DEVELOPMENT OF FORMULA STUDENT RACE-CAR

DESIGN AND MANUFACTURE OF TUBULAR SPACE-FRAME CHASSIS

&

DESIGN AND ANALYSIS OF COMPOSITE CHASSIS

A thesis

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by

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ABSTRACT

This document represents a report of a project based on the design of an FSAE race-car chassis. The author of this document is a member of NUST Bolts Racing (NBR), a team from SMME, NUST that aims at participating in Formula Student competitions.

Formula SAE is a student automotive competition held annually across the globe by Society of Automotive Engineers (SAE) in several different countries. The participating teams of the universities from around the world, comprising of students, compete with their self-designed open-wheel, single-seat prototype race-cars in various static and dynamic events.

The **first phase** of this Final Year Project concentrates on the design, analysis and fabrication of a tubular space-frame chassis to be used in 2015 FS Bolts race-car. This tubular structure uses mild steel pipes of a material that fulfills the safety and strength requirement of the FSAE competition. The second phase of this Final Year Project aims at designing and analyzing an upgrade version of the chassis for the next year FSAE race-car made of reinforced carbon fibers and a monocoque structure. The final phase of this project will be to compare the two structures and evaluate both for their comparative advantages and disadvantages.

The design of the chassis is based on the competition requirements, the stated competition rules as well as the different design criteria adopted by the project team. The main parts of the chassis structure include the front and rear roll hoops, frontal bulkhead, front and rear hoop braces, side impact structure, the driver's compartment and the engine compartment. The structure has been designed keeping in mind the maximum strength and stiffness with the minimum weight.

ACKNOWLEDGMENTS

We would like to thank all the people who helped us in completing our project.

Firstly, we would like to thank our faculty advisors for the unrelenting support they offered us with. Their technical guidance was very important in completing our work timely.

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Fourthly, we would also thank all whose work we have used or taken help from in the completion of this project, without which this project would not have been possible.

ORIGINALITY REPORT

This document is our own work and has never been presented anywhere else for evaluation. We have taken extra care to cite and/or give proper credit to whoever’s work we have taken help from.

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ABBREVIATIONS

NUST= National University of Sciences and Technology

SMME= School of Mechanical and Manufacturing Engineering

FSAE= Formula Society of Automotive Engineers

IMechE= Institute of Mechanical Engineers

SAE= Society of Automotive Engineers

NBR= NUST Bolts Racing

IA= Impact Attenuator

AI= Anti-Intrusion

CG, COG= Centre of Gravity

RC= Roll Centre

AISI= American Iron and Steel Institute

ASTM= American Society for Testing and Materials

CHAPTER 1

INTRODUCTION

PROJECT TITLE:

DEVELOPMENT OF FORMULA STUDENT RACE-CAR

DESIGN AND MANUFACTURE OF TUBULAR SPACE-FRAME CHASSIS

&

DESIGN AND ANALYSIS OF COMPOSITE CHASSIS

Basic Introduction

Formula Student is a competition organized by **Institute of Mechanical Engineers (IMechE)** and **Society of Automotive Engineers (SAE).** The competition organized by SAE is called **Formula SAE** and is a student automotive competition held annually across the globe in several different countries. The participating teams of the universities from around the world, comprising of students, compete with their self-designed open-wheel, single-seat prototype race-cars in various static and dynamic events.

NUST Bolts Racing (NBR) is an automotive team of students of School of Mechanical and Manufacturing Engineering (SMME), NUST that have taken up the project to build

SMME’s first ever Formula Student race-car and participate in of the Formula Student or Formula SAE competitions.

nustboltsracing

Figure 1: NBR Logo

A **chassis** is an internal framework of a structure that provides strength to the structure. Analogous to the skeleton of a human body, chassis is a term most commonly associated with the frame of a vehicle that is designed to support the vehicle’s components and passengers while countering the stresses encountered during the drive of the vehicle.

Project Timeline

The project of design of chassis has been divided into three primary phases.

The **first phase** of this Final Year Project concentrates on the design, analysis and fabrication of a tubular space-frame chassis to be used in 2015 FS Bolts race-car. This tubular structure uses mild steel pipes of a material that fulfills the safety and strength requirement of the FSAE competition.

The **second phase** of this Final Year Project aims at designing and analyzing an upgrade version of the chassis for the next year FSAE race-car made of reinforced carbon fibers and a monocoque structure. Fabrication of the monocoque chassis is subject to the availability of the resources.

The **final phase** of this project compares the two structures and evaluate both for their comparative advantages and disadvantages.

Aims and Objectives

The first and foremost objective of this project is to design and fabricate of a Formula Student race-car chassis that will be used by NBR in their first ever competition car. This year's chassis is a tubular space-frame chassis made of mild steel pipes. The chassis must clear all the static tests at the competition including all the rules mentioned in the 2015 Formula SAE® Rules Manual provided by SAE for this competition.

The second aim of this project is to convert the design of the tubular chassis into a carbon fiber monocoque chassis for the next year's participation. Reinforced carbon fiber structure presents obvious advantages over the steel structure and therefore this project will help the next year's team in achieving the target of **Pakistan's first ever monocoque chassis.**

The third aim of this project is to prove the superiority of a monocoque over a tubular chassis with theoretical test analysis.

CHAPTER 2

LITERATURE REVIEW

The Chassis types

Ladder Chassis

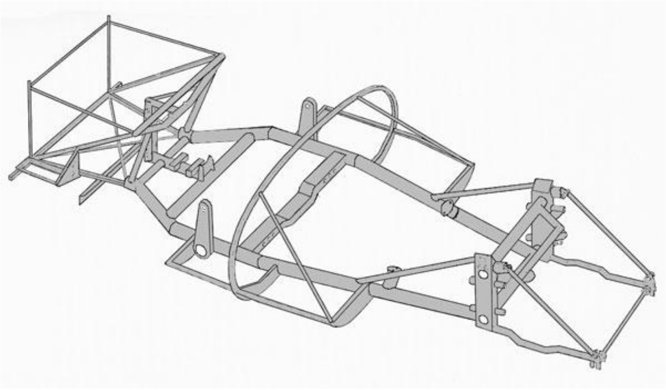
The basic ladder design as shown in Figure 2 is simple, easy to construct and functional. It is quite similar to a ladder with two main parallel beams and variety of cross member to complete the ladder like structure. Theses chassis were used up until the mid-1930s in the racing scene (Costin and Phipps, 1971), with some industrial vehicles like trucks and utilities still using this as the basis of their chassis today. Major drawbacks of this chassis include very little torsional stiffness.

(http://autoweldchassis.com/56chevy.ivnu)

Figure 2: Ladder Chassis

Twin Tube Chassis

Twin tube chassis is an improved form of ladder chassis in which main beams are replaced with large tubes. All the smaller tubes and bulkhead were then connected to these large tubes. Figure below shows the Lister Twin tube frame's main members which has a 3" diameter, fourteen gauge, seamless drawn, mild steel tubing.



(http://www.britishracecar.com/SydSilverman-Lister-Jaguar.htm)

Figure 3: Twin Tube Chassis

Space frame Chassis

Construction of space frame chassis consists of steel or aluminum tubes placed in a triangulated format, to support the loads from suspension, engine, driver and aerodynamics.

Space frames are popular today in amateur motorsport because of their simplicity. Most everyone who has access to a level workshop, a saw, measuring tools, and a welder of some kind can build one. Below is a figure which shows a space frame chassis.

(http://petrolsmell.com/2010/02/04/car-chassis-construction/)

Figure 4: Space-frame chassis

Monocoque

Monocoque is a construction technique that supports structural load by using an object's exterior, as opposed to using an internal frame or truss that is then covered with a non-load-bearing skin or coachwork. The word monocoque comes from the Greek for single (mono) and French for shell (coque).

There are two types of a monocoque chassis.

- Full monocoque:

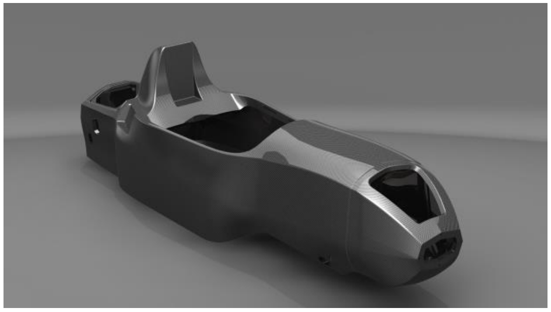
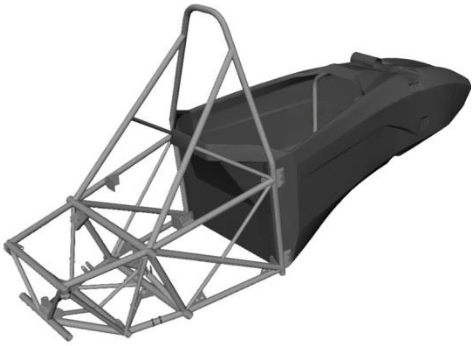


Figure 5: Full monocoque

(http://dart-racing.de/index.php/nachrichtenleser/monocoque.html)

- Hybrid monocoque



(http://www.3dcadbrowser.com/download.aspx?3dmodel=60289)

Figure 6: Monocoque Chassis

Deformation Modes

Understanding deformation modes is a must while designing of a racecar chassis. The main deformation modes in an automotive chassis are:

- Longitudinal Torsion

- Vertical Bending
- Lateral Bending
- Horizontal Lozenge

Longitudinal Torsion

Longitudinal twist or torsion of the chassis is produced by diagonal loading created mainly by a cornering vehicle or bumps in the racetrack. When diagonally opposite front and rear road-wheels roll over bumps simultaneously, the two ends of the chassis are twisted in opposite directions so that both the side and the cross-members are subjected to longitudinal torsion. A figure illustrating longitudinal torsion is shown below:

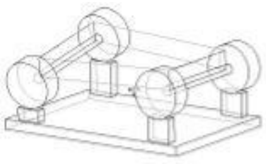


Figure 7: Longitudinal Torsion

Vertical bending

Considering a chassis frame is supported at its ends by the wheel axles and a weight equivalent to the vehicle's equipment, passengers and luggage is concentrated around the middle of its wheelbase, then the side-members are subjected to vertical bending causing them to sag in the central region. Here is a figure representing vertical bending.

Figure 8: Vertical Bending

Horizontal Bending

The chassis is exposed to lateral (side) force that may be due to the camber of the road, side wind, centrifugal force while turning a corner, or collision with some object. The adhesion reaction of the road-wheel tires opposes these lateral forces. Below is a representation.

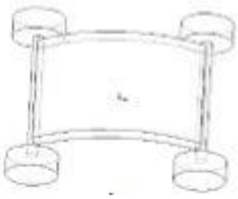


Figure 9: Horizontal Bending

Horizontal Lozenging

A chassis frame if driven forward or backwards is continuously subjected to wheel impact with road obstacles such as pot-holes, road joints, surface humps, and curbs while other wheels produce the propelling thrust. These conditions cause the rectangular chassis frame to distort to a parallelogram shape known as ‘lozenge’.

Figure 10: Horizontal Lozenging

Composites

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called reinforcing phase and one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibers, particles or flake. The matrix phase materials are generally continuous. The roles of matrix in composite materials are to give shape to the composite part, protect the reinforcements to the environment, transfer loads to reinforcements and tough- ness of material, together with reinforcements. Composite materials are used for Automobile, Ships, Aircraft, sports goods and so on.

Monocoque Material Selection

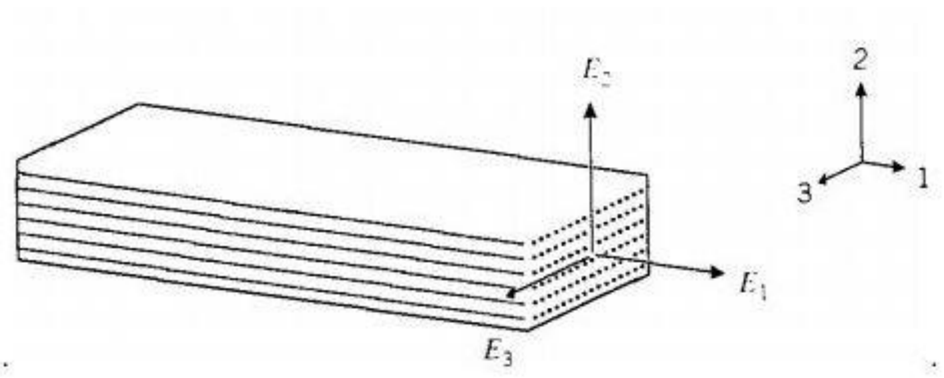
The monocoque chassis design was planned to be manufactured using a carbon fiber sandwich structure. The sandwich structure was to be constructed out of pre-impregnated (prepreg) carbon fiber skins bonded to a honeycomb core with film adhesive. This was chosen so that the laminate would have good specific stiffness. Additionally, with the use of prepreg the layup can be done over the course of a few days due to the long out-time of the resin.

Anisotropic Materials

If the material has a texture like wood or unidirectional-reinforced fiber composites as shown in Figure below, the modulus E1 in the fiber direction will typically be larger than those in the transverse directions (E2 and E3). When E1 6= E2 6= E3, the material is said to be orthotropic. It is common, however, for the properties in the plane transverse to the fiber direction to be isotropic to a good approximation (E2 = E3); such a material is called transversely isotropic. The elastic constitutive laws must be modified to account for this anisotropy, and the following form is an extension of the usual equations of isotropic elasticity to transversely isotropic materials:

$$\boxed{\left\{\begin{array}{c}\epsilon_1\\ \epsilon_2\\ \gamma_{12}\end{array}\right\}=\left[\begin{array}{ccc}1/E_1 & -\nu_{21}/E_2 & 0\\ -\nu_{12}/E_1 & 1/E_2 & 0\\ 0 & 0 & 1/G_{12}\end{array}\right]\left\{\begin{array}{c}\sigma_1\\ \sigma_2\\ \tau_{12}\end{array}\right\}}$$

The parameter ν12 is the principal Poisson’s ratio; it is the ratio of the strain induced in the 2-direction by a strain applied in the 1-direction. This parameter is not limited to values less than 0.5 as in isotropic materials. Conversely, ν21 gives the strain induced in the 1-direction by a strain applied in the 2-direction. Since the 2-direction (transverse to the fibers) usually has much less stiffness than the 1-direction, a given strain in the 1-direction will usually develop a much larger strain in the 2-direction than will the same strain in the 2-direction induce a strain in the 1-direction. Hence we will usually have ν12 > ν21. There are five constants in the above equation (E1, E2, ν12, ν21 and G12). However, only four of them are independent; since the S matrix is symmetric, we have ν21/E2 = ν12/E1.



An orthotropic material.

Monocoque Mold Layup

We had to design the monocoque and plan its manufacturing around the mold’s geometry. A two-part mold would be required so that the monocoque could be laid up on a positive draft and thereby be removed. A two-part monocoque was selected, with two stand-alone molds, as opposed to a one-part monocoque with molds bolted together. The latter option would greatly complicate the layup process, because a single person would have to go up into the bolted molds to do the layup; with a two-part monocoque, many hands could be performing the layup at one time.

Laminate

High stiffness and strength usually require a high proportion of fibers in the composite. This is achieved by aligning a set of long fibers in a thin sheet (a lamina or ply).

