Design of Fairing for Human Powered Vehicles Considering Aerodynamics & Aesthetics

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DESIGN OF FAIRING FOR HUMAN POWERED VEHICLES CONSIDERING AERODYNAMICS AND AESTHETICS

Thesis submitted in partial fulfilment
of the requirement for the degree of

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in

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by

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under the guidance of

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May 2014

Dedicated to my Mom

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May 07, 2014

CERTIFICATE

This is to certify that the work in the thesis entitled ***Design of Fairing for Human Powered Vehicles considering Aerodynamics and Aesthetics*** by Apurv Keshav Kedia is a record of an original research work carried out under my supervision and guidance in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Industrial Design. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

Prof. BBVL Deepak
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ACKNOWLEDGMENT

"If God brings you to it, He will bring you through it."
Thank you God for showing me the path. . .

I owe deep gratitude to the ones who have contributed greatly in completion of this thesis. Foremost, I would also like to express my gratitude towards my project advisor, Prof. BBVL Deepak for believing in me and providing me with the opportunity to work in this challenging area. His dedication has motivated me to work for excellence.

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Most importantly, none of this would have been possible without the love and support of my parents. My mom, whom this dissertation is dedicated to, has been a constant source of love, support, strength, motivation and inspiration. I would like to express my heart-felt gratitude to her.

Apurv Keshav Kedia

ABSTRACT

The increasing environmental, concerns mostly due to the depletion of fossil fuels and a great deal of airborne pollution have been the prime topics of interest for the researchers. This has led to the development of new transportation alternatives which are in line with the "Go Green" manifesto. One such development is the concept of human powered vehicles (HPVs). These are basically the transportation machines that use human power as the source of its energy for locomotion. Further development has led to advances in inclusion of ergonomics and aesthetics into their design, which aim at higher value and efficiency. Aerodynamic drag is a major element of obstruction in the efficiency of these vehicles which mostly run by pedalling. The major area of research in this present work will therefore be the optimised design of the fairing, an element of the HPV that contributes heavily to the aerodynamics of the vehicle since it determines the exterior shape of the vehicle. The fairing being the outermost part/cover can also be used to enhance the aesthetic feel of the HPV, something that would contribute to the rise of its market value. Taking vehicle performance as the major topic of concern, aerodynamic aspects can sometimes turn out to be a greater deciding factor than the mechanical aspects of an HPV because of the immense magnitude of drag experienced by a moving vehicle. This drag reduces the motion to the power transferred ratio, which in turn indicates a drop in efficiency. This raises the requirement of a study which is specially focussed on the aerodynamics of such a vehicle. This would help enhance the comfort for the driver and also aid in pulling up the efficiency of the vehicle. Fairing design has been identified as the most critical factor affecting the aerodynamics of any vehicle in motion. Fairing being the external cover also plays a pivotal role in enhancing its aesthetics. The study conducted was used for fabrication of the vehicles presented in the Human Powered Vehicle Challenge India'14 (HPVC) organised at New Delhi and later the results obtained from the competition were used for the new vehicle, which participated in HPVC East'14 organised at University of Central Florida, USA. These are international events organised by the American Society of Mechanical Engineers (ASME). Fairing design is also important since this is the structure that prevents the injury of the rider in case of an accident/roll-over.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE WORK

The increasing environmental, concerns mostly due to the depletion of fossil fuels and a great deal of airborne pollution have been the prime topics of interest for the researchers. This has led to the development of new transportation alternatives which are in line with the "Go Green" manifesto. One such development is the concept of human powered vehicles (HPVs). These are basically the transportation machines that use human power as the source of its energy for locomotion. Further development has led to advances in inclusion of ergonomics and aesthetics into their design, which aim at higher value and efficiency. Aerodynamic drag is a major element of obstruction in the efficiency of these vehicles which mostly run by pedalling. The major area of research in this present work will therefore be the optimised design of the fairing, an element of the HPV that contributes heavily to the aerodynamics of the vehicle since it determines the exterior shape of the vehicle. The fairing being the outermost part/cover can also be used to enhance the aesthetic feel of the HPV, something that would contribute to the rise of its market value.

1.2 PROBLEM STATEMENT

Taking vehicle performance as the major topic of concern, aerodynamic aspects can sometimes turn out to be a greater deciding factor than the mechanical aspects of an HPV because of the immense magnitude of drag experienced by a moving vehicle. This drag reduces the motion to the power transferred ratio, which in turn indicates a drop in efficiency. This raises the requirement of a study which is specially focussed on the aerodynamics of such a vehicle. This would help enhance the comfort for the driver and also aid in pulling up the efficiency of the vehicle. Fairing design has been identified as the most critical factor affecting the aerodynamics of any vehicle in motion. Fairing being the external cover also plays a pivotal role in enhancing its aesthetics. The study conducted is to be used for fabrication of the vehicles to presented in the Human Powered Vehicle Challenge India'14 (HPVC) to be organised at New Delhi and later the results obtained from the competition are to be used for the new vehicle, which would participate in HPVC East'14 to be organised at University of Central Florida, USA. These are international events organised by the American Society of Mechanical Engineers (ASME). Fairing design is also important since this is the structure that prevents the injury of the rider in case of an accident/roll-over.

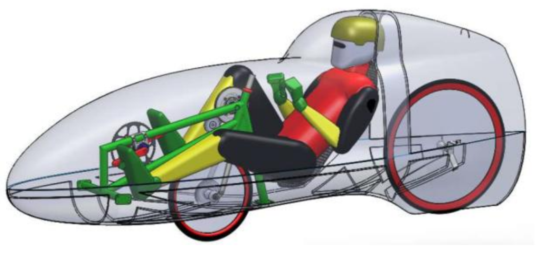

Fig 1.1 CAD Model of a Recumbent Human Powered Vehicle

1.3 OBJECTIVE OF THE WORK

- To come up with an optimised lightweight design of a fairing that:
  i) Minimises air drag
  ii) Fits to the ergonomic requirements of the HPV.
  iii) Helps in preventing roll-over.
  iv) Enhance the aesthetic feel of the vehicle.

- Device a manufacturing process for the creation of the fairing.

1.4 LITERATURE REVIEW

1.4.1 Boundary Layer Behaviour

The direction and magnitude of the forces and moments acting on a moving vehicledue to aerodynamic elements are largely determined by the behaviour of the boundary layer. These forces are related to the rapidityof the growth of the viscous boundary layer and whether or not it separates from the vehicle's surface. These factors are strongly influenced by the character of this viscous layer (i.e., laminar, transitional and/or turbulent). This character of the boundary layer is a function of[1]:
1) Vehicle shape
2) Relative roughness of the surface
3) Free stream disturbance level approaching the vehicle.
The key to the boundary layer behaviour for low Reynolds number vehicles is whether transition from laminar to turbulent flow takes place in the attached boundary layer before laminar separation occurs. Once laminar separation occurs, the subsequent laminar free shear layer is highly unstable and transition to turbulent flow takes place quite rapidly.

Several types of flow behaviour result at low Reynolds numbers.
1) A laminar separation may occur near the leading edge at high angles of attack in which case the airfoil may he considered fully "stalled," or at small angles of attack the laminar boundary layer may remain attached through an extended favourable pressure gradient near the leading edge and then separate in an adverse pressure gradient after the maximum thickness of the airfoil. In either case an unsteady oscillating wake is formed which reduces airfoil performance.
2) Another type of boundary layer behaviour may occur which is probably the most desirable at low Reynolds numbers. The best airfoil performance is achieved when the laminar boundary layer transitions to a turbulent one before reaching the large adverse pressure gradient. The turbulent boundary layer with the higher energy level is able to remain attached to the airfoil through the adverse pressure gradient. This "natural" transition (not caused by the separation bubble) is accompanied by higher lift coefficients and lower total drag coefficients. At high angles of attack, a trailing edge separation of the turbulent boundary layer provides gentle "stalling" characteristics.
3) Yet another type of boundary layer behaviour occurs which may be considered an extension of the laminar separation case. Instead of remaining separated, the laminar free shear layer in some cases may reattach shortly after separation or the free shear layer more often may become turbulent, and the growing turbulent shear layer then interacts with the airfoil surface usually causing reattachment. After reattachment, the turbulent boundary layer behaves in a manner similar to the natural transition case although it thickens more rapidly.

Theoretical prediction of the presence and location of the laminar separation bubble and experimental studies of the behaviour of separation bubbles have been the focus of many previous investigations. Separation bubbles have been placed in two classifications: the short bubble and the long bubble. The short bubble typically occurs at high angles of attack and is usually less than a few percent of the chord in length at high Reynolds numbers. However at low chord Reynolds numbers observed short separation bubbles that were approximately 28% of the chord in length, a short separation bubble at high Reynolds numbers has very little effect on the overall theoretical pressure distribution and usually decreases in size with increasing incidence. In comparison, the length of the long bubble is of more than a few percent of chord and will lengthen as angle of attack increases or Reynolds number decreases. The presence of a long bubble greatly alters the pressure distribution from its theoretical form. A separated laminar boundary layer is sometimes thought of as a long bubble extending into the wake of the airfoil. As the chord Reynolds number decreases, the laminar portion of the free shear layer in a short bubble grows in length and the turbulent portion requires more entrainment to reattach at a pressure near the in viscid pressure value. Eventually the Reynolds number becomes so low and the laminar portion of the free shear layer so long that the turbulent entrainment process can no longer support reattachment near the inviscid pressure value. The velocity peak and circulation decrease reducing the pressure gradient over the bubble. This allows the turbulent free shear layer to reattach as a long bubble and the short bubble is said to have "burst" into a long bubble. This separation bubble decreases airfoil performance (i.e., increases pressure drag and results in a much thicker turbulent boundary layer downstream of the bubble) as compared to the natural transition case, but is a large improvement over the separated laminar boundary layer which does not reattach. The presence of a short laminar separation bubble can he utilized to improve airfoil performance at very low Reynolds numbers because it acts as a trip and reduces the possibility of massive separation further downstream.

As the chord Reynolds number [2] decreases, the laminar portion of the free shear layer in a short bubble grows in length and the turbulent portion requires more entrainment to reattach at a pressure near the inviscid pressure value. Eventually the Reynolds number becomes so low and the laminar portion of the free shear layer so long that the turbulent entrainment process can no longer support reattachment near the inviscid pressure value. The velocity peak and circulation decrease reducing the pressure gradient over the bubble. This allows the turbulent free shear layer to reattach as a long bubble and the short bubble is said to have "burst" into a long bubble. This separation bubble decreases airfoil performance (i.e., increases pressure drag and results in a much thicker turbulent boundary layer downstream of the bubble) as compared to the natural transition case, but is a large improvement over the separated laminar boundary layer which does not reattach. The presence of a short laminar separation bubble can he utilized to improve airfoil performance at very low Reynolds numbers because it acts as a trip and reduces the possibility of massive separation further downstream

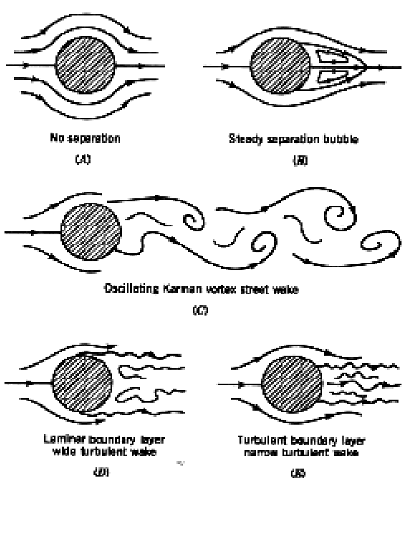

Fig 1.2 Flow patterns for flow over a cylinder: (A) Reynolds number = 0.2; (B) 12; (C) 120; (D) 30,000; (E) 500,000. [3]

1.4.2 Aerodynamic Influences on a HPV

Various studies conducted on HPVs have yielded a variety of results that can be summarised as below, depending on the factors being considered under the scanner. [4]

1.4.2.1 Seat Positioning:
The initial testing was focused on seating angle. The Magnum (the selected vehicle), had both height and rake adjustment for the seat. 3 different seating angles were found. The reason was to isolate the effects of both seating angle and seating height. The three tests were:
(i) A high seat reclined back
(ii) A high seat reclined forward
(iii) A low seat reclined back.
From the results it was observed that high-forward position had the highest drag, due to the increased frontal area and more abrupt figure. Based on aerodynamic principles, we know that wind flow must be smooth in order to reduce drag, therefore with the low reclined position a smooth airflow was observed. The important point is the difference in the seating heights. An increase in frontal area due to higher position normally leads to higher drag. This can be explained by analysis of the seating positions. The driver, although uncomfortable maintains a straighter line from his feet to head than that of the lower seating position in a reclined and high seating position. At lower velocities, the higher position allows for lower turbulence at the base of the seat, however with rising velocity lamination occurs therefore nullifying this effect, the difference between low speed and high speed design is thus indicated. The result identifies the importance of decreasing frontal area and creating smooth profiles.

