Investigation of Drag Force and Downforce on Two Racing Motorcycles in Slipstream Conditions

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ABSTRACT

The performance of modern racing motorcycles is greatly influenced by their aerodynamics. Slipstreaming occurs during a race when a rider closely follows another, especially on a straight track. The effect can reduce aerodynamic drag and increase the overall speed of the rider behind. This study investigates the aerodynamic effects of slipstreaming on a racing motorcycle using computational fluid dynamics. This study also considers its effect on both drag force and downforce, which affects motorcycle stability. A 3D CAD model of a racing motorcycle and a rider in a crouching position was used as the object of research. CFD simulations were carried out using the RANS Steady State solver with the k-ω-SST turbulence model. The simulations evaluated the effect of varying distances between motorcycles on slipstream performance, as well as varying motorcycle speeds. The results show the effect on drag force and downforce for the trailing motorcycle. This is due to the shielding effect of the motorcycle in front, which creates a low-pressure zone behind it. Additionally, the turbulence behind the racing motorcycle also affects its downforce. Optimizing the distance between motorcycles in the slipstream allows riders to improve overtaking performance. It also reduces adverse effects on motorcycle stability caused by the slipstream's influence on downforce. Furthermore, it can be used to develop aerodynamic modifications to racing motorcycles that can utilize the slipstream more effectively.

Keywords: *Aerodynamic, computational fluid dynamics, motorcycle, slipstream.*

I. Introduction

In the modern era, aerodynamics is a crucial factor in achieving victory in motorsports, from bicycle races to Formula 1 [1],[2]. Motorcycle racing is certainly no exception. By understanding and manipulating airflow, racing teams can increase the speed, stability, and performance of their motorcycles. With identical motorcycle performance, exploiting aerodynamics can be the deciding factor. Furthermore, in lower classes, where stricter regulations ensure rider skill plays a greater role, the technical performance of motorcycles is equalized [3]. This means riders in lower classes can only utilize slipstreaming or drafting, a phenomenon where a trailing vehicle experiences reduced aerodynamic drag due to the leading vehicle [4].

Essentially, when an object moves through a fluid, it creates an area of low pressure behind it [5],[6]. This also applies to racing motorcycles. When a motorcycle closely follows another, the trailing motorcycle enters this low-pressure area [7],[8]. The trailing motorcycle

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experiences reduced air resistance compared to when riding alone. This drag reduction allows the trailing motorcycle to maintain a higher speed, making overtaking easier. However, the optimal distance and relative position between the two motorcycles are crucial in determining the magnitude of the aerodynamic advantage [9].

Recent research underscores the growing importance of aerodynamics in racing motorcycles, moving beyond basic drag reduction and downforce. González-Arcos & Gamez-Montero (2023) demonstrated the effectiveness of Ducati's flow redirectors on MotoGP bikes in generating downforce while minimizing drag, particularly during cornering by managing airflow around rotating wheels [10]. Ma'Arof *et al*. (2022) also explored downforce generation using front anti-lift winglets, finding that increased flap elements enhance downforce [11]. While Peri & Capuana (2023) suggest fixed high-lift winglets are primarily advantageous on straightaways for high-powered bikes and offer no cornering benefit without active systems [12], Wiński & Piechna (2022)'s simulation study highlighted the front fairing, wheels, suspension, and rider position as key drag contributors, with rider tuck significantly reducing drag. Their findings also indicated that common turbulence models yield similar drag and lift predictions for motorcycles with clear flow separation [13].

