Design and Analysis of Bodyworks of SAE car

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Abstract - *In this paper there is manufacturing of bodywork of a race car. Design and creation process begins form virtual prototyping of a model though mold manufacturing and ends up on infusion process. In order to achieve intended properties of composite materials a proper bonding of reinforcing layers has to be conducted during manufacturing process. It is one of the fundamental quality evaluation criterion while considering fabrication processes.*

***Key Words*: Composite Parts, Manufacturing, Infusion, Mould, Epoxy**

1. INTRODUCTION

Bodyworks are the outer covering of the car. They are a sort of its first impression as they determine the outer looks of the car. The car's body is not an essential part, meaning to say, the car can run without its body, but it definitely can aid performance significantly and hence needs to be engineered.

2OBJECTIVES

[1] Weight reduction

Weight of RFR 13's body: 14.1 kg

Target weight for RFR 14's body: 8 kg

[2] Study of possible materials for a better material selection

[3] Devising a mould making process to create an accurate replica of the CAD model

[4] Ensuring rule compliance while taking care of overall appearance of the body

3. Design Process

3.1 Material study

A material study between Fibre reinforced plastics, steel and aluminium was performed to compare their properties and decide the right material

Table -1: Sample Table format

Material Comparison			
STIFFNESS (Modulus of elasticity)	2.8 x 10^6 psi (for GFRP)	29 x 10^6 psi	10 x 10^6 psi
IMPACT RESISTANCE	Brittle material. Failure after a threshold load is applied	Ductile material. Can permanently deform under impact.	Ductile material. Deforms larger than Steel under impact.
COST	Higher initial cost if CF is used. Lower installation costs	Lower initial material cost.	Part price comparable to GFRP
WEIGHT	Weighs 75% less than steel and 30% less than aluminium.	1/2-in. thick plate = 20.4 lbs/sqft	Lightweight — about a third of the weight of copper or steel.
STRENGTH	Ultimate flexural strength (Fu): LW = 30,000 psi (30 ksi) CW = 10,000 psi (10 ksi) Compression strength: LW = 30,000 psi (30 ksi) CW = 15,000 psi (10 ksi)	Homogeneous material. Yield strength (Fy) = 36 ksi	Homogeneous material. Flexural strength (Fu) = 35 ksi

The following result was inferred from the above comparison:

[1] Composites, when utilized correctly, could theoretically provide significant weight savings (30-75%) without much compromise on strength (~20%).

This led to our decision to design the body of car with composites to ensure that design targets of weight reduction are met.

3.2 Shape of bodyworks

The shape of the body should be designed with the motive of keeping the total area covered by the composite body as minimum as possible while meeting the design targets, which in this case would be rule compliance and appearance of the body.

Starting from car's design and looking at the design objectives, the body can be split up into two parts:

[1] Nose cone: The part covering the front portion of the car extending from the front extremity up to the front roll hoop.

[2] Side structures: The part covering the Side Impact Structure and other parts on either side of the car

The side structures of car's were constrained to cover the structural side pods that were part of the chassis of the car and hence had to be designed that way.

The side "pod" design for car was not considered because: The absence of structural chassis side pods meant there was no necessity for such a design

The position of the radiator above the SIS gave no reason for creating pods to channel air flow

