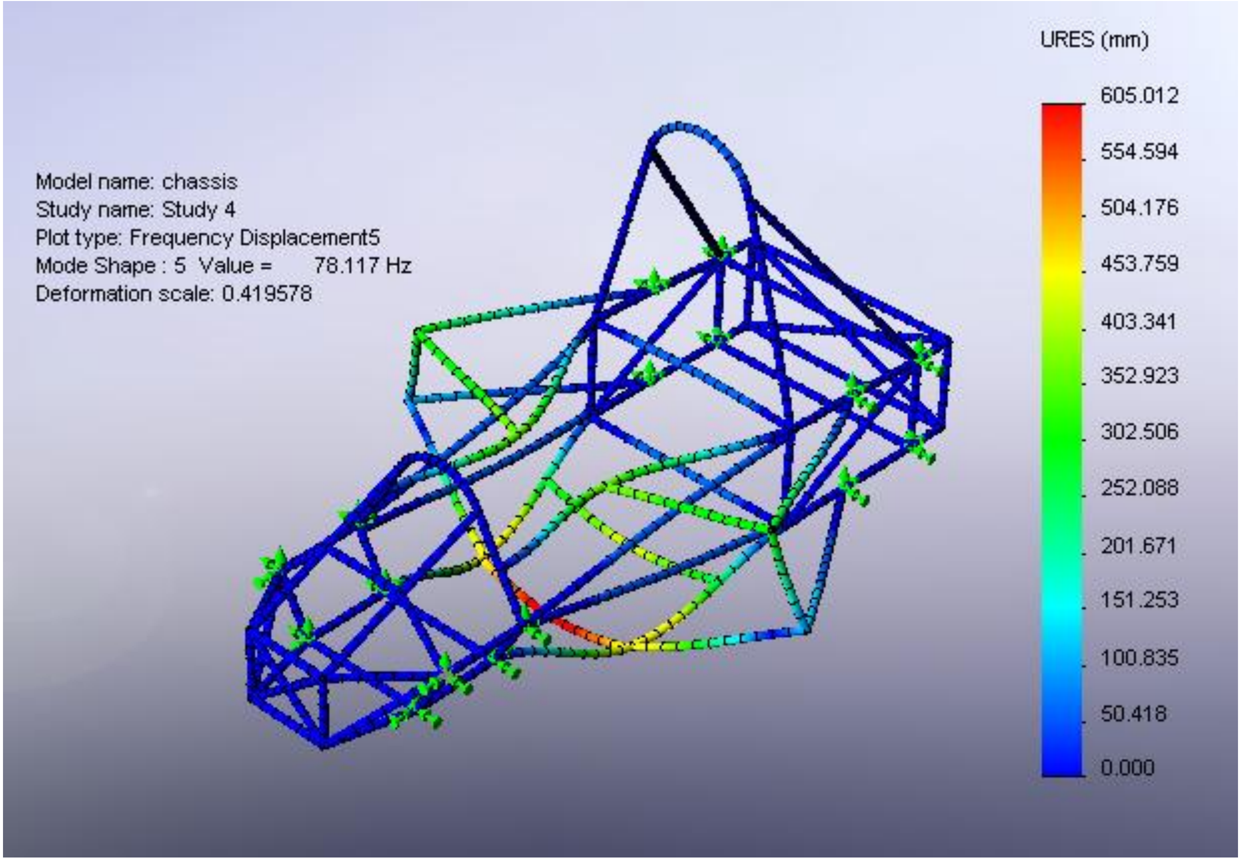
Where w_n is the natural frequency, k is the stiffness of the frame, and m is the mass of the frame. Conveniently, the term under the radical is stiffness over weight. This indicates that the natural frequency is a function of the square root of the stiffness to weight ratio. Thus, a higher natural frequency indicates a higher stiffness to weight ratio. Additionally, many bodies may contain multiple natural frequencies, called resonant frequencies, at multiples of the natural frequency, known as harmonics, depending on the vibration type, or “mode”. When a body vibrates at a resonant frequency, it will oscillate at larger amplitude than other frequencies, even those that may be larger than the natural frequency. The body will oscillate with more and more amplitude in an attempt to dissipate the energy stored within it. Since any real object has a certain amount of damping, the amount of amplitude is limited.