However, such material is highly anisotropic, generally being weak and compliant (having a low stiffness) in the transverse direction. Commonly, high strength and stiffness are required in various directions within a plane. The solution is to stack and weld together a number of sheets, each having the fibers oriented in different directions. Such a stack is termed a laminate.

Obtaining the stiffness of a laminate

Once the elastic response of a single ply loaded at an arbitrary angle has been established, that of a stack bonded together (i.e. a laminate) is quite easy to predict. For example, the Young's modulus in the loading direction is given by an applied normal stress over the resultant normal strain in that direction. This same strain will be experienced by all of the component plies of the laminate. Since every ply now has a known Young's modulus in the loading direction (dependent on its fiber direction), the stress in each one can be expressed in terms of this universal strain. Furthermore, the force (stress times sectional area) represented by the applied stress can also be expressed as the sum of the forces being carried by each ply. This allows the overall Young's modulus of the laminate to be calculated.

Laminate Composite Plates

Laminated composite plate and shell panels are becoming increasingly used in aerospace and other technical applications. The accurate knowledge of critical buckling loads, mode shapes and post buckling behavior is essential for reliable and lightweight structural design.

Laminate Stacking Sequence Procedure

The choice of coordinate system used for the laminate usually determines the stacking sequence. A coordinate system is almost always chosen such that one of the axes runs in the direction of the fibers of one of the plies of the laminates. This makes analysis much easier. The x-axis is usually chosen as the “longitudinal” axis, with the corresponding y-axis being the “transverse” direction. The main load bearing fibers are usually called the 0 degree fibers, longitudinal fibers or x-direction fibers. The other ply orientation will then be defined with this coordinate system.

Once the 0 degree fiber direction has been defined (and thus the x-axis), the plies that are not at 0 degree must be assigned an angle. To do this, start from the x-axis and rotate to the fiber direction of the ply being defined. Clockwise rotations are positive angles, and counter clockwise rotations are negative angles.

If the laminate is symmetric, then start with the angle of the outermost ply and write the ply angles separated by a comma, until the mid-plane is reached. Enclose this string of angles in brackets or parentheses and subscript the brackets or parentheses with an “S” to denote “symmetric”. If the laminate is not symmetric, then proceed as above until the bottom ply is reached. Subscript the brackets or parentheses with a “T” to denote “total” laminate.

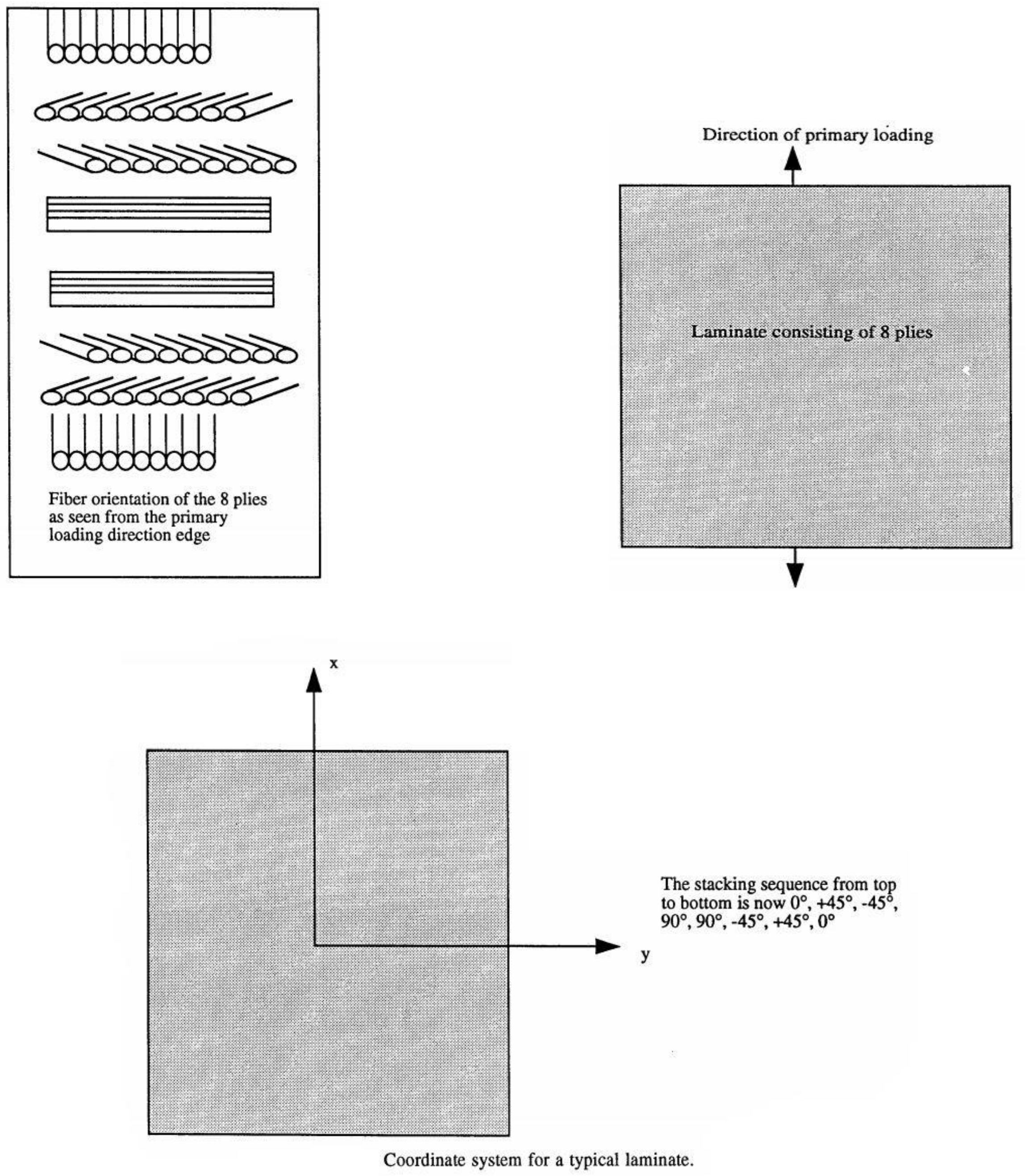


Figure 11: Laminate Stacking Sequence

Referring to the above configuration, this laminate is denoted as (0, +45,-45, 90)s, This is more convenient than writing as (0, +45,-45, 90, 90, -45, +45, 0)t.

Weight Transfer

Total weight transfer is the sum of three very important components that we can calculate:

Non-suspended weight transfer

Due to the component of lateral force applied by the weight of the wheels, uprights, brakes etc. For live axle, includes total axle assembly weight. We take the axle height as a close approximation to the center of gravity (CG) for the unsuspended mass.

Suspended weight transfer

The two components of suspended weight transfer are,

- Geometric weight transfer

  Due to the component of lateral force, applied directly at the Roll Centre (RC). Geometric WT is reacted directly through the suspension linkages, and does not induce body roll.

- Elastic weight transfer

  Due to the component of lateral force, applied at the Suspended Mass CG, and does induce body roll. This force is reacted in the springs, anti-roll bars and shocks, and is the only one of the three components of total weight transfer that does induce body roll.

CHAPTER 3

METHODOLOGY

The purpose of this study is to identify the various methods used in the process of construction of racecar chassis. The SAE (Society of Automotive Engineers) International has allowed an equivalency spreadsheet for this competition in which the material locally available can be used to make the chassis and by tabulating its equivalent properties and dimensions in the spreadsheet, the equivalency of local and standard material can be shown.

After finalizing the designs, the chassis went to the manufacturer and material locally available was used for its fabrication. The material for fabrication was chosen carefully so that it is as close as possible to the standard material recommended.

The second phase of our project will be started right after the fabrication of the space frame chassis is completed. The designing will be done on Solidworks and ANSYS will be used for analysis of forces and stresses.

There is a third phase planned as well which will show comparison between the two types of chassis designs.

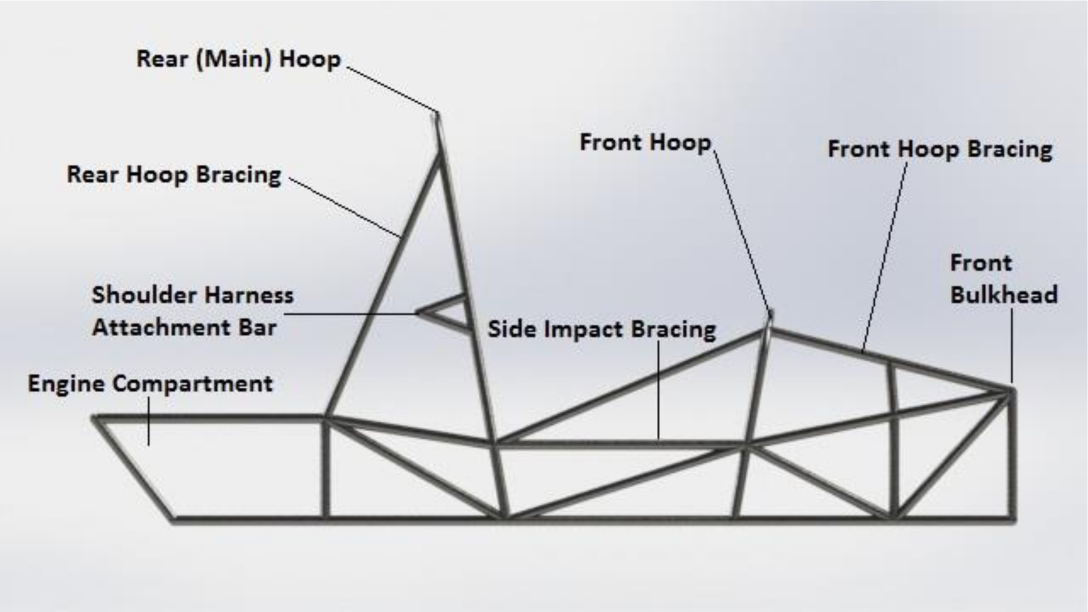


Figure 12: Different components of a chassis

Designing

Initial Designing

We began by designing the cockpit. Following are the two templates provided in the Rules Manual.

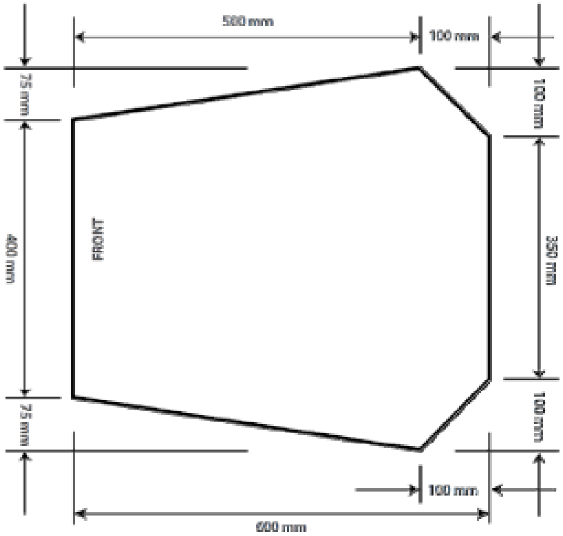


Figure 13: Cockpit template 1

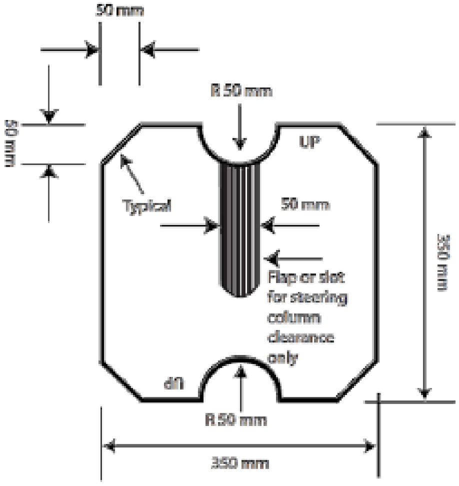


Figure 14: Cockpit template 2

Template 1 should fit in the cockpit placed horizontally, moving vertically into the cockpit. Template 2 must be able to move into the driver's legs area placed vertically, moving horizontally so that it is not hindered up until a point 100 mm (4 inches) rearwards of the face of the rearmost pedal when in the inoperative position. So, we began by designing a cockpit that would fit these templates. Soon we created a cockpit structure as shown.

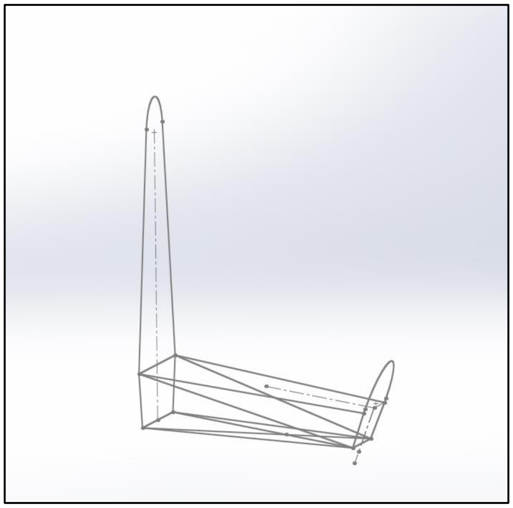


Figure 15: 1st cockpit design

95th Percentile Male

But then we realized that this was not that simple. There were many more dimensions and ergonomics considerations that could not be achievement through this approach. So, we decided to start from the very base of ergonomics, i.e. the 95th percentile male, Percy.

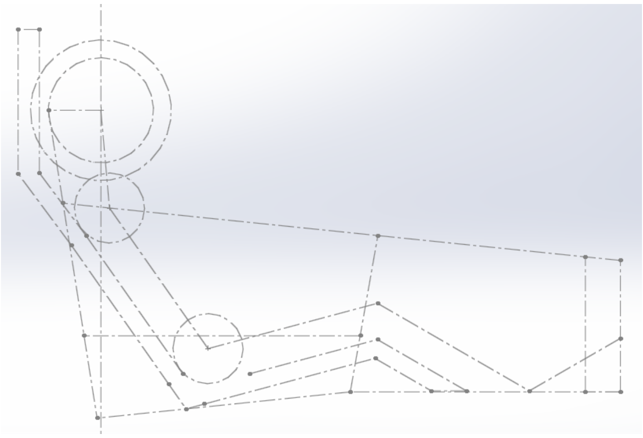


Figure 16: 95th percentile male

Then, by applying the basic knowledge of trusses and statics, and keeping the rules in mind, we developed a structure around Percy.

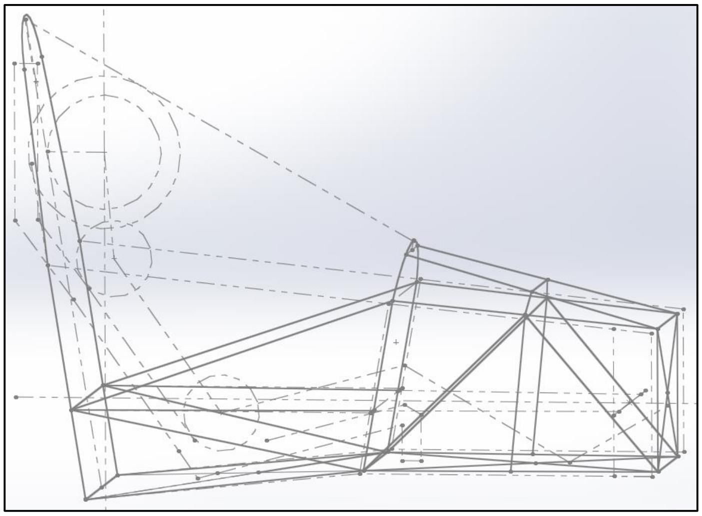


Figure 17: 1st chassis design (incomplete)

Weldments

By using the "weldments" feature of SolidWorks, we attached material to the structure.

