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Drag and Lift Characteristics of Different Handlebars and Front-Fairing Combinations Used in Two-Wheelers: A CFD Approach

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ABSTRACT

Two-wheelers with a total industrial volume of 50 million units over the past decade are one of the most popular modes of transport. Two-wheelers irrespective of the fueled engine or electric variant, are steered by means of the Handle-bar. The handlebar type and quality affects the operational characteristics of the two-wheeler as well as the physical fatigue of the rider. Handle-bar designs affect the parameters like ergonomics, maneuverability, rider comfort, and aerodynamics. The target of this study was to analyze the aerodynamic response of different handlebar types with and without the front fairings. To simulate the flow and optimize the streamline, Ansys-CFX® tool was used. In the study, focus was given to the frontal area of the two-wheeler without the rider. The key metrics considered for the aerodynamic analysis included the pressure distribution, velocity distribution, drag and lift coefficients. From the aerodynamic studies, the drag handlebar was found to offer the minimum drag while the clip-on handlebar offered the lowest lift.

1. Introduction

Two-wheelers are one of the most affordable, convenient modes of transport requiring the lowest parking space. It is noticeable from the worldwide trend of two-wheeler volumes over the past decade, that the usage of two-wheelers has exceeded 50 million units, with 50 million units being sold in 2020-21 alone [1]. Even though commuter type two-wheelers are less common in regions like North America, Japan, Europe where the culture is car-centric, in countries like India, China, Indonesia, Vietnam, the two-wheelers undeniably outnumber cars or any other mode of transport [2]. Cruiser bikes like Harley Davidson®, sports variants of Yamaha®, Honda®, Ducatti®, Kawasaki® have popular cult following in North America, Europe and Japan. The countries from the Asia-Pacific are the world's largest motorcycle markets including mopeds, scooterettes, motorcycles [1]. These countries together contributed more than 36 million units in the financial year 2020. Motorcycles are categorized mainly into three categories [3]:

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i. Mopeds: Two-wheelers with small engine (not more than 50 cc) equipped with automatic transmission and mostly bicycle like pedal.
ii. Scooterettes: Two-wheeled vehicle with step-through chassis and footrest platform. The engine capacity is typically between 50cc-250cc and mostly has an automatic transmission.
iii. Motorcycles: A motorcycle can be characterized as a two-wheeled vehicle powered by a motor. They are designed for higher speeds and are equipped with better acceleration and high-speed handling characteristics.

As the consumer’s demands are so diverse, the manufacturers are producing motorcycles in various engine capacities and designs. However modification of motorcycle to better suit individual preferences is familiar among the consumers [4,5]. By providing OEM after-market parts, the manufacturers would encourage the consumers to modify their motorcycle for better performance. For instance, KTM® providing PowerParts components to enhance the performance of their branded motorcycles [6]. Apart from performance modifications, consumers are more inclined to modifications with respect to motorcycling comfort and visual changes such as windshields, handlebars, crash guards, and custom spoilers. The handlebar influences the comfort, visual appearance and ergonomics of the two-wheeler. A variety of handlebars can be found as standard fitment as well as customized fitments. By choosing the appropriate handlebar the requirement of the rider can be achieved. The process can be difficult since changing the parts of the motorcycle can affect the aerodynamic stability of the motorcycle [7].

Aerodynamics is the branch of fluid mechanics that deals with response of bodies to air flow across them [8,9]. Aerodynamics plays a vital role in the operational performance of automobiles. Several works were emphasized on the aerodynamic performance of the whole vehicles (four-wheelers) [10–16], , whereas some of them were focused on a particular component/aggregate of the vehicle such as windshields on motorcycles, rear spoilers on cars, various deflectors on trucks [7,17,18]. Cheng *et al.,* [19] investigated the effect of the yaw angle- 0°, 4°, 8°, and 12° on the aerodynamic flow across strip spoilers fitted on hatchback cars using a RANS-based CFD simulation. The authors found the drag and lift coefficients directly proportional to the increase in yaw angles. Chin *et al.,* [20] analyzed the yaw angle effect on hatchback vehicles with combo-type spoilers. Nawam *et al.,* [21] studied the variation of lift by employing four types of rear spoilers. The simulation was carried out on a sedan car utilizing ANSYS Fluent software. The spoiler with the least increment in drag while considerable decrease in lift was adjudged to be the best. Nassir *et al.,* [22] used transient computational fluid dynamics approach to understand the wake generated on moving cars under different traffic conditions. A dynamic mesh was applied with turbulence model k-ω with Shear Stress Transport. Thus, for aerodynamic studies, the general parameters considered are velocity, pressure, drag force, lift force which can be used to compute the drag coefficients and lift coefficients. Some studies have utilized scaled down models inside wind tunnel whereas some have utilized CFD softwares like ANSYS Fluent/ CFX to simulate the flow and analyze the parameters [11,23,24].

