http://go.asme.org/HPVC

Vehicle Description Form (Form 6)

Updated 12/3/13

Human Powered Vehicle Challenge

Competition Location: LNM Institute of Information Technology, Jaipur, Rajasthan, India

Competition Date: 3–5th March, 2017

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 (VIT), Vellore

Vehicle name: Bolt

Vehicle number: 11

Vehicle configuration

Upright ______ Semi-recumbent X

Prone ______ Other (specify) ______

Frame material: Aluminium 6063 – T6and Aluminium 6061 – T6

Fairing material(s): Fiber Reinforced Plastic (FRP)

Number of wheels: 2

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

Length 94.43 in Width 21.63 in

Height 47.98 in Wheelbase 66.14 in

Weight Distribution Front 99.208 lbf Rear 121.25 lbf Total Weight 220.46 lbf

Wheel Size Front 20 in Rear 27.5 in

Frontal area 619.51 in^2

Steering Front X Rear ______

Braking Front Disc Rear Disc Both X

Estimated Cd 0.169

Vehicle history (e.g., has it competed before? Where? When?)

At the time of submission, Bolt has not competed before. It has been purposely made for competing in 2017 Human Powered Vehicle Challenge (HPVC) Asia Pacific.

VELLORE INSTITUTE OF TECHNOLOGY (VIT)

2017 Human Powered Vehicle Challenge Asia Pacific

DESIGN REPORT

TEAM ANANT

PRESENTS

BOLT

Vehicle #11

Team Officers:

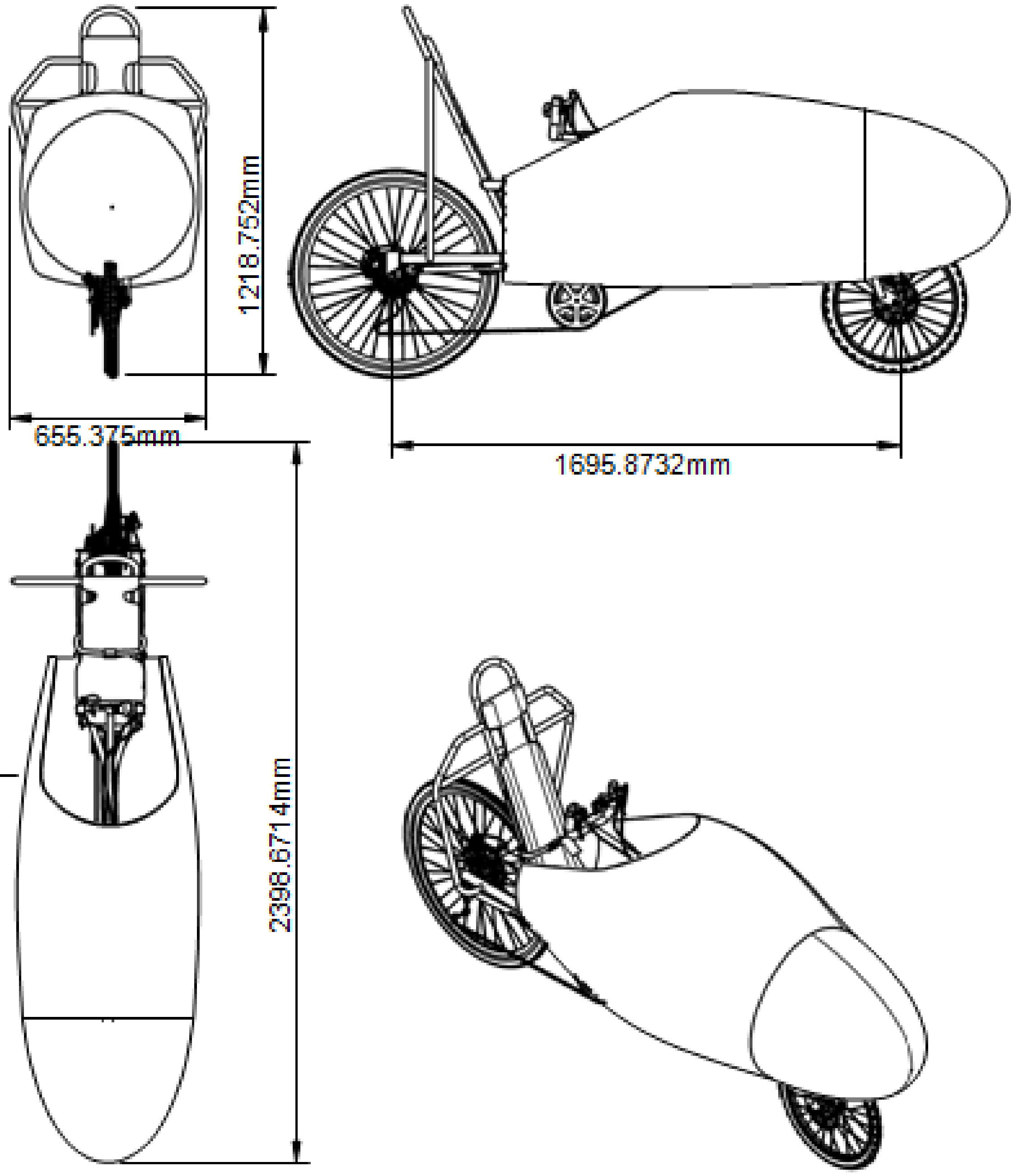
1) Gaurav Bontha, Captain
gauavbonta1995@gmail.com
2) Dhaval Kumar Patel
patel.dsp.0009@gmail.com

Team Advisor:

Prof. Jeyapandiarajan P.
Assistant Professor,
VIT University, Vellore.

Team Members

Gaurav Bontha	Mayank Dandotiya	Indraneel Choudhary
Rashmi	Dhaval Patel	Sabella Prasanna Kumar Reddy
Amit G. Dulange	Siddharth S. Narayanan	Keshav Pureha
Matthew George	Sanket Shetty	Shivangi Gupta
Hitesh Kesarla	Kaustav Chakraborty	Rohit Malik
Siddharth Kaira	Neha Benny Mathews	Shubham Todi



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Abstract

This will be the second time that Team Anant will be participating in ASME India’s HPVC, representing “Vellore Institute of Technology, Vellore”. In the aftermath of our performance in 2016, we decided that in order to build on our rank we needed a vehicle that is lighter and gives greater acceleration over short distances. Keeping this in mind our team decided to design, develop and manufacture our HPV named “BOLT” in the academic year 2016-2017 that excels in speed, efficiency, ergonomics and safety. It is a two-wheeler semi recumbent with a rear wheel drive and front wheel steering. The aerodynamic drag is reduced due to the vehicle being a semi recumbent one and the installed fairing that is developed using a hybrid of two NACA profiles 2424 and 0024. Thus, with same power input, we get greater speed and ensure rider safety.

Our team decided to use 6×1 gear system for power transmission and recycled Aluminium 6063 T6 for the chassis and other parts of vehicle due to its easy availability, less weight, less product energy and considerable cost. However, Aluminium has less mechanical strength as compared to steel, which is compensated with a design that ensures strength to the vehicle. We analyzed and tested thoroughly before and after manufacturing to support our claim. Our team performed analysis, computational modeling and physical safety tests to verify that the vehicle meets all the safety criteria required by ASME. For increasing the rider’s safety, we made RPS by bending a single long pipe hence decreasing the number of welds.

We developed an automated cornering support as an innovation to have high stability at expected riding speeds during curves and to prevent accidental tipping over while braking. With sound engineering and innovative minds, Team Anant presents BOLT as a step forward in human-powered vehicles. The developed design is a new design as compared below.

Photo comparison between Ashv-2016 and Bolt-2017

Contents

1 Design

1.1 Overview

Team Anant of Vellore Institute of Technology designed, constructed and tested BOLT during the 2016 academic year, based on the team motto “Onwards and Upwards”.
We have the goal of establishing stepping-stones to achieve better designs for human powered vehicles and manufacturing methods to ensure rider safety, speed, efficiency and affordability. We look forward to get better results from our HPV BOLT to make sure that we always put our best foot forward in order to present humanity, a vehicle that is very reliable for all needs of human and affordable so that it can reach even to common masses.
The designing and manufacturing of BOLT provided positive learning and working environment for students, so that they can use the gained knowledge, experience and spirit of team work for achieving their respective goals and contribute to the betterment of humankind.

1.2 Background

Due to lack of non-renewable resources and rising environmental problems, it is necessary to come up with a solution of travelling without worsening the condition of our already degraded environment. The conventional human powered vehicles like bicycles and rickshaw lack the practical applications for being used in day-to-day needs. Our HPV BOLT is faired to provide aerodynamic advantage to the rider that ensures more speed, less consumption of energy and more safety than a conventional bicycle, the RPS system used also ensure safety to the rider.
The innovation emphasizes on the safety of the rider by preventing the vehicle from losing balance. We also tried to reduce the overall weight of the vehicle by mostly using Aluminum 6063 T6, which is also affordable so that these types of HPV can come in practical use and being used by common folks.
We designed BOLT, keeping in mind the safety and ease of rider. The recumbent design makes it easy for the rider to ride longer distances without straining his or her back. BOLT has a storage compartment, brake lights, headlights as additional accessories for rider’s utility. Its design ensures minimal use of energy provided by the rider, more maneuverability, more speed, safety and affordable manufacturing cost. These features altogether make BOLT a more desirable vehicle than conventional bicycles and even automobiles due to urgent need to prevent nature degradation.

1.3 Prior Work

HPVC India 2017 will be the second time that the team is taking part in this competition, the previous time being HPVC India 2016. The team learnt from the mistakes it made while building the previous year’s vehicle, ‘Ashv’ and rectified the same while building this year’s vehicle, Bolt. Bolt was designed and manufactured from scratch for this year’s competition and as such does not contain any discernable similarities with last year’s vehicle. However certain steering and transmission calculations were utilized from last years’ design report to optimize the design.

1.4 Organizational Timeline and Planning: (As of Jan 19, 2017)

We truly believe that for a team to successful complete the project, proper planning of the various phases including Design, Analysis, Manufacturing and Testing processes are essential. Therefore the team utilized a Gantt chart (*Figure **19***) which was constantly updated to keep track of the delays in the development process. Following is the tabular presentation of our timeline (Date format- mm/dd/yy) which was deployed to develop the chart. The Timeline designed for the competition had to be shifted by two weeks due to certain regional and climatic reasons.

Task Name	Start	End
1. Discussion on past experience	**07/01/16**	**07/09/16**
2. Pre-Design phase	**07/11/16**	**08/08/16**
3. Design Phase	**08/09/16**	**10/03/16**
4. Analysis Phase	10/02/16	10/27/16
5. Manufacturing Phase	10/10/16	1/12/16
6. Testing	01/15/17	01/31/17
7. Safety Analysis	01/29/17	02/6/17

Table11: Organizational Timeline

1.5 Design Criteria

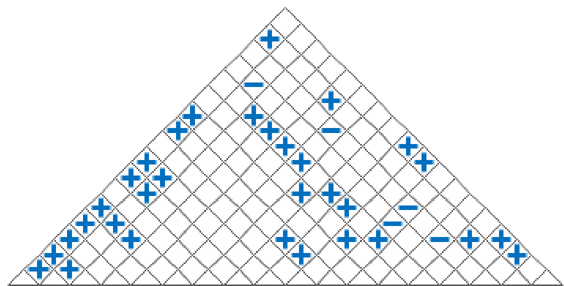
The team considered and abided by every design constraint for the design of 'Bolt' highlighted in the ASME HPVC rulebook 2017 along with the constraints laid out by the team. The constraints are plotted down in the table given below.

Criteria	ASME Constraints	Additional Team Constraints
Performance	Stopping Distance: 6 meters at(25 kmph speed)	Light Weight and Safe
	Turning Radius: 8 meters	High speed and acceleration
	Field of View: 180 degrees (min)	Low drag coefficient
	Low speed Stability: Straight line motion for 30 meters at 5-8 kmph	Comfortable Riding Position
	Storage Capacity	Drivetrain Efficiency
	New Design Entry	Constrained wheelbase
Safety	Roll Over Protection System:	Good Braking System
	Top load: 2670 N Deflection: <**5.1 cm** Direction: Applied at 12 degrees to the vertical	Helmet Requirements met
	Side Load: 1330 N Deflection: <**3.8 cm** Direction: At Shoulder Height Horizontally	Safe custom designed parts
	RPS Attachment: Structurally Attached	Stable Steering
	No sharp Edges	Innovative Landing Gear
	Harness: Safe and Firm	Chest and Lap Seat harness

Table 1: Design Criteria

The compiled constraints were used as an input for the development of the house of quality chart along with the experience gained from 2016 HPVC-India competition. Comparative analysis was also developed between the proposed design and 'The Ashv-2016' to improve and learn from failures experienced last year.

