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Design Analysis of Chassis used in Students' Formula Racing Car using FEA Tool

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Abstract: ***In this paper, the overall design process for a Formula SAE vehicle will be explored, as well as the many challenges that must be overcome. Several factors will be taken into account, including modelling and analysis, and overall manufacturing and performance of chassis. This project will be split into several phases: analysis, testing and validation of the FSAE vehicle and the design, analysis, manufacturing. All decisions for design were based on all pros and cons from previous FSAE testing and competition results. The competition consists of various sub events for which points are given and cumulative score is recorded for deciding the ranks. 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 at different track configurations.***

Index Terms*: Chassis, Design, FSAE, Line Element.*

I. INTRODUCTION

Chassis is the main supporting structure which carries all the loads. The issues related with chassis are the mounting ~~of~~ the components in proper place so that the vehicle is properly balanced. The main chassis structure is divided into several segments, which are the Main Hoop, Front Hoop, Side Impact Protection and Crush Zone. The Main and Front Hoop is tasked to protect the driver in the event if the car rolls over. The Main Hoop protects the upper part of the driver's body while the Front Hoop protects the drivers arm and hand if rollover occurs. As for the Side Impact Protection section, this section is created to protect the driver from side in the event of any collision from the either side of the car. As part of the chassis, the Crush Zone is located at foremost section of the chassis. The previous year's chassis was made by making a fixture on wooden plank by the team by our Team *UDAAAN* (2016 Batch) by modelling the chassis first in Solidworks Interface and then analysing the safety of the chassis on Ansys Workbench. The chassis was then manufactured members and then came the cutting of the pipes. Material used was AISI 4130 tubes.

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The tubes were then profiled according to the needed dimensions and were set in the fixtures to check the proper dimensions. Bending of the pipes was carried out on mechanical pipe bending machine. Drawbacks of the previous year's chassis include improper Triangulation of the members at the rear portion of the chassis, additional members and heavy mountings for the engine. This year's chassis was modelled keeping the following drawbacks in mind. The ideas for the new chassis came by reading books related to chassis and collecting ideas from the past experiences of few of the team members. The factor we kept in mind while making the new chassis was weight reduction and proper triangulation of members. Work was carried out by first listing down the inputs from the various research papers and from the rule book provided by SAE SUPRA. Then a rough model of the chassis was made in Solidworks Interface which underwent many iterations and a final model of the chassis was selected by the team members. Then came the analysis part where the chassis was subjected to various loads at different points on the chassis to check the rigidity of the chassis. The chassis needs to safely under extreme conditions so the factor of safety was considered a bit larger than the normal value.

II. VEHICLE DESIGN PARAMETERS

Following are the vehicle requirements set up by the FSAE.

A. Wheelbase and Vehicle Configuration

The car must have a wheelbase of at least 1525mm. The wheelbase is measured from the centre of ground contact of the front and rear tires with wheels pointing straight ahead. The vehicle must have four wheels that are not in a straight-line.

B. Vehicle Track Width

The smaller track of the vehicle (front or rear) must be no less than 75% of the larger track".

C. Ground Clearance

Ground clearance must be sufficient to prevent any portion of the car (other than the tires) from touching the ground during track events.

D. Templates

Vehicle Chassis should fulfil all the rules-template mentioned in rulebook

E. Chassis

Chassis is the basic supporting frame or structure supporting various components of a car, carriage or other wheeled vehicle. Considering above requirements following parameters were finalized based on drivers safety and comfort ability:

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Table I. Design Parameters

PARAMETERS	VALUES
Wheelbase	1580 mm
Track width	Front: 1200 mm, Rear: 1100 mm
Ground Clearance	3 inch
Wheels	Neo Wheels R13

III. AIM AND OBJECTIVES

The main of the project is to make a safe chassis which can be used to support various components like engine, suspension, wheels, etc. to make up a complete formula student car which can be used for the racing competition. The project should be cost effective plus must not compromise on safety of the driver. The various materials available in the market can be optimized to choose the one which suits our purpose for the race vehicle and is not much costly so as a financial burden to the team members. The input from all the other teams to be given importance and then the design is to be fabricated. After carefully reading the rules from the rulebook provided by the technical committee the design by rule should be done. Design by rule includes modelling of the chassis by the rules given in the rule book and obtaining a chassis which would easily clear the technical inspection test at the static events during the SAE SUPRA competition. Next is the design by analysis which includes optimization of the material as well as iteration of chassis members position to obtain a safe chassis with proper triangulations and should have a higher factor of safety for the racing event. The various loads would be applied on the car CG as well as forces on the suspension to check the durability of the frame when bumps occur. The analysis would be carried out on ANSYS WORKBENCH and the results obtained will be validated for the safety of the chassis.

