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Design And Fabrication Of Space Frame Chassis

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Abstract— Formula Student Racing competitions are held at various Formula SAE circuits globally. Students from different colleges worldwide thrive to build a Formula style race car to compete at these events. According to the competitions rules and regulations it is important to design the chassis of the car with utmost priority. The major challenge posed is to design and fabricate a light weight car without compromising on the safety of the driver. It requires set of knowledge on design, material selection and material joining. The car has to be rigidly fabricated at minimal expense. The work in this paper is based on the team RAIDERS racing car 2017. This paper show cases various methods of material selection, design optimization techniques and Finite element analysis (FEA) using SOLIDWORKS. The basic design is based on the anthropological data of the specified human (95th percentile male) allowing fast ingress and egress from the car. Following the final design selection the static structural analysis of the car was done and the consequent results have been plotted. The entire design and analysis process is based on FSAE 2016 rule book and knowledge of designing and manufacturing from yesteryear's ca

Keywords—component; formatting; style; styling; insert (key words**)**

I.INTRODUCTION

The purpose of this project is to design and construct a chassis for a combustion engine powered Formula SAE (FSAE) car to compete in the July 2017SAE-SUPRA competition. The competition is for students to design, build and race small open-wheeled race cars against the clock in a number of events. The competition also includes some static design events, where the cost and design of the car is judged by a panel. A unique chassis design is required as the car will be powered by 600cc combustion engine mounted within the frame.

There is much confusion over the meaning of the word chassis as discussed by Aird in the book "The Race Car Chassis" (Aird, 1997). In the early days of the automobile where coachbuilders were used, the term "chassis" was often used to describe the frame, engine and suspension as one complete unit. Essentially it described everything in a car other than the bodywork and cabin. In some other contexts "chassis" defines only the frame of the car with the drive-train and suspension being considered entirely separate items. This latter interpretation of the word is what is used throughout this project, where the terms "chassis" and "frame" mean the same thing are interchangeable.

When defined as above, a chassis is the component in a car that everything else attaches to. The most basic, common chassis design is referred to as the "Ladder Frame" due to its resemblance to a conventional lean-to ladder (Adams, 1992). A "Ladder Frame" consists of two long members that run the length of the automobile and are joined by a set of smaller member's perpendicular to the two long members. The other components that make up the vehicle are then mounted to this chassis. In the case of the Ladder Frame; the body and engine are usually mounted to the top of the chassis with the suspension being mounted below. This type of chassis dates back to horse-drawn carriages, originally made of wood, but generally being made of steel in automobiles since the 1900's (Aird 1998). While being simple and easy to manufacture this type of chassis generally has a poor torsional stiffness which makes it undesirable for a race car.

A space-frame chassis lies somewhere between the ladder chassis and the monocoque seen in fig.2 (second from right), it is constructed from an arrangement of small, simple members which make up a larger frame. A space-frame is analogous to a truss style bridge which is made up of small (generally straight) members in a triangular pattern which are always in pure compression or tension. By having members in pure compression or tension (i.e. they do not experience bending forces) they do not have to be oversized to support bending loads.

Light weight is a primary goal for all components in a race car as a lower weight requires less force to accelerate by the same amount. Newton’s 2nd law says; = × So given the same force, a lighter car will accelerate quicker. This applies in all transient conditions including braking and cornering. If a car accelerates quicker, then it reaches a higher speed quicker and therefore it is faster, which is the purpose of a race car. So wherever possible everything in a race car should be as light as possible.

Stiffness is also a desirable property for a race car chassis to have. The suspension for the 2016 FSAE car has been designed by another student under the assumption that the chassis acts as a rigid body. So if the chassis deforms too much under load then the suspension is unlikely to work as desired.

2. DESIGN METHODOLOGY

Design Requirements

The design of the chassis must work around a number of parameters and constraints in order for it to perform well and for it to be eligible to compete in the competition. These requirements can be broken into several categories which will be discussed below. If any of these requirements are not met, the consequences range from sub-optimal performance to not being eligible to compete in the competition or even chassis failure. So it is clear that all requirements must be carefully considered and even re-visited when designing and building the chassis.

Rules

The first thing that must be considered when designing the chassis is the 2017SAE- rules, there is no point in designing a chassis if it will not be allowed to compete in the competition for which it is designed. The FSAE rules require a front and rear roll hoop, a side impact structure, a front bulkhead and supports for the aforementioned components be integrated into the chassis.