However, It may be large enough to still cause damage to the part. In the context of the chassis, each member has its own set of resonant frequencies. If the member is allowed to oscillate at one of its resonant frequencies, it may displace itself enough to cause a failure in one of the welds holding the frame together. The primary source of vibrations in the chassis is from the engine. This indicates that the frequencies produced from the engine vibrations corresponded to some of the resonant frequencies of the chassis. In these chassis, special care should be taken to dampen any of these vibrations, resulting in structural damage. This leads to two conclusions: the chassis should be analysed to find its resonant frequencies, and, should those frequencies correspond to common frequencies created by the engine, that the engine should be damped to help reduce the chance of structural failure.

Similar to the static finite element analysis performed, the chassis can be analysed with Solidworks, using a technique called modal frequency analysis. This method will convert the frame to a mesh, and simulate vibrations through the chassis using several different frequencies. The frequencies that create the largest displacements are recorded, and the mode of vibration corresponding to each is also recorded. The results supply each resonant frequency and the “mode shape” for each corresponding frequency. The usefulness of these frequencies and mode shapes is twofold: they can be used to determine if the vibrations of the engine may cause damage to the chassis, and the mode shapes can be used to see which frequencies are of relevance to the design of the chassis. Additionally, this method can be used to compare two frame designs side by side. Since higher natural frequencies correspond to a higher stiffness to weight ratio, a new frame design can be compared to previous iterations to see if the stiffness to weight ratio has been improved.



Mode shape 1st to 4th order



5^{th} order mode

Mode No.	Frequency (Hertz)	Period(sec)
1	48.426	0.02065
2	49.863	0.020055
3	58.417	0.017118
4	68.241	0.014654
5	78.117	0.012801

The first order mode shape corresponds to a twisting motion along the long axis of the chassis. A longitudinal flexure is characterized by the second order harmonic. These two mode shapes are important, as two of the key performance metrics for the frame are torsional and flexural rigidity. Thus, calculation of the natural frequencies for these mode shapes can be used to judge the rigidity figures for each type of loading. While the analytical results can be used as a ballpark figure, the results should be empirically obtained using a physical test of the chassis.

The frequencies can be used for comparing two different designs and deciding which is better by comparing respective frequencies at each harmonic. The design with higher frequencies will have a better stiffness to weight ratio.

Fabrication of chassis

Fabrication is obviously the most important part of completing a Formula SAE chassis. The BHR11 is constructed of mild steel tubing MIG welded. Mild steel is chosen for its weldability and strength. Tubes are fitted together through manual notching on a bench grinder and using the manual mill. There are other methods of tube fitment including CNC laser cutting the end of each tube so that the chassis fits together like a puzzle. The chassis must be built in steps so that it is made accurate to the design.

Jig - The first step is to have a jig designed and built to locate the critical members of the chassis, or the fixed elements as referred to earlier. A jig consists of a table that is drilled and tapped at certain points to locate a fixture that holds a fixed element in place. In this case, an aluminium table top is drilled and tapped to locate fixtures for the bulkhead, roll hoops, engine, and all suspension points. These fixtures are also made of aluminium and are machined precisely to locate these critical points in space. Wood can also be used in place of aluminium. The fixtures also act as a restraint for the tubes when being welded. If there was no jig, the chassis would be warped and unusable.

Roll Hoops – The first tubes to be made are the roll hoops and the front bulkhead. These are the only parts of the chassis made off of the jig table. A large scale drawing of these features is printed (or sketched precisely) and used as a guide when making bends and welding these tubes. Once these features are completed, they are bolted to the jig table in their respective locations. The bottom of the main roll hoop is used as a height reference for other parts of the chassis because it is bolted directly to the table with no spacer.

Cockpit - The cockpit is the first section to be built on the frame. This section is built first so that it can be used as a template for seat construction. The side impact structure of the cockpit must be built from the bottom toward the top so that during tube notching and fitment, a tight fit may be achieved for each tube.