IV. DESIGN DESCRIPTION

The design process of any road worthy vehicle begins with the tires; the tires are the only point of contact between the vehicle and the road. Each tire has a different compound and different material properties. The task for the engineer is to find the tire's optimal range of operation considering slip angle, inclination angle, loading, road conditions, tire pressure, as well as several other factors. Once this range is clearly depicted, the suspension hard points are determined to make sure the tire operates within the specified range. The hard points are directly correlated to the basic suspension parameters such as wheelbase and track width. Track to wheelbase ratio should be typically a 1.2 - 1.5 ratio; for rapid steering response an optimal ratio of 1.3 should be targeted. The tire data also includes the slip angle of the tire, pneumatic trail of the tire and optimal camber of the tire. Figure 5.1: Model 2017. The chassis of the 2016 SUPRA car is the first prototype that will serve as a test bench for the 2017 chassis produced during the course of this project. This prototype offers the benefit of being a completely running and driving vehicle, from which all the vehicle dynamics adjustments and goals will be verified. This vehicle includes the chassis and its interaction with all other vehicle system components, such as braking system, power train and drive train systems, suspension, aero package and full electrical package. The following images show the model for the 2017 SUPRA Chassis. Some critical aspects to pay attention to are the way the chassis fits the SUPRA rules with the triangulated frame members and the heights of the roll hoops, providing a safety region for rollover protection. Note that this chassis contains a larger wheelbase of 63 inches. Within the design for the chassis, the use of node-to-node connections was used to fit the rules established by SUPRA.

The triangulated frame elements also allow a wider distribution of applied and translated stresses throughout the design of the chassis. A final detail is the cockpit area, which has a significant effect on handling. This area is lower than the front and rear control arm-mounting areas. This yields a lower centre of mass and maintains critical suspension geometry to allow for optimal handling.

The 2017 chassis is designed with driver ergonomics and weight reduction from the previous chassis. The chosen engine was a single cylinder KTM 390cc engine, which provides a relatively good amount of torque within a while maintaining a light weight. Following this engine choice, the car needed to be as light as possible to effectively benefit from the motor choice.

The chassis is a completely tubular space frame fabricated with Chromalloy steel round tubing selected. The rear legs of the front suspension arms will be affixed to the front roll hoop, 8 inches forward there is an identical hoop of 0.065-inch wall thickness where the front arms of the suspension will mount. These hoops were designed to provide maximum driver leg room while maintaining the desired track length, which is the length from the center of the tire on the left side to the center of the tire on the right side. The front bulkhead was designed to the exterior dimensions of the standard SUPRA impact attenuator. The width of the chassis at the bottom of the main roll hoop was chosen to provide maximum room from engine and electrical components as well as to reduce complexity of the chassis in this area by limiting the number of bends in the main hoop. The designs were made so that the engine can be inserted from the right side of the chassis, between the main roll hoop and the main roll hoop supports. The mounting system, which consists of lateral bars stretching the width of the chassis with tabs mounting to the engine, was kept simple to reduce complexity of design, improve manufacturability, and reduce overall cost.

When designing the chassis, the decision was made to minimalize the rear box for ease of access and servicing of drivetrain components as well as to reduce weight of the chassis. The section of bent tubing mounted to the rearward, upper suspension mount is placed to distribute the load of the suspension as well as to provide a location for mounting of the shocks, and chain guard.

For a typical race car, torsion rigidity is critical in chassis design. Torsion flex in the frame essentially adds another spring to the system, making suspension tuning unpredictable. It is nearly unavoidable to have some chassis flex during hard cornering.

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However, when it is minimized it will allow for calculated suspension adjustment with immediate and predictable results. Therefore our goal is to make the chassis as stiff as possible. An important constraint taken to each component being designed this year is minimizing weight.

