DESIGN AND MANUFACTURING OF 4 WHEELED HUMAN POWERED VEHICLE

A Final Year Project Report

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ABSTRACT

Transportation has been essential in the development of the human society. People have become closer than they have ever been thanks to inventions like the car, aero plane and so on.

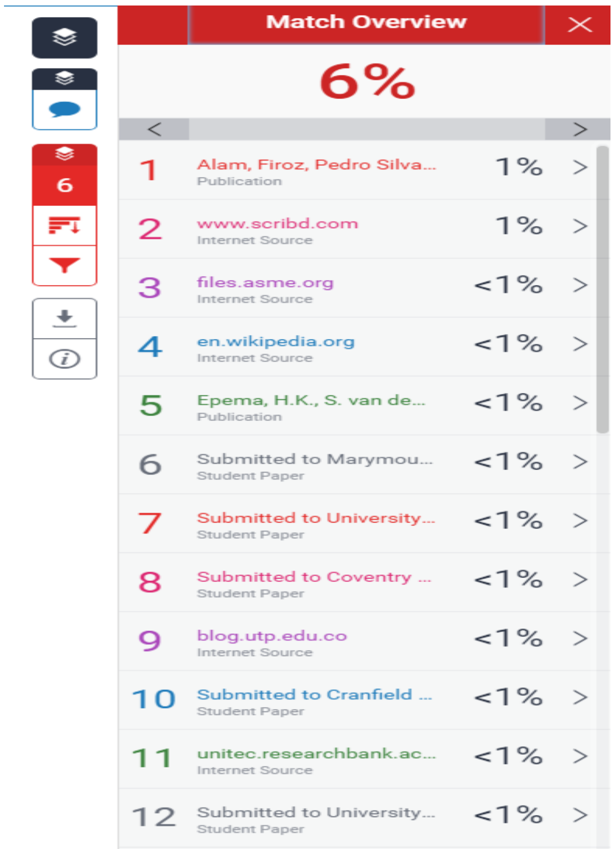
But due to the increase in their use our environment is suffering, alternate means of transport are an emerging market around the world but they still have not caught on in Pakistan. We as final year students wanted to design a comfortable human powered vehicle which can allow use over long distances and time.

The following report details the work we have done over the span of a year to develop such a vehicle. It includes the design process, analysis and the testing done on the prototype we have developed.

ACKNOWLEDGMENTS

First of all, we would thank ALLAH Almighty, who gave us knowledge and dedication to be able to complete this research. We would also like to thank our Faculty advisor who, at each and every step, assisted us, encouraged us and guided us to complete the project successfully.

ORIGINALITY REPORT



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ABBREVIATIONS

HPV	Human Powered Vehicle
FOS	Factor Of Safety
FOV	Field Of Vision
ASME	American Society of Mechanical Engineers
HPVC	Human Powered Vehicle Challenge

NOMENCLATURE

σ_b	Bending Stresses
M	Bending Moment
Y	Distance
I	Moment of Inertia about the Neutral Axis

CHAPTER 1: INTRODUCTION

1.1 Human Powered Vehicles

The term Human-Powered Vehicle or HPVs, is in some cases used to mean a sub-class of vehicles including as it were elite bikes or tricycles furnished with streamlined fairings. For the most part, the term alludes to any semi-supine bike. However, the term ought to appropriately allude to any methods for carriage, movement, or transport that is fueled exclusively by human muscles. Producers of bikes, kayaks try not to advertise their items as HPVs, however unquestionably these meet all requirements for the name. Crossover human-fueled vehicles, for example, mopeds and electric bicycles utilize human control notwithstanding different sources. While these vehicles are outside our definition of HPVs, they are unquestionably comparable, in both innovation and reasoning. Human-fueled vehicles were initially intended for transportation, and that is as yet their most essential utilize. HPVs today give spotless, calm, and efficient transportation. In most created nations, and specifically the United States, the essential transportation frameworks are intense and inefficient, creating vast measures of air and clamor contamination. HPVs might be picked essentially in light of the fact that it is pleasurable to movement unobtrusively through the wide open, encountering nature rather than shutting it out behind steel and glass. Numerous pick human power since it is fundamentally more affordable than different choices, or maybe in light of the fact that it is useful for their wellbeing. Competitors and those with an aggressive twisted mindset can discover numerous scenes for hustling. Maybe the most convincing motivation to utilize HPVs is manageability: the ecological impression of HPVs is ordinarily a whole lot littler than that of different methods of transportation. In spite of these shared characteristics, HPVs are utilized by a wide range of individuals for an extensive variety of different reasons, including entertainment, rivalry, cost, wellbeing, transportation, and worry for the earth.

1.1.1 Benefits of HPVs

Some of benefits of Human Powered Vehicles need to be looked into more closely:

1. Recreation

HPVs, are much of the time utilized for amusement. Frequently a bicycle rides or a kayak trip is a get-together with loved ones. Calm boulevards and provincial streets can offer superb cycling. The quantity of bike ways is expanding in numerous parts of the United States as surrendered railways are changed over into rail-trails and as nearby, state, and national parks give more bicycle trails and ways. These offices give tourist detours to day rides, and can give a suspicion that all is well and good to youthful riders, their folks, and other people who are worried about riding in rush hour gridlock.

1. Competition

Racing has likely existed as long as humans themselves. It is anything but difficult to envision a gathering of extreme and valiant cyclists hustling their high-wheeled common cycles over generally cleared streets in the nineteenth century. As bikes turned out to be further developed, the opposition without a doubt progressed toward becoming quicker, yet maybe no quicker. Today, bike hustling is a to a great degree prevalent game in numerous parts of the world, particularly Europe. Contenders can discover settings for dashing an assortment of human-fueled land and watercraft, and a few rivalries have included flying machine. HPV associations give numerous settings to hustling supine vehicles, including quick streamliners. Regularly these occasions exhibit mechanical advancements and plan development. Numerous are neighborhood or provincial occasions, supported by clubs. Of the more conventional races, the most surely understood is the Tour-de-France, an occasion limited to jewel outline bikes. Two eminent races that allow prostrate bikes and streamliners are the Race Across America what's more, the World Human-Powered Speed Challenge.

2. Financial aspects

While the physical difficulties and energy of dashing interest to a few, financial aspects draw in a larger number of individuals to HPVs than maybe some other reason. Human-fueled vehicles, particularly bikes, are generously more affordable to buy, claim, what's more, work than different vehicles. In the Pakistan, countless individuals with restricted or no pay utilize bikes for transportation essentially in light of the fact that they are reasonable. This gathering incorporates understudies, obviously, yet it likewise incorporates a significant number of our country's poor. It isn't elusive a ride able bike at a carport deal or on the other hand thrift store for under 2500 PKR. What numerous individuals with wages well over the destitution level don't understand is exactly how huge transportation expenses can be, especially with a transportation framework that favors individual vehicles.

3. Fitness and Health

H Medical issues identified with stationary ways of life influence a critical bit of the total populace. In 2006, Dr. Barry Popkin, in an introduction to the International Association of Agricultural Economists, reported that the number of overweight individuals around the world surpasses the quantity of hungry people. This is especially an issue in developed nations, for example, the United States. Stationary ways of life can prompt corpulence, with numerous related health dangers counting diabetes and cardiovascular disease. Conversely, customary physical movement can diminish the probability of corpulence and increment general wellbeing. Numerous individuals in the United States perceive the advantages of consistent exercise. Individuals who practice routinely have a tendency to live more, more dynamic lives. General vigorous practice keeps the cardiovascular framework fit as a fiddle, counteracts or lessens hypertension, and lessens levels of possibly hurtful LDL cholesterol. Long haul standard exercise may likewise raise HDL (great) cholesterol levels. Direct levels of activity enhance the resistant framework (albeit extremely extraordinary exercise may really impede invulnerable framework work.) Exercise additionally lifts disposition what's more, sentiments. Mind levels of endorphins, serotonin, and dopamine are raised with either concise, serious exercise or more, direct exercise. These advantages have been appeared to diminish the impacts of despondency and prompt enhanced sentiments of prosperity. Long haul work out, combined with a decent eating routine, is compelling for weight reduction. Indeed, brief, however consistent, times of activity can be advantageous, and cycling is especially compelling. For the most part, practice does not make overweight individuals hungrier. General cycling or HPV utilize gives these medical advantages. Exercise center participations what's more, wellness clubs are very prevalent, and function admirably for some. Others, be that as it may, think that it's hard to set aside a few minutes for an exercise, or drop out after a couple of sessions.

4. Portability

Human-fueled vehicles give incredible portability to nearby treks. Portability is the capacity to get to a goal in a proficient and generally speedy way. Street HPVs are especially capable at nearby outings in both provincial and urban regions, with versatility some of the time drawing closer or surpassing that of engine vehicles. For instance, in intensely congested territories, bikes are frequently speedier than vehicles. The bike detachment business exists essentially in view of this reality. Mountain bikes can give exceptional versatility in territories without streets. Kayaks and kayaks exceed expectations in conduits that different vessels can't explore, for example, shallow, rough waters or waters stifled with vegetation. A large portion of these excursions could be finished by human-control with practically zero lost time.

5. Environment

Ecological concerns give a convincing motivation to utilize human-fueled vehicles. In the created world, transportation frameworks represent an exceptionally huge division of air contamination. Emanations from engine vehicles incorporate poisons what's more, Greenhouse gasses (GHGs.) In the United States, the pervasiveness of individual vehicles and the generally minimal effort of engine fuel have prompted a transportation foundation that is transcendently in light of expressway vehicles. These vehicles are by and large wasteful, bringing about more contamination per traveler mile than other transportation modes, for example, rail. A moment result is the fast development and advancement of rural and country territories. This has put expanded weight on wetlands and natural life living space, and also empowered longer drives from home to working environment. The outcome is a mix of expanded air contamination and diminished normal assets. Autos are additionally loud, which can likewise be viewed as a sort of contamination of the earth. Transportation represents a noteworthy portion of air contamination and GHG discharges in the United States. On-street portable sources represent 51% of all carbon monoxide discharges, 29% of all hydrocarbon emanations, 34% of all nitrogen oxides, and 10% of every particulate discharge. Autos and bikes contribute the greater part of the on-street versatile hotspots for carbon monoxide and hydrocarbons, while fuel trucks and diesel vehicles represent a large portion of the on-street nitrogen oxides and particulates. Emanations incorporate burning items what's more, fuel vanishing. 33% of the ozone depleting substance emanations are delivered by versatile sources. For each liter of fuel consumed, 2.3 kg of carbon dioxide reciprocals are discharged into the environment. Ozone harming substance fixations have risen pointedly since the beginning of the modern period, prompting expanding normal worldwide temperatures. Essentially expanding the number and utilization of HPV’s utilized for transportation can lighten the ecological harm from the transportation part. This is common sense and powerful arrangement that could be effortlessly and rapidly actualized. HPVs create no contaminations amid utilize, and a little portion of the ozone depleting substance discharged via vehicles. Any elective transportation framework must decrease emanations, as well as should likewise be reasonable and utilize existing innovation. Bikes and HPVs utilize existing foundation—roadways and bike ways—and would require no extra capital expense. Actually, HPVs cause less harm to streets than autos, so it is possible that foundation expenses could really decrease with expanded HPV utilize. Cost to buyers could likewise be fundamentally diminished, as talked about above. Human-fueled vehicles fill a one of a kind part in manageable transportation options. No other alternative can give quantifiable decrease in air toxins and ozone harming substance outflows with accessible and moderate innovation that utilizations existing foundation. HPVs are, for the present, basic to accomplishing a feasible transportation framework.

1.1.2 Drawbacks of HPV

The drawbacks associated with HPVs are few but important. They are as follows:

1. Niche Market

After the industrial boom, a lot of change had been experienced throughout the coming years especially in the automotive industry. The improvements in engineering had led to a more ergonomic design on existing cars. Moreover, to cater for the ever increasing human population vehicles which could carry more people to their destination with the most comfort and safety was preferred as compared to HPVs. That is why only enthusiasts are the target markets for human powered vehicles. In order to attract more customers a strict regulation on the cost of manufacturing such HPVs needs to be maintained.

2. Length of the journey

HPVs are more suitable for short distance trips. The prime reason being that the vehicle utilizes human energy extensively. This puts a lot of pressure on an average human being to even think of going on a long distance journey. This however is also a room for improvement for HPVs as a flywheel can be installed to help transition between braking and speeding up again while conserving energy. However, the idea of a long distance journey is still far-fetched and needs more researching.

3. Weather/Climate Conditions

The energy expenditure by the human to power the vehicle needs to be effective. In essence, this calls for a lightweight vehicle. The design needs to be a tradeoff between cost and safety. The durability of the entire system cannot be matched with let’s say motor cars etc. which generally will be the yardstick for measuring the feasibility of the project.

4. Human Limitation

The human element within the designing of the HPV limits the performance of the HPV. The consistency will not coincide everywhere as each human is built differently and so the interface may not be welcoming for all.

1.2 Background

People are portable. Individuals get a kick out of the chance to move, to movement, to wander. In the beginning of mankind's history, there were no vehicles, and all transportation was by our own human control. Presumably the very first vehicles were floating logs or vegetative mats conveyed by streams or waves. At the point when an early human first kicked, paddled, or poled one of these, human-fueled vehicles appeared. Basic paddled or on the other hand paddled watercraft was very likely the most punctual human-controlled vehicles. By the time of the antiquated Greeks, human-fueled pontoon innovation had progressed to huge paddled vessels biremes and triremes that were up to 40 m (130 ft.) long what's more, controlled by a team of up to 170 men. The antiquated Greek trireme, with three columns of rowers, most likely was fit for seven or eight bunches for short bursts.1 The innovation, as usual, was driven by require—for this situation the requirement for a quick, capable military vessel. For centuries, human muscles, alongside wind and streams, were a prevailing wellspring of energy for vessels. For arrive transportation, creature control and additionally human power was widely utilized before the mechanical transformation. Wheeled vehicles presumably go back no less than 5,000 years. While these may have been essentially pulled by creatures, without a doubt some were pulled by people—maybe making a crude adaptation of the rickshaw. With the appearance of steam and inside ignition motors, and later electric engines and batteries, most high-control transportation modes changed from muscle to elective power sources. This change, which happened amid second 50% of the eighteenth century, marked a blooming of new advancements, including the bike, the car, and the soon-to-fly plane. Muscle control (both creature and human), steam control, what's more, control from the new inner burning motor were altogether seen as practical alternatives for transportation and industry. Electric power was likewise quickly creating, in spite of the fact that the power network was still amazingly restricted and batteries were overwhelming also, low-controlled. Human versatility was expanding essentially, and vehicles of all types were quickly creating. These overwhelming circumstances saw the bike create from a simple interest horse compose gadget into a down to earth, clean, and quick methods for individual transportation. We are aiming to design and fabricate a

HPV that is comfortable for the rider, cost effective and most of all useable in our environment. [12]

CHAPTER 2: LITERATURE REVIEW

The most integral part of this project was to comprehend the design of the product that was going to be fabricated (HPV). The research consisted of:

1) Reading and Evaluating Design Reports of Past Manufactured HPVs
2) Critically Understanding the design through Mark C. Archibald's "Design of Human Powered Vehicles"
3) Corresponding with students who took part in HPVC (Human Powered Vehicle Challenge) at GIKI

2.1 Evaluating Past Manufactured HPVs (ASME HPVC)

The Esteemed American Society of Mechanical Engineer's (ASME) every year holds an Human Powered Vehicle Challenge in seven different regions [19]:

1) West North America
2) East North America
3) South America
4) Mexico
5) Asia Pacific
6) Middle East/North Africa
7) Europe

Human-controlled transport is frequently the main sort accessible in underdeveloped or out of reach parts of the world, and if very much composed, can be an undeniably become a suitable type of transportation. [19]

ASME's global Human Powered Vehicle Challenge (HPVC) gives a chance to understudies to show the use of sound building outline standards in the improvement of manageable and handy transportation alternatives. In the HPVC, understudies work in groups to plan and assemble productive, profoundly designed vehicles for ordinary use—from driving to work, to conveying merchandise to advertise.