Recent literature shows many works on the aerodynamic performance evaluation of cars. The aerodynamics of two-wheelers under-explored, and hence this inspired the current work. The aerodynamics of two-wheelers affect the fuel efficiency, handling, ride comfort, and ergonomics of the rider. The handle-bar, one of the critical components of the two-wheeler and the front fairing have been taken up for the aerodynamic studies. The current work aims at understanding the influence of different types of handlebars on aerodynamic performance of the motorcycle. The aerodynamic performance was assessed based on the key metrics of pressure distribution, velocity distribution, drag coefficient and lift coefficient. Among the different two-wheelers, Motorcycles were considered over mopeds and scooterettes for the aerodynamic analysis, keeping in view their significant market share compared to the other two wheeler types. Five most widely used handlebars on the motorcycles (with and without front fairing) are classified as follows

i. Clip-on handlebar: Two separate handlebars are assembled on front forks and locked on to the stem by an upper bracket. The rider must lean forward in order to reach the handlebar and achieve perfect aerodynamic riding posture and enable good maneuverability of the bike. Clip-on handlebars are commonly used on sports bikes. The riding comfort would be poor because of the riding posture.
ii. Drag handlebar: A single piece design consisting of a straight bar with a slight backward bend, arching towards the grips. With drag handlebars, the rider must lean slightly forward for proper reach. These types of handlebars can be found on drag racing motorcycles since riding posture makes locating the centre of gravity of the two-wheeler easy and thus achieving high-speed, straight-line stability. Like Clip-on handlebars, the riding posture makes long distance riding tiresome and fatigue-prone.
iii. Tracker handlebar: These are one-piece handlebars that are raised slightly by 5°-8° and bent backward. A higher degree of upright posture and relaxed hands allow better long-distance riding comfort without sacrificing handling of the motorcycle, making them popular on cruiser motorcycles [3,16]
iv. Motocross handlebar: These are straight, one-piece handlebars with slight curve in the middle and cross-brace at the mid-section of the two handles, prevalent in off-road motorcycles and dirt bikes. Motocross handlebars allow the rider to stand up and control the bike easily and achieve maximum rider comfort while off-roading.
v. Ape hanger handlebar: The rider must lean back and maintain the position of his hands at shoulder level in order to reach the handlebar which makes the ride more comfortable, unfortunately at the expense of handling. These types of handlebars can be found on chopper bikes and custom bikes. Fairings are not considered for this handlebar [23].

2. Methodology

2.1 Modeling of the Handlebars and Front-Fairing

In this study, five widely used handlebars in the market are considered with and without front fairing for the CFD simulation and analysis. Based on the specifications of different handlebars fitted on commercial motorbikes, the cross-sectional diameter of every handlebar was taken as 22 mm, while for the other specifications like the overall width, bar-end rise and pullback, the average dimensions were considered [3]. The dimensional specifications of the various handlebars (Figure 1) are given in Table 1. In the design of the front fairing, the specifications of commonly used fairings on the commuter and sports bikes was compared [24,25], the front fairing was kept common for the different types of handlebars. Two geometric models for the different handlebars, one with the front fairing and the other without were developed for the CFD analysis.

Table 1
Dimensional specifications of different handlebars

Handlebar type	Diameter (mm)	Overall width (mm)	Bar-end rise (mm)	Pullback (mm)
Clip-on	22	757	7.5	145
Drag	22	685.5	0	51
Tracker	22	775	57	63.5
Motocross	22	787	108	70
Ape-hangar	22	813	305	229

