

## **Simulation and analysis of two wheeled upright vehicle**

**S. Chakradhar<sup>b</sup>, K. Someswara Rao<sup>a</sup>, M.V.S. Krishna<sup>b</sup>, J. Mahesh Kumar<sup>b</sup>**

*<sup>a</sup>Asst. Professor, Department of Mechanical Engineering, K L University, Vaddeswaram, Guntur Dist., A.P, India.*

*<sup>b</sup>UG Students, Department of Mechanical Engineering, K L University, Vaddeswaram, Guntur Dist., A.P, India.*

### **Abstract**

The primary objective of a human powered vehicle (HPV) is to transport its rider and the cargo safely and efficiently. A human powered ground vehicle in its most simple sense is the traditional bicycle. This paper will detail the design and development of an Upright Human Powered Vehicle which is intended to satisfy all aspects of ASME norms. Anything that transports, supports, and includes human needs to be analyzed and tested thoroughly before being put into production. Thus, physical testing was performed to ensure rider's safety and to learn unimaginative outcomes of the vehicle. The results predicted at first while designing the model were accurate in the testing of model. Its robust design, efficient transmission, elegant fabrication will be quite a fete.

The design of the HPV was guided by the mission and problem statement. The goals were set for designing the vehicle with maximum safety features and minimum possible mishaps. The modelling of HPV was carried out in SOLIDWORKS and analysis was done in ANSYS. The objective is to fabricate Ideal HPV for the normal people to use it for many different purposes. The analysis was done first theoretically and then virtually. The fabrication was also aimed to be a simple and efficient procedure. Power Transmission was also made to be the crucial stage in building the HPV. The HPV is opted to have the normal power transmission and altered with improvements. The transmission was a success as the rider was able to ride the HPV with less cadence, effort, but develop more power output theoretically.

Testing the HPV was considered to be elite aspect. So, before building the HPV each and every component, material, equipment was tested twice to ensure the safety of HPV both theoretically and practically. The results came

out as predicted with ergonomic design, speed and practicality into the HPV.

**Keywords:** Human Powered Vehicle (HPV), Bicycle, Upright, Ansys, Fabrication, Ergonomics,

## 1. INTRODUCTION

India is a fast growing nation where its primary sector of revenue is farming. That implies a farmer is the key worker for India. Farmers are generally accustomed to traditional conveyance where they have to travel long distances to farms, on uneven roads, sometimes on different terrains. In this perspective the HPV designed more resembling the traditional commuter.

This goal developed the skeleton the HPV as an upright two wheeled vehicle with possible mechanisms to eradicate traditional difficulties thereby increasing rider safety and comfort. For maximum comfort of the rider, ergonomics play major role in the design. So ergonomics was a crucial aspect in our vehicle design.

The main goals were to improve bicycle's efficiency, maneuverability, and ride-ability. We were able to finish a prototype early in order to give riders an idea of the final vehicle handling and to get feedback. As a result of this prototype, we discovered improvements to be made in our final vehicle.

The vehicle is designed specifically to be marketable solution for sprints, endurance, as well as commuting. With the onset of increasing energy costs, diminished resources, and a heightened global awareness, the demand for human powered vehicles will only continue to rise. We also increased the number and variety of performance tests. In addition to the standard FEA analysis on stress, simple methods were developed to determine the drivetrain efficiency and maneuverability of the vehicles. These tests directly informed design decisions, allowing to confidently produce an optimized vehicle design.

### 1.1 CONSTRAINTS

There were certain limits that needed to be satisfied according to ASME norms. The following are the major requirements.

- Turning radius below 8m.
- Braking from 25 to 0Kmph within 6m of distance.
- Independent and redundant braking system.
- Safety measures like rear view mirrors etc.
- Cargo carrying capacity.
- Safety harness.
- No exposed or protruded materials.
- Rider safety at all times.
- Roll bar supporting 2.67kN of top load with elastic deformation less than 5.5cm.
- Roll bar supporting 1.35kN of side load with elastic deformation less than 3.1cm.

