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Influence of the rider seating position on motorcycle aerodynamic performance

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Abstract-- Aerodynamic design is a key aspect in race car development, and is usually based on wind tunnel evaluation and CFD. This is not usually the case in motorcycle design. In recent years, some aerodynamic analyses have been carried out, but wind tunnel experimental evaluation is very seldom used. This paper addresses a specific aspect concerning the rider's position. The goal of the investigation is to provide the rider with information about the most efficient position to reduce aerodynamic resistance. Four different types of motorcycle were considered, and an experimental investigation program was carried out. During each test, real riders on full-scale motorcycles were evaluated. Each rider wore his own race suit while riding the motorcycle and each test was characterized by a specific rider position gauged by the distance between the rider's pelvis and a reference point on the motorcycle saddle. Different rider positions were compared and general trends were found. This paper illustrates the experimental procedures and presents the main results in terms of drag resistance for each test. As a final result, the most efficient rider position is suggested.

Index Terms-- **Experimental Aerodynamics in sport, Ergonomics, Motorcycle.**

I. INTRODUCTION

Aerodynamics is a paramount matter in 4-wheel car design and is considered a key aspect of modern models. As a consequence, a huge effort in aerodynamic optimization is deployed in car design today, from both a numerical and experimental point of view; however this is not the case in motorcycle design, and very limited research on this topic can be found in literature. A systematic effort to analyse the aerodynamic behaviour of motorcycles can be found in [1]. A simplified approach is presented in [2]. The main reason for this lack of information is probably due to the complex shape of motorcycles, which makes it very difficult to find reliable general rules applicable to different motorcycle shapes. To the authors' knowledge, the aerodynamic research programs carried out by motorcycle designers usually concern single detail optimization, a comparison between different solutions, and performance evaluation of specific designs, but rarely find general trends. Some experimental studies concerning specific aspects were carried out by the authors: windshield effect can be found in [3] and [4]; virtual wind tunnel simulation based on CFD is studied in [4] and [5]; in [6] the effects of aerodynamic slots are investigated. In [7] the authors describe an experimental set up developed to test full scale racing motorcycles in a wind tunnel; in [8] the effects of some "vortex generators" are investigated in order to improve the aerodynamic performances of motorcycles. In the authors' opinion improvement in the performance of racing motorcycles requires the optimization of a variety of different aspects, with aerodynamics not the least important among them. This paper focuses on an experimental investigation of the influence of the rider's position on aerodynamic performance. The underlying idea is to provide the motorcycle rider with general suggestions about the optimal sitting position in order to reduce aerodynamic resistance. The experiments were carried out in a real scale wind tunnel, in which real motorcycles were tested with their riders. The general set up of the wind tunnel was developed in accordance with [9] (see fig.1) and the data acquisition scheme is displayed in [10].

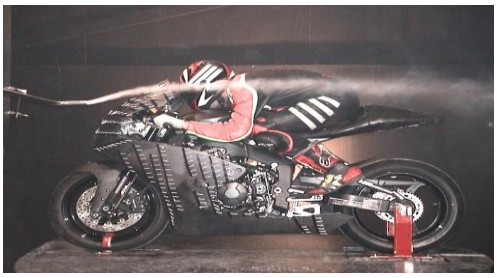

Fig 1. General experimental set up

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The absolute effect of the rider position is very small (only a low percentage) but - owing to the fact that the maximum speed depends on the inverse of the third root of the power - a very small improvement in resistance can lead to an appreciable improvement in maximum speed.

The research is entirely experimental and intends to establish general "rules of thumb" applicable to different motorcycles shapes.

Four different shapes of racing motorcycle were investigated, with different rider seating positions, and the aerodynamic resistance was recorded for each test. The wide range of shapes was chosen in order to take into account all the different "families" of motorcycles. As explained in the paper, repetitive behaviour and common trends were found in all the experimental investigations.