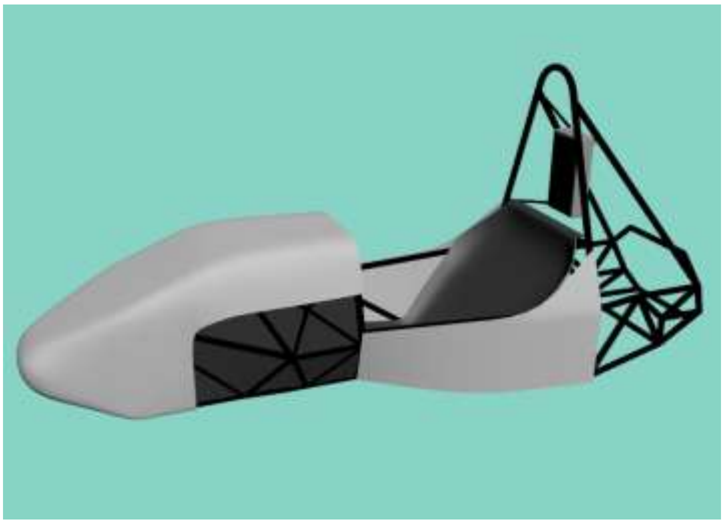


Fig -1: Cad Design

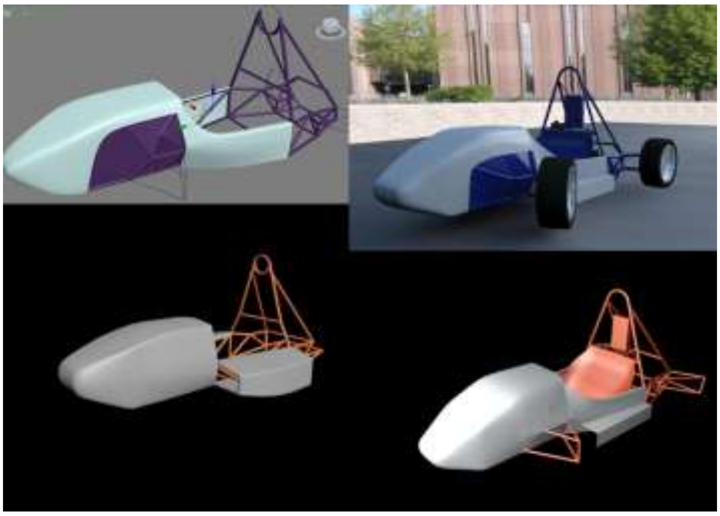


Fig -2: Cad Design Iterations

The reasons for preference of the design are as follows:

[1] To reduce the weight of composites used on the body, the side pods were reduced to side panels and this brought down the surface area covered by the body to 2.04 m^2 while ensuring rule compliance

[2] The single piece nose cone along with composite panels used near suspension openings gave the car good aesthetic appearance

3.3 Optimisation by studying fibre and resin properties

To design with composite materials, a qualitative study was performed using Glass Fibre Reinforced Plastics (GFRP). The inputs from the study provided an understanding of the designing process that was later extended to Carbon Fibre Reinforced Plastics (CFRP).

[1] GFRP QUALITATIVE STUDY

In its most basic form a composite material is one which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This reinforcement is usually in fibre form. Today, the most common man-made composites can be divided into three main groups:

Polymer Matrix Composites (PMC's) – These are the most common and what was studied here. Also known as FRP - Fibre Reinforced Polymers (or Plastics) - these materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement.

Metal Matrix Composites (MMC's) - Increasingly found in the automotive industry, these materials use a metal such as aluminium as the matrix, and reinforce it with fibres such as silicon carbide.

Ceramic Matrix Composites (CMC's) - Used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

[2] Polymer Matrix Composites

Resin systems such as epoxies and polyesters have limited use for the manufacture of structures on their own, since their mechanical properties are not very high when compared to, for example, most metals. However, they have desirable properties, most notably their ability to be easily formed into complex shapes.

Materials such as glass, aramid and boron have extremely high tensile and compressive strength but in 'solid form' these properties are not readily apparent. This is due to the fact that when stressed, random surface flaws will cause each material to crack and fail well below its theoretical 'breaking point'. To overcome this problem, the material is produced in fibre form, so that, although the same number of random flaws will occur, they will be restricted to a small number of fibres with the remainder exhibiting the material's theoretical strength. Therefore a bundle of fibres will reflect more accurately the optimum performance of the material. However, fibres alone can only exhibit tensile properties along the fibre's length, in the same way as fibres in a rope.

It is when the resin systems are combined with reinforcing fibres such as glass, carbon and aramid, that exceptional properties can be obtained. The resin matrix spreads the load applied to the composite between each of the individual fibres and also protects the fibres from damage caused by abrasion and impact. High strengths and stiffness, ease of moulding complex shapes, high environmental resistance all coupled with low densities, make the resultant composite superior to metals for many applications.