Front Section – After the cockpit is built and welded, the team moves to the front of the car to build the front suspension mounting locations and front impact structure. The first tubes to be made are the lowest tubes. On the frame, these tubes stretch from the front roll hoop to the front bulkhead. The next tubing to be notched and welded is the box tubing for the upper suspension mounts. It is critical to keep this tube jigged during all welding so that these points are not warped. If these points move in space from where they have been designed, the upper a-arms will not fit correctly and suspension geometry will be compromised. The front impact structure must form a triangle according to the FSAE rules. The two tubes that form the triangle connect to the upper suspension tube to form a node.

The final pieces to be welded to the front part of the chassis are the bell crank and shock mounts. These mounts must be jigged so that the bell crank and shock can rotate in the same plane to produce the desired motion ratio. The bell crank mount is a short length of tubing that is welded to the lower suspension tube. This small tube carries a bung that incorporates the races for needle and thrust bearings that allow rotation of the bell crank. The shock mount is a piece of 1”x2”x.049” rectangular tubing welded to the front hoop using multiple gussets.

The rest of the front section of the frame is made up of miscellaneous bracing tubes that constrain nodes and distribute loading to other parts of the chassis. These tubes are thin since most of the time, they do not carry any significant load. Weight savings can be made by designing this bracing effectively and using small tubing sizes.

Rear Section – After the front section of the frame is complete, the team works toward the rear. The first major tube to be put in place is the shoulder belt tube. This tube is located by a jig attached to the table. Once this tube is on the jig, all of the tubes that connect to it can be notched and fit up. At the same time, tubes that connect to the engine mount are fit to the main hoop and the engine mount. This mount is then bolted to one of the stock mounting holes on the engine block with a 0.5” aluminium spacer. This aluminium will reduce vibration slightly and will permit easier installation of the engine into the frame.

The rear suspension tubes are the next to be constructed. The lower points are located inside the box tubing as mentioned before. Another jig is used to locate the upper suspension tube. This jig holds a set of tabs that determine the position of this tube in space.

The upper suspension tube will stay in the jig as long as possible while other welding is being performed so that warping can be kept to a minimum. Perhaps the most critical tube of the rear chassis is the shock mounting tube that runs across the rear of the engine. Not only does this tube carry the shocks but it also contains the rearmost engine mounting tabs. This tube must have a small bend in the centre to accommodate the shocks and this bend must be perfectly in line with the centreline of the car. Once this tube is in place, the tabs that the shocks mount to must be located on the tube. These tabs must also be perfectly centred on the car.

Once the shock tabs are in place, mock shocks can be used to place the bell crank tabs on the upper suspension tube. It is important to get these bell crank tabs in plane with the shock tabs so that the desired bell crank motion ratio may be obtained. This rotation being in plane also reduces the chances of bending the shock shaft in compression and rebound when the suspension is in use.

