Aerodynamic Performance Improvement by Streamlining The Front Fairing of a Racing Vehicle

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Abstract: The paper helps to explore and demonstrate the weight reduction of a component with the help of efficient aerodynamics. This can help to reduce fuel consumption and improve the performance of a racing vehicle. The vehicle used is a KTM RC200 2015 which was tested on various factors such as aerodynamics, weight, fuel consumption, and performance. The results were eventually validated with appropriate simulation and experimental trials. To improve and sustain the performance of the engine, it is necessary to explore various factors such as weight reduction through material selection and aerodynamically streamlining the vehicle design. The main component that was tested is the front fairing of the bike. The front fairing plays a very important role in a bike’s performance. Therefore, the stock front fairing component is to be replaced with a modified component which also needs to meet all the regulatory safety standards. In the present work, two different front fairing components were used and one of them is made up of plastic representing the stock component while the second one is the customized and improved component made up of glass fiber reinforced epoxy. The results had shown promising improvements to the performance of the vehicle and it was observed that the material density and strength played a factor in the bike's performance and fuel efficiency.

Keywords: Aerodynamics, fuel efficiency, weight optimization, performance, computational fluid dynamics, front fairing, drag reduction, and motorcycle.

NOMENCLATURE:

1. Computer Aided Design - CAD
2. Kraftfahrzeuge Trunkenpolz Mattighofen - KTM
3. Bayerische Motoren Werke - BMW
4. Digital holographic microscopy - DHM
5. Electromyography - EMG
6. Rapid Upper Limb Assessment - RULA
7. Rapid Entire Body Assessment - RABE
8. Ovako Working posture Assessment System - OWAS
9. Quick Exposure Checklist - QEC
10. 2-Dimensional - 2D
11. 3-Dimensional - 3D
12. Calorific value - $C_v$
13. Density - $\rho$
14. Pressure - $P$
15. Temperature - $T$
16. Mechanical efficiency - $\eta_m$
17. Area - $A$

1. INTRODUCTION

While driving motorcycles, especially in open places such as highways, the most important resistance we feel is the wind. This resistance has a significant impact on not only the stability of and safety of the ride but also the fuel economy, reduction of noise, etc. This major retarding force that affects the movement of objects is aerodynamics drag [1].

The design of fairing for motorcycles should be considered based on the aerodynamics of its body. It is important to understand the various sources, effects, and impact of drag, then calculate their power which helps in designing fairings to reduce the drag effect [2]. The design of fairing should be such a way that it covers the rider as well as the major portion of the motorcycle body with a key objective of reducing the aerodynamic drag. The whole journal in precise states the significant role of the aerodynamic effects and performance by streamlining the front fairing of a racing vehicle supported by CATIA and CFD simulations along with its material selection, weight optimization, fuel efficiency, and also the comparison of custom side and stock side is compared and stated with an appropriate application. Also, reasons have been given on why custom side stock is mostly preferred by everyone.

Aerodynamics is characterized as the cooperation among airflow and the development of strong bodies through the air. A quick-moving motorcycle pushing its way through an air mass will meet a degree of resistance [3] which increments as the motorcycle's speed increments. This air resistance is all the more ordinarily known as drag. A machine with an enormous frontal zone will deliver more prominent degrees of drag than a motorcycle with a little frontal zone, and this connection between frontal territory and drag is legitimately relative. For instance, a motorcycle with a frontal region of one square meter, including the rider, creates twice as much drag as a motorcycle with just a 0.5 square meter frontal surface.

Auto industries emphasize a lot regarding the design of their vehicles since the movement has a significant impact due to aerodynamics and such efforts are generally called as “flow Analysis”. Usual parameters such as speed, pressure, density, and temperature with respect to the moving object are analyzed in the flow analysis [3]. The flow analysis is performed under two different categories. One of them is an external analysis where the airflow is analyzed around the motorcycle. The external analysis is performed at different parts: flow in the front of the motorcycle, flow around the body and passenger and flow behind the motorcycle.

