







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## Development of a prototype spoiler for effective braking of a racing motorcycle, utilizing active aerodynamics





### Desarrollo de un prototipo de spoiler para el frenado efectivo de una motocicleta de competición, utilizando aerodinámica activa

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#### Abstract

High-level competition motorcycles have incorporated "wings," regulated by the rules of the championships in which they are used. This article highlights the importance of these aerodynamic modifications to improve performance during braking and direction changes, crucial aspects in motorcycle competitions. Previous studies have evaluated how the wings in MotoGP increase drag and lift force according to the lean angle, fundamental to understanding their impact on the aerodynamics of competition motorcycles. Despite existing research, more study is needed on static wings, motivating this work to explore the effects of active wings, similar to those in high-end cars and F1 single seaters, through 3D modeling and computational fluid dynamics (CFD) simulations. The goal is to design wings that generate variable downforce on the sides and rear, optimizing aerodynamics and dynamics in extreme corners, improving performance and safety.



winglets, Motorcycle racing, 3D design

#### Resumen

Las motocicletas de competición de alto nivel han incorporado "aleros", regulados por las normativas de los campeonatos en los que se utilizan. Este artículo destaca la importancia de estas modificaciones aerodinámicas para mejorar el rendimiento en el frenado y los cambios de dirección, aspectos cruciales en las competiciones de motociclismo. Estudios previos han evaluado cómo los alerones en MotoGP aumentan la resistencia y la fuerza de sustentación según el ángulo de inclinación, fundamental para comprender su impacto en la aerodinámica de las motocicletas. A pesar de las investigaciones existentes, se necesita más estudio sobre alerones estáticos, motivando este trabajo a explorar los efectos de alerones activos, similares a los de coches de alta gama y monoplazas de F1, mediante modelado 3D y simulaciones de dinámica de fluidos computacional (CFD). El objetivo es diseñar alerones que generen una fuerza descendente variable en los costados y la parte trasera, optimizando la aerodinámica y dinámica en curvas extremas, mejorando el rendimiento y la seguridad.



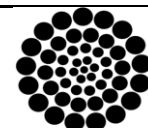
Alerón, motocicleta de competición, diseño 3D

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## Introduction

Since 2015, high-level racing motorcycles have been equipped with "winglets." These winglets have shapes regulated by the technical regulations of the championships where this type of motorcycle is used [1]. Unlike other studies, this work highlights the importance of an alternative that could take a racing motorcycle's braking and direction change to unprecedented levels. Previous studies on aerodynamic modifications and their impact on drag, ground effect, and vertical and lateral forces depending on the inclination angle are addressed. Some studies, such as those by author Van Dijk [2] or Joao Gaspar Cardoso [2], have demonstrated and evaluated the aerodynamic forces on a road motorcycle modified for high-speed competitions, as well as the aerodynamic effects of a MotoGP winglet and how these marked an increase in resistance and lift force proportional to the inclination angle. These guidelines support much of what will be discussed in this document. Although the aerodynamics of motorcycles have been studied from various perspectives, there are few specific studies on the functionality of static winglets. Therefore, this work aims to study, from an aerodynamic point of view, the effects of active winglets, as seen in high-end cars or F1 single-seaters, on the overall aerodynamics of the motorcycle and provide an initial estimation of their dynamic effects through a 3D model and CFD simulation—figure 1.

This research comprehensively analyzes the aerodynamic behavior of racing motorcycles, especially MotoGP types. We will focus on developing an aerodynamic winglet designed to generate significant and variable levels of downforce on the sides and rear end of the motorcycle, exploring its consequences for aerodynamics and dynamics. Although several recent studies on this topic [3] have been conducted, only a limited fraction of the results have been shared with the public due to competition and the confidentiality of racing teams.

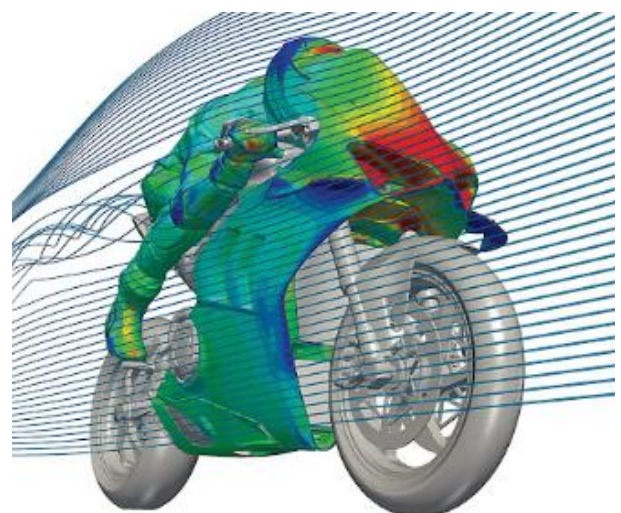
This research begins with the basics of winglet design and advances to evaluate its effects on the vehicle under the physical conditions in which it will operate. We rely on existing work on aerodynamics and aerodynamic winglets for general automotive applications [4].

The selection of the wing profile section will be based on computational fluid dynamics (CFD) analysis and studies that have been previously conducted. After choosing the most suitable wing profile for the specific conditions, we proceed with the final design of the winglets.

Once we analyze the typical behavior of the designed winglets (static) and compare their effects with others in the field, we will proceed to design and control an electronic system that will allow the winglet to switch from being static to active, thus maintaining the desired effects even during extreme angle turns. In the final phase, we will evaluate the overall aerodynamics of the motorcycle, contrasting the results obtained with static and active winglets. We will use the force coefficients from the CFD simulations to estimate each option's desired and undesired effects.