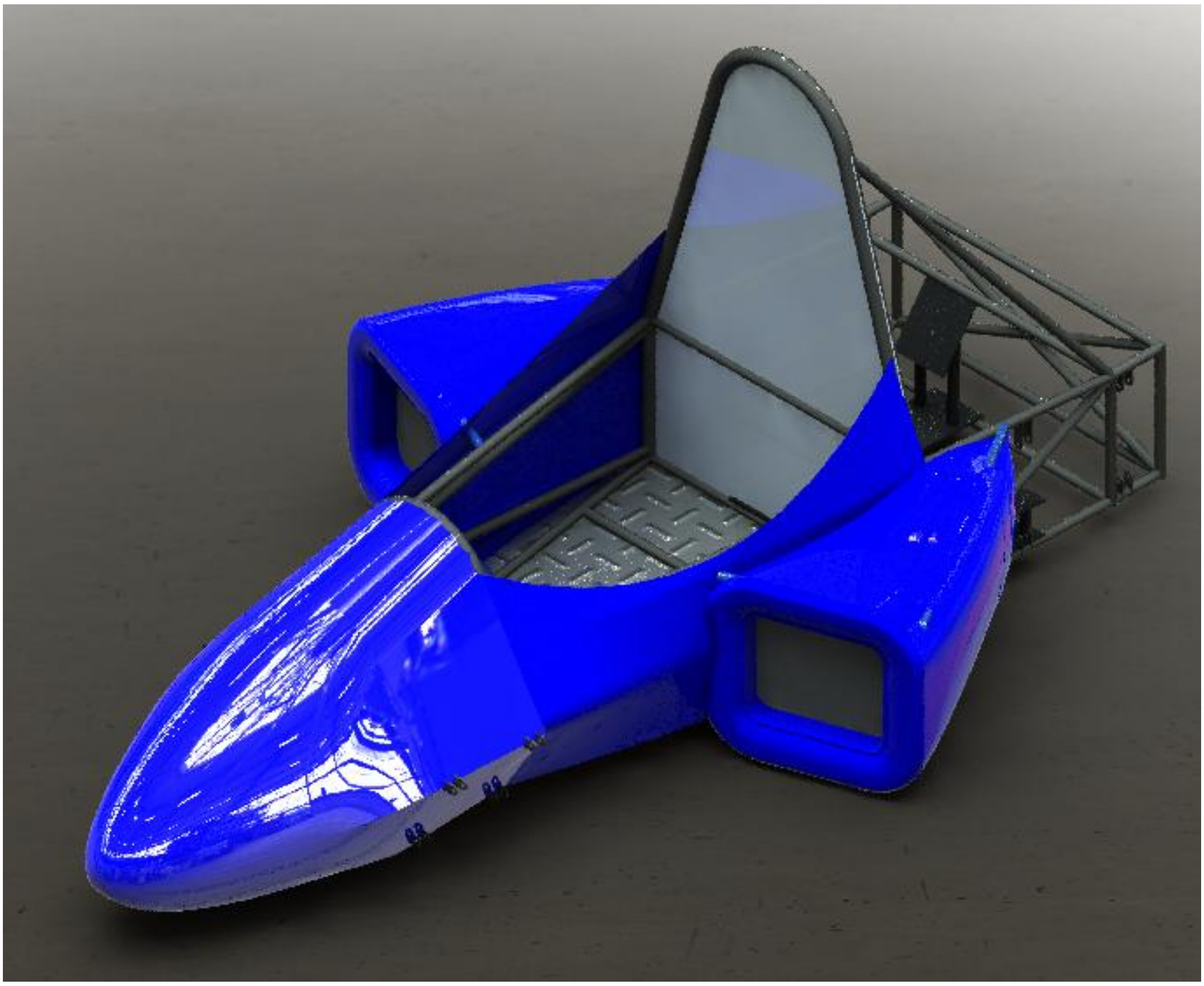
The rear section of the chassis also contains bracing tubing that connects the left and right sides and also the upper points to the lower points. These tubes must be carefully placed so that the half shafts that drive the wheels clear the frame. There is also bracing in the large open space above the engine. Small, thin tubing is used to create an X and stiffen the rear section of the frame.

Final Preparation - Once the rear section of the frame is completed, the chassis may be taken out of the jig for final welding. During construction, most welds on tubes can only be half or three quarters of the way done due to space constraints. With the chassis off of the table, welders can easily reach these places that were neglected earlier. Welding out of the jig is not normally done due to potential warping but by skipping from one location to another and spreading out the heat of welding, the chassis will remain mostly as it was in the jig with minimal warp.

After completion of welding, the car is ready to be assembled. During assembly, mounts are made to support the various components of the car that need solid mounting. Most mounting is done through the use of sheet metal tabs that are welded to the frame and have a nut plate riveted to one side. This allows for bolting of parts to the car. Careful observation needs to take place so that oversized tabs are not used abundantly as this is an easy way to lose control of the weight of the chassis. Ideally, tabs will be made of thin sheet metal and be used by multiple components.

Rivets may also be used to mount parts such as the firewall, closeout panels, and permanent bodywork. The number of rivets should be kept to a minimum because every rivet requires a hole in the chassis and subsequently produces a stress concentration feature.