II. AERODYNAMIC ASPECTS

The goal of this study is to investigate the influence of different sitting positions on the main aerodynamic parameter, i.e. the drag coefficient "Cx". In Aerodynamics this coefficient measures the resistance induced by air friction on a body in motion. The Cx coefficient, intended here as non-dependent of speed[1], is a dimensionless parameter that can be multiplied by the dynamic pressure and a reference area to compute the total aerodynamic resistance. Cx is defined as [1]:

$$C_x = {}^{R}\!\big/_{\frac{1}{2}\rho V^2\,S} \qquad (1)$$

Where: "R" represents the drag force (the force in the direction of the air velocity "x"), "ρ" the air mass density, "V" the speed of the motorcycle relative to the air and "S" is a reference area depending on wind direction and the particular shape.

The "reference area" can be easily defined for aerodynamic fired shapes (wings, airplanes...) but its definition becomes subjective when motorcycles are involved. Usually in the aerodynamics of motorcycles, the reference area is not calculated independently, as it depends on variable wake extinction (depending on wheels, rider position, fairing etc.). It is normal practice to validate models using the overall product Cx*S known as "drag area" [2]. This approach was followed in this paper.

The drag area Cx*S is the main characteristic that determines the top speed at a given power, and is linked with speed and power by the following formula:

$$V_{max} = \sqrt[3]{{}^{P}\!/_{K * C_x * S}} \;\; => \;\; V_{max} = Const * \frac{1}{\sqrt[3]{C_x * S}} \qquad (2)$$

Where P is the maximum power in Kw, Vmax is the maximum speed of the vehicle in m/s and K is a constant depending on motorcycle shape, powertrain efficiency, friction etc.

Eq. 2 shows that motorcycle performance can be improved by increasing max power, decreasing the constant K, or decreasing the "drag area".

The Cx*S parameter normally assumes values of around 0.3. Lower or higher values can display some influence on maximum speed (as well as acceleration and fuel consumption) as can be seen from eq.(2). A relation can be used to estimate the new top speed of a given motorcycle or the extra power needed to reach its top speed [2]:

$$\textbf{Power required} = \frac{\textbf{Original power} * \textbf{targetspeed}^3}{\textbf{original speed}^3} \qquad (3)$$

Usually, for a given motorcycle, max power and K are fixed (as they can be improved only with significant changes to the motorcycle) while Cx*S depends on both motorcycle shape and rider position. In particular, the rider position influences both the frontal area "S" and aerodynamic parameter "Cx". As a consequence, to increase the performance of a given motorcycle one can only work on the rider position.

[1] The validity of this assumption depends on the very narrow variation range of the Reynold's number, as all tests were performed at a constant wind speed and the dimensions of the motorcycles do not vary significantly from one to another.

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III. EXPERIMENTAL PROGRAM AND TESTING APPARATUS

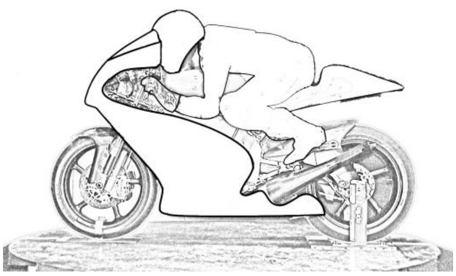
The goal of this study was to investigate whether any general rules have universal validity and are applicable to different types of sports bikes. For this specific study, four different types of motorcycle were considered: two superbike™ models, and two race models (assembled for competitive use only). The Superbike™ models were chosen because they can be used in both commercial travel and competition and are therefore more comfortable. The wheelbase is the most significant aspect affecting rider position that differentiates race bikes and Superbike™ models: race bikes typically have a lower wheelbase. All the cowlings were specially redesigned in order to improve aerodynamic performance, and as a result, the four shapes differ in many aspects from the original design. As the scope of the study is the investigation of the rider position effect, a similar set of tests has been used for each motorcycle model. In practice, in each test, the rider was asked to assume a specific position, and the resistance was recorded. In the following analysis the different motorcycle types will be identified as follows:

A. One "close" model Superbike™ championship motorcycle
B. One wide model Superbike™ championship motorcycle
C. One Moto GP™ based 2-stroke engine 250cc prototype
D. One moto2™ prototype 4-stroke engine 600 cc.

