

Aerodynamic Analysis of Fairings for Bicycles

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Abstract - Aerodynamics is the study of moving air's properties and the interactions between moving air and solids. Rider gets slammed into air particles while riding that gets compressed once rider hit them and then become spaced out once they flow over the rider. The distinction in atmospheric pressure from your front to your back creates a retardant force. The force that's perpendicular to the oncoming flow direction is the lift force. It contrasts with the drag force. Aerodynamic shapes reduce this pressure drag and lift by minimizing that difference in pressure and allowing the air to flow more smoothly over your front, reducing the low-pressure wake behind the cyclist and reducing this drag, and increasing speed in this paper; fairings designed. NACA airfoil as a base, fairings are designed using CATIA. CFD analysis is carried out on the bicycle with a fairing to calculate drag and lift force. As the position of cyclists isn't modified and due to fairing, the air resistance reduces, which may increase the comfort level of cyclists. From this analysis, the economical fairing can be determined, facilitating additional drag and producing less lift.

Index Terms - Human-powered vehicle, fairings, drag, lift, Coefficient of drag, Coefficient of lift, CFD analysis.

I. INTRODUCTION

Studies and aerodynamic equipment applied to cycling aren't only limited to the last decades, but they were already present within the late 19th century. Early samples of the aerodynamic kit include disc and four-spoke wheels. Moreover, drafting races, during which a cyclist rides behind tandem cyclists, motorcycles, or maybe trains, were popular. These were popular by tens of thousands of individuals. New bicycle designs, like recumbent bicycles in 1895 and streamlined enclosures in 1913, were also proposed. At the same

time, the primary simplified mathematical models of forces functioning on cyclists were published, and these models demonstrated the many impacts of aerodynamics on cyclist performance. The increasing environmental concerns are primarily because of the depletion of fossil fuels and airborne pollution, which also led to gaining importance to the usage of human power vehicles even in advanced countries. The transport sector attributes to 23% of the globe's greenhouse emissions resulting from the burning of fossil fuels. Out of the total gas emissions, road transport takes up a share, 75% to be precise, and this trend is projected to extend within the future if it continues unabated. All this puts plenty of pressure on the national governments to plot policies to scale back gas emissions furthermore as oil demands. In statistics, it is learned that over 90% of all road transportation relies on oil consumption, which stands at 60%. The immediate solution to this environmental pollution is greening the transport sector, which suggests any variety of eco-friendly vehicle or transportation habits and doesn't emit toxic gasses that may impact the environment and human health. This has led to the event of recent transportation alternatives, which are in line with the "Go Green" manifesto. One such development is that the concept of human-powered vehicles (HPVs). These are the transportation machines that use human power because of the source of their energy for locomotion.

Further development has led to advances in the inclusion of ergonomics and aesthetics into their design, aiming at higher value and efficiency. The renewed interest in cycling aerodynamics is significantly growing with the assembly of an enormous literature focused on increasing the comprehension of cycling aerodynamics and

improving the aerodynamics of bicycle equipment. Aerodynamic resistance may be a core focus in cycling because it is answerable for about 90% of the entire resistance at speeds more significant than 40 km/h on flat terrain. The bulk of contemporary bicycles and cyclist postures are therefore optimized in terms of aerodynamic resistance. High drag because of the turbulence of airflow, and it's been observed wake is high at the upper arm and stretched leg.

II. OBJECTIVES

- Reduce drag and give comfort to the cyclist with less cost and improve the cyclist's comfort level and visibility.
- These fairings are designed to provide maximum visibility and since the position of cyclists is not changed. As fairings resist the force of air, the comfort level of cyclists may increase.
- CFD analysis is conducted to obtain drag and lift forces through which it can be concluded that the fairings which produce less drag and lift an efficient fairing.

III. DESIGN USED FOR SIMULATION

Bicycle is designed in CATIA where the rib is used to create different parts such as frame, the spine of the manikin, handle and hands, legs of a manikin. Other operations such as sweeping, multi sections surfaces are used to design cycle wheels, other parts of the cycle frame, and pedals.

Due to the complexity of the design, which has different parts such as frame, handle, wheels, spokes, shafts (seat and pedal), bearings, pedal, sprockets (both front and rear), sprockets (both front and rear), chain and manikin. While simulating achieving mesh would be difficult. So, the bicycle design is modified.

A. Modeling of a bicycle in CATIA

Due to the complexity in meshing, the bicycle is redesigned.

