# Design and Analysis of Human Powered Vehicle

**Ritwik Jain[1], Aryabrinth Chakravorty[2], Yashraj Dhanare[3]**

[1]*Student, Dept. Of Mechanical Engineering, NMIMS MPSTME College, Maharashtra, India*
[2]*Student, Dept. Of Mechanical Engineering, NMIMS MPSTME College, Maharashtra, India*
[3]*Student, Dept. Of Mechanical Engineering, NMIMS MPSTME College, Maharashtra, India*

---

**Abstract -** *Over the recent years, the need for vehicles that have greater efficiencies along with minimal carbon footprint have arisen significantly which led to increase in demand for Human Powered Vehicle such as bicycles. In this project we have designed a Human Powered Vehicle which can act as an alternative to conventional bicycles, additionally providing better comfort, higher speed and maximum safety. The objective was to find a solution for sustainable transportation for short distances. Our vehicle has been designed as semi recumbent and includes front wheel drive mechanism with 8 speed gear transmission, both front and rear brakes along with a meticulously designed fairing. The vehicle has a carbon fiber structural chassis with 3mm thickness; it has been designed in such a way that it reduces stress concentration and bends thus allowing the manufacturing of precise fixtures that can be used to construct multiple frames quickly and efficiently. The fairing weighs 12kg (118N) and the vehicle weighs 8kg (without fairing). A combination of experimental and analytical tools was used to design a safe, practical bicycle. The vehicle is designed and analyzed with the aid of CAD tools such as Solid Works 2020, and analysis package ANSYS 2020 R1.*

***Key Words***: Human Powered Vehicle, Front wheel drive Mechanism, Carbon fiber, Design, Analysis, Solid Works 2020, ANSYS 2020 R1.

## 1. INTRODUCTION

The vehicle has been designed after diligent evaluations of the designs and materials and the best available option has been selected. The design of the vehicle has been done on Solid Works 2020 and to ensure the safety and integrity of structure different analysis has been done on ANSYS 2020 R1. Aerodynamic analysis has been carried out to provide a vehicle with aerodynamic fairing which will be useful at high speed.

## 2. ALTERNATIVES AND EVALUATION

The basic layout of the vehicle is selected with the help of evaluation of alternative designs. All the various alternatives were considered for different options available and were then compared using a scoring system on various criteria and the best option is chosen in table-3.

### 2.1. Drivetrain configuration

Drivetrain configuration is an important parameter to be considered as it affects the overall power that can be delivered along with the complexity of the vehicle. Front wheel drive and rear wheel drive were compared on the basis of efficiency, weight, complexity of assembly, traction in table-1. Front wheel drive was selected as it provides better efficiency and reduces the overall weight of the drivetrain of the vehicle.

**Table -1:** Drivetrain Configuration

| | **Efficiency** | **Weight** | **Complexity** | **Traction** | **Total** |
|---|---|---|---|---|---|
| **Front wheel drive** | 5 | 4 | 3 | 3 | 15 |
| **Rear wheel drive** | 3 | 3 | 4 | 4 | 14 |

### 2.2. Vehicle style

Vehicle style decides the number and configuration of wheels that will be used and also affects the overall weight and handling. We considered three main types of HPV; 2-wheel, tadpole, delta. They were compared on the basis of stability, weight, maneuverability in table-2. Two-wheel design was chosen for superior maneuverability, and lower weight.

**Table -2:** Vehicle Style

| | **Stability** | **Weight** | **Maneuverability** | **Total** |
|---|---|---|---|---|
| **2-wheel** | 4 | 5 | 5 | 14 |
| **Tadpole** | 5 | 4 | 4 | 13 |
| **Delta** | 5 | 4 | 3 | 12 |

### 2.3. Rider positioning

Rider positioning deals with the safety and the power that can be delivered by the rider. Recumbent, semi recumbent and upright were compared for stability, safety, power delivery in table-3. Semi-Recumbent position selected as it provides more safety to the rider and has more power delivery and provides better performance ergonomically.