Research on vehicle slipstreaming has extensively studied four-wheeled vehicles. Gan *et al.* (2020) found that close-proximity slipstreaming reduces drag for NASCAR cars, with more cars enhancing this effect, while side drafting offers an overtaking advantage [4]. Džijan *et al.* (2021) similarly showed significant drag reduction (up to 27%) for a trailing car but a substantial downforce loss (up to 82%), negatively impacting stability for both vehicles [14]. In two-wheeled research, Blocken *et al.* (2020) quantified substantial drag reductions (up to 48%) and time gains for cyclists drafting behind motorcycles, highlighting the need for stricter regulations in cycling [15]. Pimenta *et al*. (2024)'s simulations on motorcycles revealed that aerodynamic devices on a leading bike create complex wakes affecting a trailing bike's stability and performance. While turbulence can aid drafting, vortices from wings can counteract this benefit and even increase lift [9]. This study employs computational fluid dynamics (CFD) to investigate the aerodynamic impact of slipstreaming on a racing motorcycle, examining not only drag reduction but also its influence on downforce, a critical factor for stability. Building upon prior research that explored slipstreaming on both four-wheeled and two-wheeled vehicles, this research extends the analysis to the unique aerodynamic challenges of motorcycles. Unlike studies solely focused on drag reduction, this investigation considers the complex interplay between slipstreaming, downforce, and motorcycle stability, contributing to a more comprehensive understanding of the aerodynamic consequences in motorcycle racing. This study aims to quantify the reduction in drag force and downforce experienced by a trailing motorcycle due to the aerodynamic wake of a leading motorcycle.

II. Methods

This study examines the aerodynamic effects of slipstreaming on a racing motorcycle by analyzing the relationship between several key variables. The independent variables, which are deliberately manipulated, include the distance between motorcycles (varied at 0.25, 0.50, 1.00, and 2.00 times the motorcycle length, as shown in Figure 1) and the flow velocity in the test section (set at 10 m/s, 20 m/s, and 30 m/s). To ensure consistency and isolate the effects of the independent variables, certain control variables are kept constant. These include maintaining air conditions at room temperature without humidity and using a specific racing motorcycle model (Figure 2) sourced from Grabcad [16]. This motorcycle model was chosen because it resembles a lower-class racing motorcycle, such as a Moto3 motorcycle. The study focuses on measuring the resulting drag force and downforce on the trailing motorcycle as the dependent variables, providing insights into the aerodynamic impact of slipstreaming.

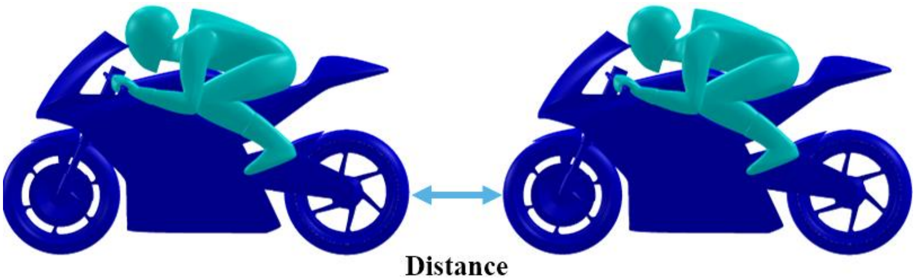

Fig. 1. Distance variable

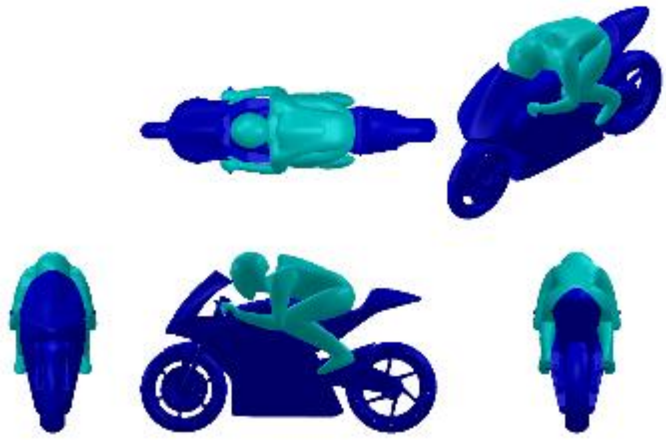

Fig. 2. CAD model

The domain used in the simulation must be sufficient. This means that a domain that is too large will result in long iteration times, while a domain that is too small will lead to inaccurate results and the desired phenomena will not be captured. In this study, the size of the CFD domain depends on the size of the motorcycle and rider, namely length (L), width (W), and height (H) (Figure 3). Because the phenomenon to be captured is the wake behind the motorcycle, the domain size is extended backward. Furthermore, a domain is provided for a finer mesh around the motorcycle (Figure 4).