Since PMC's combine a resin system and reinforcing fibres, the properties of the resulting composite material will combine something of the properties of the resin on its own with that of the fibres on their own.

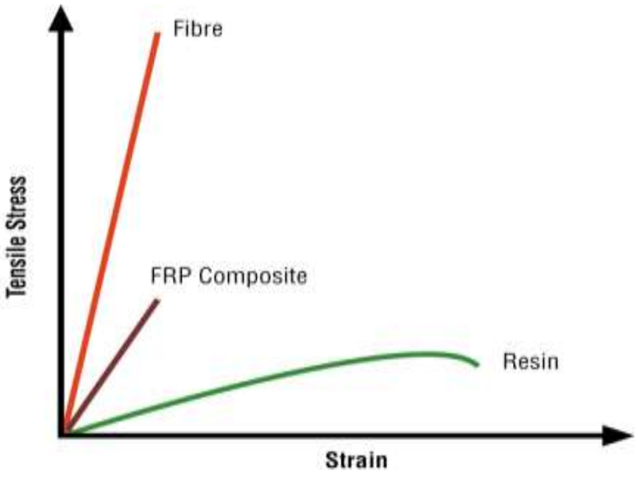


Fig -3 Strain vs Tensile Stress

Overall, the properties of the composite are determined by:

[1] The properties of the fibre

[2] The properties of the resin

[3] The ratio of fibre to resin in the composite (Fibre Volume Fraction)

[4] The geometry and orientation of the fibres in the composite

In general, since the mechanical properties of fibres are much higher than those of resins, the higher the fibre volume fraction the higher will be the mechanical properties of the resultant composite. In practice there are limits to this, since the fibres need to be fully coated in resin to be effective, and there will be an optimum packing of the generally circular cross-section fibres. In addition, the manufacturing process used to combine fibre with resin leads to varying amounts of imperfections and air inclusions.

Typically, with a common hand lay-up process, a limit for FVF is approximately 40-50% and since a plan for hand layup of the bodyworks was chosen, a Fibre Volume Fraction of 45% was assumed throughout our study. This was chosen in reference with.

Fibre

The choice of glass fibres that were accessible to us for manufacturing were of two types

Unidirectional Fabric: A unidirectional (UD) fabric is one in which the majority of fibres run in one direction only. Unidirectionals usually have their primary fibres in the 0° direction. The commercially available variant of this fabric had an areal weight of 1000 Grams per Square Metre (GSM)

Woven fabric: Woven fabrics are produced by the interlacing of warp (0°) fibres and weft (90°) fibres in a regular pattern or weave style. The fabric's integrity is maintained by the mechanical interlocking of the fibres. The commercially available variant of this fabric had an areal weight of 600 Grams per Square Metre (GSM)

Chopped Strand Mat: Chopped Strand Mat (CSM) has fibres oriented in random directions suspended in a matrix. Although these are easy to layup, they were not considered because of the higher weight of resin required to create a layup with this type of mat.

Although the Unidirectional fabric provides better directional properties when compared to the Woven fabric, the weight reduction of ~40% in case of the Woven Fabric means that a compromise can be made for the body which is not a significant load bearing part.

Resin

The two types of resin matrices that were considered in this study are as follows:

[1] General Polyester Resin

[2] LY556 Epoxy Resin

The comparison between the two type of resin were done using the Autodesk Simulation Composite Design Software under the following assumptions:

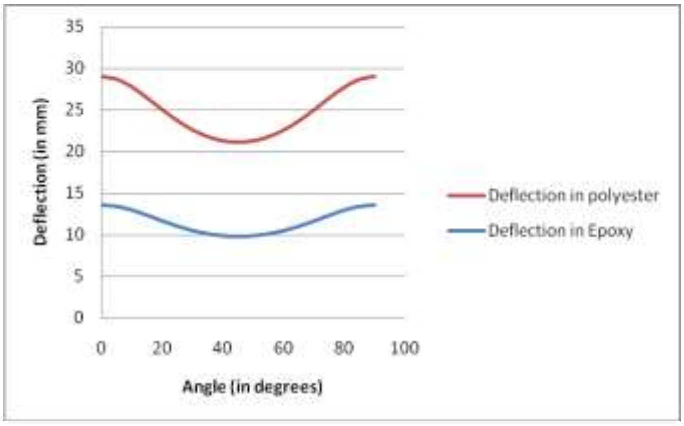
Flat plate of dimensions: 500mm X 500mm X 3mm (L X W X H)

Force applied: 500N concentrated force applied at the centre of the simply supported plate.

