ASME Report Cover Page & Vehicle Description Form

Human Powered Vehicle Challenge

Competition Location: Vellore Institute of Technology, Vellore, India

Competition Date: February 01-03, 2019

http://go.asme.org/HPVC

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

Vehicle Description

School name: Vellore Institute of Technology-Vellore

Vehicle name: Derby

Vehicle number: 01

Vehicle configuration

Upright ________ Semi-recumbent ✓

Prone ________ Other (specify) ________

Frame material: Aluminum 6061-T6 and Aluminum 6063-T6

Fairing material(s): Glass Fiber 7-mil bi-direction

Number of wheels: 2

Vehicle Dimensions *(please use m, m^3, kg)*

Length 2.146 m Width 0.722 m

Height 1.43 m Wheelbase 1.12 m

Weight Distribution Front 8.5 Kg Rear 9.8 Kg

Total Weight 18.3 Kg

Wheel Size Front 0.508 m Rear 0.6604 m

Frontal area $0.625\ m^2$

Steering Front ✓ Rear ________

Braking Front ________ Rear ________ Both ✓

Estimated Cd 0.1527

Vehicle history (e.g., has it competed before? where? when?) -N/A-

VELLORE INSTITUTE OF TECHNOLOGY (VIT)

2019 Human Powered Vehicle Challenge Asia Pacific

DESIGN REPORT

TEAM ANANT

Presents

DERBY

Vehicle Number 01

Team Officers

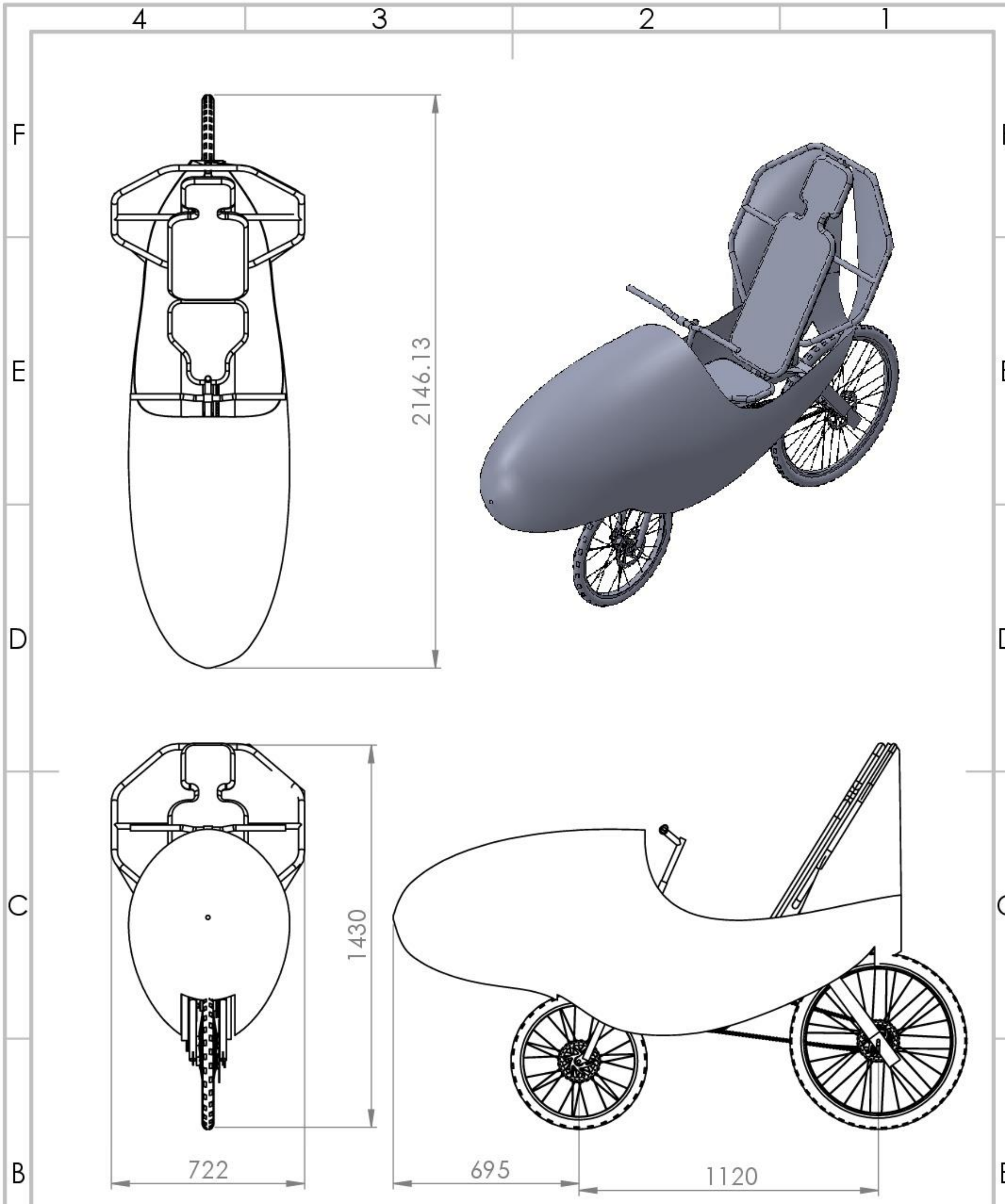
Rohit Malik, Captain (rohit.malik24071996@gmail.com)
Siddharth Kaira, Vice-Captain (siddharth.kaira16@gmail.com)
Ajinkya Zanzane, Manager (ajinkyazanzane@gmail.com)

Team Advisor

Prof Jeyapandiarajan P
Assistant Professor
VIT-Vellore

Team Members

Rohit Malik	Siddharth Kaira	Ajinkya Zanzane
Avik Dutta	Gaurav Prakash	Pratyush Shrivastava
Shivam Kenche	Shubhra Iyer	Sourabh Dubey
Sujay Singh	Vignesh Raman	Xitij Detroja
Devika RB	Shruthi Krishnamurthy	Anirudh Katoch
Sanjay M	Siddharth	Swapnil Mondal



TEAM ANANT

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	ROHIT MALIK		
CHK'D	SUJAY SINGH		
APPV'D	SIDDHARTH KAIRA		
MFG	VIGNESH V RAMAN		
Q.A	AVIK DUTTA		

MATERIAL: AL 6063-T6
GLASS FIBRE 7 MIL BI-DIRECTIONAL

WEIGHT: 18.1 KG

TITLE:

HPV DERBY TEAM ANANT

DWG NO.

Final Assembly

A4

SCALE:1:20

SHEET 1 OF 1

Abstract

Team Anant of VIT, Vellore has developed Derby in order to participate in the Human Powered Vehicle Challenge 2019. This design report contains details from the initial ideology until the manufacturing phase. As the team is participating in the event for the fourth time, the areas of importance were easily identified, and worked on. After a lot of modelling, simulations and testing, the design of derby was validated.

The semi-recumbent, 2-wheel design was adopted due to its high stability and speed. The frame was designed using aluminum 6063-T6 rectangular hollow section tubes, while the supports/reinforcements were manufactured from aluminum 6061 sheets. Derby comes with an RPS made from the same grade aluminum round tubes in order to protect the rider in case of a rollover. All the parts were made of the similar grade of aluminum, due to suitable physical properties and ease of welding process.

Various comparative studies were done using Pugh's Charts. An FMEA chart was made and analyzed for safety hazards. Based on the results of the above comparisons and analysis, the manufacturing process of Derby was modified in order to reduce the overall manufacturing time and to ensure the strength of the parts, in order to avoid any failures.

Derby contains partial fairing based on a hybrid NACA profile (2028 and 2424) that was optimized to match the dimensions of the vehicle and provide an aerodynamic shape to the vehicle. The vehicle also provides a 280 degree of visibility. A double-sided transmission system providing an 8x3-speed transmission system was decided.

Innovation for the vehicle constitutes a sequenced gear shifter mechanism that eliminates the use of gear shifting cables and mechanical mechanism and introduces sensors and actuators (stepper motors) to serve the purpose and eliminates the need of driver to remember the shifting sequence.

Figure 1: Rendered Model

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1. Design

1.1 Objective

Table 1: Objective Table

Goal	Objective	Previous Vehicle Drawbacks
Overall Weight of Vehicle	Bring weight down to 20kg	Due to heavy weight of our previous vehicles, our riders felt tired and it affected their performance in the endurance races.
Addition of Safety features	Improve the overall safety of our riders	Steering discomfort; Too small height for steering, which led to taller rider’s knees hitting the steering.
Cost Reduction	To reduce the overall cost of our vehicle	Due to an initial failure of the bottom bracket, we had to redo the welds after cutting the old bottom bracket.
Manufacturing Time Optimization	To reduce the overall manufacturing time to about 3 weeks	Due to the long manufacturing time, we had to cut short on our rider’s practice time.
Vehicle Speed	To improve our vehicle’s overall speed	Considering last year’s performance, we found scope for improvement.
Fairing Manufacture	To use suitable NACA profile and proper glass fiber composites in order to manufacture an aerodynamic fairing	Fairing was too heavy and we did not use it in drag for the said reason.
Following the ASME HPVC 2019 Rules	Adhering to the new rule book for ASME HPVC 2019	In all our previous events, we had adhered to the rulebook and are planning to do so in the following event as well.
Improving the final gear ratio and the number of gear shifts	Increasing the gear ratio to 7 and increasing the number of gearshifts to 24 (3 front, 8 rear).	Last year our gear ratio was 6.2, which we found was not enough, and the shifts were not smooth enough.

1.2 Background

This year, the team decided to go back to the roots for better understanding and more improvement of the vehicle. Therefore, we referred to different books and journals on the Human powered vehicle for better conceptual design and improvement in team's strategies and techniques, which resulted in the reduction in non-value adding activities. Initially, we referred to the "HUMAN POWERED VEHICLE DESIGN: A CHALLENGE FOR ENGINEERING EDUCATION" for the better understanding of HPVs. Other than that we referred to "Product, Design and Development", "Engineering Design Methods", "The design of everyday things", "The Aerodynamics of Human-powered vehicles", "The Role of Human Powered Vehicles in Sustainable Mobility" and "Bicycle design: A different approach to improving on the world human-powered speed records". Other than that, we also referred to some online references "http://www.whpva.org" and "http://www.velomobiel.nl". These references enhanced the team's productivity and helped us to improve the quality of our vehicle.