**Table -3:** Rider positioning

| Positions | Stability | Safety | Power delivery | Total |
|---|---|---|---|---|
| **Recumbent** | 3 | 4 | 4 | 11 |
| **Upright** | 3 | 3 | 4 | 10 |
| **Semi-Recumbent** | 4 | 4 | 5 | 13 |

## 2.4. Material

Material is one of the most important parameters to be selected and it majorly affects the total weight and cost of manufacturing. The materials considered were Aluminum 6063, AISI 4130 Chromoly, and Carbon fiber. They were then compared on the basis of cost, strength, weight, ease of use, etc. in table-4.

**Table -4:** Materials

| Material | Cost | Strength | Weight | Ease of use | Accessibility | Total |
|---|---|---|---|---|---|---|
| **Aluminum 6063** | 4 | 2 | 4 | 3 | 3 | 16 |
| **4130 Chromoly** | 4 | 4 | 3 | 4 | 3 | 18 |
| **Carbon fiber** | 3 | 5 | 5 | 3 | 3 | 19 |

## 3. DESIGN DESCRIPTION

We started our designing process by researching and fixing some parameters like wheelbase and ground clearance and then we started working on the design of main frame, the center line of our main frame is spline which help in optimizing the shape of vehicle and reduce stress concentration points all over the body, rather than straight line with fillets we optimized our vehicle design for better ergonomics and structural strength. Also, after finalizing the design of main frame, we compared rectangular, circular and elliptical cross section it is observed that elliptical cross-section has the highest bending strength and differing major and minor axis structural properties, in addition we have used multi cross sections as can be seen in figure, it is done to reduce the overall weight of the frame and for the better usage of material (fig-1). We have applied more material at critical points and joints. Carbon fiber provides us freedom to build a vehicle with multiple cross sections.

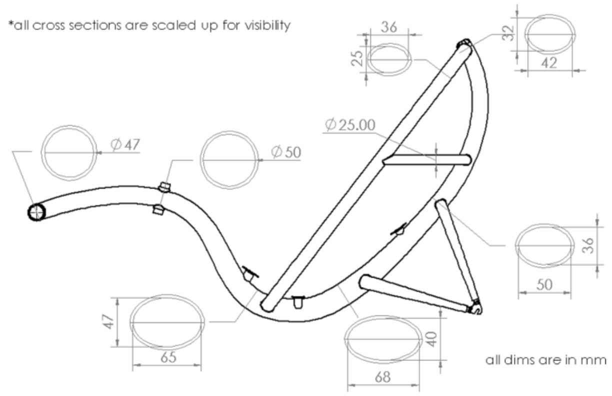


**Fig –1:** Cross-Sectional Dimension

## 4. MATERIAL

The material selected for this year's vehicle's is plain weaved carbon fiber with an epoxy matrix as it provides excellent properties such as strength and lightweight. This resulted in a light frame which has enough strength to handle all the loads that it might experience. Its increased price is justified by its advantages and it also provides. The mechanical properties and accordingly the polar properties of the carbon fiber fabric are given below.

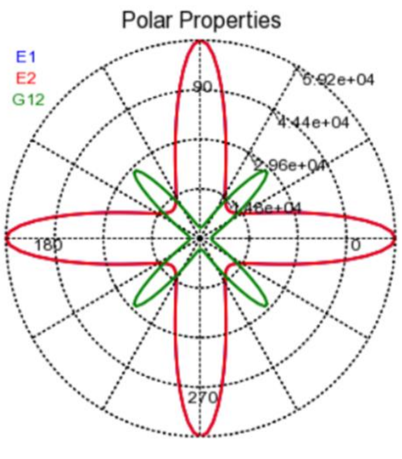


**Fig -2:** Polar Properties of Carbon fiber fabric

**Table -5:** Mechanical Properties of Carbon Fiber Fabric

| | |
|---|---|
| Density | 1.41g/cm$^3$ |
| $E_x$ | 59.16GPa |
| $E_y$ | 59.16GPa |
| $E_z$ | 7.5GPa |

| | |
|---|---|
| $G_{xy}$ | 3.3 GPa |
| $G_{yz}$ | 2.7 GPa |
| $YTS_x$ | 513 MPa |
| $YTS_y$ | 513 MPa |
| $v_{xy}$ | 0.04 |
| $v_{yz}$ | 0.3 |
| $v_{xz}$ | 0.3 |

As can be observed in table-5 this material provides high stability and rigidity thus it can absorb large amount of impact energy which help in increasing the safety of rider as well as vehicle. It can be also observed that it has least amount of density among all the available materials with same structural strength.

