ASME SETTING THE STANDARD http://go.asme.org/HPVC	# Vehicle Description Form (Form 6) Updated 12/3/13 ## Human Powered Vehicle Challenge ## Competition Location: VIT UNIVERSITY,Vellore ## Competition Date: 17-19th February'2016

This required document for all teams is to be incorporated in to your Design Report. Please Observe Your Due Dates; see the ASME HPVC for due dates.

Vehicle Description

School name: VELLORE INSTITUTE OF TECHNOLOGY

Vehicle name: ASHV

Vehicle number 11____

Vehicle configuration

Upright _______ Semi-recumbent x_______

Prone _______ Other (specify) _______________

Frame material Aluminum 6063 T6 and Aluminum 6061 T6

Fairing material(s) Fiber Reinforced Plastic

Number of wheels 2

Vehicle Dimensions *(please use in, in^3, lbf)*

Length 97.33 in Width 24.43 in

Height 49.19 in Wheelbase 52.42 in

Weight Distribution Front 35.86% Rear 64.14% Total Weight 100%

Wheel Size Front 20 in Rear 26 in

Frontal area $0.4\ m^2$

Steering Front x___ Rear _______

Braking Front _______ Rear _______ Both x Estimated Cd 0.27

VELLORE INSTITUTE OF TECHNOLOGY

2016 ASME India HPV Challenge

Design Report

TEAM ANANT

Presents

ASHV

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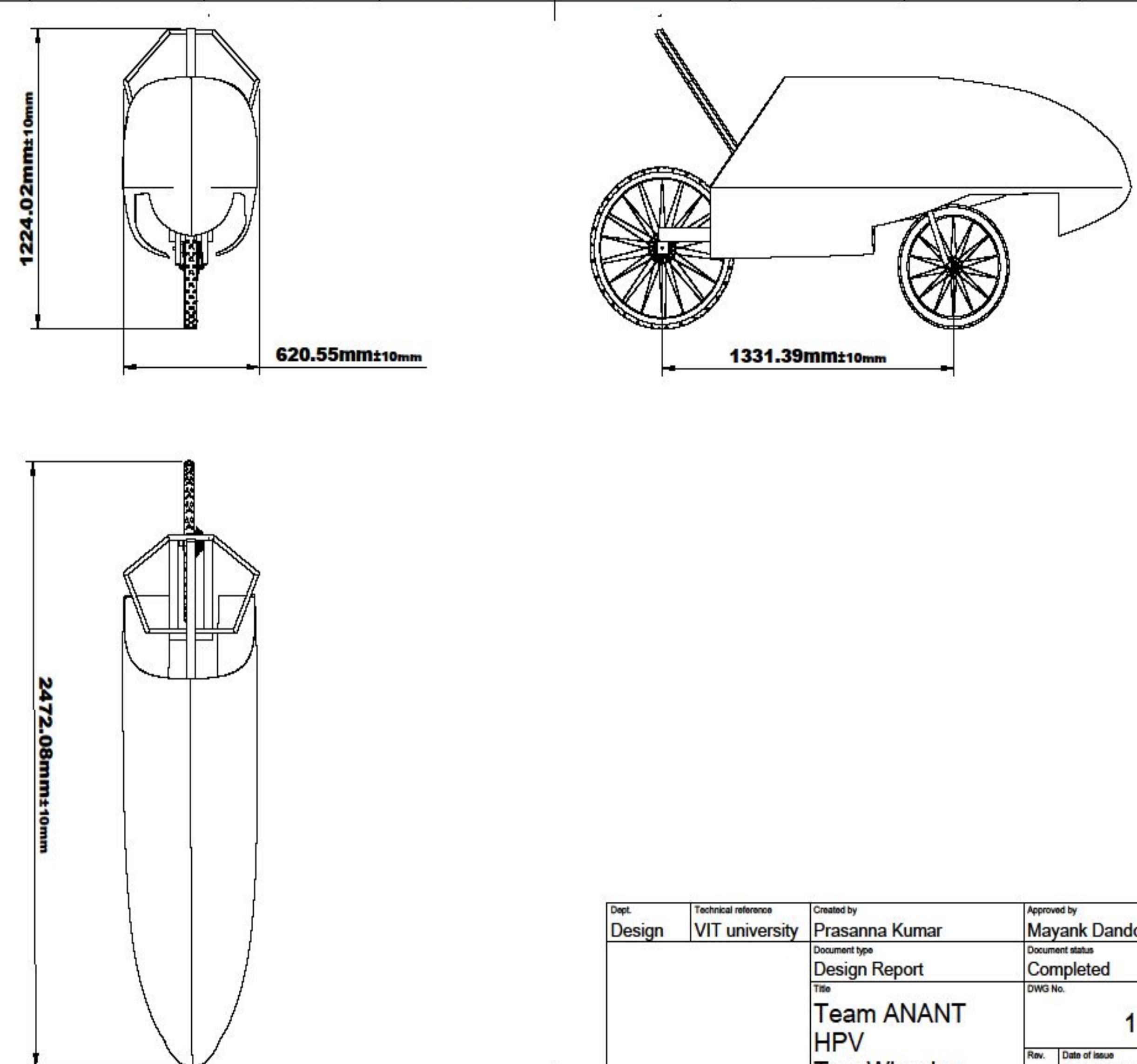

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Abstract:

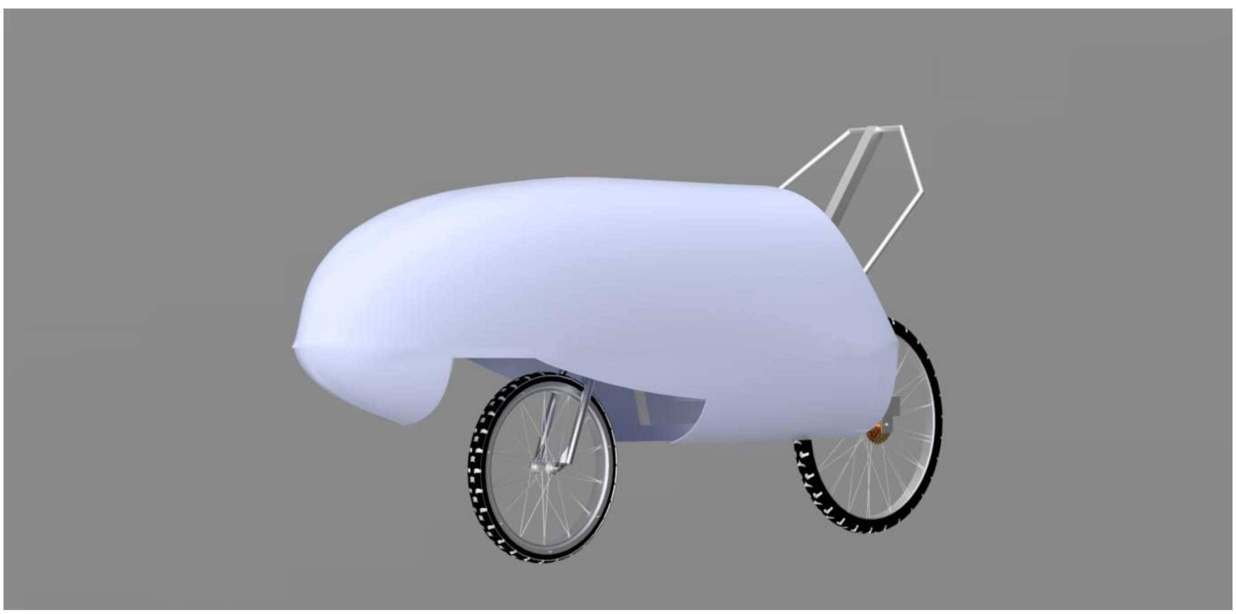
Team Anant will be participating in ASME India's HPVC for the first time. With no prior knowledge but armed with a hunger to learn, our vehicle, Ashv was designed with the knowledge we gleaned from the many design reports available on the net uploaded by teams from around the world.

For our first vehicle we followed the motto "Less is more", and as such our design reflects that. Keeping in mind weight constraints as well as cost constraints, we decided to go with Aluminum 6063 T6 as our main material of choice. The design of the RPS was done keeping in mind the safety of the rider as per the parameters defined in the rulebook.

Since our university is home to some of the best racing and aero teams in India , our manufacturing process was made easier as help was easily available in the form of students who were well versed in the difficulties most commonly faced during the manufacturing process.

Being the 'home' team we harbor aspirations of a credible result and we believe our simplistic design is a crucial factor in helping us achieve the same.

Figure 1: Design of Ashv



Contents

1. Design

1.1 Objective

Team Anant of VIT University is aimed at designing Human Powered Vehicle to compete in 2016 ASME Human Powered Vehicle Challenge. From the ASME HPVC rule book, the objective for the competition is :-
"To provide an opportunity for engineering students to demonstrate application of sound engineering principles toward the development of fast, efficient, sustainable and practical Human-powered vehicles."
The team developed, designed and analyzed Ashv (Sanskrit word for Horse) during the 2015-2016 competition season with the team's objective :-
"To develop a lightweight, efficient and high speed Hu man Powered Vehicle which ensures rider's comfort and safety."

1.2 Background

Rising energy demand, Over-exploitation of fuel resources and increasing air pollution have made the world to think about sustainable forms of energy and mass transportation. In the past few years, Bicycles are turning to be economic, efficient and sustainable mode of transportation with no involvement of fuel consumption. Thus, ASME India is providing us with an opportunity to develop Human Powered Vehicle which can be used as economic and practical mode of everyday transportation.

Our team has designed Ashv to compete in the 2016 ASME Human Powered Vehicle Challenge India, and thus must match all the rules and regulations set forth by ASME. The main reference sources we used to complete our design selection and development process came from the design reports of various teams participated in the challenge in the past few years. The "Rules for 2016 ASME Human Powered Vehicle Challenge India" packet gives all the necessary rules and considerations during the development of vehicle and was considered as an underlying reference in our design process. All specifications in this document followed including safety factors and dimensions.
Unfortunately, the unfaired upright bicycle has a low top speed and offers little storage space and safety features compared to the average automobile. Thus, the team decided to create a vehicle that has more speed than conventional unfaired upright bicycle with its rider's comfort and safety. Therefore, team Anant has designed a faired recumbent vehicle – Ashv to compete in the ASME competition.
The team has put a lot of efforts in building this year's vehicle. We already completed the manufacturing of the frame and hope to complete the fairing and its integration well within the time frame.