The prototypes are evaluated on multiple fronts [19]:

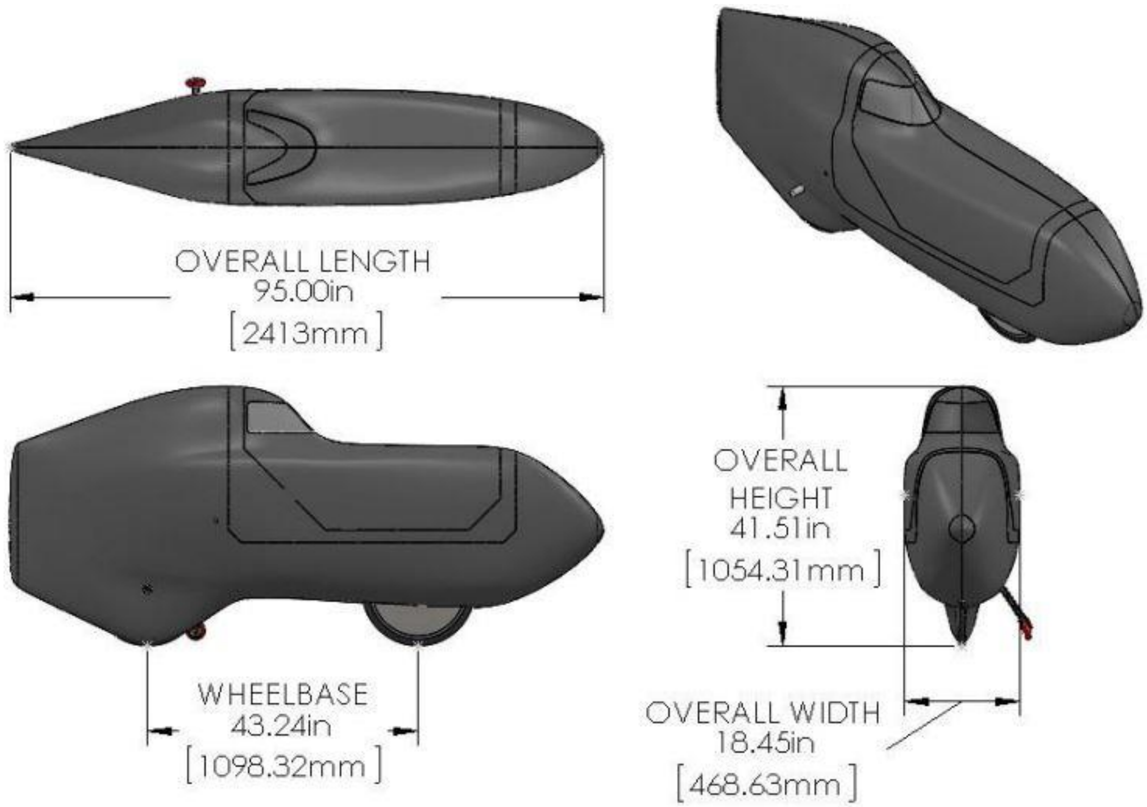
1) Design
2) Innovation
3) Speed
4) Endurance

The design reports of the winners of every event for the past 5 years were assessed for their strengths and weaknesses. The goal was to understand the design of the HPV of each winner and troubleshoot the weaknesses and consequently improve upon them in the design phase. [19]

The winners of the East North America territory for the past 5 years were [18]:

1) Rose Hulman Institute of Technology (2013)
2) University of Central Florida (2014)
3) Missouri University of Science and Technology (2015)
4) The University of Akron (2016)
5) Rose Hulman Institute of Technology (2017)

Rose Hulman Institute of Technology (2013)

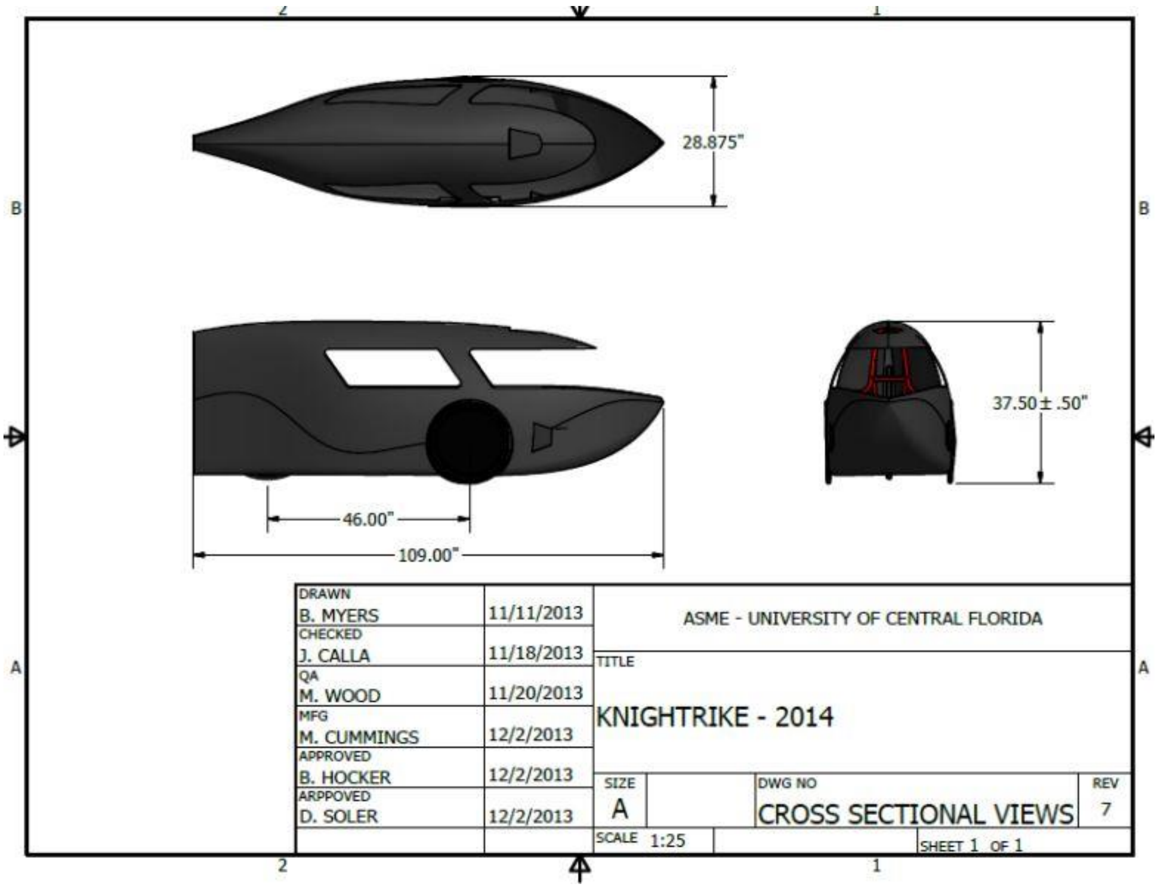


[13] Figure 1Design of Rose Hulman Institute 2013 Winners

Limitations faced by Rose Hulman Institute

Rose Hulman Institute secured 1st place in the overall package, design, speed but placed third in the endurance. This was attributed to the fact that the electrical interconnections and systems were not properly protected from water and debris from the external conditions. Moreover, their system was too reliant on ABS (Anti-Lock Braking System) and had no backup in the form of a mechanical braking system in case of power failure. [13]

University of Central Florida (2014)



[14] *Figure 2 Design of University of Central Florida 2014 Winners*

Limitations of University of Central Florida

University of Central Florida secured 1st place in overall package, speed and endurance. However, they placed second in the design phase. The problems were mostly attributed to clearances between the tie rod and the chain line. Moreover, the vehicle was a bit on the heavier side with a larger frame. Furthermore, the design was a compromise between cost and efficiency. [14]

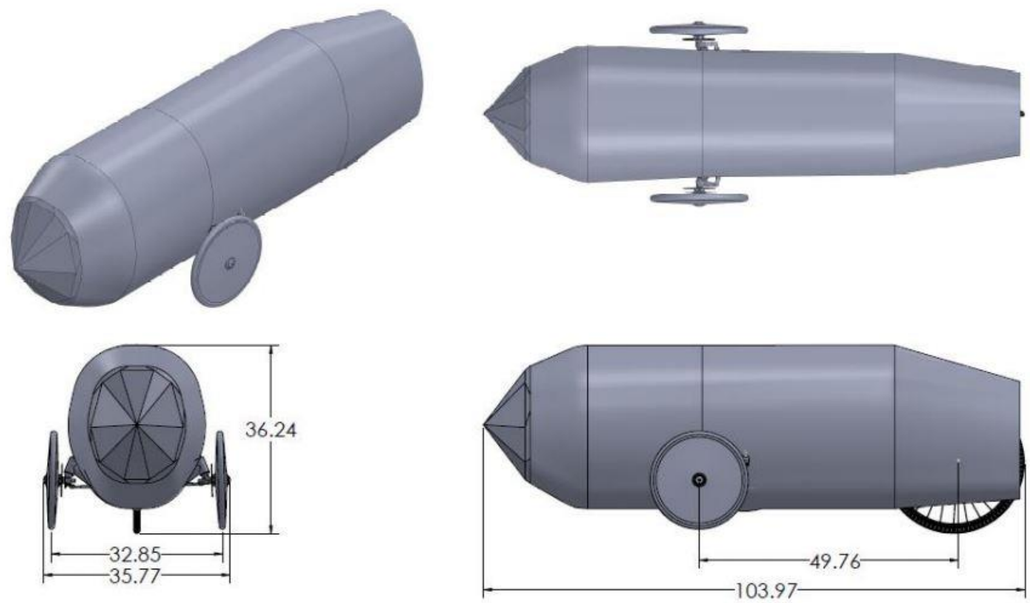
Missouri University of Science and Technology (2015)

[15] *Figure 3 Missouri University of Science and Technology 2015 Winners*

Limitations of Missouri University of Science and Technology

Missouri University of Science and Technology secured 1st place in overall package, speed and endurance. However, they placed third in the design phase. The problems were mostly attributed to larger vehicle size and weight which compromised the efficiency. [15]

University of Akron (2016)



[16] *Figure 4 University of Akron 2016 Winners*

Limitations of University of Akron

University of Akron secured 1st place in overall package, speed and endurance. However, they did not place in the top three in the design phase. The problems were mostly attributed to stiffness of the frame which could have been mitigated by using smaller rear wheels. [16]

Rose Hulman Institute (2017)

[17] *Figure 5 Rose Hulman Institute 2017 Winners*

Limitations of Rose Hulman Institute

Rose Hulman Institute secured 1st place in overall package and innovation However, they lacked in the speed and endurance phases respectively. This was mostly attributed to the time management of the project. The design was changed from rose pedal to tadpole type and not much provision was given to the durability of the product. [17]

2.2 Mark C. Archibald's "Design of Human Powered Vehicles"

This book is about the plan of vehicles with wheels that are fueled by human muscles alone. These can give moderate, economical, and solid transportation to individuals around the world. The term Human-Powered Vehicle, or HPV, is now and again used to indicate a sub-class of vehicles including just elite bikes or tricycles outfitted with streamlined fairings. All the more by and large, the term alludes to any semi-supine bike. However, the term ought to appropriately allude to any methods for carriage, movement, or transport that is controlled exclusively by human muscles. [12]

This book is restricted to plan of human-controlled vehicles for land use. There are numerous reasons why the plan and utilization of such vehicles is advantageous. In developed nations, utilizing a HPV in lieu of a vehicle (or in lieu of a second car for a family) can spare $5,000 to $10,000 every year, while enhancing wellbeing and decreasing outflows of ozone depleting substances and contaminations. Ozone harming substance outflow will be diminished by in excess of 4,000 kg for each year because of the relating lessening in energy consumption of in excess of 17,000 kWh. Also, foundation for cycling is far less exorbitant than interstates intended for car activity. [12]

Human-fueled vehicles were initially intended for transportation, and that is as yet their most imperative utilization. HPVs today give perfect, calm, and productive transportation. Maybe the most convincing motivation to utilize HPVs is maintainability: the ecological impression of HPVs is ordinarily a whole lot littler than that of different methods of transportation. In spite of these shared traits, HPVs are utilized by a wide range of individuals for an extensive variety of differing reasons, including diversion, rivalry, cost, wellbeing, transportation, and worry for the earth.

The substance incorporates assembling procedures and materials, execution, dealing with drivetrains, structures, parts, human execution, and plan techniques.

Mark Archibald is a teacher of Mechanical Engineering at Grove City College in western Pennsylvania, where he instructs a course on the outline of human-fueled vehicles. He has prompted numerous understudy ventures for both land and water vehicles. For quite a while, he was heavily required by the American Society of Mechanical Engineer's Human-Powered Vehicle Test, where he served a term as boss judge and a term as executive. A great part of the motivation for this book originated from his endeavors to revise normal plan botches made by understudy contenders. He has additionally composed and manufactured a few effective bikes that he and his family use on their mid-year bike visits.