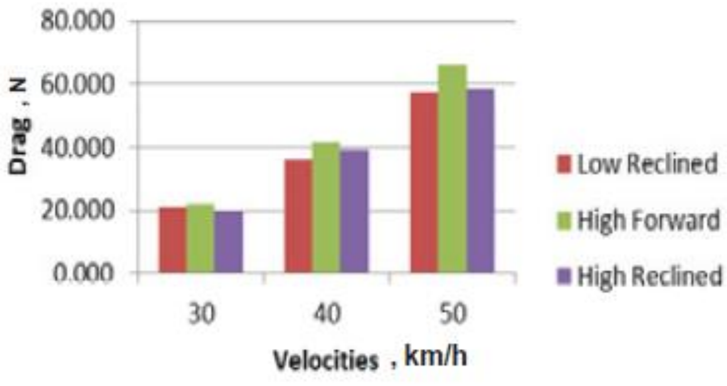

Fig 1.3 Comparison of seating positions [4]

1.4.2.2 Add-ons
A customisable vehicle was selected to allow a variety of add-ons that affect the driver's performance in terms of his functionality, ability and safety. The following add-ons were compared and analysed.
(i) Rear bags
(ii) A rear rack
(iii) A flag
(iv) A mirror
The differences in drag for the different add-ons is measured.

The following can be concluded
a) Rising velocity sees a loss in significance of the little components
b) Bags and racks are large but do not contribute too much of the drag since they are positioned behind the driver and protrude only a little bit to the either side of the driver.
c) The small flag produces maximum hindrance.
.

Fig 1.4 Examples of various add-ons (flag, bags, etc) [4]

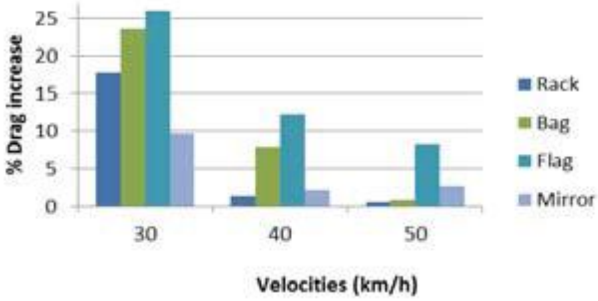

Fig 1.5 Drag comparison of various add-ons [4]

1.4.2.3 Canopy
The faired vehicle with and without canopy are shown in Fig 1.6. A cowling type canopy served as the first improvement. It was different to the previously used one. The [resent one covers the human body over the manhole made in the fairing thus reducing the opening to a minimum. It does not even obstruct entry/exit from the vehicle since it can be removed at will. Canopy helped reduce aerodynamic drag to a good extent.

Fig 1.6 Faired vehicles with and without canopy [4]

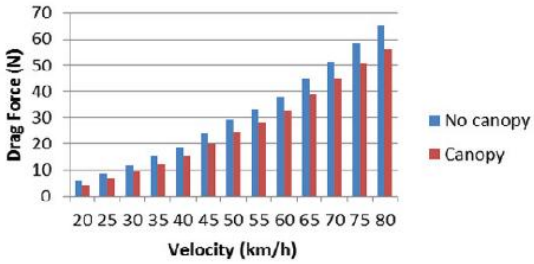

Fig 1.7 Drag comparison with and without canopy [4]

1.4.2.4 Visor
The visor is a simple piece of thin Perspex which is used to direct the wind to a direction above the driver's head. Visor design is more inspired by comfort need than by aerodynamic reasons, but it succeeds to deliver both comfort wise and aerodynamically. One of the rough bodies which is uncovered even after application of the fairing is the head of the driver. Therefore visor aims at diverting the wind away from the head and the headrest, in order to improve the condition. The visor was fixed using a masking tape to blend it with the visor-body edge. Fig 1.9 illustrates the benefit of using a visor. Visor delivers maximum efficiency at medium speeds around 50 kmph, and its efficiency is lowered at both low and high speeds.

Fig 1.8 Vehicle with canopy and visor [4]

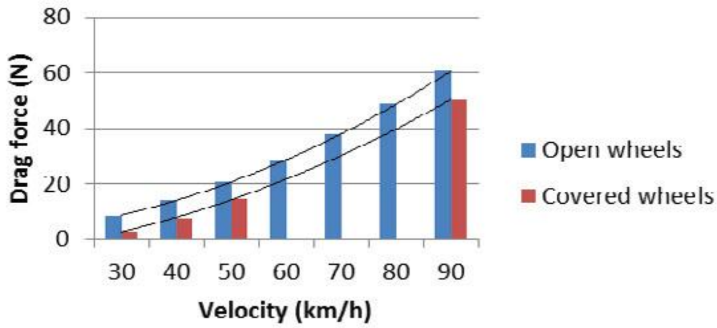

Fig 1.9 Visor comparison with moving average [4]

1.4.2.5 Wheel covers

Rotating wheel spokes and cavities lead to the creation of form (pressure) drag zones. A wheel cover is therefore used to overcome the same, the graphs below clearly indicate that the introduction of wheel cover is more instrumental in enhancing the efficiency than any other add on. The wheel cover allows the vehicle to travel at 90 kmph while experiencing the drag of a vehicle travelling at 80 kmph.

Fig 1.10 Wheel covers [4]

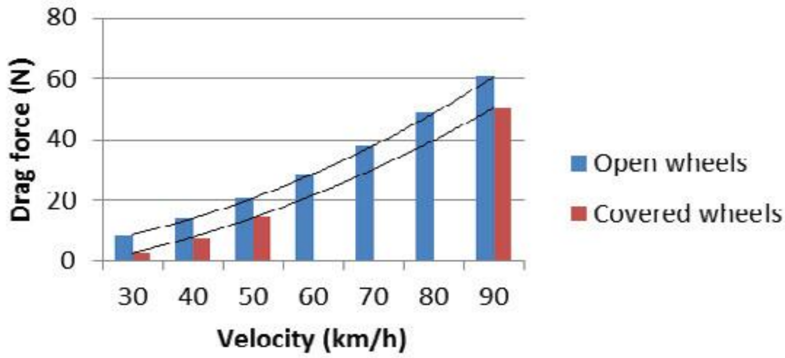

Fig 1.11 Comparison of drag with the wheel covers [4]

Bicycle Type and Rider Position	Drag Co-efficient (C_D)	Frontal Area (m^2)	C_DA (m^2)	Force to overcome the drag at 10 ms^{-1} (N)
Upright Commuting Bicycle	1.15	0.55	0.632	34.5
Road Bicycle and Amateur Cyclist	1	0.4	0.4	22
Competition Bicycle and well crouched rider	0.88	0.36	0.32	17.6
Road Bicycle with simple fairing	0.52	0.55	0.29	15.7
Moser Bicycle	0.51	0.42	0.214	11.8
M5 full faired lower racer	0.13	0.35	0.044	2.4

Table 1.1 Several data on aerodynamic of cycling [5]

CHAPTER 2

DESIGN AND ANALYSIS

2.1 2D Analysis

A teardrop shape is ideally thought of as the most aerodynamically fast shape. Fig 2.1 shows a teardrop shape, which actually is a NACA standard wing section designed for maximum lift. The design creates pressure zones that result in lifting off the aircraft. For a fairing, we want minimum drag and not maximum lift. To achieve that, such pressure zones are needed to be minimised while making sure that the air remains attached to the body of the fairing.

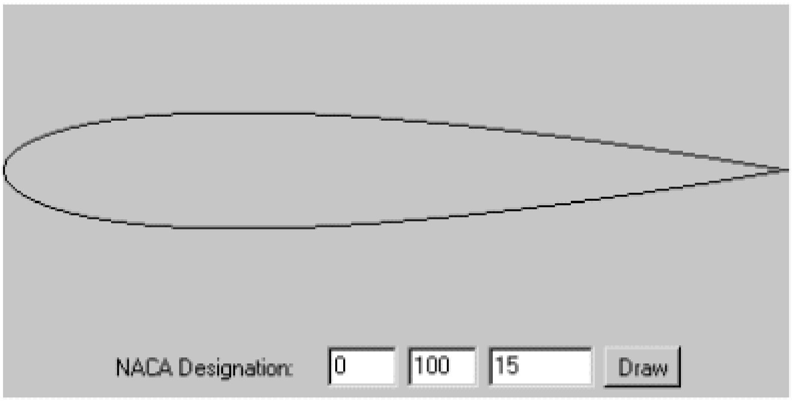

Fig 2.1 Initial Consideration of bubble shape for analysis (NACA)

To find the optimised shape we take assistance of some web based tools. A good number of java applets are available in the Applied Aero website to help generate the surfaces or sections with the desired properties [6]. Their java applet for Airfoil Pressure distribution was used to create the lowest and most uniformly distributed pressure over a symmetrical body. This applet allows us to interactively vary the shape of the section while keeping track of the varying pressures which are immediately visible on the screen. Fig 2.2 shows a NACA wing section along with the corresponding air pressure zones generated as a result of the geometry of the section.

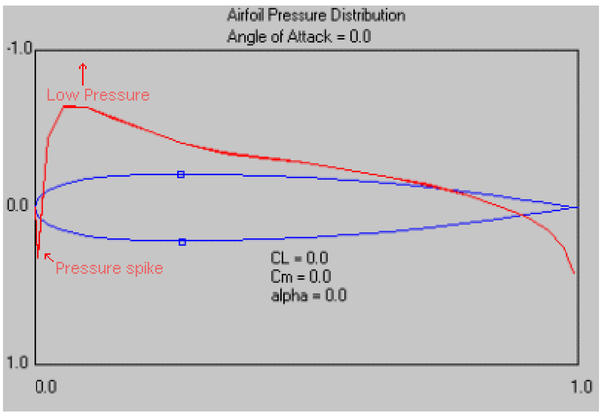

Fig 2.2 Analysis of the bubble type structure NACA

We desire a shape with little variations in pressure along the fairing, a gradual pressure drop as we move along the fairing from front to rear, followed by a not so steep rise towards the tail. This will allow the boundary layer, i.e. air layer flowing along the exteriors of the shape, to remain attached to it, and be sucked in towards the rear causing laminar flow. More laminar flow implies a greater speed. Reduce the large low pressure zone in front. Sharp nose or rear may lead to delamination of the air layer. This is prevented by making the pressure uniform throughout the body with steep rise in pressure towards the front and the rear. This would facilitate the air to remain stuck to the surface. A smoother nose surface also helps in reducing delamination. It is also elemental in reduction of the length of the vehicle.