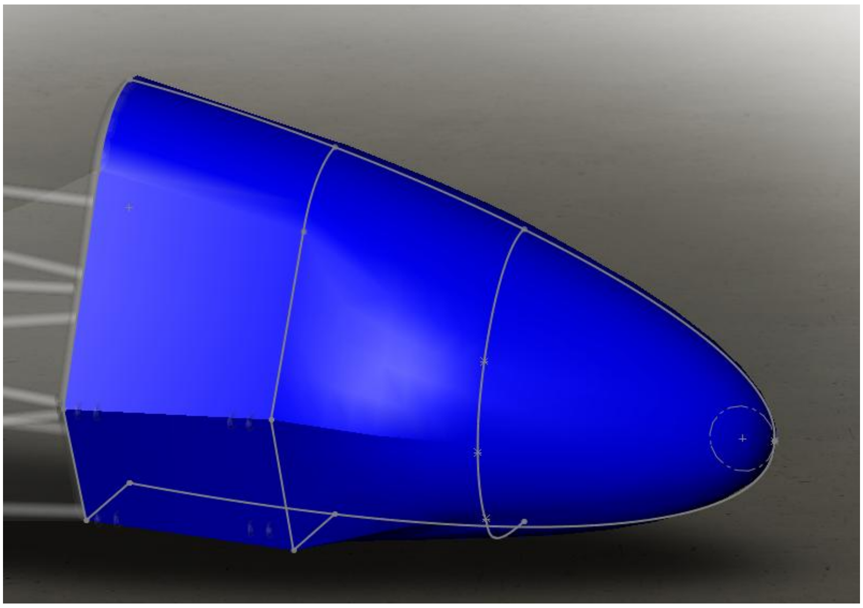
BODYWORKS and AERODYNAMICS



When developing a bodywork package for any vehicle the aerodynamics of the bodywork should be considered, this is most beneficial in racing where aerodynamics can be tailored to give better vehicle economy, handling, aesthetics, and overall performance. In reviewing race car aerodynamics pertinent to Formula SAE there are three main areas to be reviewed; use of wings, use of an under body diffuser, and the general geometry of the main bodywork.

Nose cone

The nose cone is designed according to the FSAE rule of the minimum 4” curvature at the tip. To construct the nose cone geometry, the curvature condition along with the position of the front most point is decided. Then using the bulk head and front hoop sketches foe the surface loop are constructed. After finishing the profile sketches guide curves are constructed in a way that maximum tear drop shape is attained. The surface is finished using the loft feature. The nose cone can be analysed for aerodynamic properties to ensure best design.



Wings

Inverted wings have been extensively studied for use on a Formula SAE car. The study undertaken investigated the benefits of a wing package, as well as an initial performance prediction. The results drawn from this investigation are a similar or slower time in the acceleration event, a similar or faster time in the skid pan event, slower acceleration, higher cornering potential, higher slalom speeds, higher braking potential, and an increase in fuel usage. The conclusion drawn from this investigation was that a wing package would significantly benefit the vehicles performance in dynamic events