By representing graphically these requirements one may create a “minimum chassis” which shows the simplest possible configuration of members that include the required components mentioned above. Figure 2.1 is a side view diagram of what this “minimum chassis” looks like, it does not consider driver ergonomics, cockpit entry or suspension points etc., and is merely a pictorial representation of some of the required members

The FSAE rules define a minimum size for all the chassis members shown in Figure 2 and for some other members not shown. To avoid adding un-necessary weight, the chassis design should make best use of the required members so that as few possible additional members are needed. This is where much of the design work needs to be done for the project because as the rules limit many of the members, little design work can be done in optimizing the size of the chassis members.

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

2.1 Roll Hoops

The driver's head and hands must not contact the ground in any rollover attitude. The Frame must include both a Main Hoop and a Front Hoop.
When seated normally and restrained by the Driver's Restraint System, the helmet of a 95th percentile male (anthropometrical data) and all of the team's drivers must:
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. 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)..Be no further rearwards than the rear surface of the main hoop if the main hoop bracing extends forwards.

2.2 Main Hoop

The Main Hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing per Rule. The use of aluminium alloys, titanium alloys or composite materials for the Main Hoop is prohibited.

The Main 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. 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. 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 .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.

2.3 Main Hoop Bracing

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

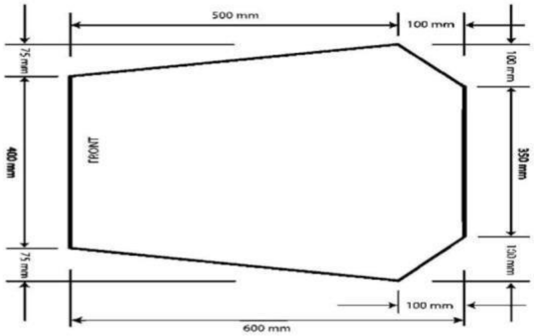
The Main Hoop must be supported by two braces extending in the forward or rearward direction on both the left and right sides of the Main Hoop.

In the side view of the Frame, the Main Hoop and the Main Hoop braces must not lie on the same side of the vertical line through the top of the Main Hoop, i.e. if the Main Hoop leans forward, the braces must be forward of the Main Hoop, and if the Main Hoop leans rearward, the braces must be rearward of the Main Hoop.

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 the figure.

2.4. Front Hoop

The Front Hoop must be constructed of closed section metal tubing per Rule The Front Hoop must extend from the lowest Frame Member on one side of the Frame, up, over and down to the lowest Frame Member on the other side of the Frame. With proper gusseting and/or triangulation, it is permissible to fabricate the Front Hoop from more than one piece of tubing. The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position. 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 centreline, from the rear surface of the Front Hoop to the forward most surface of the steering wheel rim with the steering in the straight-The FSAE rules also require a firewall barrier to isolate the engine and petrol tank from the driver,it must cover the vertical and horizontal portions of the engine that face the driver. 2.6mmaluminum sheet is suggested for this firewall but 1mm steel has been approved as an alternative by the FSAE-A rules committee. The chassis must also provide sufficient space for cockpit entry, where the driver enters the cockpit. FSAE rules require a template shown in Figure 2.5 be able topass vertically through the cockpit opening until it reaches the height of the top bar in the side impact structure.



Design and Fabrication of a Space-Frame Chassis

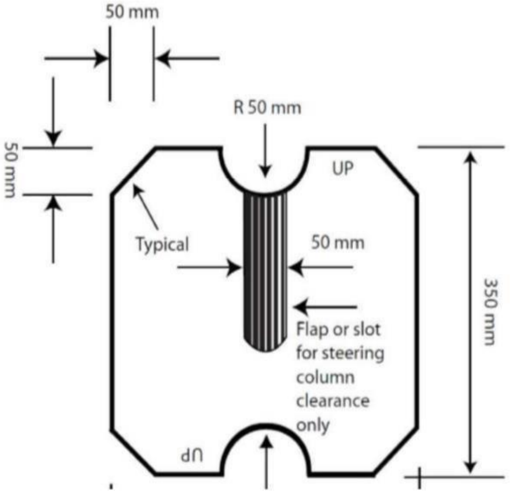


Figure Foot-well clearance

template 2.5 Human Ergonomics

FSAE rules require that a 95th percentile male can drive the car with clearance to the two roll hoops. A template of a 95th percentile male as shown in Figure 2.7 must be able to fit in the seat with a minimum of 2 inches (50.8mm) clearance to a tangential line running from the top of the front roll hoop to the top of the main roll hoop. As none of the drivers in the team are as tall as a 95th percentile male then if the design fits the template it will be known to fit any drivers from the team. The roll hoops must therefore be sized to fit this 95th percentile male template.