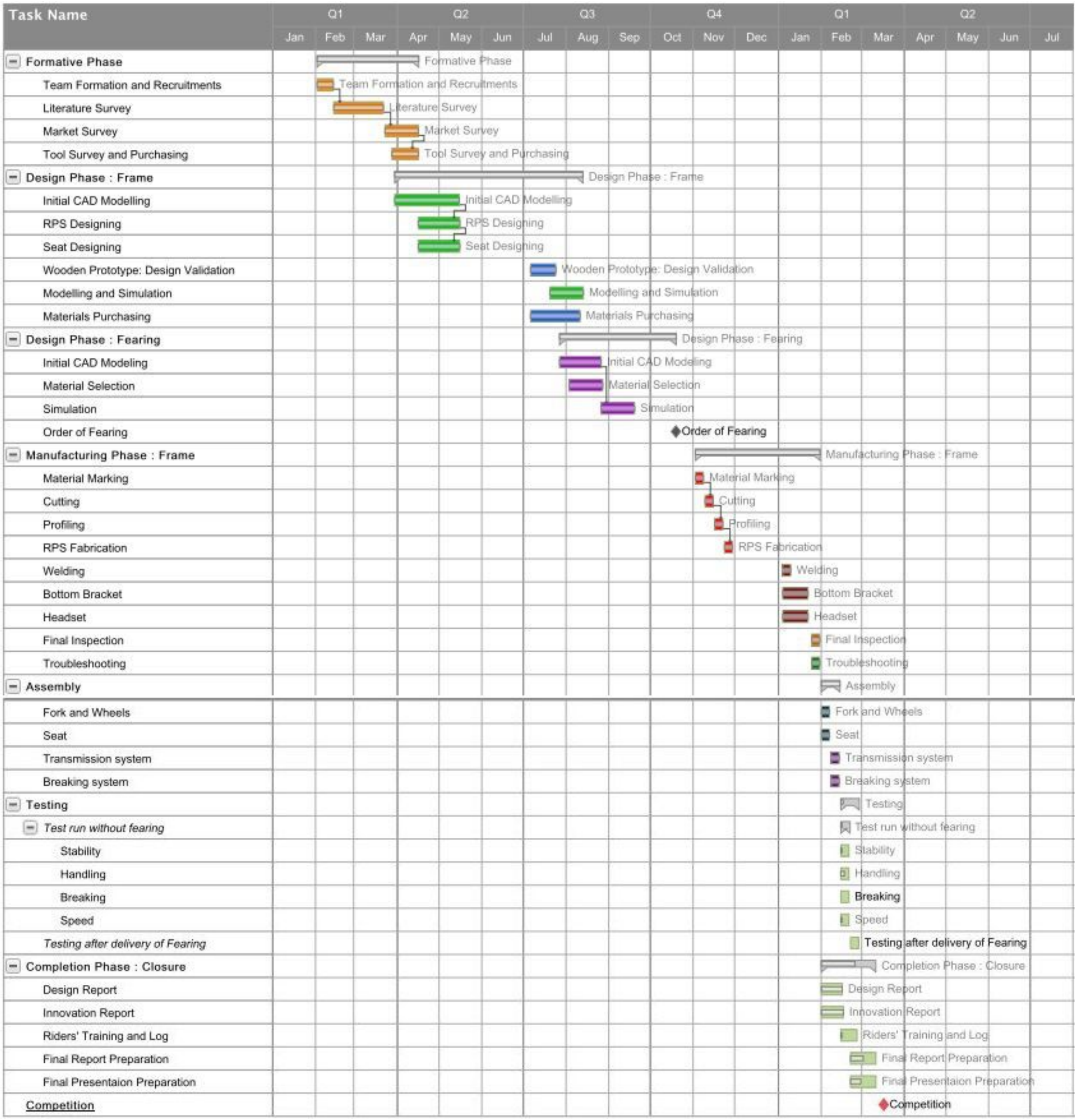


Figure 2: Gantt chart scheduling the 2016 Competition Season

1.3 Design Criteria:

Performance	ASME Constraints	Team Goals
	Storage area to store groceries of max weight of 5.5kg Should stop within a distance of 6 m when approaching at a speed of 25km/hr Turning radius of max 8 m Must demonstrate stability by moving in a straight line of 30m while moving at a speed of 5-8km/hr Demonstrate innovation in design	Weight of vehicle without fairing <20kg Top speed of more than 55km/hr Provide room for the rider to put his feet down to balance the vehicle.

Table 1: Constraints for Ashv design

The design criteria was determined by considering a mixture of both the rules as specified in the 2016 rule book and constraints set by us

Safety:	ASME Constraints	Team Goals
	The RPS should be able of sustain a top load of about 2670N showing a deflection of no more than 5.1cm It should also be able to sustain a side load of 1330N with a maximum deflection of 3.8cm The participants should wear suitable clothing that first and foremost ensures their safety while riding. The vehicle should also have a safety harness of at least 25mm webbing. The participants should wear helmets that meet CPSC Safety standards for bicycle helmets (16 CFR Part 1203) Include Head/tail light, bell or horn, front/rear/side reflectors Field of view of at least 90° to right and left of vehicle front and center	No exposed parts Room for movement Simplistic design Weight reduction

Table 2: Constraints for Ashv design

1.4 House of Quality

Determination of the design considerations was our first major step towards the development of our vehicle, we plotted the house of quality table keeping in mind various design requirements and parameters.

12 design requirements were considered and were written down along the rows whereas 14 design parameters were set and the procedure was followed to complete the house of quality table.

Based on the result of the HOQ table:

- Weight and Safety were set as main parameters.
- Ergonomics, Fairing and steering design were also highly considered.
- Furthermore the table even helped to prioritize resources and provided guidance throughout the design and manufacturing process.

However we were unable to do the competitive analysis which provides comparison between various recumbent models due to lack of experience. Being our first year into the competition, the exposure to various teams will help us gather data and improve the design in the upcoming competitions.

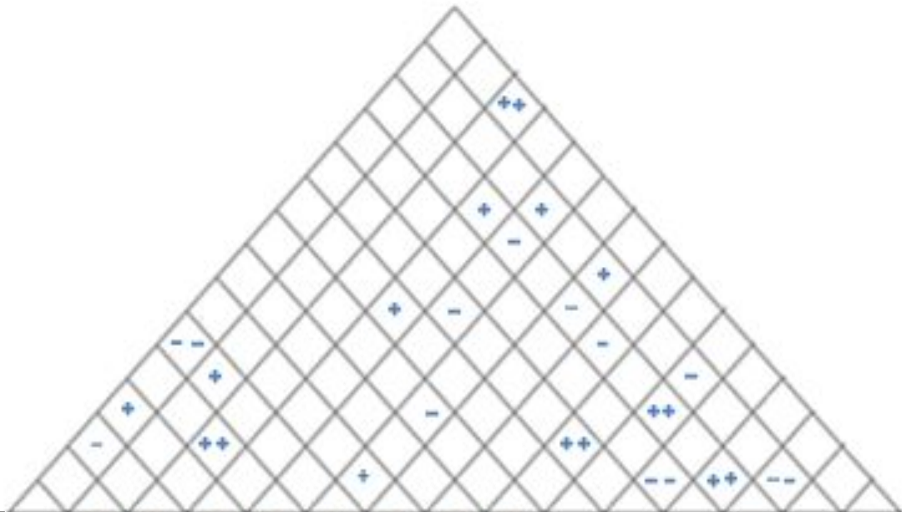
Figure 3: House of Quality on the next page

Legends:

Relations-

++ Very Strong, - - Very Weak

+ Strong, - Weak



Improvement Direction			▼	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▲	▼	▼
Design Parameters			Weight	Ergonomics	Factor of Safety, Rider Safety	Efficiency	Roll bar Contraints	Steering Stability	Turning Radius	Innovative	Integration Ease	Cd*A	Manufacturing time	Overall Cost	Fairing strength and design	Dimensions	Failure Frequency
Requiremnets/Demands	AI	RI															
Speed	4.5	12	9			9		1	3			9			3		
Safety	5	13			9		9	1							3		
Reliability	5	13			3		3	1			1		3			1	3
Proper Handling	3	7.7	3	3				9	1						1		
Innovative	2	5.1								9					3		
Storage Capacity	1.5	3.9														1	
Acceleration	3.5	6.4	9			3						1			1		
Comfort	4	10		9													
Ease of access	1	2.6		1							1						
Maintanence	2.5	6.4			3	3					9		1	1			9
Asthethics	3	7.7								3		1			1		
Cost	4	10				1	1			1	1	1		9	3	3	3
Total	39																
Absolute Importance(AI)			81	46	68	63	64	42	17	31	29	51	18	39	56	19	50
Relative Importance (RI)			12	6.8	10	9.3	9.5	6.2	2.4	4.6	4.2	7.6	2.6	5.8	8.3	2.8	7.4

Pugh's Selection Method was used to determine specific configuration of our vehicle. The tables below helped us to complete the selection process.

Type of Design:

Table 1 shows the selection process of the vehicle design. Various design concepts considered versus our design criteria is plotted and accordingly the design was selected.

According to the table and considering the weighed overall score we selected two wheel half faired recumbent design to suit our needs. Fully faired design is efficient but due to higher cost, half faired gained an extra point in comparison to it. Tadpole and Delta were not our top priorities therefore they scored low in the selection process.

	Weightage	Two wheel Fully Faired	Two wheel Half faired	Tadpole	Delta
Weight	10	0	1	0	0
Stability	7.8	0	0	1	1
Speed	8.7	1	0	-1	-1
Integration	3	1	1	0	0
Fairing	8.1	1	1	1	1
Frontal Area	5.4	1	1	-1	-1
Turning Radius	3	1	1	0	0
Steering	5	1	1	0	1
Strength	6.4	0	0	1	1
Cost	4.5	0	1	0	0
Total		38.1	44.6	8.2	13.2

Table 3: Selection matrix for Type of Design

Frame Material:

Similarly Table 2 was plotted and accordingly frame material was selected. the main design constraints we considered were machining and cost.

The Frame material selected according to the table was Aluminium 6061 T6. Carbon fibre and titanium were not selected due to cost and machining difficulties. Moreover Aluminium provided required strength at suitable cost and reduced machining difficulties.

Frame material	Weightage	Titanium	Carbon Fibre	Chromoly, AISL 4130	Aluminium 6061 T6
Cost	10.3	-1	-1	1	0
Weight	9.4	-1	1	-1	0
Welding	7.3	0	-	0	-1
Strength	6.8	1	1	0	-1
Machining	17.8	0	-1	0	1
Total		-12.9	-11.9	0.9	3.7

Table 4: Selection matrix for Frame material

Fairing Material

A 3rd table was plotted to determine the material of the fairing that would be used by us.