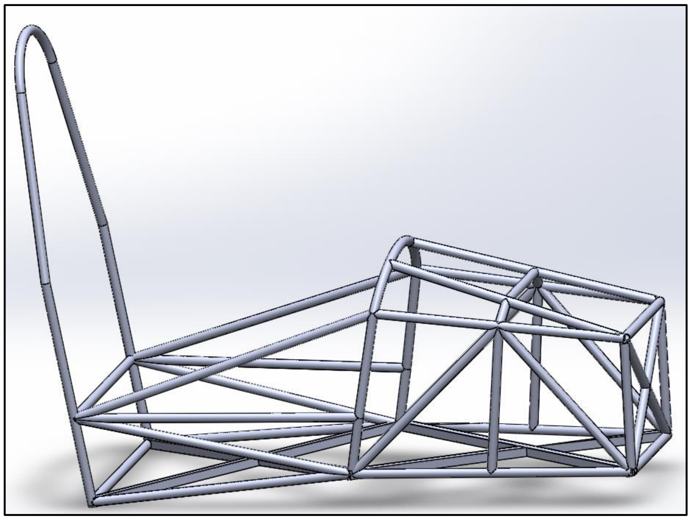


Figure 18: Weldments

Finalized 1st design

At this point of time, NBR was still thinking about what engine to be purchased. So for the sake of design completion, we assumed the CBR600's dimensions and completed the engine compartment, thus completing the 1st design of chassis.

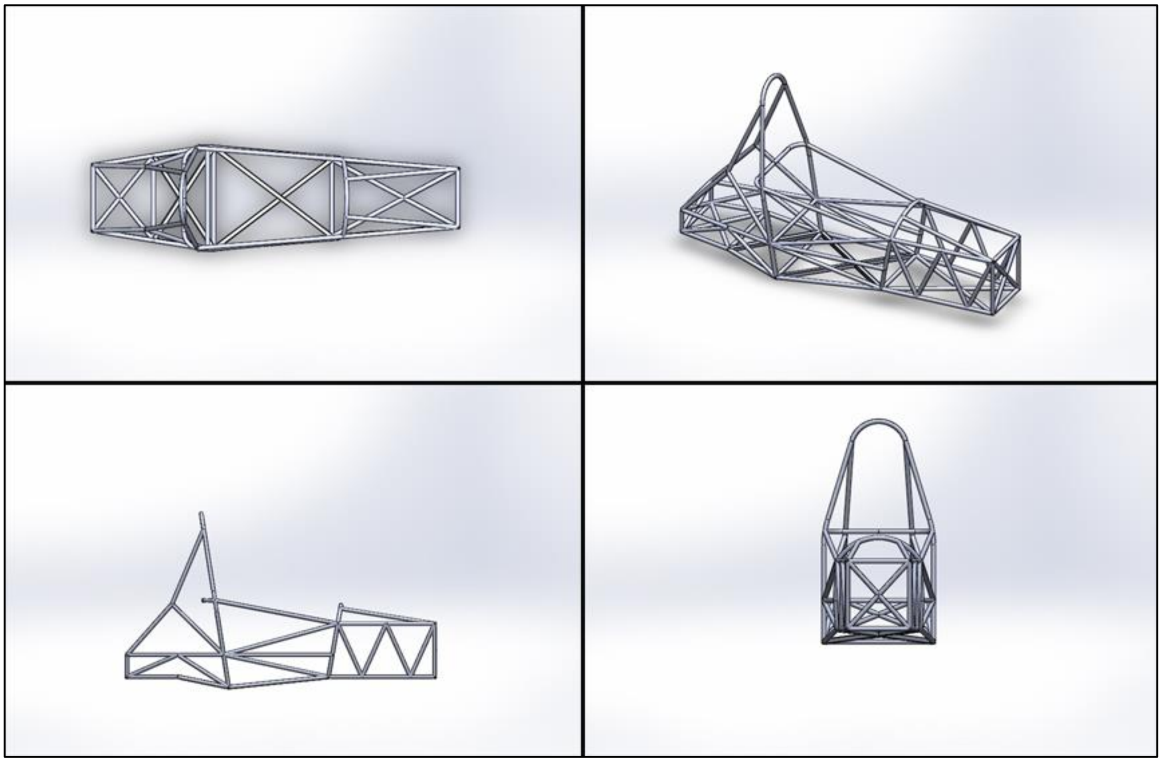


Figure 19: 1st chassis design (complete)

1st design testing

Since we followed all the design guidelines provided in the Rules Manual, we do no not need to submit simulation test results to the competition authorities. Although, this being the first ever chassis of NBR, it was very important for us that we test it thoroughly and make sure that it is completely safe and stable. By simulating, on SolidWorks

, all possible forces that might apply on the chassis during the drive on the track and also during any possible accident we obtained bending stresses, axial stresses, displacements and angular displacements of all the structure members. Most of the results were satisfactory, but some problems needed to be addressed.

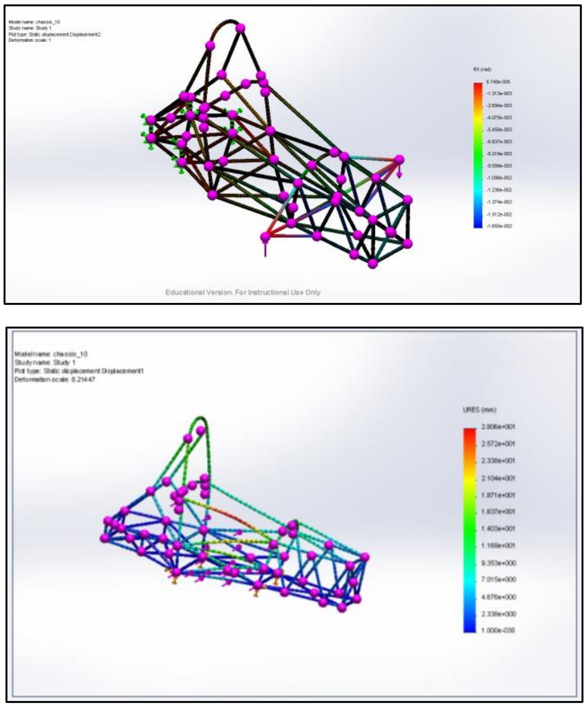


Figure 20: Sample Test Results

1st deisgn specifications

Table 1: 1st design Specs

Weight (kg)	45.25
Torsional Rigidity (Nm/deg)	1427.273

Rejection of 1st model

The reasons for rejection included,

- Too much weight to stiffness ratio

- Very low torsional rigidity
- Relatively higher displacement which could endanger the driver
- Too big for a 5th percentile female
- New engine that had very different dimensions

2nd design (rejected)

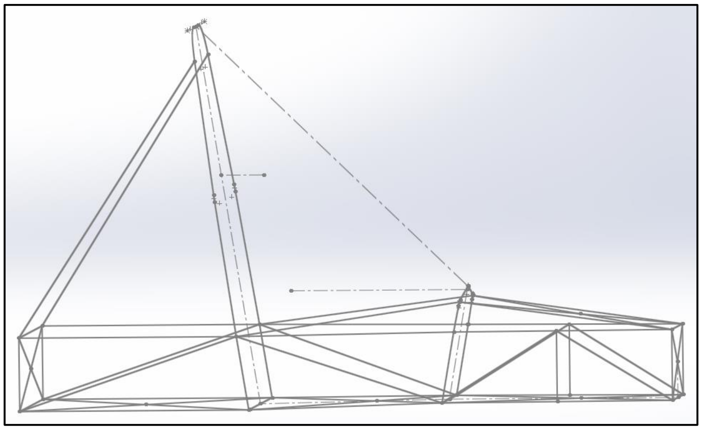


Figure 21: 2nd Design

3rd Design (rejected)

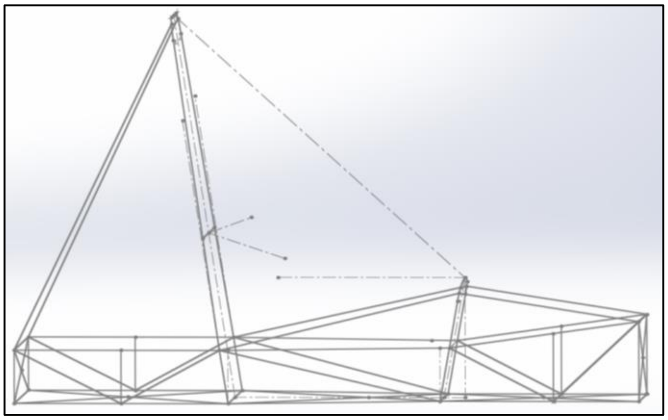


Figure 22: 3rd design

4th Design (fabricated)

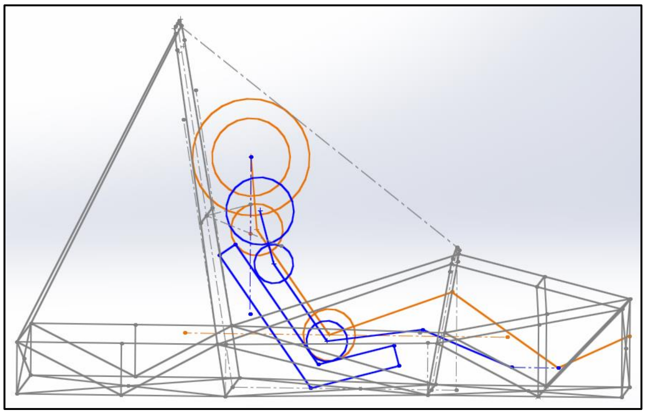


Figure 23: 4th Design (Fabricated)

After a lot of iterations, this design was finally selected for simulation testing. This design was,

- Able to fulfill all ergonomics requirements [95th percentile male (red), 5th percentile female (blue)]
- Aerodynamic
- Completely triangulated structure
- Designed according to the new engine
- Relatively smaller than all the previous versions

Although, we continued to modify the design and we had to wait at least a month for the pipes of the selected material to arrive, it was decided by the project leadership that since this chassis conforms to all the basic requirements, we should go ahead with the fabrication as soon as possible. The primary reasons for the decision included time constraints and the need to work on a prototype because of the inexperience of the team. Due to the use of ASTM A106 steel pipes instead of the more preferred AISI 1010 steel pipes, the fabricated chassis was 70% heavier than intended but 50% stiffer. We were ready to compromise on the weight for extra stiffness at that point of time because this prototype was meant for learning purposes and would not be used in a competition.

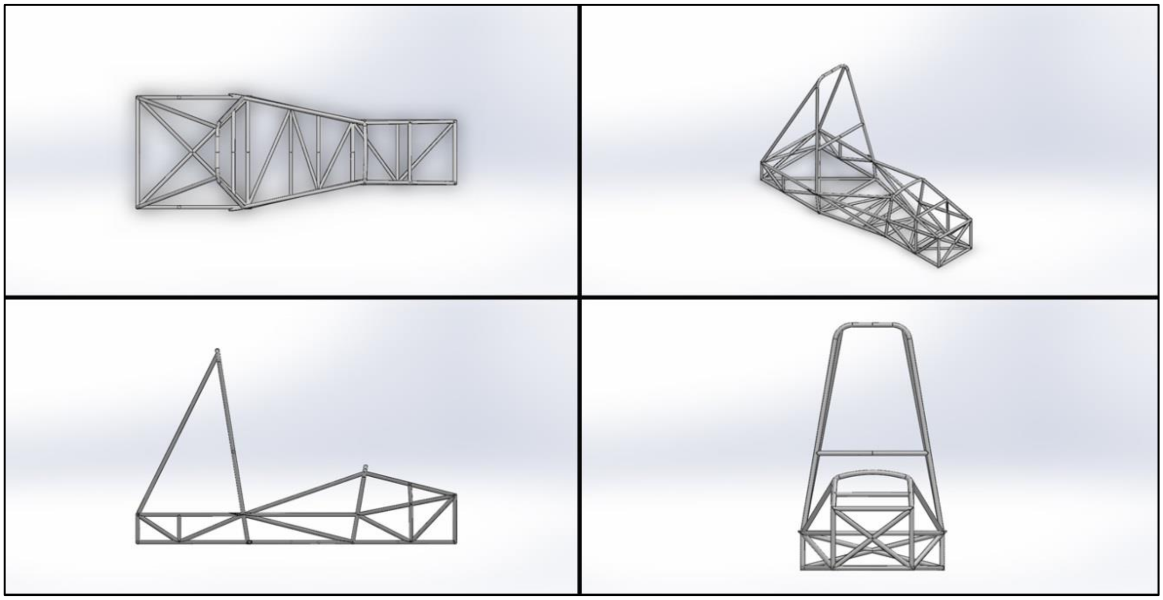


Figure 24: Fabricated Design

As apparent in the figure above, the base of the chassis was changed from crosses to a zigzag pattern in order to provide support for the steering rack and the driver's seat.

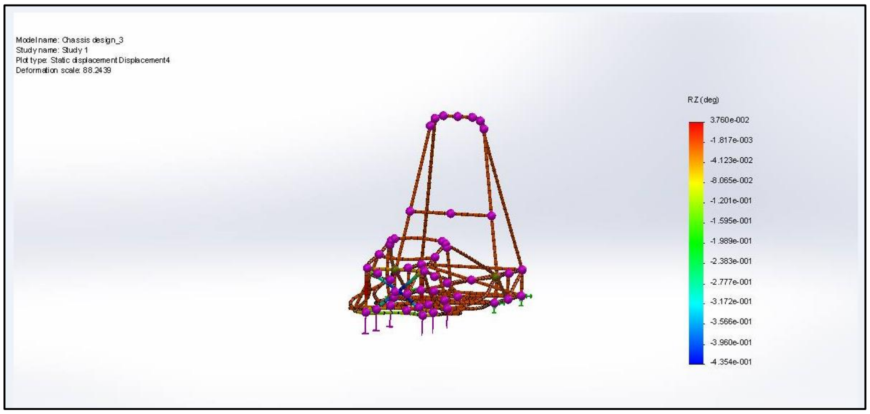


Figure 25: Testing

5th Design (Finalized)

The width of the engine compartment in the previous chassis design was 800mm, set to accommodate the large engine. In the final design, we decided to reduce the width of the engine compartment so as to lengthen the A-arms of the rear suspensions. Consequently, the gear box of the engine had to be taken out of the chassis in between the upper and lower A-arms of the rear left suspension. The weight of the chassis was reduced with a little drop in the stiffness as well.