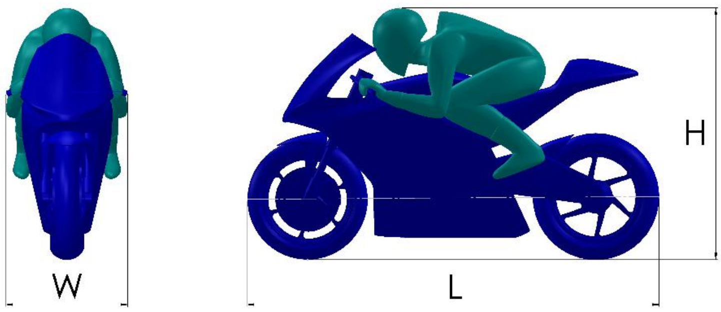

Fig. 3. Test model size

The CFD simulation setup utilizes the k-ω SST turbulence model, a robust model well-suited for a wide range of flow conditions, including adverse pressure gradients and separated flows. The steady-state Reynolds-Averaged Navier-Stokes (RANS) solver is employed to capture the flow behavior [12].

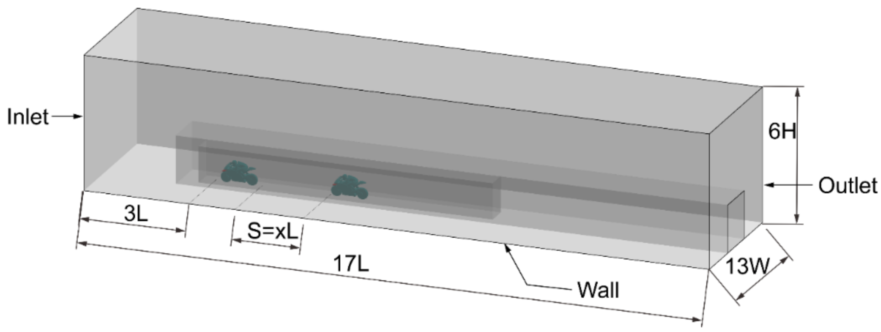

Fig. 4. CFD domain

In addition to varying the distance, the velocity is also varied. The coupled second-order upwind discretization scheme is chosen to ensure accurate solution convergence [17]. The simulation is set to run for 1000 iterations, which is expected to be sufficient to achieve convergence with residuals of 10^-3. The simulated object is complex. Therefore, more iterations are required to accurately capture the flow characteristics [18]. More detailed parameter settings can be seen in Table 1.

Table 1. CFD setup parameter

Parameter	Value
Pressure	1 atm
Temperature	25°C / 298 K
Air Density	1.225 kg/m^3
Dynamic viscosity	1.86 x 10-5
Fluid Velocity	30 m/s
Mesh	Poly-hexa core
Convergent	10-3
Turbulent Model	k- ω SST
Solver and Method	Steady State, RANS, coupled second-order upwind

The mesh employed in this study is Ansys Fluent Mosaic Meshing 2020 R1. This mesh type is chosen because it represents one of the advanced meshing technologies exclusive to Ansys Fluent. It can effectively simulate flow phenomena, particularly in complex geometries. By combining the best aspects of hexahedral and polyhedral meshing, Mosaic Mesh generates a high-quality mesh that is both accurate and efficient (Figure 5). This mesh offers faster meshing times, lower memory usage, and improved solution accuracy compared to traditional meshing techniques [19].

Mesh convergence in Fluent is an iterative process to determine the most optimal mesh element size in a numerical simulation [20]-[22]. The main objective of mesh convergence is to ensure that the simulation results obtained are independent of the mesh size. In other words, if the mesh size is further refined, there will be no significant change in the simulation results. This process is very important because a mesh size that is too coarse can produce inaccurate results, while a mesh size that is too fine can lead to very long computational times. Mesh convergence studies (Table 2 and Figure 6) indicate that results at 3 million elements are similar to those at 4.9 million. Therefore, all subsequent simulations will utilize a mesh with 3 million elements.