The properties of the Woven Roving Fibre used are listed below

Fibre Volume Fraction	0.45
E 11 (MPa)	2.24 X 10^4
E 22 (MPa)	2.24 X 10^4
E 33 (MPa)	9.52 X 10^3
G 12 (MPa)	3.15 X 10^3
G 13 (MPa)	3.07 X 10^3
G 23 (MPa)	3.07 X 10^3
Normal tensile strength in 1 direction	5.09 X 10^2
Normal tensile strength in 2 direction	5.09 X 10^2
Shear strength in 12 direction	8.77 X 10^1

The results obtained were as follows



Graph-1: Deflection in polyester vs Deflection in epoxy Graph

Thus, it can be inferred that the LY556 epoxy resin provided better resistance to deformation for the same type of loading conditions and geometry and hence LY556 Epoxy resin was chosen.

Geometry and Stacking Angle:

Laying orientation significantly affects the directional properties of the laminate. Hence, depending on where the manufactured part is going to be installed, it may need to have high shear strength or high tensile strength or a good combination of both. For example, a location where a fastener is going to be attached has to be good in shear strength than unidirectional tensile strength. A sample is shown below:

The first one is for [0°/45°/-45°/0°] and the second is for [0°/90°/-90°/0°]

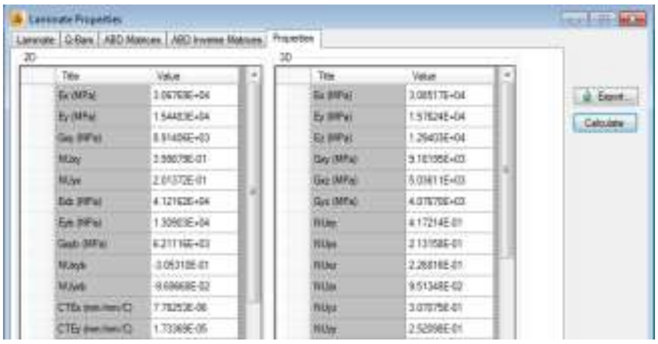


Fig -4 Laminate Properties 1

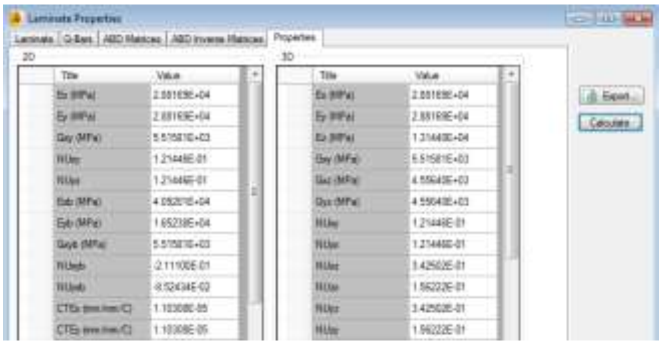


Fig -5 Laminate Properties 2

It can be inferred that the shear strength is 1.6 times higher for the (0 45 -45 0) combination as compared to (0 90 -90 0) combination.

The type of simulation that was performed in this case was to determine the ideal stacking angle (Stacking angle for which deflection is minimum) while the dimension of the flat plate that was being considered was varied.