Quality Deployment Function used to build up the House of Quality chart:



House of Quality: Bolt		
+	Positive	+1
–	Negative	-1
	Strong	9
	Medium	3
	Weak	1

	Importance weight	Safe Structured	Rider Comfortability & Ease	Field of View	Roll Over Protection System	Proper Braking System	Turning Radius	Manufacturing Quality	Steering Stability	No Protusions, Sharp edges	Innovation	Energy Consumption	Harness Quality	Overall Cost	Specified Constaints	Drag Coefficient	Vehicle Dimensions	Low/High Speed Stability	Aesthetics	Comparison: Ashv (2016)	Target : Bolt (2017)
Improvement Direction		↑	↑	↑	↑	↑	↓	↑	↑	↓	↑	↓	↑	↓		↓	↓	↑	↑		
Light Weight	5	3	9					1				9		3						3	9
Drivetrain Efficiency	5		9									3		1			3			3	9
Stable Steering	4	3	3				3		9						3			9		9	9
Ergonomics and Comfort	5		9	3					1	9									1	3	9
Innovative	4	1					3	1			9	3		3	1					3	9
Factor of Safety	4	9	1		9	9	3		3	3	1		9		1			3		9	9
Overall Stability	5						9		9									9		9	9
Good Braking System	3		1			9														3	9
Aerodynamic Fairing	3			9				3		3				9		9	9		3	9	9
Frame material & Cross section	2	9			9			3		1		9		9						3	9
Manufacturing Time	2							9				9		3						9	3
High Acceleration	3																	3		3	9
Wheelbase	2		1				9		9											9	3
Design Reliabilty	3	9			9	3				1			1							9	9
Storage Capacity	1																3		1	3	3
Vehicle Configuration	2	3					1							3	1	9	9		1	1	1
Overall Cost	4	1				1		3		1	3	3	1	9					3	1	1
Absolute Score		122	156	42	81	76	101	54	116	75	52	120	43	125	22	45	63	102	29	89	116
Preferable Ranks		3	1	16	8	9	7	12	5	10	13	4	15	2	18	14	11	6	17		

Figure 1: House of Quality

The house of quality chart was employed to prioritize the design requirements based on the score gathered during the analysis. The chart was plotted by listing out the competition constraints and specifications along the column. The team requirements were plotted out along the row. Detailed analysis depicted that the vehicle design must be **comfortable, highly stable, safe structured, cost efficient and the energy consumption** during the whole process must be minimum. Based on the results the important design features were tabulated as shown in the table. The outlined features were considered positively to develop an efficient design.

Features	**Requirements**	**Expected Target and Solution**
Rider Comfort	Highly Comfortable	Prototype was developed to chart out the most comfortable riding position
Stability	Highly Stable	The team focused on the development of tip over prevention system. (Innovation)
Safe Structured	Safe Vehicle Design	Proper selection of frame material for reducing weight simultaneously achieving highly design
Cost Efficient	Effective	Performed Cost analysis to minimize the inflow
Energy Consumption	Checked	Performed Energy consumption Analysis to minimize the utilization

Table 2: Product Design Specification

1.6 Concept Development and Selection:

The design process assisted in laying out the basic requirements for the vehicle development. Several design concepts and alternative ideas were generated during the initial phase of the development process. The feasible ideas developed were then sorted out according to the team's requirement. To finalize the design concept and various other features Pugh's Selection Technique was deployed for the entire design. The design elements considered consisted of Vehicle configuration, frame material, frame cross section, prototype material, steering system and Drivetrain configuration.

1.6.1 Pugh's Selection Technique

a) **Vehicle Configuration:** The selection of a proper configuration was essential because the rider's comfort and ease of riding depends largely on the configuration. The data collected from the prototype was parameterized and further utilized to develop a unique design around the rider's desired position. This enabled us to filter out other considered options. Selection technique was deployed for finalizing the configuration out of the two best voted two wheeled designs.

Features	**Weightage**	**Compact Long Wheelbase**	**Short Wheelbase**
Comfort	5	1	0
Rider Safety	4.5	1	-1
Capsizing Stability	3.5	1	-1
Turning Ease	3	-1	1
Weight	2.5	0	1
Drivetrain Efficiency	5	1	-1
Relative Score		15	1.5

Table 3: Pugh's selection table for vehicle configuration

Analyzing the table we selected a compact long wheelbase vehicle configuration which according to our requirements holds a strong position compared to short wheelbase.

b) **Frame Material:** The frame material selection plays a great role in the performance of the vehicle. The aim of the team was to design a light weight vehicle therefore the options were reduced to wood, aluminium and carbon fiber which represented our goals. The criteria considered for the same were weight, strength and cost. The grade of Aluminium used for our vehicle is Al 6063 T6.

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c) Prototype Material: The prototype material was added into this selection list as it plays a crucial role in analyzing the overall energy consumption and cost analysis. We clearly had an idea of using a reusable and waste material which doesn't require much integration components and therefore minimizes the utilization. Two such materials were sorted out namely wood and PVC pipes. Metal prototype was discarded as it requires intensive energy to integrate the design. Selection Table helped finalizing the material.

Criteria	Weightage	Wood	PVC Pipes
Reliability	5	1	0
Energy consumption	4	1	1
Integration Ease	3.5	1	0
Relative Score		12.5	4

Table 4: Prototype Material

d) Steering System: The long wheelbase design made it awkward to use traditional steering system as it uses huge space and even interferes with the legs. The solution was to use universal joint steering, remote steering or a bevel gear arrangement steering. Studying the table below we clearly see that universal joint is a good option.

Criteria	Weightage	Universal Joint	Remote Steering	Bevel Gear
Weight	5	1	0	-1
Integration ease	4	1	0	-1
Manufacturing ease	3.5	0	1	-1
No. of components	3	1	0	0
Relative Score		15	6.5	-9.5

Table 5: Steering Design

e) Drivetrain Configuration: Last year we used a two sided chain configuration, changing the chain side at the intermediate bottom bracket. This year we came up with a simple solution to use one sided chain configuration which enables us to reduce rotational mass by removing a chain ring from the entire assembly and even achieve a stable design. The design selection was done utilizing the Pugh's selection table as shown below.

Criteria	Weightage	One Sided	Two sided	Single chain
Weight	5	1	-1	0
Rotational Moment of Inertia	4	1	-1	1
Integration ease	3.5	1	1	0
Stability	2	1	0	-1
Relative Score		12.5	-5.5	2

Table 6: Drivetrain Configuration

1.7 Vehicle Description:

The vehicle was designed based on the decisions made deploying the Pugh's Selection Method. The several critical design components were finalized and modeled in Solidworks. The complete model is shown in the figure below this section.

1.7.1 Main Frame

Keeping in mind the Long wheelbase configuration several parameters were gathered from the design criteria analysis before starting the design process. Model was prepared using circular cross section hollow pipe. Several designs were iterated and further three models were sorted out based on better rider comfortability. The decision was validated using the ergonomic data generation prototype. Three models were prepared for analysis before finalizing the design. The best out of those was selected. The Aluminium main frame has 32 mm outer diameter and 3mm thickness. Additionally primary frame has 22 mm outer diameter which was used as supports after locating critical points in analysis.

1.7.2 Roll over Protection System

The Roll over Protection System was designed keeping in mind the design constraints set by ASME-HPVC rulebook. The Roll over protection system has the same material as of the main frame so that it can be structurally attached to the frame which is must. Furthermore the dimensions are different. We have used 22 mm outer diameter aluminium pipe for the design. The above selected frame image incorporates the roll over protection design.

1.7.3 Fairing Design

The inclusion of fairing in the design was an important requirement for the team. This year the team was sure to use a light weight material for the fairing and for its skeleton in order to reduce the overall weight and thus increase performance efficiency. NACA profiles were studied to select and include it in the designing of the fairing according to our requirements. For the selection of the NACA profile for side view, we initially developed a rough estimated fairing that enclosed the structural design. Later the chord length was set. Then approximate maximum thickness was determined. Furthermore we were left with two options, whether to use symmetrical or chambered aerofoil design. Therefore to finalize the design several NACA profiles were studied to meet our thickness requirements and achieve desired down force. Accordingly a chambered standard design was selected. Similar procedure was followed for top view profile. However a symmetrical design was chosen that provides sufficient space for rider's comfort. The final standard profiles selected for the design are listed in the following table. The profiles selected were slightly modified to increase the manufacturing ease.

View	Profile	Specifications
Top View	**NACA 0024**	Max thickness 24% at 30% chord. Max camber 0% at 0% chord.
Side View	**NACA 2424**	Max thickness 24% at 29.7% chord. Max camber 2% at 40% chord.

Table 9: Aerofoil specification

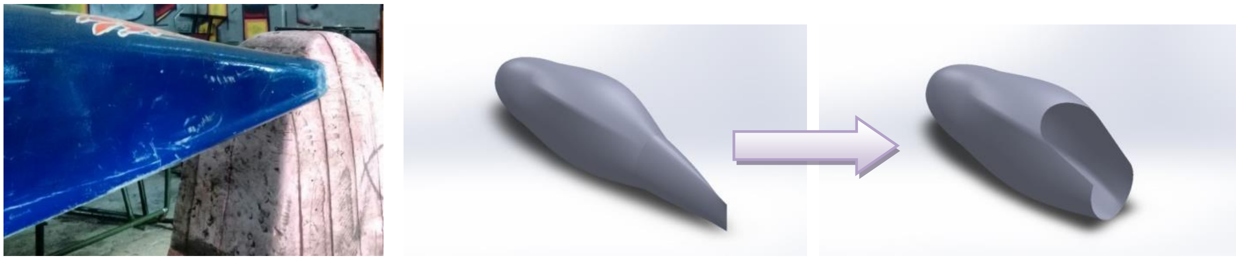


Figure 2: Fairing design and development

1.7.4 Steering Components Design
Universal Joint:
The universal joint was used in the steering system as depicted in the selection section. The joint was designed to fit our requirements. Assembly to the steering tube will be done using bolted design and therefore further analysis will show the practicality and safety of the assembly.

Fork Design:
Steering calculations from last year's design report were used to select values of trail, head tube angle and fork offset for better stability of the fork design. Fork model was prepared using a circular hollow aluminium pipe of outer diameter 32 mm and 3 mm thickness. The fork was bent and welded to the steering tube. Analyses have been done before finalizing the design.

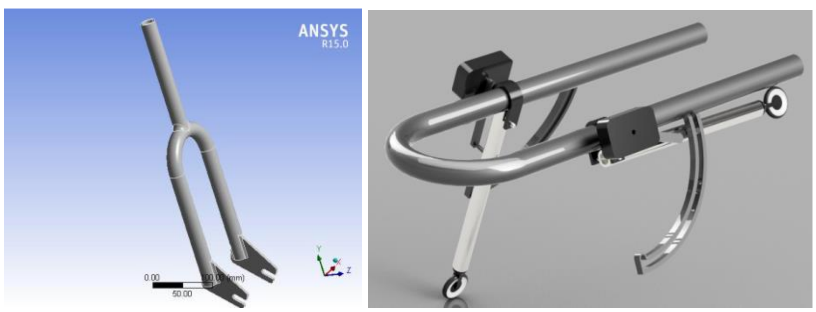


Figure 3: Fork and final Innovation Design

1.7.7 Innovation Design
The application area of innovation is the High Speed Turning Stability. A unique landing gear system was designed to implement the idea. The basic functioning of the system is to prevent the tipping over of the vehicle at high speed turning. A sensor senses a critical position and actuates the landing gear which further stops the leaning of the vehicle, thus preventing the vehicle from experiencing critical fall.

1.7.9 Other Essentials
Several other essential components and their integration were considered including safety harness belt, horn for effective communication between vehicles, brake lights, headlights for proper vision in night, Fairing mounts, side mirrors and side stand.