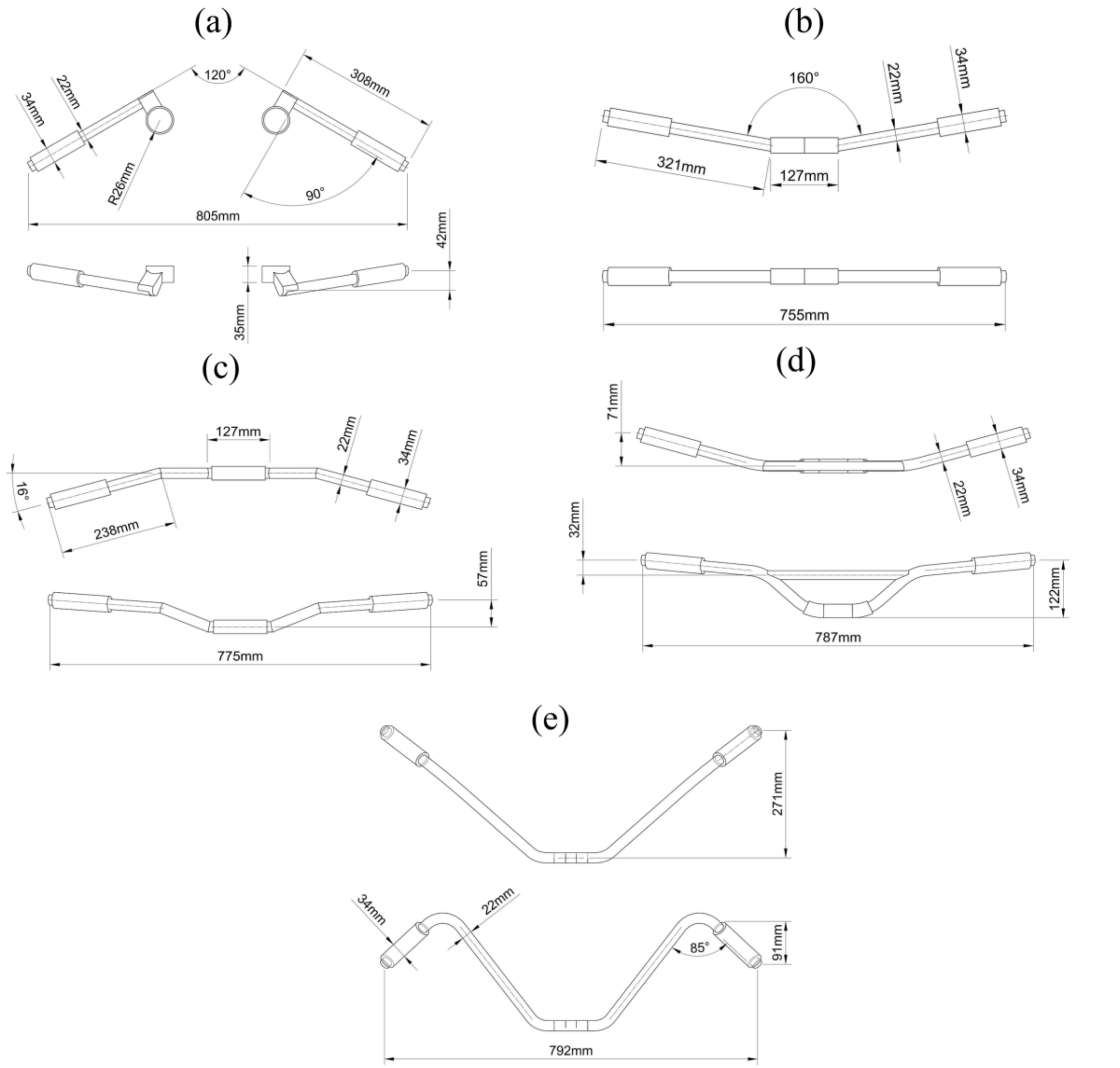

Fig. 1. Dimensions of the handlebar: (a) Clip-on handlebar, (b) Drag handlebar, (c) Tracker handlebar, (d) Motocross handlebar, (e) Ape hanger handlebar

The various handlebar types were modeled and the models were imported into ANSYS-CFX for the CFD simulation studies. The handlebars models considered were: clip-on type (Figure 2), Drag type (Figure 3), Tracker type (Figure 4), Motocross type (Figure 5) and Ape-hangar type (Figure 6).