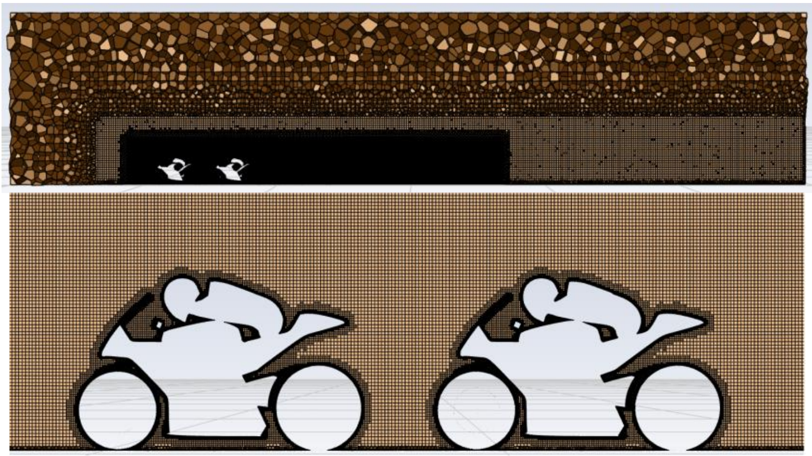

Fig. 5. ANSYS mesh mosaic result

Table 2. Mesh convergence result

Face Size (m)	Mesh Element Count	CD	CL
0.012	663,924	0.2511	0.0347
0.010	984,317	0.2569	0.0325
0.009	1,226,502	0.2594	0.0350
0.008	1,559,806	0.2528	0.0374
0.006	3,095,046	0.2462	0.0301
0.005	4,908,479	0.2452	0.0294

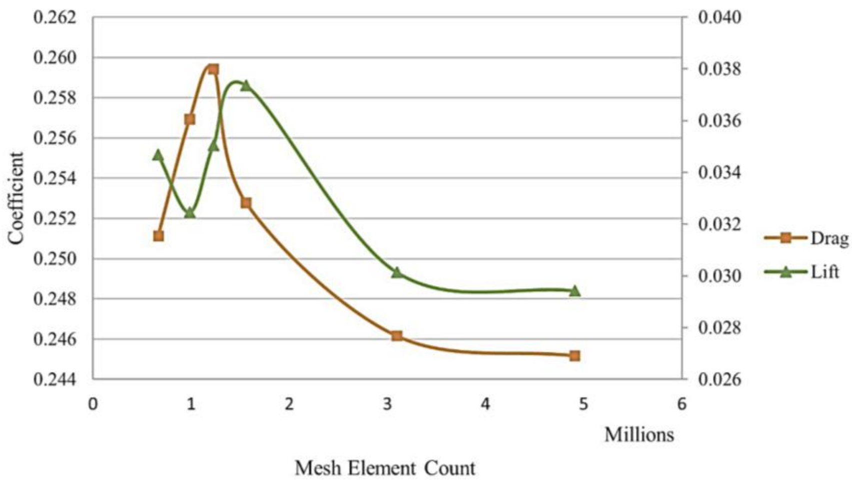

Fig. 6. Mesh convergence result

III. Results and Discussions

The results of the drag coefficient simulation (Table 3 and Figure 7) show that in slipstream conditions, both the leading and trailing motorcycles experience reduced drag.

This is consistent with previous studies that have explored the aerodynamics of slipstreaming and drafting in various vehicles, including trains [5], racing cars[4][14], motorcycles [9], and bicycles [15]. This is because the leading motorcycle experiences reduced turbulence as the trailing motorcycle pushes some high-pressure air forward. This high-pressure air helps to counteract the low-pressure area at the rear of the leading motorcycle, further reducing drag. The leading motorcycle shows a drag force reduction of 8.772% at a distance of 0.25L, which reduces to almost zero at a distance of 2L. However, the trailing motorcycle experiences a more significant drag reduction: 27.11% at 0.25L and 18.359% at 2L. The overall effect is that both motorcycles experience reduced drag, allowing them to maintain higher speeds with less effort. The trailing motorcycles benefit more, but the lead motorcycle also sees a performance improvement.