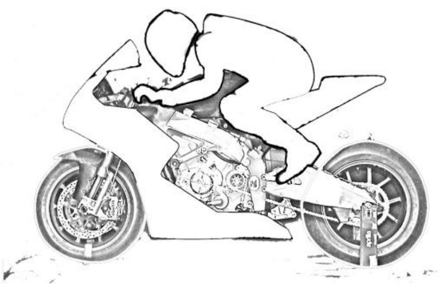
The four motorcycles are sketched below to better explain the main characteristics of each model (fig.2). Models A and B are based on a similar chassis, with a wheelbase of 1420 mm and different width; models C and D are based on a chassis with a wheelbase of 1370 mm and differing width. In addiction, the Moto2 and 250 GP categories are designed for competitive purposes only, while superbike models are designed for both competitive and touring purposes. Tab.1 summarizes the main characteristic of each model.

		Width		
	Wheelbase (cm)	Large	Narrow	Comfortable sitting
Close Superbike™ model	1420		X	X
Wide Superbike™ Model	1420	X		X
2 stroke 250 GP™	1370	X		
Moto 2™	1370		X	

Table.1: Main characteristic of tested models



2 stroke 250 GP™



Close Superbike™ model

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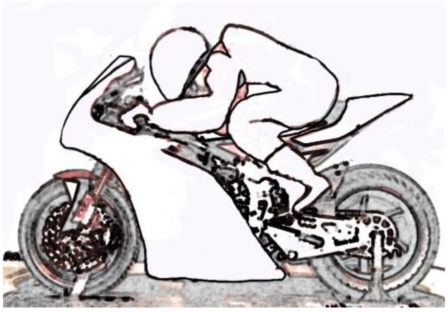
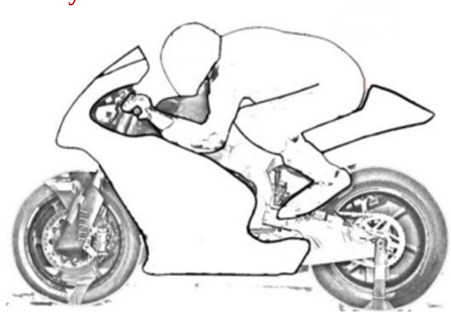


Large Superbike™ Model



MOTO 2™

Fig 2 – Sketches of the four motorcycle "families"

As a general rule, the rider tries to reduce his "resistant section" as far as possible, meaning that he attempts to have as narrow a cross section as possible, adopting a "curled" position. This is general instinctive behaviour. To achieve this goal the only aspect the rider can change is the seating position. In this study this is characterized by his position with respect to the saddle, but any change affects the posture of the entire rider's body. Three positions were considered: ahead position (the riders is seated ahead on the saddle, and his helmet remains in contact with the fairing), central position (generally the most comfortable position), and rear position. In figure 3 the "ahead" and "rear" positions are displayed, while figure 4 shows how the position was defined in this paper.