2.3 NUST winners of HPVC at GIKI

Students from ME-06 (B) took part in the Human Powered Vehicle Challenge at Ghulam Ishaq Khan Institute (GIKI) during their junior year. The event brought together 15 teams from all over Pakistan to compete for the HPV design and testing.

The NUST team achieved first place at the competition and their research, design methodology and innovation was replicated by many other teams the following years.

The design in the HPVC was a 2-wheeled HPV with minimalistic design and no faring. In essence, the design is quite different than the one proposed in this document. However, the problems that they faced during the design, fabrication and testing of the HPV provided great insight for this project.

Figure 6 SMME Bolts Winner's of GIKI HPVC

Limitations of SMME Bolts

SMME Bolts secured 1st position in the overall event. However, they lacked in a few areas which they recognized themselves. The problems were:

1) Financial Issues: Due to Lack of funding from the University and sponsors.
2) Stability Issues with the Vehicle: a Two wheeled HPV should have a self-stabilization technology implemented
3) Material Selection and Lack of Faring: Due to funding issues, the material selected was not the optimized material for such a project

2.1.4 Understandings

The literature review in general provided an exceptional knowledge base as the conception of the HPV could now be commenced knowing full well all the bottlenecks and problems that could be associated with it during the later stages of the development.

2.2 PROCEDURES, AIMS AND OBJECTIVES

The standard procedure that was followed in the fabrication of the HPV is as follows:

1) Design
2) Design Evaluation
3) Design Approval
4) Fabrication
5) Inspection
6) Testing

During each stage of the project, an evaluation was carried out to check for any bottlenecks or areas that could be improved on.

The goal of the project was to make a working model of an HPV and improve upon the design so that the HPV could become a market of its own in Pakistan. The HPV could capitalize on the lack of suitable options available within Pakistan.

Currently, a lot of man hours and equipment is being expended into building an infrastructure for human transportation. i.e Metro Bus Initiative. The HPV on the other hand provides a safe haven for passengers that do not want to indulge in an overcrowded bus and would also crave for the same comfort as in a car.

Moreover, due to the industrial revolution and the ever increasing population, vast amounts of green houses are expected to be released into the atmosphere. The advent of Electric cars and HPV could change the dynamics in the traditional motor cars regime, as it would release no emission. Many countries are following suit to this program such as Germany and Finland both exempting tax on such vehicles.

All in all, a practical, safe and durable HPV is what this project is tasked with.

CHAPTER 3: METHODOLOGY

First Order of business is to do research on what type of HPV is best suited for the team to design and manufacture. The following designs were studied and compared. Each individual of the team scored each design separately and the mean score for each category of each vehicle was used.

Table 1 Selection of Vehicle Type

Attribute	**Weightage Score**	**Upright Bike**	**Recumbent Bike**	**Recumbent Tadpole**	**Delta**	**Prone**	**Quad**
Weight	5	5	4	2	2	5	1
Speed	5	4	5	3	3	5	3
Low Speed Stability	5	4	3	5	5	1	5
High Speed Stability	4	2	3	3	2	4	5
Comfort	4	1	3	4	4	1	5
Maneuverability	4	4	3	2	2	1	5
Prior Knowledge	3	3	1	3	2	0	2
Cost	3	3	3	2	2	1	1
Total Score	37	**26**	**25**	24	22	18	27

So the best Quad scored the most points and our group decided to go for it. Scoring wasn’t the only reason though some other factors also played a role:

1. More chances to learn in designing and manufacturing
2. More challenges to face whereas all the others are heavily documented with each problem with clearly defined solutions.
3. Quadricycles are overall better for long distances and they may just be the things which can bring cycling back to the city.

3.1 Design

Before the initial design would start, the first order of business is to determine the limits of the designs and necessary features of the vehicle. So even though we didn’t have to we used some of the design specifications from ASME’s HPV Competition. The reason here is because of their wide availability and most research done in this area is because of the HPVC held everywhere around the world.

Table 2 Design Limitations

Source	Specification/Limitation
ASME HPVC Rules	1. Unassisted starts and stops 2. Minimum Clearance Height 4.5 inches 3. Minimum Turning Radius: 9ft 6 inches 4. Braking Capability: The vehicle can come to a stop from a speed of 15 miles per hour in a distance of 20 feet or less. 5. Safety Harness: Safety belts and shoulder harnesses if required for the rider. 6. No exterior or interior sharp protrusions 7. An accessory helmet with safety straps. 8. Rider's field of view: 180° without obstruction
Our limitations	1. Cost to be under PKR/- 30000 2. Time available
Location Limits	Aluminum welding unavailable
Financial Limits	1. Carbon Fiber – Unaffordable 2. Mold Casting for Frame – Unaffordable 3. Test vehicle for study - Unavailable

3.2 Concept Development:

The concept development of the vehicle followed a slow yet steady process because we started from a blank drawing board. We went into each topic one by one and with depth. The designing process is completely elaborated in the next section.

3.2.1 Chronological Designing Process:

Initial Design:

With the decision made to start the designing process of a Quad with rear wheel drive. We went through the most important things that may hinder our design which were:

1. Turning Radius

According to ASME rules of HPVC, the vehicle must be able to turn at a radius of 9ft and 6 inches. With our current idea of a quad, that turning radius would require a short wheelbase and a good steer and lean angle.

2. Comfortable Pedaling

Second major issue was getting the legs of the rider all the way from the seat to the pedals far most end easily and then ensuring their comfortable power transmission to the wheel without straining the rider much.

This would require optimum designing and spot on manufacturing so that the rider is able to reach the pedals and is able to use them without losing his comfortable seating position.

3.2.2 Human Model

The above was the initial most design of a person with the estimated dimensions of an average rider. This model was used to calculate the ideal hip to pedal ratio as per the rider's comfort so our HPV could incorporate that distance.

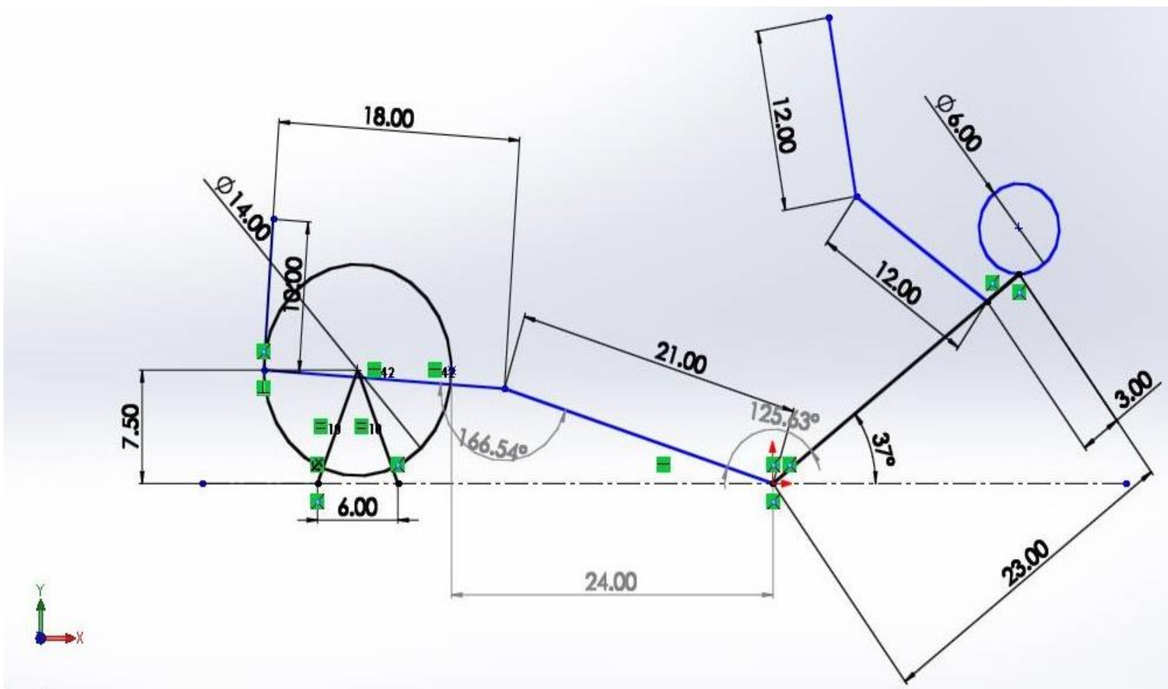


Figure 7 Human Model

3.2.3 Seat Positioning:

To start our design from scratch, we fixed the position of the pedals. From there on, using the human model in the last section, the ideal distance from pedal to seat was measured in the following way.

Calculations:

Table 3 Seat Positioning Calculations

Dimension	Value
Average Hip to Knee	21 inch
Average Knee to Foot	18 inch
Angle of Knee (Fully Stretched)	175-180°
Angle of Knee (Comfortable Stretch)	166.54°
Maximum Hip to Foot Distance without bend	39 inch
Maximum Hip to Foot Distance with a 166° bend	38.7 inch
Minimum Hip to Foot Distance for a 14 inch dia sprocket	25.1 inch
Maximum bend on Knee at minimum distance	79.7° (Maximum Bend is for 63° so our rider would be safe and comfortable)

Decided Factors are; Relations between Centre of Sprocket and Bottom of Seat The Sprocket would be situated at 7.5 inch higher and 31 inch farther than the bottom of theseat.

These values give us the constraint for the front part of our bike and provides us with the area we need to contain our steering system and drive train assembly and also allows us to draw the main frame of the bicycle with correctly placed seat and the sprocket.

3.2.4 Weight Distribution:

A safety factor introduced in vehicles is to put more weight on the driving wheel rather the dragging wheel to ensure stability in terms that the driving wheel does not slip or feel too much pressure in dragging the other wheel.

So the weight distribution for our quad was 60% on the rear wheels and 40% on the front wheels.

3.2.5 Seat Angles

The seat angle affects the model in the following manner.

Table 4 Seat Angle

Seat Angle	Attributes
Greater Angles (>30°)	• Less reclined posture • Smaller Wheel Base • Smaller Turning Radius • More powerful strokes • Less obstructed vision of rider • Fit for normal use
Smaller Angles (<30)	• More reclined posture • Better streamline design • Longer Wheel Base • Larger Turning Radius • More stability • Suitable for racing bikes

To maximize driver comfort and efficiency though the idea of designing a seat was scraped and we decided to use a car seat.

3.2.6 Initial Fairing Design

Table 5 Fairing Selection Matrix

Design	**Attributes**	**Drawbacks**
1. Fully Faired	• Streamline and Aesthetic design • Very low aerodynamic drag on high speeds • Makes the vehicle all weather durable protecting the rider from bad weather	• Congested vehicle • Restricts riders freedom of movement and reduces Field of View • Makes the lean angle for the turn smaller and riskier • Adds about 12-15 kg weight • Adds utility to the vehicle by allowing package storage to be incorporated in the fairing
2. Front Faired	• Low Aerodynamic drags on high speeds. Less weight then fully faired	• Complex design about the pedaling location • Does not protect the rider from bad weather • Makes it difficult to lean
3. No Fairing	• No cost • No extra weight added • Gives rider freedom of movement	• Aerodynamic drag on high speeds • Not an aesthetic or streamline

	and does not restrict field of vision	body

Our initial analysis suggests us that we should either go for fully faired and make our vehicle complete at the cost of weight and performance if finances and time permits. Full fairing gives the vehicle an edge in design and utility.

3.2.7 Wheel Base, Tire Sizes

So the rear wheels are the driving wheels of our vehicle so simple science suggests we make them as big as we can. Also we have to look for the cost effectiveness and their market availability.

Tire sizes are going to be 26 inches. They are widely available and they fulfill our design requirements.

3.2.8 Drive Train:

Our decision to go with rear wheel drive was based on the following research.

Table 6 Drive Mechanism

Design	Advantages	Disadvantages
1. Rear Wheel Drive	• Simple Design • More space near the rear wheel for derailleurs and gear cassettes. • No Torque Steer causing easier steering • Greater steering angle	• Longer drive chains, all the way from the pedals on top of the front wheel to all the way back on the rear wheel causing great power loss.
2. Front Wheel Drive	• Shorter drive train hence more efficient.	• Chain rub on tire during sharp turns • Need to designed to be more compact especially if fairings will be adopted.

3.2.9 Suspension Options

For any vehicle the options are;

Table 7 Suspension Options

Options	**Attributes**	**DrawBacks**
1. <u>Fully Suspended</u>	• Most comfortable position possible for a rider in a HPV	• Increase in cost. • Increase in complexity of front fork.
2. <u>Fully Rigid</u>	• No cost. • No complexity. • A good and comfortable seat can make up for lack of suspension	• Relatively uncomfortable position for the rider. • Suspension-less makes rear joints susceptible to wear and tear
3. <u>Rear Suspension</u>	• Adds enough comfort without adding much complexity • Affordable cost	• Nil

It is worth pointing out that longer the vehicle, the less there is need for a suspension. A quadricycle with a wheelbase of 52 inch is comfortable as it is. Adding a suspension is a bonus comfort for the rider. Adding two suspensions is a luxury for the rider. So we decided to scrap the suspension idea as it was adding unnecessary weight to the vehicle possibly slowing it down.

3.2.9 Material Selection

The frame of the HPV is a square hollow pipe. Our choices of materials are;

Table 8 Material Selection

Material	Attribute	Drawback
1. Mild Steel	• Low Cost • Cheap Welding	• Weight
2. Aluminum	• Great strength to weight ratio • Medium Cost	• Assembly operations like welding too expensive and not available in local market • Assembly operations involving nuts and bolts too unreliable for a moving vehicle
3. Carbon Fiber	• Most optimum strength to weight ratio	• Unaffordable Cost • Assembly operations not present in local market

The material was decided to be mild steel, although the most inefficient of the total choices, mild steel was the cheapest and easiest choice possible.

4.0 RESULTS and DISCUSSIONS

4.1 Stress Analysis

Roll over protection system:

For the RPS, our design specifications are based around the given rules. The specifications include the following:

Vehicle must have a roll cage that will protect the rider from a 2670N force at the top that is directed downward 12 degrees from vertical that faces the rear end of the bicycle. This vertical load must not plastically deform the frame, and the elastic deformation is bound to be less than 5.1cm.

Also, the roll cage must withstand a 1330N force side load that is at the level of the shoulders of the rider. This horizontal load must not plastically deform the frame, and the elastic deformation is bound to a maximum of 3.8 cm.

In the case of a roll over or tip over, the roll cage must protect the rider fully. This means that the top of the roll cage must extend over the top of the helmeted head of the tallest rider.