1.3 Prior Work

Derby's concept is an evolution of basic design geometry of our earlier vehicles. We altered our manufacturing processes, and testing techniques that helped improvise our vehicle. For instance, in welding, we profiled our components such that two joining components have maximum surface area in contact. Progressive ideas used in composition and mounting of fairing has been used in derby. The pace of our vehicle has been improved by altering the final gear ratio. Changes were made in the seating position ensuring the rider's comfort, which was a minor setback in the former vehicle. Developments made in the aerodynamic design of the fairing are used to manufacture fairing out of composites: glass fiber. The market surveys conducted during the development of previous year vehicles helped us save time and money.

1.4 Organizational Timeline and Planning (As of Dec 18, 2018):

For our team to optimally complete the task, proper arrangement of the various steps including design, analysis, manufacturing and testing are essential. We used a Gantt chart (Appendix Fig. 08) for the same which was always refreshed to monitor the postponements in the advancement procedure. Following is the table representing our course of events, which was utilized to construct the graph. We were able to adhere to the timeline because of the dedication and sincerity of our team members.

Table 2: Organizational table

	Task Name	**Start**	**End**
1.	Discussion on past experience	26/03/18	07/04/18
2.	Pre-Design phase	16/07/18	03/09/18
3.	Design Phase and Analysis phase	04/09/18	18/10/18
4.	Manufacturing Phase	19/10/18	15/12/18
5.	Testing	16/12/18	10/01/18
6.	Safety Analysis	11/01/19	24/01/19

1.5 Design Criteria

Requirements and design specifications were decided based on the background literature ([1], [2], [3]). The whole team gets involved in the process in order to express all the possible approaches and get in depth in all new aspects of competition. Rulebook assigned by ASME is studied and analyzed thoroughly according to which the design is made. The team has followed every design constraint for design and corroboration of our HPV 'DERBY' as stated by ASME rulebook 2019 along with some supplementary measures put up to advance a better HPV. (Table 03).

Table 3: Design criteria by ASME

CRITERIA	ASME REQUIREMENTS
PERFORMANCE	DEMONSTRATION- Stopping: Within 6.0 m distance with a speed of 25 km/h Turning Radius: 8.0 m radius Stability: Travelling in a straight line for 30.0 m at 5-8 km/h speed (fast paced walking speed) New design entry Storage capacity
SAFETY	ROLLOVER PROTECTION SYSTEM (RPS)- Top load: 2670 N

	Deflection: <5.1 cm [Direction- applied at 12 degrees to the vertical] Side load: 1330 N Deflection: <3.8 cm [Direction- at shoulder height horizontally] RPS attachment: Structurally Attached No sharp edges Harness should be safe and firm

Table 4: Design criteria for team

CRITERIA	TEAM REQUIREMENT
PERFORMANCE	High Speed and acceleration Constrained Wheelbase Low Drag Coefficient Drive-train proficiency and reliability Comfortable ergonomics Change in seating position for driver's comfort Advancement in fairing design and material for improved aerodynamic properties
SAFETY	Stable and reliable steering Light weight and safe Safety analysis of custom designed parts Improvised braking system Helmet and safety equipment required Wide viewing solid angle for rider Chest and lap seat harness

The above stated restrictions along with the experience procured among last sessions were used to make the house of quality chart. (Appendix Fig. 09)
Based on the outcomes the critical outline highlights were arranged as stated in the table. The sketched-out highlights were thought about emphatically to build up a productive plan.

Table 5: Features Table

Features	**Requirements**	**Expected Target and Solution**
Safety	Safe Vehicle Design	Proper selection of frame material and frame cross-section for reducing weight and providing strength.
Comfort	Comfortable	Data collected from previous competitions and prototype were used as ergonomics reference.
Feasibility	Highly Feasible	To develop a feasible and easy to manufacture vehicle.
Energy Consumption	Analyzed	To minimize the energy consumed throughout the development phase of the vehicle.
Overall Cost	Minimal	Performed Cost analysis to minimize the inflow
Stability	Highly Stable	Steering system and rider position supports stability in vehicle

1.6 Concept Development and Selection

The basic lay up for the vehicle was achieved with the help of the design process. During the design, various feasible ideas and innovations hit up our minds. Every idea could be achieved with more than one methodology and to choose the best process, Pugh's selection method was adapted.

1.6.1 Vehicle Configuration

Vehicle configuration plays an important role in ergonomic and to prevent injuries to the rider. The data were collected from previous ergonomics studies and past experience from our last three human powered vehicles. The selection technique helped us to assess and weigh each aspect for designing the HPV.

Table 6: Vehicle Configuration

Features Weightage	Weightage	Compact Long Wheelbase	Medium Wheelbase	Short Wheelbase
Rider Safety	5	0	-1	1
Capsizing Stability	4	0	1	-1
Turning Ease	4	-1	0	1
Drivetrain Efficiency	4.5	-1	1	0
Comfort	4.5	1	-1	0
Weight	3	-1	0	1
Relative Score		-7	0.5	8

1.6.2 Drive Train System

Different drive trains were tabulated and then compared against each other based on the judging parameters. After careful analysis, the two-sided drive train was chosen over others. [4]

Table 7: Drive Train System

CRITERIA	WEIGHTAGE	ONE SIDED	TWO SIDED	SINGLE CHAIN
WEIGHT	5	0	-1	1
ROTATIONAL MOI	4.5	1	-1	0
INTEGRATION EASE	4	0	0	0
STABILITY	5	-1	1	0
MINIMUM GEAR RATIO	5	0	1	0
MAXIMUM GEAR RATIO	4.5	1	1	-1
RELATIVE SCORE		4	5	0.5

1.6.3 Frame Material

The frame is one of the most important attribute for the vehicle; deciding the material for it was a crucial task. Many factors like, strength, weight, price, etc. were taken into consideration and the one, which stood out from the rest, was chosen. [5]

Table 8: Frame Material

CRITERIA	WEIGHTAGE	MILD STEEL	AL 6036	AL 6031
YOUNGS MODULUS	4	1	0	0
DENSITY	3.5	1	0	1
STRENGTH	4.5	-1	1	0
SECTION MODULUS	4	-1	1	-1
COST	5	1	0	1

RELATIVE SCORE		4	8.5	4.5

1.6.4 Steering System

A good steering system enhances the stability of the vehicle, and ensures proper turns. Hence, quite a few were compared and then chosen based upon the criteria. [6]

Table 9: Steering System

CRITERIA	WEIGHTAGE	RISER	BULLMOOSE	AERO
COST	5	1	0	0
DURABILITY	4	-1	1	1
STABILITY	4.5	1	-1	0
MANUFACTURING TIME	3	-1	0	-1
RELATIVE SCORE		3.5	0.5	1

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1.6.5 Fairing Design

The coefficient of drag is determined by the aerodynamic shape of the vehicle. This plays an important feature for the vehicles stability and performance. [7]

Table 10: Fairing Design

CRITERIA	WEIGHTAGE	PARTIAL FAIRING	FULL FAIRING
MANUFACTURING	3	0.5	0
DRAG COEEFICIENT	4.5	0	1
COST	5	1	0
RELATIVE SCORE		8.5	4.5

1.7 Vehicle Description

Table 11: Description Table

SYSTEM	DESCRIPTION
Main frame	Main Frame is designed to bear maximum load under variable loading condition and provide maximum factor of safety to vehicle. For mainframe Al-6063 T6 {Rods and RHS} and Al-6061T6 {Plates} to provide maximum tensile strength as they are used as gussets to provide reinforcement to frame. Combination of Aluminium Alloy to maintain weight of bicycle and providing maximum strength.
Steering system	We are using Riser steering design, which provide us better overall experimental results when compared with bull moose and Aero Steering Design. This steering system provides us efficient handling and control over vehicle at high speed and high turning radius as it gives improved feedback to rider with least unwanted noise. Riser steering design provide us large field view and stability.
Fairing	It is essential that we design a sturdy, ergonomic and lightweight fairing and hence we are going for fairing made of composites. Composites consists of glass fibre and epoxy resin. A 7-mil bi-directional glass fibre is used. Fairing helps in improving the aerodynamic and safety needs of the vehicle. For streamlined aspects, the shape of a tear drop is used as it has less drag and it reduces the lifting force as well , so we chose to utilize the standard curves for this shape i.e. NACA profiles for the fairing nose. Fairing helps to reduce impact during crash.
Roll over	The Roll over protection system has same material from of the main frame with the goal

protection system	that it can be attached to the frame properly. We have utilized 22 mm external and 16mm internal diameter tube of section modulus of 751.57mm^3 and Aluminium 6063-T6. The Roll over Protection System was planned considering the design requirements set by ASME-HPVC rulebook and to improve the safety of the rider.
Drivetrain	In this year's project, we have made effective changes to our drivetrain configuration. Obtaining an efficient start-up acceleration, better speed and durable setup was one of our main motives. To achieve the same, we have incorporated a combination of two-sided and double chain configuration. Calculations of gear ratios are as presented below in the excel table
Brakes	Our team decided to use front and rear disc brakes, as they are easily available, small, highly reliable and easy to mount.
Wheels and wheelbase	Dimensions of the wheels are 20-inch front and 26-inch rear. We used short wheelbase in our vehicle, taking into consideration factors like rider safety, stability, turning ease, drivetrain efficiency and comfort. All the dimensions were chosen keeping in mind the rules of ASME-HPVC.
Ergonomics	Our vehicle is semi- recumbent so that it provides extra comfort to the rider. We designed our vehicle in such a way that the centre of gravity is positioned in such a way that it provides easy handling for the rider. The wheel base for shortened to improve rider comfort. The recumbent angle we chose for our vehicle is 70˚ and this reduces risk of back injuries.
Innovation	Our innovation was made by considering the problems faced by the rider during the motion of the vehicle. We have decided to implement a sequenced gear change, which will eliminate the power fluctuation during gear change, with the help of a microcontroller and stepper motor.

Table 12: Gear Ratio

	Intermediate Gear Teeth		
Back Gear Teeth		32	42
	25	2.346667	3.08
	23	2.550725	3.347826
	20	2.933333	3.85
	19	3.087719	4.052632
	17	3.45098	4.529412
	15	3.911111	5.133333
	14	4.190476	5.5
	12	4.888889	6.416667

1.8 Innovation: Sequenced Gear Shifter

During our development of double side transmission, we identified that the rider has to learn the gear shifting sequence in order to efficiently shift the gears.

- Each gear combination has a unique gear ratio. The gear ratio does not vary linearly, rather fluctuates on increasing the gear. This "energy fluctuation" (as shown in the graph) will result in an unsteady transfer of energy to the wheels, hence resulting in increasing the difficulty of the driver to increase or slow the speed.

