Design and Manufacturing of Aerodynamic Bodyworks for Formula Student Cars

Ruturaj Mane[1], Shubham Garde[2], Omkar Taru[3], Pravin Jadhav[4]

[1,2,3,4]*Students, Mechanical Engineering Department, JSPM's Rajarshi Shahu College of engineering, Tathawade, Pune, Maharashtra, India.*

---***---

Abstract – *This paper is an overview of the Manufacturing process using Fiber Reinforced Plastic/Composite material system. Materials and processes are presented along with design procedure and comparisons to alternate materials. Considering the FSAE(Formula Society of Automotive Engineering) rules, bodyworks is design and then manufactured for a FSAE car. Analytical calculations are done based on simulated results. Materials and processes are presented along with design procedure and comparisons to alternate materials is done, because of the versatility of materials around us.*

Computational fluid dynamic (CFD) tool is used to calculate Drag coefficient of car for calculating the drag force acting on the car during dynamic conditions.

Key Words: Aerodynamic, Simulation, Drag, Lift, Downforce, MDF, FRP.

1. INTRODUCTION

The bodywork simply means that it protects driver from any small particles and objects(stones) while driving a car. It also improves the appearance of a vehicle. In formula student competition you have to follow some rules before manufacturing any part.

Hence, the suitable sketch was selected which fits the required rules and then 3D model was built in modeling software(i.e. Autodesk Fusion 360) as shown in below figures. The chassis was taken as the reference to determine the parameters like shape, dimensions and required fitment of nose. It was designed such that there was no interference with any other components of vehicle. After completing the design, materials selection and types of manufacturing methods available for the material was selected.

1.1 Necessity of Bodywork

- Working as a streamlining element to reduce drag at certain speed.
- Improves overall appearance of vehicle.
- It prevents, outside objects from coming into the cockpit during driving the car.
- It acts like external structure which covers the chassis.
- Partly work as windshield for driver.

Fig -1: Rendering of Bodyworks.

1.2 Rule constraint

The bodywork to be designed must be satisfied the rules and regulations stated for it in the rulebook. These rules have been mentioned below.

1)There must be no openings through the bodywork into the driver compartment from the front of the vehicle to the front hoop and below the side impact members. Minimum openings around the front suspension components are allowed.
2) Sharp edges on the surface of bodywork are prohibited.
3) All forward facing edges on the bodywork that could impact, e.g. the nose, must have forward facing radii of at least 38 mm (1.5 inches). This minimum radius must extend to at least forty-five degrees (45°) relative to the forward direction, along the top, sides and bottom of all affected edges.

1.3 Design key points

1) Chassis constraints.
2) Downforce should be desired and low lift and drag kept as possible.
3) Manufacturing process.
4) Material selection.
5) Cost of the bodywork.
6) Aesthetics.

1.4 Aerodynamics Nature

Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Aerodynamics is a subfield of fluid dynamics and gas dynamics, with much of theory shared between them.

Understanding the motion of air (often called a flow field) around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties.

Consideration according to aerodynamics in design:

The main objective was to create light weight and aerodynamic package and also good aesthetics, which could be tested and simulated by available resources. Design in CAD was designed by considering objective of lowering coefficient of drag as well as coefficient of lift and tried to achieve desired downforce. We used analytical method, simulation software Ansys CFD for validations and study of flow in order to achieve the objectives. We used iterative method to select the final design.

2. METHOLOGY

First step of designing was to draw a sketch. Then using some CAD software's make a 3D model. Use the cad model for doing CFD for drag force and drag coefficient. Then second step is manufacturing. Make a mold, choosing suitable method. Mold making is the most important step to achieve smooth finishing. The method used here was cost effective than other methods used. The method used was cost effective for making mold, so using CNC machine was avoided. Let's discuss the flowchart of designing the bodywork.