### 4.1 Composite Ply Structure

We have chosen a 120, 60, 0-degree ply structure as this gives superior tensile properties and the distribution is uniform as can be seen in the polar chart (fig-3). With the help of this structure, we needed to use only 3 layers on the place of conventional 4-layer structure which is 0 45 0 45, thus saving material.

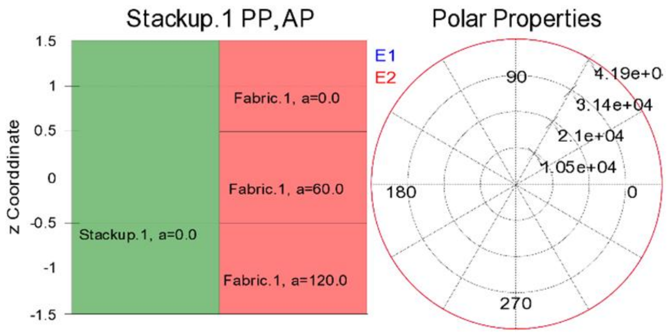


**Fig -3**: Ply Structure and Polar Properties

## 5. STRUCTURAL ANALYSIS

Different analysis has been carried out to ensure maximum safety for the rider. All the analysis was carried out on ANSYS 2020 R1. To carry on with the analysis there were some assumptions that have been made such as: Interface between metal (seat mounting points) and carbon fiber is of bonded contact type. Default fine meshing along with local mesh refinement on critical curves, eg. Fillets, was applied. Target factor of safety is 2 and maximum deflection is 5.

### 5.1 Body Weight Analysis

Body weight analysis has been carried out to analyze the structural integrity of the carbon fiber frame; to ensure that it could withstand the weight of the heaviest rider of the team (80 kg =) which was applied vertically downwards on the seat mounts.

Head tube and rear fork were considered as fixed points.