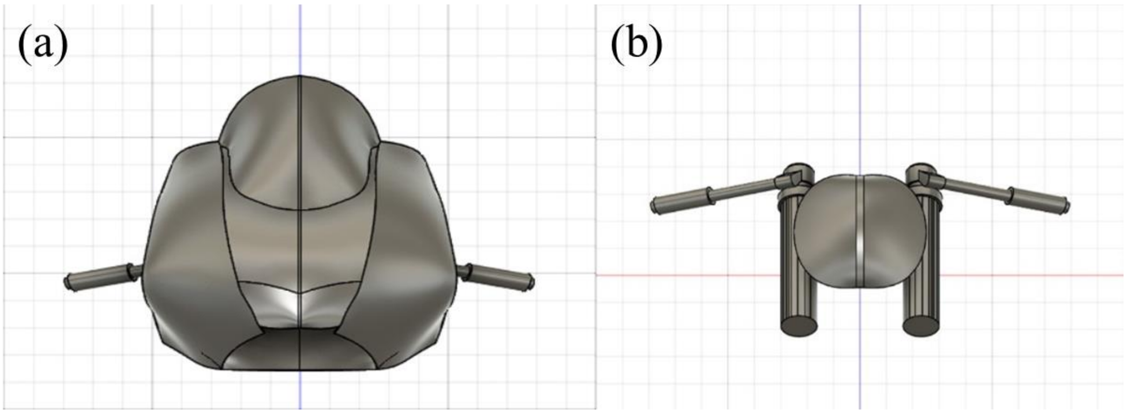

Fig. 2. Clip-on handlebar: (a) With front-fairing, (b) Without front-fairing

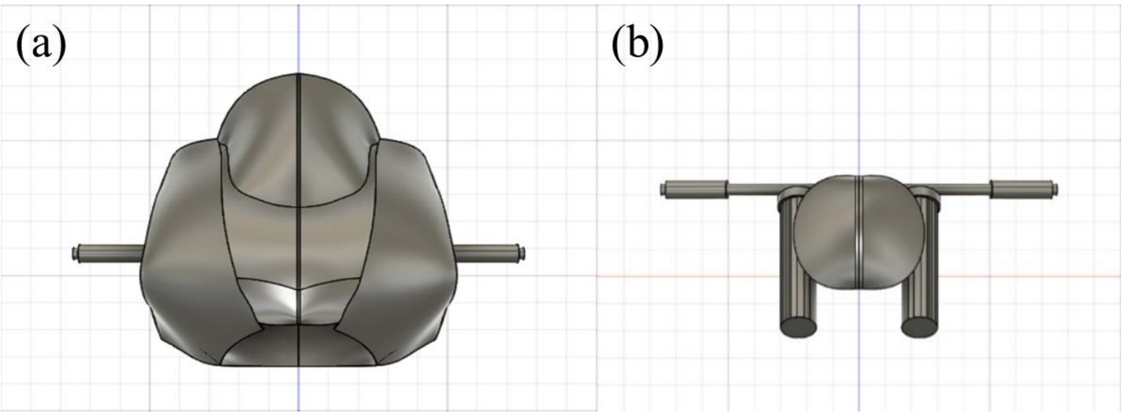

Fig. 3. Drag handlebar: (a) With front-fairing, (b) Without front-fairing

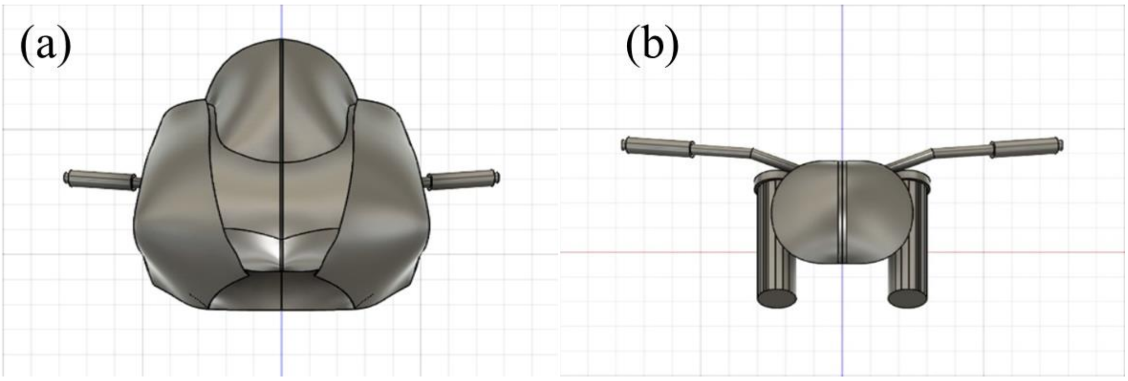

Fig. 4. Tracker handlebar: (a) With front-fairing, (b) Without front-fairing

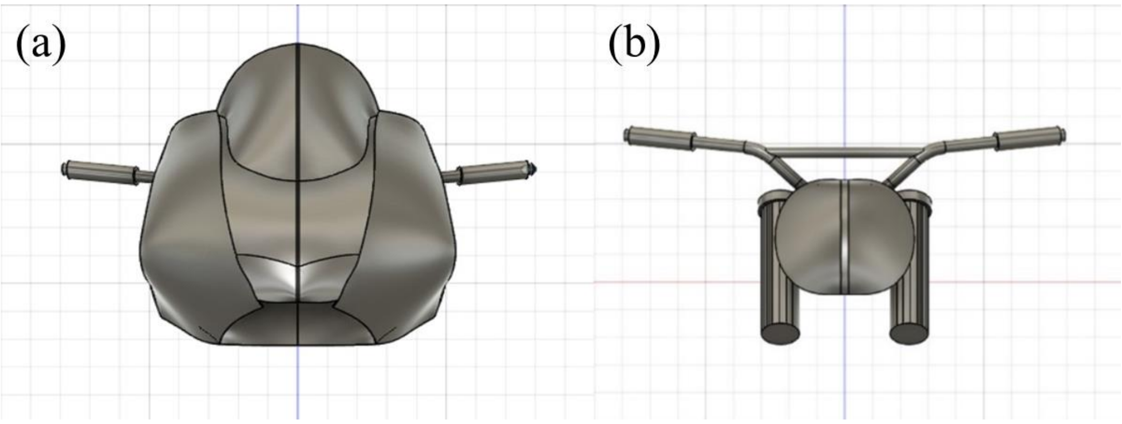

Fig. 5. Motocross handlebar: (a) With front-fairing, (b) Without front-fairing

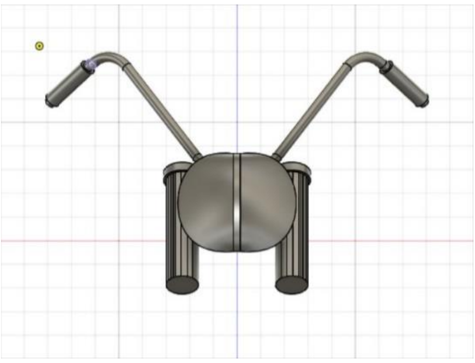

Fig. 6. Ape hangar handlebars fitted on choppers

2.2 Meshing, Boundary Conditions and Simulation

The geometry of the models with and without the front fairings were imported into the CFD solver. The meshing for the enclosure around the model was carried out on the ANSYS Mesher, with refinement of mesh at the walls pertaining to the handlebar geometry. The inlet velocity was considered as 60 km/h, assuming an average cruise speed on variable terrains- paved roads, bitumen roads, concrete roads, off-terrain, and earthen roads [26]. The atmospheric pressure was taken as 1 bar (at sea-level) and air temperature was 20°C. The enclosure with boundary conditions is shown in Figure 7. For the CFX solver, steady-state high resolution advection scheme, first order turbulence with conservative length scale, and auto time scale were employed. The velocity distribution, pressure distribution across the models, drag force and the lift force were taken as the output parameters. The coefficients of drag, C_d and coefficient of lift, C_L were calculated from Eq. (1) and Eq. (2) respectively, Where F_d is the drag force (N), A is the frontal area (m^2), F_L is the lift force (N), V_∞ is the free stream velocity (m/s), ρ is the air density (kg/m^3). The average frontal area for the various handlebar/fairing combinations was 0.65 m^2.