To optimize the overall performance of the motorcycle and the rider, we seek to address the problem of excessive suction during braking after benefiting from the slipstream of the preceding motorcycle. This issue has resulted in multiple contacts between riders, hindering them from stopping the motorcycle and freeing themselves from the generated suction. Although it does not refer to a particular motorcycle, a maximum wingspan restriction is established to ensure the safe installation of the winglets without obstructing the rider's movement or posing a risk to other competitors.

### Box 1



**Figure 1**

CFD Study of a Ducati V4 3D model

Source: (Ricardo Ferreira, 2022)

## Methodology

### *The history and early aerodynamic advancements in motorcycling*

Significant advances in researching how to enhance performance and reduce air resistance, achieving more incredible maximum speeds, have drawn heavily on previous studies of bird and fish efficiency in fluid dynamics. Implementing aerodynamic systems in automobiles took several years to ensure safety in aerodynamic requirements for motorcycle bodies.

Throughout different historical stages experienced by motorcycle brands, teams, and structures in world championships, continuous improvements have been aimed at achieving optimal motorcycle performance. The conclusion emphasizes that aerodynamic efficiency is crucial for achieving outstanding lap times, not solely reliant on engine power or displacement but also on optimal aerodynamics. Following the onset of World War II and Europe's slow recovery, aerodynamic advancements in mobile vehicles like cars and motorcycles had to wait two decades for economic recovery, allowing for their production and purchase. This delay led to subsequent regulations on production methods, making vehicles cheaper and limiting experimental design variations on a large scale. The end of World War II in 1945 saw the beginning of the space race between the United States and the Soviet Union from 1957 to 1975, influencing aerospace design elements in automobiles and motorcycles. [5]

The 1973 oil crisis played a pivotal role in revolutionizing aerodynamics in the industry. Manufacturers producing sports vehicles were compelled to develop more fuel-efficient products. Designers and engineers responded by experimenting with new designs using wind tunnels, initially used in aeronautics, leading to significant advancements in automotive aerodynamics.

While wind tunnels were not new per se, their extensive use in the automotive industry grew after World War II and the oil crisis. Over time, maintaining wind tunnels became costly, prompting a shift to computer simulations. However, wind tunnels are still used to validate results from computer simulations.

The most advanced aerodynamic technology is active aerodynamics, where components like spoilers can adjust their positions electronically based on sensor inputs to optimize vehicle performance under specific driving conditions.

Aerodynamics plays a pivotal role in enhancing performance and efficiency in the evolution of automotive and motorcycle design. Building upon historical advancements inspired by natural fluid dynamics observed in birds and fish, engineers have progressively integrated aerodynamic principles into vehicle design. This knowledge facilitated the development of vehicles with improved speed and reduced air resistance, which became crucial for achieving higher performance standards. [5]

However, the focus shifts to specific aerodynamic components' technical, mathematical, and scientific aspects, such as spoilers and wings. These components are designed not only to enhance the aesthetic appeal of vehicles but also to optimize their aerodynamic efficiency. Understanding the fluid dynamics and mathematical principles behind the design and placement of these elements is essential for engineers aiming to maximize vehicle performance and stability.

In 2016, Ducati's factory team introduced winglets similar to those used in Formula 1 cars to generate aerodynamic downforce on their motorcycles. These appendages were placed between the fairing and the side panels at the front of the bikes. [6]

This innovation was necessary because the power of these bikes often caused a phenomenon known as "wheelie" when exiting corners, resulting in the front wheel lifting and a decrease in traction. Electronics could not, and still cannot, effectively regulate the time interval from when the engine control unit cuts power until it restores it to prevent this phenomenon. Therefore, it can be stated that the primary goal of these winglets was to counteract electronic "anti-wheelie" measures. In 2016, several accidents raised concerns about the potential hazards of motorcycle winglets. Due to their sharp edges at high speeds, these appendages could cause injury upon impact. Consequently, these appendages were removed for the following season to mitigate safety risks.

In the 2017 preseason, teams sought ways to retain aerodynamic advantages while adhering to regulations. They explored new designs that integrated winglets within the fairing itself, eliminating sharp edges and ensuring compliance with safety standards. [6]

After determining they posed no additional risk to riders on the track, the organization approved these new designs as part of the fairings rather than winglets—Figure 2.

## Box 2



**Figure 2**

New winglets models

Source: (Ducati, 2017)

A deeper exploration into the technical aspects involves a detailed analysis of airflow patterns, pressure differentials, and the effects of turbulence on vehicle dynamics. Mathematical models and scientific experiments conducted in wind tunnels provide crucial data for refining aerodynamic designs and ensuring that vehicles perform optimally under various driving conditions.

### Mathematical methods

Some of the most essential mathematical principles to understand the design of a spoiler are:

- Bernoulli's equation

Bernoulli's equation [7] plays a fundamental role in understanding aerodynamic concepts, applying not only to liquids but also to gases. This equation describes the behavior of fluids by considering the work done by the fluid, its kinetic energy, and the conservation of energy.