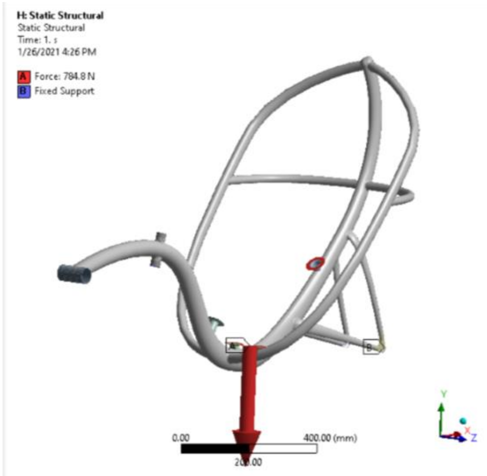


**Fig -4**: Load constraints

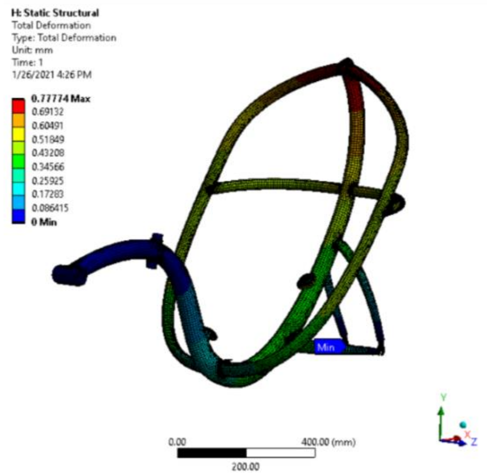


**Fig -5**: Deformation

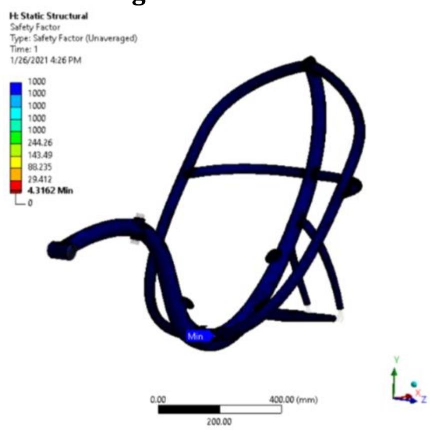


**Fig -6**: Factor of Safety

*Results:*

- *Maximum elastic deformation after applying a weight of 80 kg is observed to be 0.777 mm.*

- *Factor of Safety is 4.3162.*

### 5.2. Bottom Bracket Analysis

Bottom Bracket Analysis has been carried out to ensure structural integrity of the bottom bracket when the expected maximum force on pedal is applied.

The assumed maximum pedaling force is taken as 300N. For analysis moment of 52500 N-mm is applied on the bottom bracket in ant-clockwise direction. Moment is calculated by the formula: Moment = Pedal force x crank length = 300*175mm = 52500 N-mm.