$$C_d = \frac{F_d}{\frac{1}{2}\rho A V_\infty^2} \tag{1}$$

$$C_L = \frac{F_L}{\frac{1}{2}\rho A V_\infty^2} \tag{2}$$

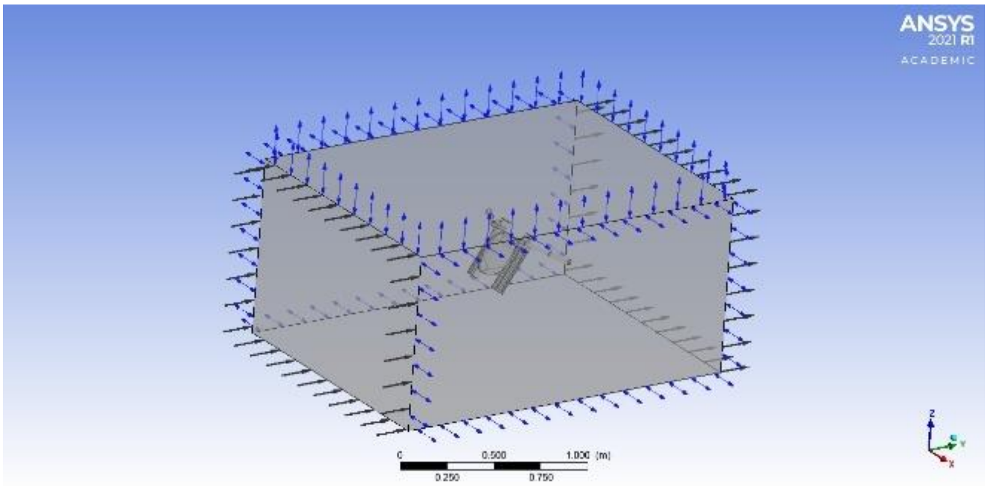

Fig. 7. Boundary conditions applied on the enclosure for CFD simulation

A grid independence study was carried out for different mesh sizes with maximum pressure as the control variable (Figure 8). It was observed that the maximum pressure stabilized in the range 28-36 mm, hence 35 mm was chosen as the common mesh size, with a grid of around 677294 elements, for the different handlebar/front-spoiler models. For effective CFD analysis, the grid size was maintained proportionate to the geometric scale of the motorbike to hatchback car [19,20].

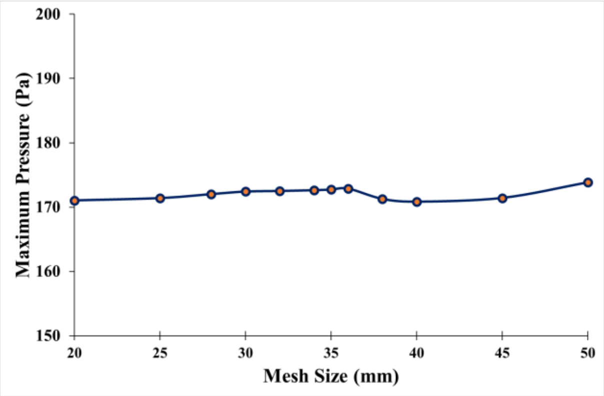

Fig. 8. Grid Independence test results

3. Results

3.1 Pressure Distribution

The pressure distribution for the different types of handlebars without considering the front fairings are shown in Figure 9. Irrespective of the type of the handlebar, the pressure peaks were observed at the central portion of the headlight, at the bottom portion of the headstock next to the lower bracket, and along the centreline of the handlebars, which could contribute to the pressure drag at these respective locations. Among the various types, the maximum value of the peak pressure was observed in the tracker type of handlebar (144.6 Pa), with the ape-hanger type displaying the least value of the peak pressure (134.2 Pa).

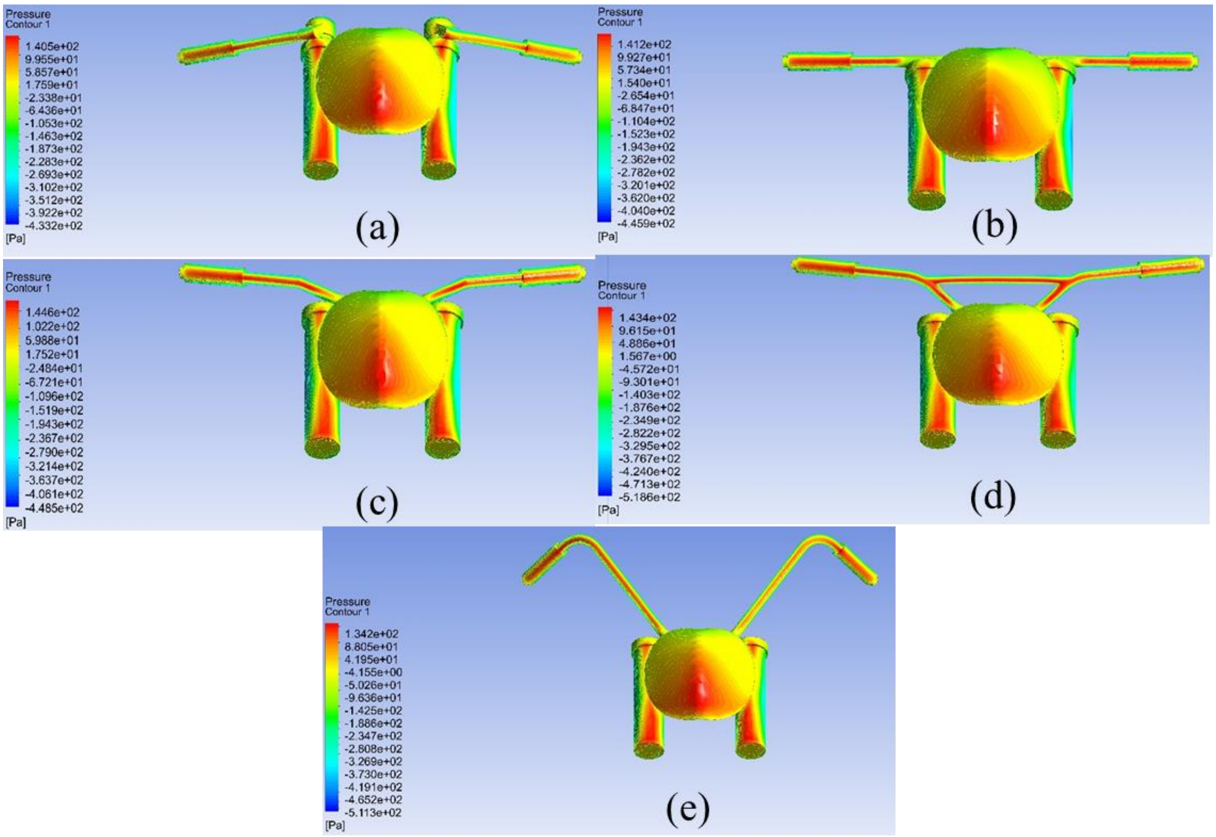

Fig. 9. Pressure distribution for different handlebars without front-fairing (a) Clip-on (b) Drag (c) Tracker (d) Motocross (e) Ape-hanger