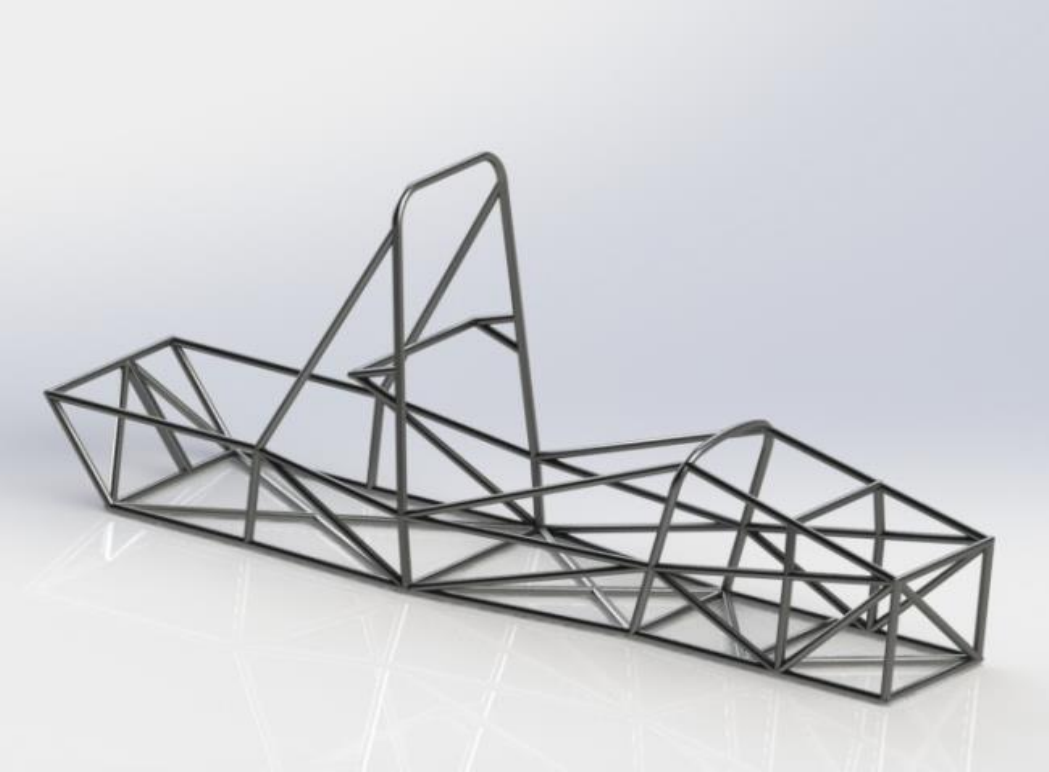


Figure 26: Final Design

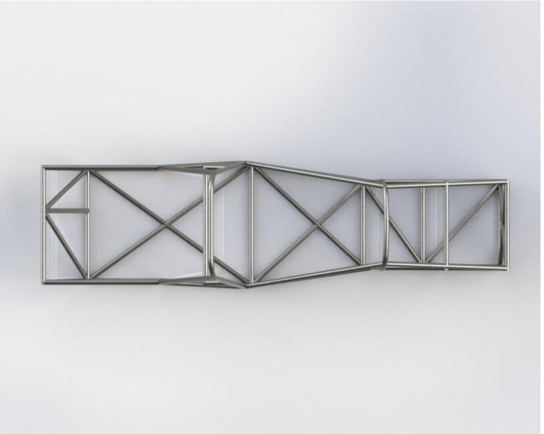


Figure 27: Top View

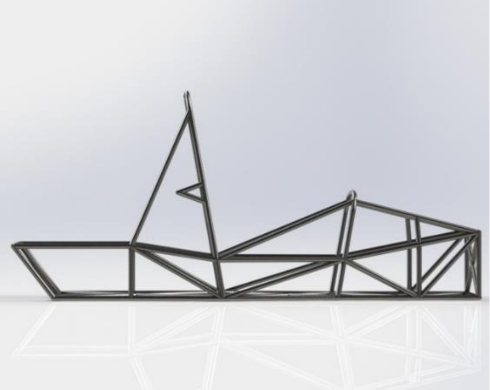


Figure 28: Side View

Figure 29: Front View

Comparison of different chassis designs using baseline material (1010)

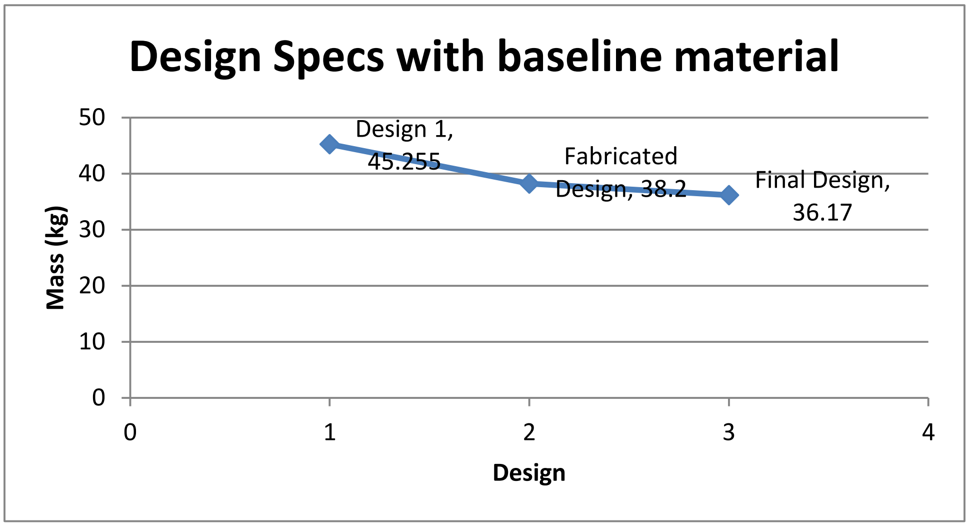


Figure 30: Design Specs with baseline material (mass)

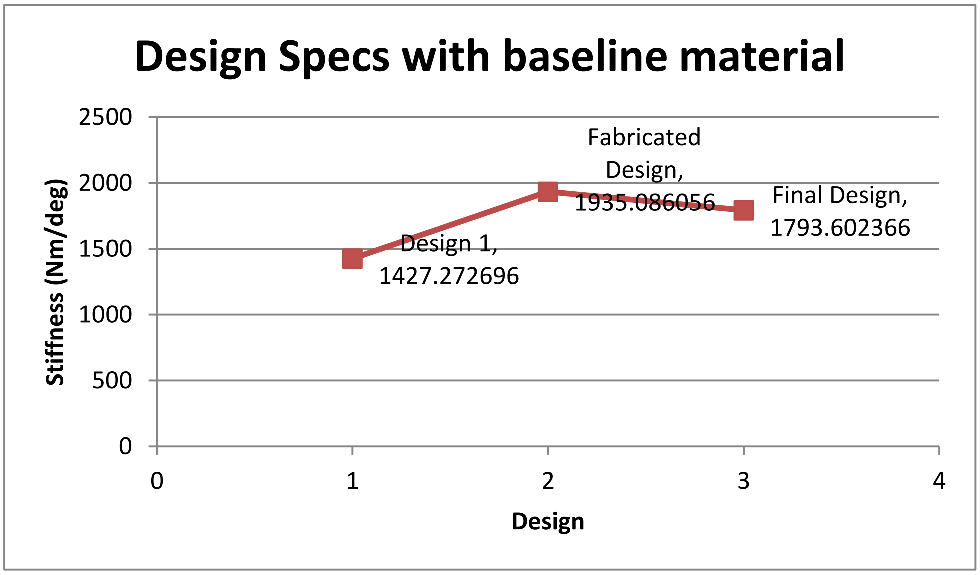


Figure 31: Design Specs with baseline material (stiffness)

The drop in stiffness from fabricated prototype to the final competition design is due to certain constraints provide by the need to reduce the chassis width while accommodating a large engine.

Comparison between fabricated prototype and final chassis designs

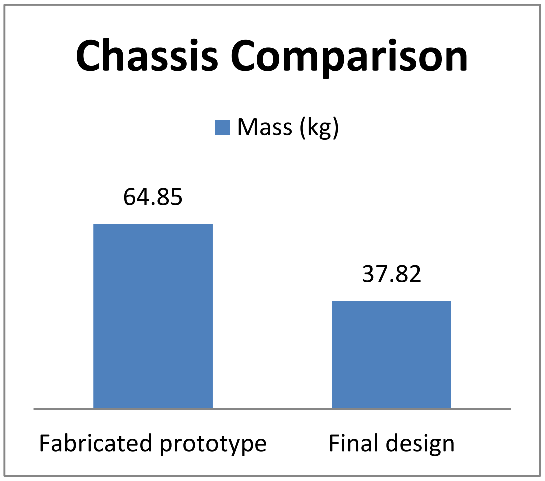


Figure 32: Chassis Comparison (mass)

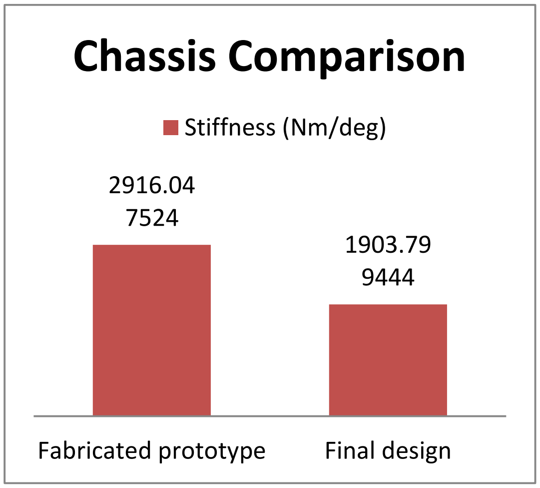


Figure 33: Chassis Comparison (stiffness)

Simulation Testing

Since the requirements mentioned in the FSAE rules booklet were all met and our chassis passed all the criteria in the Structural Equivalency Spreadsheet (SES) provided by FSAE, we need not conduct impact simulation testing. But still, we had to simulate the chassis to calculate torsional stiffness, so we decided to conduct impact testing as well.

The competition rules demand simple static testing, so we decided to conduct simulations on SolidWorks.

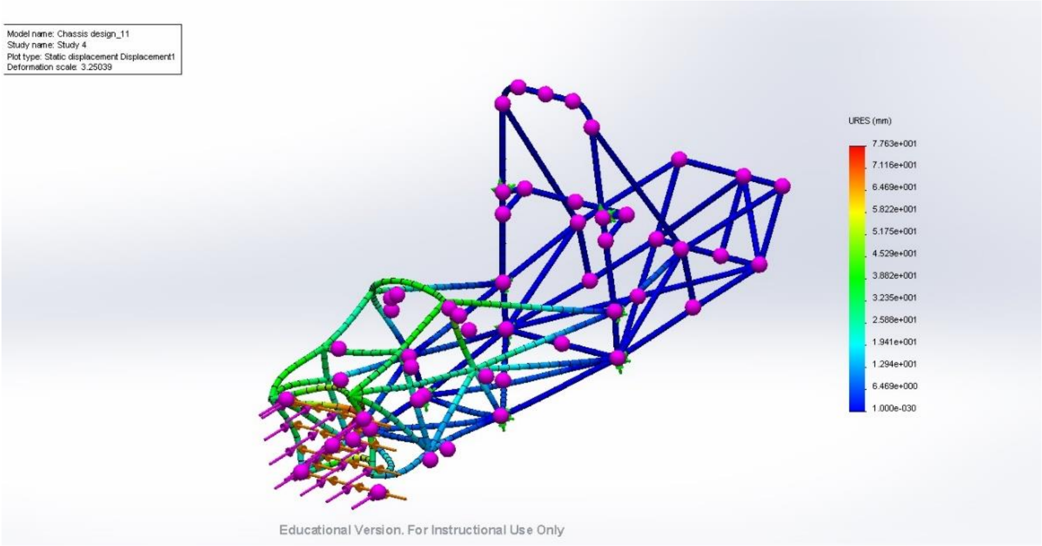


Figure 33: Frontal Impact testing

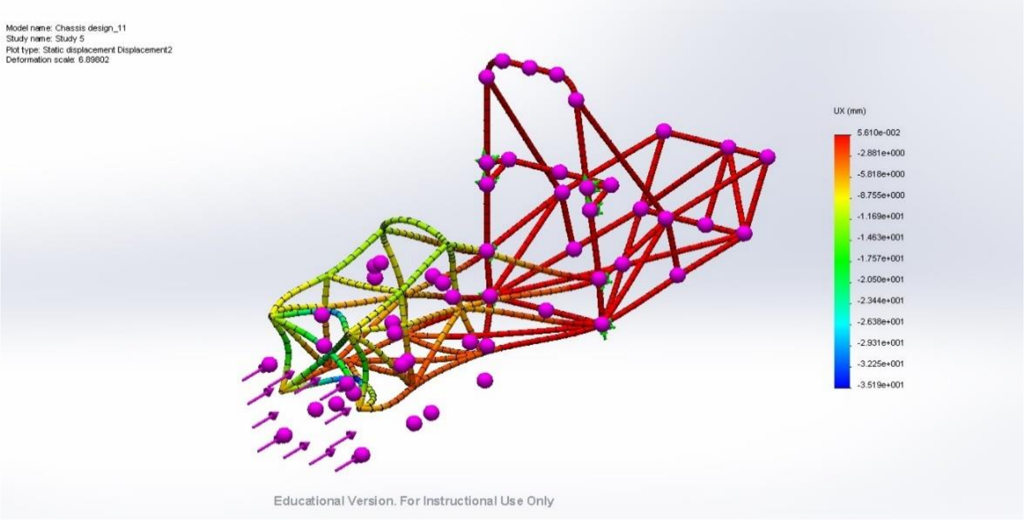


Figure 34: Frontal Impact testing (displacement)

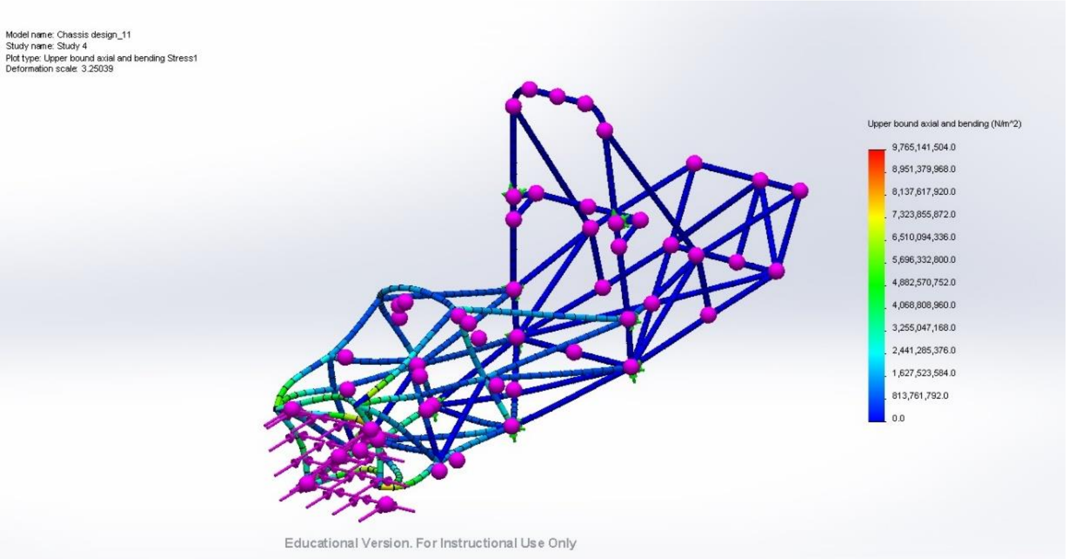


Figure 34: Frontal Impact testing (Von Mises)