1.7.10 Practicality
The experience gained in 2016 HPVC competition helped us develop a practical design which can be manufactured before assigned deadline effectively and efficiently. The vehicle

manufactured is safe to drive in normal weather and environmental conditions. However, it might not function as expected on low traction surfaces and even on highly steep roads due to long wheelbase configuration.

Figure 4: The complete design

2. Analysis

2.1 Roll Over/Side Protection System

Objective	Analysis	Results
To demonstrate a valid RPS design	Finite element method was utilized to determine the maximum deflection on application of specified loads using Solidworks simulation.	The RPS sustained the applied load and successfully met the RPS specification.

2.1.1 Top Load Analysis

Approach	Results	Modification
Beam analysis was conducted. 2670 N of force was applied at an angle of 12 degrees from the vertical on top of the RPS pipe	The maximum deflection and stress observed was **1.03cm** and 153 MPa respectively. FOS: 2.00	To increase the load sustaining ability ribs were provided at the seat and rear fork intersection.

The RPS was modeled and simulated using Solidworks. Appropriate fixtures and loads were applied considering the constraints provided by ASME HPVC rulebook 2017. The results were analyzed and further modification of the design was done. Initially the deformation observed was around 4.4cm; hence ribs were inserted at required points to further lower the deformation. The deflection observed in the final design was around 1.03 cm which was well below the limit specified in rulebook. Hence the aim of achieving low deformation was accomplished. The supports added were for additional safety.

Unanticipated benefits: The supports added to enhance the strength also eliminate the need to weld new clamps for mounting fairing skeleton and hence further reduce weight.

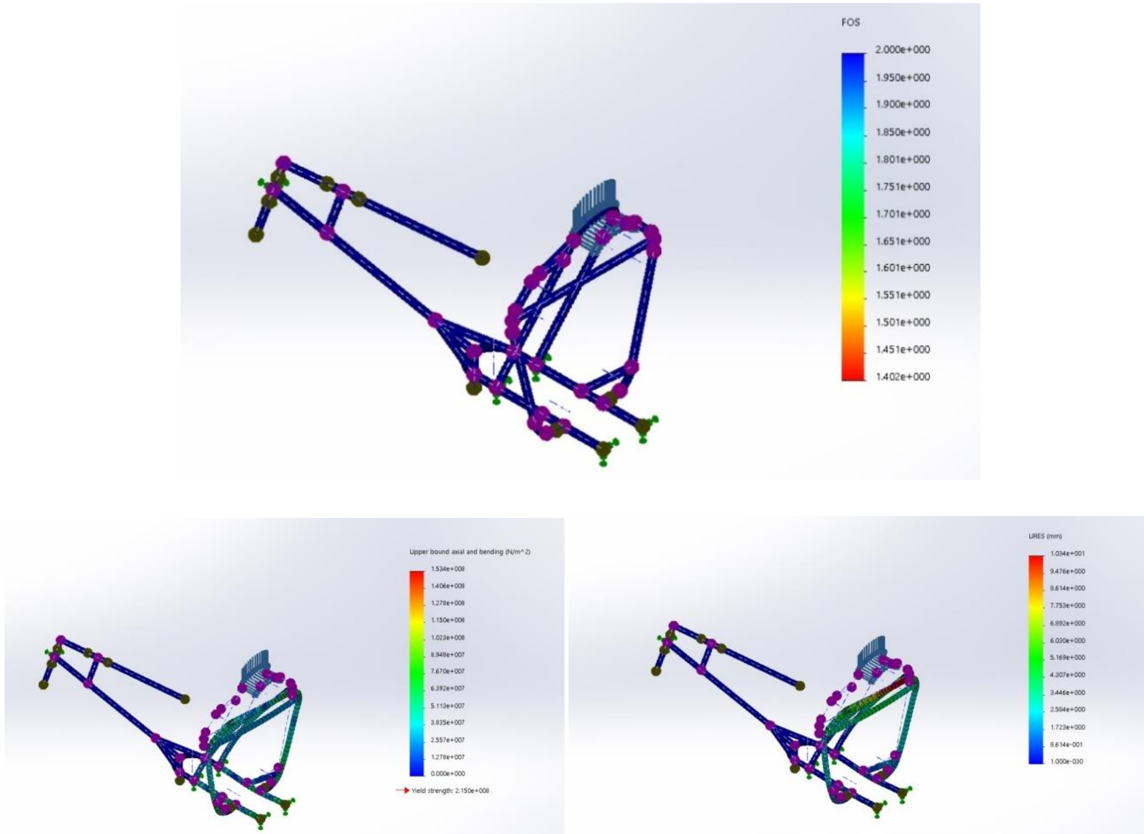
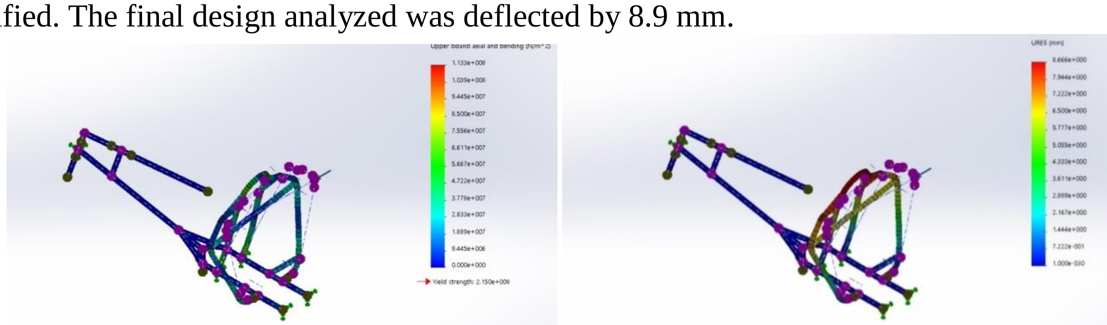


Figure 5: Top Load Analysis - FOS, Displacement and Stress in clockwise direction

2.1.2 Side Load Analysis

Objective and Analysis	Results	Modification
Analyze the design and further determine deflection on application of Side Load. Methodology similar to Top load analysis was applied.	The maximum deflection and stress observed was 8.7 mm and 113 MPa FOS: 1.87 Allowable deflection: 3.8 cm	To increase the load sustaining ability a rib was provided between the maximum points of the side RPS.

The setup followed was similar to Top load analysis. The results were closely observed. Initial deformation was 3.1 cm. Therefore to further increase the load carrying capacity the design was modified. The final design analyzed was deflected by 8.9 mm.



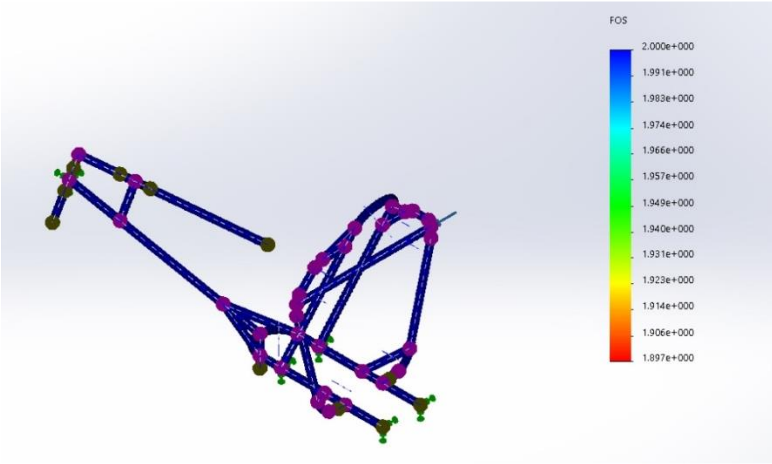


Figure 6: Side Load Analysis

The RPS as shown in the above analysis is able to sustain the loads mentioned and the deformation experienced is considerably low.

2.2 Structural Analysis

Objective	Methodology	Results
To design a sheltered frame, structural analysis was performed on the main beam and several frame components.	Analysis was conducted using Solidworks and Ansys. Proper design and practical worst case scenario constraints were modeled to obtain correct simulation results.	The frame sustained the applied loads including impact forces. Factor of safety plot was utilized to validate the safety of the design.

The structural analysis included the frame analysis, bottom bracket and rear clamp analysis. Beam analysis was conducted for the frame in Solidworks simulation. For the clamps and bottom bracket Ansys was utilized to analyze and modify the design wherever required.

2.2.1 Frame Analysis

Objective and Analysis	Results	Modification
To develop a lightweight frame that is able to withstand forces experienced during the competition. **Beam analysis** was conducted in Solidworks simulation and constraints were provided accordingly.	The maximum deflection observed 1.128 cm Maximum stress: 151.3 MPa Factor of Safety: 1.42 Goal achieved, FOS>1.3	The initial design had low factor of safety. Therefore to improve the design a triangulation was provided in the front part of the chassis.

The design was modeled in Solidworks taking into account several parameters decided during development phase. Three models were prepared before finalizing the design. Simulation was done to select the best out of those. Further complete analysis of the frame was done to find out the critical points in the chassis. The frame was analyzed for an overall loading of 1000 N which comprises of static as well as impact forces. Initial design selected was safe however the FOS (1.13) was considered low therefore a further triangulation was provided to improve the results and end up with a design that has a FOS > 1.3. The final design matches this set constraint.

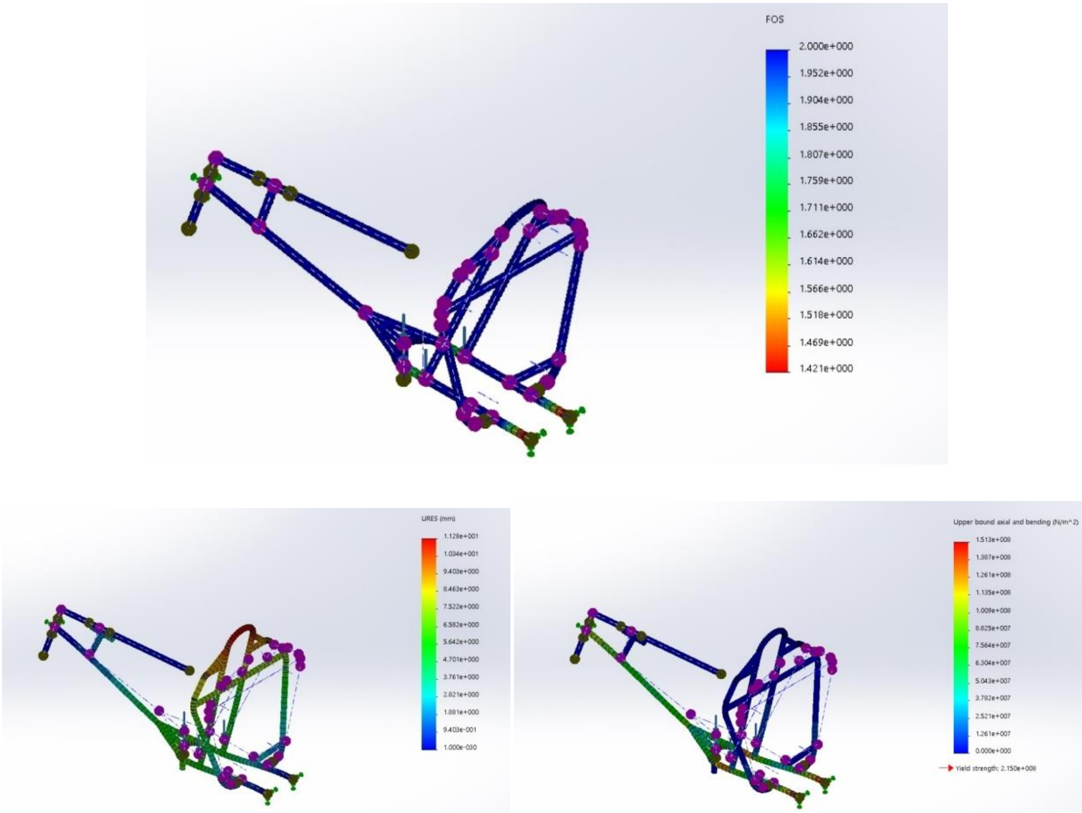


Figure 7: Structural Analysis- FOS, Stress and Displacement in clockwise direction

2.2.2 Rear clamp Analysis:

Objective and Analysis	Results
Rear Clamps: To inspect the viability of the clamps. Therefore Ansys simulation was utilized to examine the results and further qualify the design.	The clamp design was simulated against a vertical impact force of 1000N and a tangential braking force of 80 N. The FOS observed was greater than 4.3

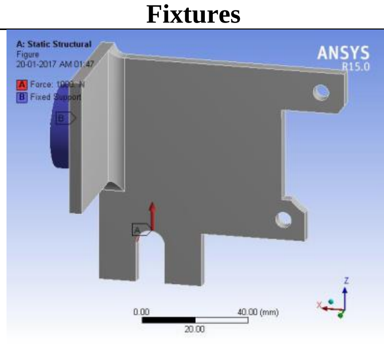
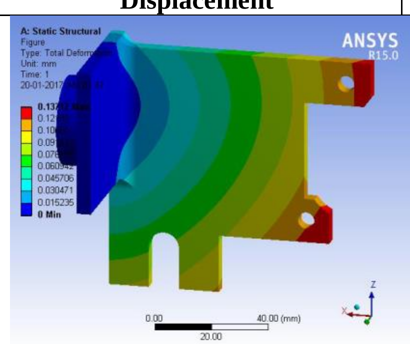
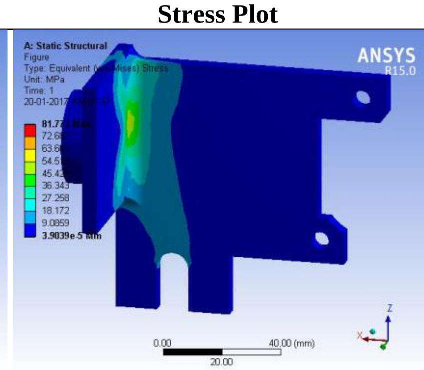
Fixtures	Displacement	Stress Plot
		
Fixed Support at the blue perimeter	Max: 0.13 mm	Max: 81.773 MPa.