Bernoulli's equation becomes an essential component of the energy conservation principle in the context of incompressible fluids along a streamline. According to this law, the sum of static pressure, dynamic pressure, and fluid height at one point equals the sum of dynamic pressure and height at another point, accounting for slight frictional losses.

$$P_1 + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

Equation 1: Bernoulli

P = Static pressure

$\rho$  = Fluid density

v = Velocity

g = Gravity

h = Height

The equation above belongs to phenomena caused by variations in height. However, when there is no change in pressure due to height, that term is removed from the formula, resulting in the equation type:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

Equation 2: simplified Bernoulli's Equation

- Reynolds numbers

The concept of Reynolds numbers [7] originated from an experiment conducted by Osborne Reynolds. In this experiment, ink was injected into a laminar flow, and it was observed that the ink maintained its constant movement. However, when the flow velocity was increased, the ink's movement changed to a turbulent pattern. This experiment laid the groundwork for determining flow regimes using the Reynolds number formula.

The Reynolds number (Re) is a dimensionless quantity that describes the type of flow of a fluid based on its velocity, density, and viscosity. It is calculated as:

$$NR = \frac{D v \rho}{\mu}$$

Equation 3: Reynold's Numbers.

Cruz-Olvera, Leonardo, Cuate-Gomez, Diego-Hernan, Garzón-Román, Abel and Lugo-Quintal, Jesús Manuel. [2024]. Development of a prototype spoiler for effective braking of a racing motorcycle, utilizing active aerodynamics. Journal of Technological Prototypes. 10[25]-1-14: e11025114.

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## Article

$D$  = is a characteristic dimension of the flow (such as the diameter of a conduit).

$v$  = is the flow velocity.

$\rho$  = is the fluid density,

$\mu$  = is the dynamic viscosity of the fluid.

The Reynolds number helps determine whether the flow is laminar, transitional, or turbulent. When “Re” is low, the flow tends to be laminar and orderly, while at high “Re” values, the flow tends to be turbulent and chaotic.

- *Aerodynamic load/ Downforce*

Downforce enhances vertical force on motorcycles through airflow to improve tire traction and stability [7]. This approach keeps motorcycles light, allowing additional weight for better grip, avoiding the need for heavier bikes that would reduce speed and performance. The aerodynamic load formula correlates directly with speed squared, increasing with higher velocities.

$$F = 0.5 * D * Cl * A * V^2$$

*Equation 4: Aerodynamic load.*

Where:

F: Downforce.

Cl: Lift coefficient determined by the shape of the vehicle and its angle of attack.

D: Air density.

A: Frontal area of the vehicle.

V: Velocity.

In symmetrical appendices, more straightforward formulas are used to calculate downforce, where the lift coefficient and shape of the object are not considered. The variation is determined by the angle of position rather than the shape of the object.

$$F = \Delta P \times A$$

*Equation 5: Symmetrical appendices equation*

Where:

F: Downforce.

$\Delta P$ : Pressure difference.

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A: Area.

- *Drag*

The drag [8] is due to the viscosity of the air in contact with the wing. This resistance increases proportionally with the vehicle's speed and generates a force that acts in the opposite direction to the motorcycle's forward motion.

$$Fd = -\frac{1}{2} * \rho * v^2 * AC * d$$

Fd =drag force.

-1/2 = It's a constant: -0.5, which is negative, indicating that the force acts in the opposite direction of the velocity (similar to friction).

$\rho$  = This is the density of the fluid.

A = Refers to the frontal area of the object pushing through the fluid.

CD = This is the drag coefficient, analogous to the coefficient of friction.

$V^2$  = Refers to the velocity vector, meaning like with friction, drag is a force that acts in the opposite direction to the velocity.

The drag force shares similarities with aerodynamic lift, as both forces oppose the motorcycle's motion. However, a fundamental difference lies in their direction: aerodynamic lift is oriented upwards, creating vertical lift, whereas drag acts horizontally and opposes the motorcycle's forward motion.

*Physical Effects*

- *Fluid mechanics*

Fluid mechanics studies the laws governing fluid motion and their interactions with solid bodies. Fluids (liquids and gases) deform easily due to their lack of specific rigidity, allowing them to adapt to the shape of their container or the surfaces they flow over.

Motorcycle winglets are aerodynamic fins added to fairings to enhance performance. To understand their function from a fluid mechanics perspective, several aspects must be considered:

**Airflow [8]:** Fluid mechanics analyzes how air flows around and through winglets as the motorcycle moves at high speeds, examining air velocity, direction, and pressure at different points around the winglets.

**Lift generation [8]:** Winglets are designed to generate aerodynamic lift, which is crucial for improving motorcycle stability and keeping it grounded at high speeds. Fluid mechanics explains how this lift is created and its impact on motorcycle dynamics.

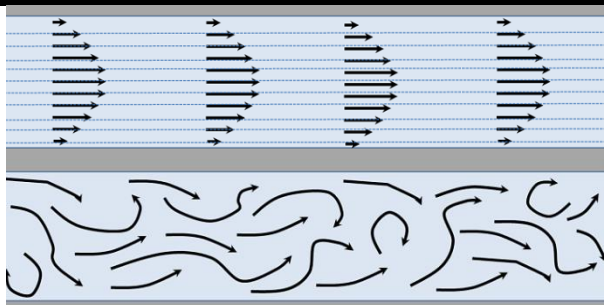
**Drag reduction [8]:** In addition to lift generation, winglets can reduce aerodynamic drag by improving airflow around the motorcycle. Fluid mechanics helps analyze how these fins contribute to overall aerodynamic efficiency.

**Design optimization [8]:** Fluid mechanics plays a crucial role in optimizing winglet design. Engineers use wind tunnel simulations and tests to evaluate different shapes, sizes, and positions of winglets to maximize their effectiveness in terms of performance and safety.