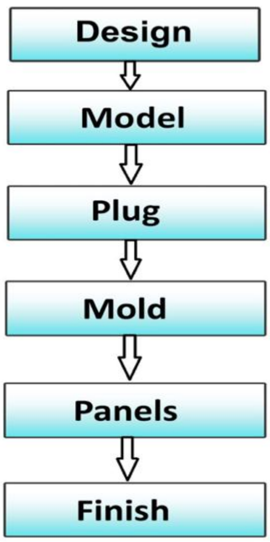

Chart -1: Flow chart of methodology

2.1 Design

The following considerations must be followed while designing the bodywork.

1. Weight should be less as much as possible.
2. It must bear the stresses produced due to aerodynamic forces acting on it.
3. Cost effective method should be implemented
4. Reduce aerodynamic drag force as much as possible by improving design and do some iterations by using CFD.
5. Minimal forces by improving outer shell structure.
6. Also focused on appearance of nose which increases the aesthetics of car.

2.1.1 Design for Manufacturing.

During the design process, consideration of manufacturing process is very important. In addition to the wide variety of material combinations, there are many choices available for manufacturing process of FRP/Composite products, such as.

- Compression molding
- Resin Transfer Molding (RTM)
- Injection Molding
- Hand Lay-Up
- Vacuum Bag Molding
- Spray Up
- Autoclave Molding
- Vacuum Infusion Molding

Design changes according to manufacturing process. Hand Lay-up method was selected, as it is easy to process and accuracy of final product is also as required.

The design was scale down in cad model. In two axis that is in lateral and vertical axis considering thickness of putty(6mm) layers and thickness of FRP(3.5mm). Smoothen curves which are hard to achieve, so the designed skeleton was checked by availability of thickness in high density Styrofoam. Thickness was used to decide the distance between two consecutive plates of the skeleton.

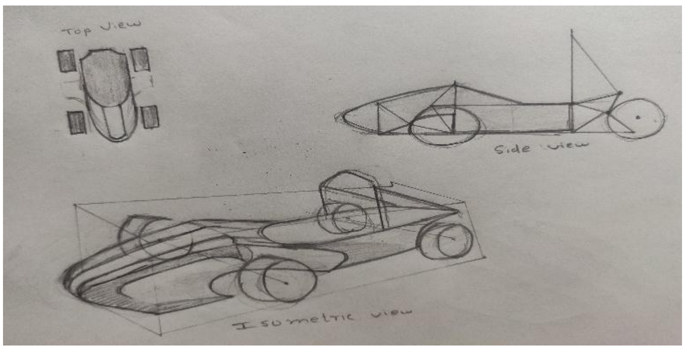

Fig -2: Sketch of bodyworks.

2.2 Modeling of bodyworks:

Selected sketch was designed and the model was designed considering interferences with various system such as Suspension A-Arm location, Exhaust routing, Radiator location, etc. considering the other mounting also. Driver egress is also to be considered while designing the bodyworks. The surfaces should be continuous and smooth across the body so that the flow will be laminar. And thus, this is the initial iteration which was modeled.

As first part which interact with air is nose, so we considered importance of this nose tip as it distributes proportion of air across car, so we tried to push air as much as below the car to reduce CD and create more downforce. We changed profile according to pressure contours until we get smooth contours. Also we considered simplicity of manufacturing so we blunt all curves.

2.2.1Nose comparison and selection:

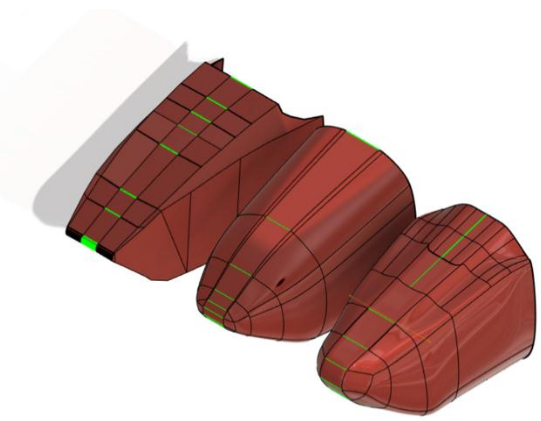

Fig -3: Iteration of nose (isometric view).