Table 7: Rear Clamp analysis

Conclusion: The complete structural frame was analyzed thoroughly and modifications were added wherever required. Several other analyses were also considered which provided useful input in design finalization such as innovation analysis, bottom bracket, impact testing analysis and frame stiffness analyses.

2.3 Fairing Analysis

Objective	Methodology	Results
To determine the final fairing shape, the coefficient of drag and to perform cross wind analysis	Computational Fluid Dynamics was used perform the aerodynamic analysis using Solidworks Flow Simulation	Coefficient of Drag was calculated to be 0.169 and lean angle was calculated to be 1.6899°.

The main objective of this study is to determine the drag forces acting on the fairing and to calculate the coefficient of drag for the fairing. The basic shape of the fairing was determined by analyzing some basic NACA Aerofoil and using this analysis to find the aerofoil which was best suited for our fairing. The analysis was performed on an aerofoil analyzing software called XFLR5.

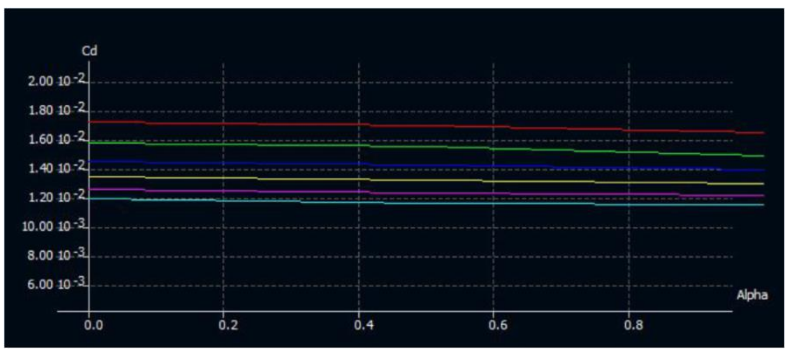


Figure 8: XFLR5 analysis

The analysis of NACA 2424 yielded the values of coefficient of drag between 1.2×10^{-2} to 1.8×10^{-2} under different setup conditions. The Cd value was found to decrease slightly with increase 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 modeled 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 25m/s (90km/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.

Fairing Analysis : Goal Results

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Normal Force (X)	[N]	10.15504639	10.16973218	10.14015212	10.19077815	100	Yes	0.005220799	0.228390244
GG Normal Force (Y)	[N]	14.70632039	14.74734199	14.67708688	14.796293	100	Yes	0.013491316	0.196297011
GG Normal Force (Z)	[N]	-0.3193658	-0.309765058	-0.353889536	-0.272848866	100	Yes	0.008060238	0.041018672

Iterations: 372
Analysis interval: 37

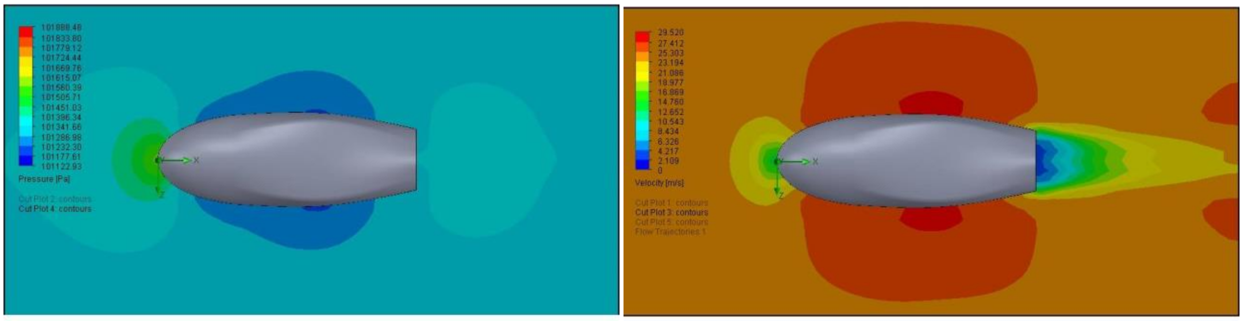


Figure 9: Velocity and pressure cut plots

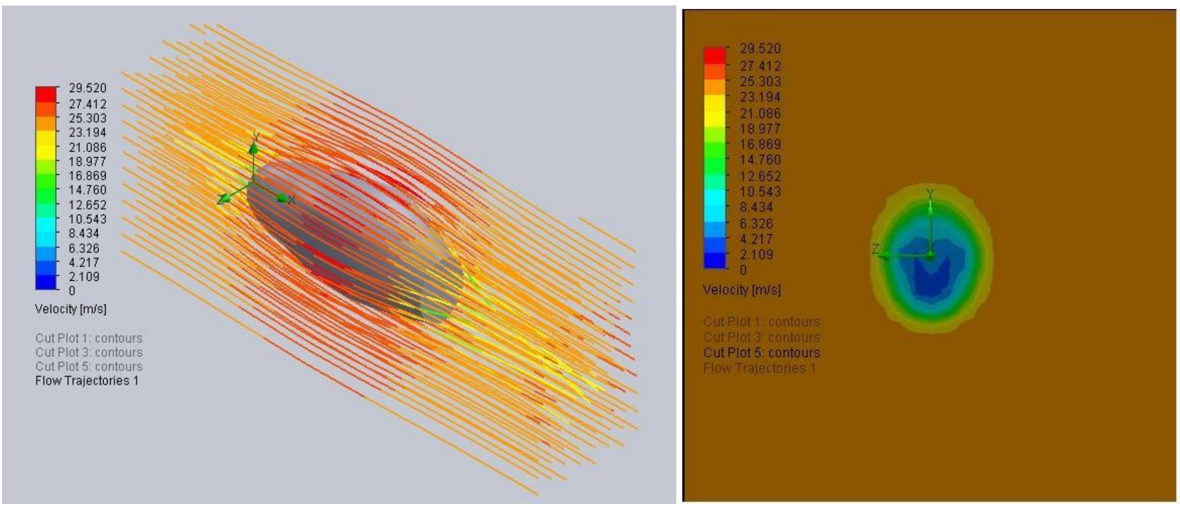


Figure 10: Vector Flow and Section View

Drag Force (N)	Frontal Area, m2	Coefficient of Drag, Cd
10.155	0.4	0.169

$$C_d = \frac{2\ .\ F_d}{\rho\ V^2\ A} = 2 * 10.155 / (1.2 * 252 * .42) = \mathbf{0.169}$$

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. Various cut plots were generated and flow trajectories were visualized for flow study. (*Figure 22*)

Cross Wind Analysis: Goal Results

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Normal Force (X) 1	[N]	-0.23941938	-0.24499409	-0.253540097	-0.239228727	100	Yes	0.01431137	0.014609991
GG Normal Force (Y) 1	[N]	-2.326552993	-2.296029262	-2.326552993	-2.243948146	100	Yes	0.082604848	0.097072868
GG Normal Force (Z) 1	[N]	-5.788488149	-5.783954182	-5.790540933	-5.779518486	100	Yes	0.006639029	0.091864916

Iterations: 136
Analysis interval: 26

Force	Value (N)
Fx	0.2394
Fy	2.3265
Fz	5.7884

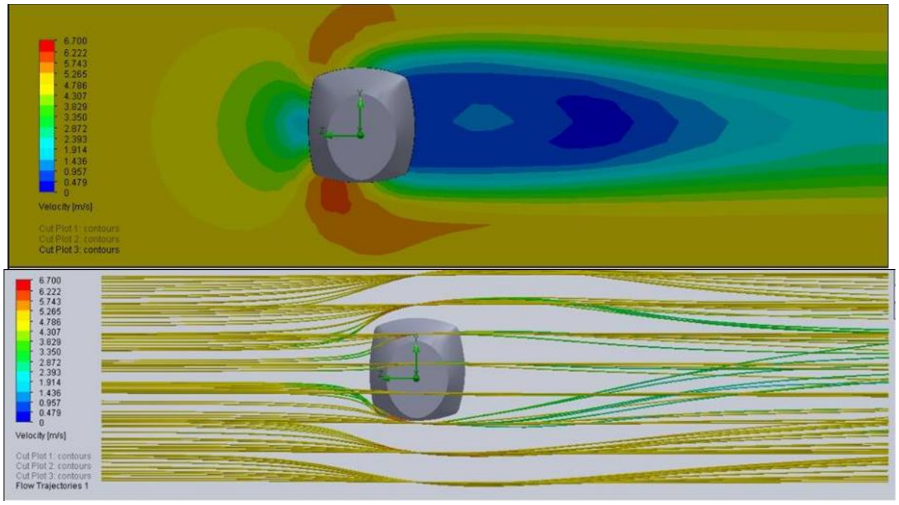


Figure 11: Side Flow analysis

Fd (N)	Mg (N)	Lean Angle, θ
5.7884	196.2	1.6899

Table 8: Results

The resultant force in cross flow direction was found to be 5.7884.

$\theta = tan^{-1}\frac{Fd}{Mg} = tan^{-1}\frac{5.7884}{196.2} = 1.6899°$

The lean angle is calculated to be 1.6899° which is very low and does not affect the reliability of the vehicle.

2.4 Cost Analysis

Objective	Analysis	Results
To analyze the overall cost of the vehicle and Examine the cash flow.	Development of a Cost sheet for lying out and adding up of various expenditures. An extensive analysis assisted in minimizing the overall cost.	The total overall cost of the vehicle amounts to Rs. 27222

The cost analysis was done through the use of a cost sheet which laid out every part and material purchased for the development of the vehicle. Cost incurred during purchase of materials, components, assemblies are as follows:

S. No.	Component Description	Rate (Rs.)	Quantity	Cost (Rs.)
A	**Materials**			
1	Aluminum Pipes (ϕ2.2cm)	320/m	2.2m	704
2	Aluminum Pipes (ϕ3.2cm)	340/m	3.2m	1088
3	Aluminum Billets (5*9*9)	6666666/m^3	0.000405m^3	2700
4	Aluminum Sheets (5mm)	6000/m^2	1m^2	6000
5	Fiber Reinforced Plastic (Seat)	834/m^2	0.6m^2	500
6	Fiber Reinforced Plastic (Fairing)	400/m^2	3m2	1200
B	**Components**			
1	Head set Assembly	170	1 set	170
2	Wheel Assembly	220	1 set	220

3	Wheels	2200	1 no(s)	2200
4	Transmission Components	1200	1 set	1200
5	Shifters	620	1 no(s)	620
6	Utilities	560	1 set	560
9	Safety Essentials	860	1 set	860
10	Electronics (Innovation)	3000	1 set	3000
C	**Operations**			
1	CNC Bending	-	-	5000
2	TIG Welding	-	-	1200
	TOTAL			**27222**

Table 9: Cost Analysis

Student labor excluded*

The above cost also includes market price of donated materials. The aluminium sheet was used from the left over plate bought last year.