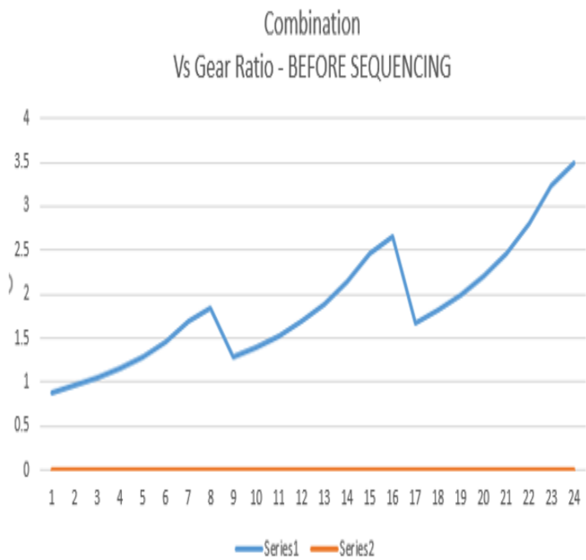


Figure 2: Combination to gear ratio before sequencing

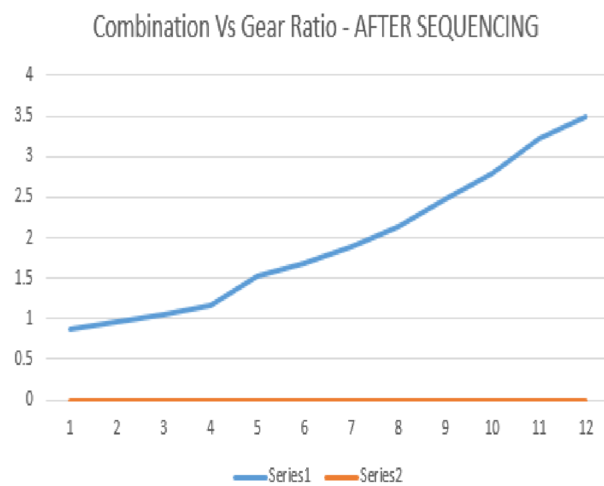


Figure 3: Combination to gear ratio after sequencing

Solution – For the given problem, we have decided to incorporate a preset gear sequence using a microcontroller and stepper motors.

- After carrying out trials, the smoothest gear sequence was found out.
- Smoothest gear sequence is the one where the gear ratio and power delivered varies linearly (almost) with the combinations (input).

Methodology – The preset gear combinations will be adjusted with the help of a shift.

- The rider will have a switch with “+” and “-“options. The former will increase the gear according to the preset combinations, while the later will reduce the gear.
- The speed will increase on increasing the gear, and decrease while doing the vice versa.
- This will ease the work of the rider, for he/she does not have to take the energy fluctuation into account while riding.
- The adapted sequence is : A1,A2,A3,A4,B3,B4,B5,B6,C5,C6,C7,C8 (A being the smallest gear cassette in the intermediate 3 speed chain ring, and 1 being the largest gear in the rear cog set).

Figure 4: Flow Chart

Benefits

- The rider will not have to take the consideration of “energy fluctuation” while changing the gears. The power delivered will now be in accordance to the need of the rider.
- The cable wires of derailleurs will be eliminated due to the implementation of microcontroller and stepper motors near the derailleurs.
- The microcontroller setting will be adjusted in such a way that the gear change occurs only when the vehicle is in motion.

2. Analysis

2.1 Roll Over/Side Protection System

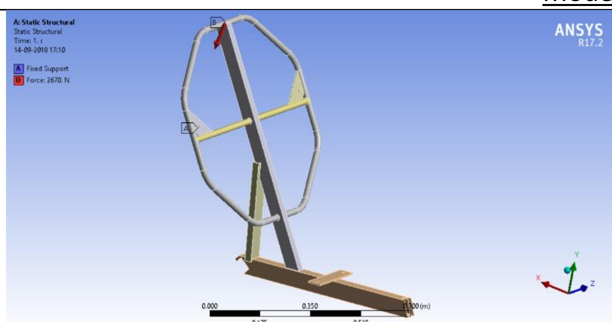
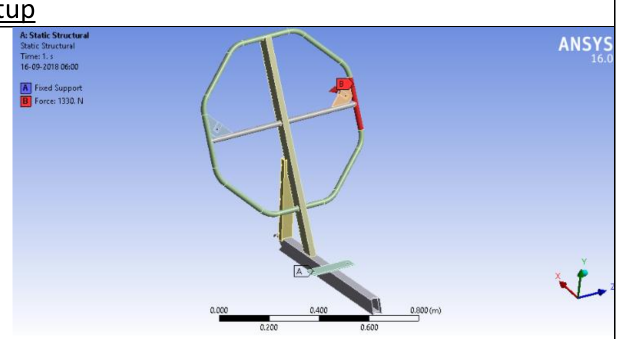
Finite Element Analysis (FEA) is done to analyze the roll over protection system and it is a critical step towards ensuring riders' safety in the event of a crash. According to the rules [8], the major analysis specifications for the RPS are:

- there should not be any plastic deformation
- All elastic deformation should fall within the specified deformation [8].
- All load cases should be constrained at the harness mounting points.

<u>Methodology</u>

The design was modelled to shorten the simulation time and simplify the analysis, removing the non-critical components to providing a proper meshing scenario.

Table 13: RPS load analysis

<table>
<tr><td><u>Top Load Analysis</u></td><td><u>Side Load Analysis</u></td></tr>
<tr><td>We provided fixed support at all the four harness mounting points. A force of 2670N was applied at top of the RPS [8] at an angle of 12◦ from the vertical.</td><td>Similarly fixed supports we provided at all the four harness mounting points. A force of 1360N was applied sideways[8]</td></tr>
<tr><td colspan="2"><u>Model Setup</u></td></tr>
<tr><td>
</td><td>
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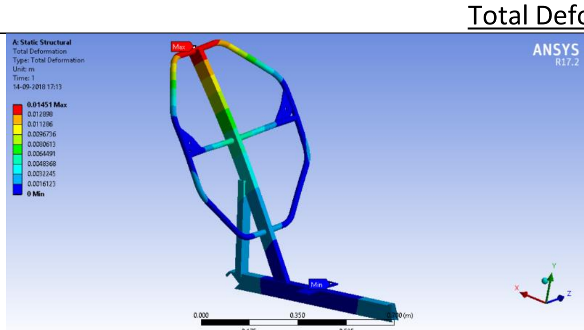
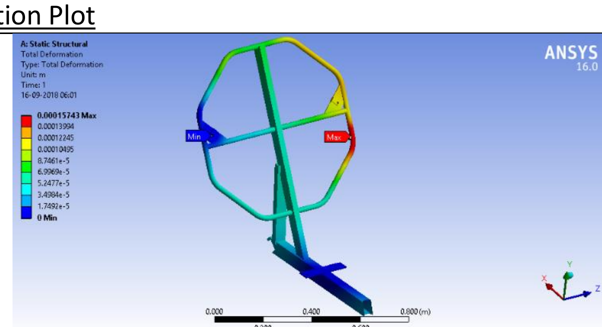
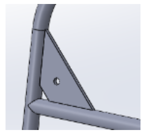
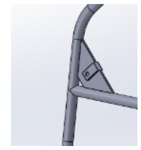
<tr><td colspan="2"><u>Total Deformation Plot</u></td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Result and discussion</td></tr>
<tr><td colspan="2">Yield strength of Aluminium 6063-T6 is 0.24GPa[9], there is expected to be no plastic deformation in both the loading case and elastic deformations are well within the limits[].</td></tr>
<tr><td>A max deformation of 1.45cm was observed with maximum stress being 0.472GPa.</td><td>Similarly a max deformation of 0.15mm was observed with maximum stress being 0.463GPa.</td></tr>
<tr><td colspan="2"><u>Modifications</u></td></tr>
</table>

A mesh refinement analysis with major mesh refinement points being the high stress areas. Accordingly design modification is shown.This reduced the stress and incresead the FOS above 3 in both case.



Original design



Modified design

2.2 Frame analysis

Table 14: Frame Analysis

Objective	Method	Results
The frame is analyzed using FEA to find the structural capacity in a critical scenario with the minimum mass possible with the required minimum FOS of 2.	The frame is modelled and optimized in Solidworks for analysis and simulation in ANSYS. Simulations were iterated with different thickness and cross-sections of the stressed parts and suitable design modifications were made.	The frame supports the loads related to the critical scenario without exceeding the yield strength. The mass of the frame was reduced by 5.34% compared to the first iteration.

Case descriptions

We decided a critical scenario, which represents the maximum stress that can be present in the frame. It covered the heaviest driver pedaling with his maximum efforts and suddenly applying brakes until the vehicle stops. Forces related to our conditions are body weight (850N), pedaling force on the bottom bracket due to pedaling (500N), and the pedaling reaction on the seat (500N). (Fig. 05). Fixed constraints were provided at the rear wheel clamp and displacement of the head-tube was restricted in Y-direction.

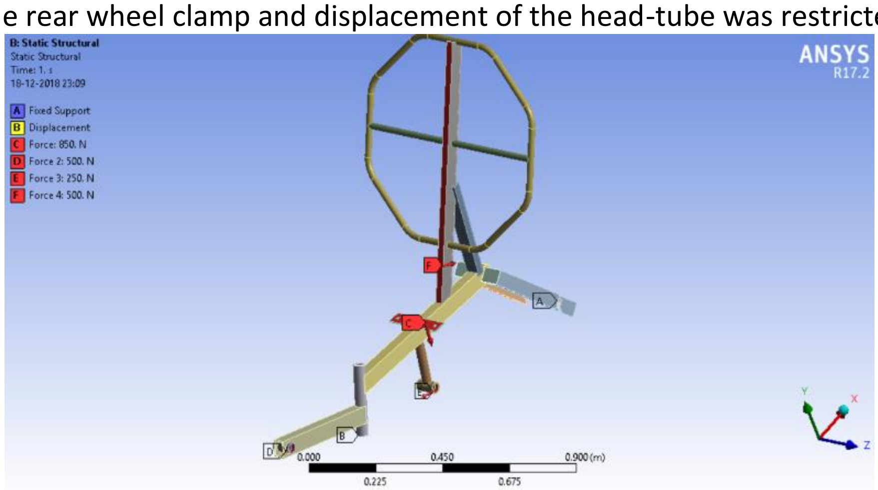
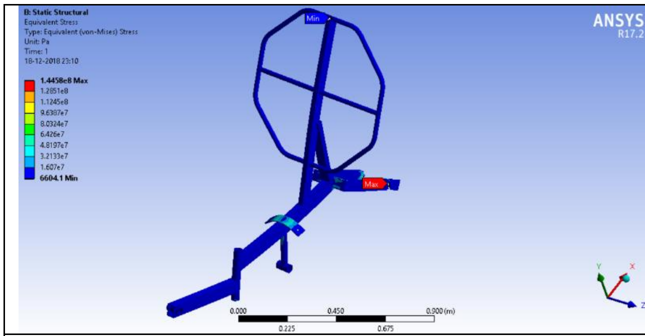
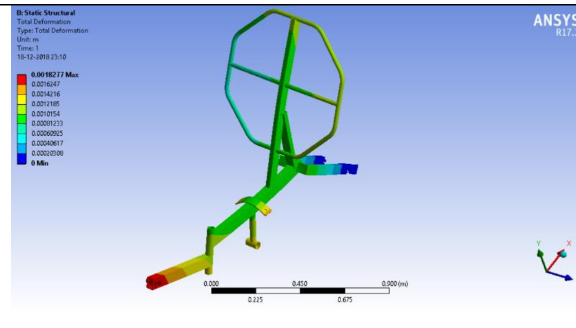


Figure 5: Applied Loads

Modelled frame is given a fine mess with relevance 75.Size function is adaptive with minimum edge length 2mm and span angle is taken coarse and transition is fast.