This was performed on a flat plate with the same properties of the Woven Roving Mat listed in the previous section and fixed width of 500mm and thickness of 1.5mm for a double layered laminate while the aspect ratio was varied. The simulation results are as follows:

[1] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 +	321.03	1.5mm	1557.49	7.13

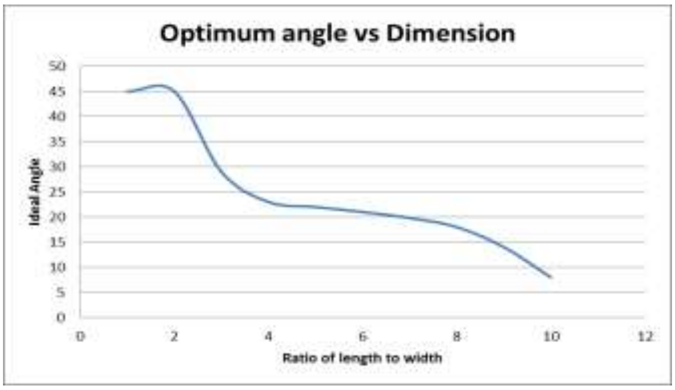
0/90	mm		N/m	kg
0/90 + 45/-45	288.88 mm	1.5mm	1730.82 N/m	7.13 kg
0/90 + 30/60	295.11 mm	1.5mm	1694.28 N/m	7.13 kg
60/30 + 45/-45	246.65 mm	1.5mm	2027.16 N/m	7.13 kg
45/-45 + 45/-45	232.16 mm	1.5mm	2153.69 N/m	7.13 kg
60/30 + 60/30	248.52 mm	1.5mm	2011.91 N/m	7.13 kg
[2] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	402.83 mm	1.5 mm	1241.22 N/m	7.13 kg
0/90 + 45/-45	409.41 mm	1.5 mm	1221.27 N/m	7.13 kg
0/90 + 30/60	408.33 mm	1.5 mm	1224.5 N/m	7.13 kg
60/30 + 45/-45	374.41 mm	1.5 mm	1335.43 N/m	7.13 kg
45/-45 + 45/-45	360.09 mm	1.5 mm	1388.54 N/m	7.13 kg
60/30 + 60/30	370 mm	1.5 mm	1351.35 N/m	7.13 kg
[3] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	392.46 mm	1.5 mm	1274.01 N/m	7.13 kg
0/90 + 45/-45	414.8 mm	1.5 mm	1205.4 N/m	7.13 kg
0/90 + 30/60	409.6 mm	1.5 mm	1220.70 N/m	7.13 kg
60/30 + 45/-45	393.47 mm	1.5 mm	1270.74 N/m	7.13 kg
45/-45 + 45/-45	385.28 mm	1.5 mm	1297.76 N/m	7.13 kg
60/30 + 60/30	384.31 mm	1.5 mm	1301.03 N/m	7.13 kg
61/29 + 61/29	384.299 mm	1.5 mm	1301.07 N/m	7.13 kg
[4] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	385.62 mm	1.5 mm	1296.61 N/m	7.13 kg
0/90 + 45/-45	408.53 mm	1.5 mm	1223.9 N/m	7.13 kg
0/90 + 30/60	402.83 mm	1.5 mm	1241.22 N/m	7.13 kg
60/30 + 45/-45	390.71 mm	1.5 mm	1279.72 N/m	7.13 kg
45/-45 + 45/-45	384.49 mm	1.5 mm	1300.42 N/m	7.13 kg
60/30 + 60/30	380.43 mm	1.5 mm	1314.30 N/m	7.13 kg
67/23 + 67/23	379.14 mm	1.5 mm	1318.77 N/m	7.13 kg
[5] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	377.11 mm	1.5 mm	1325.87 N/m	7.13 kg
0/90 + 45/-45	399.74 mm	1.5 mm	1250.81 N/m	7.13 kg
0/90 + 30/60	394.05 mm	1.5 mm	1268.87 N/m	7.13 kg
60/30 + 45/-45	383.14 mm	1.5 mm	1305.00 N/m	7.13 kg
45/-45 +	377.63	1.5 mm	1324.05	7.13