Table 3. Drag coefficient simulation result

Position	Distance (×L)			
	0.25	0.50	1.00	2.00
Single	0.246	0.246	0.246	0.246
Leading	0.225	0.229	0.240	0.245
Trailing	0.179	0.182	0.191	0.201

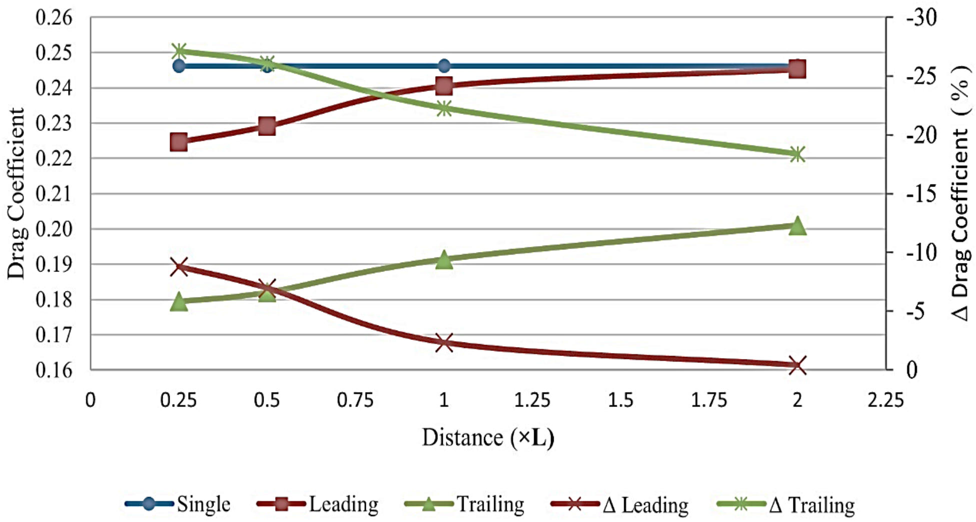

Fig. 7. Drag coefficient simulation result

Lift coefficient simulation results (Table 4 and Figure 8) indicate that in slipstream conditions, both the trailing and leading motorcycles experience changes in lift. This manifests as an increase in lift, often observed as a reduction in downforce. Interestingly, the leading motorcycle experiences a greater downforce reduction at distances closer than one motorcycle length (Distance < 1), with this trend reversing at greater distances. Specifically, the leading motorcycle shows a 35.582% downforce reduction at 0.25L, while the trailing motorcycle shows a 13.908% downforce reduction. However, at 1L, the trailing motorcycle experiences a 33.306% downforce reduction, compared to only 15.926% for the leading motorcycle. At 2L, this effect diminishes significantly for the leading motorcycle (5.846% reduction), while the trailing motorcycle experiences a substantial 61.347% reduction in downforce.

Table 4. Lift coefficient simulation result

Position	Distance (×L)			
	0.25	0.50	1.00	2.00
Single	0.018	0.018	0.018	0.018
Leading	0.025	0.022	0.021	0.019
Trailing	0.021	0.019	0.024	0.029

The trailing motorcycle experiences a smaller downforce reduction than the leading motorcycle at distances closer than one motorcycle length (distance < 1L). This is because the trailing motorcycle is within the near wake region of the leading motorcycle (Figure 9), which extends less than one motorcycle length. The near wake region effect refers to the disturbed airflow behind a moving object, in this case, a leading motorcycle. This turbulent air, containing vortices, usually reduces the downforce on trailing motorcycles [23]. However, because the near wake region has lower pressure, indicated by the high turbulent kinetic energy, the front of the trailing motorcycle experiences less force (Figure 9)[24]. Due to its geometry, the downforce on the trailing motorcycle is not significantly reduced. However, at distances greater than one motorcycle length (distance > 1L), the trailing motorcycle experiences a larger downforce reduction due to its position within the far wake region of the leading motorcycle [25].