#### - Types of flow

**Laminar flow [9]:** smooth and orderly fluid motion in which particles move in parallel paths within well-defined sections. It is characterized by uniform and predictable particle movement without turbulence or abrupt changes in velocity. Laminar flow occurs at constant velocity with high fluid viscosity, commonly seen in slow-moving fluids like steady pipe flow or applications where viscosity predominates. **Turbulent flow [9]:** Turbulent flow occurs when increasing velocity increases the friction between fluid particles, causing them to rotate. Viscosity loses its effect, and particles change direction due to this rotation—figure 3.

#### Box 3



**Figure 3**

Linear and turbulent flow

Source: (2016)

Understanding and controlling airflow is essential in competitive contexts for achieving maximum aerodynamic efficiency. One key objective is maximizing aerodynamic load, which must be done within specific limits. [10]

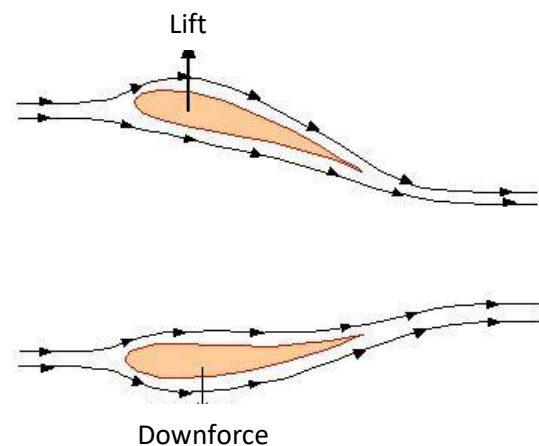
The angle of attack, typically ranging from  $0^\circ$  to  $26^\circ$ , plays a crucial role in competitive aerodynamics. This range is critical as it indicates where airflow transitions from laminar to turbulent as it passes over the wing. Approaching these critical angles generates increased aerodynamic force because the airflow behaves optimally.

However, it is essential to stay within these critical angles. Going beyond them would lead to excessive turbulence in the airflow, resulting in a loss of aerodynamic efficiency.

#### - Lift

Lift [11] refers to an object's ability to rise or stay airborne through interaction with fluid flow, as observed in aircraft wings. This phenomenon occurs due to differences in pressure and air speed variations above and below the wing. Precisely, air flowing beneath the wing moves faster than air above it, resulting in an upward force. Conversely, when a downward force is generated on the wing, it is known as negative lift or downforce—Figure 4.

#### Box 4



**Figure 4**

Lift and downforce

Source: (2014)

### - Ground effect

Initially explored in car racing, the ground effect phenomenon has intriguing applications in motorcycles, especially in high-performance racing. It aims to enhance stability and handling in curves by manipulating airflow to generate suction, improving wheel grip on the pavement. This involves applying Bernoulli's principle and the Coanda effect in aerodynamic design to achieve better traction while maintaining maneuverability despite the challenges posed by motorcycles' two-wheel structure and limited ground contact. [12]

### - Aerodynamic components

Aerodynamic forces play a crucial role in competition for motorcycles in achieving optimal performance. Minimizing drags in straight-line acceleration while managing aerodynamic load and airflow redirection is essential [13]. During turns, the goal is to increase aerodynamic load to maintain the motorcycle's grip on the asphalt, thereby improving traction.

MotoGP motorcycles incorporate various aerodynamic elements, each with specific characteristics and functions. These components are designed to optimize aerodynamic behavior and enhance the vehicle's overall performance across various track conditions. [14]

Some of them are:

**Deflectors [15]:** In motorcycles, deflectors play a crucial role by efficiently directing airflow towards strategic areas such as cooling pontoons and the diffuser, unlike in cars, where their focus is on generating aerodynamic load. Additionally, deflectors accelerate airflow over the motorcycle's fairings, creating low-pressure zones to enhance overall performance.

**Diffusers:[15]** Are essential elements for motorcycles. Their main function is to extract the airflow circulating underneath the vehicle and adapt it to the external environment. Accelerating the airflow under the motorcycle creates a low-pressure area, resulting in beneficial aerodynamic downforce.

**Spoiler [16]:** Spoilers represent the most crucial aerodynamic component with their distinctive wing-like shape. Their principle of operation lies in creating airflow with higher speed underneath than above the fin, thus generating a low-pressure area that gradually increases aerodynamic downforce. These are divided into two fundamental parts:

**Front spoiler [16]:** Front spoilers are vital in motorcycle competitions as they are the first to encounter airflow. Their primary function is to obtain additional aerodynamic load and crucially redirect airflow towards various areas of the motorcycle. For example, they prevent air from interfering with tire rotation, ensuring uninterrupted operation.

**Rear spoiler [16]:** The rear spoiler stands out as the component that provides the highest aerodynamic load while also generating the most resistance to forward motion. The aerodynamic load generated by the rear fins significantly enhances tire grip, increasing traction and braking capacity on the rear wheels and preventing them from lifting.

### *Aerodynamic profile/ Airfoil*

It is an object explicitly designed to maximize the forces generated by airflow velocity and pressure variations. [17].