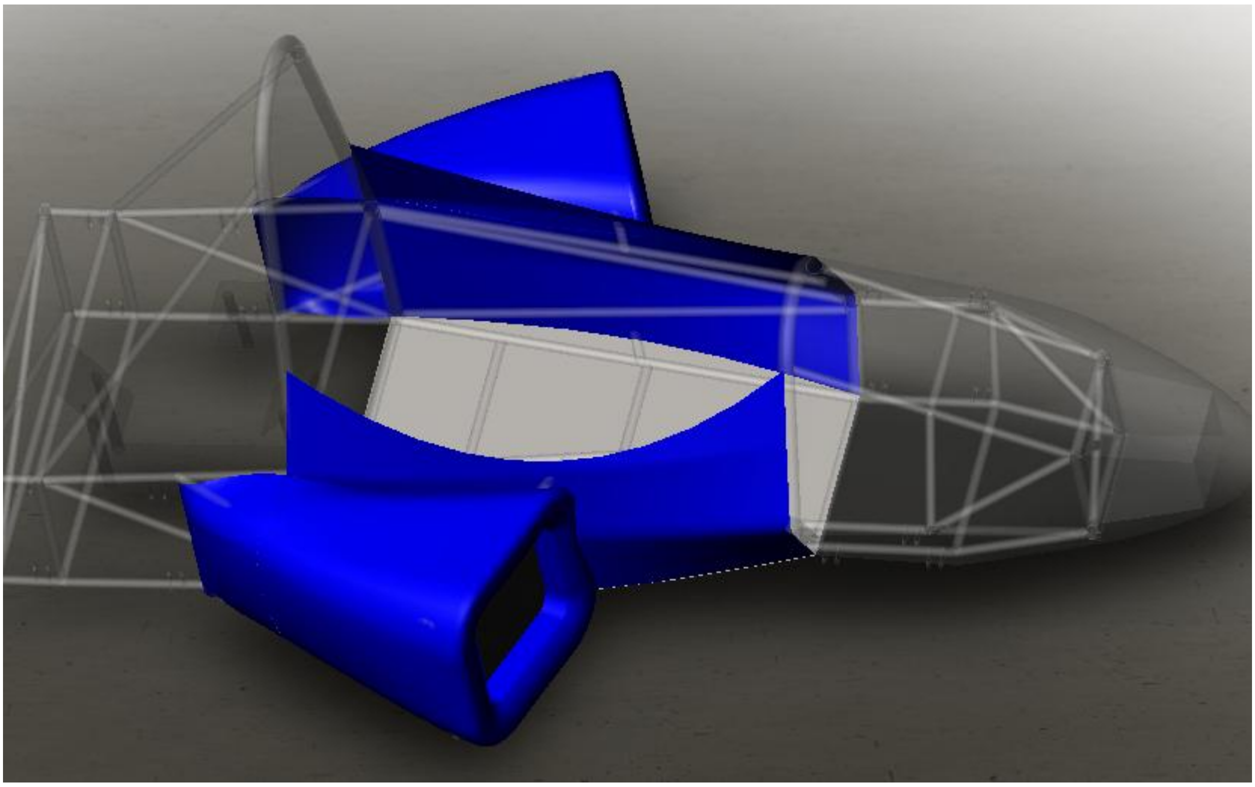
Underbody Diffuser

A secondary method of producing downforce is an underbody diffuser. A diffuser works on the principle that even a non-lifting body in the vicinity of ground effect can produce downforce. Since FSAE rules prohibit skirts to seal the underbody of the car to the ground, the research regarding underbody height to length ratio versus CL and CD must be considered. The speed required to generate sufficient downforce benefit and the length of our vehicle body (1.8m) our underbody would need to sit around 9cm from the ground, raising the CG of the vehicle above the desired.

Main Bodywork

Given the above results it seems most logical to focus on the main bodywork of the vehicle, with downforce production being a secondary objective. The bodywork is classically shaped around the occupants, and the various other sub-systems comprising of the vehicle, using this as the very basis of our design principals we move on to recognise the three dimensional as the lowest drag design. Since BHR11 has to have a side mounted radiator we must also consider the effect of sidepods, whose geometry can be used to generate downforce as well as influence the flow speed over the radiator.

The side body is also designed with help of loft surface.



CFD Analysis

Whenever analysing aerodynamics the analytical method must be established and reviewed. For development of the SAE car, aerodynamic modelling and fluid dynamics will utilise the Fluent CFD program. In a previously completed investigation into FSAE aerodynamics, the fluent program was also used and reviewed. Following loading and meshing a model of their vehicle in Gambit and Fluent, a CFD model was formed to be compared with wind tunnel and on track tests. The conclusions drawn from this report concur with the, that whilst CFD modelling is a useful tool for initial profile development it is not always reliable in calculating lift and drag for the model of the vehicle due to the complicated laminar turbulent flow transition and any vital CFD work should be complimentary to scaled wind tunnel testing.

For this project, where the necessity for detailed flow calculations is low, CFD will form a useful tool in the iterative design process.