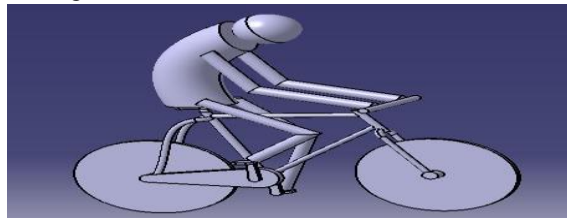


Fig.1 Redesigned bicycle

B. Bicycle dimensions

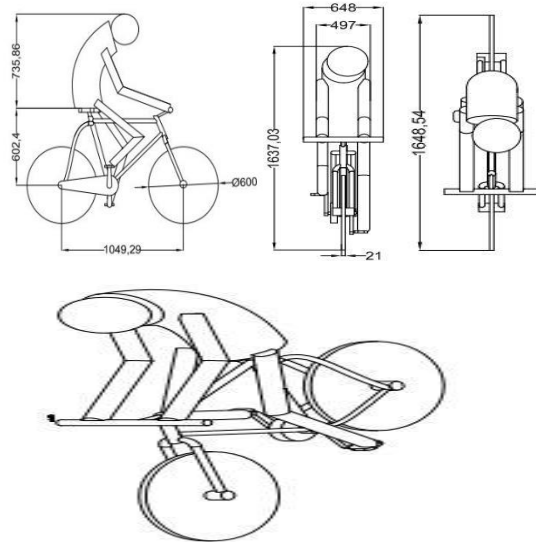


Fig.2 Dimensions and geometry of bicycle and cyclist [7]

IV. DESIGN OF BICYCLE WITH DIFFERENT FAIRINGS

NACA 63-015A AIRFOIL (n63015a-il) is used as a base aerodynamic shape for designing a fairing by changing its chord length. NACA 6 series has a very low drag over a small range of operating conditions [5]. The NACA 66-018 airfoil was chosen for its lower drag coefficient and the narrower albeit longer shape is produced. The opposite is true for the everyday use of HPV, where the NACA 63-015 airfoil has a small form. Therefore, the NACA 63-015 shape was chosen.

(n63015a-il) NACA 63-015A AIRFOIL

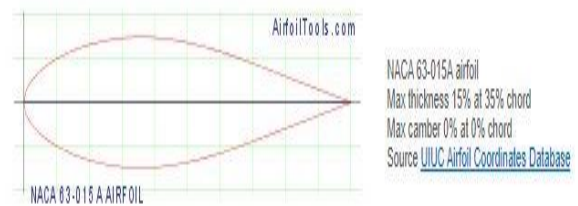


Fig.3 NACA airfoil

A. Length of the bicycle with and without fairing

Using NACA airfoil as a base profile for designing an airfoil, the overall length of an airfoil is taken into account as 100%. 10% of the airfoil length is

considered for creating the first fairing, and similarly, 25% and 40% are considered for making the second and third fairings.

From those percentages, the first fairing was designed solely to cover hands, a seat portion, and thighs of the peddler have 600mm height and 900mm width (chord length). The second fairing is designed to cover the upper half of the body along with the top of the cyclist; it has a height of 1700mm and 900mm in width (chord length); third fairing is meant to cover the upper half; it additionally covers half the wheel, that reduces the turbulence force which is created due to spokes, it has a height of 2000mm and 650mm width (chord length). Fairings are designed in CATIA using array operation to create the basic structure, and a multi-section surface is employed to get the surface. Finally, thickness is superimposed for the fairing. The front view cross-sectional profiles are made to be an oval form to reduce frontal and surface area.

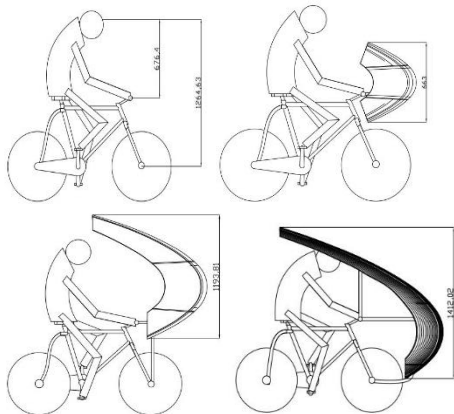


Fig.4 Lengths of the bicycle

B. Bicycle with enclosure

The main challenge in road vehicle tunnel testing is the moving ground. a spread of ways exists similar to employing a moving belt, boundary layer suction, and the ground board technique. However, they may not be enforced because of time constraints, and most are typically impossible due to the tiny size of the wind tunnel. Therefore, exploratory experiments were done by putting the model at heights of 2.6, 4.5, and 13.7 m (scale height), 1, 2, and 4m (centerline) to judge the results of model immersion within the ground plane boundary layer. All three sides of the enclosure are considered symmetrical to apply the same property, i.e., no-slip moving wall conditions, and the inlet is subjected to air velocity.