The chassis is no exception. All tube sizes that were not explicitly dictated by the SAE SUPRA Rulebook have been analysed under loading conditions and reduced in size until they were considered at a point where they would be strong enough to support the loads and still lighter than the previous design. While the chassis was stretched slightly to accommodate taller driver, several chassis members forward of the front roll hoop have been reduced in size. This helps maintain the mass moment of inertia as focused on the centre of the car as much as possible. Also chassis was made compact keeping in mind proper packaging of all components such as engine, differential, springs, steering etc. These actions were taken to simultaneously keep the weight of the vehicle low and to reduce the mass moment of inertia. Physically reducing the mass moment of inertia allows for more responsive handling characteristics.

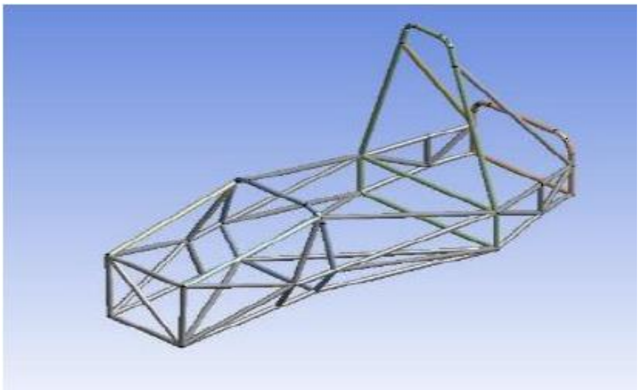

Fig. 1 Final Model (Isometric View)

The design templates dictated by the SAE SUPRA Rulebook provided several of the constraints for designing the chassis. It was found in the previous design that the chassis was not suitable for taller driver. To fix this, alterations were made to the seating position as well as the bulkhead supports.

V. MATERIAL USED AND ANALYSIS

Very first the material is selected for the car. When selecting materials for motorsport applications the most common factors considered are strength, cost and weight. In order to design a competitive vehicle it must be light and yet strong. The chassis was constructed using normalized 4130 alloy steel, which is often referred to as “Chromalloy”. This material is stronger and more ductile. It also exhibits better welding properties leading to simpler manufacturing of the chassis. Also the properties of the chassis are better than the properties required in Rule Book.

A. Design Analysis

Model of both the chassis were made in Solidworks educational version 2016. By fixing one of the vertex as origin, coordinates of all vertex or node in 3D space found using Solidworks. Coordinate file made noting the same points with help of notepad in text format.

ANSYS was used for the analysis purpose. Points were generated using coordinated files to create geometry. Line diagram or wireframe structure was made and proper cross section was assigned to respective members. 1D Analysis was preferred as it gives satisfactory resulting case of analysis of structure like chassis truss etc.

Following analysis was performed:

```
File  Edit  Format  View  Help
1    1    190     0       0
2    1    200     375     0
3    1    150     520     -700
4    1    237.7   450.22  -700
5    1    300     180     -700
6    1    200     0       -700
7    1    65      1149.2  -1500
8    1    116.95  1109.09 -1500
9    1    143.08  1009.2  -1500
10   1    360     180     -1500
11   1    360     -50.8   -1500
12   1    170     350     -2000
13   1    260     260     -2000
14   1    260     180     -2000
15   1    260     0       -2000
```

Fig. 2 Coordinates File

1. Bending under stress loading
2. Torsion:
   a. Front Bump
   b. Rear Bump
3. Impact:
   a. Front
   b. Side and
   c. Rear
4. Explicit Dynamics: Crash test

Boundary Conditions for different test are in following figures.

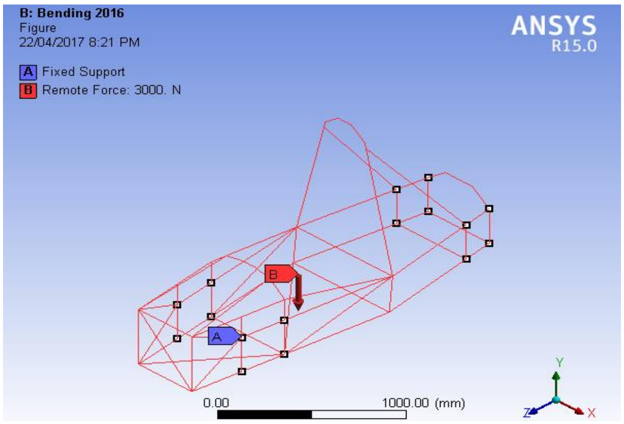

Fig 3.Boundary Conditions (Bending)