## 1.2 OBJECTIVES

The aim and goal is to meet the constraints. So, in that perspective we made the below objectives.

- To produce a marketable HPV which can be used for lay men in particular.
- Minimum weight & Maximum Stability.
- Minimum fabrication tolerances and Maximum rider practice time.
- Utmost rider power output and safety.
- Aesthetically pleasing and highly Economical.

## 1.3 DESIGN SPECIFICATIONS

- Two wheeled Upright HPV.
- Conventional resemblance and maximum safety.
- Ergonomic model as to give more comfort to the rider.
- To achieve a normal speed of 35Kmph.
- 18 speed gear train (3 front & 6 rear sprockets) for effective power transmission.
- Seat adjuster and self-suspension seat rest.
- External suspension to increase the rider comfort.
- Robust Roll over Protection System in case of accidents.

All of existing vehicles have used thin-walled steel tube, but other materials would be somewhat lighter or provide different structural characteristics. Standard 6061-T6 aluminum tubes, for example, provide the same tensile strength as our 4130 steel tubes with about half the weight. Another option we discovered with some research was the use of carbon fiber as a frame material. Carbon has the strength and weight properties prized by bicycle makers; the only difficulty comes in using carbon fiber as our main material is more expensive, more difficult to manufacture, has longer processing times (due to curing of epoxy), requires more planning and preparatory work, and involves more complex analysis in order to achieve the maximum benefits offered by the material. However, these difficulties can be worth the extra considerations for such a substantial increase in performance. The material for the HPV was decided on the basis of material analysis.

**Table 1:** Decision Matrix for Material Selection (1-low and 5-high).

CRITERIA	MILD STEEL	ALUMINUM	CHROMOLY	CARBON FIBRE
Rigidity	4	2	5	3
Yield Strength	3	2	4	5
Machinability	5	2	3	1
Availability	5	4	3	2
Cost Efficiency	5	4	2	1
Weight	4	2	4	1

Table 1 provides a summary of the properties for candidate materials. Compared to steel, aluminum has the same specific modulus, while also having a density of just

over one third. Thus, potentially a frame built out of aluminum could be stiffer and lighter than a frame built of steel. Aluminum is lighter than an equivalent steel frame, but similar in cost. Unfortunately, Aluminum also has more problems with fatigue failure than steel. This leaves us again with steel, not the lightest material, but available at reasonable cost and easily welded by inexperienced welders.

After careful analysis of the material study, Mild Steel was picked up as our HPV material. Following table gives scope to choose the type of Mild Steel.

**Table 2:** Decision Matrix for type of Mild Steel.

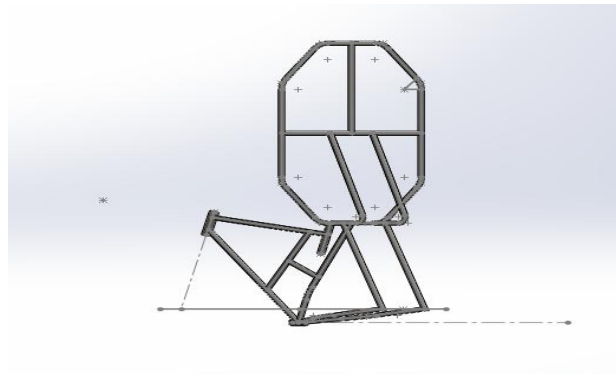
CRITERIA	Mild Steel Cold Rolled	Mild Steel Hot Rolled
Tensile Strength	67000 psi	85000 psi
Yield Strength	45000 psi	70000 psi
Reduction of Area	58	55
Elongation in 2"	36	28
Brinell Hardness	137	167
Manufacturing Tolerances	Very less	Very high
Surface finish	Very high	Very less

So, for the above reasons and requirement, the material opted for the HPV was Mild Steel Cold Rolled.