Fairing Material	Weightage	FRP	Carbon Fiber
Cost	10	10	3
Weight	3	4	6
Manufacturing	2	5	5
Strength	5	5	7
Total		147	93

Table 5: Selection matrix for Fairing material

Even though carbon fibre fainng would be a lighter and stronger option to go with, the excessive cost of the material would greatly hinder us in building the other components of the vehicle. Hence we decided that FRP or fibre reinforced plastic would be our preferred choice of material for the fairing.

Steering Design:

The steering system is a very important component of the vehicle and because of its importance many different designs were considered. It was designed to achieve two main goals- reliability and ease of manufacture. From our perspective the design which suited our requirements was the modified upright bicycle steering system.

According to our goal, we considered two steering designs- Above seat and below seat. We eventually selected the above seat steering design in order to achieve stability and proper handling. Below seat, while interesting was not our first priority because we decided not to use the short time available for experimentation. The table below depicts the reason for us selecting above seat steering. *Table 6: Selection matrix for steering design*

Criteria	Weightage	Above seat steering	Below seat steering
Comfort	7.8	1	0
Stability	7.3	1	0
Integration	8.6	1	0
Clearance (Eyesight)	6.8	0	1
Fatigue	9	1	0
Confidence	3	1	0
Total		35.7	6.8

Steering Design specifications:

Table 7: The design specifications for steering system

Parameters	
Steering axis angle(A)	74
Offset(F)	24 mm
Trail*(T)	48 mm
Wheel Flop*(Wf)	13 mm

Trail = (R-F*sec (A))/tan (A), the formula was derived using geometry.

Wheel Flop: T*sin (A)*cos (A). The table shows the approximate values as it was difficult to calculate th angle of the offset with the steering axis.

Design Criteria for automatically straightening up of handlebar after turn:

$$0<(x/y)*(T/W) <\cos (A)$$

=0.0367*1.97 =0.073, therefore the design is well under the constraints.

where; x,y = COM distance from contact patch.

T=trail,

W=wheelbase,

A=head angle from horizontal.

Head tube and Stem:

The head tube was manufactured from the Aluminium tubing at the facility provided by the university. The bearing cups were press fitted. Due to short availability of time at our disposal we didn't opt for tapered head tube which is a better design. However we will use this design in upcoming competitions. Similarly we decided to use a quill stem instead of threadless stem. The threadless stem provides great advantage over quill stem in terms of adaptability, but we decided to use quill stem because it is cost efficient, easy to install and can be removed without disturbing the headset which was our main priority. The fork was also modified to fit the measurements of the design.

Handlebars:

The handlebar was designed to provide optimum leverage when we steer. Therefore wider the handlebars, the more will be leverage. However as we spread our arms out we actually loose leverage. To optimize the handling and comfort ability, length of the handlebar was kept shorter than the shoulders.

Final Calculations

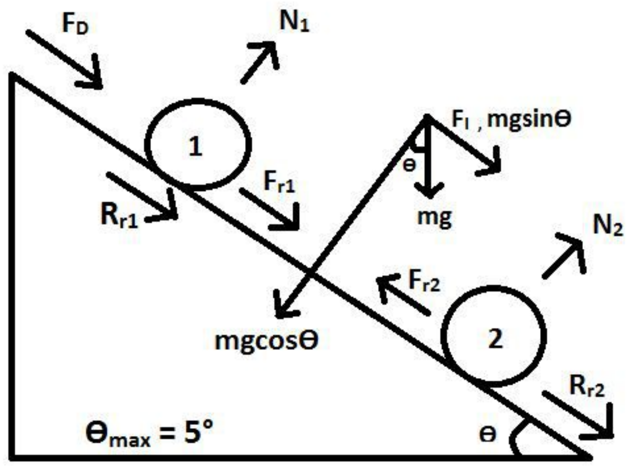


Figure 4: Free body diagram

Mass of vehicle + rider = 90kg

F_I = ma = Inertial force acting on vehicle

N_1 , N_2 = Normal reactions on both the wheels

R_{r1} , R_{r2} = Rolling resistances on both the wheels

F_D = Drag Force

F_{r1} , F_{r2} = Rolling friction on both tires

On balancing the forces, $N_1 + N_2 = mg\cos\Theta$ -(1)

TTE = $F_{r2} = mg\sin\Theta + R_{r1} + R_{r2} + F_I + F_D$ -(2)

Total tractive effort = F_{r2} =the total force required to move the vehicle with an acceleration after considering all the forces.

Maximum tractive force = the maximum force that the ground can provide ($f_{r2} \leq \mu N_2$) before the wheel starts to slip i.e. $f_{r2} = \mu N_2$

Maximum tractive torque ≥ total tractive effort

The minimum torque required for an acceleration of $0.4 m/s^2$ is calculated as

T = Total tractive effort (F_{r2}) X radius of drive wheel

Transmission for drag race:

In a drag race a rider needs to accelerate the vehicle as far as possible .Drag race is not about maintaining high speed, it is actually accelerating to the maximum speed after starting from zero velocity. Torque necessary for the required acceleration of $0.4 m/s^2$ = F_{r2} X r =125.25N

$$T= 41.357Nm$$

This is the torque required at the wheels. The pedaling range of human in rpm lies between 40 to 120rpm.

Deciding transmission ratios between chain ring and cassette:

Torque required at the wheels = 41.357Nm

Torque generated when the vehicle starts from rest when N=40rpm, m=90kg, P=190W

$$T=P/W = (190X60) /(2X3.14X40) =45.38Nm$$

Taking 1:1 ratio between chain and rear sprocket, F_{r2} = T/r =45.38/0.3302 =137.43N

Taking F_D =0 , a=0.535 m/s^2 , which is more than the expected acceleration

Maximum tractive force =μN_2 = 1 X N_2 = 577.9N

$$T= 577.9X0.3302 = 190.822Nm$$

Hence we take 1:1 ratio for drag race

Transmission for Endurance race:

In endurance race the rider needs to slowly accelerate to the top velocity possible and then maintain the velocity till the completion of the race.

Maintaining top velocity:

Taking an average power of 100W, N=80rpm

Required torque, T=29.47Nm at wheel

Effort torque = T = (100X60)/(2∏ X 80) = 11.935Nm

Gear ratio = T_2/T_1 = N_2/N_1= 2.47

N= no. of teeth on sprockets

1.5 INNOVATION:

Innovation 1:

Design

This feature helps in changing the angle of the steerer tube with respect to the handlebar for the rider’s comfort.
This feature has been implemented in HPVs before but the mechanism which is being used in our vehicle is something of our own invention.
Using this feature, riders of different height will be able to ride the vehicle without any hindrance. Thus this feature benefits the state of art of the HPV.
This innovation is possible with the existing technology. We just need to weld the steerer tube and the handle bar to the respective parts of the joint.

Concept Evaluation

The prototype of the innovation component was made up of wood. The simplicity of the model had shed light to visualise what the actual mechanism looks like and made it functional.
The prototype material was shaped to perfection, so realizing the proposed benefits was easy. There weren’t any unanticipated benefits. However the expected benefits were successfully achieved.

Learning

Our initial design was a failure but somehow we modified our designed successfully to achieve what we wanted. Initially there was a dowel pin welded to the outer side of the U shaped fork which got fitted to a semicircular arc attached with the other U shaped fork. This produced a cantilever structure and excess material was being used. So the holes were drilled in the U shaped fork itself following an arc with the bolt as the centre. This solved all the problems. The unanticipated problem was the friction produced while turning of the joint.

Execution

The transforming ability allows riders of different height to ride the vehicle and ensures the comfort of the rider. The end of the steerer tube is attached with a metal sheet bent in the shape of “U”. Let’s call this part as fork. The handlebar is attached with anotherfork faced in the opposite direction. Holes are made on them as shown in the figure and a M6 bolt is passed through the hole which is locked by a nut on the other end. The movement of the handlebar with respect to the joint with the steerer tube is restricted to a particular angle. 7 different angles are set which provides 7 different configurations. This movement locking is implemented in the design by an indexing mechanism which locks the rotation of the handlebar

Figure 5:

with respect to the steerer tube at the desired angle. In the fork connected to the steerer tube, seven holes of 4mm diameter are drilled on a circular pattern at uniform angle spacing. On the other fork one hole is made. A dowel pin of 4mm diameter that connects both the forks is used to lock the rotation at the different configuration. To operate, the dowel pin is taken out and the angle between the steerer tube and the handlebar is set in the comfortable configuration. The dowel pin is then inserted back and the rotation is locked. Between the two U shaped metal sheets some clearance space is provided for the provision of using a washer to reduce the friction while the angle is being changed.

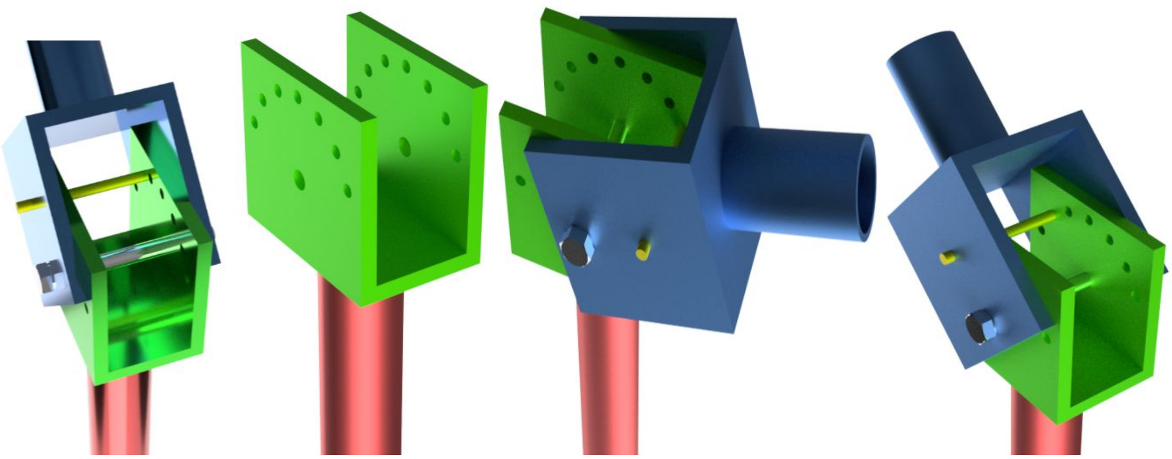


Figure 7

Innovation 2:

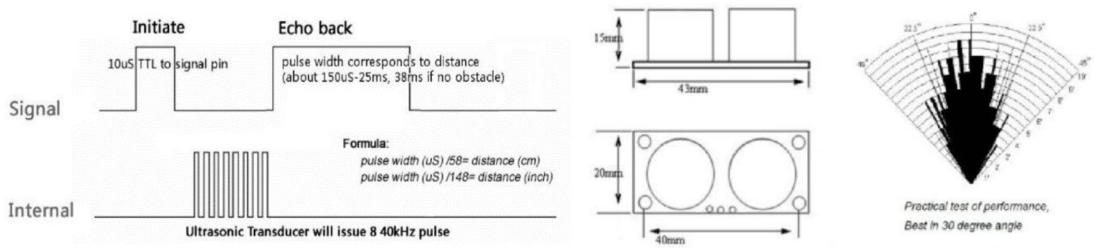
Need: Safety is an essential component of any vehicle and human powered vehicles don't usually focus much on safety enhancement. This is why safety is emphasized in this report.