For the combinations of front fairing and the handlebars, the pressure distribution as shown in Figure 10. Presence of the front fairing was found to localize the peak pressure zones at the centre of the headlight, in the case of all types of handlebars except the ape-hangar type. Additionally, there was an increase in all the pressure values over the front fairing-handlebar combinations as compared to those without the fairings. Hence, the presence of the fairing barred the interaction of the headstock, handlebar, lower and upper brackets with the air flow. Only the grip portion of the handlebars was found to interact with the air-flow, albeit negligibly affecting the pressure peak. The maximum value of the peak pressure was observed for the fairing and clip-on handlebar combination (150.9 Pa), while the fairing and motocross handlebar combination showed the least value of the peak pressure (147.1 Pa).

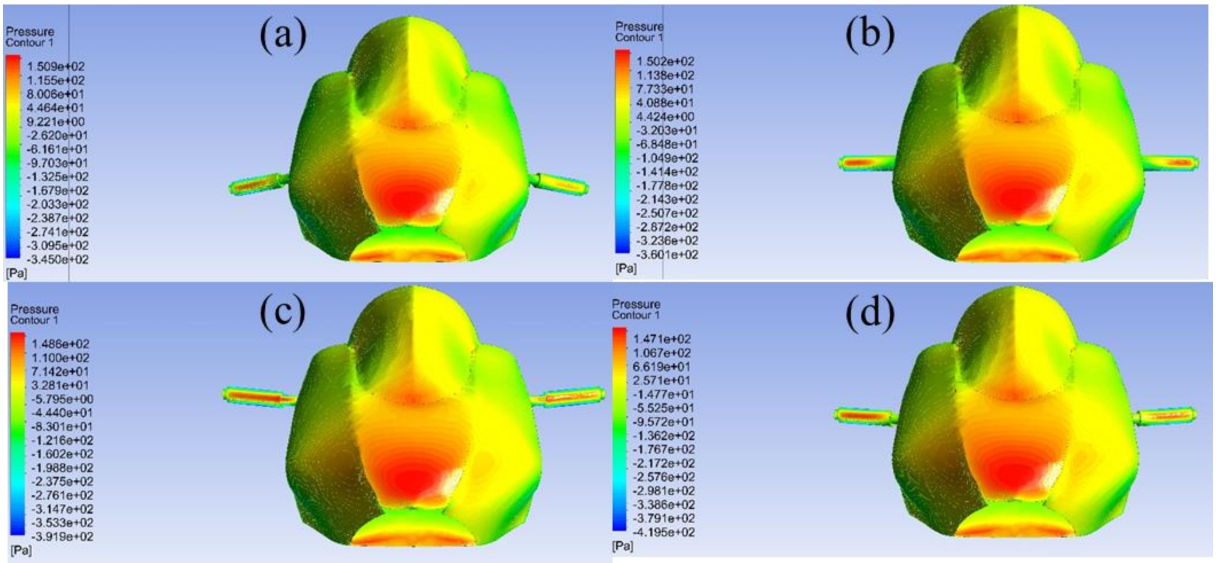

Fig. 10. Pressure distribution for different handlebars with front-fairing (a) Clip-on (b) Drag (c) Tracker (d) Motocross

3.2 Velocity Distribution

The velocity contours for the different types of handlebars without the front fairings are shown in Figure 11. In clip-on handlebars, the overflow and underflow streamlines were symmetric, with a small wake zone formed at the vicinity of the headstock, with re-attachment taking place. In drag handlebars, the wake zone was larger with re-attachment taking further behind the handlebar. The ape-hanger handlebar showed the largest wake zone compared to all the other types of handlebars, followed by motocross type. The highest values of the peak velocities were observed in Drag (27.46 m/s) and Tracker types of handlebars (27.27 m/s). Figure 12 shows the velocity contours for the combination of front fairings and different handlebar types. At the trailing end of the front fairing and handlebar, in the clip-on, drag and tracker types, the wake zone was characterized by the formation of two vortices, with the motocross type showing only a single vortex. Since the aerodynamic analysis was carried out without considering the rider, the presence of front fairing had a decreasing effect on the values of the velocities across the combinations. Among the different combinations, the Motocross type showed the highest value of peak velocity (26.82 m/s), followed by the Tracker type (26.57 m/s).