## 2. DESIGN PROSPECTS

Upon careful examination and thorough research very good design prospects were generated to be made into HPV. The HPV should be elite and light. It should resemble the natural conveyance to forbid the hesitance of the normal people to ride the HPV. It should have less no of links along with a toughest frame. The RPS should itself look safe and give gesture of assurance to the rider. After many design prospects and possible alterations, Final Frame design is as follows.

### 2.1 FRAME DESIGN



**Figure 1:** model frame for the cycle

- The RPS shape is Octahedral, giving strength and correcting the impact points to impact surface which was a major make shift to the design resulting in good outputs. The RPS material dimensions are 1" X 1.6mm.
- The Joint was cut out, the seat tube and down tube were attached to head tube separately in order to decrease the stresses. The main frame material dimensions are 1.25" X 2mm.
- The self-suspension concept is satisfied as the top tube behaves as a cantilever beam giving a chance to seat to oscillate.
- The chain stay is attached to the hub in a way that the chain stay can absorb some of the jerks, impulses etc., and giving comfort to the rider.
- There are two suspension springs which are placed at the support members extending from back wheel sprocket to the RPS. Except frame & RPS, all parts are standardized.
- This is a perfect ergonomic and an efficient aesthetic design.

This design is the best of all the prospects as it suffices the objectives and mission without compromising at any extent of engineering principles.

### 3. TRANSMISSION

For a vehicle to pace forward, the most important and crucial part is the method opted for transmission of power. An effective power transmission implies appropriate power multiplication between the pedal crank and tire hub as per requirement at that particular situation and it is apt to say that the vehicle may succeed or become a failure solely depending on the power transmission. Thus the selecting of the power transmission gears is very important.

By considering all the advantages and disadvantages of chain drive and belt drive, chain drive is the best suitable for almost all the bicycles in this world, because the major factor is that it should operate under high loads, fluctuating temperatures and in moisture conditions, there should be no slippage and friction should be less between the components. Therefore all the bicycles in today's world use chain drives. Chain drive is the basic feature of bicycle design today.

#### 3.1 CHAIN DESIGN

$L_n$  = number of links in the chain

$$L_n = 2(a/p) + (z_1 + z_2/2) + ((z_2 - z_1/2\pi)^2 * p/a)$$

a = center distance b/w axes of driving and driver sprockets (mm)

$z_1$  = no. of teeth on smaller sprocket

$z_2$  = no. of teeth on larger sprocket

P = pitch

Let's consider gear combination of 42\*11

According to the bicycle design

a = 500mm,  $z_1$  = 11,  $z_2$  = 42, p = 12.7mm

By substituting all the values

Therefore  $L_n = 105.85$  ..... approx. 106 links in the chain

**Length of the chain (L) =  $L_n * p = 1346.2 \text{ mm} = 53 \text{ inches}$  &  
**42 teeth sprocket****

Pitch diameter = 170.013 mm

Outside diameter = 177.11 mm

**11 teeth sprocket**

Pitch diameter = 45.083 mm

Outside diameter = 50.872 mm

Sprocket thickness = 2.794 mm

### 3.2 Expected Performance of the Vehicle

Drag test is the one which requires high speed for motion and this can be achieved with the gear combination f1-r1 (42\*11) at a cadence 120 rpm as specified above. The six rear sprockets no of teeth are 11, 13, 15, 17, 20 and 23. The three front sprockets no of teeth are 42, 32 and 22.

The endurance test requires slow movement. The problem is that the slower the speed of motion the more is chance of falling down. So we need to have a healthy cadence but still the speed must be less. This could be achieved by the gear combination f3-r6 (22\*23) at a cadence 50 rpm. In the stability test too there would be a problem of the vehicle falling down hence the correct gear combination is to be selected in order to avoid the fall.