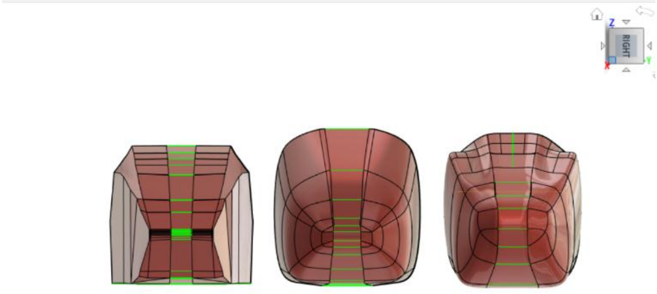

Fig -4: Iteration of nose (front view).

As seen in the above figures we worked on 3 iterations of nose and according to analysis results we finalize optimized nose which is suitable to our need. Aerodynamics has become key to success in the Formula One sport. The aerodynamic design has two primary concerns.

1. The creation of downforce to help push the car's tires onto the track and improve the cornering force.

2. To minimizing the drag that caused by turbulence and acts as to slow the car down. The drag over a body can be minimized by streamlining it. As a result, it also improves fuel economy.

Table -1: Comparison based on the outputs results of CFD.

Nose	1	2	3
CD (Coefficient of Drag)	0.82	0.72	0.69
CL (Coefficient of Lift)	0.31	0.26	0.27
Downforce	7.72	8.23	8.52

By comparing the data, 3rd iteration of nose was selected because of Optimum CD, CL and desired Downforce.

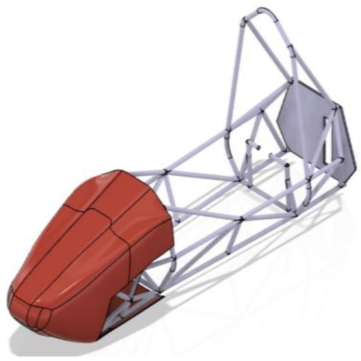

Fig -5: 3D model of Selected nose.

2.3 Analysis Reports of the Selected model.

CFD tool is used for analysis of bodyworks. As the selection of the nose design was done based on the output results. The selected nose CFD reports are mentioned below. According to this results we get optimum shape that must be produced desired amount of downforce. For reducing the drag force acting on the car we simply smoothen that curve and also we focused on appearance part of car.

For better performance, we need more down force with minimum drag. Hence the shape of the cone should be such that it gives the most optimal angle (α) as per the working conditions of the vehicle. The best design was chosen after several iterations through the simulation of the model in ANSYS.

Analysis was done at boundary condition of velocity inlet 16 m/s and taking ground clearance 50mm.

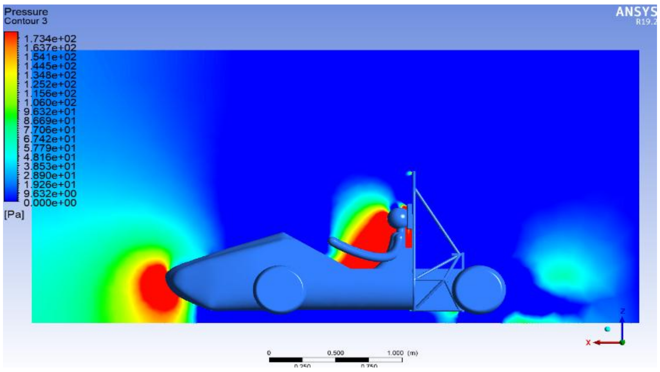

Fig -6: Analysis of bodyworks - Pressure plot of 16 m/s.