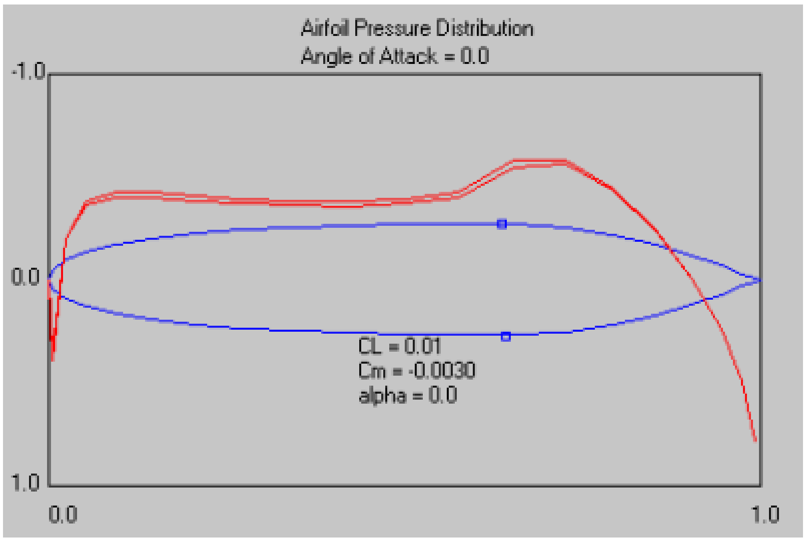

Fig 2.3 Analysis of the bubble type structure NACA after shortening the tail

The shape in Fig 2.4 looks good since it actually resembles one in which a human can easily fit into. Moreover there are no pressure spikes in this model, showing even pressure distribution which is an added positive. The rise in pressure towards the rear will help maintain the laminar flow.

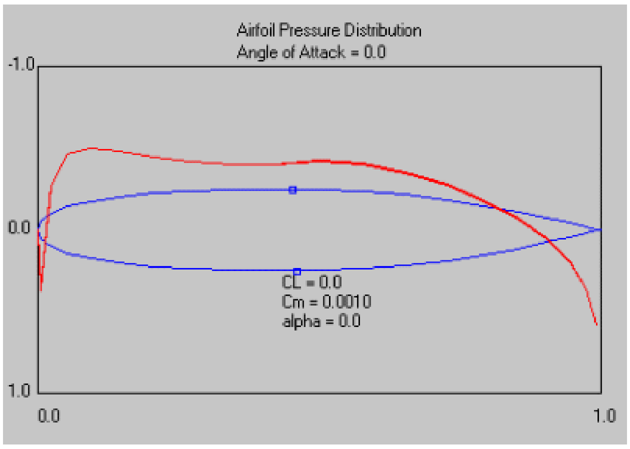

Fig 2.4 Analysis of the bubble type structure (NACA)

The pressure gradient resembles the one shown in Fig 2.5 which shows the "optimum body of revolution". The pressure towards the rear end falls slightly before rising up again thus presenting us with a very favourable condition.

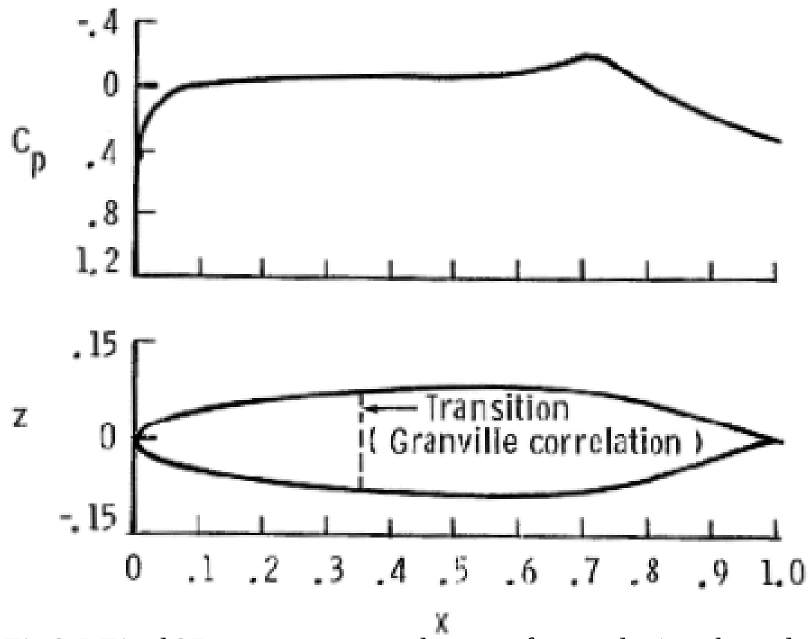

Fig 2.5 Final 2D structure agreed upon after analysing these designs

Illustrated here is one of the potential sections of the fairings that I was working on. It's very close to the "optimum body of rotation" illustrated in Fig 2.5. Fig 2.6 shows a nice illustration of the space mark-ups for the top view of a fairing.

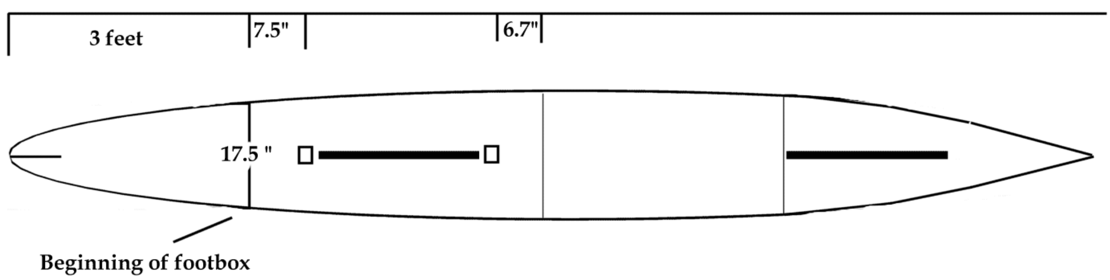

Fig 2.6 Subsequent agreed upon top view model

The next step was deciding on the side view of the shape. This field is difficult due to the lack of enough research in the field. This is because the aeronautics researchers never design vehicles that fly almost touching the ground, nor do the automotive people design vehicles taking great amount of aerodynamics as a high priority criterion. We therefore desire to reduce the turbulent forces generated under the surface of the vehicle. This implies that the fairing is to be designed to divert air from the sides and the top and not allowing much of air to flow under its surface. A fairing design with a symmetrical nose as seen from a side view, will force the air under the vehicle, resulting in venturi effect, thus constricting the airflow, and slowing. We try designing the fairing at a nice height above the ground to prevent air turbulence between the ground and the vehicle. Fig 2.7 shows a shape with a bulged top and a flat bottom. On the bottom surface, the pressure is neutral, on the other hand there is a big high pressure spike on the top which is followed by a steep change to low pressure continuing to the tail, which increases yet again. These sharp deflections might delaminate the boundary layer raising the drag. In a real 3D fairing situation, most of the air will be diverted to the sides, rather than over the top, reducing these pressure gradients.

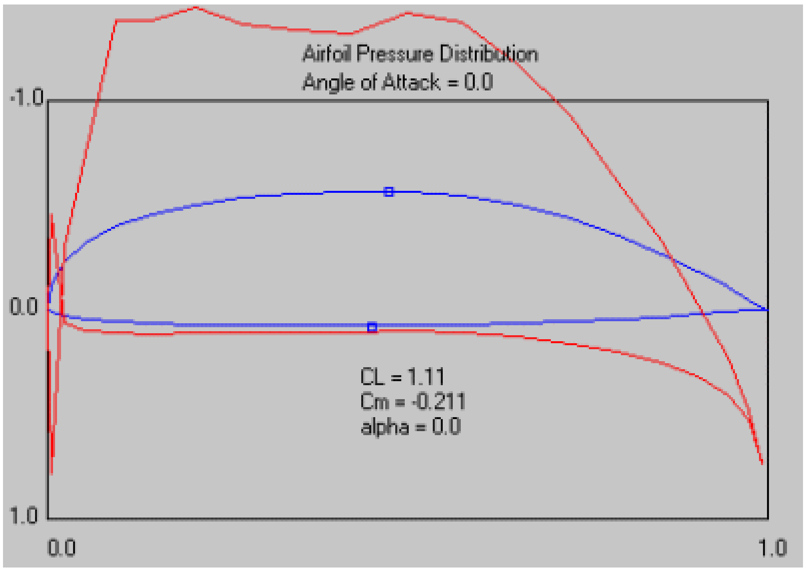

Fig 2.7 Initial Side View model considered. The top line corresponds to the top surface and the lower line corresponds to the lower surface

Coincidentally this shape is close to the aero vehicles developed by the aeronautic researchers. Note that the pressure distribution along the bottom is near zero, and along the top is not too bad, due to the gradual lead in. This is the side view shape I decided to use for the front of the fairing. The back of the fairing will need to be fairly squared off, due to the vertical shape of its human payload, and my desire to keep the length under 10 feet.

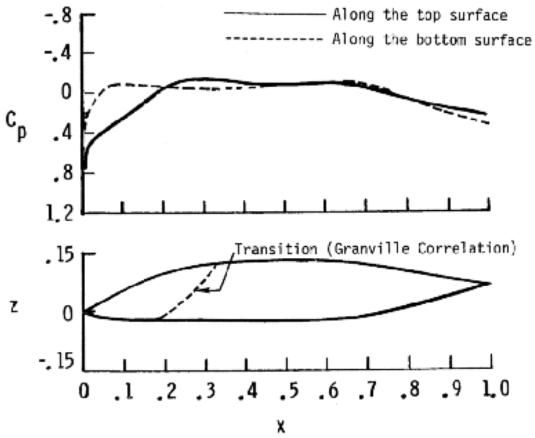

Fig 2.8 The agreed upon side view after analysis

On comparing the sharp nose v/s a rounded one, the rounded one is more preferred due to its smaller size and since it is safer. “Rounded” doesn’t mean hemispherical. A hemispherical nose on a cylindrical body experiences higher drag as opposed to a 3:1 elliptical nose. Extensive, i.e. over 50% of the body or more, should have laminar flow.

Some basic "rules" are [7]:

• Outside corners and sharp stream edges are to be avoided. Increasing frontal area by creating flat spots will raise the aerodynamic drag.

•Steep variations in stream-wise curvature is to be avoided. Hemispherical nose with a cylindrical posterior body would be a poor shape. This will generally lead to a large spikein velocity around the curvature discontinuity, which will be followed by a small zone of separation.

•Aft-facing steps and leak points of air are to be avoided, at and behind the maximum point of thickness. The small recirculating zone behind a step might not be able to close in the aft pressure rise and might precipitate large-scale flow separation. Leaking "dead" air into the boundary layer over the pressure rise is very detrimental for the same reason. Minimizing the flow out of wheel cut-outs is important. The best place to dump ventilation air flow is out of trailing edge.

As far as "truck suck" or crosswind sensitivity, there is very little that can be done other than reduce the height and side area as much as possible. The "airfoil" shape of the fairing will have little effect.

2.2 3D Modelling and Analysis

After completion of the 2D analysis, I proceeded to the 3D development of a few result based models in CATIA and their subsequent analysis in SolidWorks.

The analysis conducted in the computational fluid dynamics environment comprised of the wind tunnel testing simulation.
Wind tunnel testing involves the creation of a huge cuboid much greater than the size of the fairing. This would serve as the long tunnel. One of the sides of the cuboid is designated as the entry for the air, another side is designated as the exit. The 3 components of velocity along the 3 major axes are then set. And the simulation is generated over a series of iterations. The force acting on the fairing surface is calculated in terms of components along the 3 standard co-ordinate axes. The force acting in the direction of the flow of air is termed as the Frictional Force (F_d) or the Drag Force. The equation I is then used to calculate the coefficient of drag for the given model.

$$C_d = \frac{2\,F_d}{\rho v^2 A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I)}$$

Where C_d = Drag Coefficient, F_d = Drag Force, ρ = density of air, v = velocity of air, A = normalised area

The value of C_dA is used to compare the efficiency of the different models in terms of the drag experienced by each of them. The magnitude of the Normal Force is used in determining the efficiency of the design in terms of roll-over protection. Here are a few results of the 3D analysis that I conducted.

2.2.1 Model 1

Velocity flow analysis was conducted on this model. The results obtained are as depicted in Fig 2.9 and Table 2.1.