Displacement plot	Stress Plot

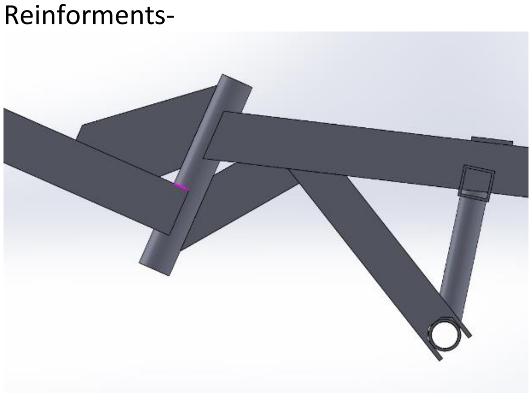
	
Results and Discussions	
The frame is observed to have a maximum deformation of 1.8cm.There is no plastic deformation.	Maximum equivalent stress observed in the frame is 0.144GPa .The factor of safety observed for the frame is 3.

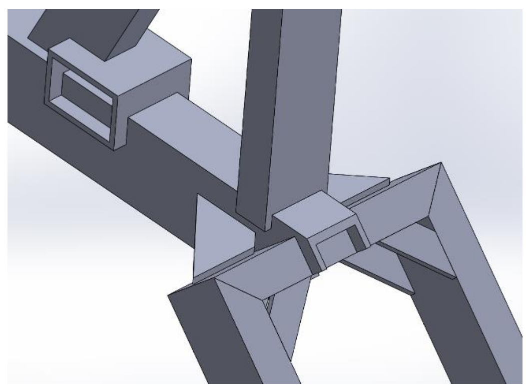
Design Modifications

Several iterations were carried out to reduce the over the overall weight and increase the strength of the vehicle. It helped to reduce the frame's mass and certain design modifications were made to make the vehicle more robust.

Iterations	RHS Dimensions (lxbxt) mm	Maximum stress[GPa]	Maximum displacements[mm]	Frame's mass[kg]
1	50x25x3	0.082	3.06	7.86
2	40x40x3	0.124	2.16	8.75
3	60x40x3	0.144	1.82	9.13

Reinforments-



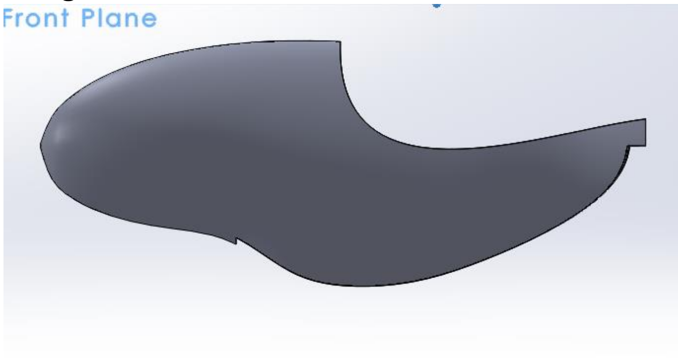


2.3 Aerodynamics Analysis:

ITEM	DESCRIPTION
Objective:	Analyze and optimize fairing design to reduce aerodynamic drag area.
Assumption:	Steady state air, constant density, constant atmospheric pressure and temperature
Method:	CFD analysis using Ansys Fluent
Result	Drag Co-efficient- 0.1527, Drag area-0.0751m^2

The fairing model was created in Solidworks by using 2424 and 0024 NACA profile. Cord length was calculated accordingly was imported in ANSYS 18.1 to analyze aerodynamic drag. ANSYS CFX fluent was used to analyze the aerodynamic behavior of the fairing. Designs considered have been presented below.

Designs Considered:



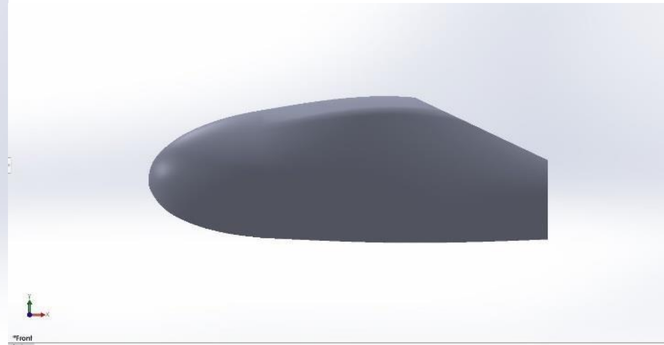


Figure 6: Improved Design

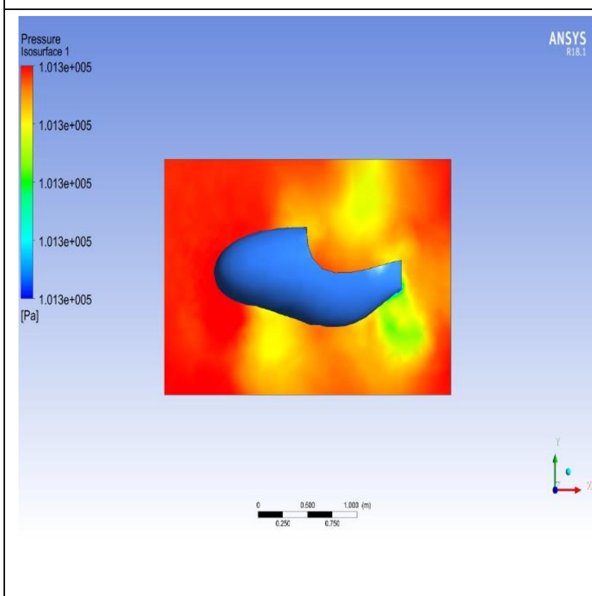
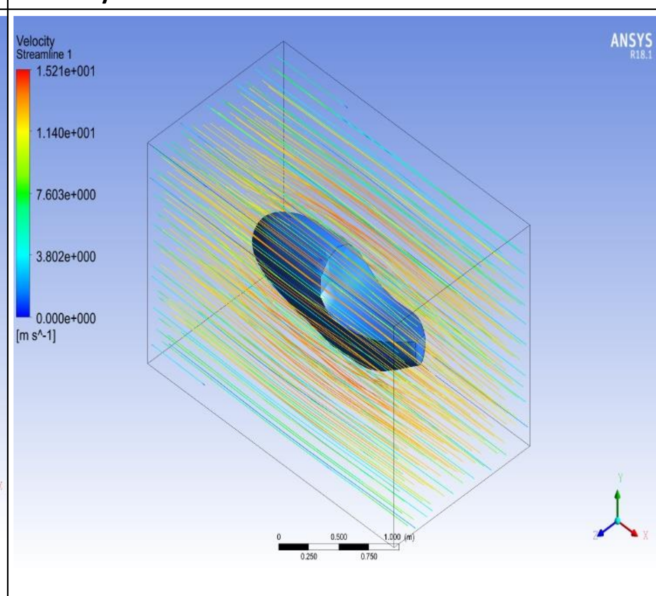
Figure 7: Original Design

The analysis was done in ANSYS CFX fluent. The designs considered were analyzed. The second fairing developed covers the lower region of the chassis; this provides an added benefit to the previous design by reducing the air resistance. [10] The pressure contours, velocity streamlines and drag area was compared for finalizing the design.

2.3.1 Front Flow Analysis

The front flow analysis tries to analyze the aerodynamic behavior of the vehicle while in motion. The geometry was imported in ANSYS design modeler and enclosed according to suitable dimensions. Inlet, Outlet and Wall naming were done. The setup was appropriately meshed by taking relevance as -100.Relevance center was taken as coarse material. Further, the inlet was provided to the one side of the enclosure and the opposite side as the output. The other sides were provided with wall boundary conditions. Atmospheric temperature (25 degrees C) and pressure (1 atm) was provided. Air velocity of 12 m/s was considered. No slip conditions were provided for the fairing and the wall. The setup was analyzed for this boundary condition. The counters were plotted for pressure and velocity streamlines. The results are presented below.

Table 15: Front flow Analysis

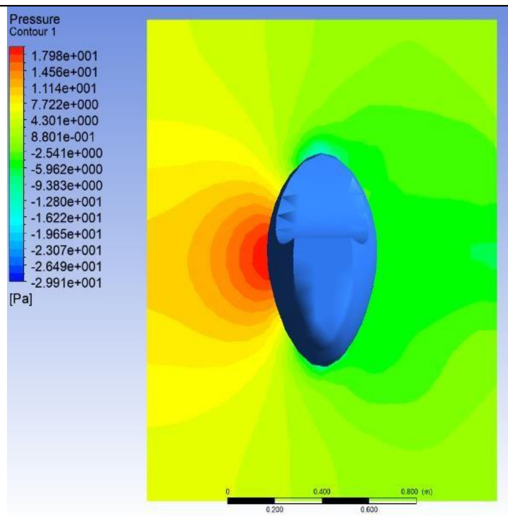
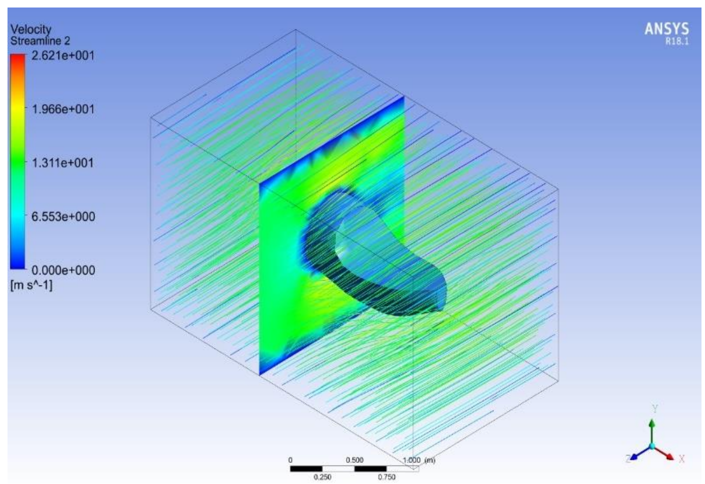
Pressure Counters	**Velocity Streamlines**
	
Results	

The maximum pressure of 1.013e+005 Pa is observed at the front end of the fairing. The pressure difference observed between the front end and cut section is 130.97	The velocity streamline shows the flow of the wind around the fairing. The maximum velocity was found out as 15.21 m/s, which was optimized from the earlier results.