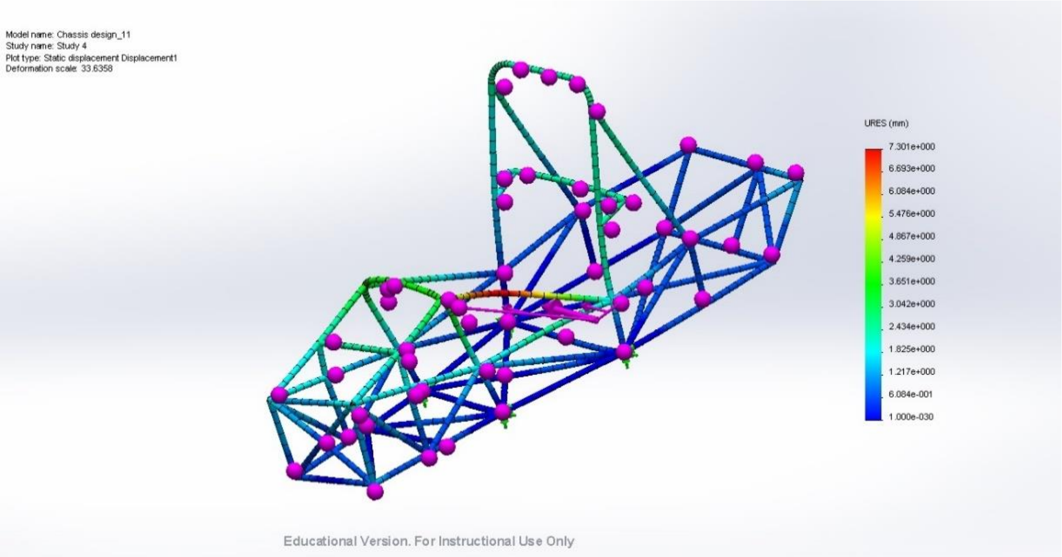
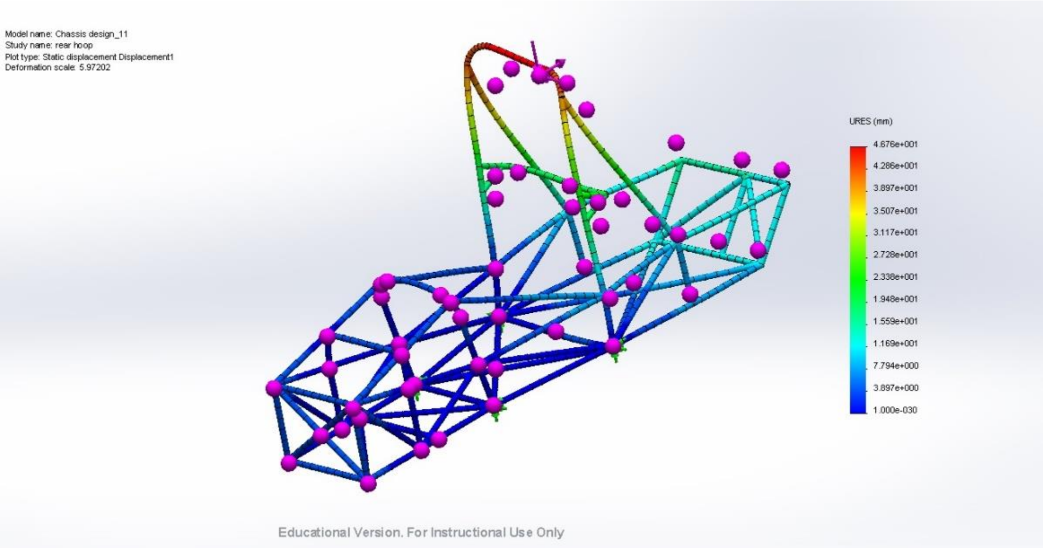
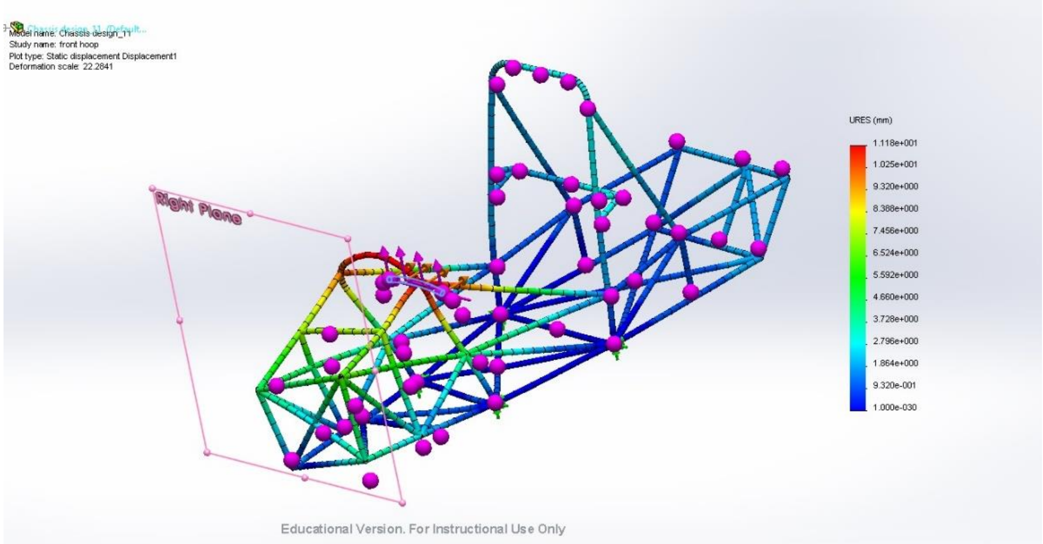


Figure 35: Main Hoop testing



Model name: Chassis design_11
Study name: rear hoop
Plot type: Static displacement Displacement1
Deformation scale: 5.97202

Figure 36: Main Hoop testing (displacement)



Model name: Chassis design_11
Study name: front hoop
Plot type: Static displacement Displacement1
Deformation scale: 22.2841

Figure 37: Front hoop testing

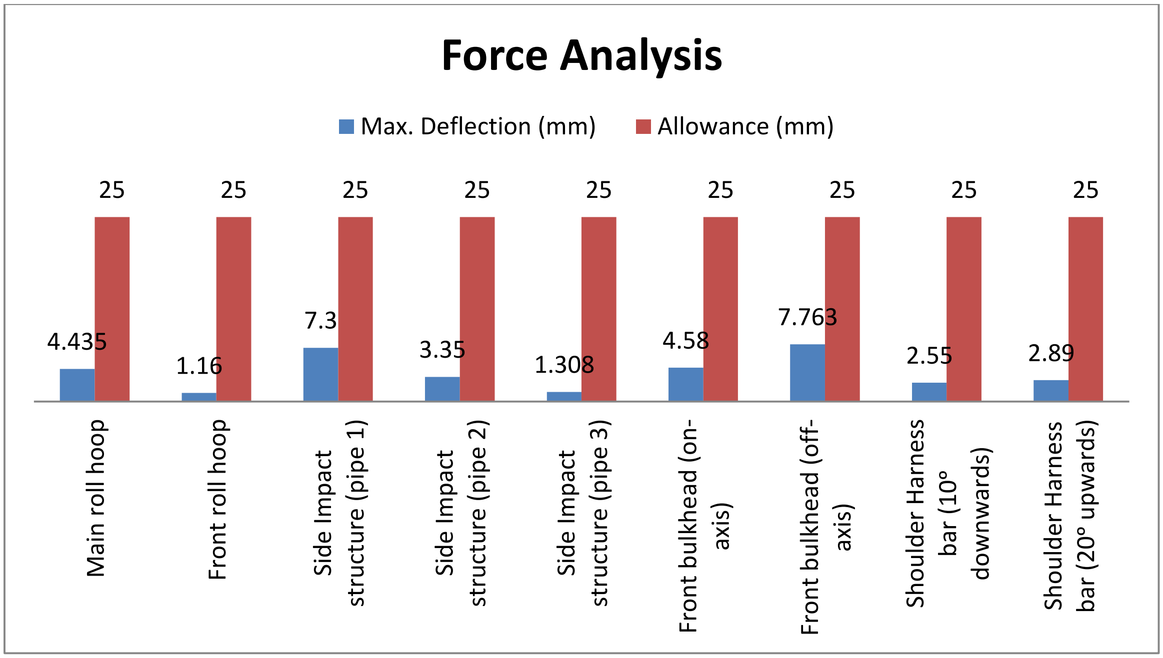


Figure 38: Force Analysis

Material

Minimum Material Requirements

Baseline steel properties used for calculations to be submitted in an SES **may not be lower than** the following:

Bending and buckling strength calculations:

Young’s Modulus (E) = 200 GPa (29,000 ksi)

Yield Strength (Sy) = 305 MPa (44.2 ksi)

Ultimate Strength (Su) = 365 MPa (52.9 ksi)

Seemless vs. Seemed Pipes

These values clearly indicate that the use of seamed pipes is completely out of context because they are very weak as compared to drawn seamless pipes. The seamed pipes are weak because of the fact that they offer stress concentration at the seams.

(http://www.mechwerks.com/Frame_Tubing.htm)

Figure 39: Seamed pipe

(http://www.mechwerks.com/Frame_Tubing.htm)

Figure 40: Seamless pipe

Shortlisted Materials

Table 2: Shortlisted materials

Material	**ASTM A 106 Grade B**	**AISI 1010**	**Requirement**
Young's Modulus	207 30,000	200 29,000	**200 29,000**
Yield Strength	240 35,000	305 44,200	**305 44,200**

Ultimate Strength	415 60,000	365 52,900	**365 52,900**

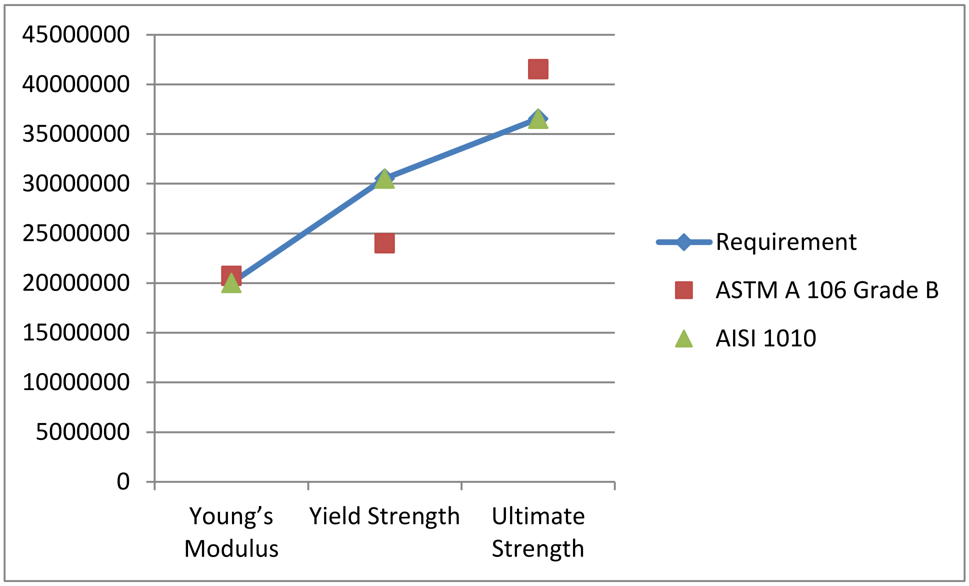


Figure 41: Physical Properties

As apparent from the graph, the requirement figures were matching exactly with AISI 1010 MS Steel. This seemed a better option. But, ASTM A106 was available in Rawalpindi markets whereas AISI 1010 was available only in Karachi. Therefore, we decided to purchase ASTM A106 for the test bed and start its fabrication and order AISI 1010 to be used for the competition vehicle.

Comparison of different pipe materials and sizes,

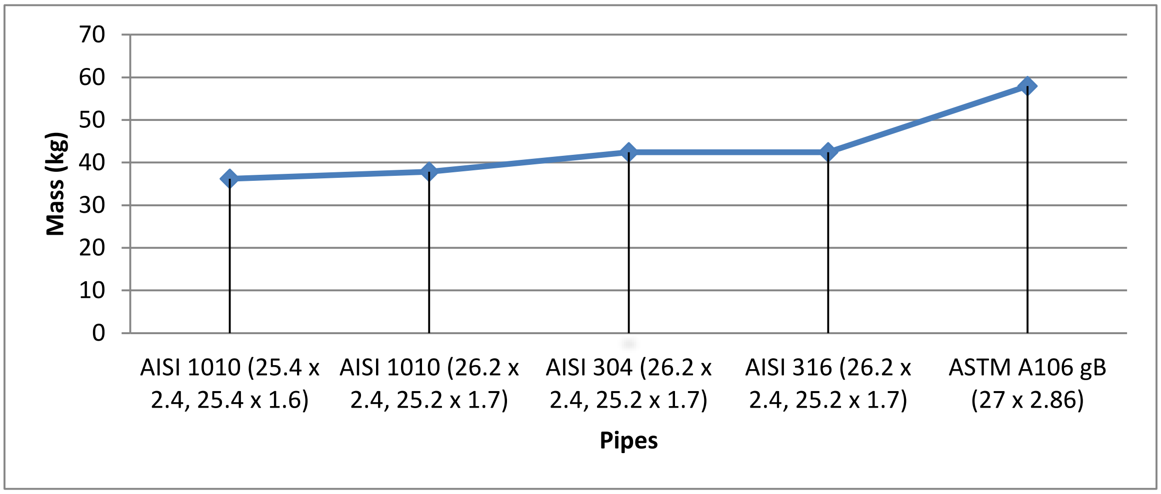


Figure 42: Different Pipes with respect to mass

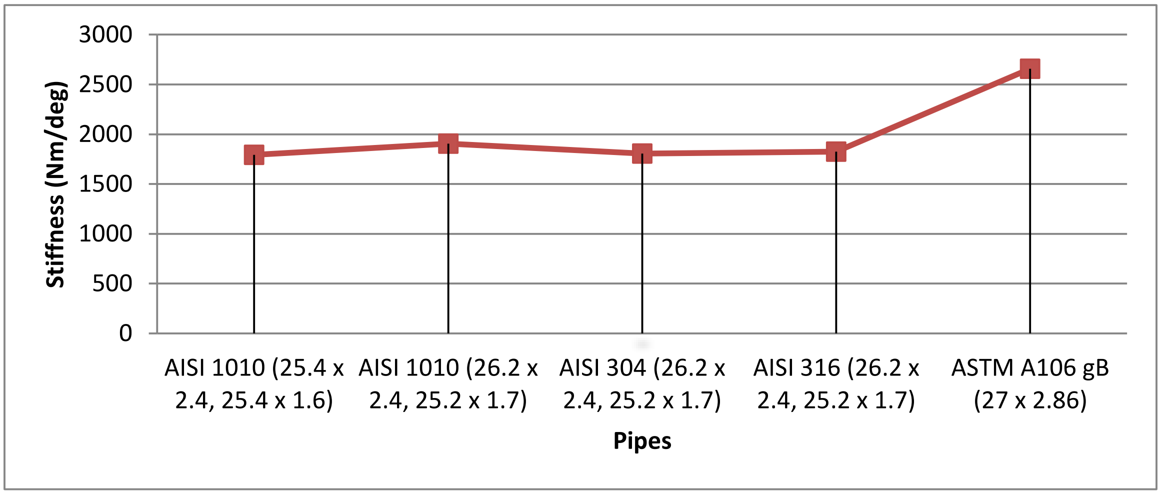


Figure 43: Different Pipes with respect to stiffness

Pipes requirements (as given in SES)

Hoops pipes' thickness

Pipe (mm x mm)	**EI ($\times10^3$)**	**Yield Strength (x10^4) (N)**	**UTS (10^4) (N)**	**Max deflection (mm)**	**Energy absorbed (J)**

Baseline (25.4x2.4)	2.32	5.29	6.33	12	7.98
26.2x2	2.24	4.64	5.55	12.4	7.25
26.2x2.1	2.33	4.85	5.8	11.9	7.53
26.2x2.2	2.41	5.06	6.05	11.5	7.79
26.2x2.3	2.49	5.27	6.3	11.2	8.05
26.2x2.4	2.57	5.47	6.55	10.8	8.3

Regular pipes' thickness

Pipe (mm x mm)	**EI ($x10^3$)**	**Yield Strength (x10^4) (N)**	**UTS (10^4) (N)**	**Max deflection (mm)**	**Energy absorbed (J)**
Baseline (25.4x1.6)	1.7	3.65	4.37	12	5.86
25.2x1.6	1.66	3.62	4.33	12.3	5.8
25.2x1.7	1.74	3.83	4.58	11.7	6.09

Pass	fail	baseline

Fabrication

Such a complex structure required very skilled technical expertise for fabrication. We needed high precision welding for our structure because we certainly do not want the chassis to fail during dynamics due to a weak joint since the stress would be very large.