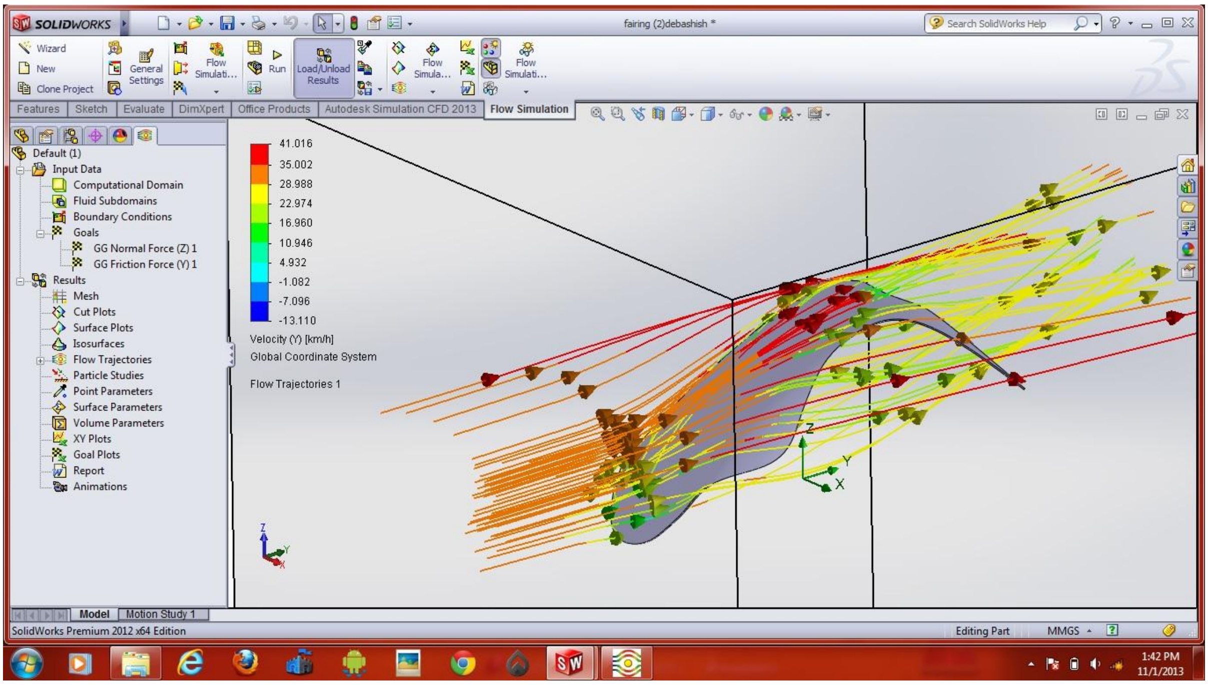

Fig 2.9 Velocity Flow Analysis Conducted on Model 1

The table of data obtained from this preliminary model is given as below:

Goal Name	Unit	Value	Averaged Value	Min. Value	Max. Value
GG Normal Force (Z) 1	[N]	-0.989473911	-1.018552936	-1.056307169	-0.989473911
GG Friction Force (Y) 1	[N]	0.012884242	0.013363988	0.012846516	0.014600455

Table 2.1 Analysis Results for Model 1

The table shows the details of Normal force and Frictional Force acting on the fairing profile. The results obtained thus were used further to create successive models using different approaches. The positives of this model include a very low drag force but the magnitude of normal force is also considerably low.

2.2.2 Model 2

Another model representing a flatter bottom and resembling a bullet on the upper edge was developed and subsequent velocity and pressure analysis was conducted on it.
Mentioned below are the results thus obtained as shown in Fig 2.10, Fig 2.11 and Table 2.2.

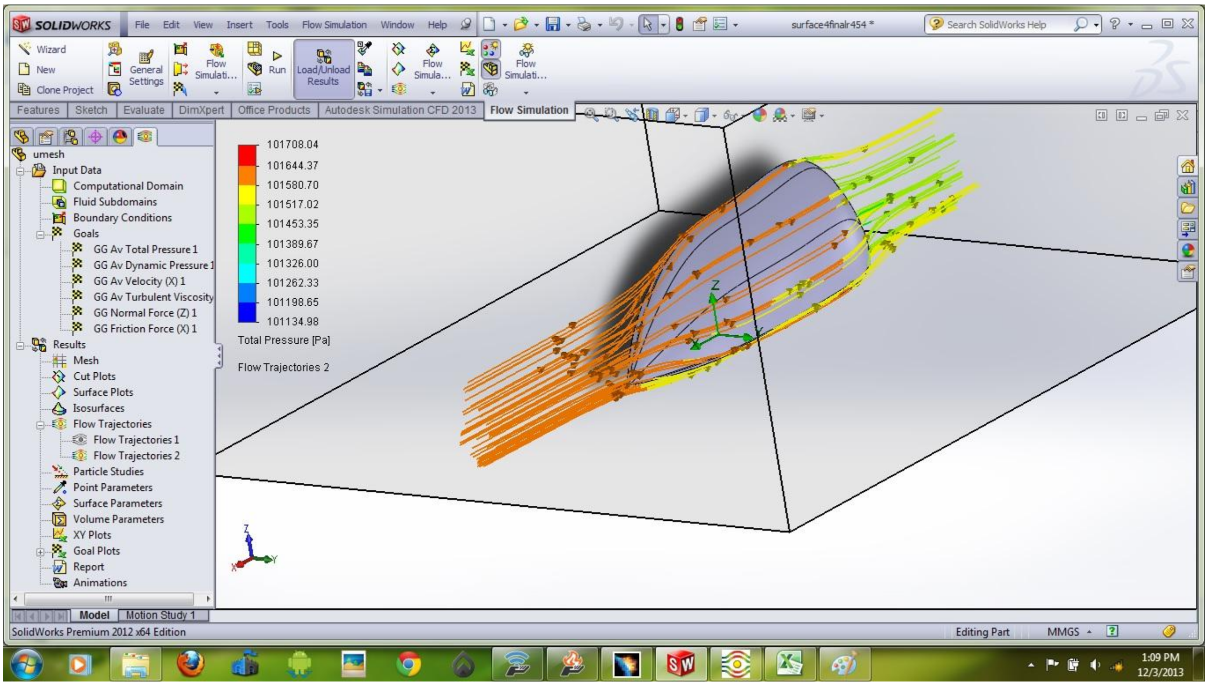

Fig 2.10 Pressure Flow Analysis Conducted on Model 2

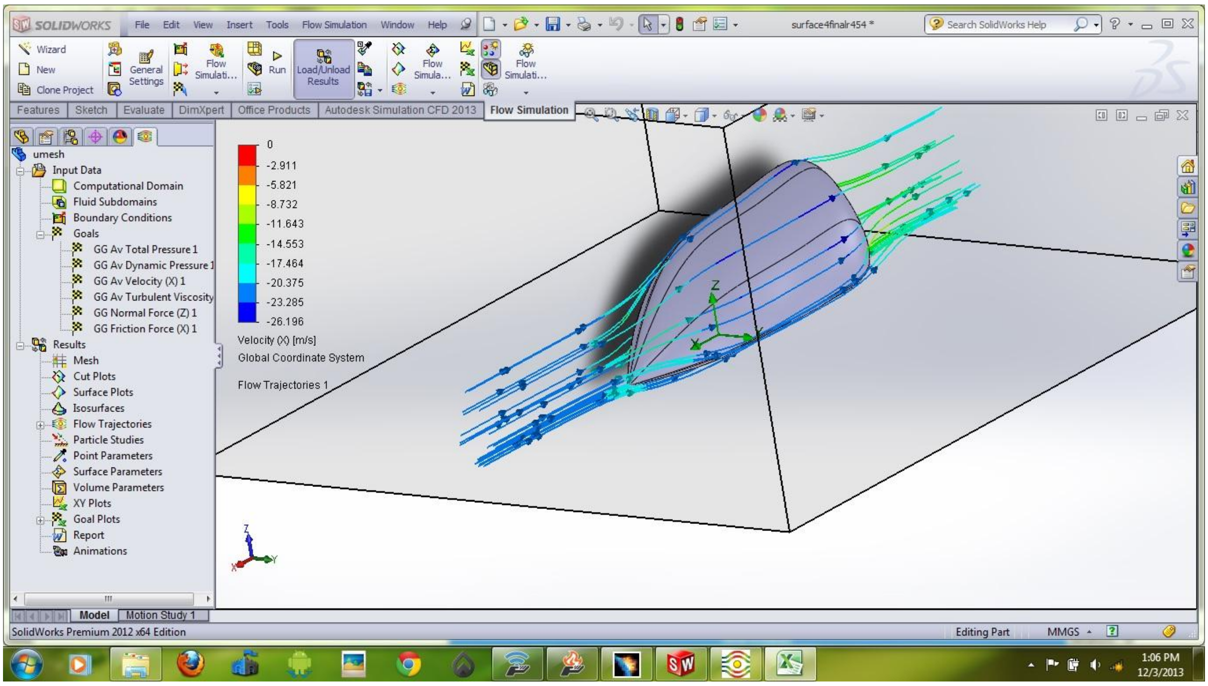

Fig 2.11 Velocity Flow Analysis Conducted on Model 2

The analysis data obtained from the above analysis is given as below in Table 2.2

Goal Name	Unit	Value	Averaged Value	Min. Value	Max. Value
GG Normal Force (Z) 1	[N]	14.14193853	14.0655695	13.96302206	14.15902098
GG Friction Force (X) 1	[N]	-1.367127277	-1.3539923847	-1.411212466	-1.323848486

Table 2.2 Analysis Results obtained for Model 2

2.2.3 Model 3

A third type of model roughly resembling an automobile fairing was designed and tested using CAE analysis. Wind Tunnel Testing Simulation was performed.

The results obtained are shown below in the Fig 2.12 and Table 2.3.

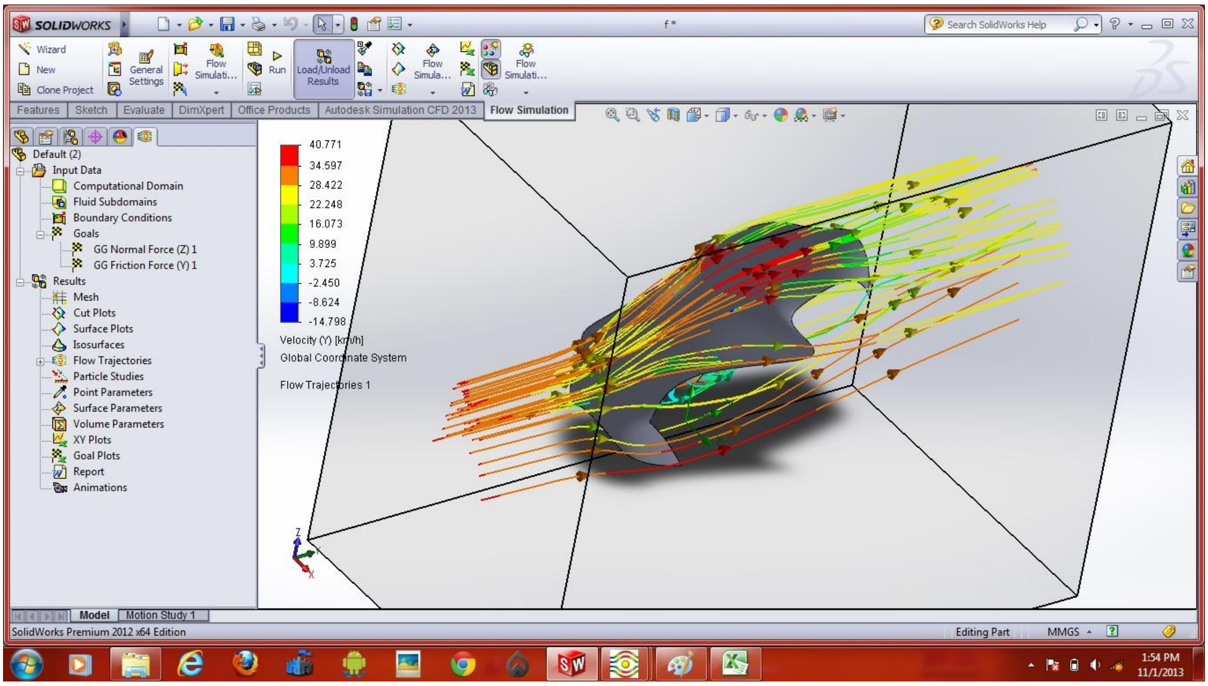

Fig 2.12 Velocity Flow Analysis Conducted on Model 3

The above mentioned figure gives the details of the velocity flow over the designed structure. The table below gives the details obtained from the analysis showing the details of the normal forces and the frictional forces acting on the fairing.