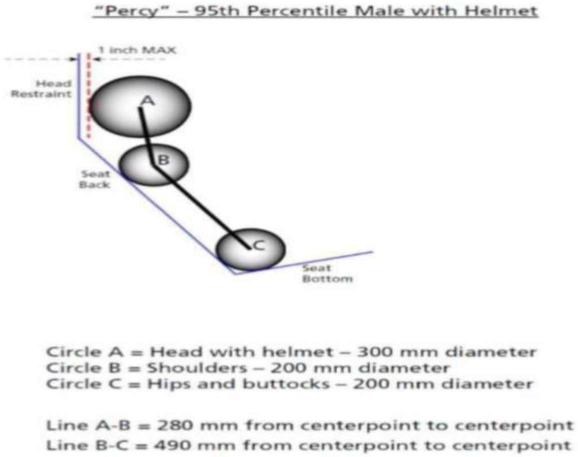


Figure 95th Percentile Male Template

2.6 Steering and Suspension Forces

In addition to ensuring the design meets the SAE competition rules there are predefined suspension points which the chassis must provide support and attachment for. The suspension system for the 2016 SAE car has been designed in another student's thesis and in order to maintain the designed suspension geometry, the suspension points should not be moved from their designed locations.

To produce a space-frame chassis with sufficient stiffness and to ensure the chassis is safe, the design must be constructed so that bending moments are not introduced into any of the chassis members. Figure 2.8 shows a basic layout of the ends of the chassis that are required to hold the suspension pivots in their correct locations.

Material

It was decided that the frame would be constructed from steel due to its availability and relatively low cost. There are many different grades of steel available however many of the FSAE teams around the world from universities such as UWA (for the rear space frame section), Curtin, RMIT, Missouri S&T use 4130 SAE grade steel (which contains Chromium and Molybdenum alloying elements) due to its higher yield strength. In the first part of the design phase when the chassis material was chosen, the team had a limited budget which resulted in the decision to use mild steel instead of 4130.

Lightweight and stiffness are the most important properties of a chassis and the stiffness of the completed chassis will be affected by the stiffness of the material from which it is built. Material stiffness is known as Young's Modulus and the controlling mechanism for stiffness in a material is the inter-molecular forces. So stiffness or Young's Modulus is a material constant which cannot be significantly changed by any mechanical or chemical processes. Alloying elements also have little effect on stiffness meaning that more expensive grades of steel have the same stiffness as mild steel. This justifies the decision to use mild steel for chassis construction as more expensive steels are unlikely to improve the chassis' stiffness.

Aside from cost there are other advantages to using mild steel over more expensive alloy steel, it is easy to machine and weld, also it does not become brittle in the heat affected zone when welding. The FSAE rules also state that using stronger steels does not allow the use of smaller chassis members so there would be no weight advantage in using the more expensive SAE grade 4130 steel for these members. The downside to using mild steel comes with its lower yield strength, in the event of a collision or some other impact the chassis may become damaged at a lower stress than if it were built from 4130.

3. Manufacture considerations

In order to improve manufacturability, round tubing may be used for frame members. This makes cutting planar joints easier and simplifies suspension mounting points. Due to availability 31.75mm x 2.0mm tubing was used, which is larger than the minimum size required by the FSAE rules.

Modeling Design procedure

Front and rear sections The first thing to consider in the design is location of the nodes for the suspension mounts as these cannot be moved, all other components must then work around these points. Table 2 and Table 3 list the locations for all the required suspension pivots in XYZ coordinates where X is the horizontal axis that runs down the length of the car, Y is the horizontal axis that runs across the width of the car, Z is the vertical axis. Figure 3.4 shows these node coordinates in isometric view, joined by lines to make the points easier to see.