Novelty: This idea implements in sending a wave signal out and analyzing the echoed back signal to gauge the distance and velocity of the obstacle and vehicle with respect to obstacle. Ultrasound hasn't been used in any commercial appliance for this purpose commonly The most commonly used mediums for this purpose are Radars and Lidars in automobiles, but they are not effective for a cheap solution. This is a first for obstacle detection technology.

This method is extremely feasible for daily applications and at much cheaper cost than alternative mediums and can be implemented using commonly available components like HC SR04 ultrasound sensor, Arduino, Motor and MOSFETs.

Working;

To start measurement,Trig of SR04 must receive a pulse of high (5V) for at least 10us, this will initiate the sensor will transmit out 8cycle of ultrasonic burst at 40kHz and wait for the reflected ultrasonic burst. When the sensor detected ultrasonic from receiver, it will set the Echo pin to high (5V) and delay for a period(width) which proportion to distance. To get distance of obstacle measure width of echo relative to sound wave. *Figure 9*



If obstacle is present within 400CM a H bridge complementary motor bridge is activated from the logic outputs from Arduino, thus running the motor of 32 Kg-CM torque, which couples with the braking wire in forward or reverse direction.

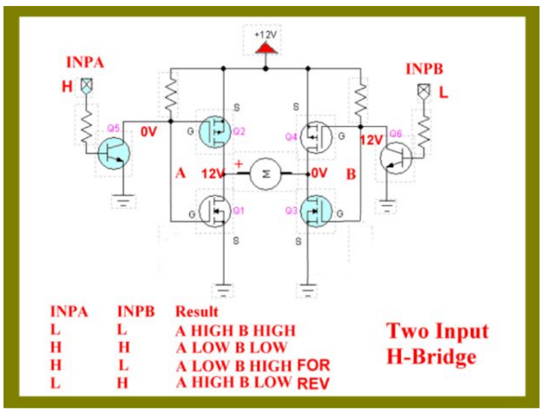


Figure 4 Q2, Q3 turned on motor runs in forward direction.

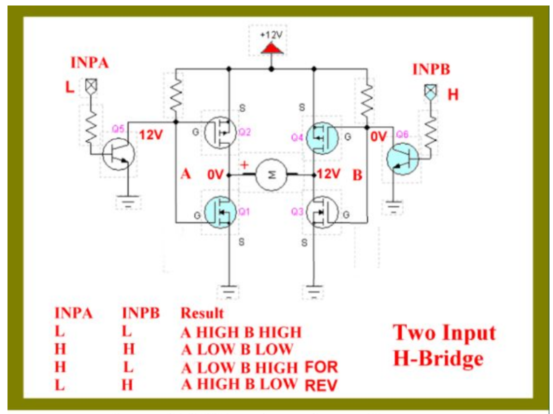


Figure 5 Q1, Q4 turned on motor runs in reverse.

The prototype tested was fully able to detect the obstacles, with relative accuracy. For detection range selected to 400 CM it was able to detect obstacles with accuracy up to 95%.

Absence of rider intervention is an unanticipated benefit as the process is completely automated, though motor position need to checked for subsequent operation.

There was an instance where when the vehicle would be at rest and the motor still acted. This was needed to be solved by taking the speed into consideration as well. Since HC SR04 only took 20 readings every 1 second, a delay of 500 ms is introduced in measuring in the distance at both the points and dividing the difference with delay to measure the speed. The main we came to learn from this obstacle was effective utilization of a simple delay function that came to be a big help in detecting the speed without the need to resort to complex mechanisms and reliably control braking motor.

The proposed innovation effectively includes under the targeted innovation category; safety in traffic.

2. ANALYSIS:

2.1 Rollover Protection System Analysis

OBJECTIVE	METHOD	RESULTS
To prove that the RPS met ASME standards	Finite Element Analysis (FEA) method is used to find deflection with the help of ANSYS software	The RPS met the ASME specification with vertical load deflection of 12.779mm and horizontal load deflection of 14.052mm

The objective of RPS analysis was to check and improve upon the load bearing capacity of RPS and make sure it does not yield as fracture upon load applications. It ensures the safety of the driver in case of any accidents

The modeling of the RPS was done using Solidworks and the simulations were run using ANSYS- static structural module

The material properties used were of Aluminum alloy with consideration of both linear and non-linear effects. The mesh was created with a relevance value of -50(medium fine) with 4303 elements and 8271 nodes , using tetrahedrons elements with mesh refinements.

The simulations were run for 2 different models – one with rib and one without rib under two different load conditions (2670N at 12 degree to the vertical 1330N in horizontal plane).

Assumptions:

Loads are static and applied uniformly.

The supports for RPS are fixed and inelastic.

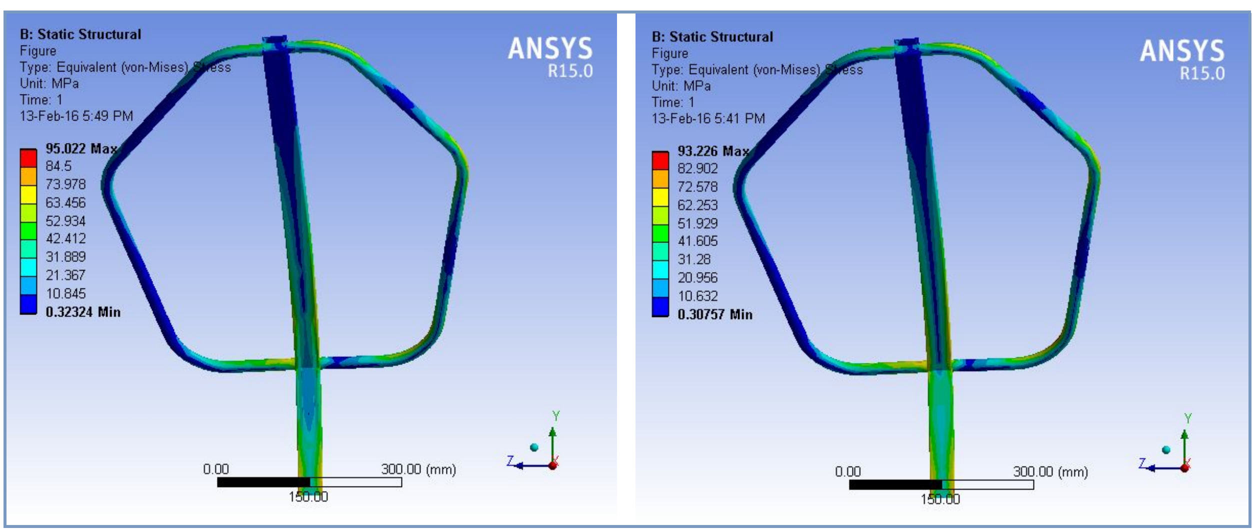


Figure10 : Von-mises stress analysis for RPS– With rib horizontal (left) and without rib horizontal(right)

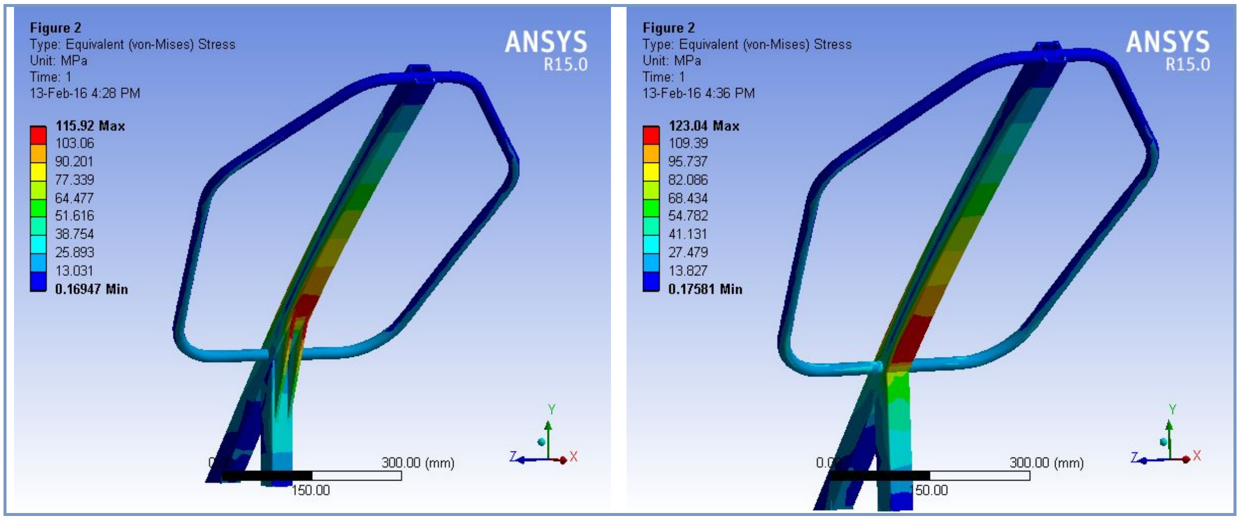


Figure11 : Von-mises stress analysis for RPS– With rib vertical (left) and without rib vertical(right)

case	2670N at12° with vertical plane			1330N in horizontal plane		
	Max. Deflection (mm)	Max. von-mises stress (MPa)	FOS	Max. deflection (mm)	Max. von-mises stress (MPa)	FOS
Without rib	15.768	123.04	2.2757	14.779	93.226	3.0034
With rib	12.779	115.92	2.4154	14.052	95.022	2.9467

Table 8: Summary of roll bar analysis

Based on the results, the RPS model with rib provides a better FOS as well as von mises value in vertical load conditions where stresses were higher. But more significantly as can be observed in the figures, the stress concentration at the joint is highly reduced just by using a rib which ensures the failure would also be highly delayed dynamic and fatigue. So the RPS model with a rib as it reduced stress concentration and deflection also.

2.2 Structural Analysis of the Vehicle

OBJECTIVE	METHOD	RESULTS
Stress and Deformation Analysis of Mainframe	FEA was used as the method for analysis using Solidworks Simulations	Maximum stress was found to be 7.36982 N/mm^2 and maximum displacement was found to be 0.127004 mm.