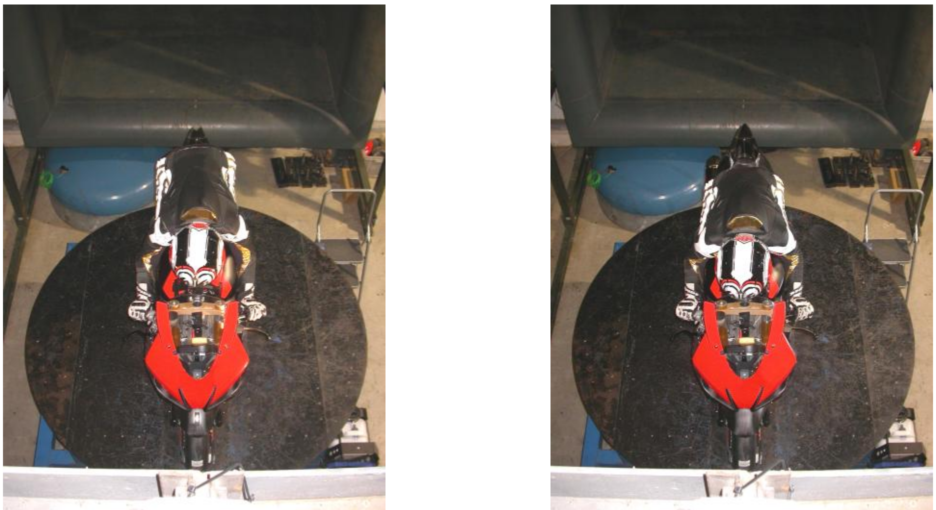


Fig 3 - Comparison between "rear" and "ahead" position

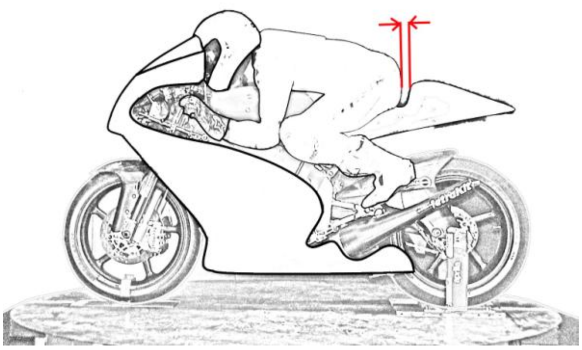


Fig 4 – Parameter defining the rider's position

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In order to investigate the influence of the position of the rider, the four sets of different types of motorcycle were tested in the "R. Balli" wind tunnel at the University of Perugia. This wind tunnel allows for real scale testing of motorcycles in a context very similar to real motion, with the rider seated in race position. This is an important characteristic that permits an immediate response for each specific configuration. The principal dimensions of the facility are reported in Tab.2.

Table.2 - wind gallery features

	Feature	Dimension
Test section	Jet Length Width Height	4,25m 5m 6m
Nozzle	Jet frontal area	2.20m x 2.20m
Fan	AC Motor Power Blade number Max. Wind speed Wind speed range	375 KW 11 50m/s (180 Km/h) 0 to 50m/s
Confidence	Max. error on drag force	<0.5%

The wind tunnel is equipped with a turning table, which allows variation of the incidence angle. The motorcycles can be clamped on the turning table and the clamps are linked to load cells recording the three direction components. This set up permits the evaluation of both the resistance in each direction and the three aerodynamic moments induced on the motorcycles (fig.5). In this study all tests were carried out with the same wind incidence, i.e. 0°.

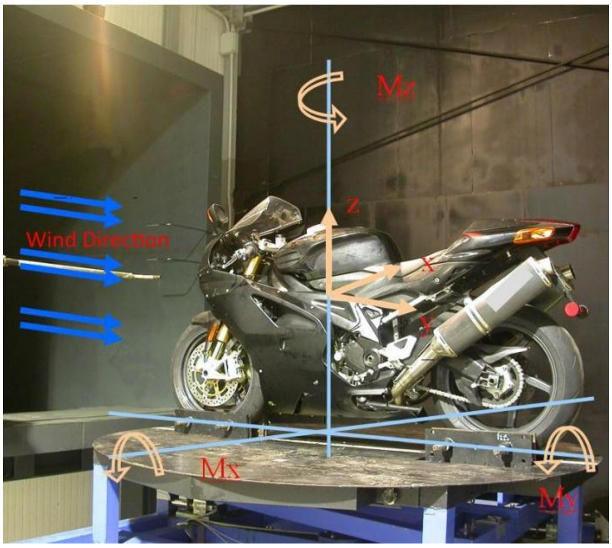

Fig 5 - Force recorded during a typical test

The same experimental set up was maintained during all the tests, independent of the differences between the motorcycles. The main parameters are listed in Tab.3.