From the above figure it is observed that when car goes forward it creates some amount of high pressure zone at the tip of bodywork. We got smooth pressure contour on this tip profile of nose compared to others iterations.

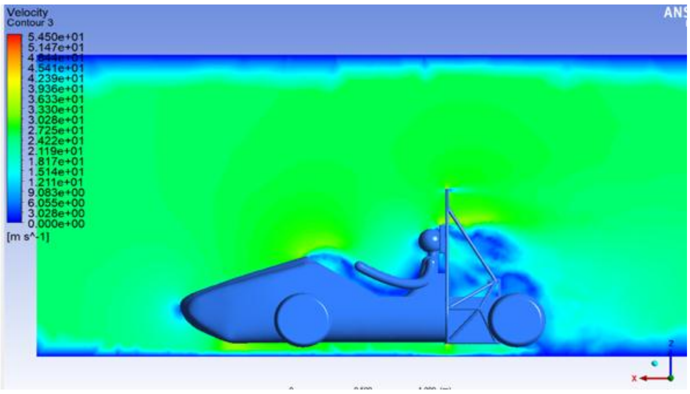

Fig -7: Analysis of bodyworks- velocity plot at 16m/s.

From above picture we can see that we accelerated air under the flour as much as possible. Which means we created downforce as we desired. As more air goes under nose. Area decreases so it gets accelerated due to this pressure difference created, it leads to creation of downforce.

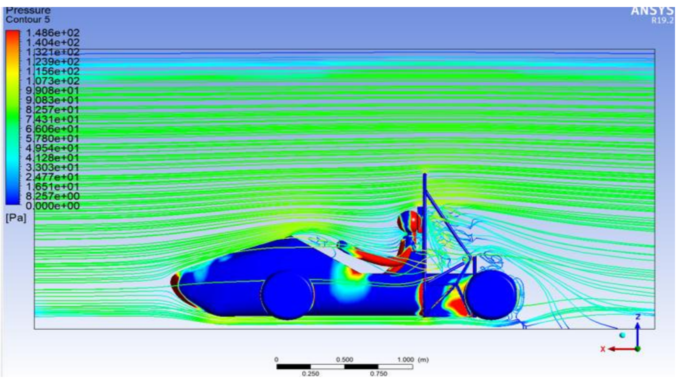

Fig -8: Streamline at velocity 16 m/s .

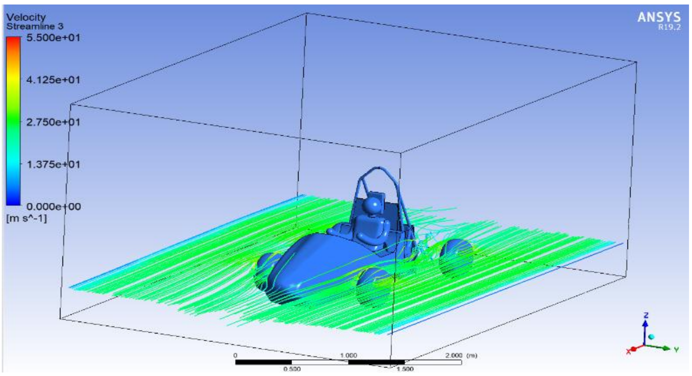

Fig -9: Streamline at velocity 16 m/s.

As we do CFD of fully assembled car we can see wake formation behind tires. Vortex generating and turbulence behind firewall and at the of end of nose can be observed due to low pressure zone. Air is forced to go from high pressure region to low pressure region. This are the reasons for formation of eddies.

The flow over the final iteration is shown in the above figure. Most of flow is laminar as seen in the figure. Average pressure is 101301 Pa. and atmospheric pressure is 101325 Pa. and calculated from obtained values of CFD is -83N so downforce is -8.52N. Thus we achieved desired downforce and minimum drag .