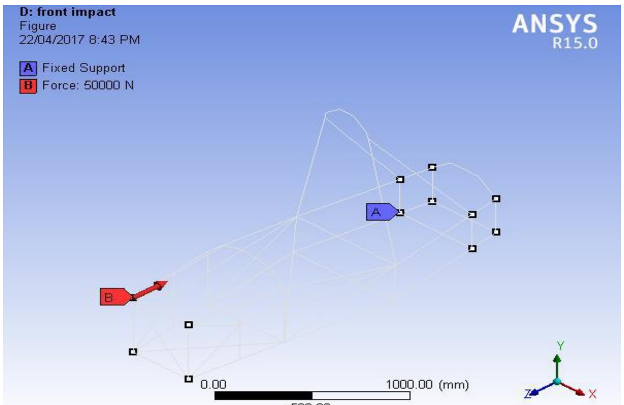

Fig 4.Boundary Conditions (Front Impact)

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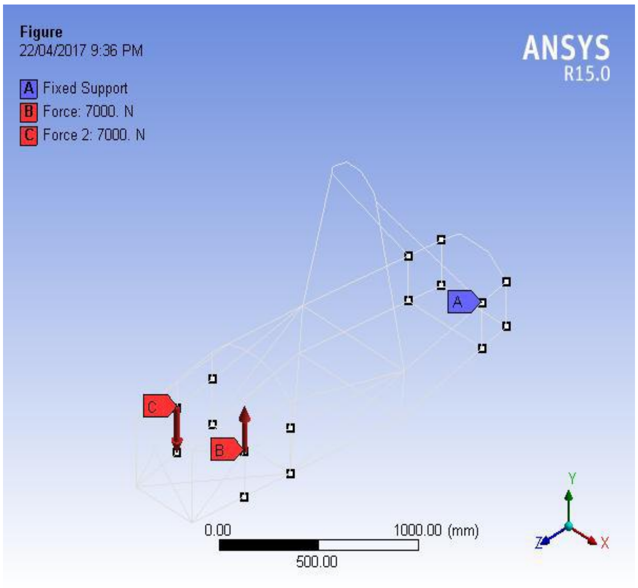

Fig. 5. Boundary Conditions (Front Torsion)

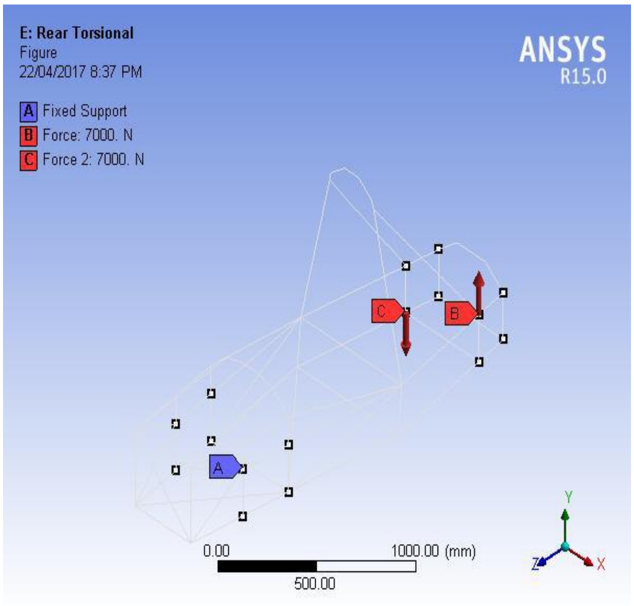

Fig. 6 Boundary Conditions (Rear Torsion)