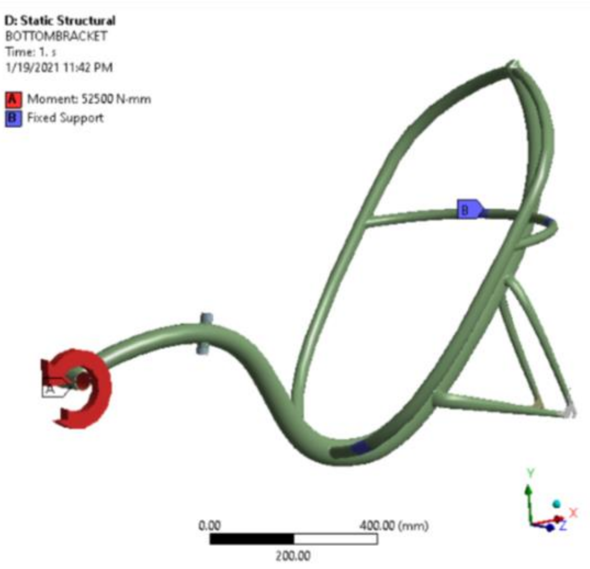


**Fig -7** Load constraints

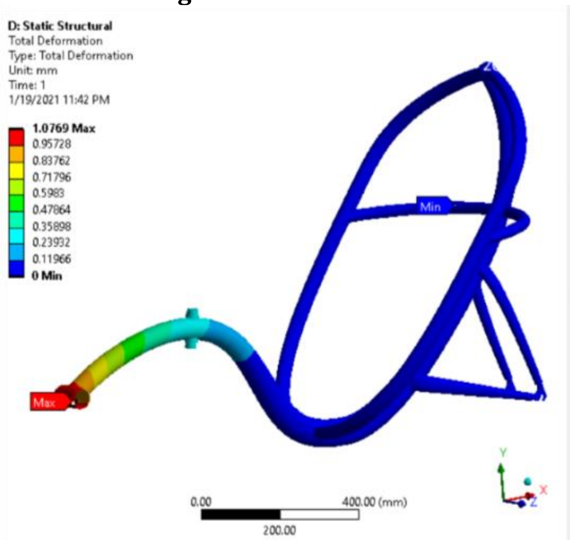


**Fig -8** Deformation

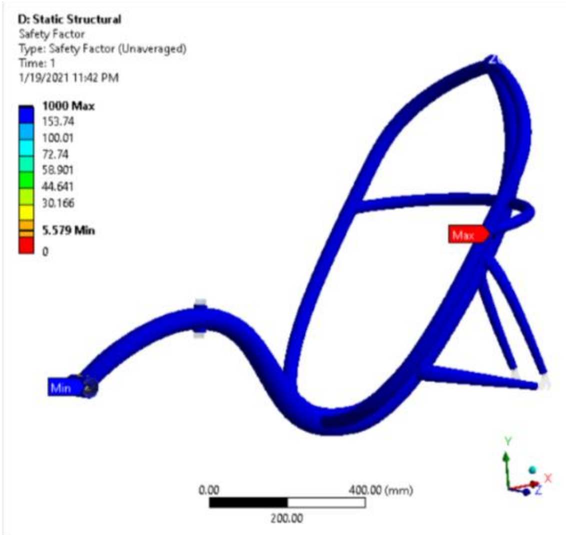


**Fig -9** Factor of Safety

*Result*

- *Maximum elastic deformation is 1.0769 mm.*
- *Factor of safety is 5.579.*

### 5.3 Bump Analysis

Bump Analysis has been carried out to check the structural integrity during a bump. A force of 981 N was applied on the head tube in the vertically upward direction. Seat belt mounting points were considered as fixed points.

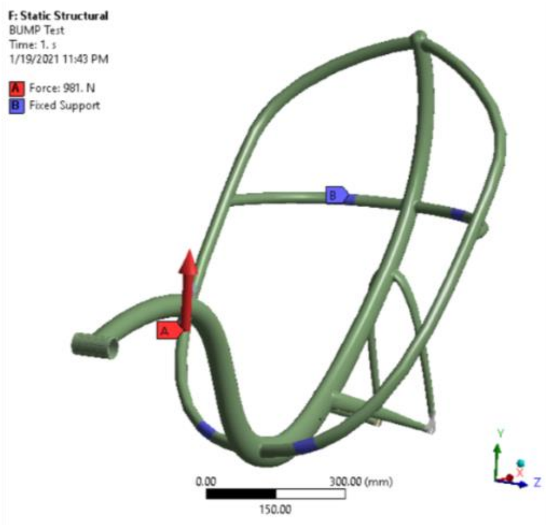


**Fig -10** Load constraints

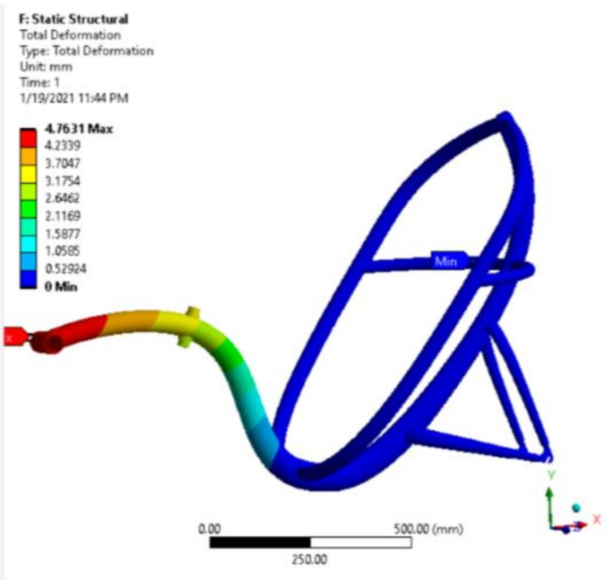


**Fig -11** Deformation

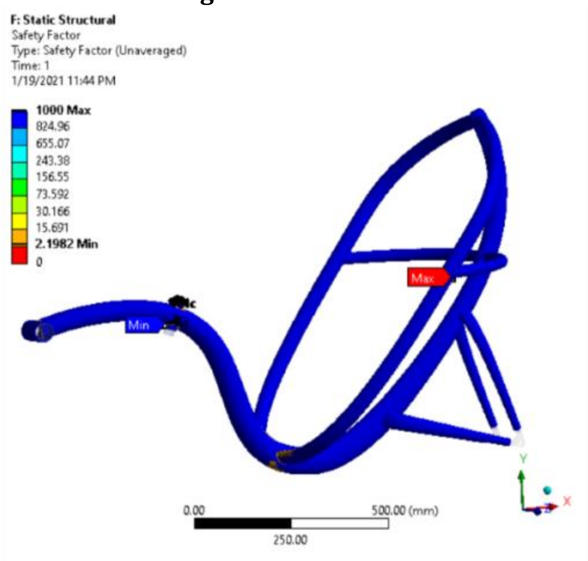


**Fig -12** Factor of Safety

*Result*

- *Maximum elastic deformation is 4.7631 mm due to bump.*
- *Factor of safety is 2.198*

## 5.4 Side Impact Analysis

Side Impact Analysis has been carried out to check the structural integrity during side impact. This is the impact on the first point of contact when the vehicle is tilted sideways during inspection or when the vehicle undergoes failure during crash or accident; the force exerted is 100kg to be on the safe side.