To allow room for fixings, the A-arms do not mount directly to the nodes but are is mounted as close as is practical so that minimal bending is introduced into the chassis. The nodes required for the suspension also define the minimum length required for the chassis, and by making the chassis no longer than this, no un-necessary material is used which would increase weight. The front and rear bulkheads will be constructed at the location of the front-most and rear-most nodes in Figure 3.4 to provide maximum strength to support the suspension loads.

Bulkheads are very stiff points on the chassis and include horizontal transverse members which directly connect nodes 1, 2, 7 and 8 with their mirrored counterparts. This means there is minimal deformation at these points under loads induced by breaking, cornering and acceleration. Minimizing potential deflection is essential for each suspension mounting as this ensures the wheel does not move and change its geometry under load. If the wheel's geometry were to change under load the suspension may become difficult to tune and optimize as the wheel would move away from the position which provides the best grip for the tyre. To comply with the FSAE rules, it is not practical to include the member that runs between node 3 and its mirrored counterpart in Figure 3.2 as this would obstruct the foot-well area of the chassis. This means that other members will have to be placed around this node to support the forces which generated by the suspension that connects to the node.

With the A-arm pivot locations defined, the remaining components for the suspension must then be mounted to the frame. The suspension design uses a push-rod and rocker arrangement to connect the wheel's motion to the inboard mounted spring. This introduces significant loads into the chassis even when the car is stationary so the arrangement of the members around it must ensure no bending forces result.The rocker is mounted to the upper chassis member via a pivot, the forces from the spring and rocker act in a plane parallel to the driver seat alignment and thus have Y and Z components but no X or moment (torque) components

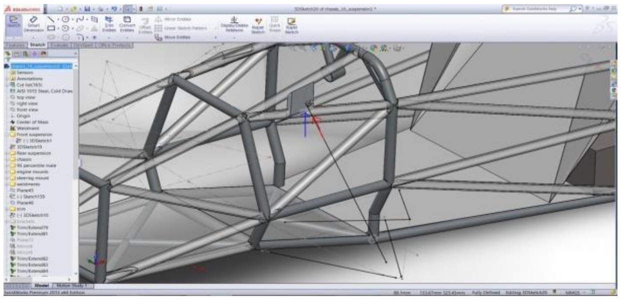
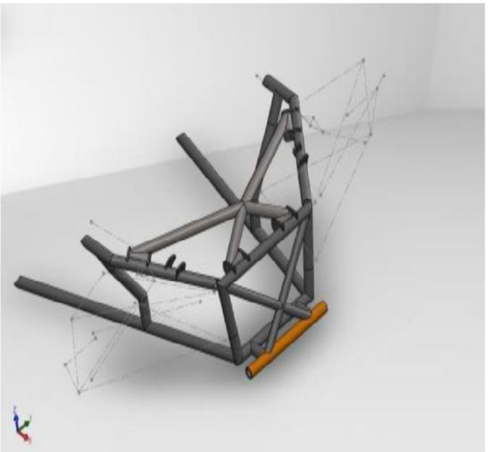
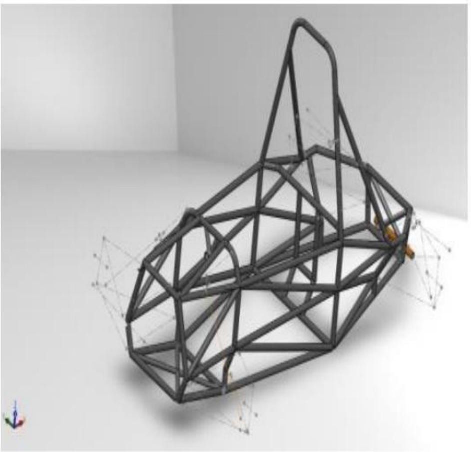


Figure shows the force components introduced into the frame by the suspension rocker. The Z component of these forces (blue vector) can be supported by adding diagonal members between the front hoop bracing and the front hoop upper member, this forms into a triangular structure which increases its strength. The added members are required by the rules as part of the "front hoop bracing" and thus they must meet the minimum size requirement detailed in table 1.

The Y component of the force shown in Figure 3.3 (red arrow) could be supported by adding a similar arrangement of members in the horizontal plane. To support this Y component of force from the rocker a 4 mm plate is placed between these members provides an additional triangulation. The 3mm plate spring holders are placed on bracing member.

The same design can't be applied to the rear of the frame because due to our budget we had keep our old Nano engine which wide and gives us the foundation of the chassis, to which all other members must be added. The rear section can be completely triangulated as there is no foot-well or other requirements restricting the members in it.