Table 9: Summary of Frame FEA

The objective of the structural analysis of the mainframe was to verify that the mainframe can take up the loads that it would be subjected to,without any yielding on fracture .The analysis also intended to find out the areas that are subjected to major stresses in the mainframe and areas of high deformation, so that additional strength and stiffness can be provided to these areas.

The two ends of the main frame were treated as fixed support. The uniform load of 1000N (equivalent to the weight of a 100 kg rider) was applied at the central beam of the frame upon which seat is supposed to be mounted.

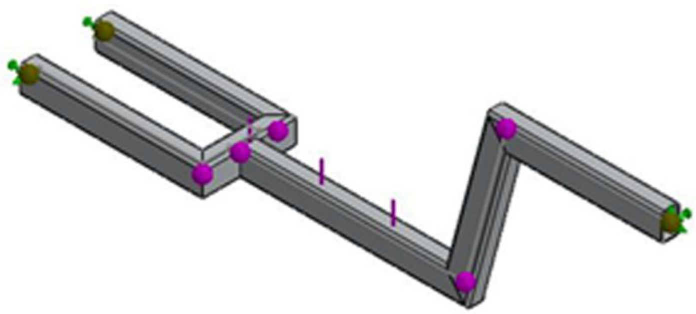


Figure 12: Model with loading conditions and fixtures

The material used is Al-6063and the cross section used was 60X40X4 mm standard Rectangular Hollow Section (RHS),which were intended to be used according to design.

The modeling was done using weldments in solidworks. The analysis was done using Solidworks Simulation Package in Solidworks. The element type used for meshing was a beam element in order to neglect small and unrealistic stress concentrations at the joints .The total no. of nodes used was127 and the total no. of elements used were120.

Beam Forces

Beam Name	Joints	Axial(N)	Shear1(N)	Shear2(N)	Moment1(N-m)	Moment2(N-m)	Torque(N-m)
Beam-1(Structural Member2[5])	1	-336.539	-161.363	1.2662e-008	1.50376e-009	-17.3034	4.14036e-009
	2	336.539	161.363	-1.2662e-008	-5.80882e-009	-37.56	-4.14036e-009
Beam-2(Structural Member2[4])	1	242.967	283.308	1.26637e-008	-3.60999e-009	-17.3034	-2.52411e-009
	2	-242.967	176.692	-1.26619e-008	9.43456e-009	-7.21817	2.52412e-009
Beam-3(Structural Member2[3])	1	-121.484	-88.3462	8.14547	-0.910926	-30.8459	-0.305343
	2	121.484	88.3462	-8.14547	-2.1029	-1.84216	0.305343
Beam-4(Structural Member2[2])	1	8.14547	88.3462	121.484	7.61579	-6.76235	1.84216
	2	-8.14547	-88.3462	-121.484	2.1029	-0.305343	-1.84216
	3	8.14547	-88.3462	-121.484	-2.1029	0.305343	-1.84216
Beam-5(Structural Member2[1])	1	-121.484	-88.3462	-8.14547	0.910926	-30.8459	0.305343
	2	121.484	88.3462	8.14547	2.1029	-1.84216	-0.305343
Beam-6(Structural Member2[6])	1	242.967	-283.308	-1.26619e-008	-1.9358e-009	61.5977	-6.68247e-009
	2	-242.967	283.308	1.26604e-008	-2.49568e-009	37.56	6.68245e-009

Figure 13: Beam forces results

Beam Stresses

Beam Name	Joints	Axial(N/m^2)	Bending Dir1(N/m^2)	Bending Dir2(N/m^2)	Torsional (N/m^2)	Worst Case(N/m^2)
Beam-1(Structural Member2[5])	1	587666	-0.000213803	-1.95107e+006	0.000450416	2.53874e+006
	2	587666	-0.000825897	4.23515e+006	-0.000450415	4.82281e+006
Beam-2(Structural Member2[4])	1	424271	-0.000513269	1.95107e+006	-0.000274589	2.37534e+006
	2	424271	-0.0013414	-813897	0.00027459	1.23817e+006
Beam-3(Structural Member2[3])	1	212136	129515	-3.47809e+006	-33217.2	3.81974e+006
	2	212136	-298990	207716	33217.2	718841
Beam-4(Structural Member2[2])	1	14223.7	1.08281e+006	762501	200402	1.85954e+006
	2	14223.7	-298990	-34429.5	-200402	347643
	3	14223.7	-298990	-34429.5	-200402	347643
Beam-5(Structural Member2[1])	1	212136	-129515	-3.47809e+006	33217.2	3.81974e+006
	2	212136	298990	207716	-33217.2	718841
Beam-6(Structural Member2[6])	1	424271	-0.000275233	-6.94555e+006	-0.000726963	7.36982e+006
	2	424271	0.000354836	4.23515e+006	0.00072696	4.65942e+006

Figure 14: Beam stress results.

The forces and stresses on each beam were calculated as above and were used to find the area of stress calculation and high loadings

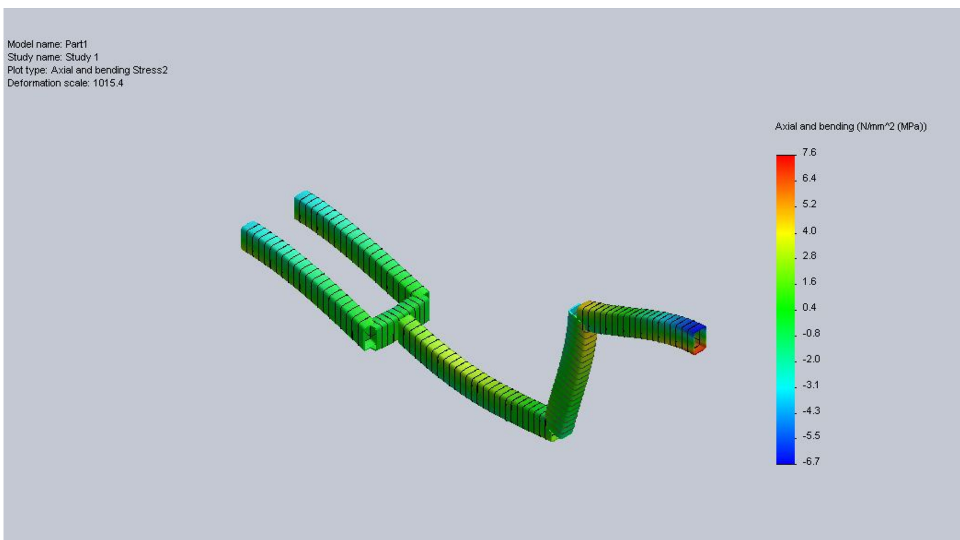


Figure 15: Result of analysis for axial and bending stresses in the simplified main frame

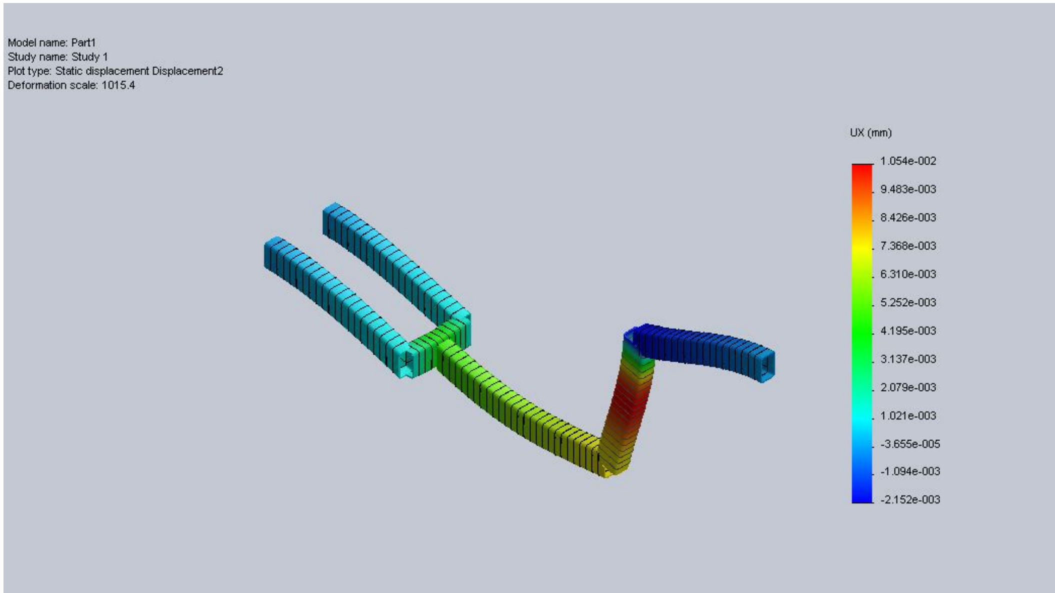


Figure 16: Result of analysis for static displacement in the simplified main frame

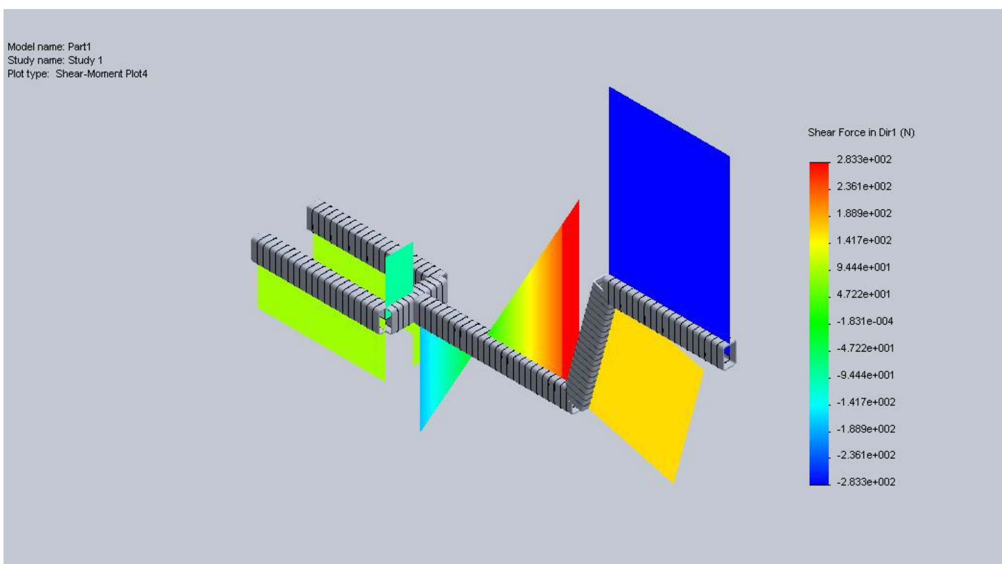


Figure 17: Result of beam analysis in the simplified main frame

The stress and deformation were calculated. Maximum stress was found to be 7.36982 N/mm^2 and maximum displacement was found to be 0.127004 mm. Also shear force and bending moment diagram is plotted.