2.3.2 Cross Flow Analysis

Similar procedure was followed for this case study. The cross wind of 4 m/s was provided. The results have been presented below.

Table 16: Cross flow analysis

Pressure Counters	Velocity Streamlines
	

The maximum pressure of 17.98 Pa is observed at the side end of the fairing. The velocity streamline shows the flow of the wind around the fairing. The maximum velocity was found out as 26.21m/sec.

Design Substantiation:

The fairing can have a major impact on speed of the vehicle. So the analyzed design was selected for the fairing. On further analyzing the real-life conditions, considering the motion of chain rings and wheels. The initial design will encounter more drag force. However, this problem is solved in the second design as it covers the most of the transmission components. The drag area calculated from the analysis is 0.625 m^2. The drag coefficient observed is 0.1527.

2.4 Cost Analysis

Table 17: Cost Analysis

Objective	Method	Results
To study and analyze the cash outflow segment wise and compute the total cost in manufacturing the vehicle.	Analyzing capital investment, miscellaneous expenditure and total cost of production.	The following results were obtained and the vehicle was manufactured within the budget.

Table 18: Investment

Capital investment	Cost (Rs)
Fairing	5800
Innovation	600
Frame	2100
Transmission and brakes	25000
Safety	860
Seat and tires	3120
Steering	1500
Total	38980
Cash outflow(miscellaneous)	**Cost (Rs)**
Tooling	2000
Labor Cost	4000
Total	6000

Table 19: Total cost

Total cost of production	Cost (Rs)
Capital investment	38980
Cash Outflow(miscellaneous)	6000
Total	44980

This year's vehicle has enhanced transmission and fairing components to help assist the speed of the vehicle. The total cost of the vehicle including parts and other miscellaneous expenses amounts to **Rs.44980.**

2.5 Product Energy Life Cycle/ CO2 analysis

We studied the survey of different materials used in manufacturing and inferred the following:

Table 20: Product Energy/CO2 Analysis

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	Aluminium (recycled)	11860000	2600	8.7	10318200	22620	Easy	Easy	Easy
2	Fibre Reinforced plastic	17820000	860	0.502	891000	430	Moderate	Hard	Moderate
3	Steel	16000000	4000	1.6	25600000	6400	Moderate	Easy	Easy
4	Rubber	2320000	3600	0.59	1368800	2124	Easy	Easy	Easy
5	Glass fibre [1]	120000000	860	1.23	147600000	1057.8	Difficult	Difficult	Moderate
6									
	TOTAL	168000000	11920	12.622	185778000	32631.8			

The total energy consumption per unit mass of the materials used in the vehicle is 185.77 MJ and total CO_2 of 32.63 kg is produced. The core material used to build the vehicle is Aluminium 6063-T6. Aluminium produced from Bauxite requires energy of 227-342 MJ/kg, which is more than the energy produced by using recycled aluminium, which is 11.86 MJ/kg. Team Anant will try to work with the environmental club in our institution by planting trees in order to compensate for CO_2 emitted.

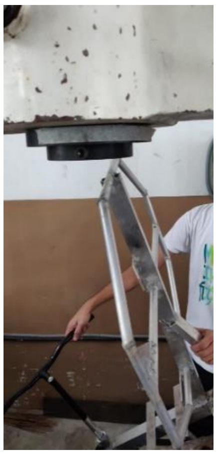
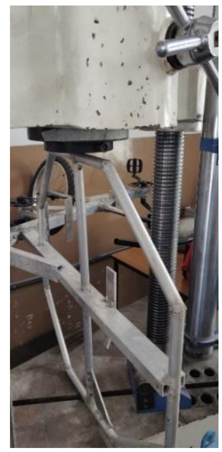
3. Testing

3.1 Roll Over/Side Protection Testing

Objective: Perform the top load and side load testing on RPS to determine its deflection under stated loading conditions by ASME.

Equipment Utilized: Universal Testing Machine. The tests were performed in the strength of materials laboratory. The results and discussions have been presented in the table.

Table 21: UTM Testing

<table>
<tr><th colspan="2">Top Load Setup</th><th colspan="2">Side Load Setup</th></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><th colspan="4">Methodology</th></tr>
<tr><td colspan="2">The lower part of the chassis was fixed rigidly. An initial load of 1600 N was applied at the top point of the RPS and was gradually increased to 2700 N. The total deformation was observed and noted. RPS was checked for any severe deformations.</td><td colspan="2">The other side of the RPS was fixed rigidly at the base of the machine. An initial load of 400 N was applied at the top point of the side point and was gradually increased to 1400N. The total deformation was observed and noted down.</td></tr>
<tr><th colspan="4">Results</th></tr>
<tr><td colspan="2">Maximum Deflection</td><td colspan="2">Maximum Deflection</td></tr>
<tr><td>Test Setup</td><td>1.40 cm</td><td>Test Setup</td><td>0.20 cm</td></tr>
<tr><td>FEA (without supports)</td><td>1.45 cm</td><td rowspan="2">FEA</td><td rowspan="2">0.15 cm</td></tr>
<tr><td>FEA (with supports)</td><td>1.23 cm</td></tr>
</table>

Correction – After the failure of the first test result, an aluminum rod of dimension 22mm (OD) and 16mm (ID) is fixed horizontally to further support the side loading conditions.

Conclusion - The design is appropriately safe and no further modifications are necessary. The FEA results of the modified design are clearly in close proximity to the observed results presented in this test. The load conditions applied in the test were slightly higher than that specified in the rulebook to accommodate the difference in the least count of the machine.

3.2 Developmental Testing

3.2.1 Aluminum Tube Tensile Testing –

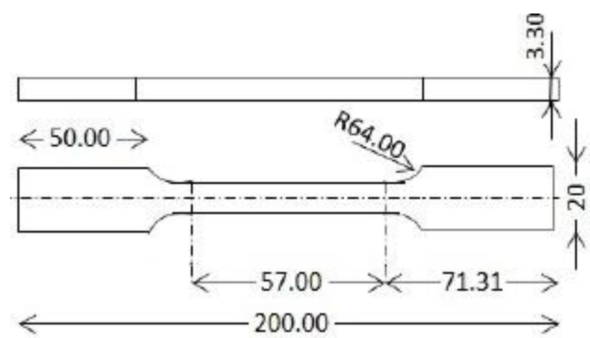
Objective - Perform a tensile test on samples of Aluminum tube to determine if the tubes are satisfactory tie-rod materials and can with stand the required loading conditions.

Equipment Required – MTS Machine.

Methodology – In an effort to save weight of the vehicle components, aluminum tubes were considered for use for making the mainframe material and other components. The longest tie rods used in the mainframe geometry were measured at 900mm. At this length, an Aluminum with a 40mm outer width (W) and 32mm inside width (w) was found to weigh 1.3 kg, while an aluminum rod of the same dimensions would weigh 1.47 kg. This weight savings would help towards the team goal of building a vehicle under 20Kgs.

To test if the thin walled Aluminum tubes would be able to safely handle the forces that would be exerted on them while riding, three samples, whose dimensions were based on the ASTM standard E 646-98, were tested with an MTS tensile test machine. The test results are shown below.

Table 22: MTS Testing

	
Results : Tensile Strength : 180MP Elongation% - 9.2%	

Discussion – The sample we have made was based of the ASTM E 646-98 specimen, with a thickness of 5mm. Due to the above-generated values by the system; we were able to confirm that the quality of the aluminum that we bought from the vendor was of good quality and of reliable nature for our vehicle.	
Error Sources – • The material specimen may not be properly machined. • The assumptions may be approximate.	Uncertainties – • The machine may not be functioning properly. • Human error in taking the readings.

Conclusion – To make our vehicle lightweight and provide sufficient strength to bear different loading conditions, aluminum 6063 T6 is the most optimal choice.

3.2.2 Prototype Development

Table 23: Prototype development

Objective	To determine the riders' comfortable ergonomics and feasibility of the initial design.
Methodology	A prototype replicating the basic design of the vehicle was made using wooden planks and hinges and different rider positions at different parameters were noted down.
Results	The below stated parameters were the most ideal for the feasibility of the vehicle.

Prototype to select the best riding position for this year's requirement and compared it with the rider's experience to develop a prototype.

Discussion: The riding position considered best last year, created a comfort difference for riders with different heights and that limited them to provide optimum input power. This was experienced largely in the drag race and the race outcome clearly highlighted the issue. To overcome this limitation, the data collected last year was analyzed for other good ergonomic positions and iterated to decide the best out of them. The best recumbent angle chosen for further analysis were 60, 65 and 70 degrees. The seat position from the primary BB was also considered. This testing assisted in developing an efficient design. The parameters selected for the development of initial prototype of the vehicle are presented in this table.

Table 24: Parameters

Specifications Decided	Value
Recumbent angle, α	65
Angle b/w backrest and line joining hip point to BB, β	97.08°
Bottom Bracket (BB) height from seat base	116 mm
Bottom bracket to hip point distance	250 mm
Hip to crank distance	1011 mm
Height of the seating position	635 mm

Conclusion: The decided geometry produced the most comfortable riding position.

3.2.3 Determination of Centre of Gravity (COG)

Table 25: Effect of COG

Forward COG	Vehicle tends to over steer.
Rear COG	Vehicle tends to under steer.
High COG	The front wheel may lift in acceleration & rear where lifts in braking.
Low COG	Rear wheel tends to slip in acceleration & front wheel tends to slip in braking [11].

Form the above conclusions we can see that the position of the Centre of gravity (COG) of the vehicle is very important. Centre of gravity of the vehicle is to be considered for the stability and speed of the vehicle. To have proper vehicle dynamics, braking, acceleration and mass transfer an optimal COG position as to be chosen. Henceforth, for the determination of the COG a test was conducted on our vehicle 'Derby'. The results has been discussed in the table below.