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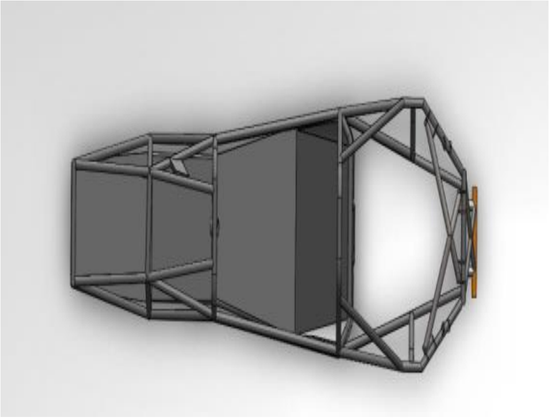
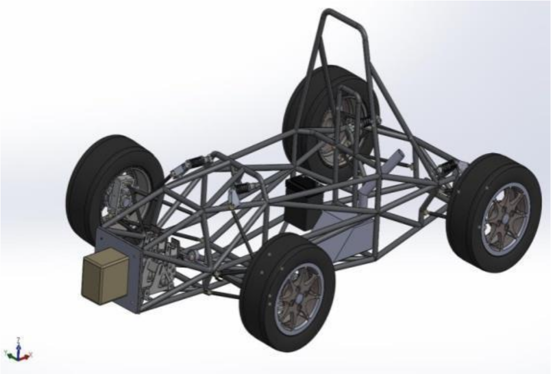




The final chassis design meets all the requirements placed on it by the rules and suspension design. It makes the most of the members required by the rules, requiring few additional members to support loads and add triangulation..On many chassis designs The chassis is 2300mm long, 725mm wide, rides 50mm from the ground and the roll hoop is 1115mm tall.

4. ANALYSIS

4.1 Analysis of designed chassis

After completion of design process the frame is analyzed in **solid works simulation** software the chosen material is assigned for the model (AISI 1018):

4.2 Assigning material to the model Material specifications

AISI 1018 mild/low carbon steel has excellent weld ability and produces a uniform and harder case and it is considered as the best steel for carburized parts. AISI 1018 mild/low carbon steel offers a good balance of toughness, strength and ductility. Provided with higher mechanical properties, AISI 1018 hot rolled steel also includes improved machining characteristics and Brinell hardness. Specific manufacturing controls are used for surface preparation, chemical composition, rolling and heating processes. All these processes develop a supreme quality product that are suited to fabrication processes such as welding, forging, drilling, machining, cold drawing and heat treating.

AISI 1018 mild/low carbon steel can be instantly welded by all the conventional welding processes. Welding is not recommended for AISI 1018 mild/low carbon steel when it is carbonitrided and carburized.

Low carbon welding electrodes are to be used in the welding procedure, and post-heating and pre-heating are not necessary. Pre-heating can be performed for sections over 50 mm. Post-weld stress relieving also has its own beneficial aspects like the pre-heating process.

Bending

Bending operations of the roll cage material i.e., the main hoop and the roll hoop materials are performed on CNC’s.
The basic bending requirements are first calculated and then performed the operations on the CNC’s.

Meshing

Finite Element Analysis (FEA) provides a reliable numerical technique for analysing engineering designs. The process starts with the creation of a geometric model. Then, the program subdivides the model into small pieces of simple shapes (elements) connected at common points (nodes). Finite element analysis programs look at the model as a network of discrete interconnected elements.
The Finite Element Method (FEM) predicts the behaviour of the model by combining the information obtained from all elements making up the model.
Meshing is a very crucial step in design analysis. The automatic mesher in the software generates a mesh based on a global element size, tolerance, and local mesh control specifications. Mesh control lets you specify different sizes of elements for components, faces, edges, and vertices.
The software estimates a global element size for the model taking into consideration its volume, surface area, and other geometric details. The size of the generated mesh (number of nodes and elements) depends on the geometry and dimensions of the model, element size, mesh tolerance, mesh control, and contact specifications. In the early stages of design

analysis where approximate results may suffice, you can specify a larger element size for a faster solution. For a more accurate solution, a smaller element size may be required.

Meshing generates **3D tetrahedral solid elements, 2D triangular shell elements, and 1D beam elements**. A mesh consists of one type of elements unless the mixed mesh type is specified. Solid elements are naturally suitable for bulky models. Shell elements are naturally suitable for modeling thin parts (sheet metals), and beams and trusses are suitable for modeling structural members.