### 3.3 Calculations

Circumference of rear wheel =  $2 * \pi * r = 2.09 \text{ m}$  ..... (r = 13 inches)

When the vehicle is at maximum transmission

Highest gear ratio =  $42 * 11 = T_1 / T_2 = 42 / 11 = 3.81$

Distance travelled for 1 cadence = 7.9629 m

Average cadence of vehicle = 50 rpm

Then, distance travelled by vehicle for 50 rpm =  $398.1 \text{ m/min} = 23887 \text{ m/hr} = 23.887 \text{ km/hr}$

When the vehicle is at minimum transmission

Less gear ratio =  $22 * 23 = T_1 / T_2 = 22 / 23 = 0.956$

Rear wheel circumference = 2.09 m

Distance travelled for 1 cadence = 1.998 m

Average cadence of vehicle = 50 rpm

Distance travelled by vehicle for 50 rpm = 5.99 km/hr

To achieve the expected top speed of the HPV i.e., 50 km/hr

For highest gear ratio

Distance travelled for 1 cadence = 7.9629 m

$50 = (7.9629 * x * 60) / 1000$

Cadence of vehicle for 50 km/hr =  $x = 105 \text{ rpm}$

For less gear ratio

Distance travelled for 1 cadence = 1.998 m

$50 = (1.998 * x * 60) / 1000$

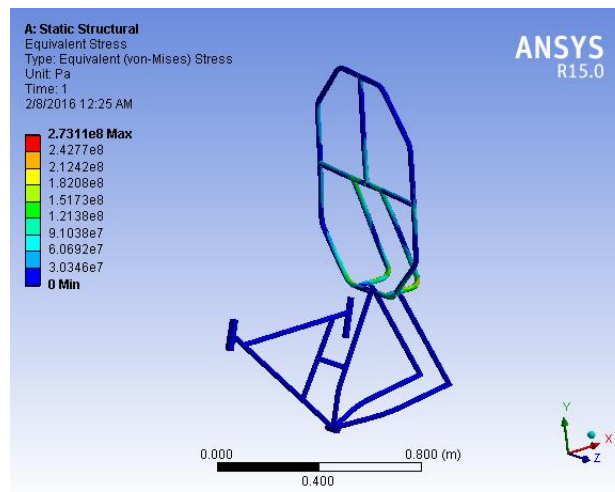
Cadence of vehicle for 50 km/hr =  $x = 417 \text{ rpm}$

#### 4. ANALYSIS

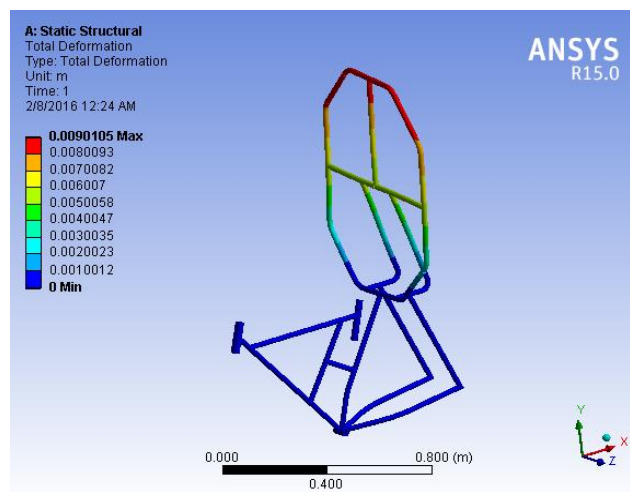
For any object the procedure is first design, then the very next step is to analyze its capacity and capability according to the constraints. Until and unless the analysis results are satisfactory, the design will not make up to the fabrication. The HPV was tested and analyzed especially on the three categories. Virtual way of analysis is performed after a clear and sound theoretical analysis using the Mechanics of Materials.