In large automobiles such as a car, bus, etc., the flow analysis underneath the body of the vehicle (between body and the ground) is also performed while that is minimal for motorcycle and is usually neglected [3]. The second type of analysis is internal to the body of the vehicle. The sudden disturbances caused by heavy crosswinds and the effect of air circulation while passing big vehicles are well established in the literature. Such air streams will flow through the radiator fins, which helps in cooling the engine [4].

Fairing design has more impact on external analysis and hence the internal analysis is not a vital part of the present study. To improve the flow path, boundary-layer separation happens to be very important. The
boundary layer is the sheet of air adjacent to the body. While moving at slow speeds, motorcycles with fairings and smooth surface, this layer is thin and smooth. This becomes turbulent and thick layer if the surface is rough [4, 5].

The forces such as drag, lift, and side forces are the significant inertia forces that we have to deal with for effective aerodynamic effect. Drag is the most prominent force amongst these as this is the major obstruction for the forward movement of the motorcycle [5]. To calculate the drag, it is important to understand the airflow during the motorcycle ride. The drag is not consistent during the airflow from the front to rear of the motorcycle [6]. The air that hits the front of the motorcycle immediately forms a boundary layer and gets separated like a fierce stream. With fairing and smooth surface, this effect can be minimized. Continuing its journey towards the body of the motorcycle, once the stream is split, during the middle part of the motorcycle (around the body & passenger), the stream becomes unstable and oscillate. [6] Finally, it loses energy sufficiently to separate from the body surface (boundary layer). The separated flow continues to travel behind the motorcycle, and it forms a turbulent wake. The sudden hit we feel when a truck crossed us is due to this turbulence. The surface variations around the body of motorcycles are the major cause of such changes in aerodynamic forces [7]. Identifying various parts of the airflow and boundary layer, especially where it becomes turbulent and the distance it traveled over the body, and flow speed are important factors for analysis.

Vehicle design plays a significant role in flow separation. This is mainly in the body as well as If the object is flat and straight, then the separation is consistent throughout the body causing a significant drag effect at the end [8,9]. Any uneven surface will cause an additional drag component. Hence, one of the design considerations of fairing should be such that the air deflection towards the top should be higher than the passenger level. Otherwise, there will be an additional drag. If the body of the motorcycle is designed in a concave manner, then the boundary layer will stick close to the body and cause significant drag. A convex design (one that deflects air away from the motorcycle), makes easy separation and, hence reducing the drag [10].

The design patterns and considerations are to reduce the drag effect and force of the motorcycle during movement. The main objective of design considerations is initial approaches were taken at the overall motorcycle itself shaped in a curve, smooth and tapered [11]. Later, the design went to the level of components also. The reason for the curved fuel tank and every component comes with a tapered edge and curved shapes are primarily due to drag. Many design ideas were borrowed by airplane and ship development. Similarly, the design of the frontal part of the motorcycle should be curved and convex (deflect boundary layer away from the motorcycle body). The faring on the motorcycle should be angled as well rather than a straight vertical one. An angle of 8° to 11° gives a drag coefficient reduction of up to 8% [12].

This work mainly attempts to showcase the correlation of various factors in a racing bike. Firstly, the effect of a better shape for the front fairing on the drag is observed using CFD analysis, and subsequently, the material selection to make the aftermarket part is explored to make it lighter than the stock part. Subsequently, the effect of the combination of both materials used and better aerodynamic shape on the performance of the vehicle is highlighted.
2. METHODOLOGY

2.1 Material selection

Material selection plays a very important role on a motorcycle as they have to be as light as possible at the same time strong and sturdy. Material selection helps achieve this, the motorcycle industry and the racing industry have always been ahead on this in finding new composite materials that offer strength and lightweight components. Material selection affects all the performance factors if done correctly. The only downside is that some materials can be very expensive to acquire. There are various and countless composite materials but very few materials meet the specific need in the racing industry. Materials like aluminum, fiberglass, epoxy, plastics, resins, etc. are very common materials used in the lower end of the racing industry as they are cheap and strong at the same time provided the components are made correctly and accurately [13].