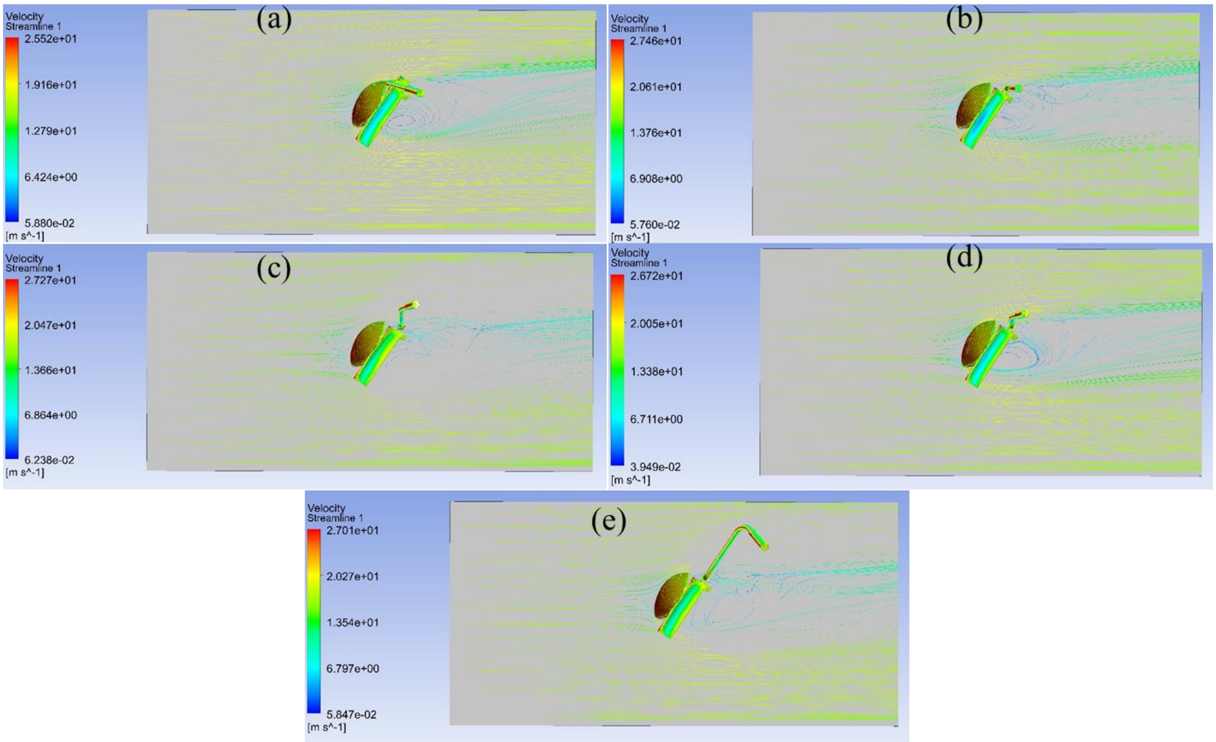

Fig. 11. Velocity distribution for different handlebars without front-fairing (a) Clip-on (b) Drag (c) Tracker (d) Motocross (e) Ape-hanger

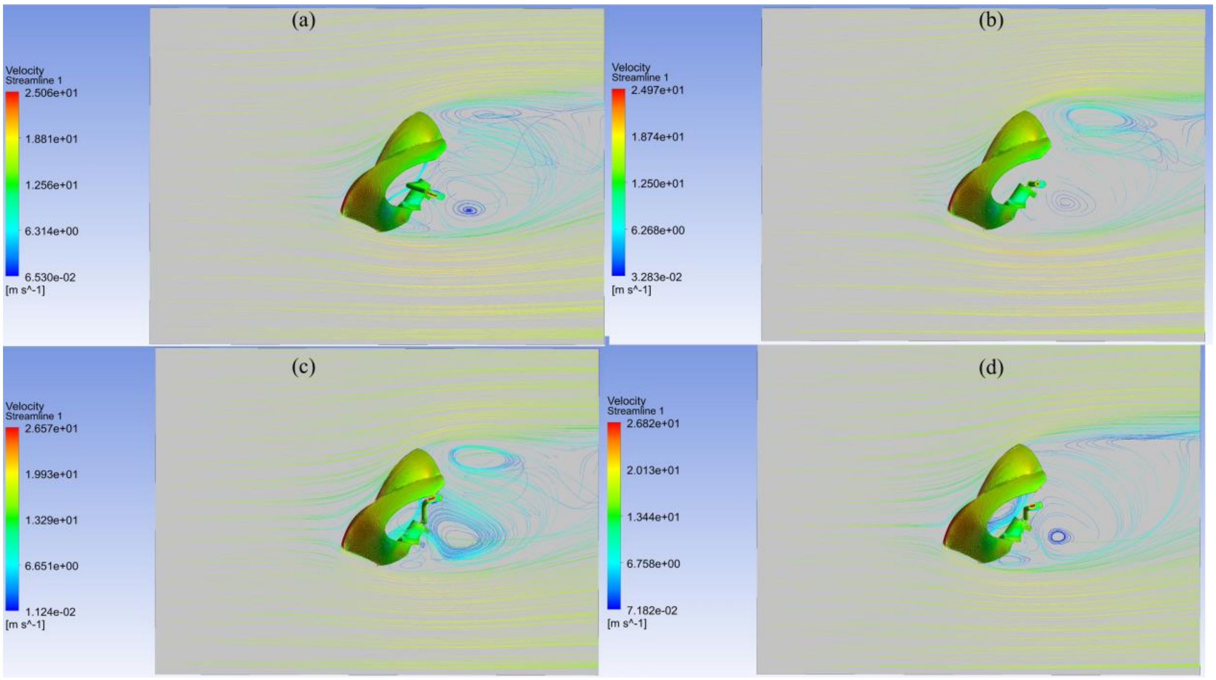

Fig. 12. Velocity distribution for different handlebars with front-fairing (a) Clip-on (b) Drag (c) Tracker (d) Motocross

3.3 Drag and Lift Coefficients

The coefficients of drag for the different handlebar types is shown in Figure 13. In handlebar types without the front fairing, the highest drag coefficient was shown by the motocross fairing, while the drag handlebar showed the least drag coefficient. Presence of the front fairing directly affected the pressure drag and in turn, the drag coefficients were increased by 89-97% in all the handlebar types combined with the front fairing. Figure 14 shows the coefficients of Lift for the handlebar types taken for the study. The lowest lift coefficient was shown by the Clip-on handlebar which is advantageous for maintaining aerodynamic stability during racing with sports bikes. The drag handlebar showed the highest lift coefficient for cases without the front fairing. Addition of the front fairing along with the handlebars augmented the lift coefficient by a factor ~5, which shows that without considering the upper body of the rider in the aerodynamic analysis, the performance diminishes with the presence of standalone front fairings.