It consists of the following parts—Figure 5:

**Airfoil Shape:** This is the cross-sectional shape of the wing as seen transversely.

**Leading Edge:** The front part of the wing first encounters the airflow, typically having a rounded shape.

**Trailing Edge:** Located at the rear of the wing, where the upper and lower surfaces of the airfoil meet.

**Upper Surface:** The top part of the wing between the leading and trailing edges.

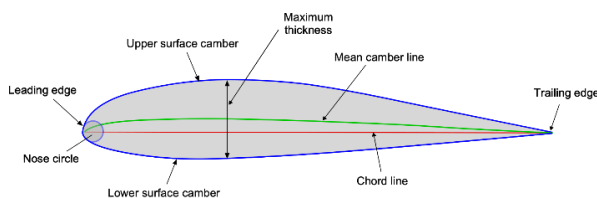
**Lower Surface:** The bottom part of the wing between the leading and trailing edges.

**Maximum Thickness:** The most significant distance between the upper and lower surfaces of the wing.

**Chord line:** An imaginary straight line between the leading and trailing edges of the airfoil section.

**Curvature:** The curve of the wing from the leading edge to the trailing edge. Maximum curvature refers to the upper surface camber, while average curvature refers to the lower surface camber.

### Box 5



**Figure 5**

Airfoil (2023)

### Angle of Attack

The angle of attack emerges as a highly influential factor in aerodynamic lift. It is defined as the angle formed between the chord line of the wing and the horizontal airflow, — Figure 1.6. It is clear that as the angle of attack increases, so does the lift or aerodynamic load.

When the angle of attack reaches a critical point, a phenomenon known as stall occurs. This involves a sudden loss of lift because the airflow over the airfoil cannot follow the entire wing contour. In our context, this refers to the inability of the airflow passing over the upper surface to adhere to the airfoil shape, leading to a stall entirely. [17].

The geometry of the airfoil profile plays a crucial role in our wing's performance. Its design aims to accelerate airflow on the lower surface and decelerate it on the upper surface, thereby generating higher pressure on the upper region. This increase in pressure increases the aerodynamic load, enhancing the front wheel's grip on the ground and enabling quicker corner exits.

### Aerodynamics

Aerodynamics, a discipline derived from physics within fluid mechanics, specializes in studying the principles and laws governing interactions between air and objects [18].

This field examines how the object's physical characteristics and the surrounding medium give rise to specific motion dynamics, determining acceleration, direction, and speed.

Air flows around an object, whether a motorcycle or any other vehicle, directly impacting its behavior and performance. Understanding and optimizing aerodynamics is crucial for maximizing efficiency and improving stability in various driving conditions.

### Active Aerodynamics

**Aerodynamics:** Refers to the branch of fluid mechanics dealing with the movement of air and other gaseous fluids, as well as the forces acting on bodies immersed in such fluids. [18].

**Active:** Implies action that demands agility, effectiveness, and continuous movement.

**Active aerodynamics:** in the context of vehicles, involves the ability to generate and modify aerodynamic forces on a surface in response to vehicle movement. Instead of relying solely on the static shape of the vehicle to interact with the air, active aerodynamics entails dynamic and controlled adjustments that can vary according to driving conditions. These adjustments may include changes in the position of wings, deflectors, and other aerodynamic features to optimize vehicle efficiency and real-time performance. [19].

### Design 2.0 SpoilerDesign.

The design process of the spoiler begins with a thorough analysis of fundamental aerodynamic principles. The primary goal of the active spoiler is to counteract the suction effects generated in the slipstream, which hinder trailing riders when attempting to overcome inertia and brake into corners. This type of wing adjusts automatically to increase aerodynamic load on the sides of the motorcycle, adapting to the lean angle and direction of the curve. For instance, it adjusts its angle of attack on the right side of the motorcycle when anticipating a right turn. It reduces this angle as the bike leans to avoid undesired aerodynamic loads at critical lean angles.

This dynamic adjustment significantly enhances stability, agility, and grip on the pavement by increasing the motorcycle's lateral aerodynamic load. This results in improved traction on both wheels, allowing riders to navigate curves with greater precision and efficiency while reducing the physical effort required to handle the motorcycle in high-competition scenarios.

For the design of this wing prototype, SolidWorks software was used to create 3D models, and Computational Fluid Dynamics (CFD) simulations were conducted to thoroughly study aerodynamic effects, including pressures, velocities, and wind directions. These tools provided crucial insights to optimize the design and ensure the wing met specific aerodynamic requirements for high-level competitions such as MotoGP.

This active wing, designed for MotoGP motorcycles, dynamically adjusts the wing's angle of attack when cornering, both left and right. This adjustment optimizes aerodynamic pressure as needed, enhancing stability and safety during overtaking by reducing drag when closely following another rider and increasing downforce while braking.

For its design and manufacturing, SolidWorks 2022 software was utilized. The "right plane" was chosen as the starting point, where the main body of the design, based on the current fairing design of the KTM MotoGP RC16, was created—figure 6.

### Box 6



**Figure 6**

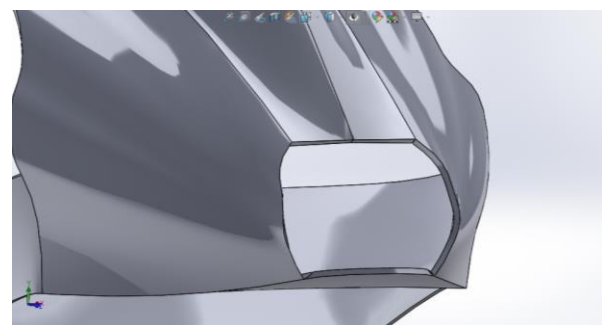
KTM RC16 fairing

Source: (2024)

The motorcycle fairing was created, and 3D sketches were employed for their ability to handle complex shapes with extreme curves viewed from various angles. First, starting with the front section to replicate its primary shape, additional lines were drawn to depict different perspectives, such as the windscreen from the right plane. After generating at least four views in a closed 3D sketch, the surface function in SolidWorks formed a smooth, continuous three-dimensional surface. This surface entity allows intricate and detailed models, which is especially beneficial for crafting curved forms that are not easily achievable with standard solids. The focus was on the motorcycle's front section to facilitate fluid simulation analyses.