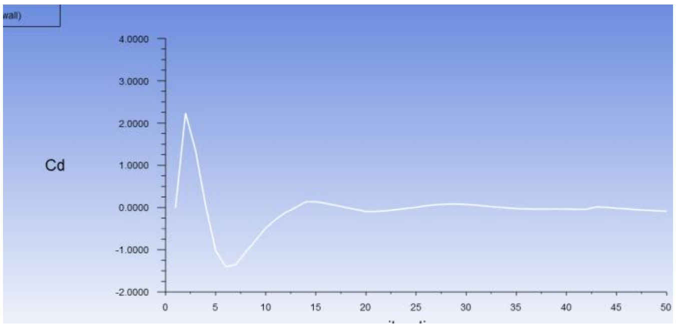

Fig -10: Graph plot of CD (Average- 0.69).

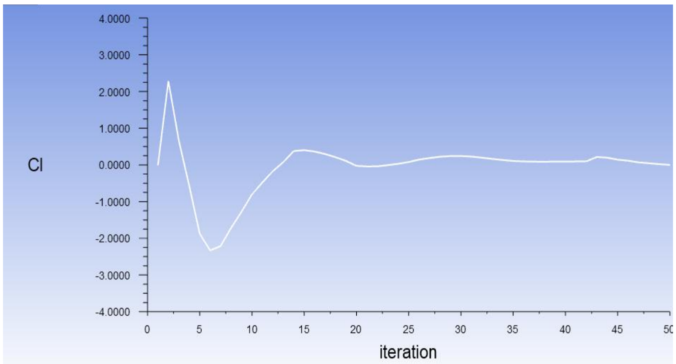

Fig -11: Graph plot of CL (Average-0.27).

3. MATERIAL SELECTION

Table -2: Types of Material Available.

Materials	Fiber glass (FRP)	Carbon Fiber (CF)
Density gm/cm3	0.5"	1.8-1.9
Availability	More	Less
Manufacturing method	Open Molding	Vacuum molding
Cost	High	Low

By observing the above table, Fiber glass is the best suitable material for our application due to its availability lower cost and easy in manufacturing process. The manufacturing setup is more simple and it seems lot easier.

3.1 Material Description

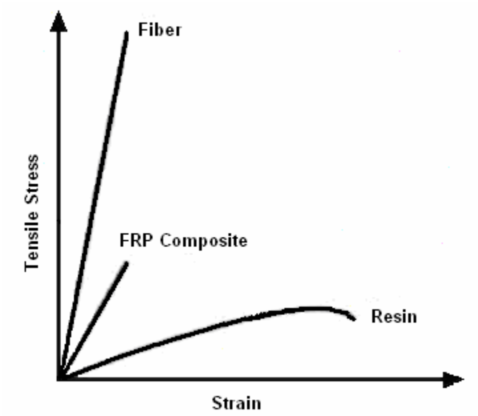

Chart -2: Stress strain graph.

FRPs are commonly used in the aerospace, automotive, marine, and construction industries.

Fiberglass(FRP) are best suited for any type of design approach, that demand precision engineering, specific tolerances, weight savings and simplification of parts in production. A molded polymer product is lot easier to manufacture it faster in less cost. It also maintains similarity, better tolerances and product strength as compared to other materials.

FRP is also used in designs that require a measure of strength or modulus of elasticity for which non-reinforced plastics and other material choices are less suitable, either mechanically or economically. The primary design consideration for using FRP is to ensure that the material is used economically and in a manner that takes advantage of its specific structural characteristics, but this is not always the case. The orientation of fibers is very important to understand, or else it creates a weaker product. Thus the use of fiber reinforcement and their orientation affects the strength, rigidity, elasticity and hence the functionality of the final product itself.

4. MANUFACTURING PROCESS.

- **Basic skeleton**
- **Nichrome wire cutter**
- **Mold preparation**
- **Hand laying**
- **Final product**
- **Assembly of Bodyworks**

As this paper focused on the manufacturing of bodywork and Stepwise explanation of this new approach method are as shown.