Table 26: Determine position of COG

<table>
<tr><td colspan="2">Position of Centre of Gravity</td></tr>
<tr><td>Longitudinal Position</td><td>Height</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Methodology: The weight of the vehicle in its longitudinal position, without the fairing was measured using two weighing balances, one to measure the reaction of each wheel. The normal reactions were noted down. The longitudinal position of COG was demined using the below formula.</td><td>Methodology: The height of the COG was determined by rising the front wheel of the vehicle to a specified height. The normal reaction at the rear wheel was measured using the weighing balance and the height of COG was estimated using the formula given below.</td></tr>
<tr><td>Formula -</td><td></td></tr>
<tr><td>b : distance of the COG from the rear wheel
h : Height of the COG from the ground
p : wheelbase of the vehicle
m : mass of the vehicle
H : height of the raised front wheel</td><td>N_{sf} : reaction at front wheel
N_{sr} : reaction at rear wheel
R_r : radius of the rear wheel
R_f : radius of the front wheel</td></tr>
</table>

Results : b = 48 cm, h = 74 cm	
Error sources : • Measurement errors.	Uncertainties : • Calculation errors. • Weighting machine may not be accurate.
Discussion : The above stated position of the COG is the most optimal position for proper acceleration and mass transfer of the vehicle. This position of COG helps the vehicle to be highly stable under high speeding conditions as well as in low speed.	

Conclusion – The position of the COG found was perfect for the vehicle so that it does not tends to over steer or under steer. It also does not provide any lift or slipping to the vehicle in case of braking or acceleration.

3.2.4 Frame Deflection Test

The challenges faced during the initial testing of the vehicle and problem faced during the previous year E-fest were critical while developing the frame. One of such challenges is the rumble strip challenge of the endurance event were periodic shock force is suffered by the rear fork. Since no damping or shock absorbers are present in the vehicle, therefore the forces experienced will be transmitted directly to the chassis. To analyze the stiffness of the final frame this developmental testing has been performed. The Rinard frame deflection test procedure [12] was followed. The test setup was developed and weights (30kgs) were utilized to apply load.

Methodology – The RPS and the intermediate bottom racket was fixed using fixtures and from the front end, a load of 30kgs was applied on the front end of the frame. Anglo-meter is used to determine the deflection before and after the loading condition.

Similarly for testing the deflection at the rear fork the front bottom racket and the front frame was fixed to the fixtures and 30kg load is applied on it. The deflection of the needle of the Anglo-meter is noted down.

Table 27: Frame deflection test

Front End Test Setup	**Rear End Test Setup**
	

Results - No permanent deformation is observed in the front end as well as in the rear end of the frame. The deflections were under the accepted values i.e. 2° in the Front End and 2.5° in the rear end.	
Discussion – Minimal deflection is seen in the setups. Hence, the chassis has the required strength and is sufficiently rigid.	
Error Sources : • Fixation of the frame may not be proper. • Not very accurate results are produced.	Uncertainties : • The Anglo-meter may not be very accurate. • Fixtures may sometime not be permanently fixed.

Conclusion – Since there is no permanent deformation after performing the test, hence we can conclude that the frame material and the design is highly safe for the rider.

3.2.5 3 Point Bend Test: Testing of fairing material –

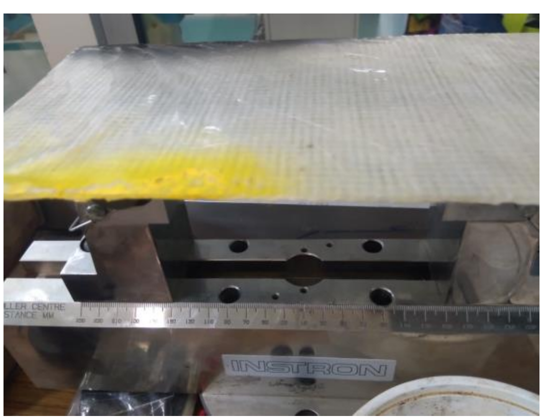
Three point bending testing help us to find the Bending Stress, Flexural Stress, and Flexural Strain of the glass-fiber composite, which will be used to design the fairing of our vehicle. The 3-point bending test is carried out in an Instron Testing Machine in the vibration lab of our collage.

Citing our needs, requirements and keeping the cost dedicated for making the faring of the vehicle we decided to for 7mil Bi-directional glass-fiber [12] as the reinforcement material of the faring. The performance of fiber-reinforced composites is mainly controlled by the efficiency of load transfer from the matrix to the reinforcement fiber [13].

Methodology –

A glass-fiber with rectangular flat cross-section is placed on two parallel supporting pins. The loading force is applied in the middle by means loading pin. This allows their free rotation about: axis parallel to the pin axis, axis parallel to the specimen axis.

Table 28: Fairing material test

Formulas : M= (PS/4) I= $bh^3/12$ σ_{max}= $3PS/2bh^2$ δ_c(deflection) = $PS^3/48EI$ Flexural Stress = $3PL/2bd^2$ Flexural strain = $6Dd/L^2$	P = Load at given point on the load deflection curve(N) L = Support span (mm) b = Width of test beam (mm) d = Depth of tested beam (mm) D = maximum deflection of the center of the beam (mm) m = the gradient of the initial straight-line portion of the load.
Results : Bend – 0.8cm(400N) Flexural Stress – 170MPa Flexural Strain – 380MPa	Error Sources : • Uneven finishing of the test piece. Uncertainties : • Failure of the machine.

Discussion – The sample of glass-fiber composite, we have made was based on the ASTM has sufficient strength that we require to make the fairing of the vehicle. It is low weight, has high strength to absorb the impact in case of crushing forces, and has high rigidity.

Conclusion – The standard chosen for the fairing material is most preferable standard for the fairing as it is light weight as well as the correct bending and flexural stress , which is required ,so that is further enhance the vehicle performance.

3.3 Performance Testing

3.3.1 Brake Testing: Optimal Braking –

Objective **-** This test is performed to check braking force on front wheel and braking force on rear wheel under regular conditions and to find the optimal brake force distribution at the front wheel and rear wheel for optimal braking condition.

Methodology –
As we see, the braking distribution does not depend on mass but on the geometry.

Table 29: Brake testing

Parameters -	Theoretical Formula –
p: wheelbase. h: height of COG from the base. b: distance of COG from the rear wheel. The braking coefficient of -- for the front and rear wheel [Appendix]. F: sum of rear and front braking force	$Equilibrium\ of\ the\ horizonatl\ forces:\ ma = -F_f - F_r$ $Equilibrium\ of\ the\ vertical\ forces: mg - N_r - N_f = 0$ $Equilibrium\ of\ the\ moments\ around\ the\ COG: -Fh - N_r b + N_f(p-b) = 0$ $Front\ braking\ \%;\ \frac{F_f}{F} = \frac{\mu_f(b + h\mu_r)}{p\mu_r + b(\mu_f - \mu_r)}$ $Rear\ braking\ \%;\ \frac{F_r}{F} = \frac{\mu_r((p-b) - h\mu_f)}{p\mu_r + b(\mu_f - \mu_r)}$

Front Braking Force, F_f : $\mu_f N_f$ Rear Braking Force, F_r : $\mu_r N_r$	
$Front\ braking$ %; $F_f F = \mu f(b + h\mu r)\ p\mu r + b(\mu f - \mu r)$	$Rear\ braking$ %; $F_r F = \mu r((p - b) - h\mu f)\ p\mu r + b(\mu f - \mu r)$

Solving the above equations, we get the ratio of force distribution of the F_f and F_r, which is around 70:30 for a tuning of 20.
Results and Discussion: The inference laid out from this analysis is that to attain optimum braking distance and force distribution, the braking system must be developed accordingly.
Front Braking force % Rear Braking Force %. The brake levers are tuned to attain this braking force distribution.

Experimental setup -
Using a piezo sensor, which was fixed on both the brake calliper, force applied on the rear brake and front brake was measured. Multiple times the force applied on the rear and the front brakes were varied by tuning the brake callipers and the optimal braking force required on the vehicle at the minimum possible stopping time at a speed of 30km/hr, without any shocks were noted down.

Table 30: Brake testing observations

F_f/F_r Ratio	Time to stop (seconds)
85/15	3
80/20	2.6
75/25	2.4
70/30	2.1
65/35	2.4

Results – The optimal braking force distribution for the vehicle must be in the ratio 70:30 for Front braking and rear braking.
Discussion – The test conducted clearly show that in optimal braking condition there is no jerks on the vehicle and the stopping time is minimum.
Conclusion **–** The optimal braking helps to use the forces most efficiently, without causing any damage due to sudden braking force exerted on the vehicle.

3.3.2 Minimum Turning Radius –

For sudden turning, it is very important to identify the Minimum turning radius of the vehicle.
Further, the wheel diameters also effect the stability and the acceleration of the vehicle. Therefore, it is very crucial to find the minimum turning radius with optimal stability and acceleration values. The wheelbase of the vehicle is considered as 1.1m.

Methodology –
Using different Combination of rear wheel (26”, 24”) and front wheel (20”, 18”, 16”) the most efficient and minimum possible truing radius for the vehicle was found. The raider is made to turn over the minimum possible turning radius while riding the vehicle. For testing the stability and the acceleration the vehicle

run on a straight line across a fixed path (80m) and the initial and final reading and the time taken to complete it was noted down.

<table>
<tr><td>Front Wheel (inches)</td><td>Rear Wheel (inches)</td><td>Minimum turning radius(m)</td><td>Stability</td><td>Acceleration</td></tr>
<tr><td>24</td><td>16</td><td>2.4</td><td>Low</td><td>Very High</td></tr>
<tr><td>24</td><td>18</td><td>2.8</td><td>Slightly low</td><td>High</td></tr>
<tr><td>24</td><td>20</td><td>3.3</td><td>High</td><td>Moderate</td></tr>
<tr><td>26</td><td>16</td><td>3</td><td>Medium</td><td>High</td></tr>
<tr><td>26</td><td>18</td><td>3.5</td><td>Medium</td><td>Low</td></tr>
<tr><td>26</td><td>20</td><td>3.8</td><td>Very high</td><td>Moderate</td></tr>
<tr><td colspan="5">Results – 26-inch rear wheel and 20-inch front wheel gives the suitable minimum turning radius, considering the stability and acceleration of the vehicle as well.</td></tr>
<tr><td colspan="2">Error Sources :
• Human errors.
• Time lapse in noting the exact readings.</td><td colspan="3">Uncertainties :
• Exertion to the raider due to repeated testing.</td></tr>
</table>

Discussion – 26 inches rear wheel and 20 inches front wheel will give the perfect combination of stability as well as the acceleration required to improve the dynamics of the vehicle considering the minimum turning radius in mind.

Conclusion – 26 inches rear wheel and 20 inches front wheel is chosen which gives the permissible minimum turning radius for the vehicle and the required stability and acceleration to it.