2.5 Product Energy/CO2 Lifecycle Analysis

2.5.1 Materials:

We inquired various companies to get the estimate of energy used and CO_2 produced during manufacture of material.

S. No.	Component Description	Energy Consumption per unit mass (J/kg)	CO2 Production per unit mass (g/kg)	Mass (kg)	Total Energy Consumption (J)	Total CO2 Production (g)	Reusability	Recyclability	Disposability
1	Aluminum (Recycled)	11860000	2600	7.3	86578000	18980	Easy	Easy	Easy
2	Fiber Reinforced Plastic	17820000	860	0.2	3564000	172	Moderate	Hard	Moderate
3	Steel	16000000	4000	1.6	25600000	6400	Moderate	Easy	Easy
4	Rubber	2320000	3600	0.62	1438400	2232	Easy	Hard	Hard
	TOTAL	**48000000**	**11060**	**9.72**	**117180400**	**27784**			

Table 10: Materials Energy consumption

Total energy used in manufacturing of materials used by us is 32.55kWh and produced 27.78kg of CO_2.As Aluminum is the main material for the production of our vehicle, we used recycled Aluminum so that its production uses less energy as producing Aluminum from Bauxite requires 227-342 MJ/kg of energy while recycled Aluminum used by us required only 11.86 MJ/kg of energy.

2.5.2 Operations:

We noted the hours of operation and then multiplied it by the average power ratings of the operations.

S. No.	OperationDescription	Power Rating (W)	CO2 Production per hour (g/hrs)	Time for Operation (hrs)	Total Energy Consumption (J)	Total CO2 Production (g)
1	CNC Bending	3820	0	6	82512000	0
2	TIG Welding	4620	Negligible	5	83160000	Negligible
3	Lathe Operations	2700	0	7	68040000	0
4	Milling Operations	720	0	19	49248000	0
5	Drilling and Boring Operations	750	0	8	21600000	0
	TOTAL	**12610**	**0**	**45**	**304560000**	**0**

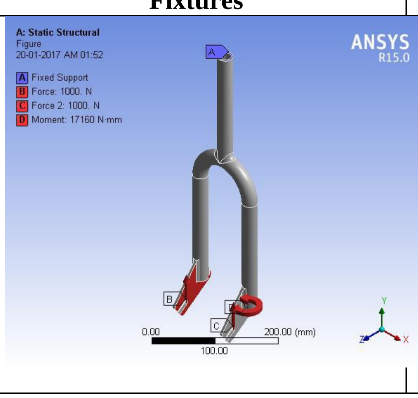
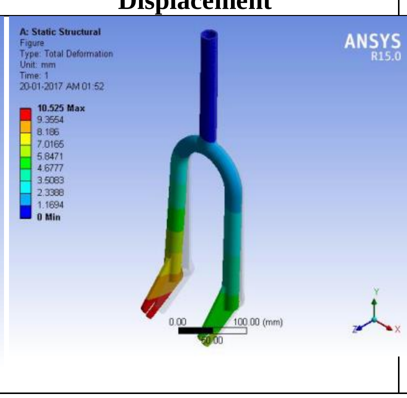
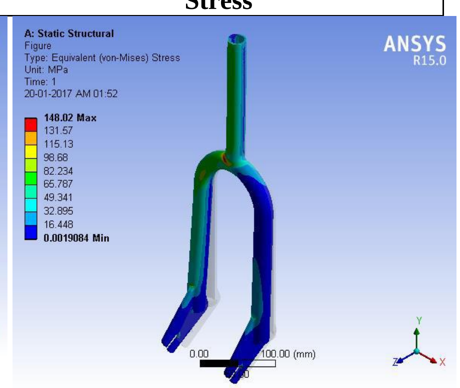
Table 11: Operations Energy consumption

Total energy used by different operations used by us is 84.6kWh and CO_2 produced is negligible. We preferred TIG welding because it produces less CO_2 then the oxy-acetylene welding.

2.6 Other Analysis

2.6.1 Fork Analysis

Objective and Analysis	Modification
The fork was analyzed to determine the factor of safety of the design. Ansys was used to analyze and determine critical areas of the fork.	The critical point of the design was the intersection of steering tube and the fork bend. To improve the factor of safety of the design a large fillet was provided at that point. In manufacturing three passes of TIG welding will be performed to improve weld strength around that point.

Fixtures	Displacement	Stress
		

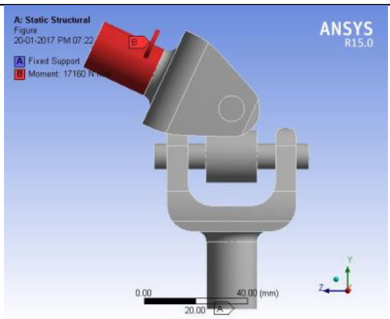
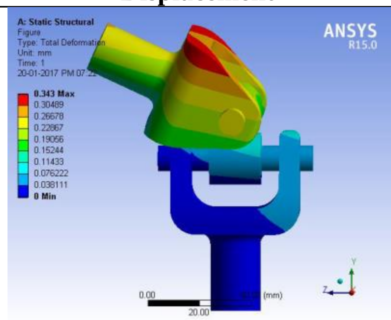
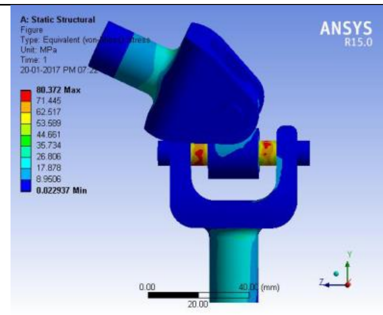
Result	Maximum stress	Maximum Displacement	FOS
Values	148.02 MPa	10.525 mm	2.12

Table 12: Fork analysis and results

The analysis was done keeping in mind the aluminium fork failure experienced normally. The upper part of the tube was fixed and 1000 N of vertical force was applied on each clamp representing the impact if the vehicle lands completely on the front wheel after jump. A torque of 15.8 Nm was applied which is calculated by considering the maximum cornering force that can be taken from the ground.

2.6.3 Universal Joint Analysis

Objective: To validate the universal joint design

Fixtures	Displacement	Stress
		

Result	**Maximum stress**	**Maximum Displacement**	**FOS**
Values	80.372 MPa	0.343 mm	3.47

Table 13: Universal Joint analysis and results

The design analyzed for the universal joint was safe and proceed able. The torque applied is similar to that applied for fork. The center portion was the most critical and therefore while manufacturing it will be kept in mind that there should not be any stress concentration at that point.

2.6.3 Transmission Analysis

Objective and Analysis	Discussion &Modification
To select appropriate gear ratio for efficient performance of the vehicle. Theoretical calculations were done to measure the required maximum torque. (*Figure **20***)	One side drivetrain configuration was selected. A triple chainring was selected at the intermediate bottom bracket having teeth ranging from (48-38-28). A single chain ring of teeth 40 was selected at the pedaling point. The selection of freewheel was done after conducting the acceleration test.

The transmission theoretical calculations were referred from the 2016 Team Anant design report and ratios were selected appropriately.

2.6.4 Brake Rotor Analysis

The front brake rotor will be designed and manufactured by the team as the rotors which are available (stock) in the market don't suit our requirements. Thermo mechanical analysis of the same will be presented in the improvement report. However the rear rotor is a stock component since there is not much braking required in the rear. The analysis will be performed in the Ansys

APDL software to incorporate the temperature dependence of mechanical properties. Matlab code was developed for brake calculations. (Figure 24)

3. Testing

3.1 Roll Over/Side Protection Testing

Objective	Setup and Analysis
To validate the RPS design and determine the actual deflection experienced by the RPS on application of specified load.	Machine : Universal Testing Machine (Strength of Material Laboratory) Analysis: Application and determination of load until deformation under constrained limit.

a) TOP loading Setup:

Methodology followed was similar to last year's testing system. Universal Testing Machine was employed. The lower part of the frame was fixed manually in such a manner that the top load applied is at an angle of 12 degrees. The load was gradually applied in steps. Initially the loading was performed till 1800 N. The frame was checked for drastic deformation. As it was safe to proceed, the next limit was set to 2600 N. The deformation imparted was analyzed. However the team decided to further apply the load in small steps to test the RPS for destructive failure. We considered it safe to apply an additional 200N and check for any drastic deformation. The results obtained were tabulated along with the FEA analysis and checked for correctness of the analysis.

Figure 12: RPS setup and testing

b) Side loading Setup:

Similar setup was executed to analyze the side protection testing system. One side of the RPS was fixed on the base of the machine. The other end was subjected to loads in two steps. Initially load was gradually applied till 800 N and the RPS was analyzed for deformation. As it was found to be under the safe limit, 1400 N was applied gradually. Additional 200 N was applied to demonstrate the strength of the RPS. The loading values were closely matched as specified in the rulebook. The loading values were more than the minimum required values due to limitations arising from the least count of the equipment.

Type of Testing	**FEA Results (Deformation)**		**Testing Results**	
	Without Ribs	With Ribs	Without Ribs	With Ribs
Top Load Testing	4.4 cm	1.03 cm	4.8 cm	To be done
Side Load Testing	3.1 cm	0.87 cm	2.9 cm	To be done

Table 14: RPS testing results compared with FEA results

Modification based on testing: To reduce deflection, ribs were added between the RPS and the seat pipe. This helps in reducing the deformation observed during testing and thus increases load carrying capacity of the RPS.

3.2 Developmental Testing

3.2.1 Geometry data generation prototype

Objective	Methodology	Results and Discussion
To develop a design that meets our decided specifications.	A geometry development prototype was idealized and developed to iterate several ergonomic positions and optimize it.	The prototype helped in iterating for several riding positions and therefore determines a design which has acceptable riding position.

The prototype was developed keeping in mind the rider ergonomic specifications determined by using the house of quality chart. The prototype consists of a simple system that resembles a basic geometry of the riding position. It was developed by reusing waste wooden material that could easily be machined as it required less electricity. The prototype was initially idealized by drawing the basic components required and finding a system that could incorporate an adjusting system- Recumbent angle is denoted by **α,** Seat Position from the BB is denoted by **X** and Height of BB from seat base is denoted by **Y.**

Unanticipated benefits of developing the prototype: Prototype coupled with transmission assembly helped us find position which is not only comfortable but even provides high power output.

Statistical Methodology:

The data collected was finalized to be the starting point of the design. However there was quite a variation in values. This data couldn't be averaged as it reduced rider satisfaction. Therefore Statistics was employed to solve the issue. Firstly three sets of data for various comfortable riding positions were tabulated for each rider. A variable was defined that had minimum deviation for different positions. That variable interestingly was identified to be the angle between the back rest and the line connecting the hip point to the bottom bracket center, **β**.

This angle was further noted during iterations and the mode was determined for this angle. The resulted angle was later incorporated in the prototype for further iterations. Several more readings were taken with bottom bracket height set as a constraint (15 cm) and the recumbent angle and complete riding geometry was finalized using the same technique.