2.2. Modelling

Initially, a conceptual design has been created for the custom fairing in order to measure the angle using multiple views. Figure 1(a) represents the side view and top view of the conceptual design for the custom fairing. Moreover, CATIA V5 was used to create the basic 2D models which are the precursors for the study (Figures 1).

Using CATIA we will design both the stock side and custom side model. The dimensions of the CATIA model for the stock side (fig 1 c and e) are that the baseline is 74 cm, the length is 45 cm and the breadth is 15 cm. On the other hand, the dimensions for the custom side model (fig 1 d and f) are that the baseline is 64 cm and the length is 50cm and the breadth is 20cm. The angle that we have measured for the bends is 50 cm and 30 cm respectively. Figure 1 shown below is the completed picture of the CATIA diagram shown with the above-given dimensions. The basic methodology to create these diagrams starts with opening the CATIA workbench where which we select and move through the mechanical design and part design. Once we have clicked part design. In fig 1 image the PAD operation has been used to produce a geometry. The stock top diagram dimensions are 28mm and for the custom top diagram, the dimensions are 30mm.
Figure 1: Design of faring: (a) conceptual design of the custom fairing, (b) 3d of the custom fairing, (c) stock side view of the fairing, (d) custom side view of the fairing, (e) stock top view of the fairing and (f) custom top view of the fairing

The figure 2 a and b depict the stock side and top view of the meshing. Figure number 2 c, and d depict the custom side and top view of the meshing. In the meshing, there are two different types of the element have been used to maintain a flow. One quadrilateral element and the other in a triangular mesh.
Table 1 depicts the meshing criteria and parameters for the mesh. The mesh criteria play a major role in the meshing. It’s mandatory to use the meshing criteria before generating mesh. In order to maintain the mesh flow, the targeted length was 5, the minimum and maximum lengths are 3 and 7. Also to maintain a right angle on the plane, the given aspect ratio, warping and skewness are 1, 45°, 10.

Table 1 Meshing criteria and parameters for the mesh

| Sl. No | Mesh Criteria                  | Value |
|--------|--------------------------------|-------|
| 1      | Aspect Ratio                   | 1     |
| 2      | Skewness                       | 45°   |
| 3      | Warping                        | 10    |
| 4      | Taper                          | 0.35  |
| 5      | Jacobian                       | 0.7   |
| 6      | Minimum length                 | 3     |
| 7      | Maximum length                 | 7     |
| 8      | Targeted Length                | 5     |
| 9      | Minimum angle quadrilateral    | 45°   |
| 10     | Maximum angle quadrilateral    | 135°  |
| 11     | Minimum angle triangle         | 30°   |
| 12     | Maximum angle triangles        | 120°  |
3. RESULTS AND DISCUSSION
Consequently, as a result, given in table 2, shows and discusses about the boundary condition of the existing models and proposed model. Its shows various parameters of the computational domain and the solver such as materials, solver, density, viscosity, etc.

| Sl.No | Computational Domain | Conditions         |
|-------|----------------------|--------------------|
| 1     | Processing Series    |                    |
| 2     | Solver               | Pressure Based     |
| 3     | Timer                | Steady State       |
| 4     | Dimensional 2D       |                    |
| 5     | Models               | Energy/Viscous –   |
| 6     | Material             | Air                |
| 7     | Viscous Model        | K Epsilon - Standard |
| 8     | C_p, Specific Heat   | 1006.43 j/kg - K   |
| 9     | Density              | 1.225 Kg/m³        |
| 10    | Thermal Conductivity | 0.0242 w/ m –k     |
| 11    | Viscosity            | 1.789 e⁻⁵ Kg/m –s  |
| 12    | Boundary Condition   | Velocity Inlet     |
| 13    | Reference temperature| 300 K              |
| 14    | Inlet total Pressure | 0 Pa (assumed)     |
| 15    | Outlet Static Pressure| 0 Pa               |
| 16    | Wall                 | no Slip conditions |