The result of the study clearly showed that the frame could easily handle the loading conditions without much problem. Moreover, the areas with high deformation were identified and additional supports were provided to stop deformations.

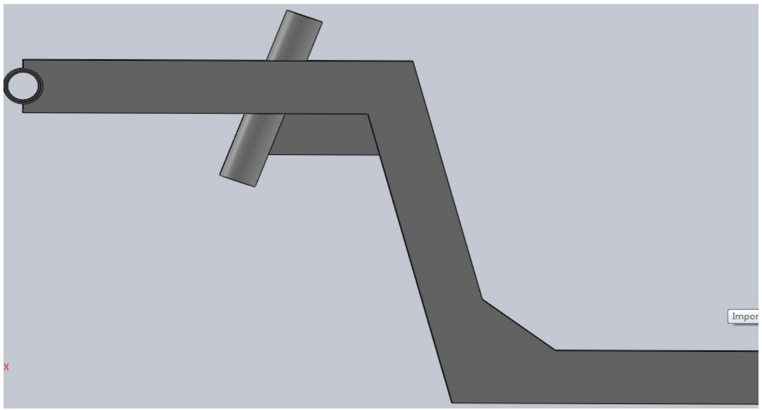


Figure 18: Supports added to mainframe based on structural analysis

2.3 Aerodynamic Analysis of the vehicle

OBJECTIVE	METHOD	RESULTS
Determination of fairing shape, determining the coefficient of drag and cross--flow analysis.	Computational Fluid Dynamics (CFD) was used to do aerodynamic analysis using Solidworks Flow simulation.	Coefficient of Drag was calculated to be 0.27 and lean angle was calculated to be 2.5̊ .

Table 10: Summary of CFD analysis.

The objective of the study was to determine drag forces the fairing is subjected to and to calculate the coefficient of drag for the fairing.

The primary design of the fairing was started with analyzing some basic NACA aerofoils and using these analysis to find the aerofoil which was best suited for our fairing. These analysis were carried out on a open-source aerofoil analyzing software called XFLR5.

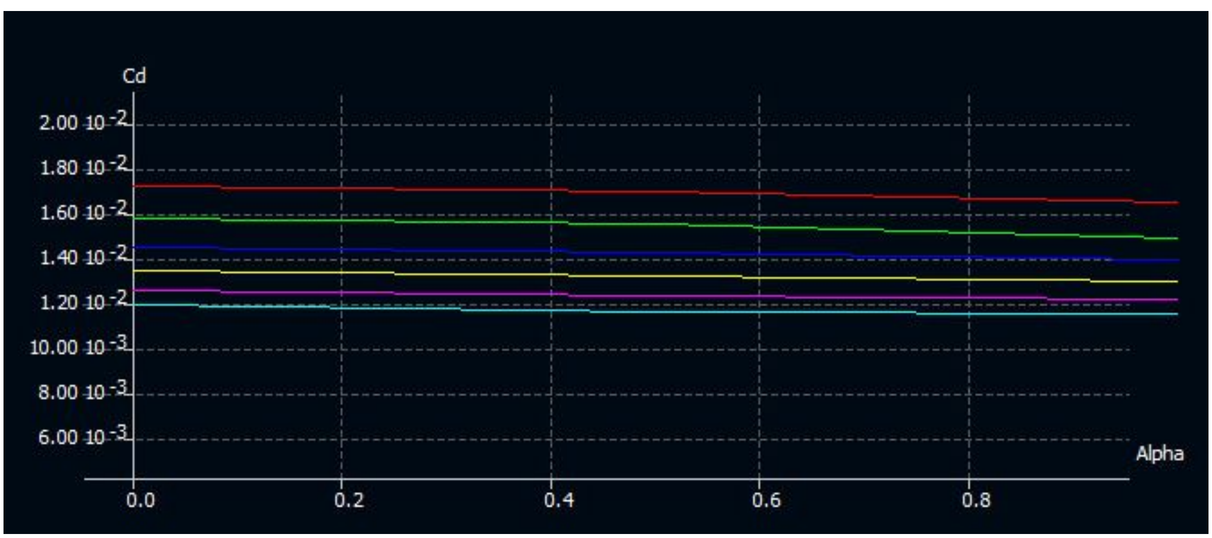


Figure 19 : Results of batch analysis of NACA 2412 aerofoil.

The analysis of NACA 2412 yielded that the coefficient of drag varied between 1.2×10^{-2} to 1.8×10^{-2} under different setup conditions. Also the Cd value decreased slightly with in angle of attack for the initial 5°.

The aerofoil was then developed into a 3D model of the fairing which was based upon the dimensions of the vehicle. In order to avoid any interface, a kinematic motion simulation of driver’s leg was used. Then a primary model was modelled in Solidworks and refined to the need of a design.

The aerodynamic analysis was carried out using Solidworks Flow simulations. The effects of motion of the vehicle were neglected and the fairing was made to be stationary. Standard temperature and pressure conditions were used to analyze the fairing. The surface of the fairing was taken to be perfectly smooth with no roughness.

The velocity of fluid was set to 20m/s (72km/hr) and the flow was kept parallel to the length of the fairing. The goals for convergence were set as force in X direction (drag force) and force in Y direction (lift force). The simulation was done using a 7 resolution mesh setting with narrow channel refinement.

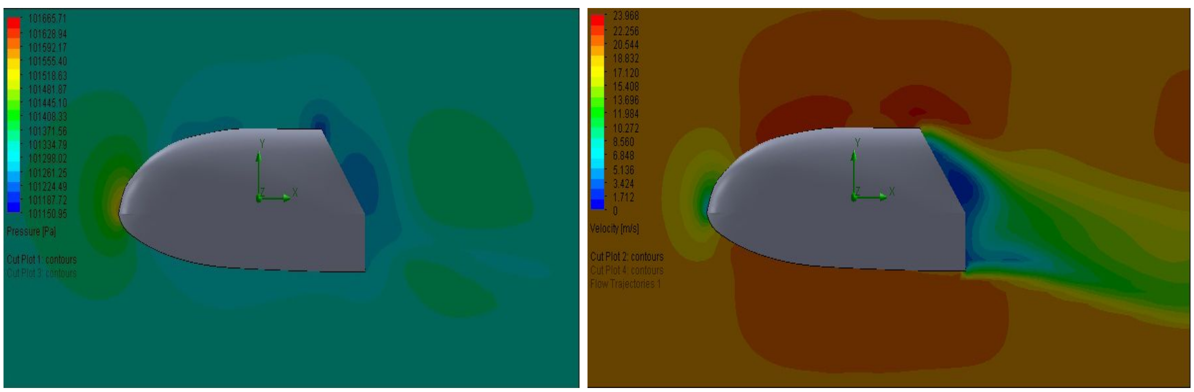


Figure20 : Pressure and velocity cutplots in Front view.

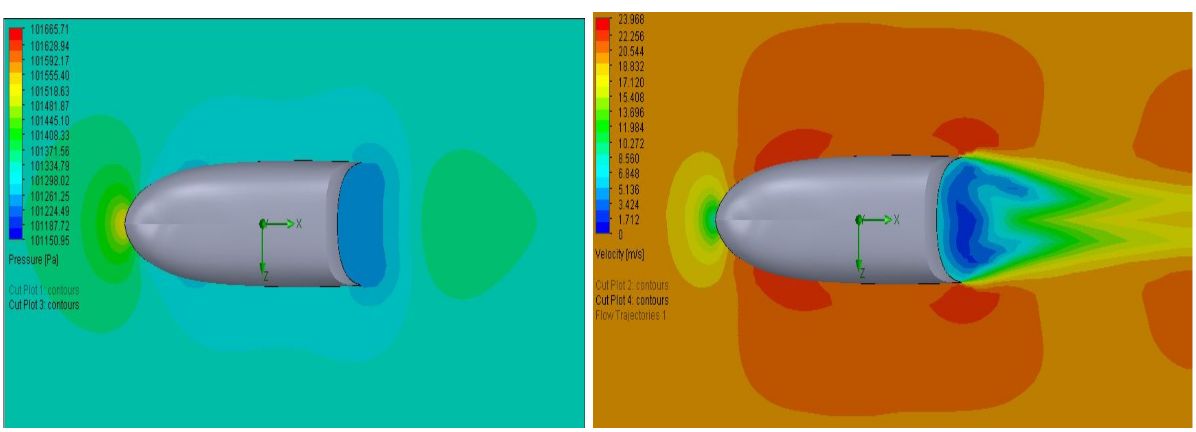


Figure21 : Pressure and velocity cutplots in Top view.

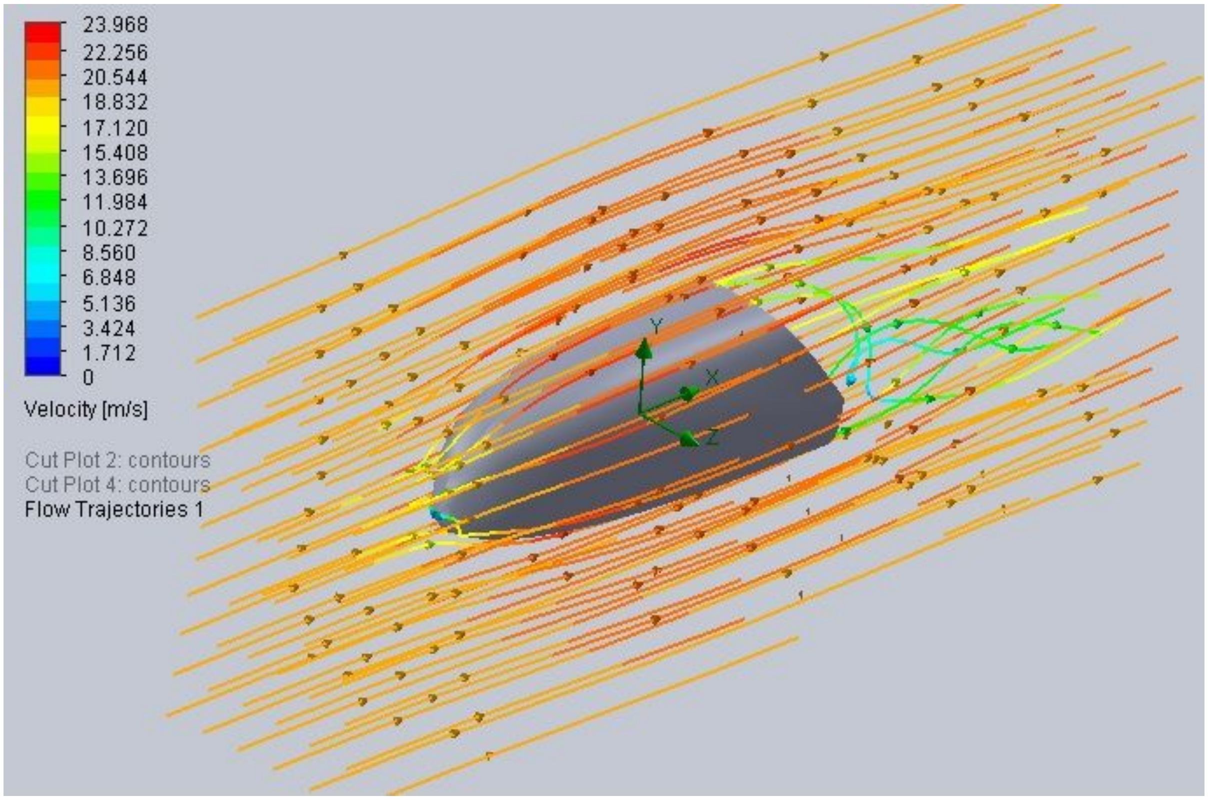


Figure 22: Flow Trajectories representing velocities and stream lines.