After finalizing the frame along with its material and cross section, it is very essential to test the rigidity and strength of the frame under severe conditions. The frame should be able to withstand the impact, torsion, roll over conditions and provide almost safety to the driver without undergoing much deformation. Following tests were performed on the roll cage.

(i) Front impact (ii) Side impact (iii) Rear impact (iv) Torsional

Front impact analysis

Impact load calculation:
Using the projected vehicle/driver mass of 280 kg, the impact force was calculated based on a G-load of 20.

F= ma…. (1)
= 280x20x10= 56000 N
Impulse time= weight x (velocity/load)… (2)
= 280 x (25/56000)=0.126seconds

We apply 56000 N from the front for the test of front impact of the roll cage structure of the vehicle for determining strength at the time of front collision.

Rear impact analysis

Impact load calculation:
Using the projected vehicle/driver mass of 280 kg, the impact force was calculated base on a G-load of 20.

F = ma
= 280*4*10= 56000 N
Impulse time= weight*(velocity/load)
= 280*(25/56000)=.126seconds We apply 56000 N from the front for the test of rear impact of the roll cage structure of the vehicle for determining strength at the time of rear collision.

We apply 56000 N from the Rear for the test of Rear impact of the roll cage structure of the vehicle for determining strength at the time of Rear collision.

Side impact analysis

Impact load calculation:
Using the projected vehicle/driver mass of 280 kg, the impact force was calculated base on a G-load of 10.
F=ma=280*10*10=28000 N
Impulse time= weight*(velocity/load)
=280*(25/28000)=0.249

We apply 28000 N from the side for the test of side impact of the roll cage structure of the vehicle for determining strength at the time of side collision.

Suspension forces are feed into chassis during cornering and braking .Vehicle is subjected to twist due to these forces. Analysis is done by using vehicle weight, effective wheel track and angular momentum of chassis.

Torque= load x radius=113.6 kg x10 x 0.64 m=713.45 Nm
Torsional stiffness= Torque / angular momentum=713.5 Nm/ 0.0349 rad= 20,422 N/rad
Vehicle chassis having torsional stiffness value below 100,000 Nm / rad's usually categorized as soft, torsional stiffness values ranging from 100,000 to 250,000 Nm / rad categorized as medium-hard and values above 250,000 Nm / rad as hard. Vehicles chassis design may vary according to its functional expectations and its service conditions. For this reasons described above trailer chassis have to be in mid-hard category and should be designed accordingly

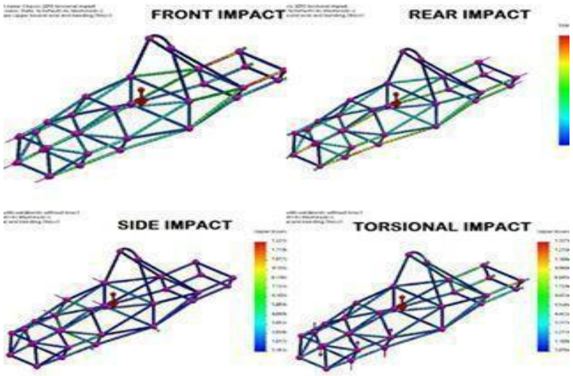
5. FABRICATION

The space-frame part of the chassis will be constructed by cutting straight lengths of tube at precise angles and welding them together. There is a large number of welds in the space-frame so it is important to ensure they are strong enough to withstand the loads placed on the chassis and that they do not warp the chassis during construction**.**

The suggested welding process for constructing the chassis would be MIG (Metal Inert Gas) welding as it is one of the quickest manual welding processes (Black, 2008). Due to availability reasons the process used was TIG (Tungsten Inert Gas) welding which is slower than MIG welding. TIG welding consists of a Tungsten electrode an inert gas (Argon) shield and a filler metal rod. TIG welding produces neat welds which are similar to MIG welds with no slag that needs to be removed after welding, however TIG welding does have the advantage of having more control of the weld current and feed rate of the filler.