3.1 Stock Results
Aerodynamics velocity results of stock side velocity, stock top velocity stock side view pressure, custom side velocity, and custom top velocity are depicted in Figures 3 to 6. Figure 3 a and b depicts the stock side velocity and the stock top velocity. These figs 4 a and b show that the stock fairing is less streamlined and the stock fairing has a lot of turbulent flows and pressure spots, Compared to the custom side. The faring stock available and its performance from both sides and the top view is shown in the respective diagrams with the results on the left.
Figure 3 (a, b) depicts the stock side view and top view velocity magnitude (km/hr.) contours: (a) fairing side view and (b) fairing top view.

Figure 4 (a, b) depicts the stock side view and top view turbulence. The turbulence shown here represents the turbulence kinetic energy. Mostly the turbulence describes the turbulent fluctuations of the velocities. The turbulence is calculated with the help of the Reynolds number.

Figure 5 stock side view pressure distribution
Figure 5 depicts the stock side view pressure. When we consider the weight as a major factor the pressure plays a major role which supports deformation and helps in creating stress in the entire model and simulation till it reaches the equilibrium state. In other words, this is also called a static structural model. According to our simulation Figure 6 states the simulation image of the static pressure.

![Figure 6: A stock side view and top view particles path lines: (a) fairing side view and (b) fairing top view](image)

Figure 6 a and b represent particle pathlines of the stock side and top view. In this figure, it can clearly see the flow path line are understandable with color codes. With the help of path lines, the air flows, turbulent flow, and velocity flows can be verified.

### 3.2 Custom Fairing Results

Fig 7 a and b depict the custom side velocities. It can be noticed that with respect to the differences in the above Fig 5 a and b, where the stock fairing has a lot of turbulent flows and pressure spots. However, in the custom fairing, it can be seen that the flow is much cleaner and more streamlined compared to the stock fairing. This means the custom fairing has lesser drag and more velocities which was the objective of these tests. Custom results and simulation would be much sharper because the fairing has been modified and kept accordingly to the user’s comfort. Hence observing from the below picture, we can find the velocities are sharper and faster. The overall custom side velocity result is 650 km/hr. that is observed from the simulation for custom fairing.

![Fig 7: A custom side view and top view velocity magnitude (km/hr.) contours: (a) fairing side view and (b) fairing top view](image)
Figure 7 a and b depict the custom side velocities. It can be noticed that with respect to the differences in the above Fig 9 (a) and (b), where the stock fairing has a lot of turbulent flows and pressure spots. However, in the custom fairing, it can be seen that the flow is much cleaner and more streamlined compared to the stock fairing.

Figure 8 a and b represent the custom side view particle path line. These path lines are the lines that are traveled by the neutrally buoyant particles in equilibrium with the fluid motion. These particle path lines are also called as the dimensional flow. From the image, we can see that how the air flows are passing towards the top and side view.

Figure 9 a and b depict the custom turbulence and the solution converged graph. Mostly the turbulence describes the turbulent fluctuations of the velocities. The graph tells us the final result is converged this means that the solution we have obtained is correct. Now that we know that the boundary of separation and its design has a huge impact on aerodynamic drag. If the force is huge around the boundary layer and if the separation is not smooth, the drag will be more. So, it is important to custom design the faring and makes sure the boundary layer separation and flow throughout the body of the vehicle is important. The type of turbulence stated here is the turbulence kinetic energy.