3.3.3 Stability Testing –

Stabilization of a two-wheeled vehicle plays a vital role in the complex transportation system. Stability is an important criterion to determine conformance, safety, reliability of a bicycle. It helps us to attain maximum velocity in short period by providing us maximum handling. Bicycle are single-track vehicle, which require dynamic stability while turning over wider range of speeds [15]. Self-stabilisation of the vehicle at particular velocity can help us in further in improving our design and help us to achieve high-speed stable vehicles.

Methodology –
The two wheelers are statically unstable like the inverted pendulum, but can be stable when the speed increases. Successful control and manoeuvring of a two-wheeler depend critically on the forces between the wheels and the ground. Acceleration and braking require longitudinal forces; whereas balancing and turning depends on lateral forces [16].Self-stability is generated by a combination of several effects that depend on the geometry, mass distribution, and forward speed of the bike. Tires, suspension, steering damping, and frame flex can also influence it, especially in motorcycles.

Through MATLAB analysis done above, we got an approximate velocity at which the vehicle can self-stable itself. On a long straight track, the vehicle was test run so that it can attain the particular speed required for self-stabilisation. When the speedometer showed the particular speed required, the raider gradually removed his hands from the steering and tried to self-balance it. The test was carried several times to get the most accurate values.

Table 31: MATLAB result comparison

<table>
<tr><td rowspan="3">Results :</td><td>MATLAB : 27.21 km/hr</td></tr>
<tr><td>Theoretical : 28.4 km/hr</td></tr>
<tr><td>Experimental : 29.5 km/hr</td></tr>
<tr><td colspan="2">Discussion –
The velocity that we get from the experimental setup is in close range with the velocity value that we got from theoretical equations and MATLAB. Thus we can conclude that our vehicle is highly stable at high speeds, which was our at most goal. Any values of speed above 29.5Km/hr is suitable to make the vehicle self-stabilize.</td></tr>
<tr><td>Error Sources –
• The vehicle may have be to the approximate velocity for self-stabilisation.
• The ability to balance the vehicle also depends from raider to raider.</td><td>Uncertainties –
• The speedometer may not be accurate.</td></tr>
</table>

3.3.4 Transmission Efficiency Testing –

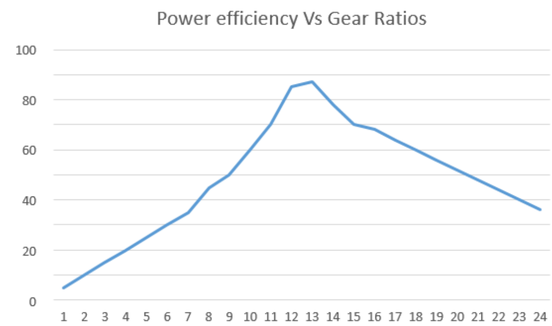
Since proper tuning of the transmission and gear ratios combination determines the speed of the vehicle, therefore it is very necessary to test the transmission efficiency of the vehicle. We decided to incorporate 24 possible gear ratios (3 Speeds, 8 Speeds). Due to change in orientation of the chain for different gear ratios, the efficiency varies significantly. This test will help us to identify which of the intermediate chain ring, which will match with the rear cog, which will in turn help us, eliminate wrong shifting and to attain optimum gear ratio for higher efficiency.

Methodology –

The rear wheel was lift up and its spindle was fixed on a fixture so that it can rotate freely. An input RPM (25) was provided at the paddles and the output RPM was measured using a contactless tachometer. The observed values of tachometer were noted down and power efficiency was calculated. The power efficiency vs gear ratios curve is plotted in Microsoft excel which has been given below.

<table>
<tr><td rowspan="2">Result: A transmission efficiency of 87% was obtained for the gear ratio of 1.88 i.e. 32 teeth in the front chain ring and 17 teeth chain ring in the rear cassette.</td><td>Error Sources –
• No proper tuning.
• The losses can also be frictional and other losses.</td></tr>
<tr><td>Uncertainties –
• Tachometer not accurate.</td></tr>
</table>

NUMBER	GEAR RATIO
1	0.88
2	0.956521739
3	1.047619048
4	1.157894737
5	1.294117647
6	1.466666667
7	1.692307692
8	1.833333333
9	1.28
10	1.391304348
11	1.523809524
12	1.684210526
13	1.882352941
14	2.133333333
15	2.461538462
16	2.666666667
17	1.68
18	1.826086957
19	2
20	2.210526316
21	2.470588235
22	2.8
23	3.230769231
24	3.5



Discussions: The transmission efficiency of 87 % was obtained from the result. The best result came for the gear combination of 32 teeth in the front chain ring and 17 teeth chain ring in the rear cassette. In this combination of gear ratio, the chain is almost aligned in a straight line and there is minimal power loss.

Conclusion: Henceforth, after conducting the above test we came to a conclusion that the gear ratios around 1.88 is highly efficient in power transmission. Further, it also helps us to eliminate wrong shifting of gears.

4. Safety

Potential Failure Mode and Effects Analysis (Design FMEA)

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s)	Occ	Current Design Controls	Det	RPN	Recommended Action(s)	Action Results: New Sev	New Occ	New Det	New RPN
Frame	Sharp edges	Cut to self	5	Exposing ends of frame	7	none	1	35	Cover sharp edges	1	1	1	1
Moving parts	Body parts, hairs, clothing	Wheel will no longer support rider and bike	2	Snare	6	none	5	60	Cover moving parts and check for moving parts after each ride	2	3	1	6
Vehicle	Roll over	Harm to rider	8	Unstability or bad riding conditions	6	none	3	144	Use roll over protection system and determine optimal COG	4	2	3	24
Brakes	Brak wire or callipers may break	Slow or no reduction in speed of vehicle	7	Jerks, collisions, wrong placement of vehicle	5	Break wire is protected with plastic sheath	4	140	Break wire is given a defined path and it is fixed firmly with the use of extrusions from frame and brakes to be inspected after every ride	7	2	2	28
Welded parts	Fracture	Frame will break	8	Abrubt jerk, Load above the permissible load, Fatigue	5	Will fail according to the quality of welding by the welder	3	120	Special concern about failure is to be taken during welding, every joint should be welded properly. Extra member were added to ensure enough surface for welding	8	1	1	8

Risk of Injury due to Hazards- The above-mentioned factors may lead to various damages in HPV. Braking force may affect the pace, while the vehicle is moving at high speed there might be chance of crash or collision causing great injuries to the rider. Structural failure may lead to a great threat to the rider's and the surrounding vehicle safety. During commercializing of the vehicle, structural inefficiency may lead to great loss.

Control Measures-

- Moving parts of the vehicle fitted with great precision.
- Low center of gravity is ensured for HPV stability.
- Safety accessories such as RPS, seat belt, helmet, etc. provide assistance.
- Riding gears are made sure for the rider's safety.

Rollover/Side Protection System-

The system guarantees tested standards of safety for the rider and it is constructed to provide maximum stability of the HPV.

Sharp Edge, Protrusion or Pinch Point-

Methods like chamfering and grinding were used to secure the vehicle from any sharp edges.

5. Conclusion

5.1 Comparisons

The comparisons presented is between the aim and the testing, experimental results. The required goals were met.

Table 32: Comparisons

Metric	Marginal/Target Values	Actual Values	Justification
Factor of Safety	4/10	8.7	Structural Analysis
Weight (Kgs.)	20/16	18.3	
$C_dA(m^2)$	0.3/0.1	0.1527	Aerodynamic analysis
Speed (km/h)	35/45	43	Gearing Analysis
Cost (rupees)	70000/40000	44980	Cost Analysis
Salom Test	Pass	TBD	Endurance Tests
Safety	Pass	TBD	Safe design
Shifting Sequence	Optimum	Selected	Acceleration Test
COG	Low	Obtained	COG Test

5.2 Evaluation

The team has tried to overcome challenges faced during the designing and manufacturing of previous year vehicles by the team. The present vehicle is designed to clear all Product Design Specification {P.D.S} and provide us with best possible results. With every HPVC event passing by, we want our principle product to be more reliable, stable, comfortable, easy to manufacture and ergonomic in design than the previous one.

Our HPV Derby has cleared all experimental tests and has given positive results so far. Our vehicle is designed to provide speed and rider safety, as well as reducing negative environmental impact.

Derby is compliant with all ASME HPVC Asia Pacific constraints, proving precise technical information about our capabilities. Our ultimate goal is to improve and learn from previous mistake and come up with better results using our knowledge of Engineering. The team feels that the present goal is achieved, while there still are chances of improvement in design, safety, and material selection that we will take lessons for further endeavours.

5.3 Recommendations

Analysis is an important aspect for the vehicle, be it material or aerodynamic. The former takes care of the design criteria, waste to be generated and the overall strength of the vehicle, while the later considers the drag force and performance into the account. These factors decide the comfort of the rider, as well the manufacturing process to be chosen. Apart from the comfort point of view, safety is also taken in the picture. We strongly feel that safety is a part of science and engineering. We wish to develop safety standards for the team for the upcoming years. Henceforth, we build up a strong foundation for analysis, which helps us to seek a good result.