45/-45	mm		N/m	kg
60/30 + 60/30	372.72 mm	1.5 mm	1341.49 N/m	7.13 kg
68/22 + 68/22	370.98 mm	1.5 mm	1347.78 N/m	7.13 kg
[6] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	366.56 mm	1.5 mm		7.13 kg
0/90 + 45/-45	389.236 mm	1.5 mm		7.13 kg
0/90 + 30/60	383.527 mm	1.5 mm		7.13 kg
60/30 + 45/-45	373.772 mm	1.5 mm		7.13 kg
45/-45 + 45/-45	368.762 mm	1.5 mm		7.13 kg
60/30 + 60/30	363.368 mm	1.5 mm		7.13 kg
69/21 + 69/21	361.195 mm	1.5 mm		7.13 kg
[7] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	354.191 mm	1.5 mm		7.13 kg
0/90 + 45/-45	377.409 mm	1.5 mm		7.13 kg
0/90 + 30/60	371.579 mm	1.5 mm		7.13 kg
60/30 + 45/-45	363.385 mm	1.5 mm		7.13 kg
45/-45 + 45/-45	358.918 mm	1.5 mm		7.13 kg
60/30 +	352.976	1.5 mm		7.13

60/30	mm			kg
19.8/71.2 + 19.8/71.2	350.043 mm	1.5 mm		7.13 kg
[8] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	340.382 mm	1.5 mm		7.13 kg
0/90 + 45/-45	364.657 mm	1.5 mm		7.13 kg
0/90 + 30/60	358.610 mm	1.5 mm		7.13 kg
60/30 + 45/-45	352.382 mm	1.5 mm		7.13 kg
45/-45 + 45/-45	348.537 mm	1.5 mm		7.13 kg
60/30 + 60/30	341.918 mm	1.5 mm		7.13 kg
72/18 + 72/18	337.754 mm	1.5 mm		7.13 kg
[9] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	325.654 mm	1.5 mm		7.13 kg
0/90 + 45/-45	351.373 mm	1.5 mm		7.13 kg
0/90 + 30/60	345.050 mm	1.5 mm		7.13 kg
60/30 + 45/-45	341.057 mm	1.5 mm		7.13 kg
45/-45 + 45/-45	337.891 mm	1.5 mm		7.13 kg
60/30 + 60/30	330.499 mm	1.5 mm		7.13 kg

76/14 + 76/14	324.475 mm	1.5 mm		7.13 kg
[10] Aspect Ratio				
Combination	Deflection	Thickness	Dimensionless	Weight (for the area 2.5 sq. m)
0/90 + 0/90	310.535 mm	1.5 mm		7.13 kg
0/90 + 45/-45	337.898 mm	1.5 mm		7.13 kg
0/90 + 30/60	331.244 mm	1.5 mm		7.13 kg
60/30 + 45/-45	329.639 mm	1.5 mm		7.13 kg
45/-45 + 45/-45	327.179 mm	1.5 mm		7.13 kg
60/30 + 60/30	318.967 mm	1.5 mm		7.13 kg
82/8 + 82/8	310.346 mm	1.5 mm		7.13 kg

The following plot shows how the ideal angle varies with the aspect ratio of the plate:



Graph 2- Ideal Angle vs Ratio of length of width

The following observations were made:

[1] As the ratio is changed from 1:1 to 10:1, the optimum angle has changed from 45◦ (or -45◦) to 8◦ (or 82◦). This is consistent with the fact that if the length would be much larger than the width, then the ideal angle would be 0◦ (or 90◦).

[2] For a given aspect ratio, the optimum angle is fixed; it does not change with the thickness.

Conclusions of qualitative study

The qualitative study provided an insight on the various parameters that affect the strength of a flat plate made of Glass Fibre Reinforced Plastic. Although they were just basic simulations on a simple geometry they proved a good starting point for designing the team's first carbon fibre parts, the nose cone and the side panels.

The ideas obtained from the study were implemented in the manufacture of the above mentioned parts as the following sections will highlight. Further plans with the study will be to simulate much more complex geometries than flat plates using appropriate software and eventually design parts that serve more than the purpose of aesthetics.

Although the study was performed only on GFRP (due to the late procurement of Carbon Fibre), the final body was manufactured in Carbon Fibre using ideas mentioned above. The work done with CFRP is highlighted in the coming sections.