The design was analyzed using *ANSYS* and comparing the Maximum Von-misses stress with the yield stress of the material. All the members were taken as circular tube as far as possible in order to minimize the stress concentration (fatigue failure) and considering the safety of the driver during any contact with chassis, tubes with edges like square & rectangular cross section have been avoided.

Analysis was done taking the dimensions of tube as 25.4mm Outer Diameter and the Wall Thickness as 1.5mm.

a) Top Loading

In case of top loading a load of 2670N was applied at the top of RPS downwards at an angle of 12° from the vertical.

The end of rod, that would be attached to the roll cage, and the bottom most rod of RPS were constrained i.e. All DOF = 0. The analysis was done using *ANSYS academic*. A maximum displacement of 0.78 mm was seen and a factor of safety (FOS) = 215/88 = 2.44 was obtained. The values obtained were fine and thus validated the final design

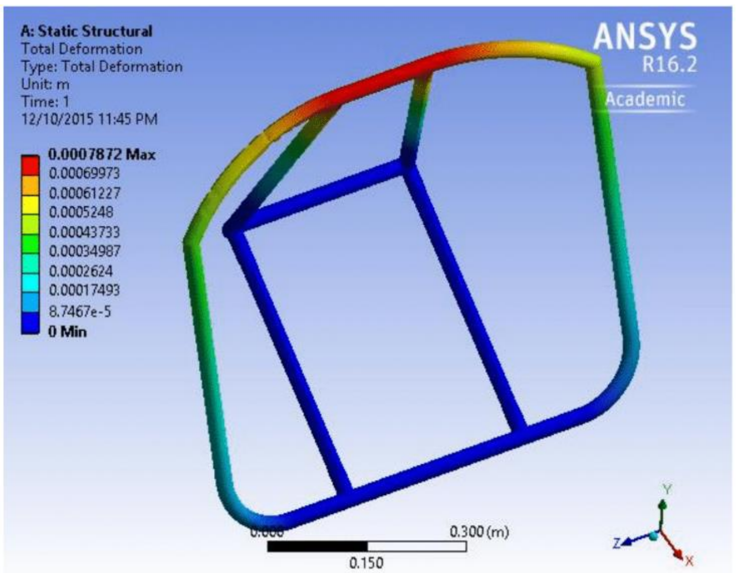


Figure 8 Displacement due to top loading

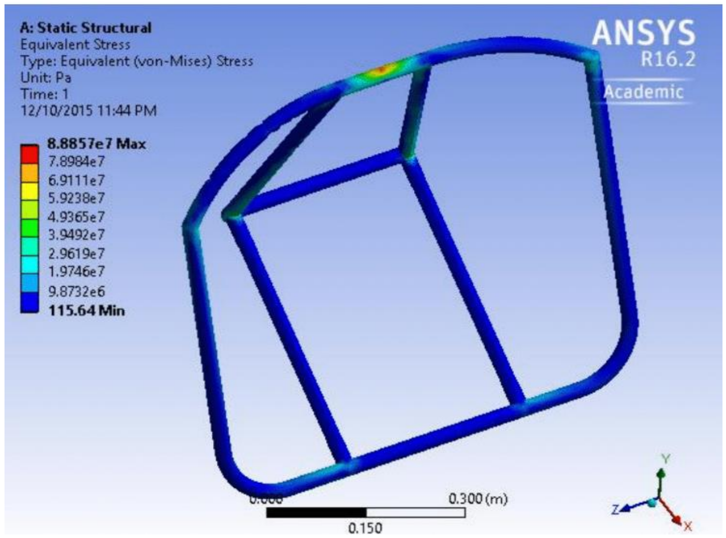


Figure 9 Equivalent Stress (Von mises) stress due to top loading

b) Side Loading

For side loading a load of 1330N was applied horizontally on the side of the RPS at shoulder

height. The points constrained were same as those in case of top loading. The analysis produced a small displacement of 0.78mm and a FOS =215/97=2.21 was obtained which was desirable.

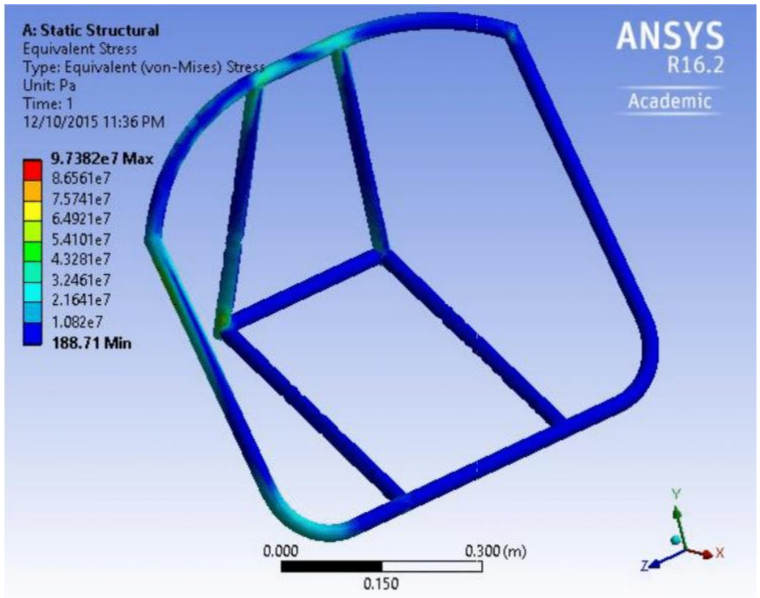


Figure 10 Equivalent Stress (Von mises) stress due to side loading

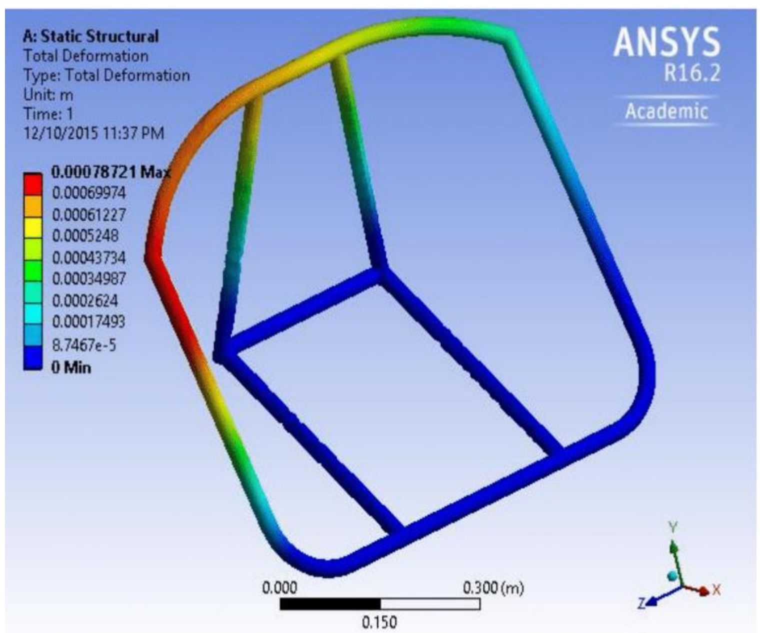


Figure 11 Displacement due to side loading

c) Static Loading

In static condition i.e. when the vehicle is at rest there will be only one considerable force that it will be experiencing i.e. the weight of the driver. The chassis was analyzed to see the stress conditions in the rods of chassis when the driver is sitting. So a load of 1000N was applied downwards at the points where the seat was mounted. It produced a maximum displacement of 0.47mm and a maximum von-misses stress of 75.44 MPa which gave a FOS= 2.84.

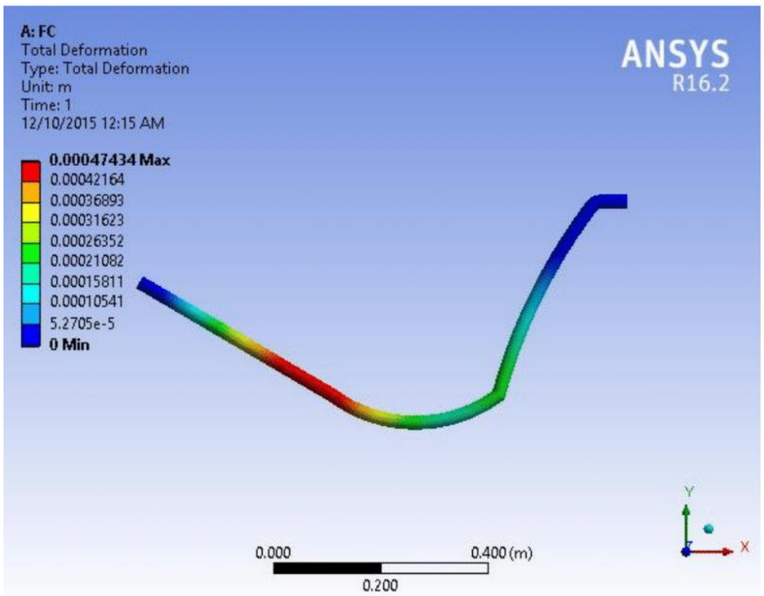


Figure 12 Displacement due to static loading

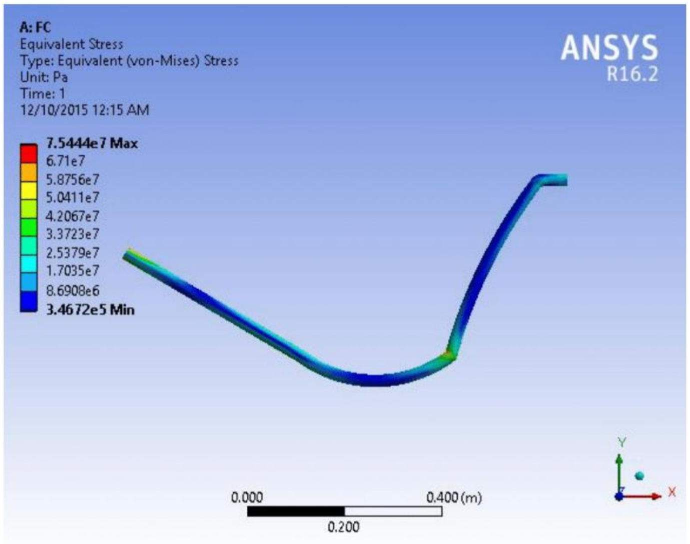


Figure 13 Von mises Stress due to static loading

From the above analysis we can make the following observations:

Table 9 Observations from the stress analysis

Type of Loading	Entity Measured	Maximum Value
A load of 2670N is applied to the top of the roll bar, directed downward and (towards the rear of the vehicle) at an angle of 12° from the vertical	Displacement	0.78mm
	Von-Misses Stress	88.85MPa
Load of 1330N acting on the side at shoulder height of the Driver	Displacement	0.78mm
	Von-Misses Stress	97.38MPa

Static Loading	Displacement	0.47mm
	Von-Misses Stress	75.44MPa

The analysis of the model yielded a minimum Factor of Safety of 2.21 during Side loading (1330N on the ide) and 2.44 during Top load test (2670N at an angle of 12°with the vertical). Such a factor of safety would allow us to alter the outer diameter and the thickness of the tubes used according to the availability in the market. Since our team decided to incorporate a minimum factor of safety of 2 in our design, the above design was according to the standards that we set for our vehicle. Also, the maximum displacements in all the cases were observed to be well under the restrictions set by ASME HPVC. Thus the above design was accepted and finalized. Note that maximum elastic deformation in all cases is negligible (<1mm).

Rear Axle Analysis

Determine the structural integrity of the rear axle, estimate deformation in the rear axle when loaded, determine weak points in the rear axle.

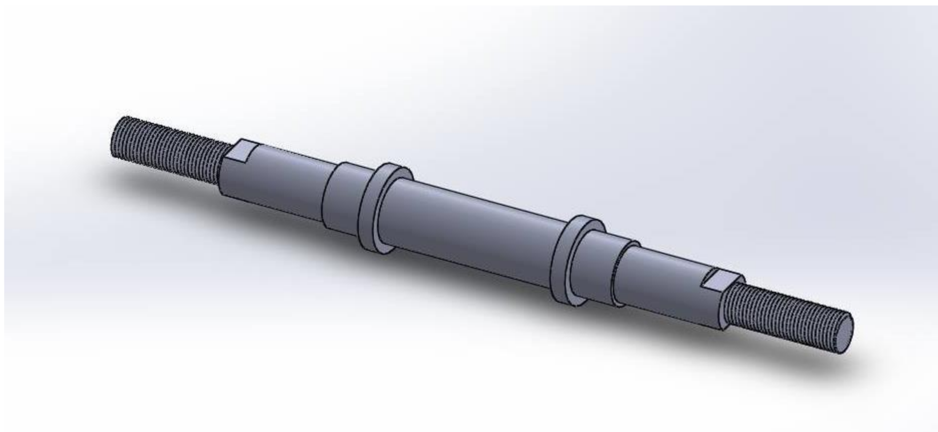


Figure 14 Rear Axle Model 1

Two forces of 1000N are applied on each end of the axle. The analysis was done using Solid Works simulation system. The results are as follows:

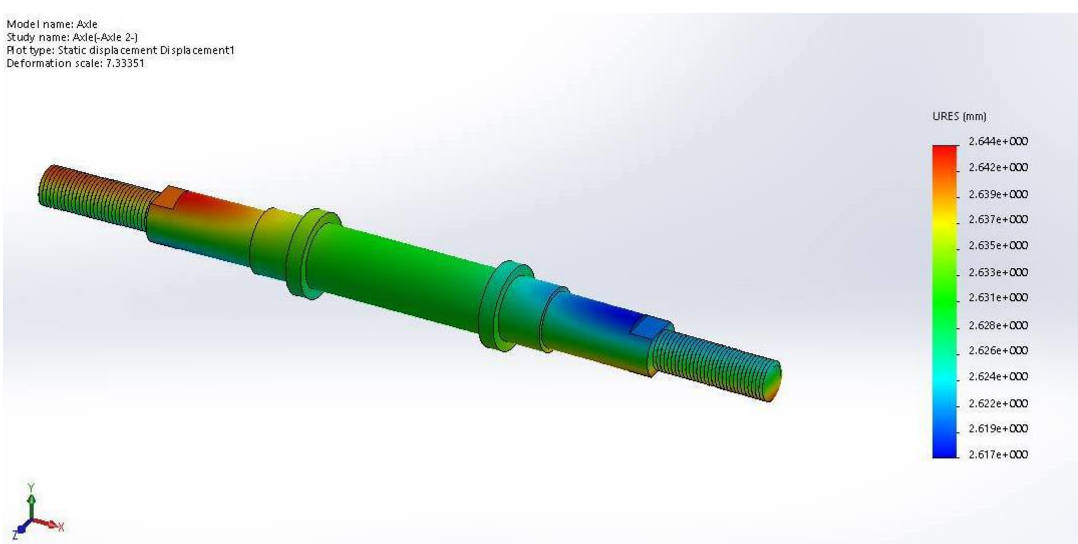


Figure 15 Analysis on Rear Axle - 1

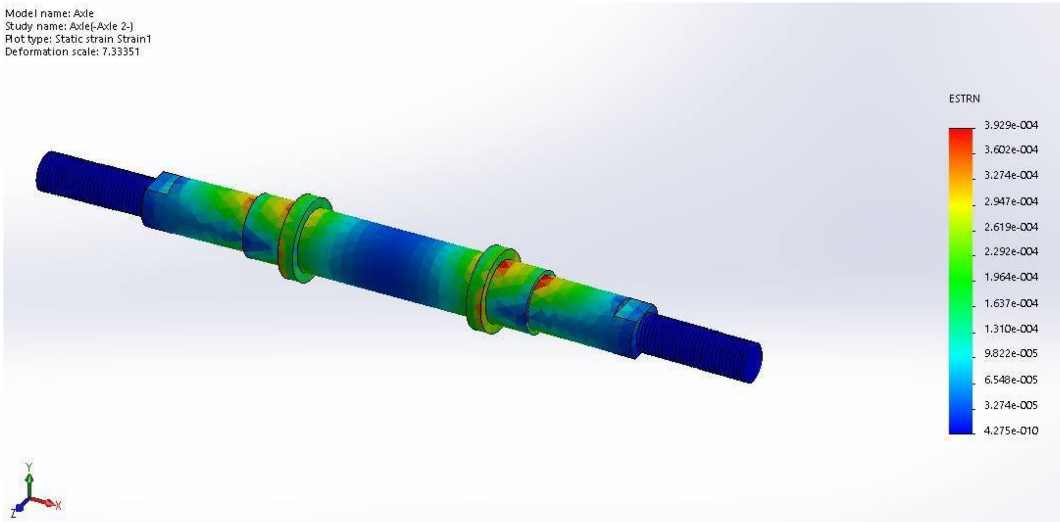


Figure 16 Analysis on Rear Axle - 3

The stresses produced in the rear axle due to the applied loadings are shown in von Misses. The minimum factor of safety is 4.2. The rear axle can easily bear the applied loads which will be the combination of the weight of the HPV, the weight of the rider and the reaction of the forces applied on the pedals.

The strain produced in the rear axle due to the applied load of 2000 N is shown in the above photograph. The maximum strain of 0.00039 is under control and its deformation will neither affect the design's stability nor the HPV performance. The rear axle passes the analysis with a good factor of safety of 4.2. It will be able to support the HPV without any need for strain hardening or any other treatment process to increase its strength.

Front Axle

Front axles are also analyzed against the axial load of tie roads that were placed on the port of tie rod joint to the front axle while steering is on work. The material used for the axles is ASI-4140. Theoretically calculated load of 490 N forces were placed on the axle in which the stress generated is under the safe mode and the factor of safety obtained is 1.8 hence the overall analysis shows that the axle would be safe while working on the specified load conditions.

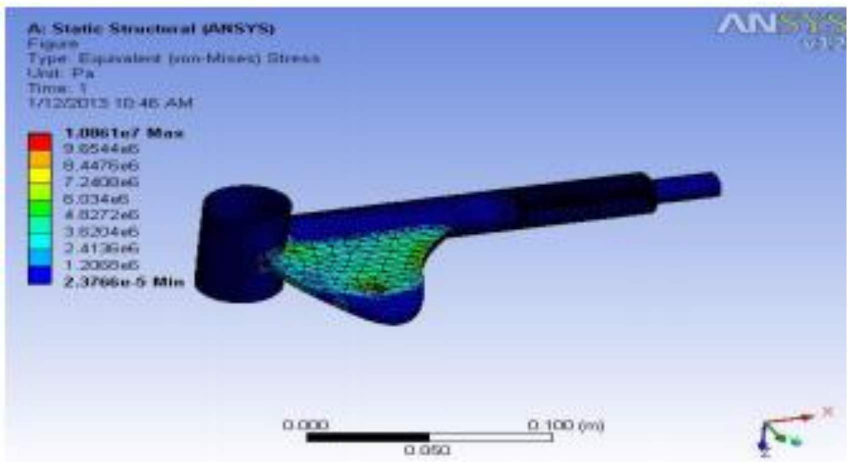


Figure 17 Analysis on Front Axle

4.3 Aerodynamic Analysis

The mechanical efficiency and performance of a human powered vehicle depends greatly on its aerodynamic design. The speed of the vehicle can be enhanced significantly through proper design. Use of principles of fluid mechanics to design has resulted in a dramatic increase in the speeds reached from the 1974, 200m speed record of 69.23km/h to the present record which stands at 133.284km/h.

By application of different principles like reducing vehicle mass and frontal area the efficiency of a HPV can be greatly improved. Wind tunnel testing has been used to identify key characteristics of HPVs. By identifying the different results obtained, it is now possible to understand more about the aerodynamics of HPV. Drag force values are obtained during wind tunnel testing; these drag values can be compared for different models.

A key result is the importance of fairings, where travel could require significantly less effort as the faired vehicle tested provides only a quarter of the aerodynamic hindrance of any of the un-faired vehicles. Another significant finding is the effect of vehicle add-ons (flags, mirrors etc.) which show how some apparently small components can have a relatively large negative impact on drag.

By studying the behavior of different designs under different circumstances in ANSYS, it would be easier to choose the most energy efficient and aerodynamically streamline tricycle. This will help save energy of the driver and help avoid transport that uses fuels like gasoline and natural gas.

1. Application of Bernoulli equation along a streamline

Referring to the pressure contour for the 30 km/hr. simulation of model 3 (picture found in the results obtained in numerical solver section), we can apply Bernoulli equation as follows to calculate the stagnation pressure:

Here

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

V1 = 8.33 m/s

V2=0

Density=1.53 kg/m3

Substituting the values, we should get the value close to that predicted by the CFD.

P2=stagnation pressure = 53.10 Pa

The maximum pressure represents the stagnation pressure. Here the fluid comes to a halt after hitting a surface.

2. Flow of fluid in the virtual wind tunnel and around the object

The **virtual wind tunnel** is comparable to a square duct. In Chapter 8 of Fundamentals of Fluid Mechanics (Munson), the flow inside square ducts has been discussed briefly. When the fluid enters the tunnel, it fills whole of it. The fluid that hits the walls / boundaries come to a stop because of the **no-slip condition**. The CFD should show these areas to be having stationary fluid. There is a **boundary layer** adjacent to the boundaries where the viscous effects are important and the fluid loses its kinetic energy.

The velocity profile adopts the following shape:

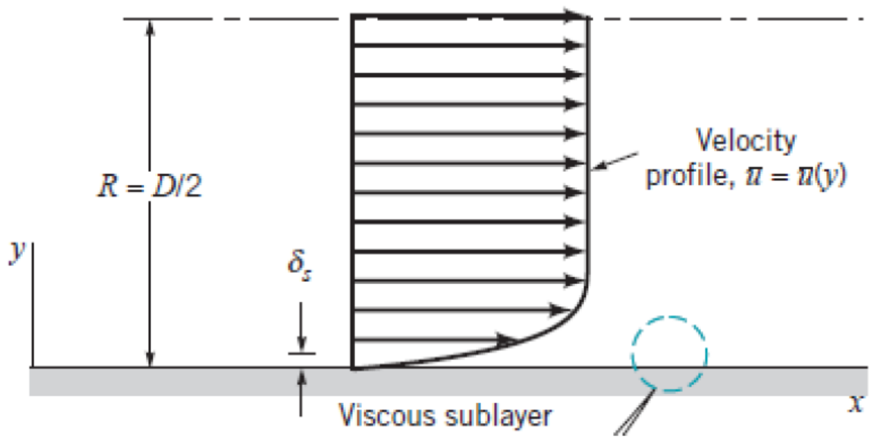


Figure 18 Velocity Profile

When it comes to flow around obstacles, the bluntness of an object dictates flow of fluid around an object. If the object has a relatively streamline design as in models 2 and 3, it would show no or little **flow separation**. However, there should be some flow separation in model 1 virtue of its design.

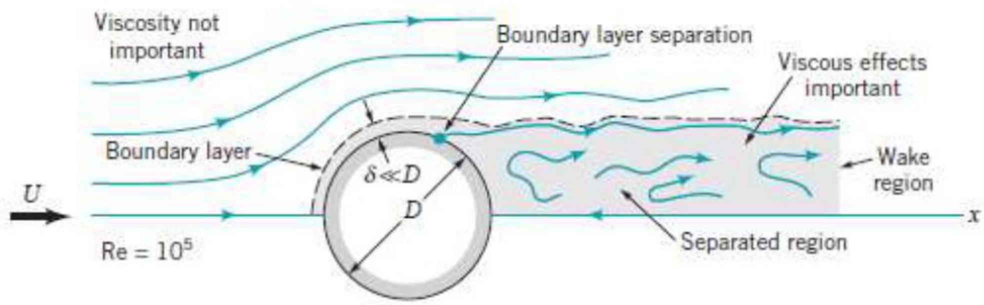


Figure 19 Boundary Layer Formation of the Vehicle

Another factor important in the study of external flows is the force of drag and lift experienced by a body. For a body like an HPV moving at „small" speeds the lift is not important, however, the drag is a quite important factor that can influence the performance and stability of the object. Since model 1 has a large area open to air flow, it is predicted to have a higher value of coefficient of drag (Cd) as compared to the other two models. From theory we know that as close as the design gets to the teardrop shape we will have a smaller force of drag experienced by the object.

Since the drag is given by:

$$C_D = \frac{F_D}{\frac{1}{2}\rho U^2 A}$$

A larger frontal area and a larger speed should cause a greater force of drag acting on the body.

Assumptions and boundary conditions in numerical solver with justification

The following settings were used for the CFD performed in ANSYS Fluent.

1. Viscous model

K-epsilon:

It was used because it Is robust and easy to implement. It includes two extra transport equations to represent the turbulent properties of the fluid.

Realizable:

It satisfies certain mathematical constraints on the Reynolds stresses, consistent with the physics of turbulent flows.

Non equilibrium:

Performs better for adverse pressure gradients

Turbulence intensity: 1% for inlet and 5 % for outlet

Turbulence viscosity=10

An inviscid model would have not have been a good idealization for such low speed air flow as in viscid flow is considered for very high Re flows.

2. **Density**: 1.53 kg/m3

3. **Viscosity**: 1.568 kg /ms

4. **Steady state of object**: Transient is much more complex

5. **Density based solver**: Because of the flow conditions the flow was considered incompressible (Ma<0.3).

6. **Gravity** was ignored because it does not affect horizontal flows significantly.\

7. Default roughness parameter

8. Second order upwind conditions

9. Velocity inlet and pressure outlet

10. 3-wheeled model was used because of the complexity involved in doing one for a 4-wheeled vehicle. We just wanted to know how different types of fairing affected speeds so putting in extra effort to produce the same result wasn't quite efficient.

Results obtained

Three designs were used for the CFD analysis. One model was without a fairing while two had fairings that were different in design. The following pictures show the geometry of the three models.

Model 1:

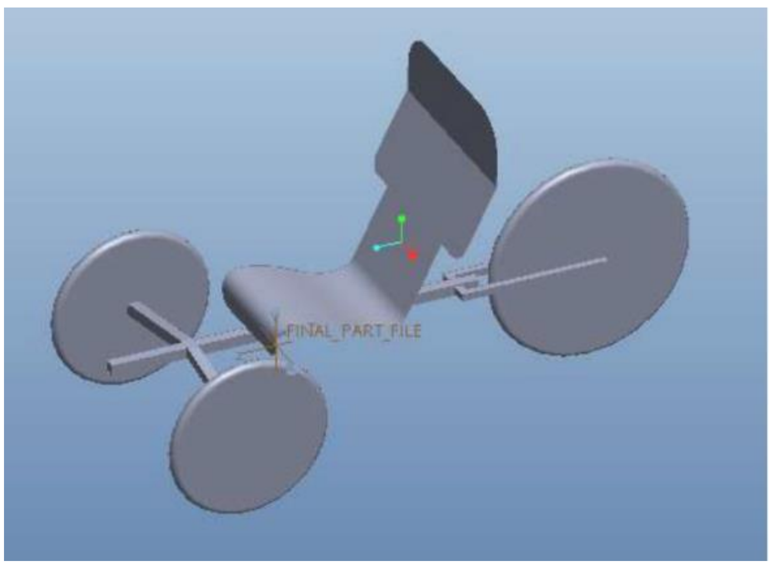


Figure 20 Model without fairing

Model 2:

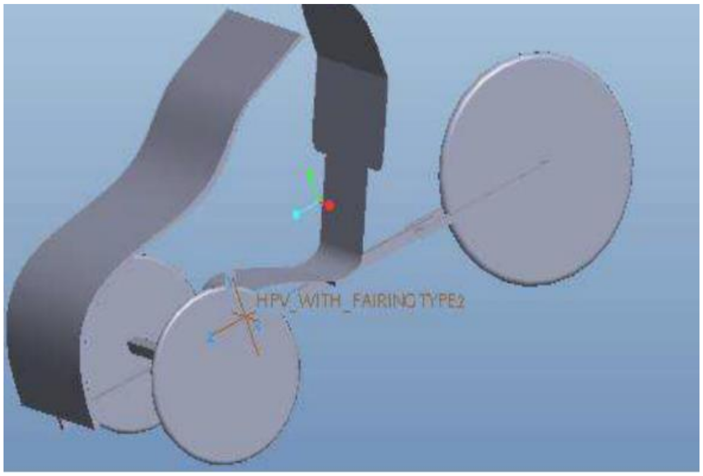


Figure 21 Model with fairing #1

Model 3:

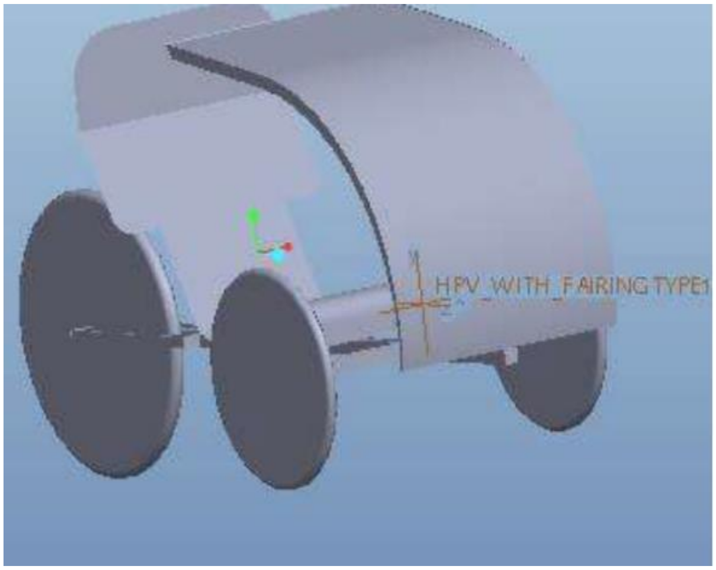


Figure 22 Model with fairing #2

The CFD was performed for two speeds, 30km/hr. and 40km/hr.