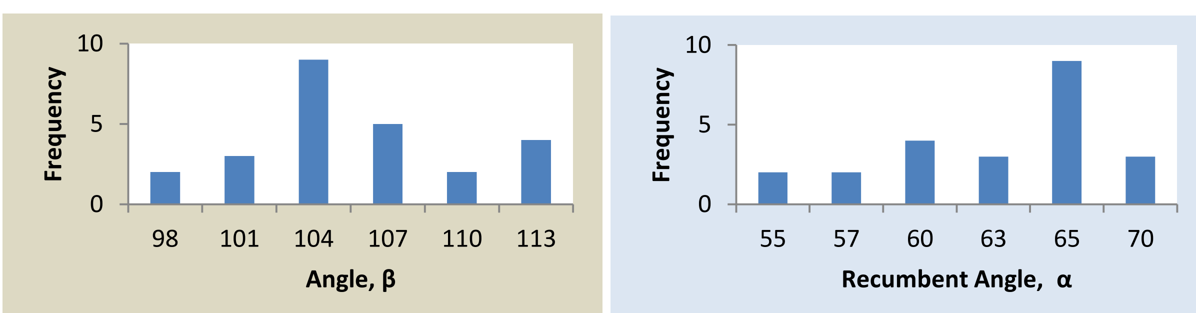


Figure 13: Histograms developed from the collected data

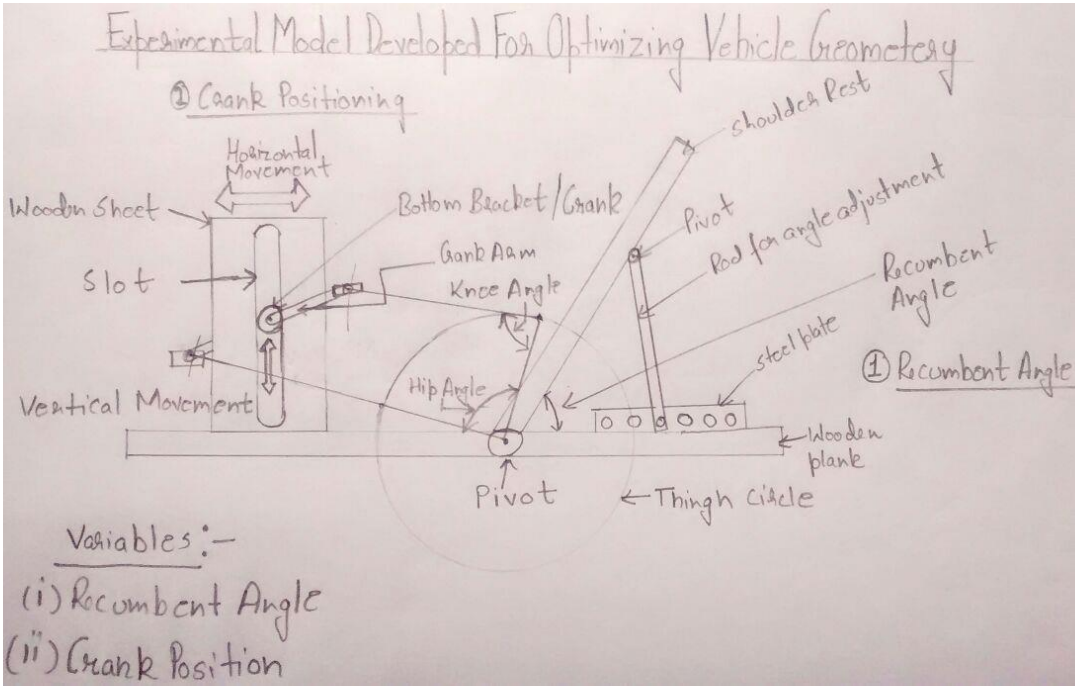


Figure 14: Prototype Development Drawing, the CAD model for the same was prepared for the estimation of wooden blocks needed.

Figure 15: Prototype

Conclusion: The **mode** was used to determine both the angles. Having set angle β and Y, X was approximately determined by using formula tan β= (Y/X) and verified for comfort using the prototype. Parametric table developer (*Figure* ***21***) Following is the table of final decided values.

Specifications decided	Result
Recumbent angle, α	65 degrees
Angle b/w backrest and line joining hip point to BB, β	104 degrees
Bottom Bracket (BB) height from seat base	15 cm
Bottom bracket to hip point distance	80 cm

Table 15: Finalized specifications of the geometry

Conclusion: The developed design was considered the most comfortable riding position.

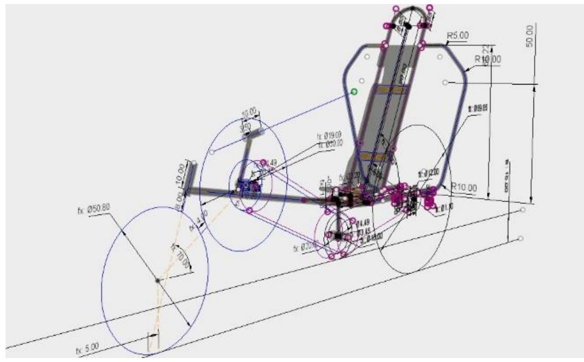


Figure 16: Final Geometry

3.2.2 Weld Test

Objective	Methodology	Results and Discussion
To compare the weld strength of GAS and TIG welding.	Machine: Universal Testing Machine Setup: Two different samples were prepared and tensile test was conducted.	The testing was successfully performed and results indicated higher strength of TIG welding

In the last year, gas welding process was employed to weld the chassis since there were no proficient welders near Vellore and the gas used in TIG welding is argon which is very expensive. We had to face great challenges during testing phase and thus to compare gas and TIG weld strength, weld test was deployed. Inference and results of the test were used to finalize the welding process.

Report No	: **1**	Date	: 16/09/2016
Competition	: HPVC'17		
Description	: Destructive testing of TIG, GAS Weld joints		
Ref Standard	:	Material	: Aluminium6061-T6
Instrument Used	:Universal Testing Machine	Material Thickness:3.23mm	
Quantity	:2	Welding Process	: TIG,GAS Welding
Cross-sectional Area : 158.8 mm^2		Type of Joint: BUTT WELD JOINT	

Table 16: Weld Test Description and Results

Sr. no	Weld type	Ultimate tensile force	Breaking tensile force	Ultimate tensile stress	Breaking tensile stress	Preference of usage
1	TIG Welding	14.4 kN	12.2 kN	256.16 N/mm^2	226.56 N/mm^2	OK
2	GAS Welding	10.2 kN	8.6 kN	165.12 N/mm^2	192.42 N/mm^2	



3.2.3 Frame testing

Objective	Methodology	Results and Discussion
To demonstrate the impact failure resistance of the welded frame	Setups were developed to proceed with the test. Potential energy along with added weight was used to provide the impact. Several runs were performed and the results were analyzed.	The test successfully validated the impact resistance of the frame.

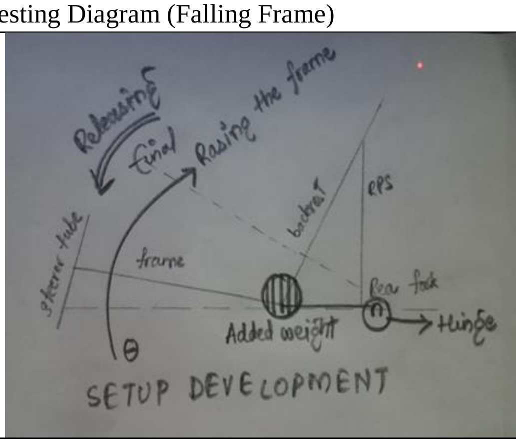
a) Falling frame Impact Testing

The falling frame impact analysis imitates the practical scenario of the vehicle falling from a reasonable height after sudden impact with obstacles. (Example impact load due to bumps). The initial drawing was developed to analyze the scenario and setup was organized to demonstrate the test. Slight deflection was observed at the cantilever type main beam. It was measured by determining the change in the main beam angle. Distance referred is measured from seat base.

Initial angle	Initial Distance	Final angle	Final distance
11 degrees	17 cm	9.5 degrees	15.5 cm

Tested Vehicle Frame	BOLT
Test Conducted	Falling Frame Test
Description	Mass was attached to the seat base and approximately at the COG with frame pinned at the rear axle. The front end was lifted above a hard surface and dropped causing an impact vertically upwards at the front end.
Setup	Mass added: 70 kg at hip point Release height: Balance point with frame at 40 degrees.
Result & Inference	PASSED: No visible cracks or fractures.No drastic alteration of the frame design but a slight variation in the angle of the main beam was observed. (1.5degrees)

Table 17: Falling Frame Impact Test Description and Results

<table>
<tr><td>Testing Diagram (Falling Frame)</td><td>Testing Setup</td></tr>
<tr><td>
</td><td></td></tr>
</table>

a) Frame Stiffness Test:

The frame stiffness test was essential to determine the frame stiffness. Rumble strip endurance challenge was also considered while performing this test. The determination of applied load was considered after studying forces that will be experienced by the frame and dividing them accordingly. Image of the setup shown on the next page.

Tested Vehicle Frame	BOLT
Test Conducted	Frame Stiffness Test
Description	The intermediate bottom bracket was **held** in the horizontal frame. 23 kilogram of weight was suspended on the front end of the frame. Similar load was applied at the rear clamp. Measurements were done in the vertical plane before and after the application of load.
Result	No visible cracks or fractures. Anglo meter was used to find the deflection in angle and further this angle was used to determine the vertical deflection imparted. Front end deflection: 3.8 cm — FEA result: 4.3 cm Rear end Deflection: 1.4 cm — FEA result: 1.8 cm

Table 18: Frame Stiffness Test Description and Results

a) Falling Mass Impact test:

Falling mass impact test was additionally performed to imitate a practical case. The test takes into account the forces imparted by the front fork on the frame due to impact load acting on it. Test setup was developed and the frame was tested by holding the frame vertical to the ground. Weights were released to provide impact load on the duplicate fork which further transferred the impact to the main frame. The table shows the test methodology.

Tested Vehicle frame	BOLT
Test Conducted	Falling Mass Test
Description	Allowed a mass of 40 kg to strike a pipe attached to the front head tube from a height of 300mm above the front end. The frame was rigidly held in the position using clamps as well as holding the RPS manually.
Setup	Striker mass – 40 kg Release height – 300 mm No visible cracks or fractures and no separation of any part of any system. The initial deformation measured at the wheel base : 20 mm where a solid-steel rod is fitted in place of a fork
Result	PASSED - Frame survived impact with no visible cracks or fractures. Post impact deformation in the wheel base was 35 mm approximately. FEA result: 43mm

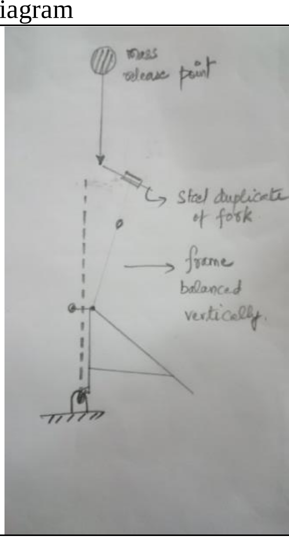
Testing Diagram	Testing Setup
	

Table 19: Falling mass Setup

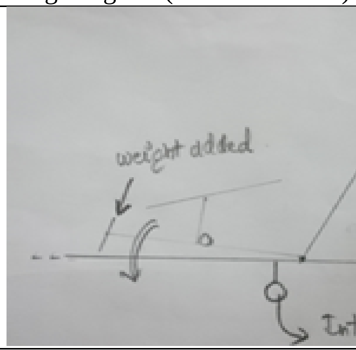
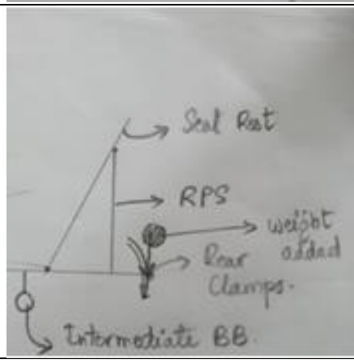
Testing Diagram (Frame Stiffness)	Testing Setup
	
	

Table 20: Frame Stiffness Test

3.2.5 Fairing Material Testing

Objective	Methodology and Description
To verify the selection of the fairing material and further optimize the number of bolts utilized to attach various section of the fairing	1) Application of paper friction theory to optimize the number of bolts. 2) Crush testing to validate the point load carrying capacity

The material used for fairing is a moldable light weight fiber reinforced plastic of thickness 2 mm. The fairing was divided into three parts which would be assembled using bolts. The material was selected due to its considerable point load carrying capacity. Point load was considered due to its bolting assembly with the skeleton. If it doesn't have good tearing and crushing resistance then the joints might fail due to fatigue and unexpected impact stresses experienced during accidents. The concept of friction between two similar materials was utilized (Example phone book friction).Additionally the concept assisted in reducing the number of bolts required to connect two parts of the fairing. Optimization of the idea further helped in reducing the overall weight of the fairing. Unstable points in the fairing were determined and a lap joint bolting was done at those positions to impart high stability in the fairing. Crush testing was performed by applying point load using bolts and weight (3 kg).

Test	**Result**
Crush Resistance	Sustained point load of 30 N
Optimization of number of bolts	Paper friction concept helped in reducing the number of bolts to one third of the initially expected amount.