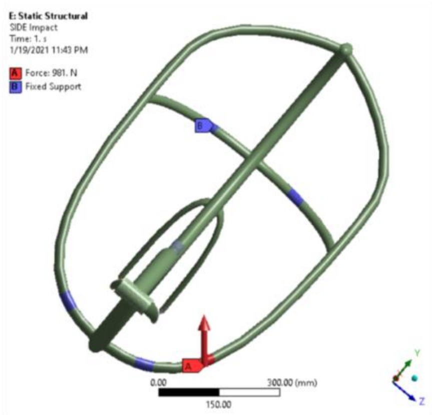


**Fig -13** Load constraints

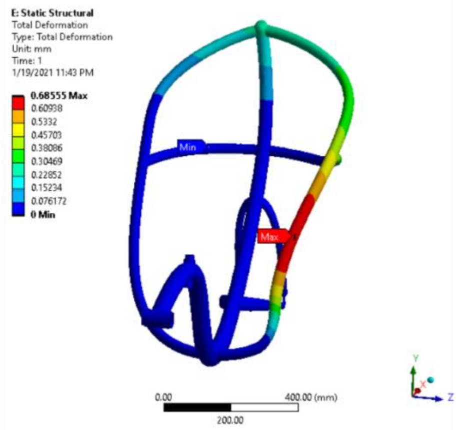


**Fig -14** Deformation


**Fig -15** Factor of Safety

*Result*

• *Maximum elastic deformation was observed to be 0.6855 mm.*

• *A minimum factor of safety is 5.879*

## 6. AERODYNAMIC ANALYSIS

Flow simulation was tried on the bare frame with the rider to analyze the air flow and calculate the drag, this was done via Solidwork's Flow Simulation. For the meshing of the fluid volume, local mesh was done with 4 level of refinement which help in accurate yet fast solution. For the general setting of the flow simulation, the walls were considered to be adiabatic and the surface roughness of 500 µm, along with the surrounding temperature of 25°C and a global pressure of 1 atm, and lastly max flow speed of 40km/h (11.11m/s) was considered. This setup was used for all the flow analysis and the velocity contours were noted.

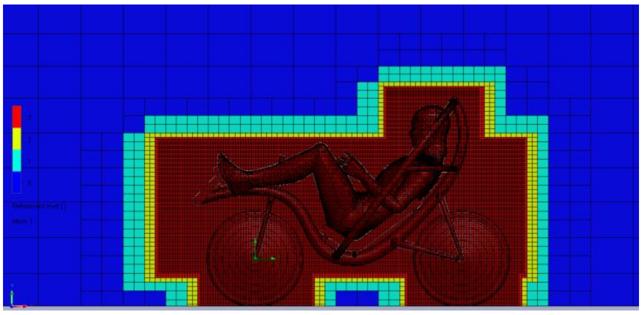

**Fig -16***:* Meshing in solidworks flow simulation.

Observing the bare model air drags 3 different fairing were modeled which are most commonly used and can be manufactured and then aerodynamic analysis of these fairings was carried out to determine the design which have the least amount of drag.

