Design of Student Formula Race Car Chassis

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Abstract: ***SUPRA SAEINDIA is an annual national level competition organized by the Society of Automotive Engineers India. From all over India, the selected Under Graduate & Post Graduate Engineering Student teams are asked to design, model, fabricate and compete with a small open-wheel, open cockpit type race car. The major challenge posed is to design and fabricate a light weight car without compromising the safety of the driver. The car has to be rigidly fabricated at minimal expense. This paper is an introduction to the design process of a steel tube space frame chassis for use in SUPRA SAEINDIA based on the experience of the team UFO RACERS. The design is based on the anthropological data of the specified human (95th percentile male) allowing fast ingress and egress from the car. The basic theories and methodologies for designing these systems are also presented so that new teams will have a baseline for their first SUPRA SAEINDIA race car design. SOLIDWORKS 2014 CAD software is utilized for the design of the chassis because of its exceptionally powerful capability in the field of design and analysis of engineering products. The one-stop package of comprehensive FEA and all-round design capability make it an ideal tool for the race team to be used to develop components of the race car and thus the chassis. The entire design process is based on SUPRA SAEINDIA 2015 rule book and knowledge of designing and manufacturing learned so far.***

Keywords: SUPRA SAEINDA, Tubular space frame chassis

1. Introduction

SUPRA SAEINDIA is a national level student competition, organized by Society of Automobile Engineers India, wherein students are asked to design, manufacture and run a prototype of open wheel racing car. This competition is conducted annually in India and about 180 colleges participate every year from all over India. Following the technical inspection are the sub events which include the static events like tilt test, brake test, cost report presentation, engineering design report and business presentation, dynamic events like acceleration test, skid pad, autocross and endurance test. In this high octane scenario a car is expected to perform high on acceleration, handling, braking, aesthetics, ergonomics, fabrication and maintenance with least investment in fabrication without compromising on safety of the driver. The purpose of the thesis is to design and manufacture tubular space frame chassis that should be strong enough to absorb the energy when front, back, side, torsional loads are applied.

For the purpose of the application on a high performance racing car, it has to meet the following criteria:

- Minimize the weight to stiffness ratio
- Maintain Low Center of Gravity
- Reasonable material and manufacturing costs
- Create a solid base chassis to evolve on for years to come
- Aesthetically pleasing design

2. Design Development

The purpose of the frame is to rigidly connect the front and rear suspension while providing attachment points for the different systems of the car. Relative motion between the front and rear suspension attachment points can cause inconsistent handling. The frame must also provide attachment points which will not yield within the car's performance envelope. There are many different styles of frames; space frame, monocoque, and ladder are examples of race car frames. The most popular style for SUPRA SAEINDIA/FSAE is the tubular space frame. Space frames are a series of tubes which are joined together to form a structure that connects all of the necessary components together. However, most of the concepts and theories can be applied to other chassis designs. A Space frame chassis was chosen over a monocoque in spite of being heavy, as its manufacturing is cost-effective, requires simple tools and damages to the chassis can be easily rectified. The chassis design started with fixing of suspension mounting coordinates and engine hard points.

2.1 Design Considerations

The design process of the chassis consists of many steps, from the initial assignment to the task of chassis design to the start of construction. These steps are; to identify the restriction, determine the required performance criteria, research design techniques and methodology, use of CAD software to design chassis and lastly start construction. Throughout these steps, choices must be made based on the targets that are to be achieved to meet the performance requirement. The designer of the chassis must have an idea as to how all components of the car are going to function in relation to each other. As a result, the designer must know how all parts must interact and take this interaction into account when designing the frame. The design of a racing car chassis, or any racing chassis for that matter, is going to be based on suspension points, powertrain layout, driver position controls, safety, etc. These important points must come together to form an effective package for the car to perform as intended.