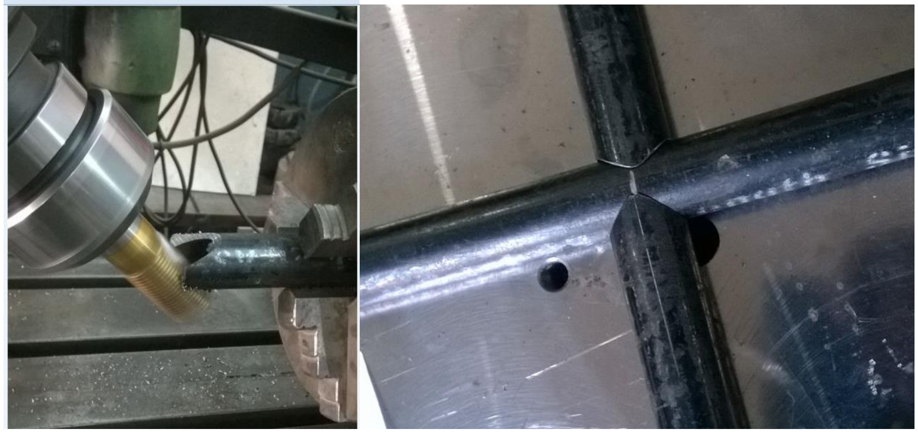


Figure 44: Fabrication

Seat

The seat has been designed for Percy. It is a bucket seat that has support for shoulders, lower back and theighs as well. These supports make sure that the driver does not slip off the seat while steering. In case of sip, the driver would not be able to steer properly. Shown below is the design of the chassis that has been fabricated using aluminuim sheets of __mm thickness. Aluminuim sheets were welded together using Argon welding. This seat fits on a frame by means of four screws mounted inside the cockpit and can easily be removed. Once the car gets assembled, we will mark the un-crucial areas of the seat and try to remove as much material as possible for weight reduction before installing paddings and 5 point harness onto the seat.

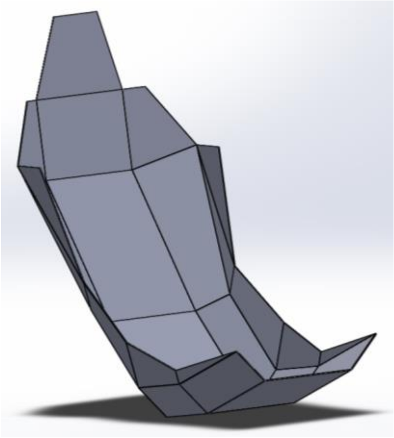


Figure 45: Seat

Impact Attenuator (Energy Absorber)

For our project we are using a standard impact attenuator as. An impact attenuator is a structure used to “decelerate impacting vehicles gradually to a stop”. By gradually decelerating the racecar, the frame and driver are protected from significant deformation and injury. The bulk of impact energy is transferred into the deformation of the impact attenuator structure. Below are some part drawings of a standard impact attenuator:

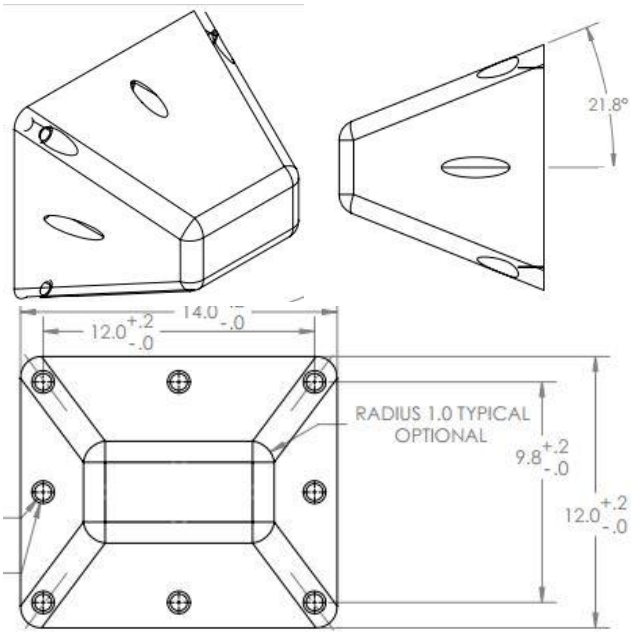


Figure 46: Impact attenuator

Standard impact attenuator uses Dow Impaxx® 700 energy absorbing foam. It fulfills the requirements of FSAE competition.

MONOCOQUE CHASSIS

After the design, simulation and fabrication of the tubular space-frame chassis, the next stage of the project was to design an upgrade model of the chassis that is being used by advanced cars and compare our tubular chassis with it. The goal was to analyze the room for improvement and give verdict on how soon should the team try and switch to the monocoque structure.

A monocoque chassis can be explained as a frame-less chassis in which the body of the car is strong enough to provide all the stiffness and support all the weight.

Types

As explained earlier, a monocoque can be a;

1. Full monocoque
2. Hybrid (between a full monocoque and a tubular chassis)

Full monocoque structure is made entirely of the composite from the front bulkhead; all the way back to the end.

A hybrid is made of composite from the bulk head to the end of the driver's compartment with the rear part made up of tubes.

Materials

There are plenty of materials that can be used to make a monocoque structure. Some broader categories are;

1. Sheet metal
2. Aluminum honeycomb sandwich structure
3. Carbon fiber composite (with some core)

Sheet metal monocoque are very rare in formula race-cars because of lesser stiffness to mass ratios and complexity of fabrication since high precision and high strength bonding cause issues.

Aluminum honeycomb sandwich structure is often used by teams but the sandwich structure is very thick and limits the design contours.

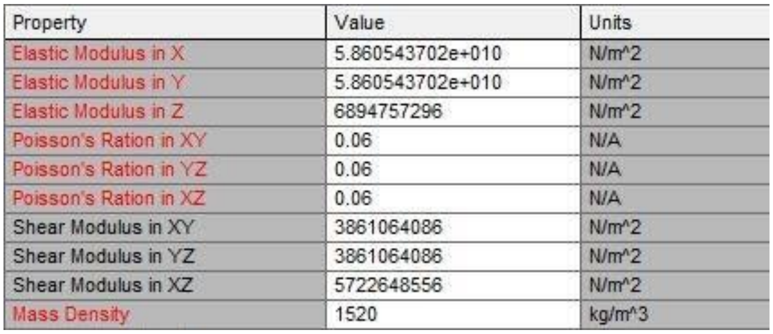
Carbon fiber is the red hot technology for the monocoque structures. It offers high stiffness to mass ratios and freedom of design.

Selected Material

Because of obvious superiority and the scope of our project, carbon fiber composite was selected among all the possible materials. The carbon fiber selected was CF T300 twill weave pre-preg. The core to be used in the composite was Aluminum 5250 honeycomb.

Both of these materials were modelled as orthotropic using the SolidWorks composite analysis.

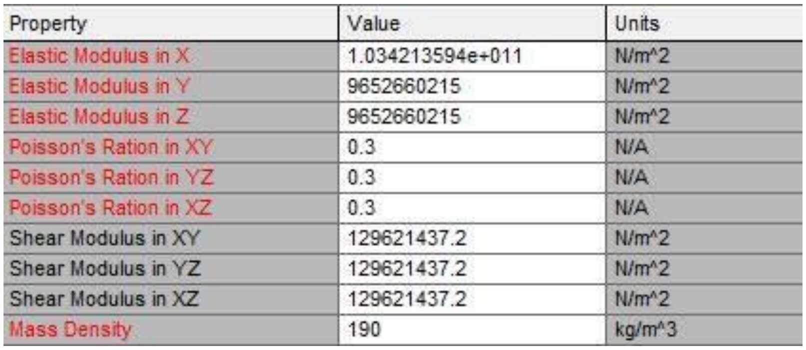
Properties of CF:



Property	Value	Units
Elastic Modulus in X	5.860543702e+010	N/m^2
Elastic Modulus in Y	5.860543702e+010	N/m^2
Elastic Modulus in Z	6894757296	N/m^2
Poisson's Ration in XY	0.06	N/A
Poisson's Ration in YZ	0.06	N/A
Poisson's Ration in XZ	0.06	N/A
Shear Modulus in XY	3861064086	N/m^2
Shear Modulus in YZ	3861064086	N/m^2
Shear Modulus in XZ	5722648556	N/m^2
Mass Density	1520	kg/m^3

Table 3: Properties of CF (orthotropic)

Properties of Al 5250 Honeycomb:



Property	Value	Units
Elastic Modulus in X	1.034213594e+011	N/m^2
Elastic Modulus in Y	9652660215	N/m^2
Elastic Modulus in Z	9652660215	N/m^2
Poisson's Ration in XY	0.3	N/A
Poisson's Ration in YZ	0.3	N/A
Poisson's Ration in XZ	0.3	N/A
Shear Modulus in XY	129621437.2	N/m^2
Shear Modulus in YZ	129621437.2	N/m^2
Shear Modulus in XZ	129621437.2	N/m^2
Mass Density	190	kg/m^3

Table 4: Properties of Al 5250 Honeycomb (orthotropic)

Design

The team decided to go for a hybrid chassis instead of a full monocoque because of a number of factors including;

1. Ease of mounting and dis-mounting engine and other components
2. Retaining the tub and changing the rear in case of a different engine being used
3. Ease of access to the installed equipment

The final design of the tubular chassis was used as the baseline for the design of the monocoque. The new chassis design has a curved base that lowers the driver’s compartment and lowers the COG significantly. A window was left in the front bulkhead that will be used to access the area of the chassis between the front hoop and the front bulkhead simply by removing the AI plate. The simplicity of the design offers an excellent aerodynamic shape.

Final design

Figure 47: Final Design

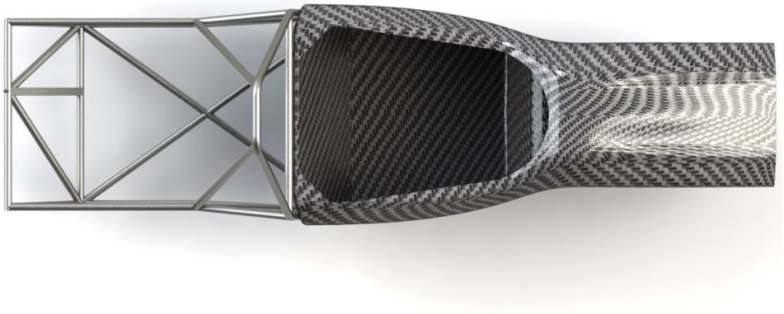


Figure 48: Top View

Figure 49: Front View

Figure 50: Side View

Figure 51: Rear part view

Figure 52: Front Hoop

Layup

The layup of the composite was probably the most important part of the project. It would decide the specifications of the chassis. Different variables that needed to be determined were;

1. Number of plies
2. Core thickness
3. Ply angles

A massive amount of simulation studies were conducted in order to determine relationships of stiffness, impact and mass with respect to these variables. The graphs generated by the results of those studies have been shown below.

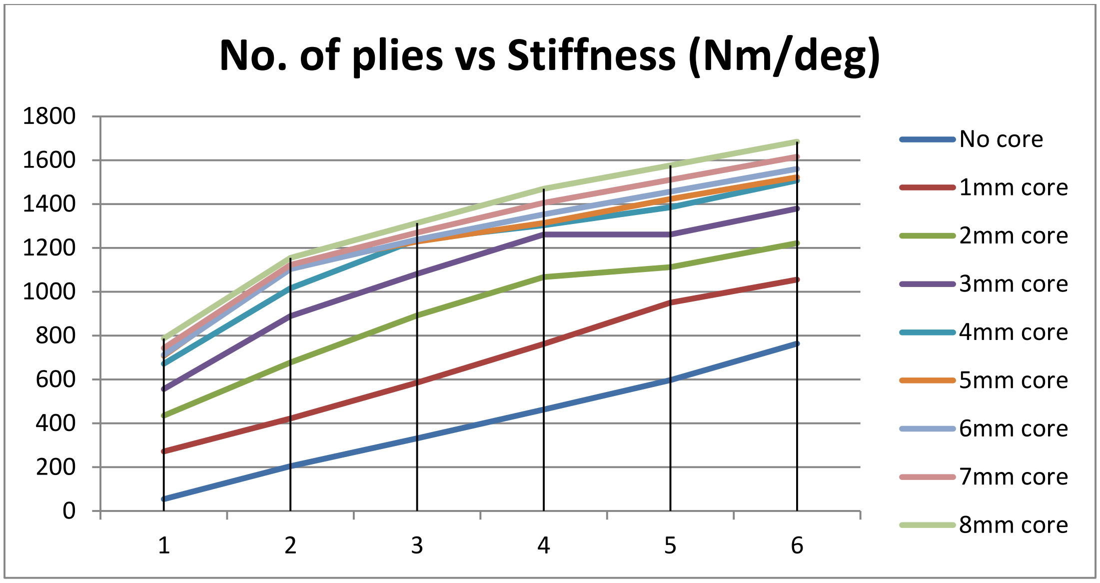


Figure 53: Number of plies vs Stiffness

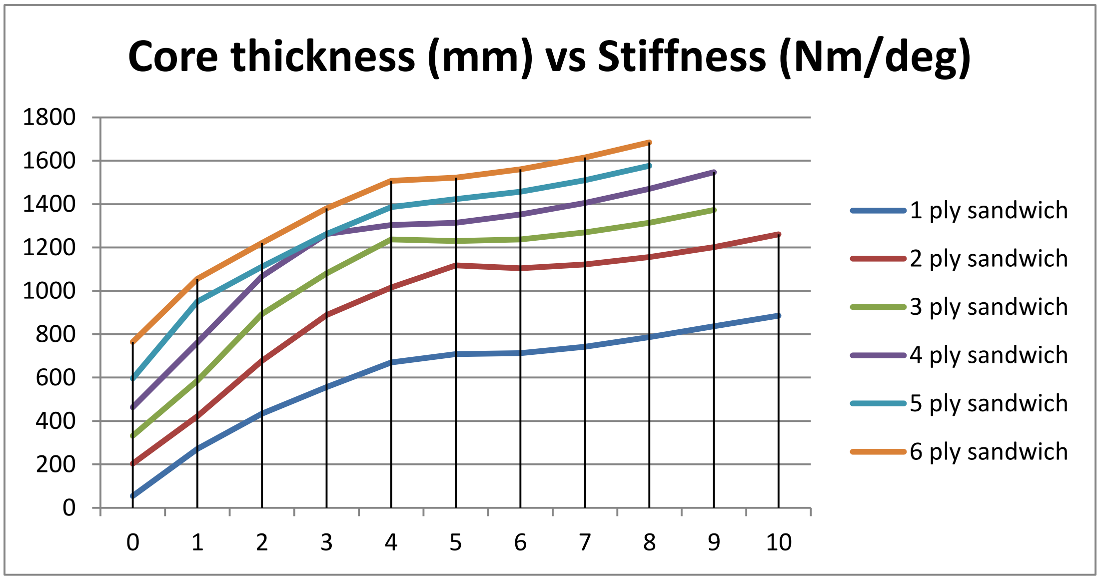


Figure 54: Core thickness vs Stiffness

As expected, increase in either of the core thickness or the number of plies increases the stiffness of the chassis. The graph also revealed that the slope decreases with the increase in the values.