Various cut plots were generated and flow trajectories were visualized for flow study.

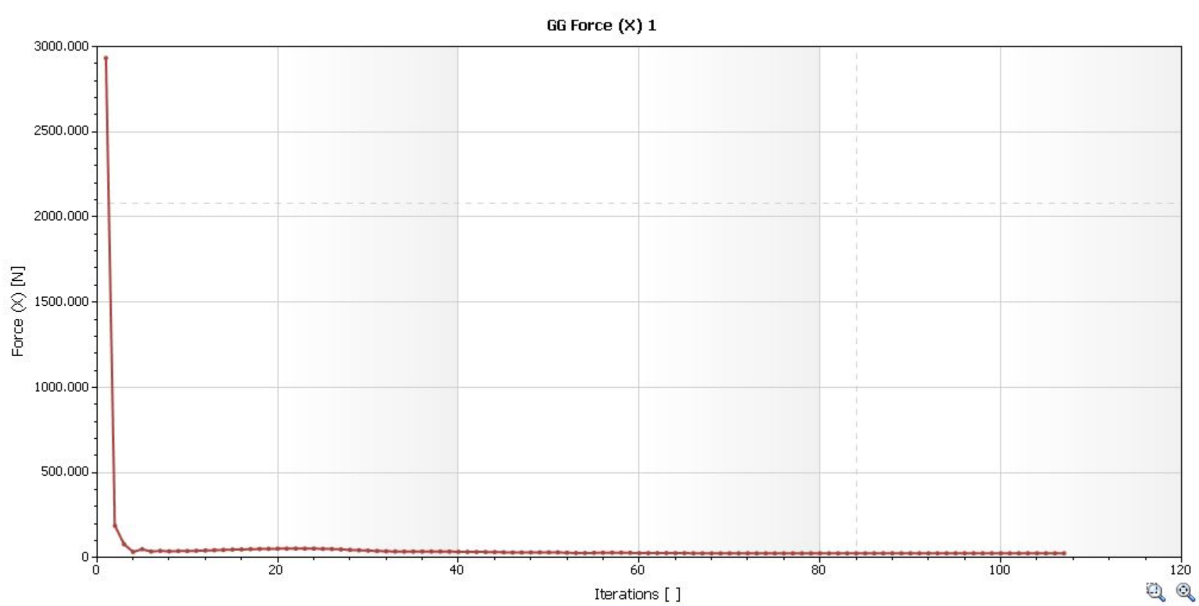


Figure 23: Convergence plot graph for Drag force (F_{D}).

The drag force on the fairing was found to be 26.578N (F_D) and the lift force was found to be 16.755N(F_L).

Drag force, F_D(N)	**Frontal Area, A.(m^2)**	**Coefficient of Drag C_d**
26.576	0.4	0.27

Table 11: Results from solidworks flow simulation

$$c_d = \frac{2 . F_d}{\rho V^2 A} = \frac{2 \times 26.576}{1.2 \times 20^2 \times 0.4} = 0.27$$

To ensure that the vehicle fairing would not lean in case of the cross winds, a cross wind, a cross wind analysis was performed on Solidworks flow simulation. The velocity of cross wind was set to 5m/s (18km/hr) which is the average speed of the breeze. This was done to ensure that side winds Drag force doesn't become a major problem in vehicle stability.

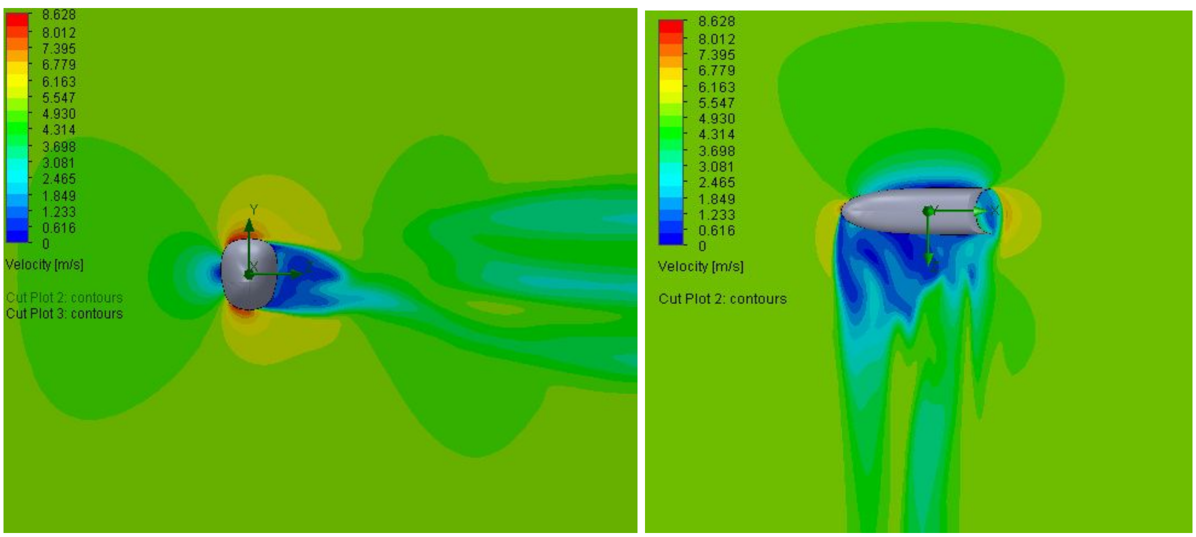


Figure 24: Velocity cut plots in Front and Top view for Cross-flow.

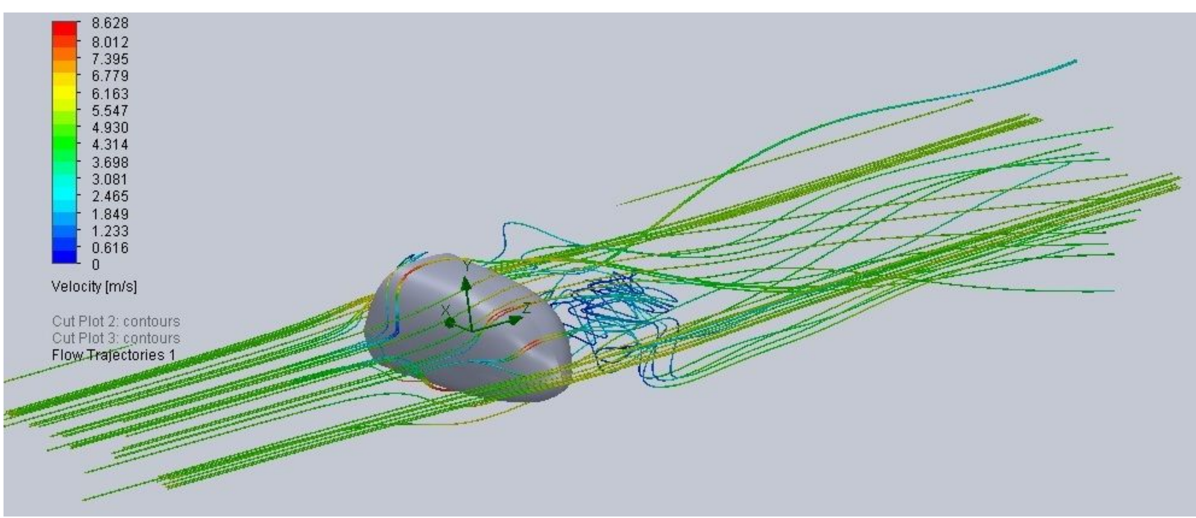


Figure 25: Flow Trajectories representing velocity in Cross-flow.

Various cut plots were generated and flow trajectories were visualized for flow study.

Force		**Value(N)**
Fx		1.304
Fy		1.850
Fz		8.490
Fd(N)	**Mg(N)**	**Lean angle,θ**
8.49	196.2	2.50

Table 12: Results from solidworks flow simulation

The resultant force in cross flow direction was found to be 8.490.

$$\theta = \tan^{-1}\left(\frac{F_d}{mg}\right) = \tan^{-1}\left(\frac{8.49}{196.2}\right) = 2.5^{\circ}$$

The lean angle is calculated to be 2.5° which is very low and does not affect the reliability of the vehicle.