<u>Stiffness</u> - The suspension is designed with the goal of keeping all four tires flat on the ground throughout the performance range of the vehicle. Generally, suspension systems are designed under the assumption that the frame is a rigid body. For example, undesirable changes in camber and

toe can occur if the frame lacks stiffness. An image of a frame subjected to a torsional load is superimposed on an undeflected frame. Generally, a chassis that is stiff enough for competition will not yield. However, some care should be taken to ensure that the attachment points of the frame do not yield when subjected to design loads. For example, the engine mounts should be made stiff enough to reduce the possibility of failure.

Torsional Stiffness - Torsional stiffness is the resistance of the frame to torsional loads. FEA was used to analyze the torsional stiffness of the chassis. In order to design a car of maximum torsional stiffness the basis or generalized equation for torsion must be examined.

$$T = \frac{\theta J G}{l} \quad (1)$$

The above equation is a simple formula that relates the angle of twist to the applied torque, with J representing the shafts polar moment of inertia, with θ denoting the resultant twist of the shaft, G representing the shear modulus of the material and l being the length of the shaft. Now a chassis can be made extremely stiff by adding significant amounts of material to the frame. However, this additional material might degrade the performance of the car because of the added mass. Therefore while designing a race car chassis it is important to get a balance between the weight and stiffness of the chassis.

Triangulation - Triangulation can be used to increase the torsional stiffness of a frame, since a triangle is the simplest form which is always a structure and not a mechanism. Obviously, a frame which is a structure will be torsionally stiffer than a mechanism. Therefore, an effort should be made to triangulate the chassis as much as possible. Visualizing the frame as a collection of rods which are connected by pin joints can help frame designers locate the mechanisms in a design.

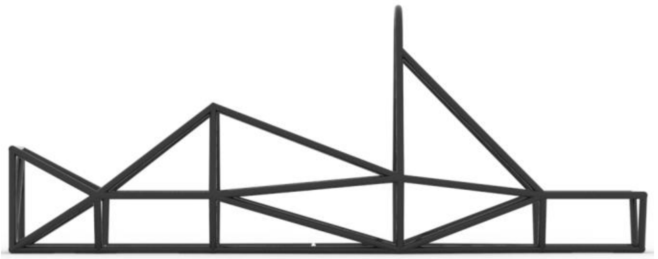

Figure 1: Frame Triangulation

Designers can also evaluate their frame by checking to see if each pin jointed node contains at least three rods which complement the load path. It was decided to use thin wall steel tubing for the frame design. This required significant triangulation of the frame, since thin wall tubing performs very well in tension and compression but poorly in bending. The components which produce significant amounts of force, for example the engine and suspension, should be attached to the frame at triangulated points.

Suspension Points - The suspension geometry is what determines how well the car controls the tires that connect the vehicle to the ground. Should the suspension not control the tires correctly, the car will not corner as quickly and therefore be slower overall. Through testing, data analysis, and simulation we have developed effective suspension geometry for our SUPRA SAEINDIA race car. Packaging of the suspension to the frame is generally not an interference problem since most of the components are exterior to the frame. However, it is especially important to attach the suspension components to stiff portions of the chassis to correctly distribute the loads that will be passed through these components.

Designing the frame so the control arms are attached to a stiff portion of the chassis can sometimes be very difficult. By changing the distance between the control arm pivot points can help to optimize the load path for the control arms. This distance can be changed because it will not affect the suspension geometry, since the rotational axis of the control arm is not affected. However, decreasing the span of the control arms will reduce the arm's ability to react to the forces which are generated by accelerating or braking. It is advised that suspension should be designed concurrently with the frame. This allows the designer to concentrate on the load paths from the push rods and rockers so that the frame can efficiently react to the loads.

Powertrain Layout - Correctly attaching the components of the drivetrain to the frame is very important for extended frame life. The relative stiffness between the engine, differential, and frame is not as critical as when attaching the suspension. This is due to the fact that most race car chassis layouts have short distances between the drivetrain components. The main design point is to ensure that the frame does not break during an incorrect downshift or a violent release of the clutch.