As mentioned earlier, surfaces in SolidWorks are irregular geometries without a defined thickness, which is evident in the program when zooming in on material edges, where no thickness is visible, and they are highlighted with a blue outline. Next, the SolidWorks 'Knit Surface' tool merges multiple surfaces into a single entity, creating blends between edges to ensure tangency and avoid intersections that could affect the geometry. Once merged into a single entity, the surfaces are converted into solids by assigning them a specific thickness of 5 millimeters using the 'Thicken' function. Figure 7.

### Box 7



**Figure 7**

Thicken command in fairing

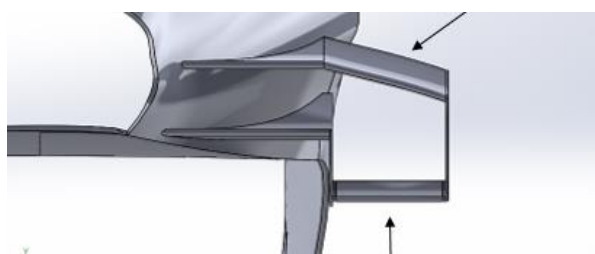
Source: (2024)

The design of the winglets begins with creating a sketch on the right plane and defining the wing profile geometry. An asymmetric profile is chosen for its ability to generate more excellent lift at high angles of attack, which is crucial for maintaining elevation at low speeds or in reduced airflow conditions.

After tracing the cut on the fairing using the "extrude cut" function, an extrusion of the sketch is created with a slight downward inclination to maintain the wing angle even when tilted, with dimensions of 22 cm in length and an initial attack angle of  $13^\circ$ . A T-shaped configuration is implemented on the upper part of the winglet to close it and allow activation in a specific section, with an initial attack angle of  $10^\circ$ . Its symmetric design optimizes airflow direction, generating a Venturi effect that increases airspeed and counteracts loss when following another rider—figure 8.

Finally, a 1 mm thick cut is made on the edges to separate the movable winglet from the T-shaped winglet walls. This is followed by creating symmetry between the solids towards the right plane, thus completing the comprehensive design of the motorcycle.

### Box 8



**Figure 8**

T-shape winglet

Source: (2024)

### Electronic control

An Arduino Uno board based on the ATmega328 microcontroller, which is crucial in the process, was chosen to ensure precise motor control and execute exact movements. This highly programmable microcontroller efficiently performs complex mathematical operations at considerable speed. In programming, an intermediate-level C-like language was used, featuring mathematical functions and tools such as *and*, *if*, *else*, and *for*, facilitating the implementation of system logic.

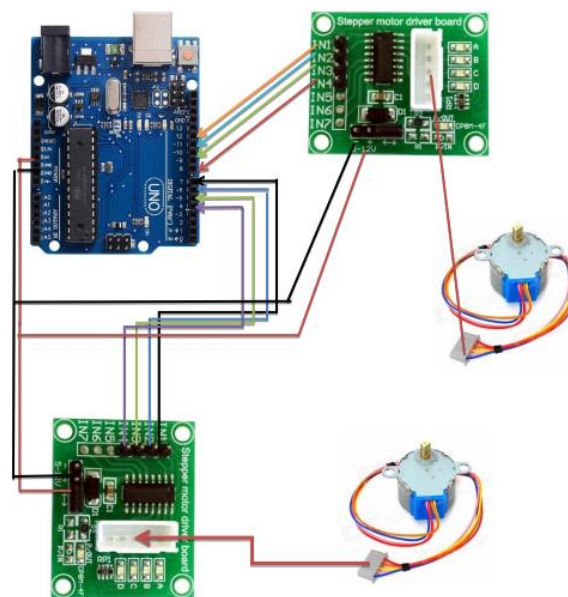
The function was used to execute specific instructions outside the normal cycle, conditioned by an *if* statement. Depending on the condition set, the *if* statement triggers winglet movements, including lifting, returning to the initial position, or maintaining position. All these actions occur if the condition in the *if* statement is satisfied.

The MPU6050 emerges as a critical tool in instrumentation. It features a 6-degree-of-freedom sensor with a 3-axis accelerometer and a 3-axis gyroscope. It enables precise motion detection in three dimensions and integrates easily with Arduino through four primary connections. Widely used in motion control systems, virtual reality, and object tracking, it stands out for its versatility and utility in prototypes.

Stepper motors were chosen for their efficiency and cost-effectiveness in controlling the winglet's angular movement. These motors provide precise position and speed adjustments, with a movement angle of 0.7 degrees per step. This capability ensures optimal adjustment of the winglet's angle of attack, which is crucial for dynamically adapting to flight aerodynamic conditions.

The pins 4 to 11 were used to connect the stepper motors. These pins were explicitly chosen to connect cables leading to the control module or H-bridge. Each stepper motor requires four output cables because the chosen motors are bipolar, meaning they have two internal coils. Therefore, a specific sequence is needed to activate each coil and rotate the rotor—Figure 9.