**Fig -17***:* HPV without fairing, the drag came out to be 17.567N

To calculate the reduction in drag HPV without any aerodynamic device has been analyzed (fig-17) and drag is noted down which came out to be 17.567N

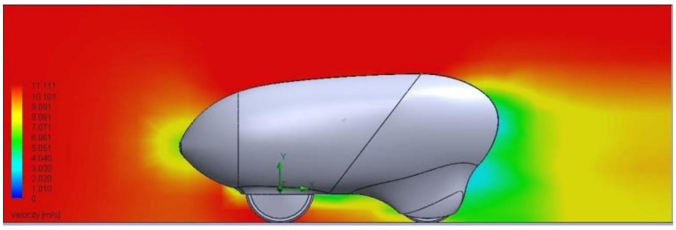

**Fig -18***:* HPV with TORPEDO fairing, the drag came out to be 12.562N

Next, analysis is carried out on TORPEDO fairing (fig-18), this fairing design is compact and requires less material in addition with the simple design but it resulted in only small amount of drag reduction from 17.56 N to 12.56 N.

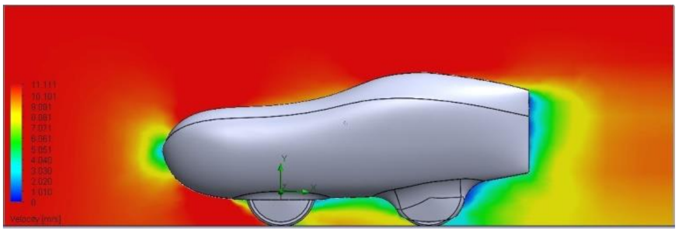

**Fig -19***:* HPV with BUBBLE fairing, the drag came out to be 8.95N

Next, analysis is carried out on BUBBLE fairing (fig-19), this fairing design is having superior aerodynamics along with more leg space for driver and it resulted in significant amount of drag reduction from 17.56 N to 8.95 N.

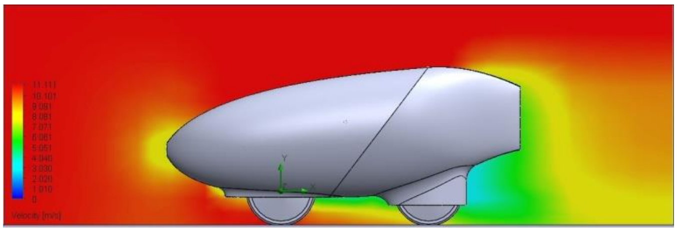

**Fig -20***:* HPV with WEDGE fairing, the drag came out to be 11.31N

Last analysis is carried out on WEDGE fairing (fig-20), these fairing designs is compact and has enough leg space for driver in addition with the simple design and it resulted in considerable amount of drag reduction from 17.56 N to 11.31 N

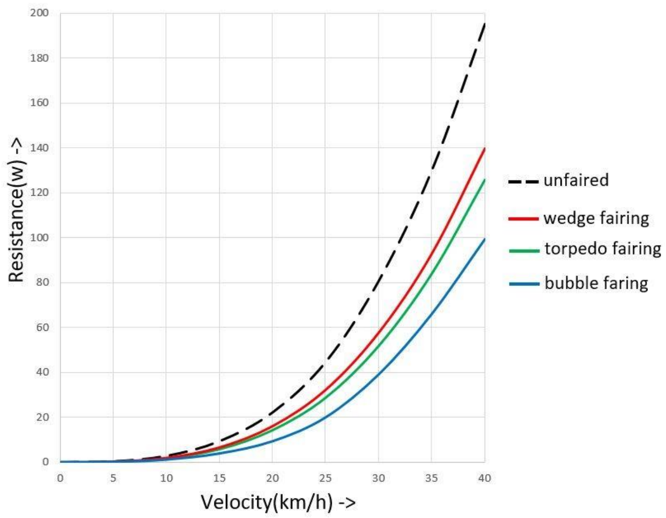


**Chart -1**: Resistance v/s Velocity Graph

The graph above shows the resistance offered by 3 designs with respect to velocity of vehicle and as observed earlier bubble fairing stands out with the least amount of drag and is correct choice for the type of fairing that should be used. With the help of above graph and analysis data the bubble fairing has been selected for the vehicle as it reduces the drag by approximately 50 percent and provide lesser resistance with increase in speed as compared to other fairings. Here is a 3 view drawing of the final vehicle with fairing (fig-21).