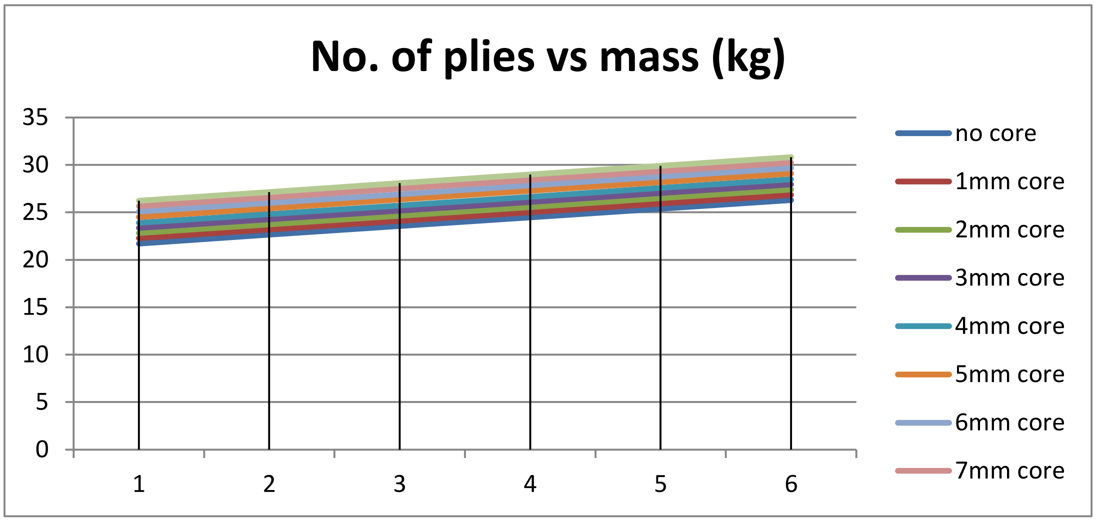


Figure 55: Number of plies vs Mass

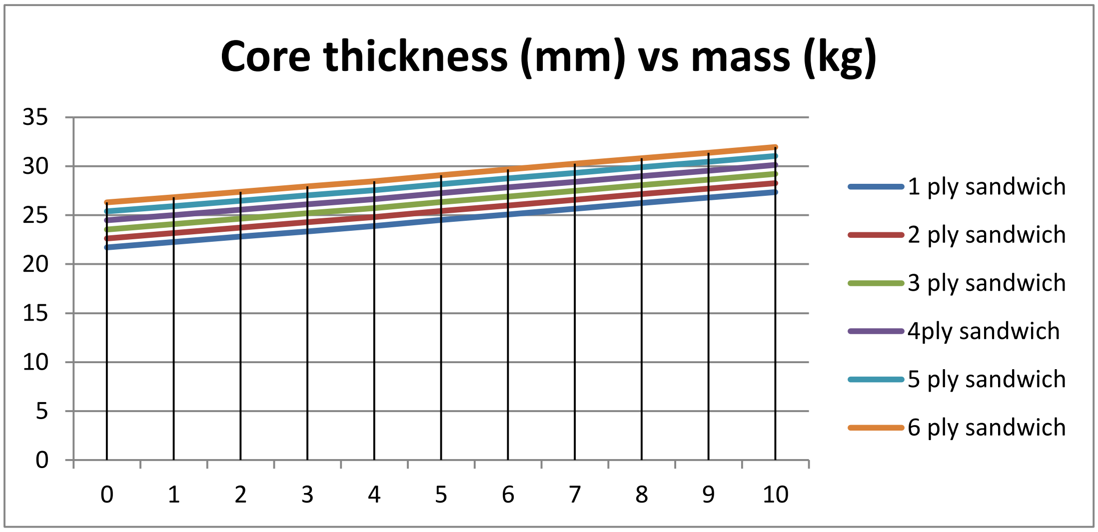


Figure 56: Core thickness vs Mass

The graphs reveal that plies have more effect on the mass as compared to that of core thickness. This again was expected since the plies have a greater density than the less dense core.

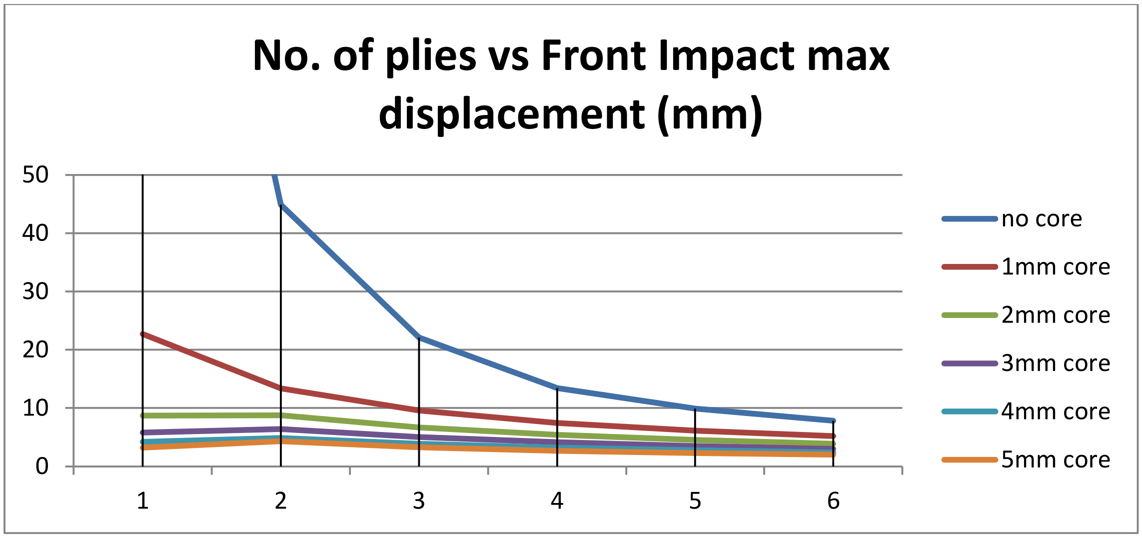


Figure 57: Number of plies vs Displacement (front impact)

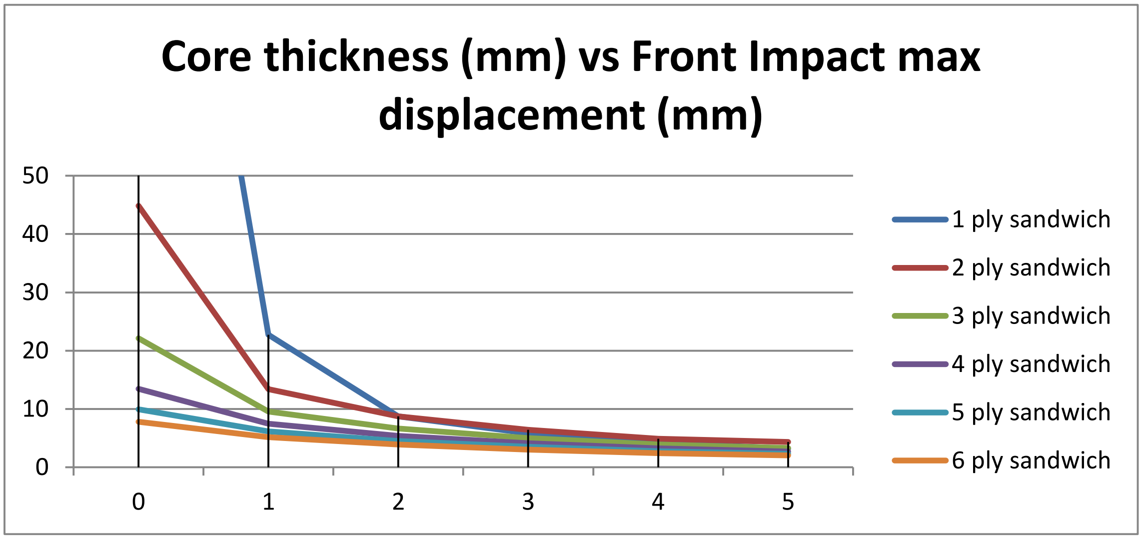


Figure 58: Core thickness vs Displacement (front impact)

With increase in core thickness and number of plies, the displacement due to front impact decreases significantly.

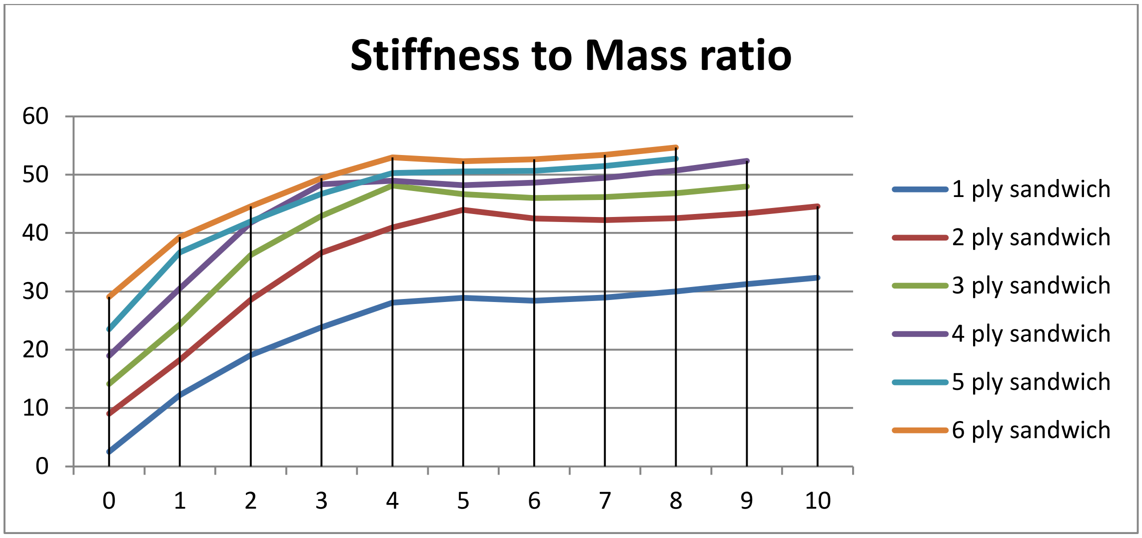


Figure 59: Stiffness to Mass ratio

We wanted our chassis to have the maximum stiffness possible. The graph above shows a stiffness graph.

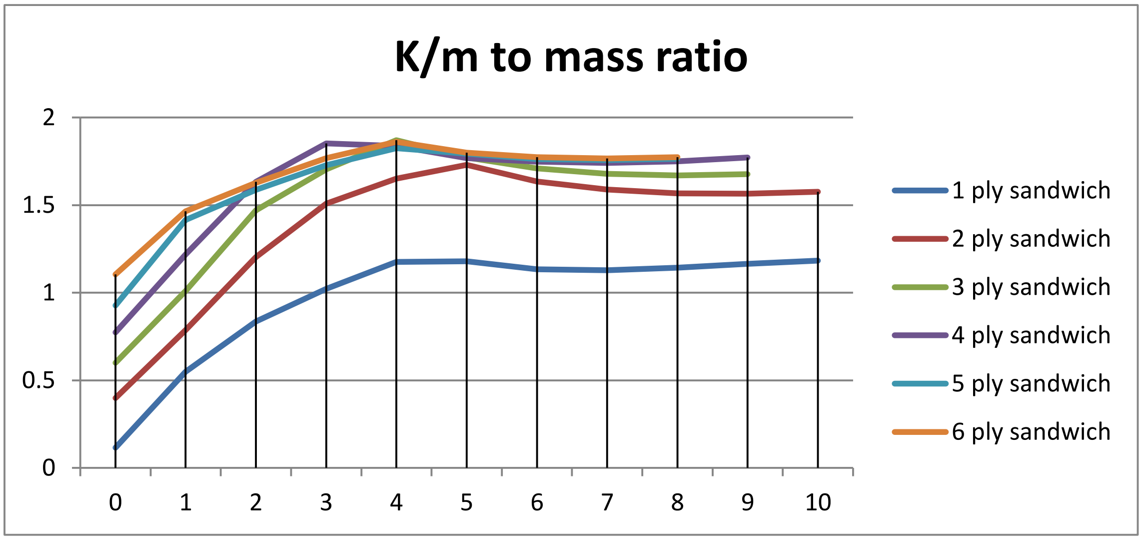


Figure 60: (Stiffness to mass) to mass ratio

Our primary target was to maximize the Stiffness to Mass ratio (K/m).