Model 1:

For model 1 the coefficient of drag came out to be approximately **1.04**. Only one graph is shown here because of same value of Cd at different speeds.

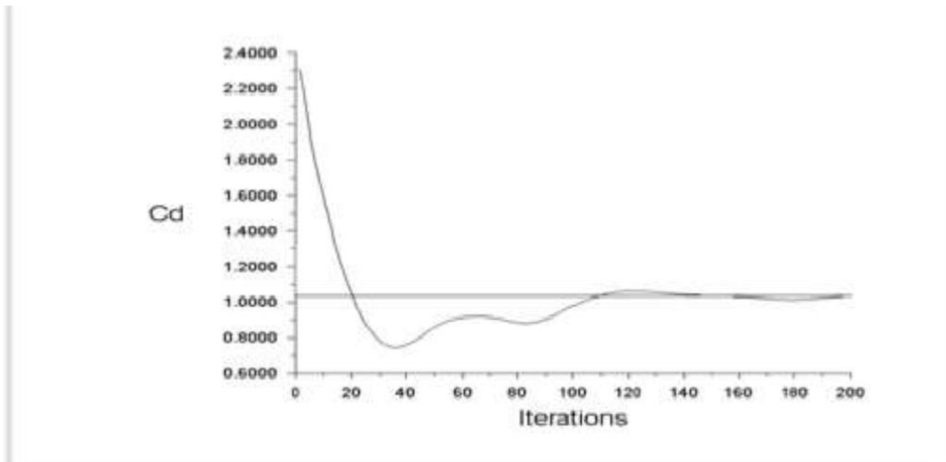


Figure 23 Coefficient of drag for Model 1

The velocity contours, pressure contours and streamlines for the different cases were found as follows:

a- 30 km/hr.

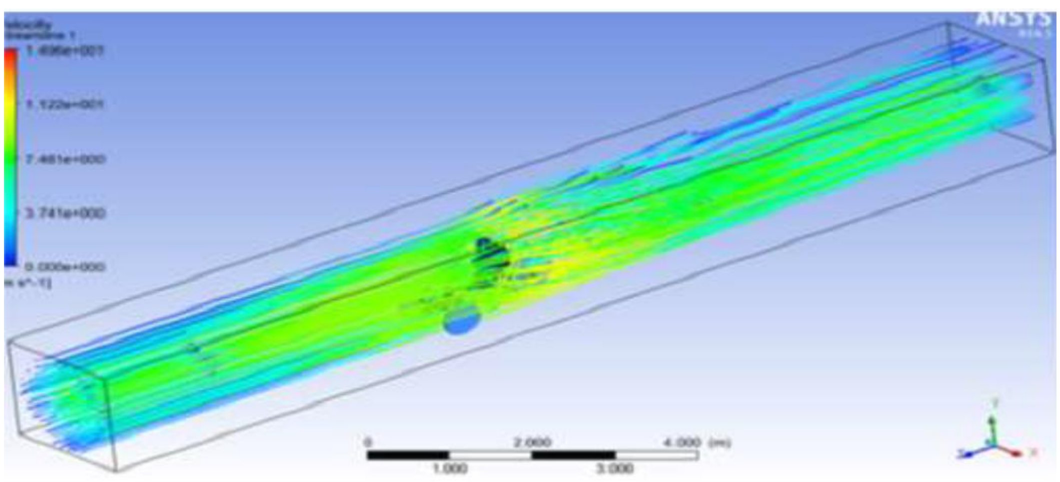


Figure 24 Velocity contour for Model 1 @30 km/hr

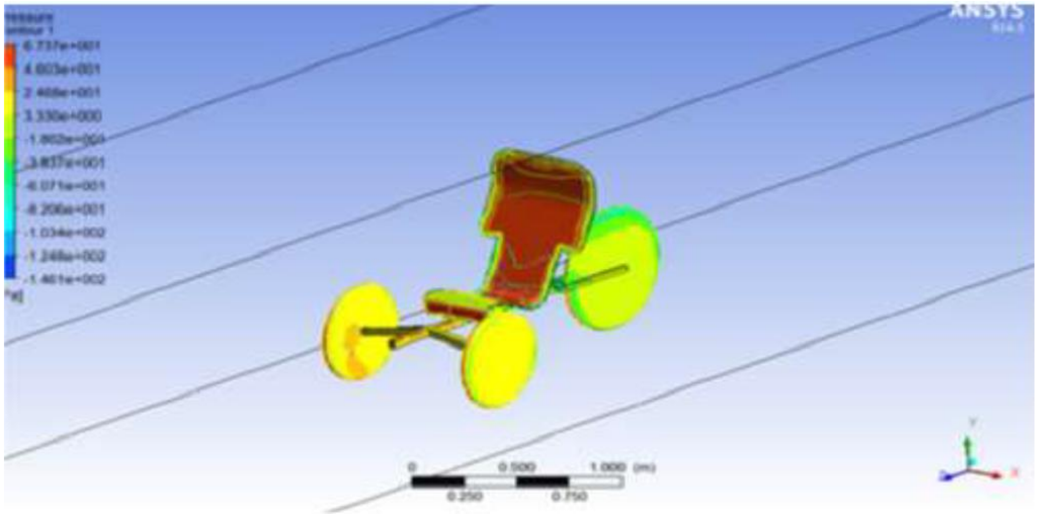


Figure 25 Pressure Contours for Model 1 @30 km/hr

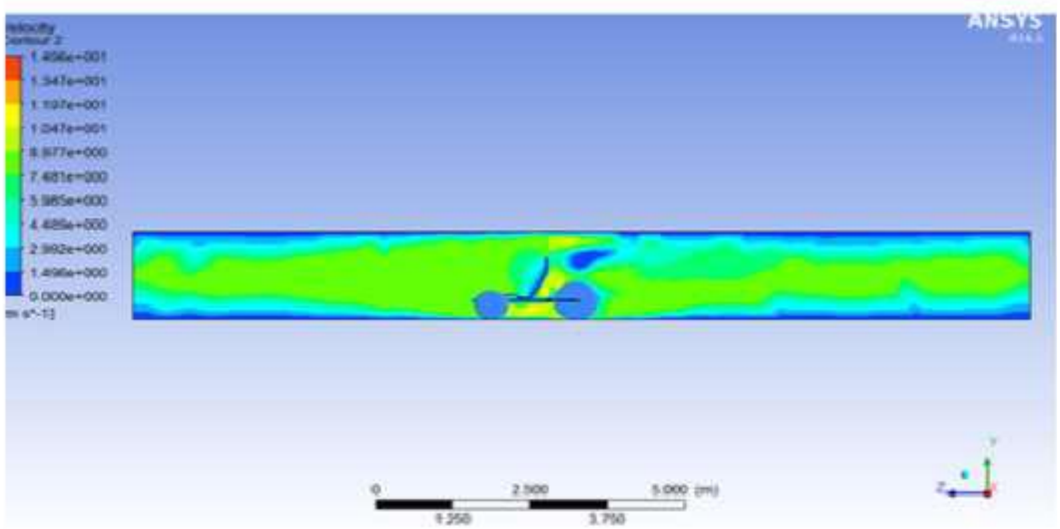


Figure 26 Streamline Contours for Model 1 @30km/hr

b- **40 km/hr.**

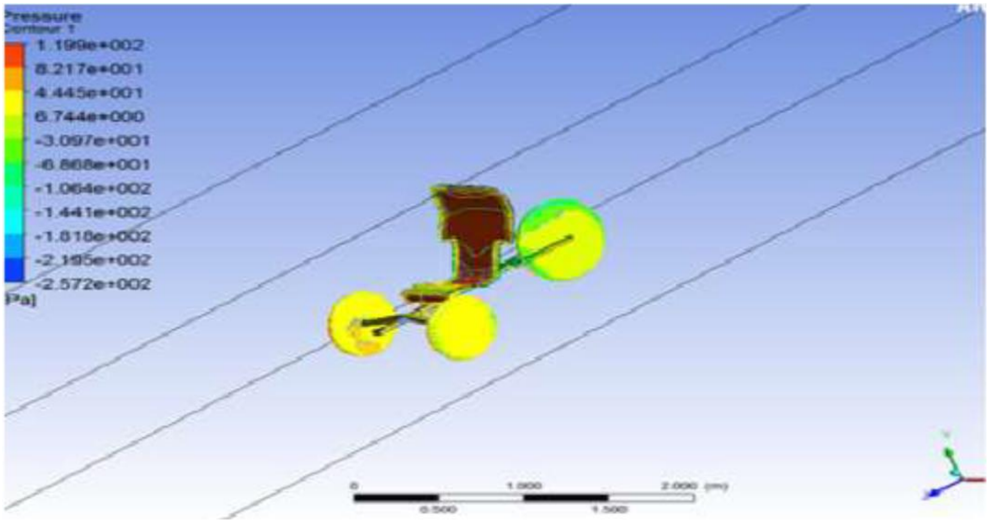


Figure 27 Pressure Contour for Model 1@40km/hr

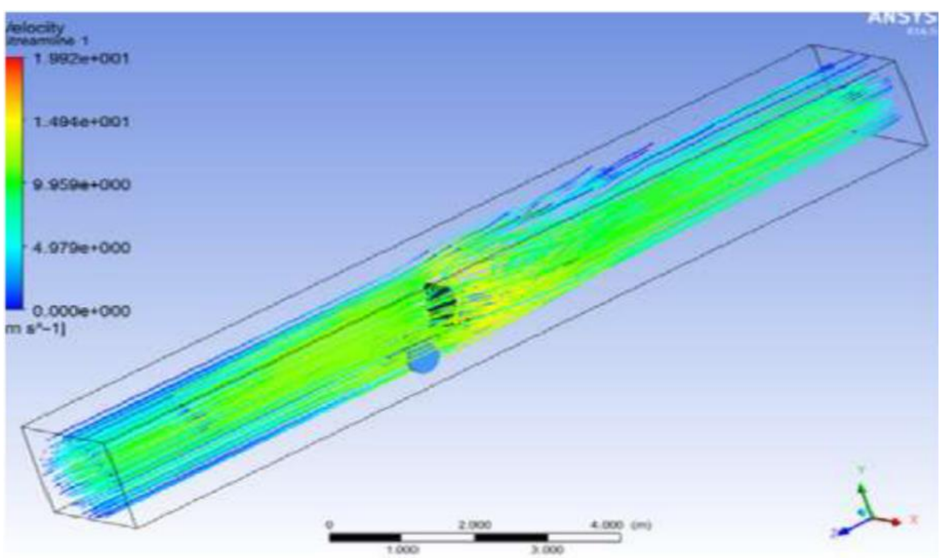


Figure 28 Velocity Contour for Model 1 @40 km/hr

Model 2:

The following results were obtained:

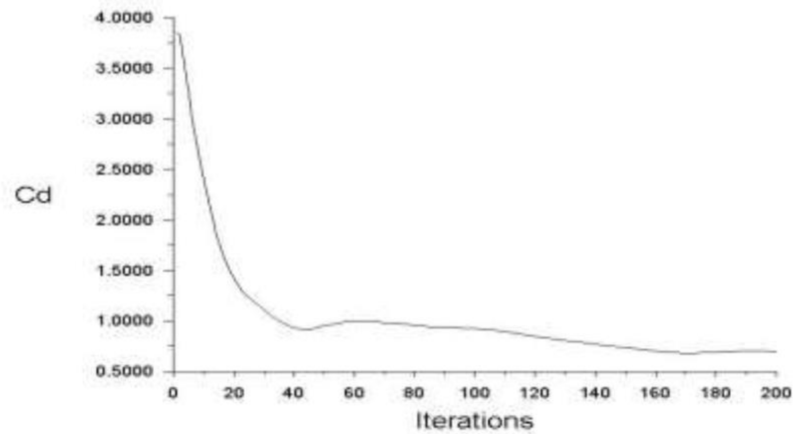


Figure 29 Coefficient of Discharge for Model 2

The value for Cd came out to be approximately **0.69**.

The velocity contours, pressure contours and streamlines for the different cases were found as follows:

a- 30 km/hr.