4.1 Basic skeleton

Fig -12: Skeleton made of MDF.

1) As per the designed cad model, we measured possible maximum distance that we can put between consecutive section of CAD model, by iterations on hot wire cutting tool that we have made as per our requirement and by considering thickness available of Styrofoam .
2) After deciding a distance then we took cross-section of each and we reduced distance between consecutive cross-section where more accuracy is needed.

3)Then we choose MDF material to make slices and we used laser-cutting to achieve accuracy.
4)Assembly of skeleton was done on jigs to develop basic rigid structure, jigs are used to maintain desired distance between them.
5)Gaps are filled using Styrofoam and shape was given by hot wire cutting and surface finishing was done using smooth emery paper.

4.2 Nichrome wire cutter

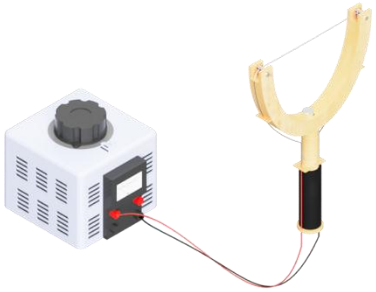

Fig -13: Setup of Nichrome wire cutter.

For cutting the foam in a proper shape we simply use nichrome wire and Variac. It consists of wooden handle for protecting the user from shocks of Nichrome wire and Variac. Variac is a variable transformer. Construction of variac like knob is attached to the wiper that makes contact with transformer coils. This coils allows electricity to be passed according to knob movement. Application of variac is it allows user to vary the output voltage by controlling the knob attached to the coils. For implementation of this setup variac is connected to Ac voltage source. Then output of variac is connected directly to nichrome wire. According to user control the voltage of variac is vary and it simply controls heating of the nichrome wire.

Fig -14: Variac.

Fig -15: Product After Using Nichrome wire cutter.

4.3 Mold preparation

Mold preparation is the time consuming part of bodywork. Where sudden changes in geometry take place. Proper approach is to be implemented for manufacturing of the mold.

1) As studied the chemical behavior of Styrofoam and epoxy resin. It goes under exothermic reaction. So implementation of a protective layering on a skeleton is necessary.
2) First apply JANTA, car patch duel compound filler putty on the skeleton. As it doesn't react with Styrofoam.
3) For surface finishing and easy for polishing we used NC (nitro-cellulose)putty.
4) For final layer, polyester putty (metaplast) is used
5) Desired smoothness, different grades of emery paper are used.

4.3.1 Putti composition

1) JANTA car patch duel compound filler putty
2) NC (nitro-cellulose) putty.
3) polyester putty (metaplast)

Putty is suitable for Styrofoam melts by reacting with epoxy resin

Different putty were used for different purposes. JANTA car patch duel compound filler putty was used as it does not go under exothermic chemical reaction with high density Styrofoam. NC putty used as bonding material for JANTA car patch duel compound filler putty and polyester putty (metaplast). Polyester putty was used for strengthening mold as well as polishing easy and better surface finishing .

Fig -16: Putty composition at different stages.

Fig -17: Final product after applying all layers of putty and surface finishing the product.

4.3.2 Resin Selection

Two types of resin were available in the market.
1) Epoxy resin(local)
2) LY557 resin.
Epoxy resin is better binding material for chopped glass fiber and high availability due to low cost. So Epoxy resin was used to make the negative mold. And LY557 resin was used for final product. LY557 was not used for negative mold because, there was no need weight to strength ratio for negative mold.
As decided to use destructive manufacturing method. For which firstly skeleton structure was manufactured. And followed next mentioned steps.

4.4 Hand Laying

As Destructive mold manufacturing method was selected Hand laying was the best suitable method because of the unique properties mentioned below.

1) Low setup cost.
2) High Reliability and Accuracy.
3) Less Setting time.
4) Less Heat generation in Exothermic reaction with resin.
5) Cost effective.