Materials

Once the bodywork geometry has been selected, and refined through CFD, a material for its production must be selected. During the early 1980's composites worked their way into the racing circles of Formula 1, and today form the majority of the material used in such vehicles (Davies 2003). Not to rule out other materials this review will address three light weight and easily accessible materials; Aluminium, GFRP, and CFRP.

- Aluminium

Generally, aluminium is used because of its low density (2.69g/cc) and this is also the case in this project. When considering aluminium, like any material, we must consider the advantages, disadvantages, and possible production processes. Aluminium is a favourable material such that it has a low density, it is corrosion resistant, it is easily obtained and can be recycled; however aluminium also has a high and fluctuating cost, is less formable than steel and less readily welded. There are many aluminium alloys available which can be selected to suit the formability and strength requirements.

- GFRP

Commonly known as fibreglass, GFRP is widely used in the automotive industry. GFRP is favourable due to its high formability, controllability of material properties, wide scope of applications, and relative ease of production, especially in small scale operations. GFRP has a lower density than that of aluminium however its production must be carefully controlled to achieve the desired material properties. It is easily formable but not easily repairable and cannot be recycled. GFRP offers good corrosion resistance as well as good dimensional stability and scratch resistance qualities.

- CFRP

Commonly known as carbon fibre, CFRP is very similar in its advantages and disadvantages to GFRP however it has a lower density and higher strength. These improved material properties invariably lead to a high material cost however weight savings of up to 30% make this cost an acceptable one.

Production Method

In this project the bodywork designed is to be constructed and integrated onto the SAE car, as such an investigation into the production methods available to produce this bodywork is required. Since we have investigated both composites and aluminium and the depth of investigation to date does not allow a decision on the material to be made the investigation will cover the production methods available for sheet metals, and composites.

- Sheet Metal Production

When producing a one-off, non-mass production, sheet metal bodywork, the most cost effective method is hand working sheet metal (Giles 1971). There are four basic methods of producing short run sheet metal bodywork as suggested in Giles.

1 - By scribing the blank directly onto the sheet metal, followed by cutting and hand forming. This method can only be used where pieces are of relatively simple shape, because of this limitation this method would not be appropriate for the main bodywork of the vehicle, but possibly the floor pan.

2 - By the aid of templates. These are plotted on to sheet metal directly and used to check the accuracy of the part in two dimensions. Whilst this method allows complex shapes to be formed they are still formed by hand and reproduction of a CAD model perfectly is virtually impossible.

3 - By the aid of formers. These are normally softwood patterns shaped to the contours of the panel required, and used as moulds to beat the metal over. This provides ease of manufacturing for an exact model of the CAD design. This method is suitable for most designs however does require operator skill in the final hand production.

4 - By use of press tools. These are used to press the metal into the required shape. Whilst these provide all the benefits of the use of formers it removes the need for operator skill enabling ease of complex geometry construction. This method is, however, also the most expensive and labour intensive to set up and is aimed at projects requiring large numbers of complex shape panels.

Of the above methods the use of formers appears to be the most appropriate for use in this project.

- Composite Production

When producing composite bodywork there are two main methods both requiring use of a mould

1 - Open Die Moulding. Open die moulding is the process where the layers of fibre are laid-up over only one mould surface. The resin is then applied by brushing or spraying. This method can produce good quality parts however working with dry cloth and wet resins can produce heavier parts compared to the same part produced with pre-preg. The layup can then either cure at room temperature under no pressure, or for a higher grade part, cure under pressure and/or temperature through the use of a vacuum bag, autoclave, or various other methods.

2- Compression Moulding. Compression moulding is similar to open die moulding however it involves the use of two mould surfaces, a male and female part; these two moulds are pressed together to form a cavity in the shape of the component. Advantages of this method include excellent dimensional control, high quality finish on surfaces, high production rates, and high fibre content. Whilst this method provides many advantages over open die moulding, the moulds require hardened faces to enable them to be pressed together with sufficient pressure and the cost of this is very high. Again, wet or pre-preg laminating procedures can be used in this method.