2.4 Cost Analysis of the Vehicle:

Table 13:Cost analysis 1

INDIRECT COSTS					
	Component Description	Qty	Cost/ unit	unit	Total
Safety equipments					
1	Welding helmet	1	₹200	-	₹200
2	Leather gloves	2	₹50	-	₹100
3	goggles	2	₹50	-	₹100
4	Apron	1	₹200	-	₹200
Miscellaneous COST					
1	Welder		₹	Per shift	₹500
2	Machining cost		₹	Per shift	₹500
3	Fairing charges		₹	Per shift	₹40000
4	Other		₹1000		₹1000
			Total	=	**57,352**

Table 14: Cost analysis 2

Direct costs					
	Component Description	Qty	Cost/ unit	Unit	Total
	Direct Material costs(Raw material)				
1	6063 T6 Al RHS (40*60mm)	1	₹684	3.8m	₹2600
2	6063 T6 Al tube(19)	1	₹68	3.8m	₹68
3	6061 T6 Al sheet(30sq.cm)	1	₹0.75	30^2cm	₹675
4	6061 T6 AlRHS (40*40mm)	1	₹368	1m	₹368
5	6063 T6 Al tube(39dia)	1	₹370	0.5m	₹185
6	FRP (seat)	1	₹500		₹1000
7	Fibre glass		₹5000		₹5000
	Purchased parts and/or assemblies				
	Drivetrain				
1	Pedal	2	₹83	-	₹166
2	Derailleur	2	₹250	-	₹500
3	Driving chain	1	₹100	-	₹100
4	Sprocket	2	₹150	-	₹300
5	Crank set	1	₹180	-	₹180
6	Gear shifter	1	₹350	-	₹350
7	Chain	2	₹100	-	₹100
8	Idler	1	₹80	-	₹80
	Wheel Assembly				
1	Front wheel (20inch)	1	₹600	-	₹600
2	Rear wheel (26inch)	1	1100	-	₹1100
Steering Assembly					
1	Fork (20inch)	1	₹500		₹500
2	Steering handle	1	₹500		₹500
Brake System					
1	Clutch lever	2	₹60	-	₹120
2	Brake wire	2	₹80	-	₹80
3	Power brakes	2	₹180	-	₹180

cost of the production of the single vehicle=57,352		
Capital expenses		
PARTICULAR	SPECIFICATION	COST(on rent)
1. welding	Gas Welding.	Rs 200/- per day
2.Hand Driller	10mm,15mm,20mm	Rs100/day
3.Lathe machine Universal Lathe		Rs 300/day

Total Capital expenses per day= Rs 600/-

Tools used:	
Wrenches All set	
Cutter All set	
Grinder	
Drill bit	
Hammer	2.5 inch
Screw driver	
Spanner No	No 9-22
Sprocket	
Safety equipment	
Helmet	IS 2925
Eye Glasses cost	
Hand Gloves	2 pairs
German glass	
Fire Extinguisher	
First Aid Box	
UV Screen	

Table 15: Tools used.

Total cost of the safety apparatus is 3000

Table 16: Other costs

Labor cost(Considering Rs 150 per shift/day/person)		
Welder and Assembler	2 persons	₹300/day
Machine Operator	2 persons	₹300/day
Foundry man (Fairing casting)	1 person	₹150/day
		Total Labour Cost= Rs 750/day
OVERHEAD COST		
Property Rent	Size (15*15 sq. ft.)	₹3000/month
Electricity Considering	Rs 5/unit	₹ 5000/month
Administration Including executive and maintenance expenses		₹ 5000/month
		Total overhead cost= ₹ 13000/month

If we consider 24 working days in a month, for producing 10 vehicles per month, we are trying to make an estimate the commercial price of the vehicle produced in the factory. The basic assumptions on this process are as follows:

- Workers work in a 5hour shift per day.
- All the workers can be shuffled to each other's work.
- Total working days in a month are 24 days including all holidays

Particulars	***Total expenses in 3 years***
Total material cost All set	₹62,46,720
Total capital expenses	₹5,18,400
Total Labor cost	₹648000
Total Overhead cost	₹4,68,000
Total tooling and safety cost	₹6000
TOTAL COST IN 3 YEARS= ₹2,22,87,120	
Net cost of Vehicle ₹61,908	
Commercial cost of a vehicle ₹62,999	

Table 17: Total expense

3. Testing:

- Rollover and Side Protection System Testing
- Development Testing
- Performance Testing

3.1 Rollover and Side Protection System Testing

Objective: The objective of the RPS testing is to corroborate the stress analysis performed during the design phase, safeguard manufacturing standards, and also rider safety.

This is the most important component of a Human Powered Vehicle, where we designed with utmost attention such that it would be safe for our riders to ride in it, and of course it adds strength and protection to the passenger. The material used to build the roll cage of the vehicle is **Aluminium 6063-T6** has good weldability and machinability while testing (Brinell Hardness 75 HB). This guarantees that it is strong and hard enough to get welded and altered at any level of manufacturing.

<u>Procedure</u> (**Top Load Testing**): The top load test is designed to imitate the impact loads the vehicle may suffer in accidents. A top load was applied on the roll bar with the help of UTM indenter arrangement. Supports were provided manually by holding it with hands.

Loads were applied in 0.2 kN increments, up to a total load of 2670N (2.67 kN). While the load was being applied, the structure was closely monitored for failure signs, with displacement measurements taken at each increment.

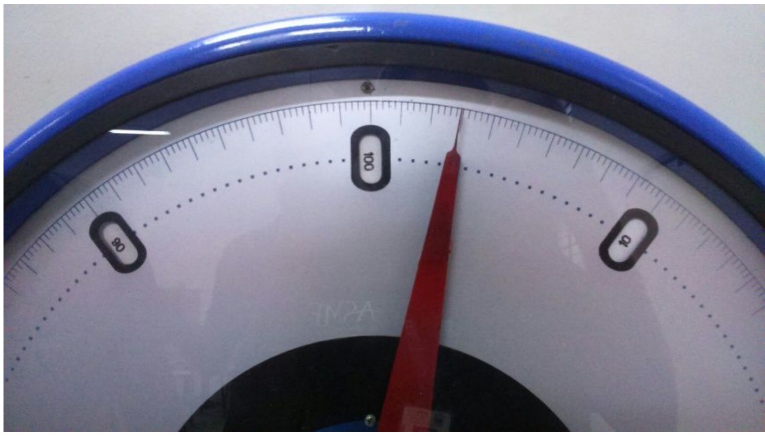
Procedure (**Side Load Testing**): Force was applied with calibrated weights under gravity load. For side load to we supported the RPS (welded with chassis) manually by hands. The load was applied in 0.2 kN increments, up to 1350 N while the load was being applied; the structure was closely monitored for failure signs, with displacement measurements taken at each increment.

Deflection test:

Applied load	Total deflection	Allowed deflection
2670 N (LOAD) from top	18 mm	51 mm
1330 N (LOAD) from side	7 mm	38 mm

Table no. 18: RPS testing

Side Load: 1330N



Top Load: 2670 N

(**14 divisions** covered by the needle)

Figure 26

(L.C is 0.2 kN - So, **7 divisions** covered by the needle)

Results: Thus, the HPV satisfies the load criteria as mentioned in the ASME HPVC 2016 rulebook.

Figure 27

3.2 DEVELOPMENT TESTING

The team conducted a series of tests during development stage to arrive at the optimal design specifications, as illustrated below:

<u>Wooden Prototype:</u>

<u>Objective</u> In order to ascertain the best specifications for the seat, and the distance of pedals from the frame's main linkage, a prototype was built using wood and RPS using PVC pipes.

(a) Validation of Bottom Bracket distance:
<u>Method</u> The drivers were asked to sit on two separate chairs and a rough estimate was obtained for the range at which the pedals should be placed, with regard to their leg length.
<u>Result</u> Considering crank length and knee angles, the BB was fixed at 81 cm from the hip joint.

Conclusion At this stage it was found necessary to increase the Prototype's length, in design from 50 cm to 56 cm, for the main tube, since there wasn't enough space for the driver's legs.

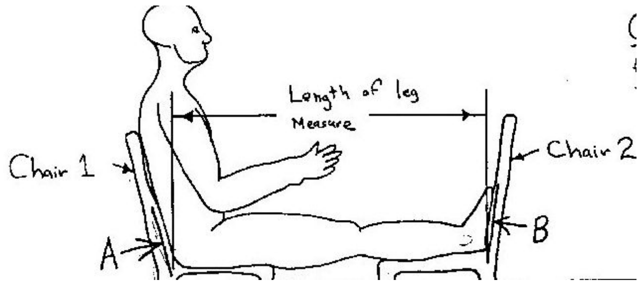


Figure 28: Measuring leg length to ascertain BB location

(b) Seat Angles:
Method The pedals were fixed at the mean distance, and riders were asked to position their seat at various angles and a comparative study was carried out.
Result The optimal angle for seat was found out to be 35 degrees for the leg rest and 125 degrees for the back rest.
Conclusion These values were in lieu with the ergonomics range that had been used in the design.


Figure 29: Wooden Prototype

(c) Validation of BB height:
Method A cardboard was attached with pedals, and held at various heights for the drivers to assess their comfort level, and their ability to deliver maximum Power Output.
Result The average of all the values the length and pedals were fixed as 15 cm crank length, at a height of 66 cm.
Conclusion The Cadence that was obtained was within the range of 90 to 110 rpm, without too much discomfort to the driver.

3.3 Performance Testing

Braking Test

This test was conducted to examine the braking system of the vehicle. As per the rules the vehicle should come to rest from a speed of 25 km/hr within a distance of 6 metres. The vehicle is fitted with power braking system to accomplish this goal.

Turning Radius

The vehicle is ought to have a maximum turning radius of 8m as per the rulebook and is designed accordingly to achieve the same and the outcome of the test achieved was acceptable.

Vision Test

The driver's visibility from inside the vehicle is a essential factor of safety. This test was done to determine the vision range of the driver. As our vehicle is half faired the driver's vision is not restricted and driver is able to see all the obstacles.

4. Hazard Analysis

HAZARD	FREQUENCY	SOLUTION
Vehicle needs to be stopped suddenly	Low	
Vehicle Topples	Low	Seat belt is provided to ensure rider does not come into contact with the surface directly
If the driver is stuck inside	Medium	We are using half fairing
If the tires get punctured	High	They can be easily replaced
If the seat breaks	Low	Our seat is made of Fibre Reinforced Plastic
If breaks fail	Low	Vehicle can be stopped in case of emergency by the feet.
If the vehicle crashes	Low	Fairing and RPS will ensure rider's safety.
If driver gets suffocated	Low	We are providing with a small fan attached to the fairing OR Air gets self-circulated while driving through the lower gap of our Fairing
If rider is uncomfortable in the vehicle	High	We designed our HPV after making its prototype on a wooden model for testing its ergonomics.
If HPV is supposed to drive on slippery surfaces	Medium	Our driver is well trained for such conditions

Table 19: Hazard analysis

Other hazards: No other obvious hazards were observed in our vehicle

5. Conclusion:

Comparison:

Design Parameters	Testing Result
RPS (as per rule book)	Successfully Passed
Aerodynamic	Cd of 0.27
Ergonomic	Sufficiently ergonomic
Weight	Weight reduction achieved via material selection

Table 20

Evaluation:

As mentioned our main goal was to keep the design as simple as possible so that we may achieve a maximum weight reduction and our chances of failure of the frame go done. We believe that we have successfully achieved the goal that we set for ourselves and we believe our vehicle is more than capable to achieve a respectable result in our first ever competition.

Recommendations:

Places where improvements could be made are in the use of the rectangular tubes, as thinner tubes could also be safely used and would improve the speed of the vehicle. We also could not use carbon fibre in our fairing as we could not afford it. We hope that in next year's competition we will be able to use carbon fibre.

6. References/Bibliography:

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