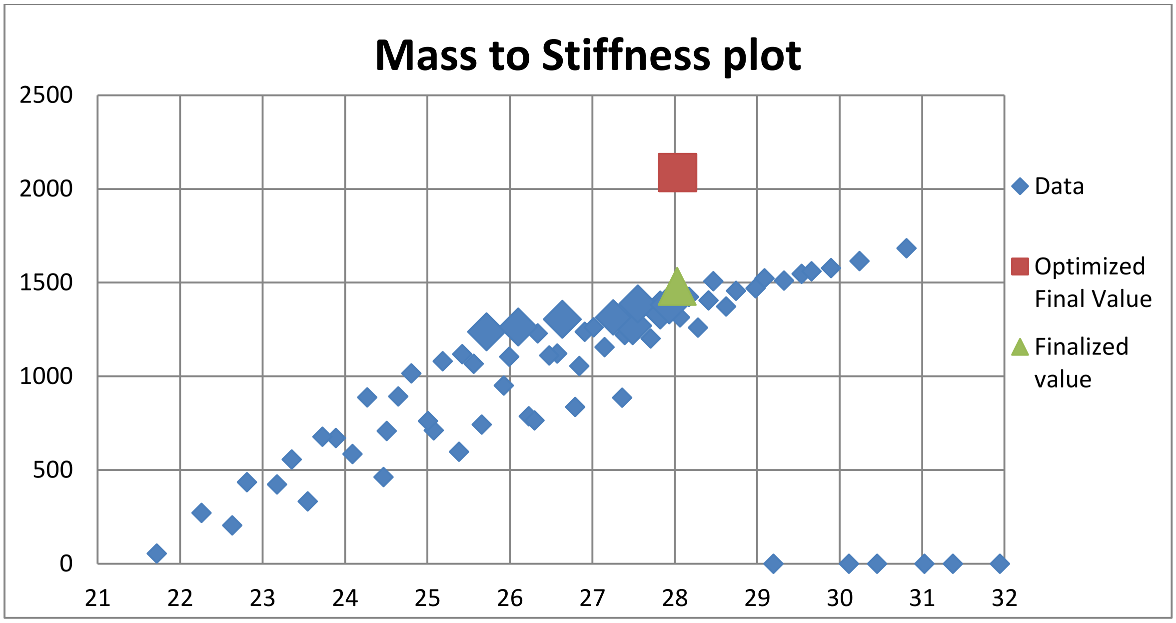


Figure 61: Mass to Stiffness plot

Selection Criteria

A criteria was developed for the selection of the values for the required variables from the results of the simulations. The criteria included;

1. Mass less than or equal to 28kg (75% of the tubular chassis mass)
2. Optimized stiffness to be greater than 2200 Nm/deg (115% of the tubular chassis stiffness)
3. Maximum stiffness to mass ratio
4. Maximum K/m to mass ratio
5. Impact max. displacement less than 5mm
6. Availability of material

The core thickness of 6.35mm and four CF layers on each side of the core were selected.

The symmetry was necessary so as to cancel out the internal stresses and moments that develop during the process of curing.

Optimization with Ply Angles

After the utilization of all the acquired data, only thing left from the criteria was the optimization using different ply angles.

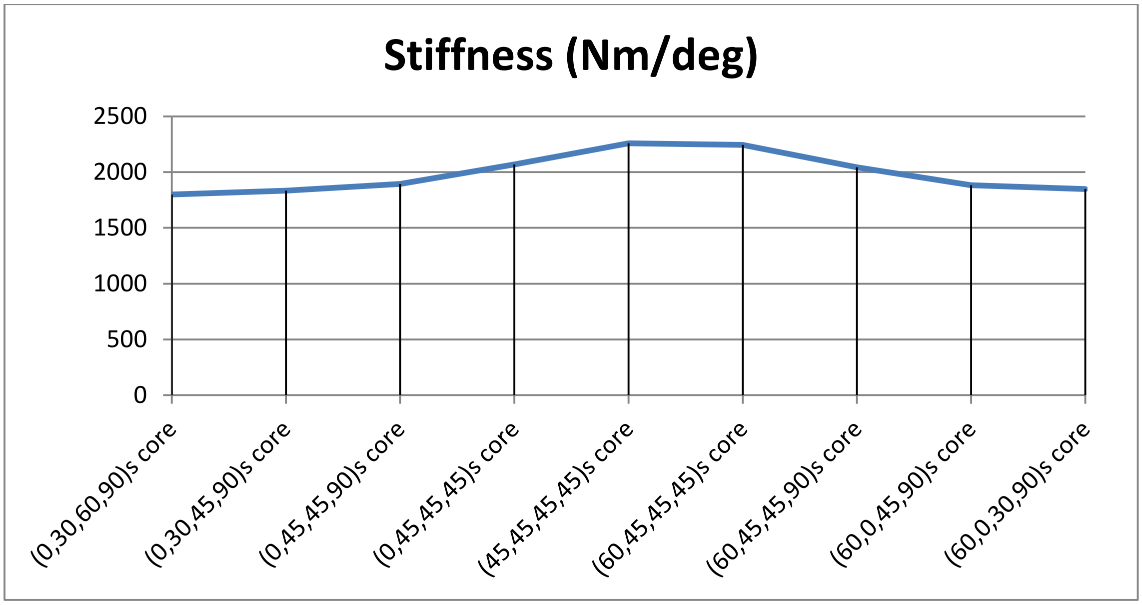


Figure 62: Stiffness with varying ply angles

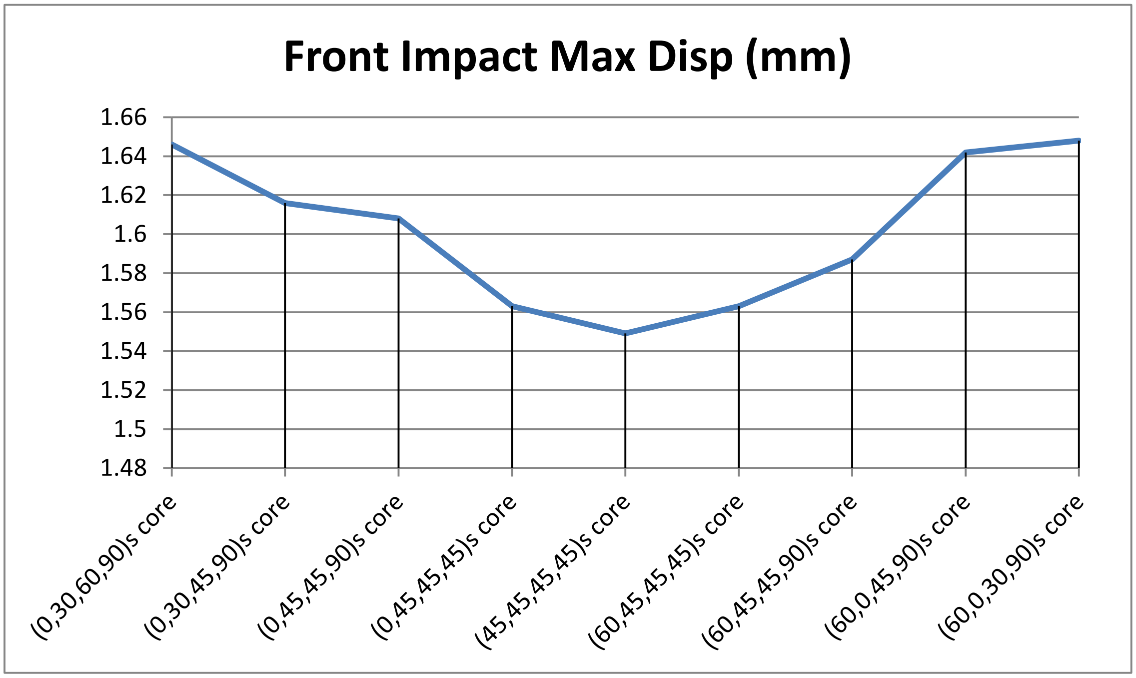


Figure 63: Max. Front Impact Displacement with varying ply angles

Intensive simulations revealed the best specs at the following layup:

$$(\mathbf{45°}, \mathbf{45°}, \mathbf{45°}, \mathbf{45°})_s \mathbf{0°}$$

The values within the bracket represent CF plies and the one outside is the core.

s represents symmetry.

With the help of all the collected data and the criteria developed, the final specs of the monocoque chassis are:

1. **Mass = 28kg**
2. **Stiffness = 2257 Nm/deg**

Simulation Studies

SolidWorks was selected to be used for the simulations because of the fact that it offers options for composite studies using orthotropic properties and different ply angles.

The pipes were modelled as beams using circular meshing while the tub was modelled as shell using triangular meshing. For stiffness analysis, a couple was applied to the front suspensions at the point of the attachment of tires keeping the joints of rear suspension fixed. The maximum torsional displacement about the axis of the chassis was measured. Stiffness was calculated through the formula:

$$Torsional\ Stiffness = \frac{Force \times Moment\ Arm}{Torsional\ displacment}$$

Front impact analysis of the chassis was done by fixing the rear part of the chassis and applying a force of 120kN on the front bulkhead as required in the FSAE rules booklet.

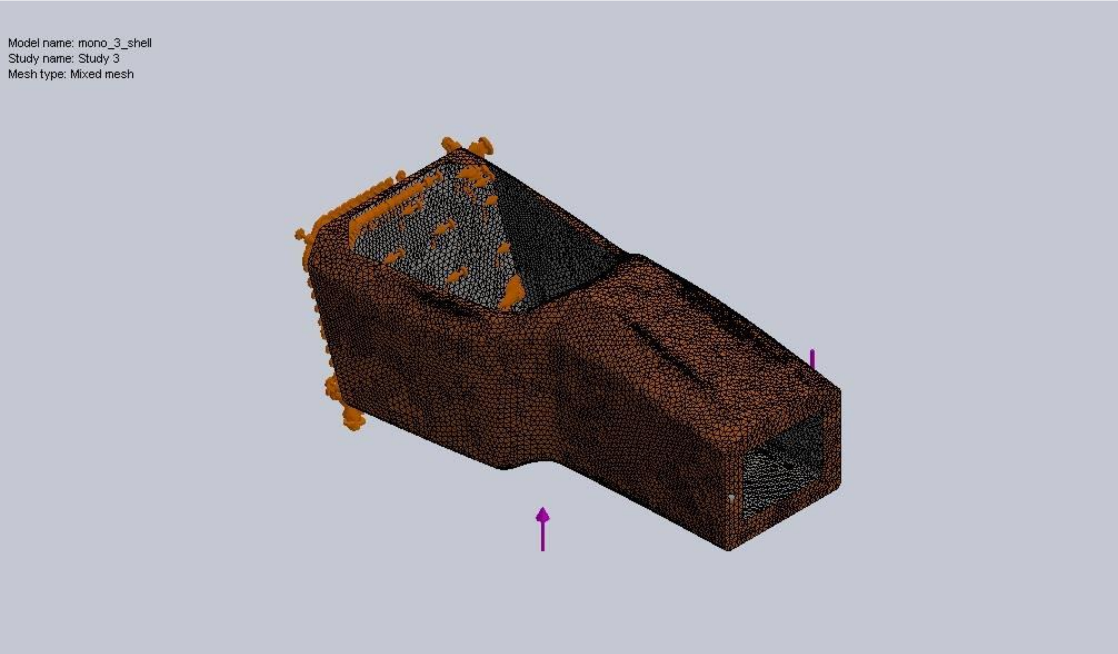


Figure 64: Mesh

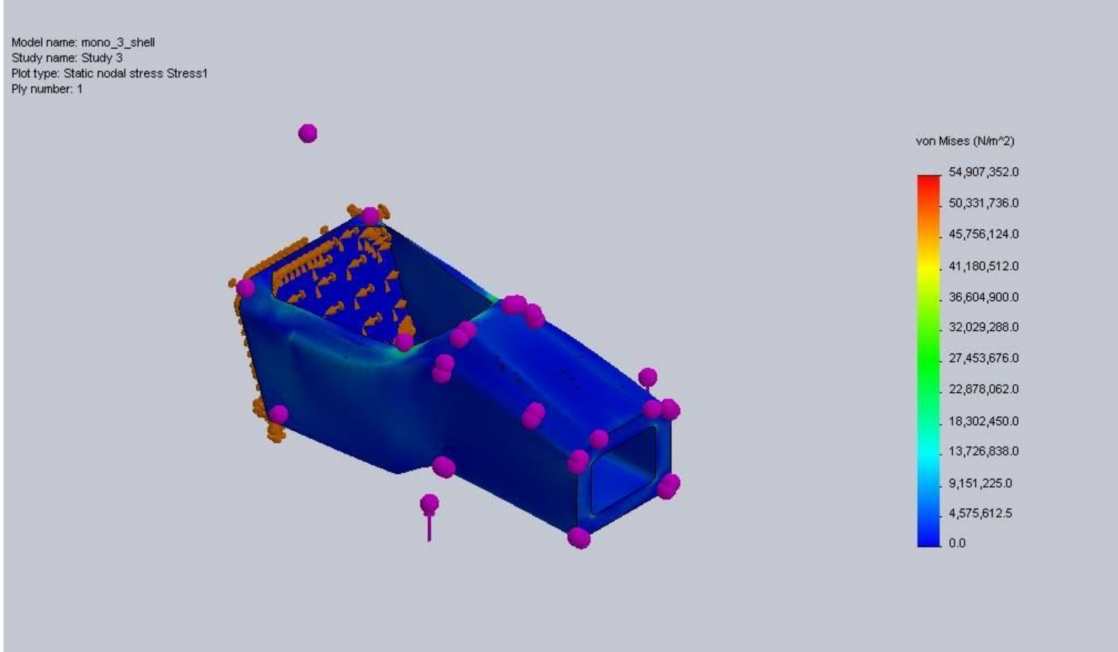


Figure 65: Stiffness Analysis

COMPARISON

Material

Tubular chassis is made from steel pipes generally AISI 1010, which is available in Pakistan at a very cheap price.

Monocoque comprises of carbon fiber fabric and a core material, generally a honeycomb structure of either aluminum or aramid. Both of these materials are very hard to get hold of in Pakistan since they are not manufactured locally and very few companies import them for selling purposes.

Cost

Material

The material of a tubular chassis costs around PKR 30,000 to 35,000.

The Cost of carbon fiber fabric alone required for the monocoque tub of a hybrid chassis costs around PKR 128,000. The cost of Aluminum honeycomb is 1500 $\$/ft^3$.

Fabrication

The cost of fabrication of a monocoque chassis is quite higher as compared to that of a tubular chassis given the equipment required for its fabrication.

Ease of operations

Fabrication

Fabrication of a tubular chassis involves profile cutting and welding of the pipes according to the design.

Fabrication of a monocoque tub is quite complex that involves CNC model to make the mold. It then requires a very long process of setting CF fabric and core layers, applying resin, drying and vacuum pressing.

Modification

If the design of a tubular chassis needs modifications after fabrication, the pipe can be cut off and re welded.

Once fabricated, CF monocoque cannot be modified.

Equipment Installation

Installing equipment in a tubular chassis are relatively easy because of the fact that the pipes have ample space between them to pass hands and tools.

Windows have to be cut into the monocoque where equipment needs to be installed.

Separate Aerodynamic Skin

A tubular chassis needs to be covered with a body layer that provided aerodynamic properties to the car and protects the driver from track debris.

A monocoque does not require any such layer because it has a solid floor underneath and is designed according to the aerodynamic aspects.

Stiffness to Weight Ratio

A monocoque chassis has a K/m ratio almost 2 to 3 times that of a tubular chassis. It offers more stiffness at considerably lower weight.

CONCLUSION AND RECOMMENDATION

From the list of comparisons shown above, it is evident that a tubular chassis is easier and cheaper while a monocoque chassis is better but expensive. When NBR reaches a level where they compete to win the competition, the use of a monocoque will be inevitable. But for now, given the inexperience of the team, a tubular chassis serves the purpose better than okay. To the future team of NBR, we would like to recommend them to keep on improving the designs as there is always room for improvement. Certain aspects of the projects can also be improved in the future. For example, this year, the chassis was designed first and the rest of the components were designed or selected accordingly. We recommend this to be the other way around. All the components should be assembled together on a bed and then the chassis should be designed around them. This would give better supports to the un-sprung masses and lesser design iterations.

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