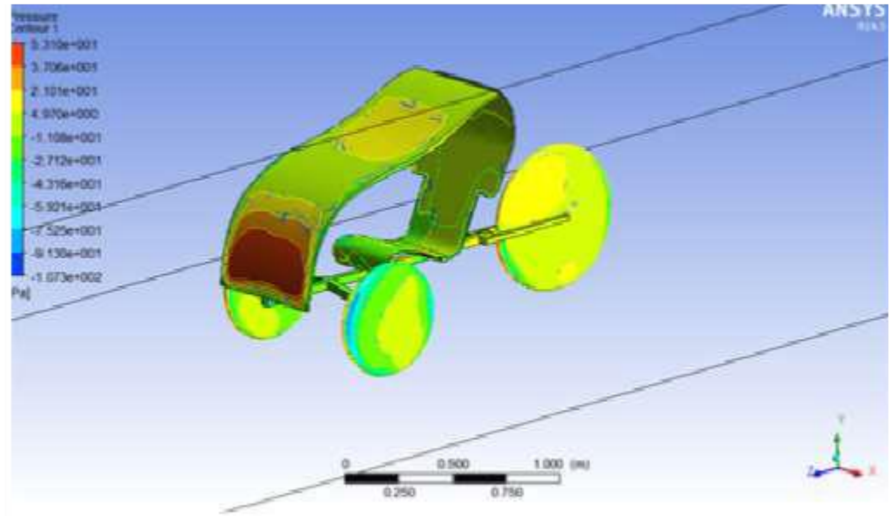


Figure 30 Presure Contour for Model 2 @30 km/hr

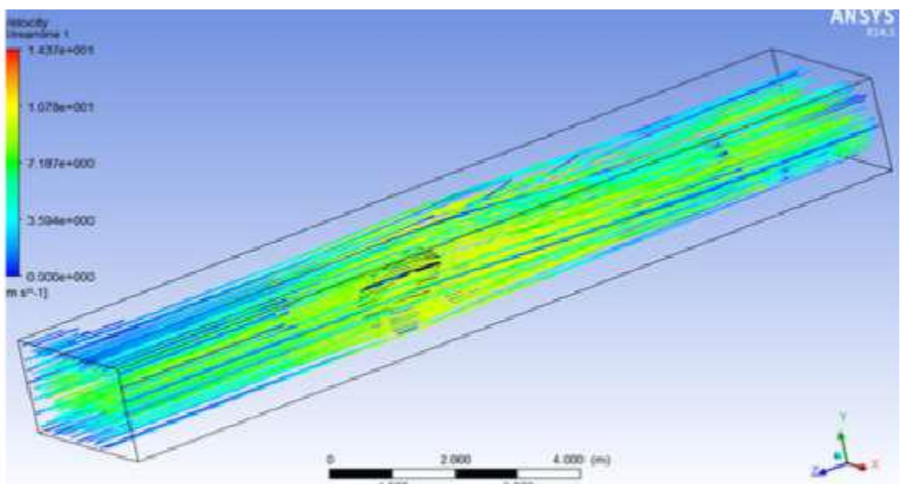


Figure 31 Velocity Contour for Model 2 @30 km/hr

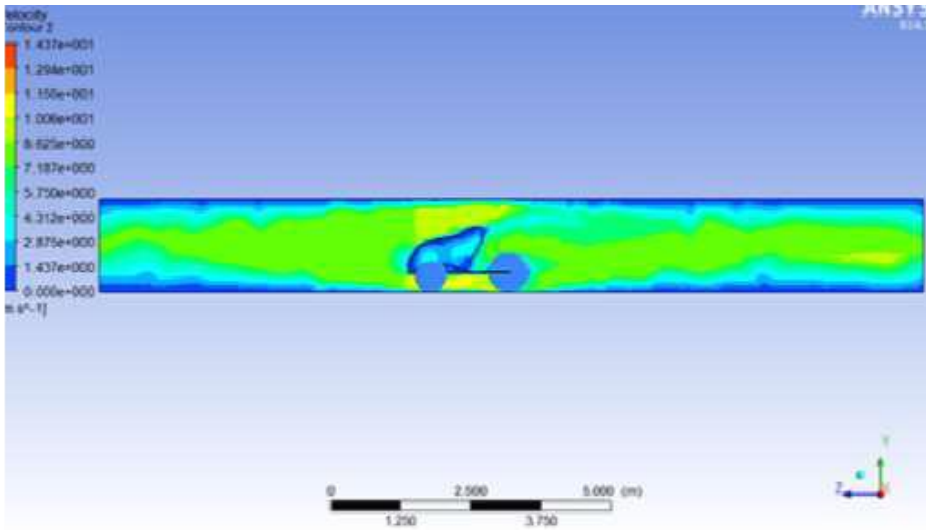


Figure 32 Streamline Contour for Model 2 @30 km/hr

b- 40 km/hr.

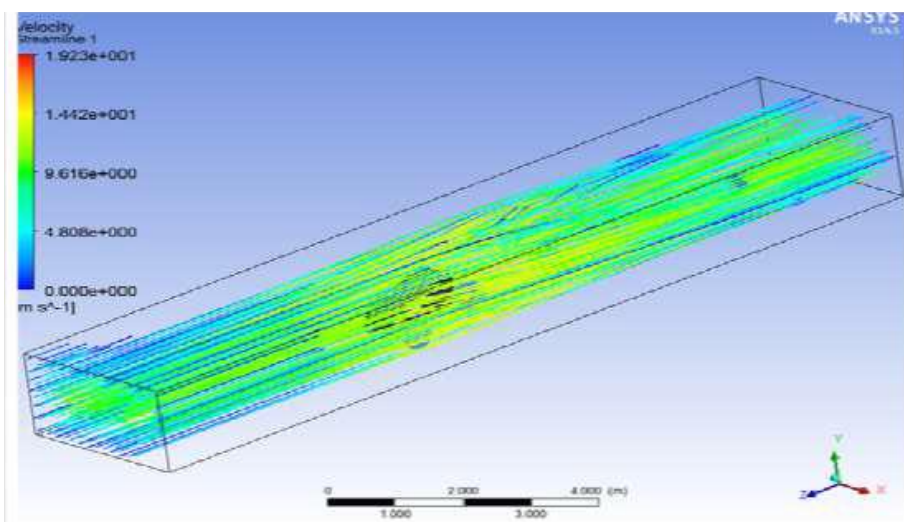


Figure 33 Velocity Contour for Model 2 @40 km/hr

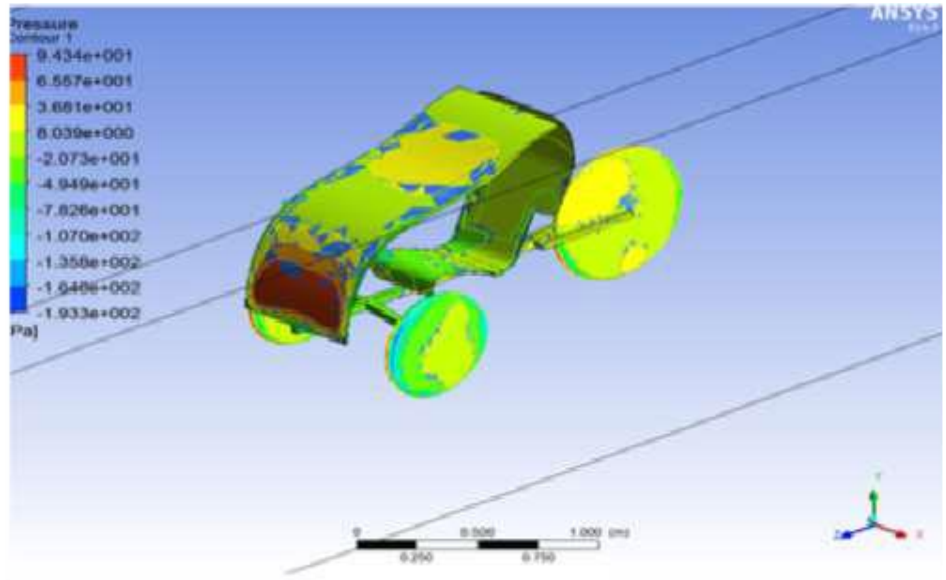


Figure 34 Pressure Contour for Model 2 @40 km/hr

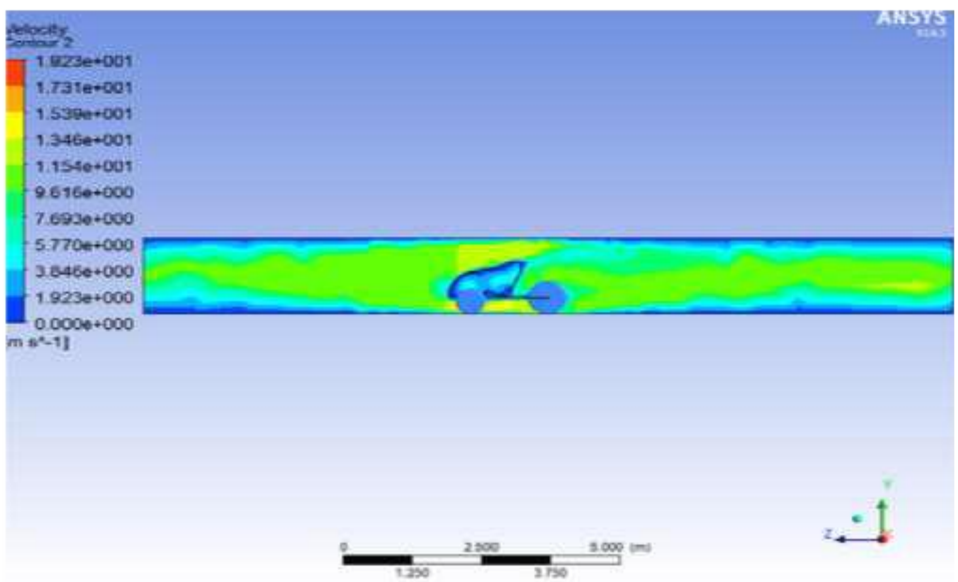


Figure 35 Streamline Contour for Model 2 @40 km/hr

Model 3:

The CFD yielded the following results. The Cd came out to be **0.67.**

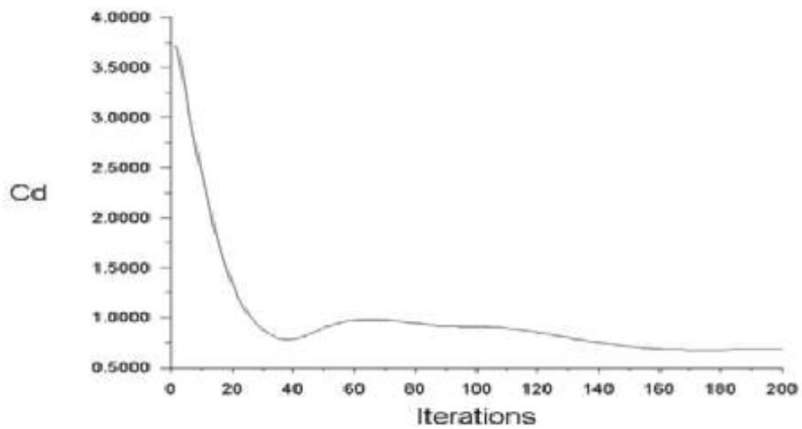


Figure 36 Coefficient of Discharge for Model 3

The velocity contours, pressure contours and streamlines for the different cases were found as follows:

a- 30 km/hr.

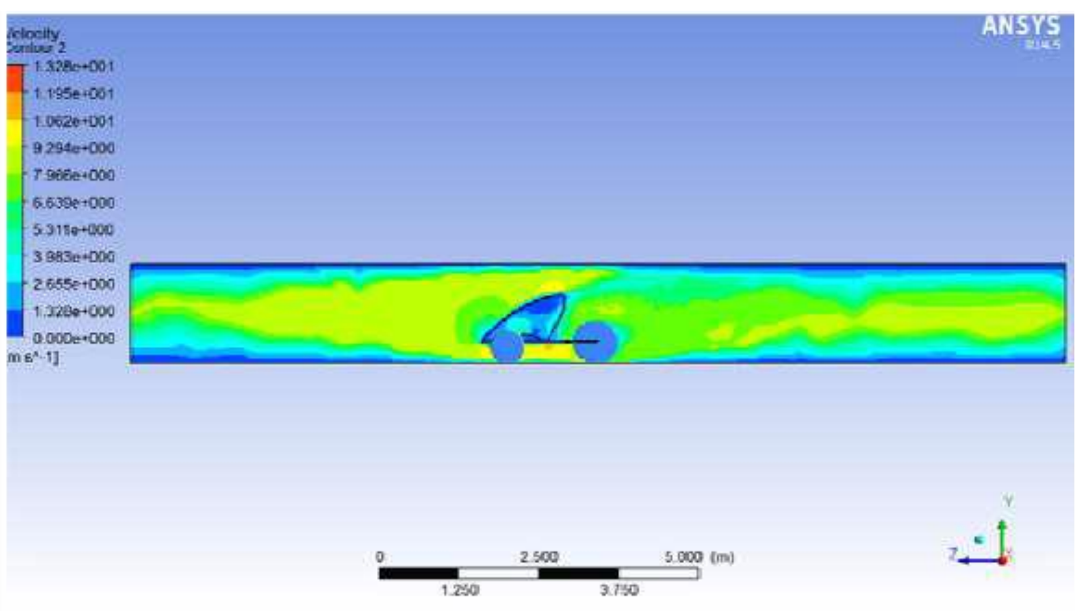


Figure 37 Streamline Contour for Model 3 @30 km/hr

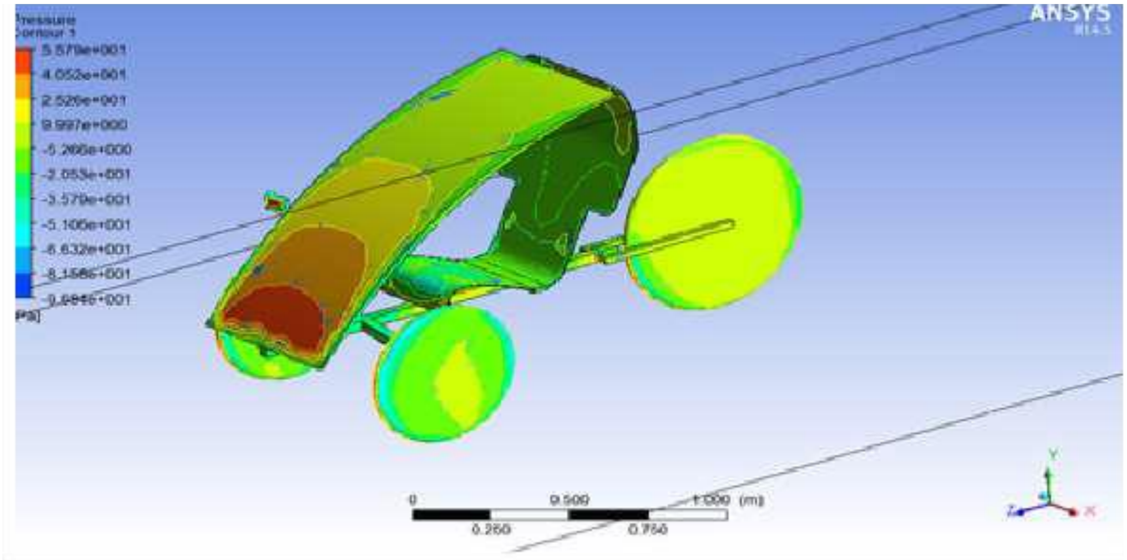


Figure 38 Pressure Contour for Model 3 @30 km/hr

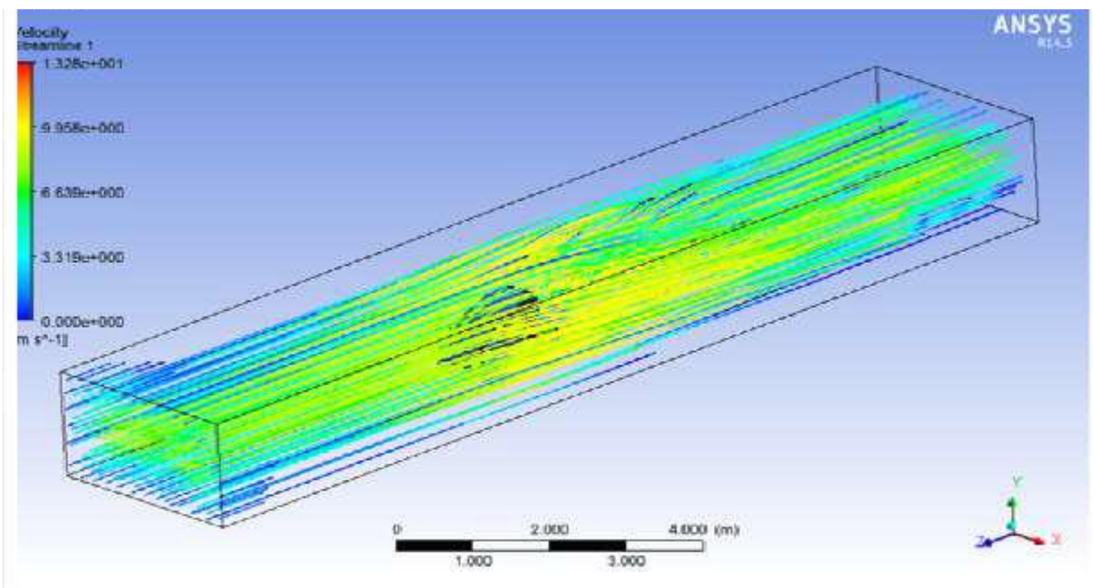


Figure 39 Velocity Contour for Model 3 @30 km/hr

40 km/hr.