Table 21: Fairing Material testing Results

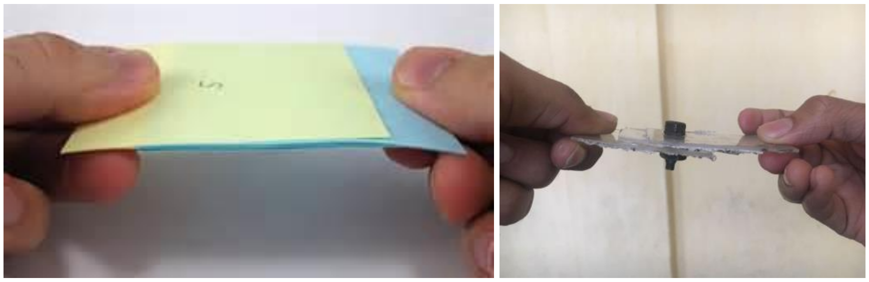


Figure 17: Fairing material testing concept and selection

3.3 Performance Testing

3.3.1 Maximum Acceleration for Drag Race

Objective	Methodology	Results and Discussion
To verify and select the best cassette suitable for higher acceleration during the drag race.	Three types of Cassettes were tested. Several runs were performed and timed accordingly. Mean time taken was tabulated and utilized for the selection of the same.	The test clearly helped us distinguish the selected cassettes. The most optimum one was finalized based on theoretical and practical results obtained.

The team experienced one of the most important things from last year's competition. To perform effectively in drag race good amount of acceleration is essential. To attain the best results three cassettes were tested for maximum acceleration. According to the ASME rules and regulations drag race course consists of 450 meters. The same distance was set as a constraint while testing and the time was noted for each run. The **mean** of the runs were tabulated and the best cassette was finalized.

The setup requirements mainly included cassette, and vehicle to be tested. As the testing was done right after the design phase to finalize the gear ratios and sprockets, Our previous year's hpv Ashv was utilized to collect the data. The results can be approximately matched with BOLT as they have nearly the same COG position with respect to the hip point. The collected data was simplified using mean of the time noted for a particular cassette. It turned out that 6 and 7 speed cassette gave almost same acceleration of about 0.2 m/s^2, while 9 speed cassette showed better results for longer distances, however failed to overpower the other two. The data was collected using a single rider throughout the test. Each cassette was tested on different days to fairly test the cassettes. The constraints considered along with the test to finalize the cassette are tabulated in the following table

Constraints	6-speed cassette	7-speed cassette	9-speed cassette
Acceleration	Decided from the data collected		
Weight	1	0	-1
Cost	1	0	-1
Speed	0	0	1
Relative Score	2	0	-1

Table 22: Selection Matrix for rear wheel cassette

Analyzing the nature of the competition, if a 9 speed cassette is utilized it won't reach its maximum output neither in the drag race nor in the endurance race. Observing the difference between 6 and 7 speed cassette it was outlined that they provide same final end gear ratios but differ in the step ratio while shifting. Focusing more on acceleration and weight a light weight cassette was selected which provides optimum acceleration for 450 meters.

3.3.2 Visibility Test

The rider’s performance and safety depends largely on the field of view during riding. Normally, for both eyes combined the field of view of a human eye is 200 degrees (horizontal) and 100 degrees (vertical). The vehicle was designed keeping this in mind. Furthermore a duck shaped fairing was eliminated to provide high field of view to the rider. Therefore 200 degrees of horizontal field of view can be easily achieved in the design. But due to the fairing this field of view is obstructed. It gets reduced by a certain degrees. The fairing is elevated by 55 cm from the seat base. Therefore the ground point till 5 meters won’t be visible to the rider. Solution for these as been outline in the table below.

Features	Result	Modification & Finalization
Horizontal field of view	200 degrees	To increase the field of view, rear view mirrors were added
Vertical field of view to the ground	13 degrees	To increase the field of view, transparent fairing was selected
Visible road point from the eye level	>5 meters	To have more visibility of the road in front, visible fairing chosen

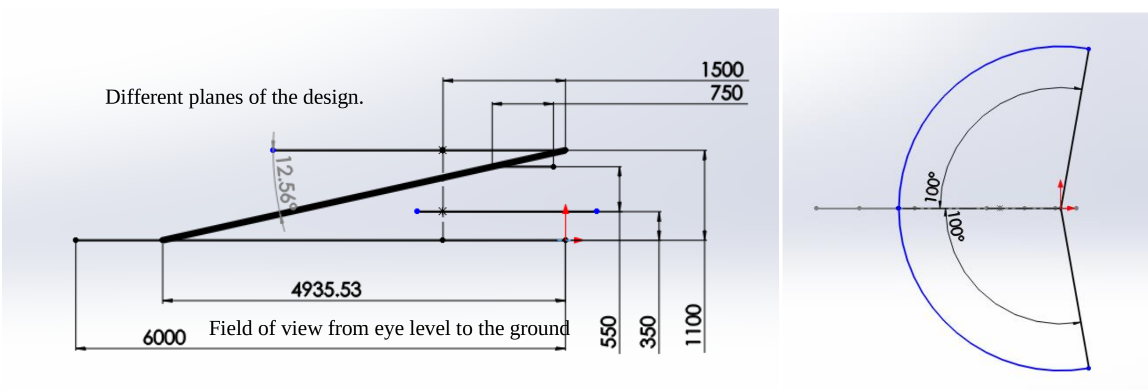


Figure 18: Field of View Testing

4. Safety

4.1 Rollover/Side Protection System

The Rollover Protection System ensures safety of the rider. It has been designed in such a way so that it can withstand forces encountered should the rider fall along with the vehicle. The RPS installed in BOLT is able to absorb sufficient energy in case of an accident to minimize chances of injury. The shape of the RPS is such that it can prevent significant body contact of rider with ground and provide adequate abrasion resistance to protect sliding along ground. To maximize safety, the RPS is bent instead of being welded which distributes force along its circular profile.

4.2 Sharp Edge, Protrusion or Pinch Point

While designing and manufacturing BOLT special attention was given to avoid any sharp edge, protrusion or pinch point that can hinder the safety of rider or anyone nearby. Any sharp edges produced during manufacturing were either chamfered, grinded or covered with rounded edging.

4.3 Seat Belt

In order to ensure that the safety of the driver is not compromised, a commercially available standard automotive seatbelt is used . The length of the belt itself has been chosen after physical examination with the rider present.

4.4 Safety Accessories

For passing signal and communicating with other riders on the road, BOLT is equipped with horn, headlight, taillight, braking lights and side reflectors.

4.5 Steering System

The steering system has been designed to ensure that there is no impediment while rotating the wheel. This will ensure that that safety of the rider is not compromised and also ensures smooth turning on sharper turns.

4.6 Indicators added to the vehicle

As additional safety feature of vehicle, the team decided to integrate indicators to signal the riders behind and avoid any fatal accident.

4.7 Hazard Analysis

Hazard analysis was an important step towards the development of a vehicle that is safe to ride. The following table was developed to highlight possible hazards and find optimum solutions.

<table>
<tr><th>Hazards</th><th>Possibility</th><th>Risk level</th><th>Description</th><th>Control Measures</th></tr>
<tr><td>Entanglement in moving parts</td><td>Moderate</td><td>Medium</td><td>Body parts, long hair, loose clothing and jewelry may become entangled in moving parts.</td><td>All moving parts in the vehicle are appropriately guarded.
Also, ensured that the mentioned parts are kept clear of moving parts.</td></tr>
<tr><td>Material may fall off</td><td>Minor</td><td>Low</td><td rowspan="6">Risk of injury due to:
▪ Mobility of the HPV;
▪ Crash or collision (e.g. at high speed);
▪ Brake or structural failure;
▪ Instability of the HPV (e.g. poor design/traversing a critical slope); and
▪ Operating environment (e.g. adverse weather conditions, terrain etc.).</td><td rowspan="6">▪ Low Centre of gravity to ensure stability of HPV.
▪ Incorporate appropriate safe design features (e.g. RPS, seat belt etc.).
▪ Ensure helmet, knee/elbow pads and appropriate footwear is worn
▪ Vehicle designed as per riders' compatibility.
▪ Ensured vehicle is compatible to be operated on different surfaces and environments.</td></tr>
<tr><td>Movement may become uncontrolled</td><td>Minor</td><td>Low</td></tr>
<tr><td>Vehicle may lose capability to slow down or stop</td><td>Minor</td><td>Medium</td></tr>
<tr><td>Vehicle may roll over</td><td>Minor</td><td>Medium</td></tr>
<tr><td>Parts may collapse or disintegrate</td><td>Minor</td><td>Medium</td></tr>
<tr><td>Contact with moving parts during testing, inspection, operation, maintenance, cleaning or repair?</td><td>Minor</td><td>Medium</td></tr>
</table>

Table 23: Hazard Analysis

5. Conclusion

Comparison:

Design Parameters	Testing Result
RPS(As per rule book)	Successfully passed
Aerodynamic	Cd of 0.169
Ergonomic	Sufficiently ergonomic
Weight	Weight reduction achieved via material selection and selection of circular tubes for chassis.

Evaluation:
As stated before our main goal was the reduction in weight and improvement of acceleration while maintaining rider comfortability and stability. We have succeeded to a significant extent with regards to this and believe we are well placed to improve upon the 7th place finish we achieved last time around.

Recommendations:
We believe that using carbon fibre could give us an added edge however due to its high price we could not afford it. However we hope that next time around we may be able to incorporate this material and build an even better vehicle.

6. References:

[1] www.recumbents.com Bicycling Science by David Wilson

[2] www.explainthatstuff.com

[3]Design Reports Rose-Hulman (2009-2014)

[4]Design Reports Olin College (2007-2014)

[5]Design Report – Team Anant – VIT University (2016)

7. Appendix

1. Gantt chart

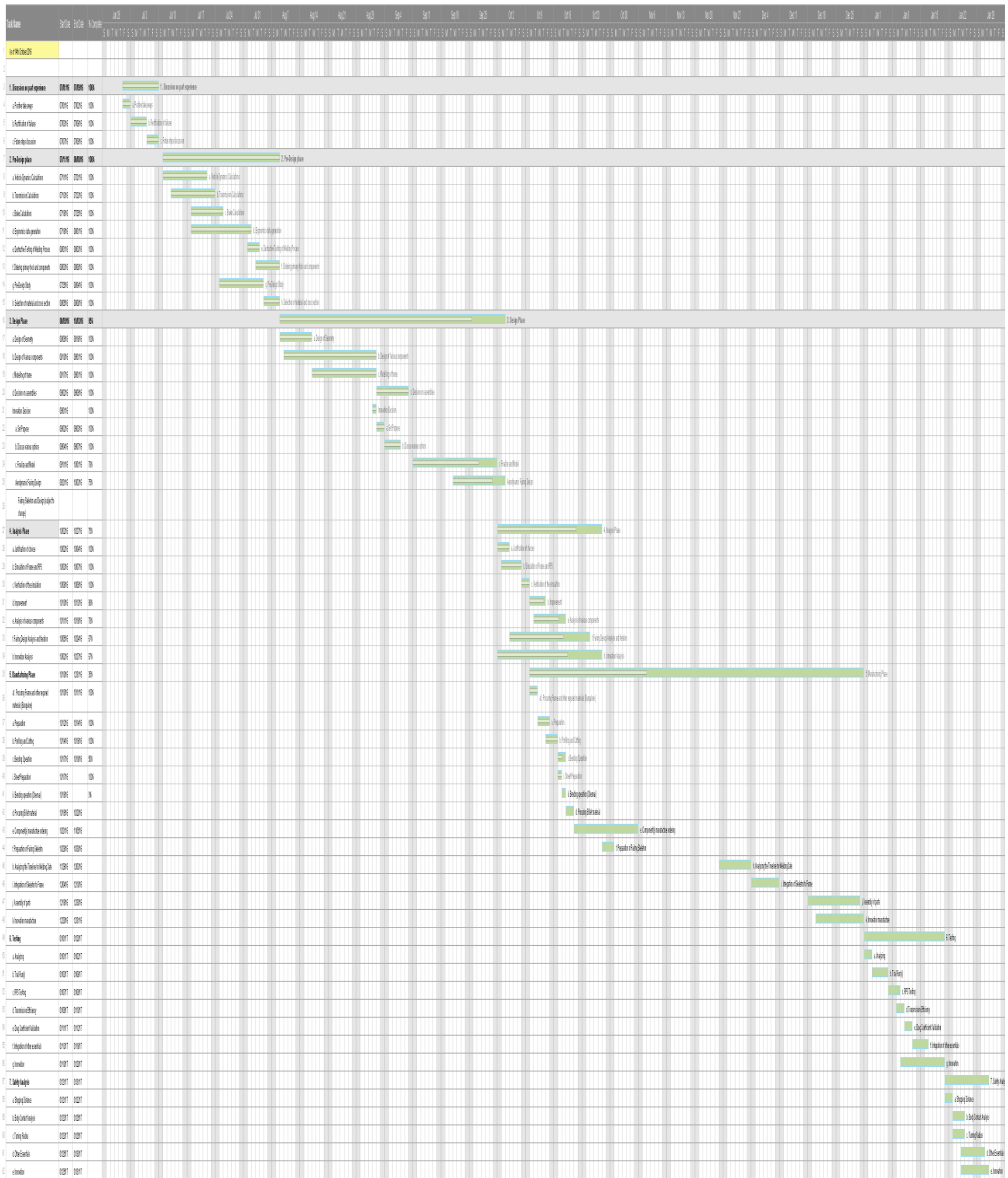


Figure 19: Gantt chart.