##### 4.1 Roll over Protection System ANALYSIS

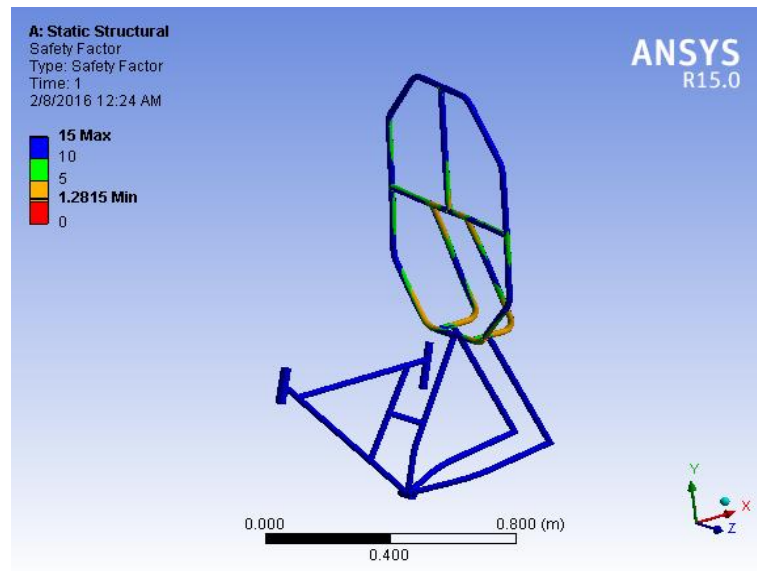
The sole purpose of RPS analysis is to ensure the safety of the rider in the case of any mishaps where the vehicle topples onto the ground experiencing an impact force of 2670 N. The results were



**Figure 2:** Von- Mises Stresses developed upon 2670N top loading towards aft

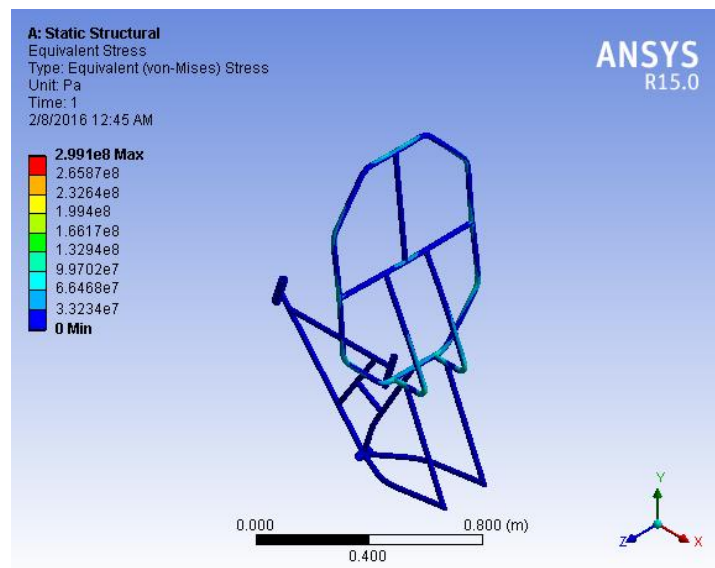


**Figure 2:** Total Displacement of 0.9cm upon top loading of 2670N towards aft



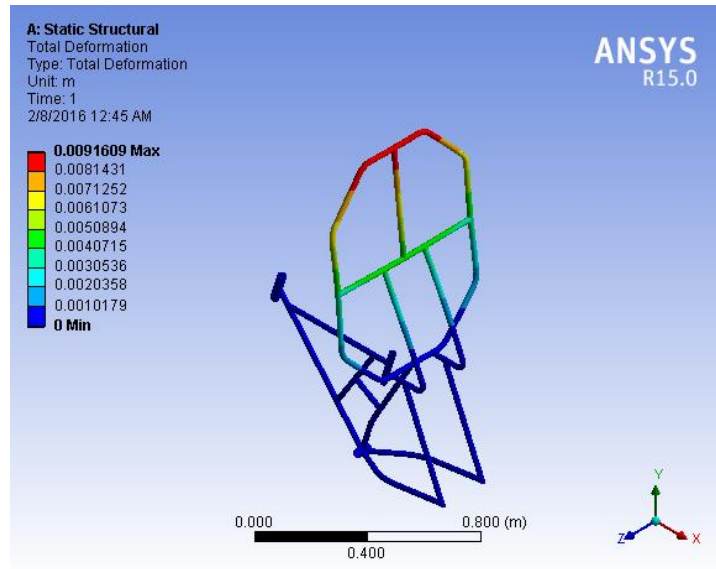
**Figure 3:** A Factor of Safety of 1.28 achieved upon top loading 2670N towards aft

Toughness of HPV is analyzed when it is hit sideways subjecting to a force of 1350N.