Goal Name	Unit	Value	Averaged Value	Min. Value	Max. Value
GG Normal Force (Z) 1	[N]	-12.2270227	-12.89040686	-13.87608098	-12.2270227
GG Friction Force (Y) 1	[N]	0.169213526	0.170204346	0.157691612	0.201338227

Table 2.3 Analysis Results for Model 3

2.2.4 Model 4:

The concept is derived from the aerodynamic design of front part of the car. From the CFD analysis, it is found that maximum velocity of the air is about 38 kmph with a flow trajectory of 35 kmph at the top. The detailed results of wind tunnel testing simulation carried out on this model is shown in Table 2.4 and is depicted pictorially in Fig 2.14 and 2.15

Goal Name	Unit	Value	Averaged Value	Min. Value	Max. Value
GG Normal Force (Z) 1	[N]	-10.18945173	-10.34894466	-10.45633286	-10.25672972
GG Friction Force (X) 1	[N]	-0.205233672	-0.533230034	-0.576430441	-0.400892717

Table 2.4 Analysis Results for Model 4

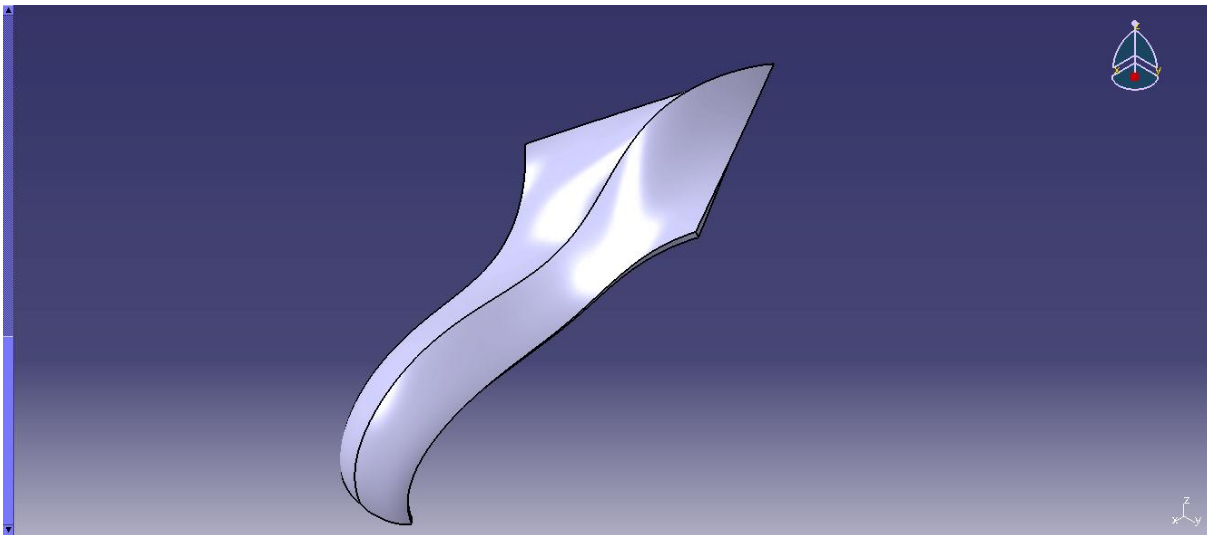

Fig 2.13 3D CAD Model for Model 4

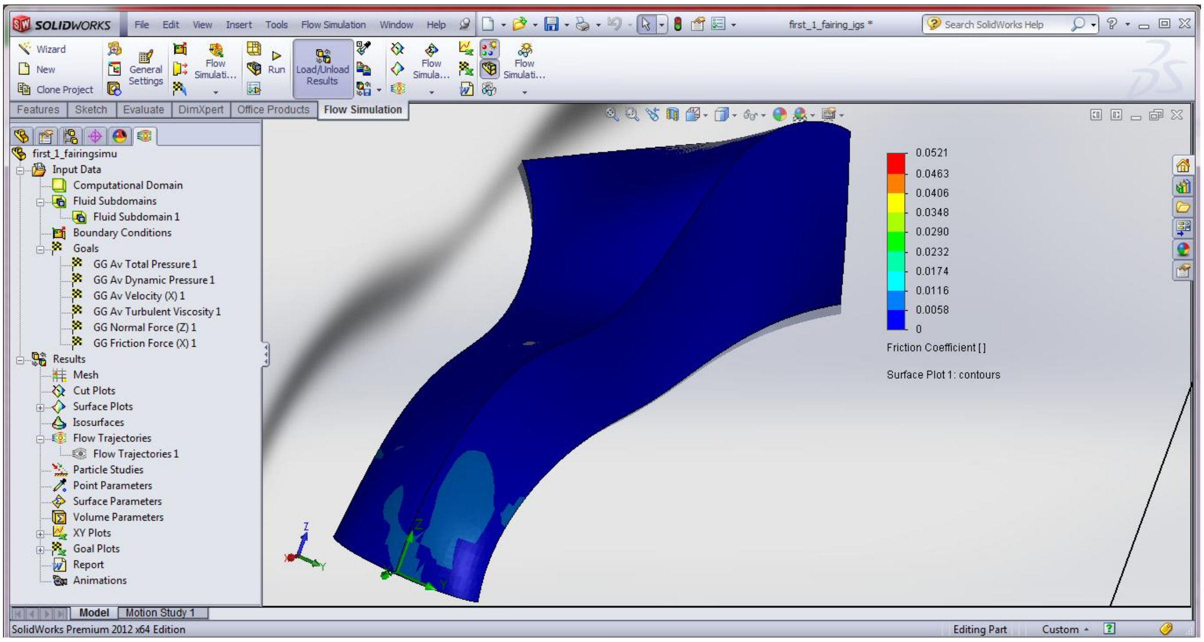

Fig 2.14 Friction co-efficient analysis for Model 4

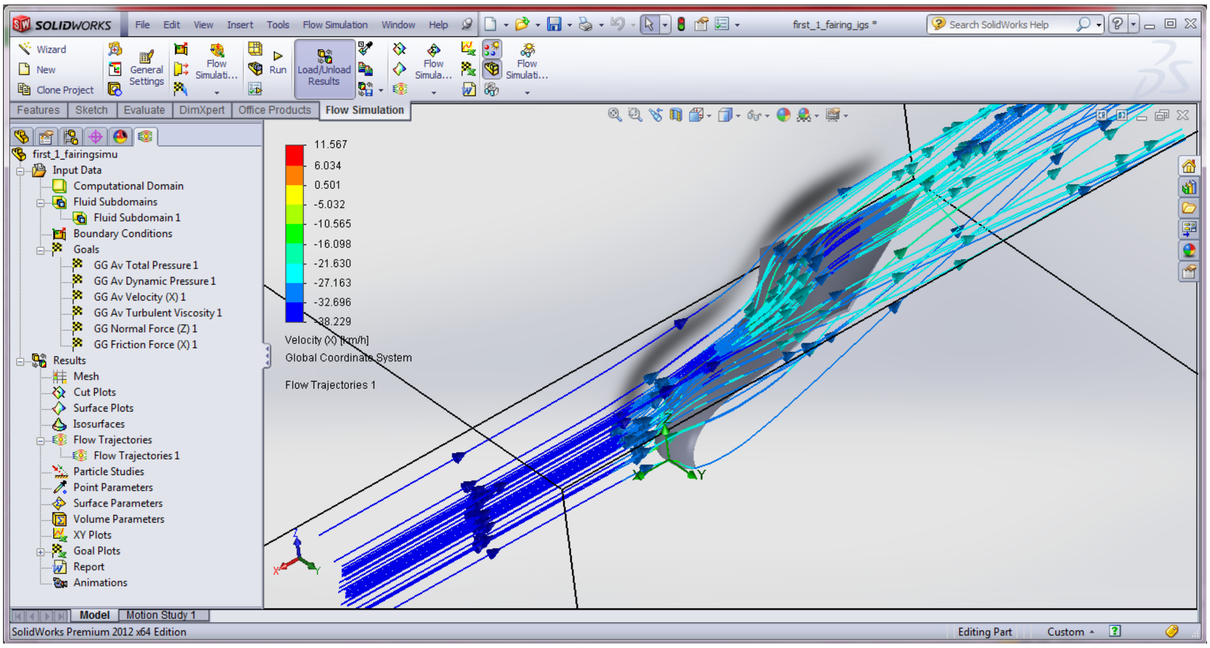

Fig 2.15 Velocity flow analysis for Model 4

2.2.5 Model 5:

This model was resembles a cut section of a bullet and is also inspired from the streamlined shape of the anterior body of a fish, the family of animals with a shape best suited to the complications of fluid dynamics.

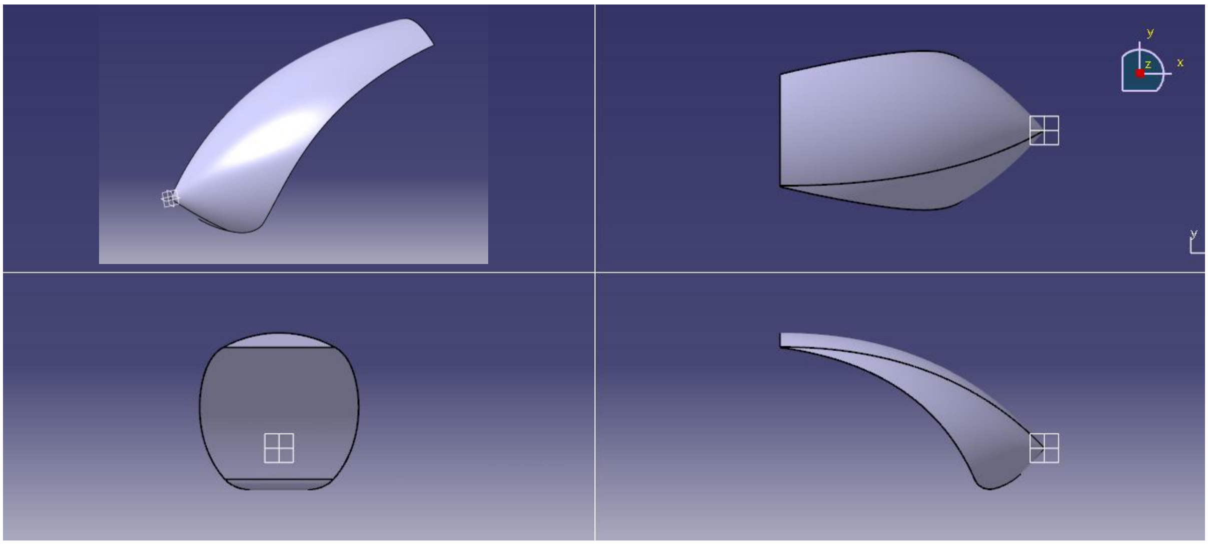

Fig 2.16 3D CAD Model for Model 5

From the CFD analysis, it is found that maximum velocity of the air is about 40.6 kmph with a flow trajectory of 35 kmph at the top. The friction coefficient comes about 0.0022 and the drag force to be about 0.28N. Yet another reason for developing this model was its simple shape which would make its fabrication simpler compared to the other complex designs. The plots for Velocity and the corresponding Frictional Force experienced by the fairing are shown clearly in the Fig 2.19 and 2.20 with the number of iteration being represented by the X axis in each case.