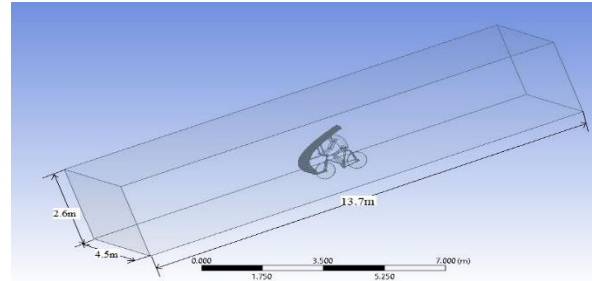


Fig.5 The geometry of bicycle with enclosure and lengths

C. Boundary conditions

Flow Simulation is used for the CFD analysis. Flow Simulation uses a time-implicit solver to approximate convective/diffusive equations for low compressible flows similar to those within the current study. Studied numerous turbulence models and over that, the aerodynamic drag of cyclists was most accurately foretold by the $k-\epsilon$ model compared to the corresponding structure result. Taking these findings as a basis, the $k-\epsilon$ model was used for the present study. The 3D steady Favre Averaged Navier ruled the analysis–Stokes (FANS) equations solved with second-order accuracy exploitation of the $k-\epsilon$ model, which was then, discretized over the domain exploitation the finite-volume technique. Favre-averaging is applicable within the given physical conditions since it simplifies the averaged equations considerably by suppressing terms concerning density fluctuations incompressible flow. The finite-volume method ensures that abstraction discretization is performed in the physical space, reducing the likelihood of errors derived from transformation between the physical and process coordinate systems.

V. SOLUTION METHODS

This model was used with low-Reynolds number modeling (LRNM) to manage the viscosity-affected region. For that, a turbulence model is required, and also the Realizable $k-\epsilon$ was selected. This model was used with low-Reynolds number modeling (LRNM) to manage the viscosity-affected region. This model bestowed higher convergence stability compared to standard $k-\epsilon$. Moreover, the Realizable $k-\epsilon$ turbulence model presented a better computation economy and rate histograms the same as the quality $k-\epsilon$, RST, and RNG $k-\epsilon$ models.

For pressure-speed coupling, a simple algorithmic rule was used. The pressure, convection terms, and viscosity were outlined as second. The least-squares cell-based technique allowed us to reckon the gradients. Force and moment were traced as second and 1st order upwind. The turbulence K.E. and dissipation rate were set as first-order upwind.

Inlet velocities of 6, 8, and 10 m/s were applied as a uniform velocity profile on the upstream face of the computational domain, whereas the downstream face was given an ambient pressure outlet. The following equations were used to outline the coefficient of drag and lift coefficient.

$$C_D = \frac{\text{Drag force}}{(\rho V^2 A)/2}$$

$$C_L = \frac{\text{Lift force}}{(\rho V^2 A)/2} \quad [6]$$

VI. RESULTS AND DISCUSSIONS

CFD analysis was conducted to predict drag coefficient for different types of fairings, for constant velocity, at velocities, 6 m/s, 8 m/s, and 10 m/s. From the velocity contour figures of the analysis drag experienced by the cyclist due to the presence of a pressure differential. The complex geometry of the cycle and peddler makes the prevalence of adverse angles of attack for the airflow inevitable. This ends up in adverse pressure gradients that more separation of the flow from the body. This separation of flow leads to the event of a wake behind the cycle. It's ascertained that a substantial wake is generated behind the cyclist, leading to vortices. Within the wake region, vital losses in pressure happen because of eddy formation, which contributes to the creation of an occasional pressure region. This further will increase the drag force intimate with the cycle and cyclist.

A. Drag and lift at different speeds for 3 fairings

From the above table, the coefficient drag of drag without fairing is 1.1565, and the coefficient of drag for a bicycle with first fairing is 0.4686, which is 3 times less when compared to a bicycle without the fairing. Therefore, using first fairing allows the cyclist to use 3 times less muscle power to achieve that speed. Similarly, the coefficient of drag for a bicycle with a second fairing is 0.2739. Which is also twice smaller than the first fairing allowing the cyclist to use less muscle-power than the first fairing, and the third

fairing coefficient of drag is 0.2571 which is 0.05 times less.