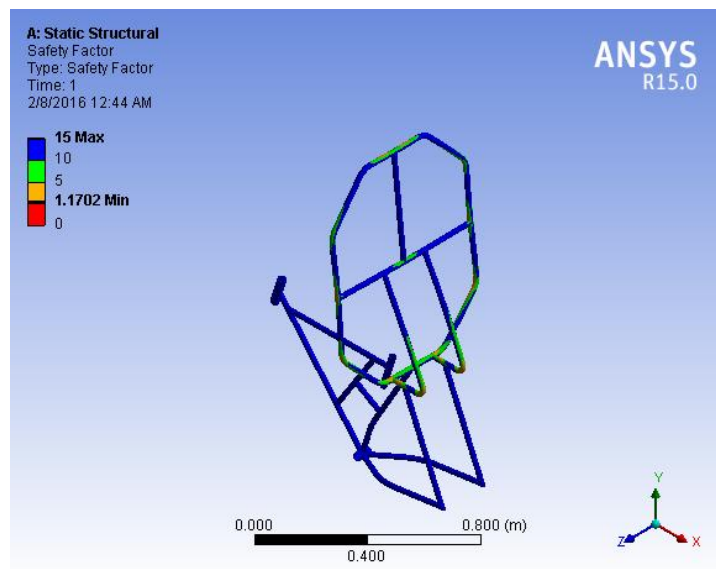


**Figure 4:** Von-Mises Stresses developed upon side loading of 1350N





**Figure 5:** Total Displacement of 0.91cm upon side loading of 1350N



**Figure 6:** A Factor of Safety of 1.17 achieved on side loading of 1350N

The results were under the permissible limits.

Top loading of 2670N towards the aft

Maximum Stress endured = 273.1 MPa (<310MPa)

Maximum Displacement = 0.9cm

Minimum FOS = 1.28

Side loading of 1350N on the surface

Maximum Stress endured = 299.1 MPa (<310MPa)

Maximum Displacement	= 0.91cm
Minimum FOS	= 1.17

#### 4.2 COST ANALYSIS

The target area of HPV development is the rural people who are economically low. So, vehicle was made highly economical and can be easily purchased by common man.

TOTAL COST for one vehicle = Rs.9, 160

### 5. TESTING

#### ROLL OVER PROTECTION SYSTEM

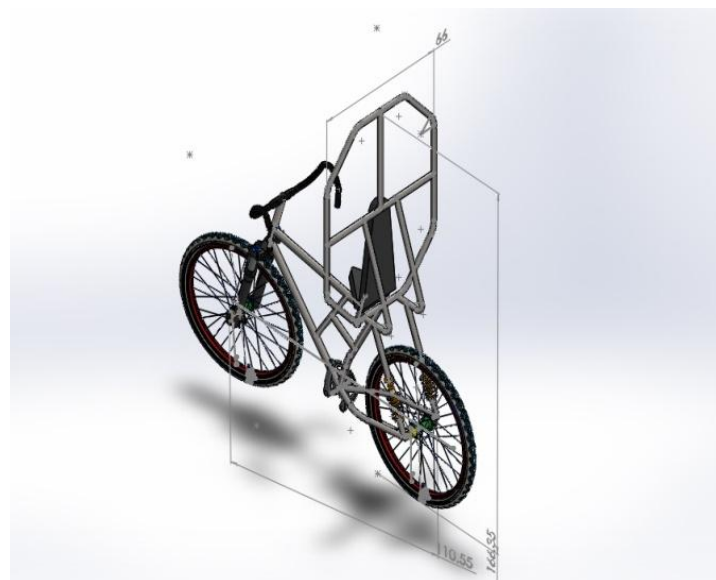
Though the results predicted by FEA, as validated by our previous experience with standard materials, analysis of composites creates an abstraction away from the real world in assuming uniform construction. This major flaw can produce erroneous results which, given the implicit relationship between rollover protection system and rider safety, necessitates real-world testing. Specifically worrisome is the crumpling and intense deflection composite construction can undergo, both of which would endanger riders. So, Roll Protection System (RPS) still needs testing.