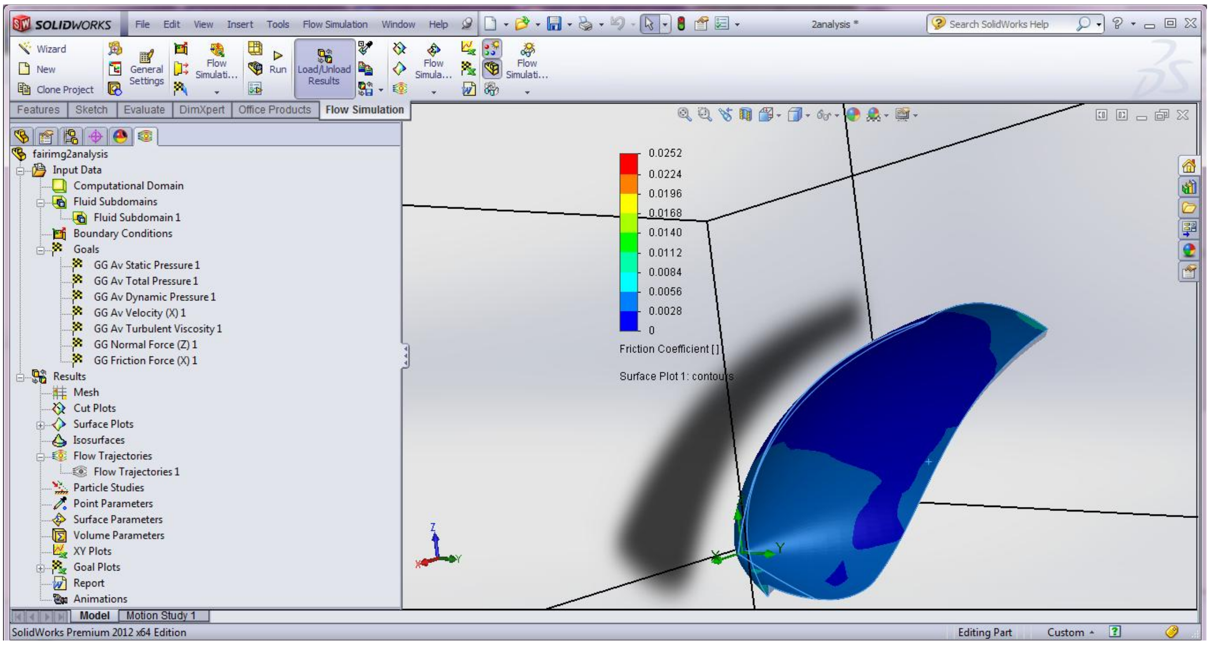

Fig 2.17 Friction co-efficient analysis for Model 5

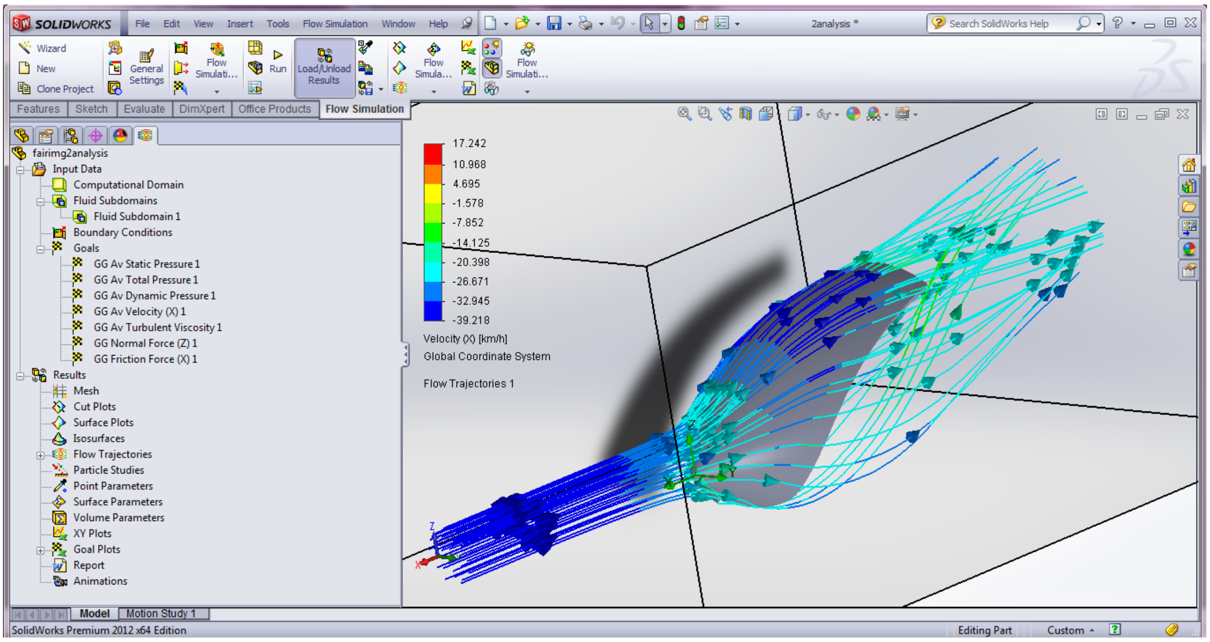

Fig 2.18 Velocity Flow analysis for Model 5

Goal Name	Unit	Value	Averaged Value	Min. Value	Max. Value
GG Normal Force (Z) 1	[N]	-16.18936173	-16.30894466	-16.45633286	-16.15152972
GG Friction Force (X) 1	[N]	-0.205458672	-0.203230034	-0.206430441	-0.200892717

Table 2.5 CFD Analysis Results for Model 5

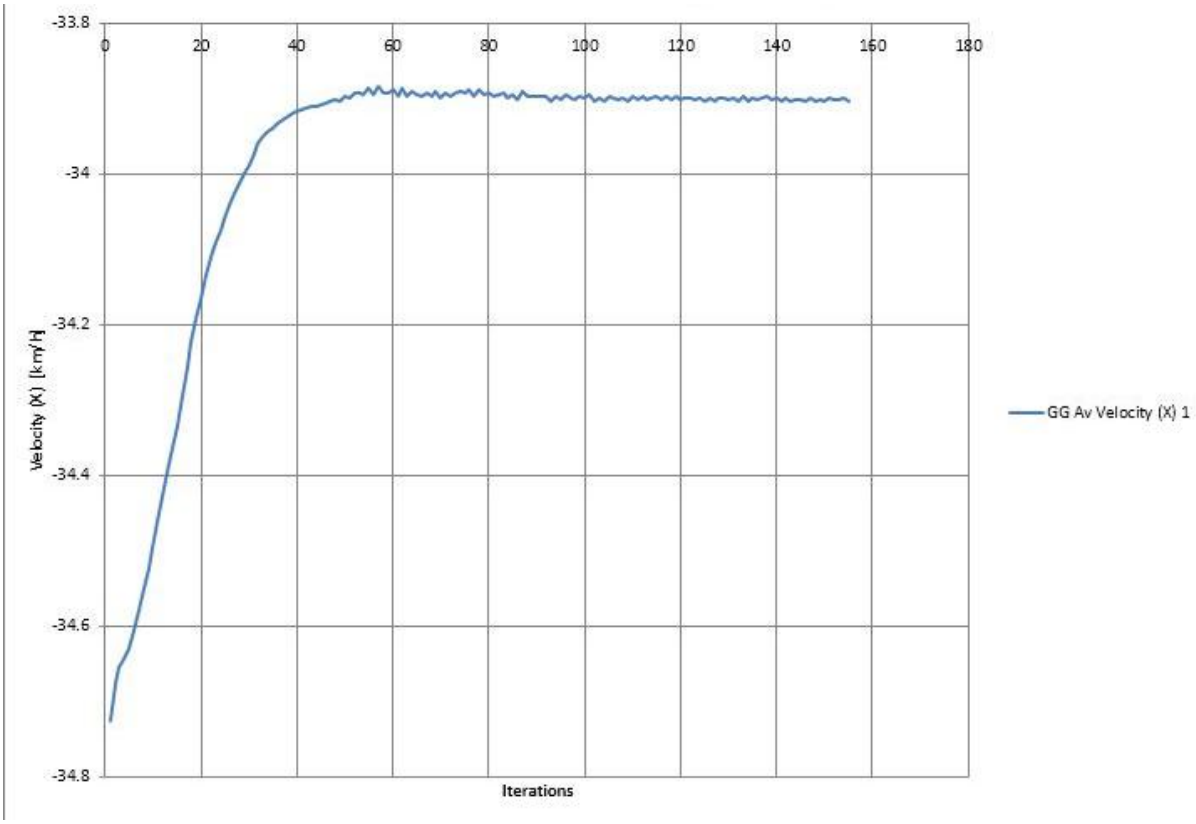

Fig 2.19 Velocity graph for Model 5

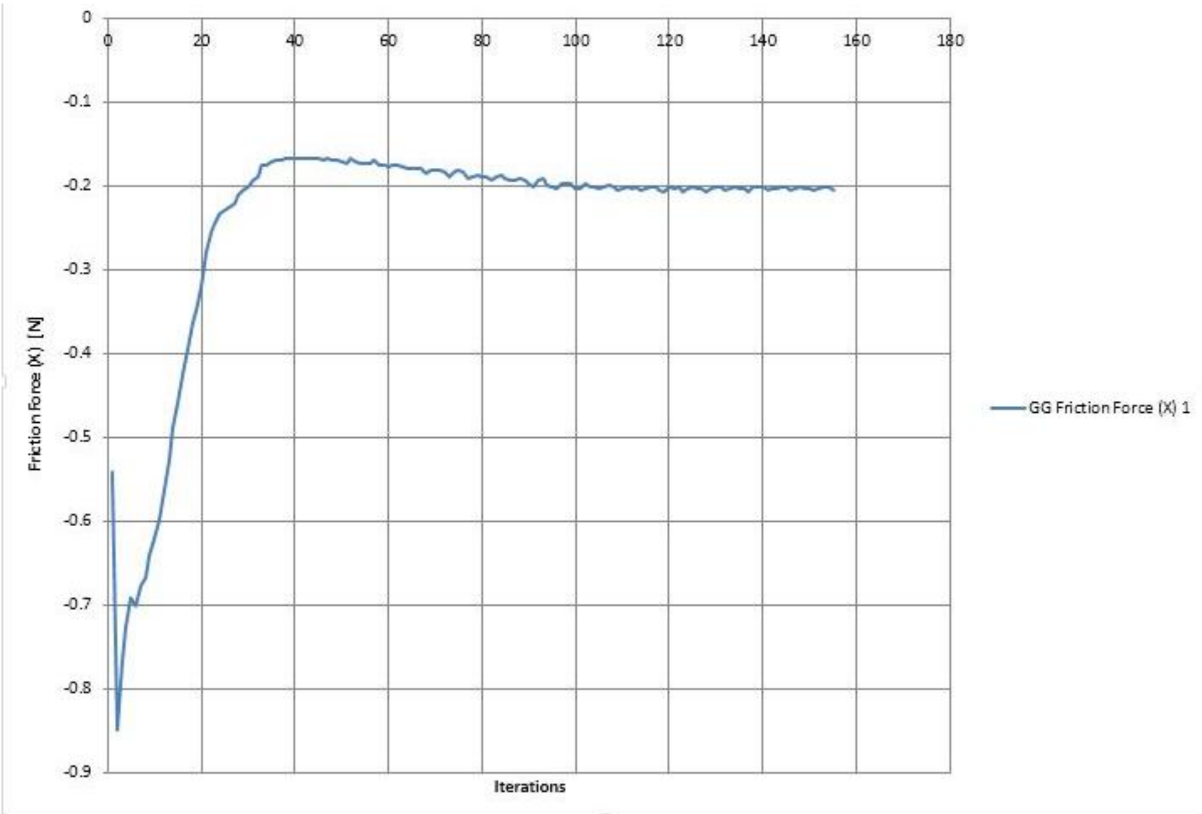

Fig 2.20 Friction Force Graph for Model 5

CHAPTER 3

FABRICATION

3.1 Suggested Method for Cheap Fabrication of Wheel Cover

The wheel covers available in the market may not suit to the dimensions of the vehicle and are costly too. Here is an easy method to fabricate a really cheap wheel cover.

We will be testing it.

3.1.1 Materials

i) Foam insulation sheeting

ii) Super adhesive

iii) Mold release agent

iv) Fiberglass cloth

v) Epoxy Resin. Less toxic than polyester resin

vi) Compass (small and large)

vii) Tape rule

3.1.2 Procedure

The process starts with the creation of molds for the disks, after that the disks are laid up, trimmed, sanded and finished. They are subsequently attached to the wheels at the hubs by means of wire ties. One mold is needed for each rim dish.