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Appendix: Gantt chart

	Task Name	Duration	Start	Finish
1	Derby	305d	03/26/18	01/24/19
2	Discussion on past experience	13d	03/26/18	04/07/18
3	Positive take away	5d	03/26/18	03/30/18
4	Rectification of failures	5d	03/31/18	04/04/18
5	Future stepS discussion	3d	04/05/18	04/07/18
6	Pre-Design Phase	50d	07/16/18	09/03/18
7	Erogonomics data generation	8d	07/16/18	07/23/18
8	Drive train Calculations	8d	07/24/18	07/31/18
9	Brake Calculation	8d	08/01/18	08/08/18
10	Vehicle Dynamics calculations	5d	08/09/18	08/13/18
11	Destructive Testing of Welding Process	4d	08/14/18	08/17/18
12	Ordering primary tools and components	6d	08/18/18	08/23/18
13	Pre-Design Study	7d	08/24/18	08/30/18
14	Selection of material and cross section	4d	08/31/18	09/03/18
15	Design and Analysis phase	45d	09/04/18	10/18/18
16	Design of Frame Geometry and other components	5d	09/04/18	09/08/18
17	Simulation and verification of Frame, RPS and various componen	10d	09/10/18	09/19/18
18	Decision on assemblies and their compatibility	2d	09/20/18	09/21/18
19	Set Purpose	3d	09/22/18	09/24/18
20	Justification of choices	4d	09/25/18	09/28/18
21	Modelling of Aerodynamic and Fairing Design	3d	09/29/18	10/01/18
22	Fairing Design Analysis and Iteration	6d	10/02/18	10/07/18
23	Implementing required Improvements and finalization.	11d	10/08/18	10/18/18
24	Manufacturing Phase	58d	10/19/18	12/15/18
25	Procuring Frame and other required materials (Bangalore)	4d	10/19/18	10/22/18
26	Preparation	4d	10/23/18	10/26/18
27	Profiling and Cutting	7d	10/27/18	11/02/18
28	Sheet Preparation and Bending operation (Chennai)	4d	11/03/18	11/06/18
29	Procuring Billet material	2d	11/07/18	11/08/18
30	Component(s) manufacture ordering	4d	11/09/18	11/12/18
31	Preparation of Fairing Skeleton	11d	11/13/18	11/23/18
32	Analysing the Timeline for Welding Date	7d	11/24/18	11/30/18
33	Integration of Skeleton to Frame	7d	12/01/18	12/07/18
34	Assembly of parts	8d	12/08/18	12/15/18
35	Testing	26d	12/16/18	01/10/19
36	Analysing	5d	12/16/18	12/20/18
37	Trial Run(s)	5d	12/21/18	12/25/18
38	RPS Testing	2d	12/26/18	12/27/18
39	Transmission Efficiency	2d	12/28/18	12/29/18
40	Drag Coefficient Validation	2d	12/30/18	12/31/18
41	Integration of other essentials	3d	01/01/19	01/03/19
42	Make changes according to results obtained	7d	01/04/19	01/10/19
43	Safety Analysis	14d	01/11/19	01/24/19
44	Stopping Distance	2d	01/11/19	01/12/19
45	Body Contact Analysis	2d	01/12/19	01/13/19
46	Turning Radius	2d	01/15/19	01/16/19
47	Other Essentials	3d	01/17/19	01/19/19
48	. Make changes according to results obtained	6d	01/19/19	01/24/19

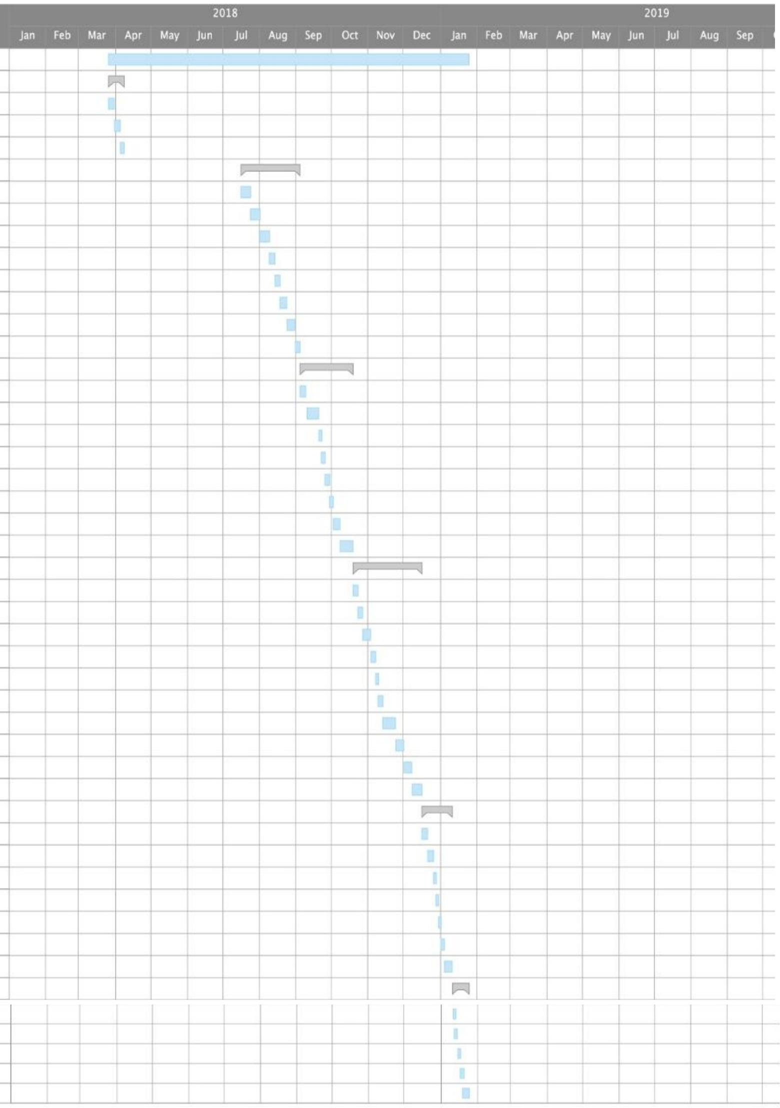
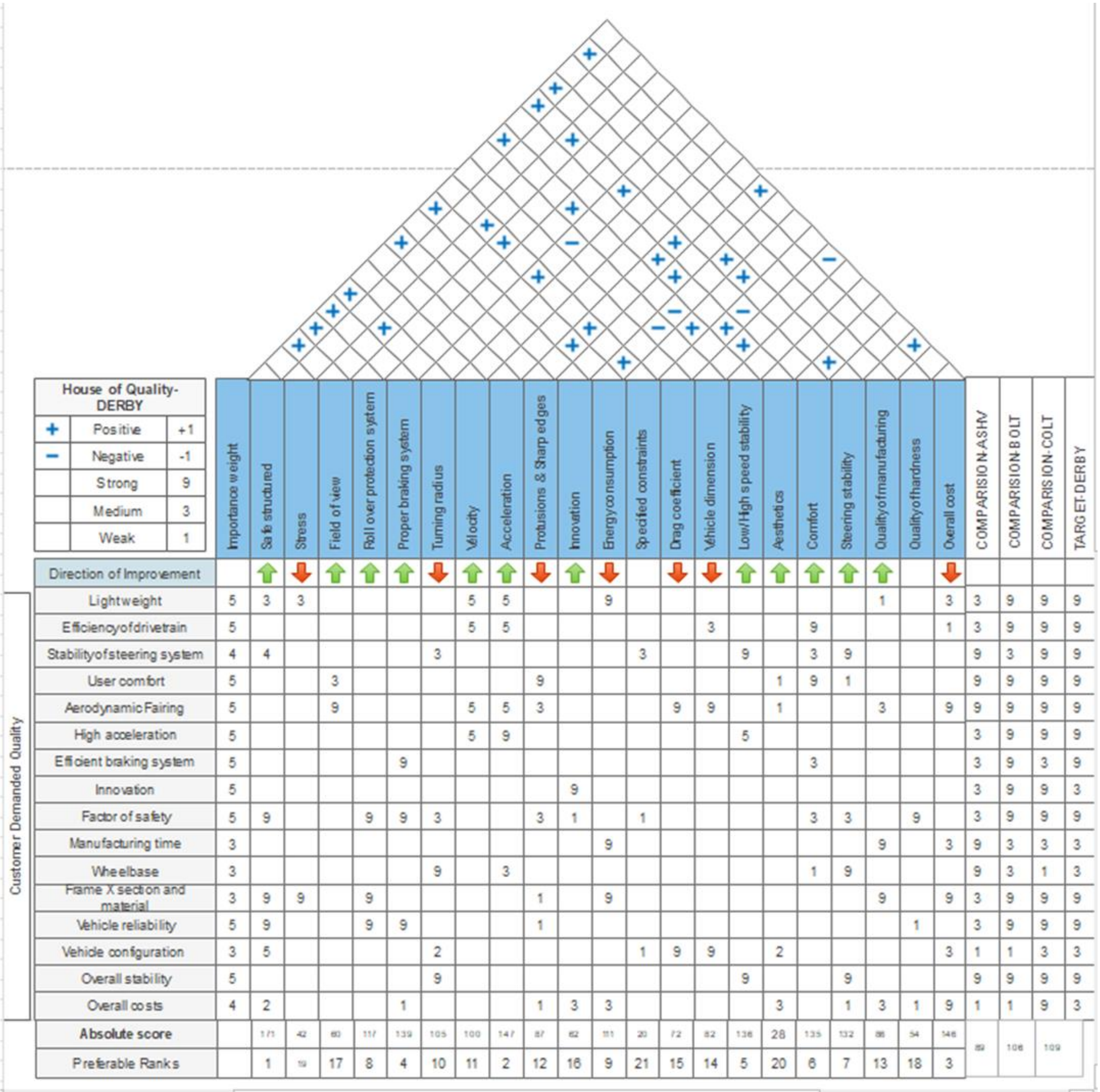


Figure 8: Gantt chart



House of Quality-DERBY		
+	Positive	+1
−	Negative	-1
	Strong	9
	Medium	3
	Weak	1

Customer Demanded Quality	Importance weight	Safe structured	Stress	Field of view	Roll over protection system	Proper braking system	Turning radius	Velocity	Acceleration	Protusions & Sharp edges	Innovation	Energy consumption	Specified constraints	Drag coefficient	Vehicle dimension	Low/High speed stability	Aesthetics	Comfort	Steering stability	Quality of manufacturing	Quality of hardness	Overall cost	COMPARISION-ASHV	COMPARISION-BOLT	COMPARISION-COLT	TARGET-DERBY
Direction of Improvement		↑	↓	↑	↑	↑	↓	↑	↑	↓	↑	↓		↓	↓	↑	↑	↑	↑	↑		↓				
Lightweight	5	3	3					5	5			9								1		3	3	9	9	9
Efficiency of drivetrain	5							5	5						3			9				1	3	9	9	9
Stability of steering system	4	4					3						3			9		3	9				9	3	9	9
User comfort	5			3						9							1	9	1				9	9	9	9
Aerodynamic Fairing	5			9				5	5	3				9	9		1			3		9	9	9	9	9
High acceleration	5							5	9							5							3	9	9	9
Efficient braking system	5					9												3					3	9	3	9
Innovation	5										9												3	9	9	3
Factor of safety	5	9			9	9	3			3	1		1					3	3		9		3	9	9	9
Manufacturing time	3											9								9		3	9	3	3	3
Wheelbase	3						9		3									1	9				9	3	1	3
Frame X section and material	3	9	9		9					1		9								9		9	3	9	9	9
Vehicle reliability	5	9			9	9				1											1		3	9	9	9
Vehicle configuration	3	5					2						1	9	9		2					3	1	1	3	3
Overall stability	5						9									9			9				9	9	9	9
Overall costs	4	2				1				1	3	3					3		1	3	1	9	1	1	9	3
Absolute score		171	42	60	117	139	105	100	147	87	62	111	20	72	82	136	28	135	132	86	54	146	89	106	109	
Preferable Ranks		1	19	17	8	4	10	11	2	12	16	9	21	15	14	5	20	6	7	13	18	3				

Figure 9: House of quality