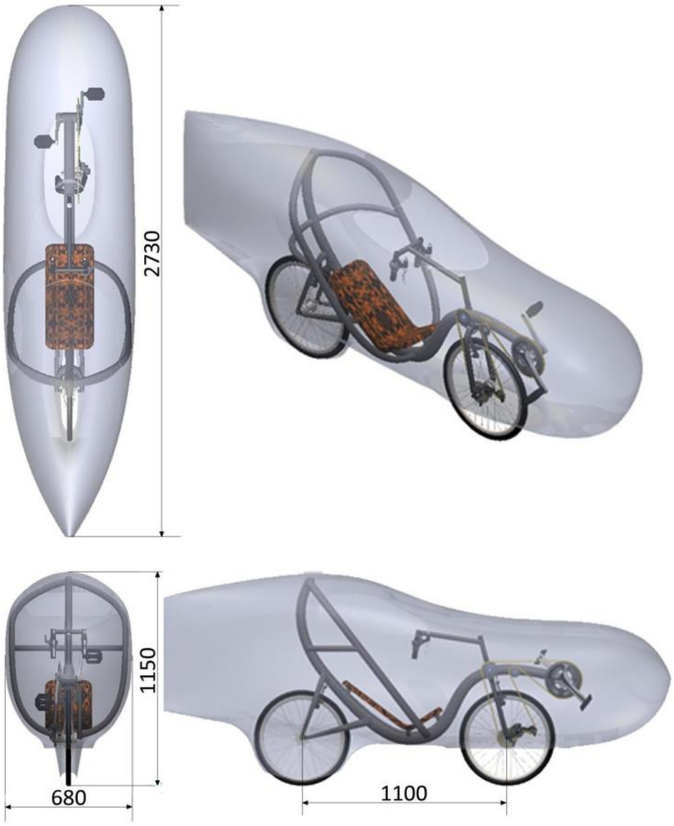


**Fig -21:** 3 view model of the vehicle

## 7. CONCLUSION

In this project, design and analysis of Human Powered Vehicle has been carried out. The design process was done very meticulously to obtain best performance and have highest safety for riders. Structural analysis results satisfy the minimum factor of safety of 2 and maximum deflection of 5mm conditions; thus, it can be concluded that the designed vehicle is safe. Aerodynamic analysis results are used to select perfect aerodynamic device for the vehicle which will help in reducing overall drag and help the driver to attain more speed with maximum safety.

## References

(1) The recumbent bicycle and human powered vehicle information center. (n.d.). The Recumbent & HPV Information Center. https://www.recumbents.com/wisil/brown/bicycleframedesign.htm
(2) Human control of a bicycle. (n.d.). figshare. https://figshare.com/articles/Human_Control_of_a_Bicycle/4244963/1
(3) (PDF) On the design of a recumbent bicycle with a perspective on handling qualities. (n.d.). ResearchGate. https://www.researchgate.net/publication/267490117_On_the_Design_of_a_Recumbent_Bicycle_With
(4) The recumbent bicycle and human powered vehicle information center. (n.d.). The Recumbent & HPV Information Center. https://www.recumbents.com/wisil/stickbike/
(5) Bike frame design – the influence of tubing diameter and wall thickness. (2020, July 13). Rolling and tumbling. https://valvejob.wordpress.com/2016/01/18/bike-frame-design-the-influence-of-tubing-diameter-and-wall-thickness/
(6) Available website. (n.d.). Available Website. https://carbonbent.bravehost.com/woodwork.html
(7) Ride Velocite, feel invincible. (n.d.). Velocite Bikes. https://www.velocite-bikes.com/?dispatch=pages.view&product_id=51
(8) A journey of discovery, Part 5: Frame stiffness. (2011, February 27). https://janheine.wordpress.com/2011/02/27/a-journey-of-discovery-part-5-frame-stiffness/
(9) (n.d.). Rose-Hulman Human Powered Vehicle Team. https://hpvt.rose-hulman.edu/design-reports/2012/2012OlinDesignReport.pdf