2. Transmission Analysis

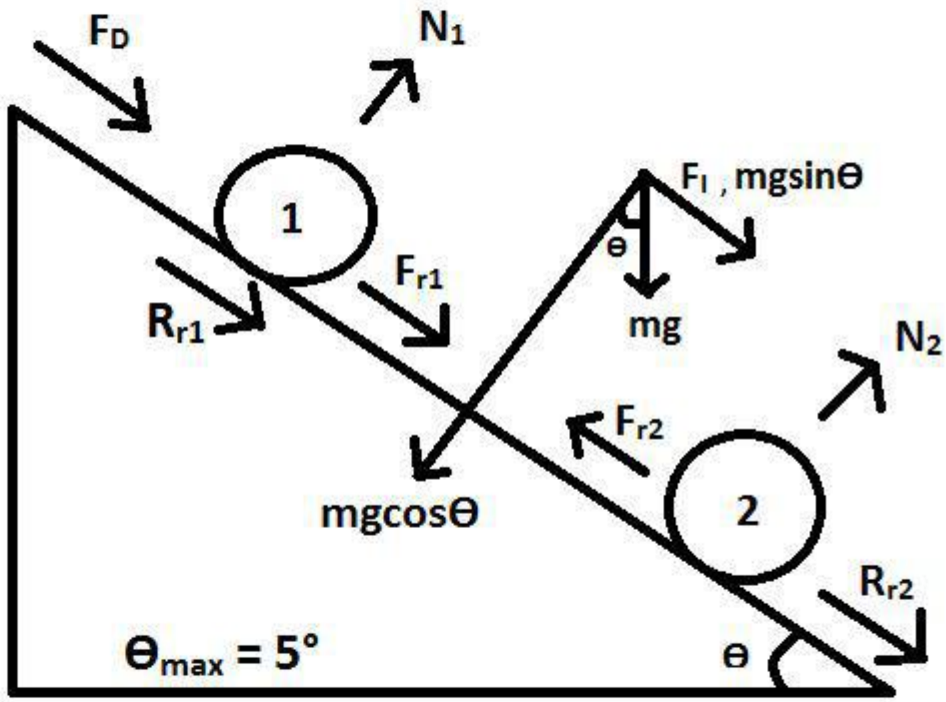


Figure 20: Free Body Diagram for Transmission

Calculations for θ=0 :-
Static situation:
$N_1+N_2=m*g$
$N_1*L = m*g*l_2$
$N_2=697.73$ N
$N_1 = 283.27$ N
Acceleration condition:
$N_2*L+-m*g-F_I*h=0$

$N_2=717.165$ N
$N_1=263.83$ N
Retardation condition:
$N_2*L-m*g+F_I*h+F_D=0$

$N_2=461.86$ N
$N_1=519.14$ N

3. Parameters Table set before starting the design

User Parameters					
User Parameter	Rearwheel	"	27.5 "	27.50	Aluminium rim#thin tyre
User Parameter	Frontwheel	"	20"	20.00	
User Parameter	Groundclearance	cm	16 cm	16.00	NOTHING below this limit#only wheels
User Parameter	Trail	cm	5 cm	5.00	Most common value#No mathematical identification
User Parameter	Headangle	°	70 °	70.00	Most common value#No mathematical identification
User Parameter	Pedallocus	cm	50 cm	50.00	Diameter of a imaginary circle made by the pedals
User Parameter	Panangle	°	12 °	12.00	Most common value#No mathematical identification
User Parameter	Backrestangle	°	65 °	65.00	Value obtained from prototype
User Parameter	Pedalreach	cm	75 cm	75.00	Value obtained from prototype
User Parameter	Clearance1	cm	4 cm	4.00	Minimum distance from pedallocus to front wheel
User Parameter	Clearance2	cm	6 cm	6.00	Minimum distance from backrest to rear wheel
User Parameter	Studdiameter	cm	1.1 cm	1.10	Hole in the rear clamp
User Parameter	Seatbase	cm	10 cm	10.00	Length of the seat clamp
User Parameter	PipeOR	cm	1.6 cm	1.60	Aluminium 6063 T6
User Parameter	Pipethickness	cm	0.3 cm	0.30	Aluminium 6063 T6
User Parameter	Rearclampsdistance	cm	14 cm	14.00	minimum distance between rear clamps
User Parameter	Neha	cm	168.91 cm	168.91	Height
User Parameter	Prasanna	cm	170.18 cm	170.18	Height
User Parameter	Siddharthkaira	cm	187.96 cm	187.96	Height
User Parameter	BottombracketID	cm	2.9 cm	2.90	Cup OD#Including thread height
User Parameter	BottombracketOD	cm	3.9 cm	3.90	As daval measured on a bicycle at INR
User Parameter	Clearance3	cm	8 cm	8.00	minimum distance from front wheel to front fork U
User Parameter	HTcenterlength	cm	10 cm	10.00	Random value
User Parameter	Backrestlength	cm	80 cm	80.00	Random value
User Parameter	Firstgeardiameter	cm	12 cm	12.00	Diameter#28 teeth#Left
User Parameter	Frontsprocket	cm	19 cm	19.00	diameter#44 teeth#Right
User Parameter	Intermediatesprocketright	cm	15 cm	15.00	Diameter#40 teeth
User Parameter	Intermediatesprocketleft	cm	20 cm	20.00	Diameter#48 teeth

Figure 21: Parametric table

4. Aerodynamic Analysis cut plots

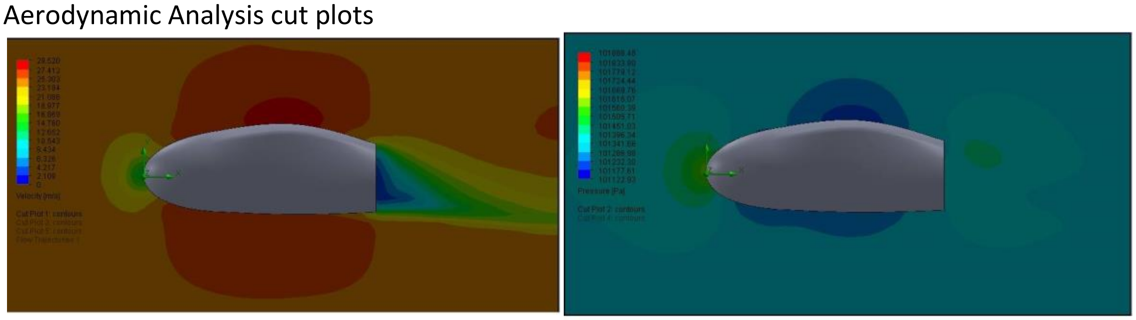


Figure 22: Side view cut plots

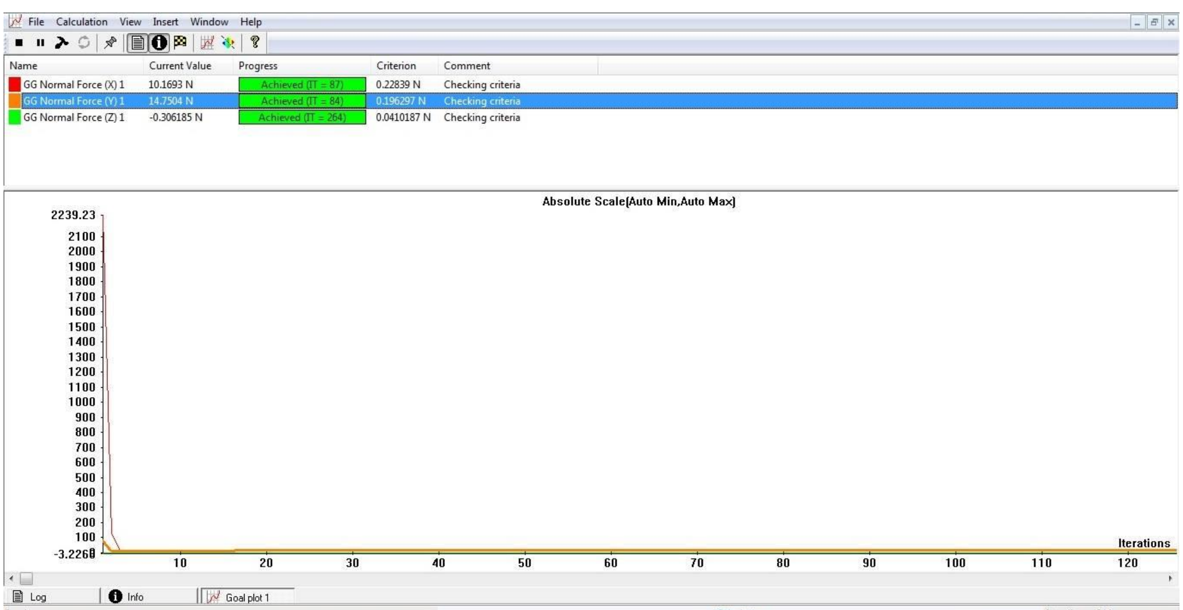


Figure 23: Convergence plot

5. Matlab Code for brake analysis

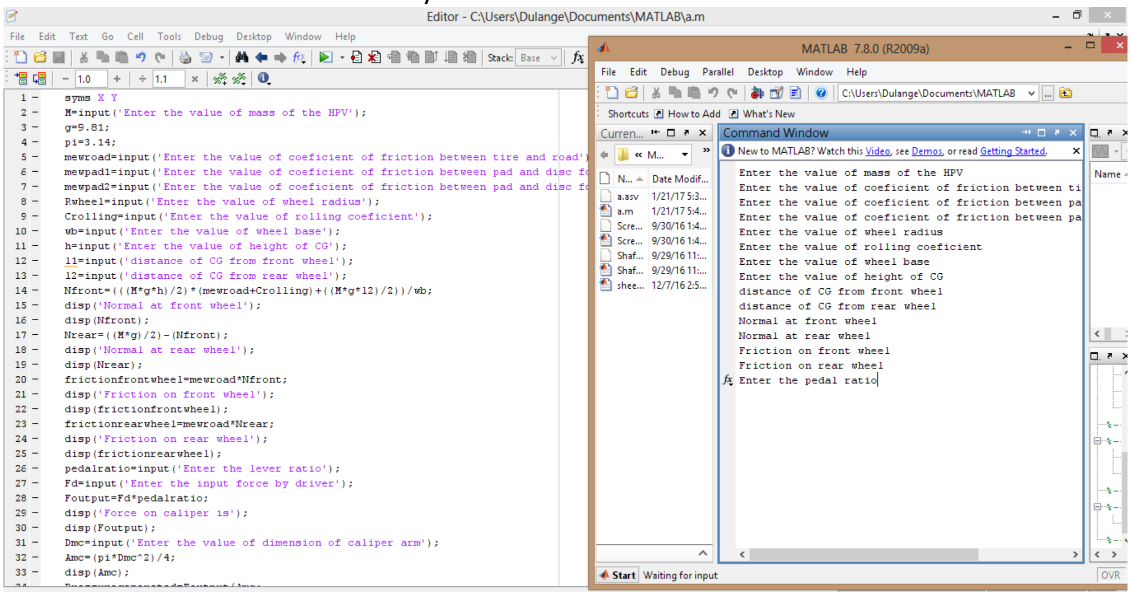


Figure 24: Matlab Code