As per ASME safety rules, load testing was done on the final roll bar in addition to FEA analysis. the roll bar was manually loaded with dumbbell weights suspended on a wood platform. The FEA predicted a 0.9cm maximum displacement of the roll bar under top loading, and a 0.9cm displacement under side loading. The height of the roll bar was measured before, during, and after each loading in order to measure the deflection and determine if the deformation was elastic. The top displacement along the Z axis of the HPV to be 1cm in top loading and the displacement along the X axis of the HPV to be 1cm in the side loading was measured. These numbers are consistent with the predicted values and thus both below the allowable deflections. For the vertical load test, the bicycle was tilted until the wheelbase was 12° off the horizontal in order to ensure that the vehicle could withstand critical moments. Then a load of 270kg was placed on a platform suspended from the top of the roll bar as dictated in the rules. The roll bar expanded at

the corners in the horizontal direction and tilted backwards, but both displacements were under the 0.5" maximum allowable deflection, verifying computational results. After unloading, the roll bar returned to its original shape and original height as measured before and after testing with no visible damage to the structural integrity, indicating that the roll bar deformation was within the elastic region on the stress strain curve for steel. The success of this test confirms the conclusion in the roll bar analysis section that the stresses shown above the yield stress were a function of the uncertainties of FEA and not a weakness in design. To test the side loading, a load of 133kg was placed on the side bar at shoulder height. The measured displacement due to loading was 1cm and the roll bar returned to its original measured height once unloaded. These results were once again well within the allowed displacement and consistent with the FEA.

## **6. SAFETY**

Rider safety was an important constraint in all design decisions hence; all components, vehicle systems, and manufacturing methods were evaluated for their safety mechanics prior to implementation. Safety of the rider is held paramount when considering any of the components that make up the vehicle. The design also specifically addresses some of the known hazards; thereby the mounting system was designed to ensure that the rider is protected in the event of a crash. Fairing materials were selected to ensure that any vehicle damage would not create hazardous conditions within the vehicle. Stability improvements help the rider to avoid crashing. The Rollover/Side Protection System was designed to the ASME HPV specification and can support at minimum a 2670N at 12 degrees from vertical with a maximum of two inches of deformation as well as a 1330N on the side with less than one and half inches of elastic deformation. The RPS bar forms a large loop above the head of the rider which is robust enough to insure that, in the event of a rollover, the rider remains safely in the envelope that's created by the RPS and the wheels/pedals. There is a strong seat belt system to enhance the safety of the rider at any mishaps. The rider's field of view has been designed to ensure that they can see their surroundings and react to them. To help the rider communicate their intentions and make their presence known to other vehicles and pedestrians, standard equipment such as headlights, taillights, brake lights, turn signals, side reflectors, have been installed.



**Figure 7:** Final Model of Upright vehicle

## **7. CONCLUSION**

The goals were very distinguished and affirmative so as the results. The objectives were satisfied sufficiently to engender a HPV. A look through of our objectives and results.

OBJECTIVES	RESULTS
To produce a marketable HPV that can be used for laymen in particular.	Conventional look and ease of access of HPV
Minimum weight & Maximum Stability.	Weight < 20Kg. The wheelbase to height ratio is maintained in such a way to give maximum stability to HPV
Utmost rider power output and safety.	The design gave maximum safety results showing FOS of 1.20. The rider can achieve 50KMPH speed easily.
Aesthetically pleasing and highly Economical.	The aesthetic look was the feature on which the team never compromised, So the HPV is aesthetically extraordinary. The cost analysis is made and the total vehicle cost is

### ACKNOWLEDGEMENT

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