It is observed that the coefficient of lift of bicycles keeps on decreasing for the bicycle. The coefficient of lift pushes the body downwards, which in turn increases the coefficient of drag. Therefore, the muscle power required to achieve this speed will be more. So, to reduce this effect, the airfoil is cambered to make the underside flatter which minimizes the decrease in pressure in that region and thus decreasing drag. Cambered airfoils were chosen and cambering the airfoil shape reduces drag by up to 5–10%.

Table.I Drag and lift at different speeds for 3 fairings

Speed		Without fairing	1 st Fairing	2 nd Fairing	3 rd Fairing
6 m/s	Drag	1.1565	0.4686	0.2739	0.2571
	Lift	0.0694	0.0638	0.0629	- 0.0432
8 m/s	Drag	1.1530	0.4638	0.2709	0.2554
	Lift	0.0689	0.0671	- 0.0429	- 0.1409
10 m/s	Drag	1.1509	0.4619	0.2689	0.2549
	Lift	0.0658	0.0645	- 0.0401	- 0.1415

B. Streamline and contour representation for without fairing

Due to direct contact with the body, high turbulence is created, increasing the drag and reducing the speed of the bicycle. It is observed that the head, body, shoulders create high turbulence. Similarly, the legs and hands' overall length acts as obstruction of airflow, creating more turbulence. Therefore considering this, all the fairings were designed.



Fig..6 Streamline representation for without fairing

C. Streamline and contour representation for first fairing

This fairing covers the hands and upper half of the body, allowing air to flow in a streamline and

increasing the speed. From the above contours, it is observed that because this fairing the high pressure.

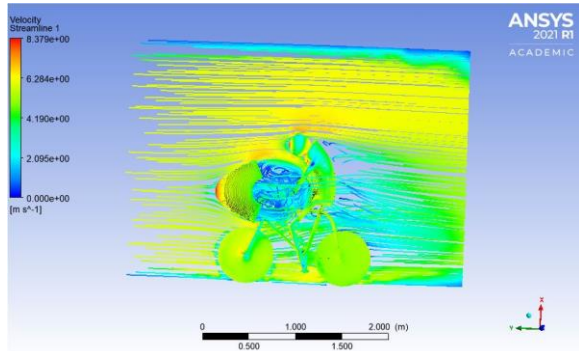


Fig.7 Contour and streamline representation for first fairing

D. Streamline and contour representation for second fairing

This fairing covers the head, hands, and upper half of the body, decreasing the turbulence created and increasing the speed.

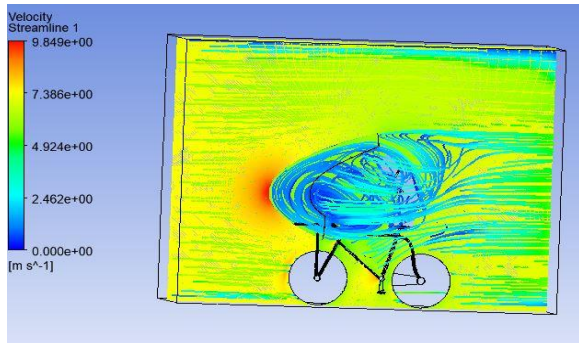


Fig.8 Contour and streamline representation for second fairing

E. Streamline and contour representation for third fairing

This fairing covers half of the wheel and the whole upper body, allowing reducing turbulence created at the spokes of the bicycle.

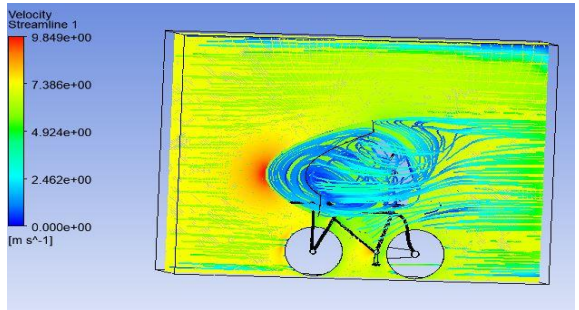


Fig.9 Contour and streamline representation for third fairing

VII. CONCLUSION

The drag coefficient is less compared with cycles that don't have fairings allowing the cyclist to move at high speed. Since cambered airfoils are used, which helps increase the coefficient of lift and decrease the drag coefficient. The third fairing has less coefficient of drag which is 0.257, compared to the remaining fairings, 0.468, 0.273, which means it can acquire high-speed comparing to remaining fairings. It is observed that as velocity increases from 6 to 10m/s coefficient of drag decreases allowing the cyclist to move at high speed. Cyclists can ride bicycles in their comfort level because the fairings are placed according to average human height. Cyclists don't require streamlined helmet or different clothes to achieve this speed with fairing.

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