### Box 9



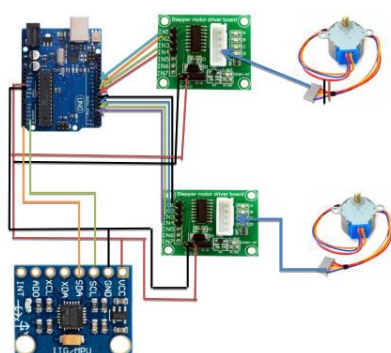
**Figure 9**

Step motor electronic diagram

Source: (2024)

The connection of the gyroscope is quite simple, requiring only four connections: one for 5V power supply (VCC) and another for ground (GND), which can be shared with or grouped alongside those of the motor on a protoboard. The remaining two cables, SDA (Serial Data Line) connected to A4 and SCL (Serial Clock Line) to A5, are controlled by the I2C library, which is responsible for data transmission through these two cables. It is important to note that both the master and slave devices send data over the same cable, which is controlled by the master and generates the clock signal—figure 10- figure 11.

### Box 10



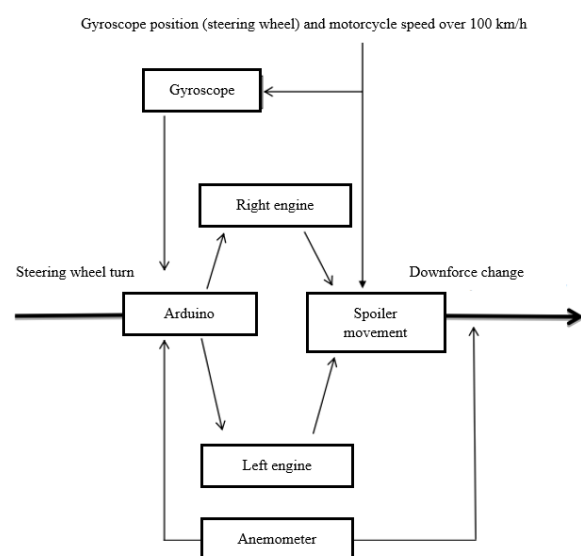
**Figure 10**

Gyroscope electronic diagram

Source: (2024)

- Control diagram

### Box 11



**Figure 11**

Control diagram

Source: (2024)

## Results

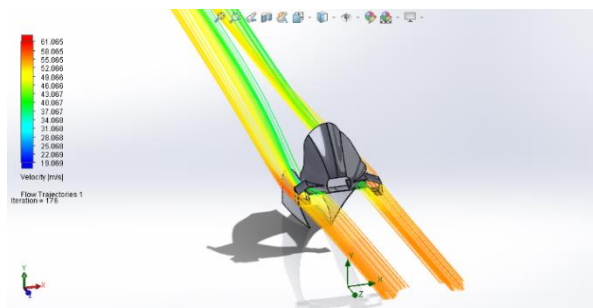
The prototype successfully achieves the overall objective of designing an electronic control system using an Arduino board for an active winglet on a MotoGP motorcycle. Its primary functions include generating increased aerodynamic load where needed, improving performance and stability during high-speed cornering, and integrating advanced aerodynamic technologies for competitive MotoGP racing.

The winglet design is based on fundamental physical theories to ensure proper functionality, with specific dimensions tailored for 1000cc MotoGP motorcycles under current regulations until 2027 by the FIM. The upper appendix maintains a fixed  $13^\circ$  angle of attack, while the T-shaped winglet allows variations from  $0^\circ$  to  $26^\circ$ .

A system was developed to implement effective electronic control that responds to specific conditions such as vehicle speed (exceeding 130 km/h for significant aerodynamic effects) and motorcycle lean during turns. The angle range for initiating winglet movement is set from  $0^\circ$  to  $10^\circ$  for right turns and  $0^\circ$  to  $-10^\circ$  for left turns, ensuring precision in vehicle response.

Key components include an Arduino board programmed to coordinate all components, a gyroscope to detect motorcycle angle, an anemometer to measure airspeed, and two stepper motors to adjust winglet angles.

Based on the established design, fluid dynamics simulations (CFD) using SolidWorks were conducted to evaluate winglet efficiency. These tests illustrated the airflow distribution over the winglet at different speeds, demonstrating its aerodynamic performance in generating the desired downforce. Figure 12.

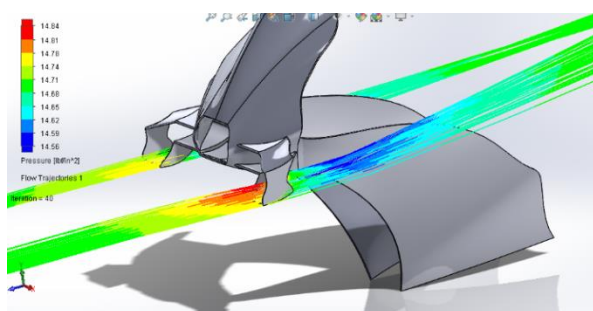
**Box 12****Figure 12**

Neutral winglet position

*Source: (2024)*

The winglet has demonstrated optimal operation by maintaining vehicle stability without significant crosswind turbulence or vibrations. It provides an adequate aerodynamic load to keep the vehicle grounded without excessively increasing drag, which could slow down the motorcycle.

In the simulation with the winglet set at a 20° angle of attack, airflow lines show a reduction in speed from 220 km/h to 130 km/h, indicating efficient downforce generation, illustrated by pressure variations depicted in Figure 13, where the winglet angle influences pressure increase from 14.6 psi to 15 psi, highlighting the winglet's capability to provide the necessary force for cornering maneuvers and mitigate adverse effects of wake turbulence.