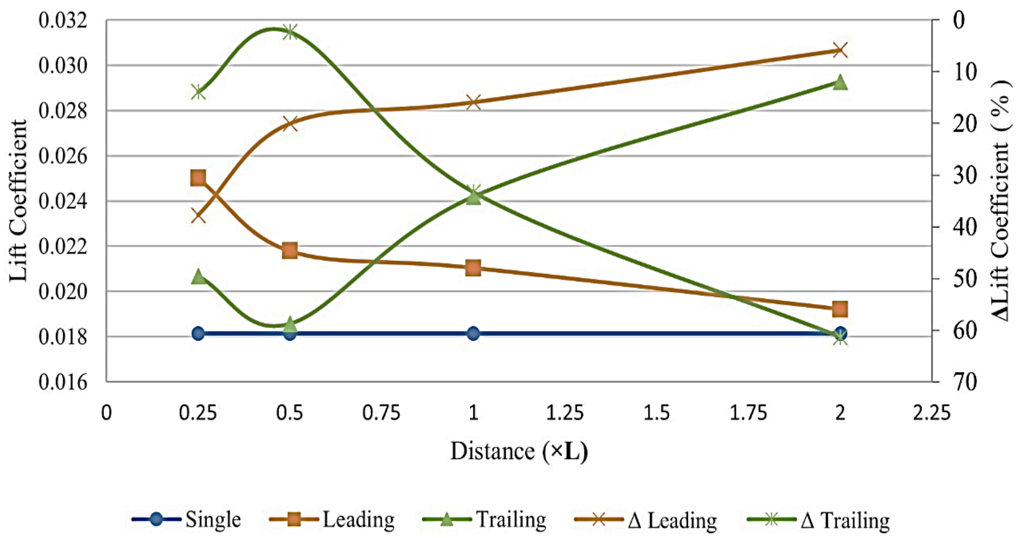

Fig. 8. Lift coefficient simulation result

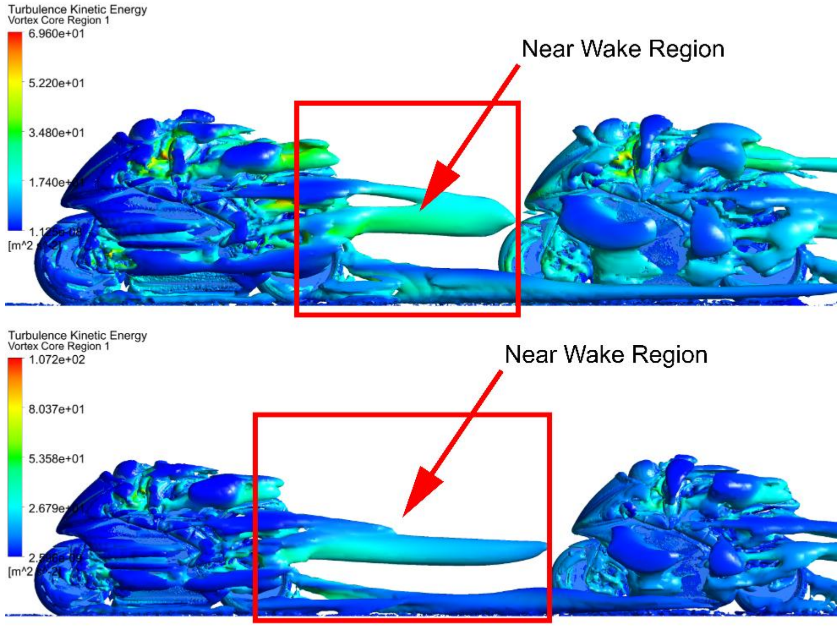

Fig. 9. Turbulent kinetic energy at 0.5 motorcycle length (top) and 1 motorcycle length (bottom)

IV. Conclusions

Simulations revealed that slipstreaming offers a considerable aerodynamic advantage in motorcycle racing. The leading motorcycle experiences reduced drag, as the trailing motorcycle pushes some high-pressure air forward, which helps to counteract the low-pressure area at the rear of the leading motorcycle. The trailing motorcycle experiences a more significant drag reduction due to the low-pressure region created by the leading motorcycle. However, slipstreaming also affects the downforce of both motorcycles. The leading motorcycle experiences a greater downforce reduction at closer distances, while the trailing motorcycle experiences a smaller downforce reduction due to the near-wake region effect. At greater distances, the trailing motorcycle experiences a larger downforce reduction due to its position within the far wake region of the leading motorcycle. The optimal distance for slipstreaming is between 0.25L and 0.5L, where L is the length of the motorcycle. At this distance, the trailing motorcycle experiences the greatest drag reduction and the smallest downforce reduction. However, riders should be aware of the potential for instability and loss of control at close distances.

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