3.4 Weight Calculation

A theoretical estimation of the weight of the parts with CFRP was made (without paint)

[1] Front Nose Cone

Total area of Nose cone	1.121 meter square
Standard thickness of nose cone	4 layers of CF
Extra layers at critical locations Upside corners Downside corners Upper mount position Lower mount position Front face	2 layers * 2 sides 2 layers * 2 sides 2 layers 2 layers 2 layers
Standard layers Upside corners Downside corners Upper mount position Lower mount position Front face Total area of fibre used	4*1.121 = 4.484 1.108*.100*2*2 = .432 .550*.1*2*2 = 0.22 .720 *.1* 2 = .144 .400 *.05*2 = .04 .200*.300*2 = 0.12 5.44 meter square
Estimated weight (2:1 resin fibre ratio)	1.65 kg
Length of scissors cutting	44.5 m

Length of finishing done using angle grinder	2.7 m

[2] Right side panel

Total area of side panel	.256 meter square
Standard thickness of panel	4 layers of CF
Fibre Area for standard thickness Total area of fibre used	.265*4 = 1.02 1.02 meter square
Fibre mass	.102 kg
Estimated mass of part(2:1 resin fibre ratio)	.307 kg
Total scissors cut length	7.5 m
Finishing length with angle grinder	1.89 m

[3] Left side panel

Total area of side panel	.256 meter square
Standard thickness of panel	4 layers of CF
Fibre Area for standard thickness Total area of fibre used	.265*4 = 1.02 1.02 meter square
Fibre mass	.102 kg
Estimated mass of part(2:1 resin fibre ratio)	.307 kg
Total scissors cut length	7.5 m
Finishing length with angle grinder	1.89

[4] Front triangular panels

Combined area of panels	.41 meter square
Standard thickness of panel	3 layers of CF
Fibre Area for standard thickness Total area of fibre used	.41*3 = 1.23 1.23 meter square
Fibre mass	.123 kg
Estimated mass of part(2:1 resin fibre ratio)	.369 kg
Total scissors cut before layup	4 m
Finishing length with scissors	10.52 m

The total estimated weight came out to be equal to 2.633 kg without paint. Considering around 1.5kg for painting, we estimated weight of around 4kg is obtained which is much lesser than our expected design target. This was possible due to the usage of Carbon Fibre Reinforced Plastic

[4] Manufacturing

Initial samples were made with Carbon Fiber, using manual hand laying. Due to the simplicity of layup of the fibre and the non-availability of vacuum bagging capabilities, a hand layup process was chosen.

Carbon Fiber has very good unidirectional properties, making it an extremely strong material, with relatively much lesser weight i.e. the strength-to-weight ratio is very high. As a result, weight reduction became much easier without compromising on the strength.

The carbon fiber that was used is plain weave, which has fibers in 0 and 90 degree directions. As a result bidirectional strength is obtained. The fiber was used with Epoxy LY556 resin. We used 3-5 layers, depending on the location. It is a 100 gsm fabric, meaning, which is significantly lighter than the Glass Fiber which was initially planned to use, which was 600 gsm.

4.1 Mold manufacture

As mentioned in the design objectives, devising a method to accurately create a replica of the CAD model was imperative. This was achieved by the following:

[1] Creating sections in the CAD model at various distances from the nose and finding the curves of the nose cone at each location.

[2] Preparing a model of the profiles that need to be made at these locations to form a skeleton like structure for the mould.

[3] Manufacturing the skeleton using CNC Milling machine for accuracy.

[4] Assembling the skeleton to form a basic structure of the mould.

[5] Filling up the spaces with styrofoam and shaping it by hand as accurately as possible.