Since SUPRA SAEINDIA race cars use bike engine it is easier to place the engine as it was in the bike. The location of the engine in relation to the wheelbase of the car plays the biggest role in weight distribution of the car. An easy way to combat this is to distribute more of the weight of the car toward the driven wheels to increase vertical load on the tires. Any relatively large mass, being far away from the centerline of the car, potentially have a negative effect on the yaw inertia of the vehicle.

By moving the mass to a location in the center of the car will decrease the yaw inertia which is favorable for race cars. When designing the frame around the motor and differential on chain driven designs, sufficient clearance must exist so that several front and rear sprockets can be used. This clearance allows a wide selection of final drive ratios. Well the excess space can be neglected based upon the designer's choice, but it is recommended to have sufficient clearance as inability to change the final drive ratio has proven to be a drawback when trying to drive the race car in the confined space of the SUPRA SAEINDIA competition and the more open spaces of autocross. Ease of maintenance is also an important design consideration when designing the frame around the drive train. By providing clearance for direct removal of the engine will reduce the amount of mechanic's stress involved with engine changes.

Driver Position and Controls - Another important aspect of chassis design is driver positioning and controls. If the driver is not able to operate the car comfortably, it will not meet its full potential. Designing the frame around the controls, such as the steering wheel and pedals, is a matter of ensuring that the structure of the frame does not interfere with the driver's task. Also, the controls must be adequately supported by the frame so that the attachment points do not yield while the car is being driven. Driver comfort concerns include seating angle, elbow space, head height in relation to the front of the car, and controls operation (pedals, shifter, and steering wheel).

Safety – Fortunately, the FSAE rules committee has set up a group of rules requiring certain tubing sizes in areas of the frame critical to driver safety in the event of an accident. These rules define outer diameters and wall thicknesses for the front bulkhead, front roll hoop, main roll hoop, side impact tubing, roll hoop bracing, and front impact zones. The stated rules are adhered to without deviation so that the driver may be safe and the car can pass technical inspection at competition.

2.2 Design Process

A tubular space frame is designed in several steps that are based on the design considerations previously stated. A methodical plan must be followed so that all parameters are considered and the design incorporates every part of the car correctly. We designed the SUPRA SAEINDIA race car in Solidworks 2014 using the weldment feature to model tubes easily and accurately.

Initial Setup – The design was initiated by determining the height, track width, wheel base, and overall length dimensions of the vehicle. Stemming from these dimensions were roll hoop locations, bulkhead location, cockpit location, engine mounting location, and wheel centerlines for an estimation of weight distribution. Once these dimensions were selected, a series of planes were created in Solidworks at these points so that these locations could be visualized. Some thought was given to the placement of other important or hard-to-package systems. For example, the fuel system had to be packaged near the center of gravity to reduce the effects of its varying mass during the race.

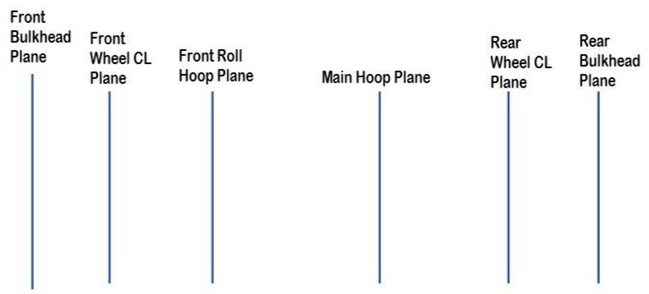

Figure 3: Chassis Planes - Side Views

Modeling of Fixed Elements - Fixed elements include roll hoops, front bulkhead, suspension points, and engine mounts. These features will not be moved around during chassis design iteration so that the number of variables able to be manipulated may be decreased. This allows for a quicker design period so that construction may begin sooner than usual.