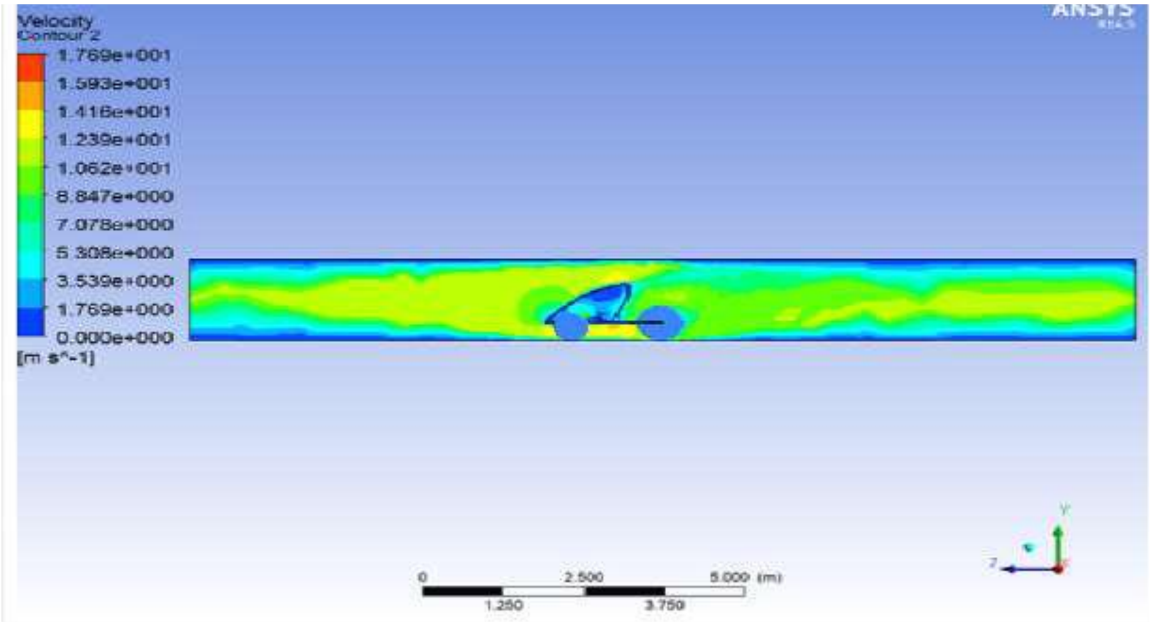


Figure 40 Streamline Contour for Model 3 @40 km/hr

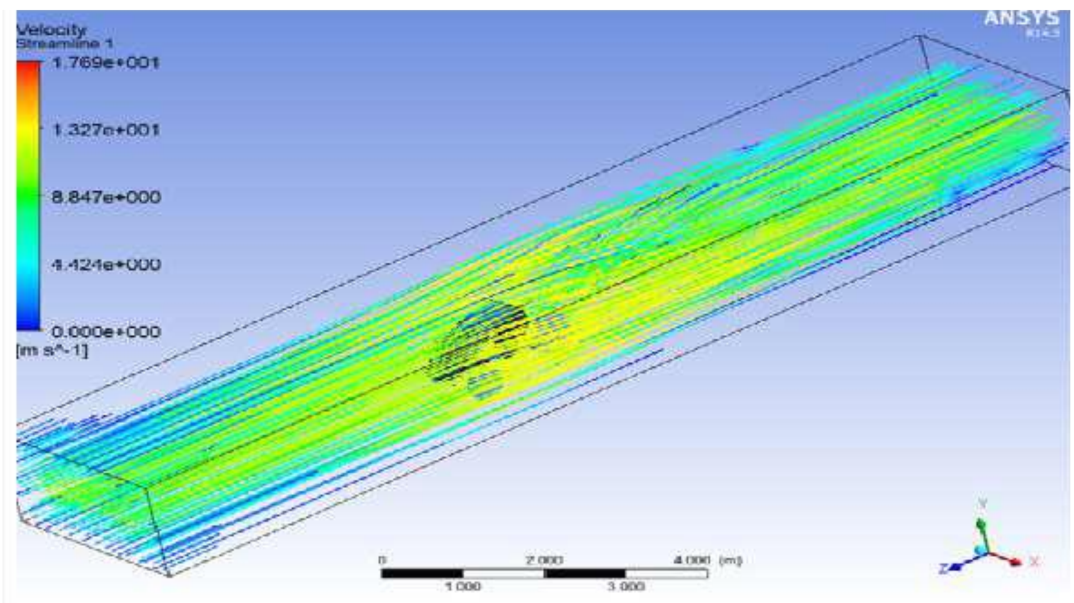


Figure 41 Velocity Contour for Model 3 @40 km/hr

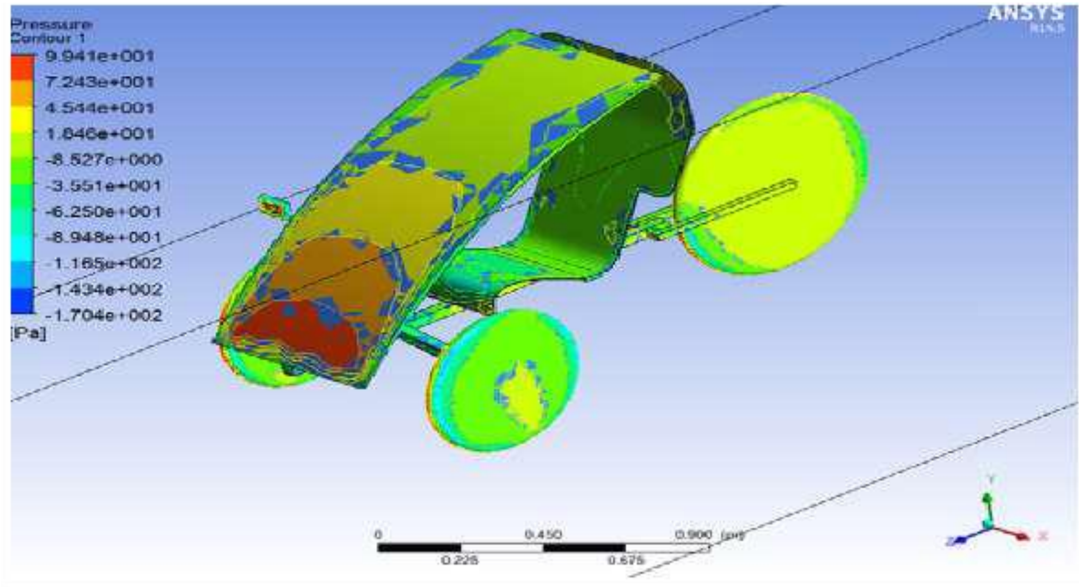


Figure 42 Pressure Contour for Model 3 @40 km/hr

Summary of results:

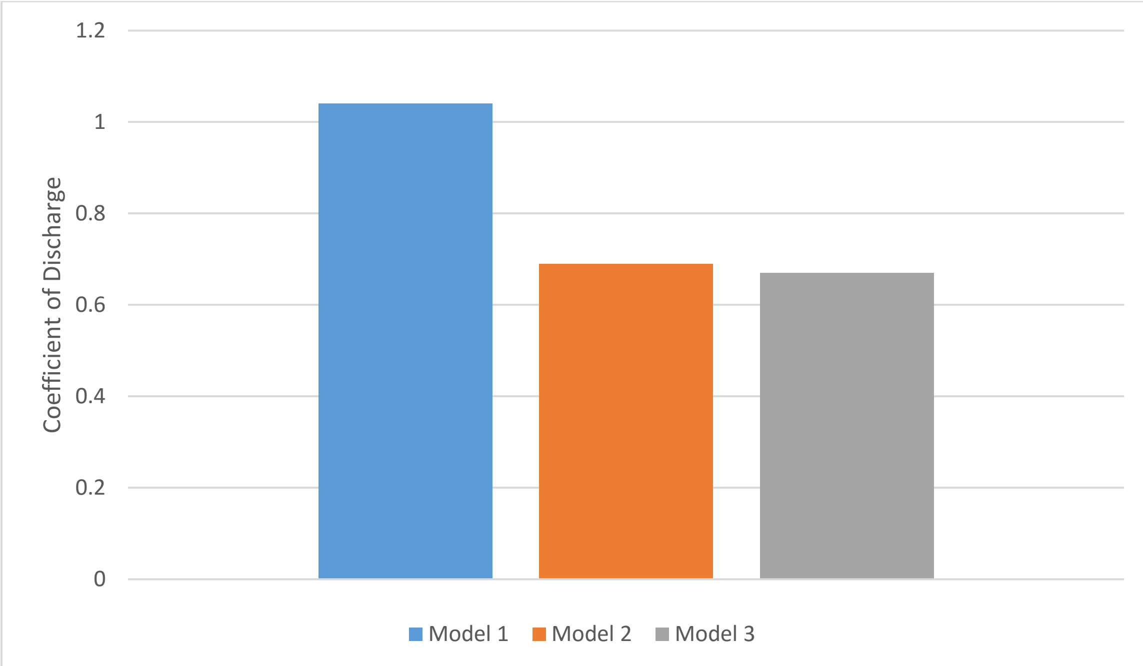


Figure 43 Coefficient of Discharge Comparison for each model

As far as the flow over the body is concerned, model 1 has a region of flow separation downstream; it has the shape of a teardrop. The sudden change in flow path and geometry can be held responsible for the phenomenon. This phenomenon is absent in case of models 2 and 3 because the air stays with the body for a longer interval. The streamline design of the models has helped avoid flow separation downstream. The Cd value for model 1 (1.04) is higher than models 2 (0.69) and 3 (0.67) despite having a low frontal area. This can be attributed to the absence of fairing in model 1 due to which a large drag force is experienced by the HPV. Since the amount of air hitting the models 2 and 3 is smaller, the drag force is substantially smaller.

4.4 Cost analysis

Table 10 Cost Breakdown

Item	Quantity	Cost
26’ wheels	4	6000
Mild steel 18 gauge square pipe and labor	-	10000
Seat	1	1500
Steering and steering assembly	1	2000
Brakes	2	2500
6 Speed gear system	1	4000
Total cost		**29500**

Mass production of this vehicle would yield less cost per vehicle. The prime reason would be bulk volume purchasing of parts. Furthermore, one of our limitations was that the minimum size of pipe which could be bought was 10 ft. from the market. The had to buy two 10 ft. pipe pieces of different diameters even when the needed pipe size were 5ft and 3 ft. Mass production would decrease the cost by eliminating this wastage of material.

Labor costs would also be decreased due to optimization of processes slowly buildup of skill of the labors. However, mass production would require leasing of warehouses for storage, capital for daily wages, capital for tooling and its maintenance and heavy machinery.

A business plan can be looked into to further simplify the finance sheet needed for a production run of the vehicle for the general public.

4.5 Testing

The vehicle was tested in 3 different criteria's:

1) Weight of the vehicle

The overall weight of the vehicle is 54 kilograms. It was done in the workshop using a standard weighing machine.

2) Speed test

The top speed achieved is 20 km/hr. Due the lack of a proper speed test machine we checked this by using a car's speedometer. The car and the HPV were driven alongside each other and the speed was recorded from the cars speedometer.

3) Turning test

Measurements were outlined in chalk and radii were measured with string and/or similar methods.

The turning radius recorded was 1.82 m.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The lowest Cd achieved was that of model 3 but since it’s not that aesthetically pleasing and also because of the larger amount of material required we have decided to use the design proposed in Model 2.

Table 11 Expectations vs Reality

Metric	Marginal/Target Value	Actual Value	In Text Justification
Drive Train Efficiency	70/80	66	Drivetrain Section
Turning Radius	9.5 ft. / 8 ft.	9 ft.	Steering Section
FOV (degrees)	180/300	300	Fairing Section
Rider Satisfaction	8/10	7	
Weight (kg)	50/60	54	
Cost (PKR)	30000/20000	29500	Cost Analysis

5.2 Recommendations

Following recommendations are made to the future teams which may be doing research work for designing an HPV of their own.

1. Time Management:

   Due to a late and slow start with the research period, the original timeline was disturbed and did not leave enough time for testing different aspects which make a difference in performance of the HPV. These are some of the things we wanted to incorporate in our design but could not do due to poor time management and should be studied from somewhere other than this report.

    a. Effects of tire pressure on performance

    b. Detailed research into rolling friction co-efficient of the tires.

    c. Physical model making of RPS and its testing.

    d. Scaled model of HPV for wind tunnel testing

    e. Accurate model of HPV for ergonomics purposes.

2. Financial Management:

   Due to financial constraints, the options for using composite materials like carbon fiber or high strength to weight ratio materials like aluminum and titanium were unaffordable.

3. All Wheel Steer:

   For a quad, large turning radius is one of the biggest issue. To make it smaller, all wheel steering system can be used. The design involves having a second steer which can steer the rear wheel if needed. Albeit harder to use, it is effective and should be incorporated in racing HPVs which involve trained riders.

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