Metal in the weld region heats up to and above its melting temperature during welding, it then cools after welding and the material shrinks. Often this heating and shrinking will not occur evenly over a join and thus the weld can cause warping. To avoid or minimize this effect the welding process must be performed in a particular order. One method of reducing the warping due to weld shrinkage is to tack joints in place before making a complete weld. The order of welding also plays a part in how the structure reacts to weld shrinkage. Welds that will cause shrinkage and warping in opposite directions should be done consecutively so the residual stresses balance one another. When welding to square tubing pieces together this means that the joint should be tacked first, then one face welded, followed by the opposing face, then the remaining faces can be welded. For welding of the tubes in the frame a weld current of 50 amps DC is used with a fixe polarity current. The Electrode is machined to a point like a pencil and 2mm steel filler rod is used. As the tubes in the chassis have relatively thin walls no gusseting is required in the joint to achieve complete weld penetration.

6. RESULTS



Simulation values obtained of moment and deflection was plotted in SOLID WORKS SIMULATION and the best suited linear polynomial fit was performed. Results obtained are good approximation of the analysis carried out. The torsional rigidity or the stiffness of the chassis obtained from the analytical analysis is performed and it is comparable to the value obtained from Solid works.

The frame was designed and manufactured with mass of 50kg and torsional stiffness from the experiment of 20,422 N/rad. Another factor of steel tube sizes was studied using FEM analysis to show an increase in sectional area of the tube would in effect the increase in the torsional stiffness of the frame as well. So we can conclude that the future frame would pass the rules and regulations and also the weight requirement. Even though our future frame's torsional stiffness is 20,422 N/rad, but the 20,422 N/rad of torsional stiffness is required for the whole car and not only the frame. The frame would have more components such as anti-roll bars and engine mounted to the frame. When these components attached to the frame would increase the overall torsional stiffness of the car, it can be concluded that the torsional stiffness of the car would be more than the required.

7. CONCLUSION

The design has been done based on the inputs given by the various departments such as steering, suspension, driver ergonomics and engine mountings i.e., drive train department. The complete design has been done on the SOLID WORKS software. Simulation analysis of the design is done in SOLID WORKS. The results were best and suitable for our requirements.

This paper reviews three different approaches; analytical, simulation and experimental, to design the FORMULA STUDENT RACE CAR chassis at the different stages of development. A comparison of two Finite Element based methods is also conducted. The goal of the analytical method would be to determine the stiffness based only on the geometry but could prove too costly in terms of time as a large number of long calculations could be required.

The presented FEA-based method is a more practical method that can be employed in industry. This method uses finite element analysis to apply loads and measure the resulting deflections. Overall any of the methods presented could be applied in order to determine the torsion stiffness but it is suggested that a combination of methods, especially simulation and experimental methods, in order to verify the results. While increasing the torsion stiffness is an important goal in automotive design a more practical measurement would be a function involving the torsion stiffness and vehicle mass to ensure the increases in torsion stiffness will not greatly increase the weight of the vehicle.

8. FUTURESCOPE

Construction

At the time of writing, the majority of the space-frame construction has been completed. Some triangulating members need to be added to the frame and the sheet metal battery boxes and seat need to be bent into shape and welded into the frame. These will be completed by the end of 2011 however the car will no longer be entering the 2011 FSAE competition so the deadline is less strict now.

Chassis testing

The chassis testing mentioned in the safety section needs to be performed to measure the chassis' performance and to ensure it is safe. The torsional test will be performed on the frame both before and after welding the battery boxes into place in order to get an experimentally recorded value for the amount that they improve the stiffness of the chassis in practice.

Ultrasonic weld testing

To further ensure the safety of the chassis and the quality of the welds the completed frame should have the welds ultrasonically tested. This testing would have to be outsourced to a third party but would provide a very accurate way of testing the welds in the chassis itself. Testing of sample welds as mentioned is useful but does not guarantee the quality of the welds in the frame, even though the welds were completed by the same person with the same technique, many of the welds in the frame a in awkward positions with limited access which may have reduced weld quality. Ultrasonic weld testing can detect defects such as voids and cracks within the welds (Black, 2008) which could weaken the structure. If any welds are found to have large defects then they will be ground back and re-welded and re-tested.

Future designs

If the team decides to put a 600cc bike engine then the chassis designed in this project provides a good starting point for future designs. Due to the nature of the rules, it is unlikely that it would be possible to significantly lighten the frame or significantly increase its torsional stiffness. Investigations into the use of alternative materials may improve stiffness without increasing weight so this would be an area worth investigating. This design uses steel tubing in the frame, replacing

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