The roll hoop and bulkhead shapes are decided upon to minimize the length of tubing for the elements. Since the roll hoops and bulkhead are required to be at least 1" OD .095" wall and 1" OD .065" wall, respectively, the lengths of this heavy tubing need to be minimized to reduce weight. Once shapes of the features are decided upon, they are drawn on their respective planes. A structural member feature is added to the sketch and the first tubes of the model are drawn.

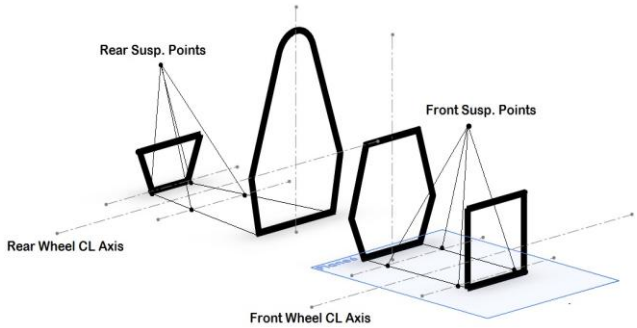

Figure 2: Roll Hoops and Suspension Points

The suspension mounting points are the next to be designed. These are drawn as fixed points in space in the Solidworks model. During suspension design, an optimal a-arm span was determined and this dimension must now be integrated into the chassis.
Suspension mounts needs to be welded to the chassis so the position of this mounts are needed to be acquired from the suspension calculation. Engine mounting locations are also decided upon and fixed so that the engine design team can accurately place their individual part models in the car assembly without having to change their parts. This keeps the team from making drastic changes when farther along in the design process.

Modeling of Variable Elements - The next step is to model the tubes that connect the fixed elements to each other. Arrangements of these tubes are variable and careful consideration of weight, manufacturability, and chassis stiffness must be taken, so that the chassis does not become heavy and too flexible. The competition rules must also be taken into account when drawing these connecting tubes.

Since the weight of the chassis is critical to car performance, connecting tubes must be kept short and thin.

All the connecting tubes must be of the dimensions specified in the rule book i.e., 1" .049" wall. The only connecting tubes that may not be of this size are the required roll hoop bracing tubes which must be 1" .065" wall. These bracing tubes are kept to a minimum length.

The first chassis design below had a lot of structural members which in-fact increased the weight of the chassis. The main intention of increasing the number of structural members was to increase the torsional stiffness. By Finite Element Analysis the members which weren't of any use were removed and hence it reduced the weight without affecting much the torsional stiffness.

Figure 4: First Chassis Design Model

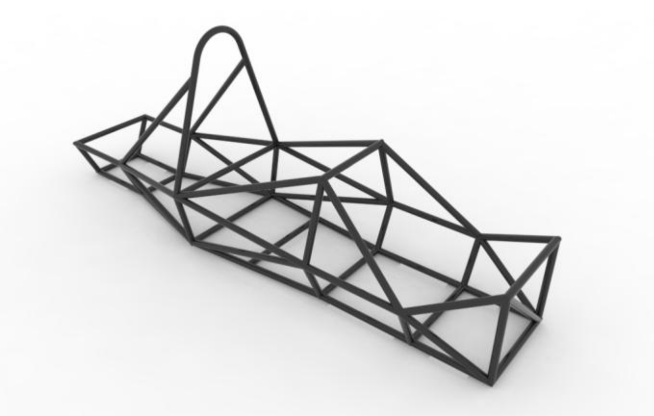

Figure 5: Re-designed Chassis

Manufacturability is important to bear in mind because the more complex the chassis, the harder it will be to fabricate. If the connecting tubes have extremely difficult notches on the ends, it will take the team member who is making that tube much longer to finish. Subsequently, if each tube on the chassis takes 2 or more hours to notch, then it will take much longer to complete the frame.