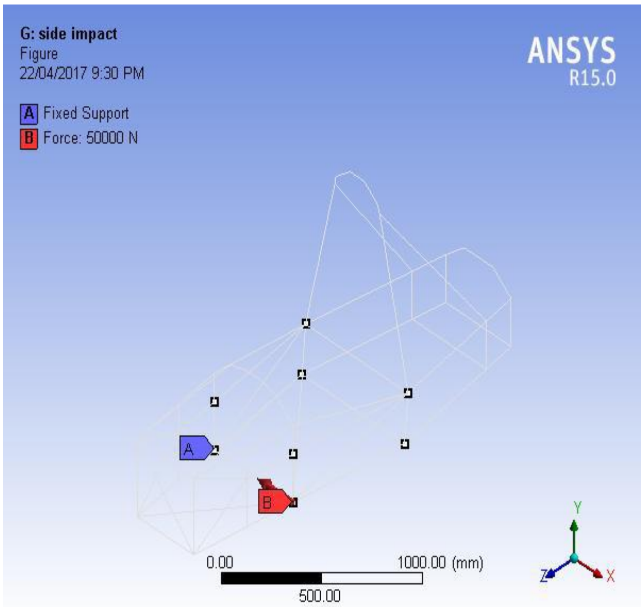

Fig. 7 Boundary Conditions (Side Impact)

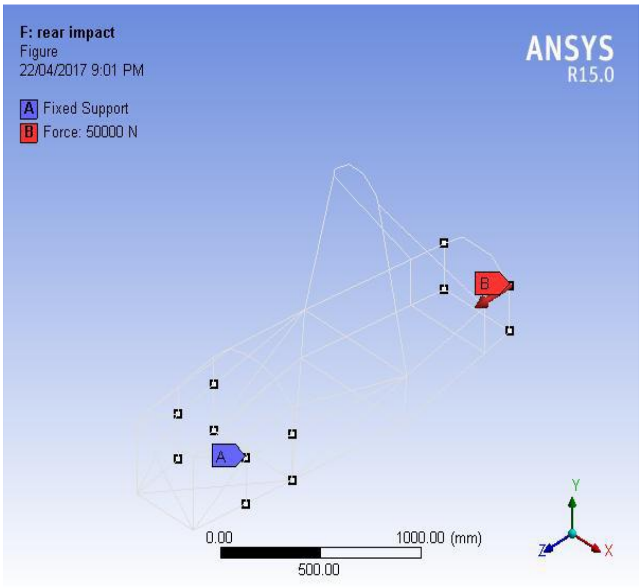

Fig. 8 Boundary Conditions (Rear Impact)

Analysis with same boundary condition was performed on both chassis models. Results obtained were tabulated as follow:

Table II. Comparative Results

Parameters	Old Chassis	New Chassis
Analysis 1: Bending under Static loading.	Deformation: 0.2647mm Stress: 4.095 MPa	Deformation: 0.186 mm Stress: 4.11 MPa
Analysis 2: Torsion due to front bump.	Deformation:23.65 Stress: 99.12MPa	Deformation: 14.07 mm Stress: 126.25 MPa
Analysis 3: Torsion due to rear bump.	Deformation:19.61 Stress: 83.97MPa	Deformation: 7.48 mm Stress: 118.74 MPa
Analysis 4: Deformation due to front impact.	Deformation:3.25 mm Stress: 44.82 MPa	Deformation: 8.33 mm Stress: 62.27 MPa
Analysis 5: Deformation due to rear impact.	Deformation: 1.22 mm Stress: 28.41MPa	Deformation: 2.35 mm Stress: 35.30 MPa
Analysis 6: Side impact analysis.	Deformation:13.36 Stress: 9.72MPa	Deformation: 10.88 mm Stress: 48.19 MPa

VI. RESULTS

The team of SUPRA 2017 working under the author of this article has successfully completed the fabrication of the chassis of the vehicle. The major shortcomings of the 2016 Chassis were analysed and remedies were implemented in the best possible ways. Chassis analysis was performed and results showing maximum stress in members under the ultimate tensile strength of the tubes were found (minimum FOS in case of Front torsion test was found to be 4.84) Following are the points showing the major variation in the chassis 2017:

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A. *Change in engine reduced engine space.*
B. *Cockpit area increased for driver ergonomic consideration.*
C. *Fulfillment of 95th percentile rule.*
D. *Reduction of weight (51kg-37kg)*
E. *Reduction in redundant members (No. of members reduced from 46 to 42).*
F. *Reduction in height of Centre of gravity.*
G. *Taken in account the manufacturing considerations such as difficulty in grinding, welding and bending.*
H. *Improved strength at nodes by merging of members by bending instead of cut and welds.*
I. *Triangulation at some crucial points to help better force distribution and lower stress concentration.*

Driver's Safety being the primary objective which was taken in consideration as all the analysis performed were found to be safe before actual fabrication process.

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