[6] Finishing the surface with white plaster and Epoxy coat (for strength to the mould)

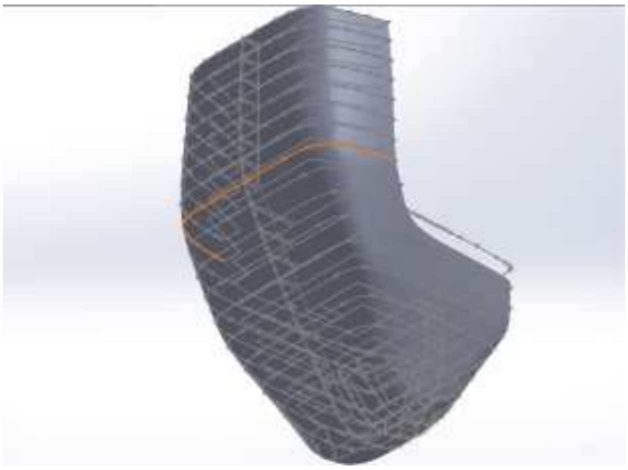


Fig -5 CAD Model of Front Panel

Fig -6 Manufacturing of Skeleton

Fig -7 Finishing the surface with white plaster

4.2 Layup process

As already mentioned the technique used for layup was hand laying, keeping regards of analysis done on laying patterns and variable thicknesses. Vacuum infusion molding was also taken into consideration initially, but later we decided not to go for it due to the difficulty in making the necessary mold for that. Given the facilities that we had, fully manufacturing a mold by CNC machining was not possible.

5. Aerodynamics

According to the feedback obtained in Formula Student Germany 2014, aerodynamics was one area which was not ventured into. Work in this area started with a simplified simulation of the existing car to obtain relevant data. The data obtained is as follows:

[1] A pressure plot of the car was obtained with a Peak Pressure of 80Pa over atmospheric occurring at the tip of the nose cone.

[2] The coefficient of drag (Cd) obtained was 0.641 (without wheels) and 0.598 with one wheel.

[3] The coefficient of lift (Cl) obtained was -0.0236

All these simulations were performed without the suspension assembly and wheels

Further observation is the presence of a large vortex at the rear end of the car. Hence, the decision to develop a diffuser for the next year's car was realized.

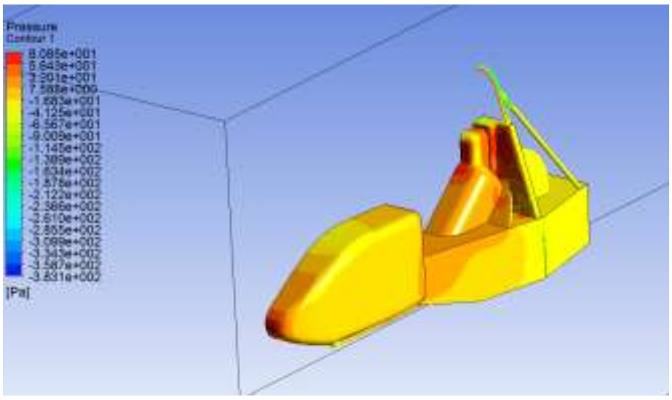


Fig -8 Aerodynamic Simulation

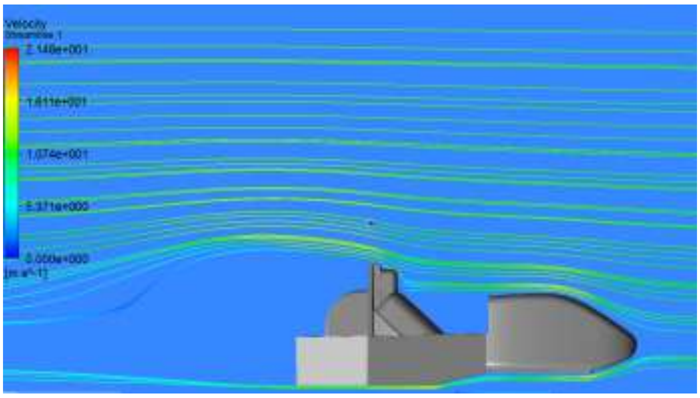


Fig -9 Aerodynamic Simulation

6. Conclusions

The composite simulations that we did may not have been used on this year's car, but they can certainly be used and implemented when there is an unavailability of Carbon Fiber that was the purpose of going towards the design and simulation of the GFRP. When using GFRP, this technique can be resorted to, to save a significant weight.

Running composite simulations for CF for the bodyworks may not serve much purpose as bodyworks do not bear much loads and the weight reduction that would be achieved may not be significant.

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