Chassis stiffness relies on the effective arrangement of the connecting tubes. This will be discussed in further detail later. Modeling of the connecting tubes is relatively simple in Solidworks using the 3D sketch tool. Drawing the lines is much like connecting the dots, or in this case, nodes. Once a line is drawn between two of the nodes, a structural member may be placed along that line. A network of tubes may then be drawn by connecting nodes in certain places and inserting structural members.

Figure 6: Full Car Assembly Model

3. Material Selection

The chassis undergoes various kinds of forces during locomotion, it has to stay intact without yielding, and it should be stiff to absorb vibrations, also it should resist high temperatures. The material property of the chassis is an important criterion while designing and manufacturing the car. A tubular space frame chassis was chosen over a monocoque chassis despite being heavier because, its manufacturing is cost effective requires simple tools and damages to the chassis can be easily rectified. The two very commonly used materials for making the space frame chassis are Chromium Molybdenum steel (Chromoly) and SAE-AISI 1018. Both these materials were analyzed for different parameters and finally decided on to use Chromoly steel 4130 for making the tubular space frame chassis because of several reasons.

SAE 1018 grade steel is better in terms of Thermal properties but weaker than Chromoly in terms of strength. But the main priority of design is safety for the driver hence the material with better stiffness and strength was chosen. The material should not cause any failure even under extreme conditions of driving as defined in the rule book. Chromoly steel 4130 exhibits better structural property than SAE 1018 Grade steel hence the former was considered as the basic material for building a tubular space frame chassis. Even though the cost of Chromoly is marginally higher than that of SAE 1018 grade steel, the safety of the driver remains the utmost priority for the team.

Table 1: Material Properties

Properties	SAE AISI 1018	Chromoly 4130 Steel
Density (g/cc)	7.8	7.8
Young's Modulus (GPa)	210	210
Elongation at break (%)	19	19
Brinell Hardness	120	200
Strength to weight ratio at Yield (kN-m/kg)	38	100
Yield Strength (MPa)	360	480
Ultimate Strength (MPa)	420	590
Thermal Conductivity: Ambient (W-m/K)	50	42
Thermal Expansion: 20C to 100C (μm/m-K)	11	12
Specific Heat Capacity Conventional (J/kg-K)	370	370

4. Conclusion

The purpose of this thesis project is not only to design the roll cage for the 2015 SUPRA SAEINDA car, but also to provide an in depth study in the process taken to arrive at the final design. With the overall design being carefully considered beforehand, the manufacturing process being controlled closely, and that many design features have been proven effective within the performance requirement of the vehicle. During the design process, the team must achieve a compromise between cost, manufacturing, performance, and design time so that their car will be competitive in all aspects of the SUPRA SAEINDIA competition. The timeline of the competition, combined with the rigorous schedule of college, limits the number of iterations for each design. However, the team should understand that it will take several iterations to converge on a satisfactory design. The amount of time used for the design process subtracts from the time available for manufacturing and testing. Although this paper has concentrated on design, it is very important to test the car so that any design oversights will be highlighted before competition.

References

[1] SUPRA SAEINDIA 2015 rulebook
[2] Herb Adams, “Chassis Engineering”, Penguin Group (USA) Inc., 1993, ISBN 1-55788-055-7
[3] Carroll Smith, “Drive TO Win”, Palos Verdes Estates, CA: Carroll Smith Consulting 1996
[4] Carroll Smith, “Engineer TO Win”, Aero Publisher, Inc., 1978, ISBN 87938-071-3
[5] http://www.fsae.com/forums/forum.php
[6] William Davis, “Design and optimization of Formula SAE Race car”, Worchester polytechnic Institute of Technology, Jan 2011.
[7] William B. Riley and Albert R. George, “Design, Analysis and Testing of a Formula SAE Car Chassis”, Cornell University, 2002-01-3300
[8] Andrew Salzano and Eric Klang, “Design, Analysis and Fabrication of a Formula SAE Chassis”, College of Engineering, North Carolina State University, 2009

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