Foam is used to make molds, because of their easy availability. Plastic coated foam is peeled off to make bending easier. The disk diameter and height are the two most important parameters required for the construction. Disks are desired to be aligned to the braking surface to achieve maximum aerodynamic efficiency

After measuring the disk diameter it is divided into two and a big compass is set to that distance, subsequently a circular foam is cut out. Pie shaped sections are then cut out by drawing lines from the edge to the centre of the disk. This is done to match the disk height when the edges are pulled together. Repeated trials maybe necessary for this step but foam is cheap.

A circle is cut out of the centre of the foam disk (diameter is equal to the hub's diameter) using a smaller compass to help the foam obtain a nice cone shape form. After cutting the pie shapes we need to join the seam, adhesive is used for the same. Duct tape holds things together while the adhesive is left to dry. A long strip is also cut out to be attached to the cone shaped disk at its rim thus strengthening the cone. 3 to 4 layers of mold release agent is painted. The picture below shows the top and bottom of the mold, after painting the mold release agent.

Fibreglass sheet is laid after drying the release agent, and epoxy is painted. Two layers of fibreglass is used, epoxy is applied while its excess is squeezed out after every layer. Fibreglass disks peel out comparatively easily after the epoxy is cured. Thus making the moulds reusable. Sanding and trimming is then carried out to get rid of imperfections, if any. Smaller compass is used to mark the inside hole, which must be slightly larger than the hub diameter.

After finishing and painting the disks, they need to be attached. We drill a number of holes in the fiberglass disk at the diameter of the first spoke crossing, keeping some margin between holes. Wire ties are used to attach the disk. Tightness must be maintained to prevent gaps. Wiring from inside enables grater finish and better aesthetics

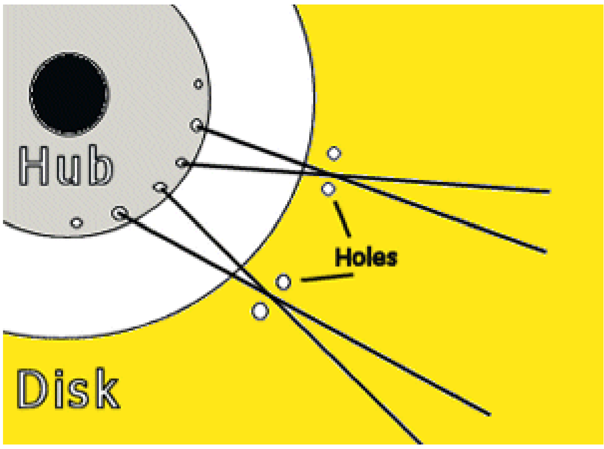

Fig 3.1 Demonstration of Wheel Cover Fabrication

3.2 Fabrication of the Fairing

Most of the fairings are fabricated using materials like tough plastic or fibre due to their light weight and their strength. They also use composite (especially graphite) materials where possible, due to their higher specific strength and stiffness when compared to isotropic materials (such as aluminium or steel).They also help attain the exact contours that would be necessary to improve the aerodynamics of the system.

But the major issue for us here is fabrication. The use of the above said material requires moulding. But we have limited resources. This led us to explore more. We have come up with the following ideas for the fabrication as of now.

i) Use of TI rods to create the wireframe of the model and then cover it with plastic in order to make it aerodynamic.

ii) The use of compressed foam blocks in order to fabricate the fairing.

In this method we pile up a set of foam blocks joined to each other by means of adhesives. When the entire setup is set firm, the blocks are carved out by sanding to result in the resulting fairing.

In this method we would carry out the fabrication in 2 parts. The front part and the rear part are to be constructed separately and then later joined.

iii) Use of Bamboo to create the design.

Bamboo is widely known for its flexibility and strength. The idea of bamboo made furniture led us to develop upon a thought that would help us make the desired structure with absolute perfection. We aim at making the bamboo based frame and then later covering it with plastic to enhance aerodynamics.

Bamboo is also cheaply available. And shaping and bending by means of moisture based heating is quite easy to perform. The use of bamboo will also aid to enhance the aesthetic feel of the vehicle which wasn't being considered as of now in the previous designs.

CHAPTER 4

RESULTS

The studies and analysis conducted on the models discussed in Chapter 2, led to the following results as summed up in Table 4.1.

Model No.	C_d Value	Surface Area A [m^2]	C_dA	Drag Force F_d [N]	Normal Force [N]
1	0.8	5.53467291	4.428	0.013	1.087
2	0.6	4.12010638	2.472	1.354	-14.065
3	0.009	2.98201202	0.027	0.17	12.89
4	0.66	3.00236556	1.981	0.53	10.34
5	0.0022	3.34839392	0.007	0.2	16.456

Table 4.1 Comparision of results for the tested models

A detailed description of the results is provided as below.

4.1 Model 1:

Low value of Normal Force (1.087 N) is experienced by this model, would hardly help in preventing the roll-over. Lowest drag force was experienced among the tested models but the C_dA value (which is used as the parameter to judge efficiency of the fairing's aerodynamic performance) was found to be high (4.428). This model is therefore discarded.

4.2 Model 2:

High value of Normal Force (-14.065 N) was observed in this model, but in the direction that would assist roll-over instead. High drag force was also experienced (1.354 N) and the C_dA value was also high (2.472) among the tested models. These results clearly indicate that the above model would aid in generating lift instead of preventing roll-over, moreover the low aerodynamic efficiency clearly prompts towards the non-compatibility of this model as a fairing for the Human Powered Vehicle.

4.3 Model 3:

This model would offer the best aesthetic appeal since the fairing is designed to resemble that of a commercial automobile. Extremely low drag force (0.17 N) and a very high magnitude of normal force (12.89 N) would help in the prevention from roll-over. However the complexity in the contours of this model make its fabrication process challenging and might pose good amount of expenses. A cheaper and simpler model with a better efficiency is further worked upon. The C_dA value (0.027) for this model was found to be fairly low signifying high aerodynamic efficiency.

4.4 Model 4:

This model assures a nice aesthetic feel for the vehicle if implemented, but the coefficient of friction (0.66) is not as low as expected, as revealed by the results. The C_dA value is pretty high (1.981) depicting low aerodynamic efficiency. Moreover the velocity flow diagram in

Fig 2.15 clearly depicts the formation of less laminar flow zones throughout the surface of the design which is least desirable. Furthermore the complexity in shape will make fabrication cumbersome. Hence this model was discarded.

4.5 Model 5:

This model was developed keeping in mind the feasibility of manufacturing and hence has a simple shape. Tests show highly favourable results, lowest drag coefficient (0.0022) implies lower drag force (0.2 N). The C_dA value (0.007) is also the lowest for this model as found by various tests, which clearly depicts highest aerodynamic efficiency. The tunnel test simulation in Fig 2.18 clearly shows that there is a laminar flow around it for a long time. The design being jointly inspired by the shape of a fish-head and a bullet, definitely provides positive aesthetic appeal. The Normal Force experienced by this model is also the Highest among the tested models thus providing maximum protection from roll-over. Based on the theoretical studies, this model was therefore finalised for fabrication. The above mentioned 5 models were developed for the vehicle shown in Fig. 4.1, which went on to participate in HPVC India 2014 event held at IIT Delhi conducted by ASME.

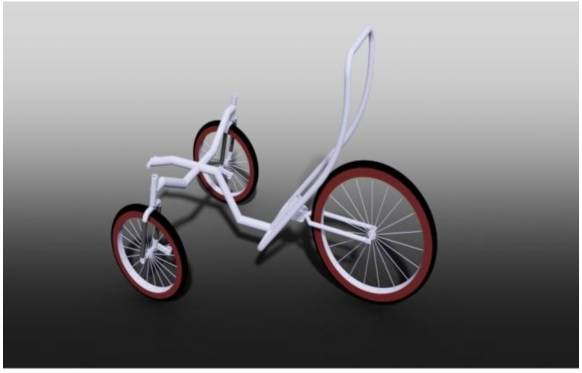

Fig 4.1 HPVC India vehicle without fairing

After comparing the above mentioned 5 models, the Model 5 was zeroed upon, since it provided the best results, be it the drag reduction, aesthetics or ease of fabrication. The final model of the vehicle is shown in Fig 4.2, which shows a manikin seated. The gap between the chassis and the manikin is to indicate clearance for the Seats which aren't included in the CAD model.

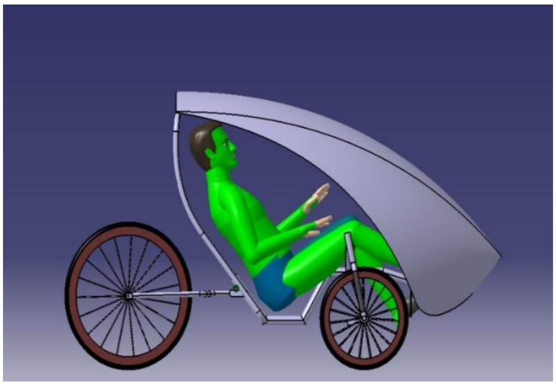

Fig 4.2 HPVC India vehicle with fairing and manikin

Fig 4.3 HPVC India vehicle rendered view showing aesthetic appeal

The fairing was finally fabricated using bamboo which helped in creating the main frame, this frame was later covered using thick transparent laminates to allow proper vision for the driver and subsequently stickers were pasted on the laminates to enhance the aesthetics of the vehicle in compliance with the rules laid down by ASME. The Fig 4.4 shows the vehicle completing the race with the above proposed fairing on.

Fig 4.4 HPVC India vehicle finishing the race. The fairing is clearly visible

The various factors therefore considered while designing the fairing are given as below:

i) The frame of the vehicle.
ii) The relative speed of the vehicle w.r.t. the wind.
iii) The ergonomic consideration to allow free movement and comfort of the driver inside the vehicle.
iv) The Height of the fairing above the ground to avoid ground turbulence

To judge the effectiveness of a faring design the following parameters were considered:

i) The Drag Coefficient ($C_{d)}$ and the Normalised Area (A) projected by the surface of the fairing, i.e. C_dA.
ii) The Drag Force (F_d) experienced by the fairing.
iii) The Normal Force experienced by the fairing that would prevent the vehicle from roll-over
iv) The cost-effectiveness of the design.
v) The ease of fabrication.

vi) The ease of material availability, an attempt was made to use eco-friendly material as the fairing.
vii) Mounting points for various add-ons and sensors, e.g. collision avoidance sensor, mirror, etc. were also considered.

CHAPTER 5

CONCLUSION

The design proved to be effective, the vehicle was the Highest Scorer in *Analysis*, and 3rd Highest Scorer in *Design* among all the participating vehicles at the HPVC India 2014 Event held at IIT Delhi. The vehicle also successfully featured in the Top 20 in the *Endurance Event*, this very well proves the effectiveness of the design. The average speed of the vehicle as officially recorded as 12.43 kmph.

The results hence obtained after the event highlighted the following issues:

- A recumbent vehicle occupies a great deal of volume which in turn makes transportation of the vehicles for the competitions a great problem. It also leads to the usage of more material, which in turn causes the weight of the vehicle to rise drastically. Thus demanding greater effort on the part of the rider.
- The fairing was developed as a huge single unit with a laminate cover making it vulnerable to damage despite of having a strong bamboo base. Moreover the huge volume occupied by the fairing created a lot of transportation related complexity.

These shortcomings along with the other results were analysed and further developed and implemented in a fresh vehicle that was developed by the ASME-NITRkl Chapter in order to participate in the HPVC EAST 2014 Event at the University of Central Florida, USA in the month of April, 2014.

REFERENCES

[1] Zimmer G and Alam F. The Effects of Aerodynamic Design on Lightweight Human Powered Vehicles. In: The Impact of Technology on Sports III, 2009; p. 125-9.

[2] Hucho WH. Aerodynamics of Road Vehicles, 4th Edition, USA: SAE International, 1998.

[3] Van Valkenburg P. Race car Engineering and Mechanics, USA, 2000.

[4] Becker M and Dedini FG. Vehicular Dirigibility Study Applied to Human-Powered Tricycles (HPT). SAE Paper No 982882, USA, 1998.