Figure 9 a and b depict the custom side view and top view turbulence (m²/s) contours: (a) fairing side view and (b) fairing top view.
Figure 10 indicated the converged solution graph. The graph has plotted with 5 different colors. The black color indicates continuity, the blue color indicated energy, blue and green indicated x and y velocity. In this graph, x-direction indicates the iterations, and y-direction indicates e. From the graph we can see that continuity increasing compare to others, the x and y velocity increasing the iterations and decreasing the e. We can conclude that the converged solution is based on continuity, energy, x, and y velocity.

3.3 Comparison of Stock and Custom Fairing
The stock weight represents the actual weight of the product based on and brought out by its manufacturing. In Fig 10 (a) if we observe the picture of the stock weight the weight can be observed which 2.215kg. The stock weight is also represented as the default weight of an object. On the other hand, when we look at 10 (b) custom weight can be observed. Custom weight represents the modified weight of an object as per the user’s interest. For example, taking the below pictures as an example it can be observed that the look of the fairing is modified and the custom weight has been drastically reduced by 1.15 kg.

![Weight of the fairing in kg. (a) stock fairing and (b) custom fairing](image-url)
With the newly modified component in place, the bike was run for 5 km at an average speed on the same roads, and the mileage was recorded. The difference in the performance was very profound and proved that the custom fairing made a huge difference in the fuel consumption rates as seen in Fig 12 (a) and (b).

The two components that were used are made of plastic (stock) and glass fiber reinforced epoxy (custom) respectively. Therefore, the influence of material weight on the bike’s performance and fuel efficiency is to be inferred.

Using Catia, a solid block of dimensions 10 cm length, 5 cm breadth, 0.2 cm depth was modeled to depict a part of the front fairing panel. The component is then attributed with two different materials mentioned in the previous sections. Boundary conditions are applied to test them under 10 N force with two sides fixed. The simulation was done for both of the materials (the plastic and the GFRE) separately (Figure 13 (a) and (b)).
The stock of RC200 has a stock speed of 134 km/h. On the other hand, the custom fairing has a speed of 137 km/h as shown in fig 14. Looking at aspects like the weight and fuel efficiency the performance and advantages were totally supportive for the custom fairing. Since we have customized the fairing the difference in the performance was very profound and it proved that the custom fairing made a huge difference in the fuel consumption rates. On the contrary, as we have modified and customized it ourselves the weight has decreased. Since the weight has decreased the motorbike now has more aerodynamic, speed, less weight, and more fuel efficiency. Overall, the performance of the custom fairing has been good and more effective compared to the stock fairing.

![Fig 14 custom top speed](image)

Table 3 denotes the stock and custom design comparison, and the custom design provides a high efficiency compared to the existing one. Similarly, the top speed, weight, and velocity also obtained better variation and results. It can see that custom results have increased efficiency. The table gives the detailed values of each aspect and differentiating and stating how the custom design is mostly preferred and efficient.

| Sl.No | Parameters      | Stock    | Custom   |
|-------|-----------------|----------|----------|
| 1     | Velocity        | 471 km/h | 650 km/h |
| 2     | Material Displacement | 0.051cm | 0.008cm |
| 3     | Weight          | 2.215kg  | 1.150kg  |
| 4     | Fuel Efficiency | 36km/l   | 48km/l   |
| 5     | Top Speed       | 134 km/h | 137km/h  |

Figure 15 a) represents the custom fairing for the race bike and b) represents the stock (existing) fairing for the race bike. It shows vehicle comparison of custom fairing and stock. In conclusion, custom fairing has more aerodynamics compare to stock.
4. CONCLUSIONS

From the results and outcomes from various analysis and tests from the present work, it can be clearly seen how material selection and relatively better aerodynamic component helps in reducing the weight of the vehicle and with resulting enhanced performance of a motorcycle, the fuel consumption will be reduced. The objective of this work was to test and analyses various factors and incorporate them into a single component and see how each of these factors complement each other in practical conditions. Hence, an aftermarket component can increase fuel efficiency and performance and reduce weight, and suitably changing the material and shape of a component.

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