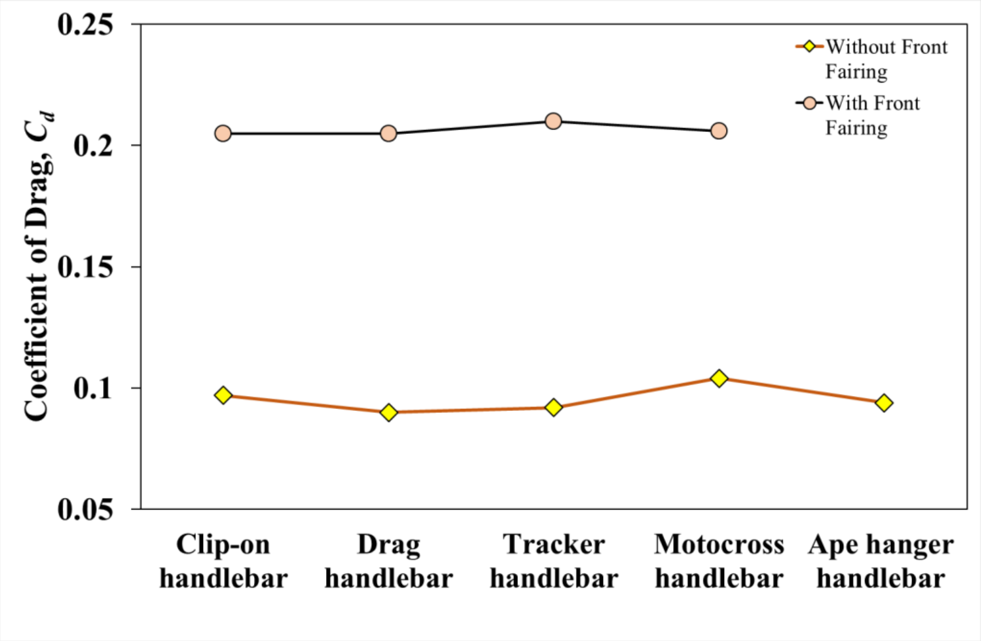

Fig. 13. Drag Coefficients for different types of handlebars

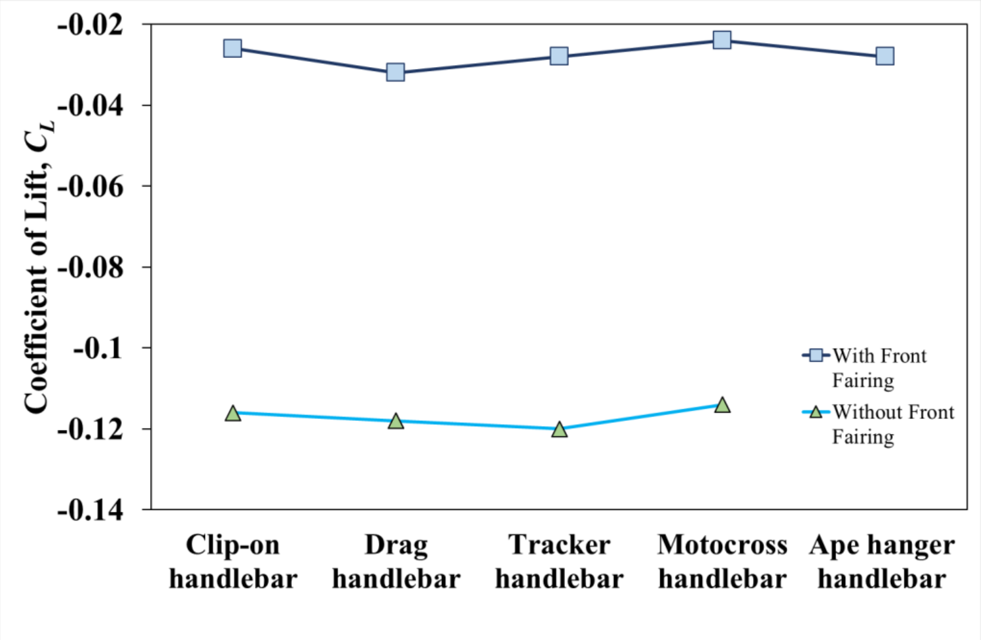

Fig. 14. Lift Coefficients for different types of handlebars

4. Conclusions

The paper investigated the effect of handlebar on aerodynamic performance of a motorcycle. Five different handlebar designs were designed and simulated, with and without the presence of the front fairings. Using ANSYS-CFX Workbench, the lift and drag coefficients were derived for the different types of handlebars. Among the different handlebars, the drag handlebar showed the least value of C_d, while the clip-on handlebar showed the least C_L. On including the front fairings along with the handlebars, there was a significant increase in C_d as well as C_L.

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