**Box 13****Figure 13**

Pressure flow in activate winglet

*Source: (2024)*

Simulation results and mathematical calculations were used to determine the downforce generated by a wing using the aerodynamic load formula  $F = \Delta P \times A$ . Pressures were converted from PSI to Pascals, and the difference between 15 psi and 14 psi was calculated, resulting in approximately 2757.904 Pa.

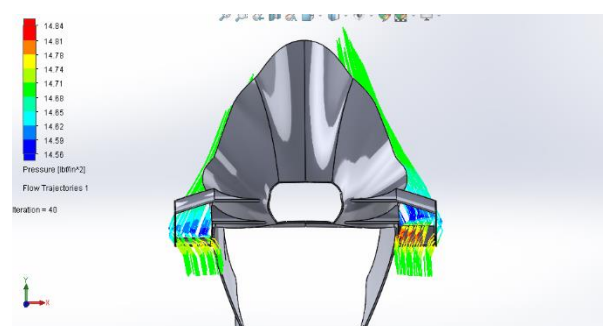
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This difference was then multiplied by the wing area, which is 94 cm<sup>2</sup> converted to m<sup>2</sup>. The result in Newtons indicates that the wing can generate around 2.6 kg of additional load, aiding the rider in leaning the motorcycle efficiently and overcoming suction trails.

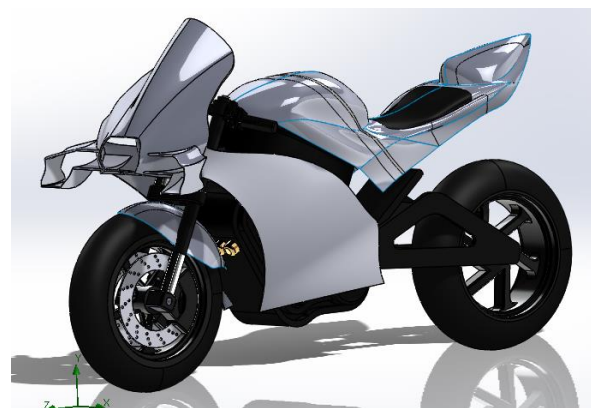
Figure 14 illustrates the flow and pressure differences between the right-wing (in motion) and the left wing (in neutral position). These differences demonstrate the effects of aerodynamic principles such as Bernoulli's law. The right-wing shows higher pressure and lower velocity on the upper surface, while the lower surface exhibits lower pressure and higher velocity. In contrast, the left wing, with minimal angle of attack, shows minimal pressure variations and a slight vacuum at the rear due to the uniform airflow speed through the upper and lower parts.

**Box 14****Figure 14**

Flow differences

*Source: (2024)*

Next, here is the result of the motorcycle prototype—figure 15.

**Box 15****Figure 15**

Final Prototype

*Source: (2024)*

Cruz-Olvera, Leonardo, Cuate-Gomez, Diego-Hernan, Garzón-Román, Abel and Lugo-Quintal, Jesús Manuel. [2024]. Development of a prototype spoiler for effective braking of a racing motorcycle, utilizing active aerodynamics. Journal of Technological Prototypes. 10[25]1-14: e11025114.

DOI: <https://doi.org/10.35429/JTP.2024.10.25.1.14>

## Conclusions

The prototype developed in this research successfully achieved all its design objectives. As observed in the results section, the obtained values are beneficial across all aspects, generating significant aerodynamic loads that assist riders in braking and maneuvering more efficiently while in the slipstream of other riders. However, some areas could be improved, such as the wing lifting system, which could benefit from a more efficient mechanism or powerful motors. Another area for enhancement is the wing's electronic control, where using more precise sensors could mitigate data variation, allowing for more accurate readings. It is recommended that data extracted from ECU or real-time telemetry systems be utilized to enhance precision. These recommendations are proposed because the data extraction instruments operate independently in the prototype and, when applied to a real motorcycle, must synchronize with the bike's computer to ensure optimal performance.

Ultimately, it can be affirmed that the active wings achieved the project's primary goal by not generating counteracting forces during turns or turbulence, thereby improving the motorcycle's behavior at critical braking points and at the initiation of leaning. The wings' independence allows for varying the angle of attack based on downforce and motorcycle lean, which means a higher angle of attack can be maintained when the bike is straight. Braking begins by reducing this angle during leaning to avoid undesirable external forces.

When the motorcycle is leaned, the force plane shifts laterally rather than vertically, potentially generating undesired lateral forces that reduce front-wheel contact with the ground and affect cornering trajectory. Reducing the angle of attack as lean increases is advantageous because it alters airflow dynamics, resulting in less efficient airflow over the wing and reduced aerodynamic performance, which is instrumental during extreme leans when strong aerodynamic effects from the wing are undesirable.

It is important to note that this prototype has certain limitations that should have been addressed in this project.

One limitation involves factors interacting with the motorcycle, such as tire wear toward the end of a race, which could significantly impact grip and subsequently applied force, posing a potential risk. Another limitation concerns suspensions. Suspension adjustments can significantly influence the motorcycle's agility by altering its position. Therefore, the wing's response speed should depend on the motorcycle's suspension components' reaction time, allowing the degree of aerodynamic wing effect to be adjusted based on suspension response.

## Declarations

### Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

### Authors' contribution

*Cruz-Olvera, Leonardo, and Cuate-Gomez, Diego Hernan* will conduct the development, experimentation, and article writing.

*Garzón-Román, Abel, and Lugo-Quintal, Jesús Manuel*, helped with the correction of the manuscript.

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