[5] Central Goldfields Shire, (2004, 2008, 2011) Final results, RACV Energy Breakthrough, 2004, 2008, 2011respectively.

[6] http://www.desktop.aero/appliedaero/airfoils1/interactiveaf.html

[7] Low Reynolds Number Vehicles [Advisory Group for Aerospace Research and Development], NATO, AGARDograph No.288, Thomas J. Meuller, February 1985. ISBN – 92-835-1486-6, Pg. 3-6

Appendix A. HPVC EAST 2014

The results obtained from the HPVC India 2014 event led to the following important decisions:

The new vehicle design will no more remain recumbent unlike the previous design. We decided to develop a new design which resembled a normal bicycle (the most efficient human powered vehicle that exists) in order to boost performance. This vehicle was to be equipped with more technological innovations which would help storage of energy out of the developed human power. A normal bicycle model was to be customised according to the rules of HPVC East 2014 specified by ASME, E.g. Addition of a ROPS (roll-over protection system), fairing, etc. to boost productivity.

The fairing was initially a single huge part, which made its transportation cumbersome. Moreover, the driver was required to lift the entire fairing to mount or dismount oneself from the vehicle, this was a tedious job due to the large size of the fairing, it sometimes called for external aid.

A detachable fairing has been designed made out of transparent plastic. The fairing can be detached, folded, and carried wherever we want. During precipitation, riders can use the fairing to prevent rain or snow from wetting the rider.

It was thus decided to design a fairing which would consist of two units, fixed and movable as shown in Fig A.2. The movable unit would involve the use of a hinge attached to the fixed unit around which the movable unit would revolve. Each unit would be consisting of two symmetrically identical parts which would be joined to for a single unit.

The design was modelled and tested.

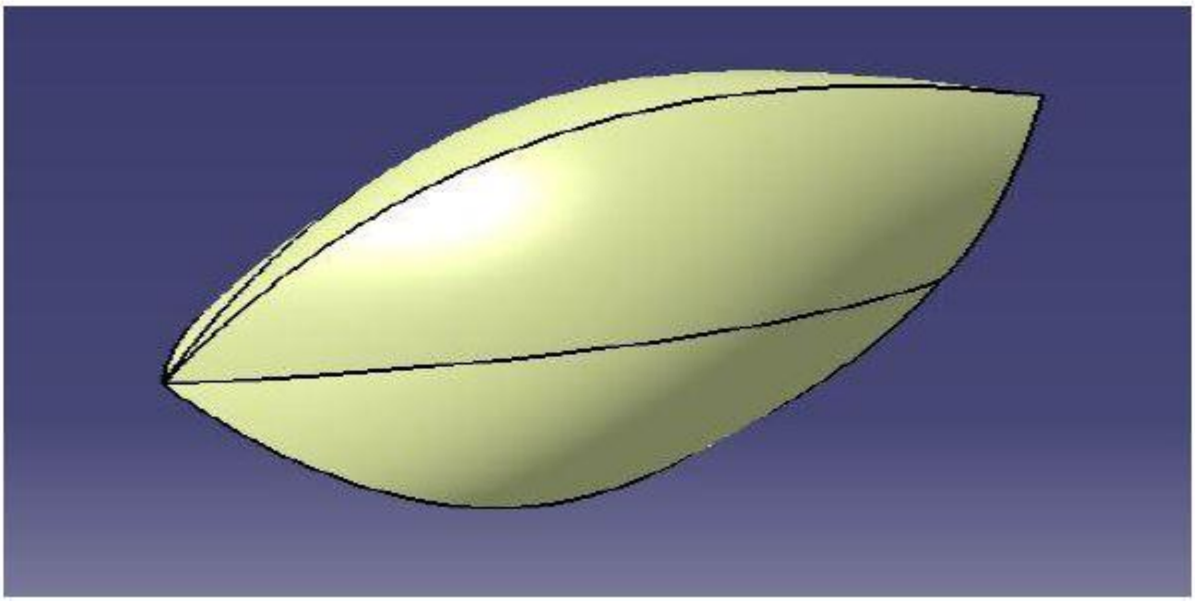

Fig. A.1 New 3D Model developed for HPVC EAST Vehicle

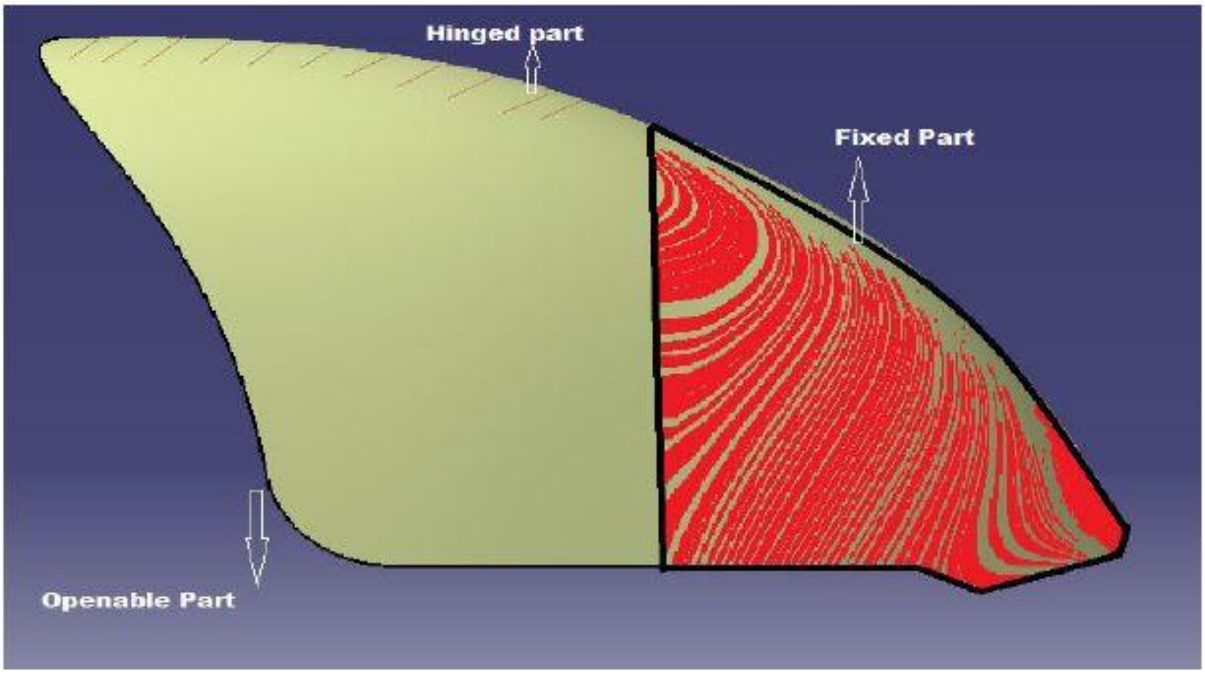

Fig. A.2 Concept for New Model

The C_d is the drag coefficient. This relative amount depicts the "formal quality" of bodies, independent of their size. Various elements impact the C_d value, including the vehicle shape (saloon, estate or hatchback). Thin crevices and joints lessen rocking and keep drag low. The lesser this value is, the all the more aerodynamically proficient will be the vehicle's design. An exact articulation with respect to the vehicle's aerodynamic must be made once both the Cd value and the vehicle's frontal normalised area (the projection of the vehicle's front diagram onto a plane surface) are known.

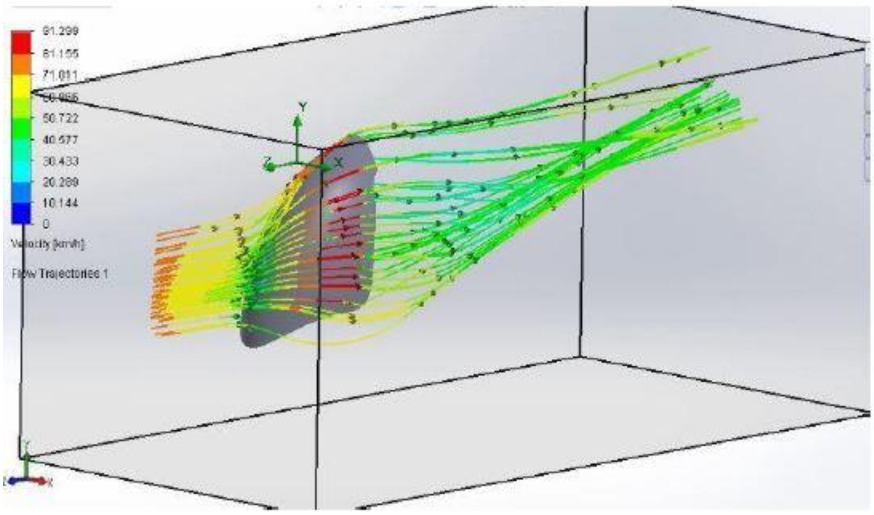

Fig. A.3 Velocity Flow analysis for the front unit of the New Model

We used a computational fluid dynamics (CFD) model to simulate the air flow around the fairing in order to minimize aerodynamic drag. SolidWorks CFD module and Autodesk Falcon was used to test both headwind and crosswind conditions. Tests were conducted near the vehicle's desired top speed of 73.0 km/h with crosswinds of 0 km/h on the concept designs.

Concept Number	Cd Value	Surface Area (m^2)	Cd X Surface Area
1	0.6	4.12010638	2.472
2	0.66	3.00236556	1.982
3	0.009	2.98201202	0.027

Table A.1 Result of Tests on New Model

The results obtained as shown in Table A.1, establish the fact that the new model is theoretically more efficient than any of the previously suggested concepts. It also helped in overcoming the shortcomings of the design which was used for the HPVC India 2014 Event. Thus the fairing was installed on the newly designed vehicle as shown in Fig A.4.

Fig A.4 3D model of the HPVC EAST 2014 vehicle with the newly designed fairing shown in Isometric view

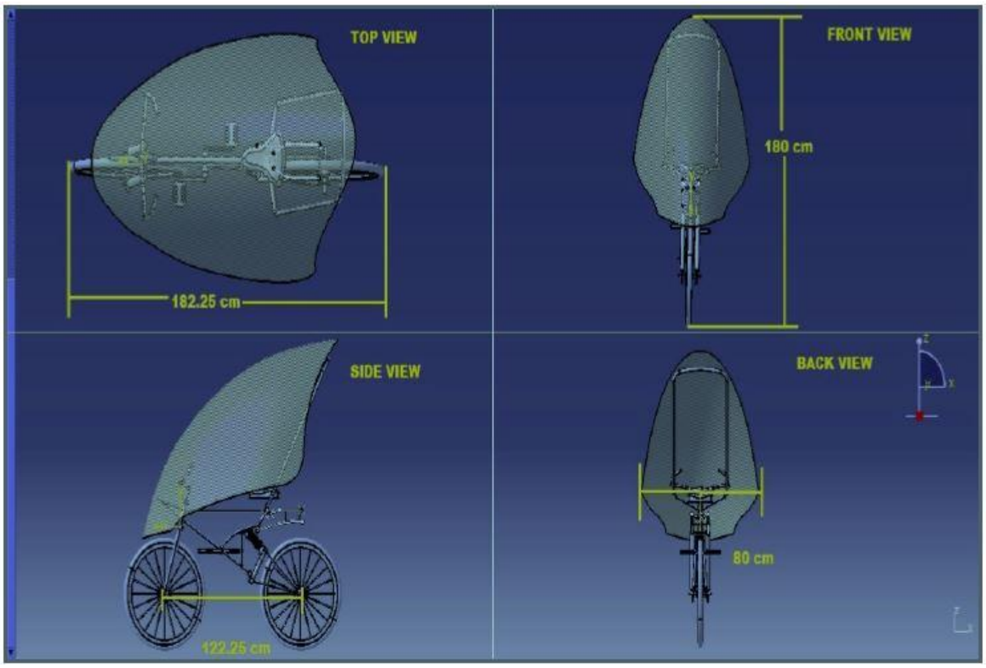

 Fig. A.5 3D model of the HPVC EAST 2014 vehicle with the newly designed fairing shown in detailed dimensional parameters