4.4.1 Negative mold

1) Two layers of gelcoat were applied on outer surface of mold(skeleton with putty) by using paint brush.
2) Varnish was sprayed all over mold.
3) Chopped fiber (FRP) sheets and Epoxy resin used for hand laying method on the mold. All the sides were covered by a single layer of FRP.
4) Extra layer was added on corners and the curves to get a proper shape.
3) After 30 min. the negative mold became hard/stiff. Now it was ready to remove over from the skeleton mold.
4) Inner surface was examined. And some minor cracks were filled using polyester putty. Smooth finishing was obtained by applying gelcoat on the inner surface of the negative mold.

4.4.2 Main product

1) Gelcoat was applied on inner surface of negative mold two times. And one layer of varnish was also sprayed.
2) Bidirectional FRP glass mat was used for first two layers, then to gain required strength chopped FRP was used at the corners. LY556 epoxy resin was used as binding material.
3) After 30 min. the main product was removed out of the negative mold.
4) Clear coat and varnish were used for smooth surface finishing of the nose.

Fig -18: Main product after surface finishing.

4.5 Final Product :

1)Vinyl wrapping was used for improving aesthetics looks and vinyl sticker were designed using Coral draw software. Coral draw software is useful for making proper cutout of the vinyl wrap designs. And the design are obtained by vinyl laser cutting work.
2) The vinyl wrap was pasted on the main product using heat gun. Heat gun was used because it eliminates the wrinkles formation on the surface and gives proper, smooth and continuous finishing to the bodyworks.
3) Vinyl wrap was selected over Paint because of less weight property.

New approach towards manufacturing of bodywork was implemented. And as in the figure below, successfully attempt of designing Bodyworks was completed.

Fig -19: Final nose with vinyl wrap and stickers.

4.6 Assembly of Bodyworks

Following methods are used for the assembly of bodyworks.

1) Nut bolts.
2) Zip tie.
3) Pop Rivet.

Pop Rivet were used for assembling the bodyworks with chassis. It is easy to attach or detach. As it saves times and remains attached to the body panels after removal of panels. Comparatively the weight is saved and also cost efficient.

Fig -20: Pop Rivet.

5. CONCLUSIONS

In this research paper, Bodywork has been designed using Generative Design Function and being solidified by using part design. In order to make the analysis more effective and accurate results, complete bodywork analysis was carried out through CFD simulation. And perform stepwise experimentation as we discussed in this paper. Implementation of new approach towards manufacturing of bodywork is also explained in detailed.

ACKNOWLEDGEMENT

The authors would like to thank Team Redline Racing to help them implementing this design part on the car.

REFERENCES

[1] SAE SUPRA 2015 Rulebook.

[2] Race Car Vehicle Dynamics by W. Milliken & D. Milliken 1995, Society of Automotive. Engineers (SAE)

[3] http://www.moldedfiberglass.com/materials/reinforcements (Accessed: 05/06/2020; 2250 hrs. IST)

[4] Automobile Engineering by Kripal Singh (Vol-I and II)

BIOGRAPHIES

Ruturaj R. Mane
The Author is currently in the third year of bachelors of Mechanical Engineering from the JSPM'S RSCOE Pune, India. Author is passionate about aerodynamic and graphic design of Automobile.

Shubham R. Garde
The Author is currently in the final year of bachelors of Mechanical Engineering from the JSPM'S RSCOE Pune, India. Author is passionate about Automobiles, and interested in Designing and Manufacturing.

Omkar C. Taru
The Author is currently in the third year of bachelors of Mechanical Engineering from the JSPM'S RSCOE Pune, India. His interest include mechatronic works and Products Design.

Pravin S. Jadhav
The Author is currently in the Final year of bachelors of Mechanical Engineering from the JSPM'S RSCOE Pune, India. The Author is interested in Product design using modeling software's.