Table.3

Parameter	Dimension
Wind speed	45m/s
Clamping	Both wheels clamped (not rotating)
Test duration	60s
Reference position	Same position of rear wheel[2]

[2] The choice of a common spatial reference for all tests is intended not to effect resistance measurement due to different wake extinction

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IV. DATA PROCESSING AND RESULTS

The parameter taken as significant in order to compare performance is the distance between the centre of the saddle and the actual position of the rider with reference to the centre of the saddle (figure 4). To better illustrate the results, the “central” position will be given the value 0 and the other value will show the distance (in cm) from the central position.

In order to verify the rider's position, a set of pictures was taken as the resistance force was recorded.

During each test the horizontal resultant force was measured through two load cells mounted on the wind tunnel table and the value of Cx*S was obtained from (1).

Tab.4 summarizes the test results for the four sets of tests. In this table the average performances – the Cx*S value - for each set of test are reported as a percentage of the central position performance, as the purpose of this study is a comparison between the different positions, and not the numerical evaluation of the resistance in a single test. While the experimental setup remained unchanged, the motorcycles and riders changed every time (along with their helmets, boots, suits etc.).

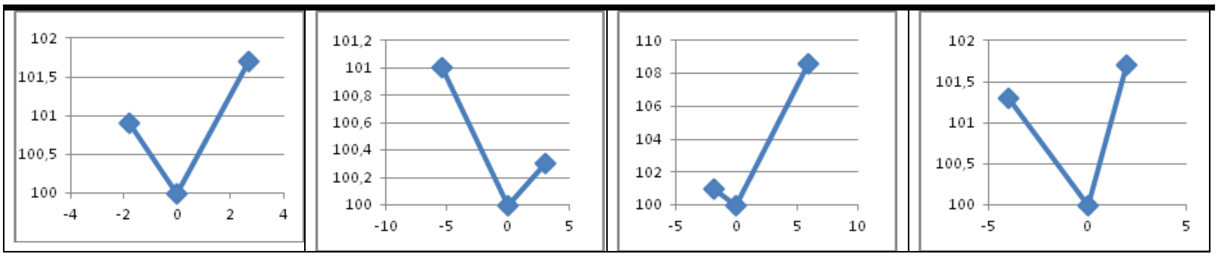
In Tab. 5 the results are displayed in a graphical form, with the Cx*S (dimensionless) plotted (y axis) versus the dimensionless rider position (x-axis).

Table. 4

Positi	2 stroke 250		Close		Large		MOTO 2™	
	D	Cx*S	Di	Cx*	Dist.	Cx	Dist.	Cx
Rear	-	100,9	-	101,	-1,8	10	-4	10
Centr	0	100	0	100	0	10	0	10
Ahea	2	101,7	3,	100,	5,9	10	2	10

Table. 5

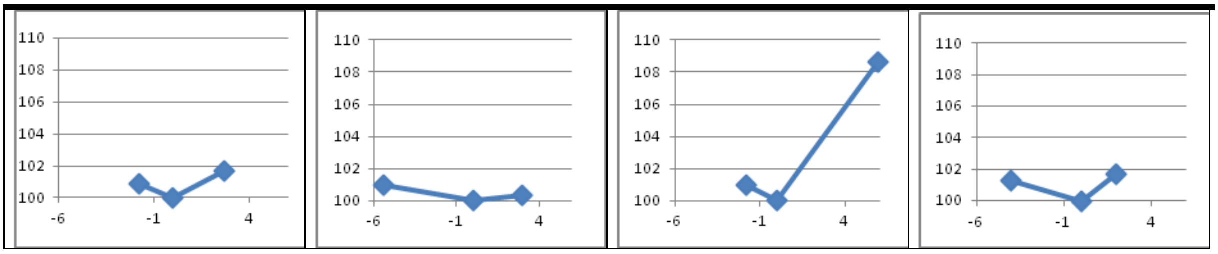
2 stroke 250 GP	Close Superbike model	Large Superbike Model	MOTO 2™



To better compare the results, Tab.6 shows the graphs in the same scale. The large Superbike model has the largest variation in terms of Cx*S

Table.6

2 stroke 250 GP	Close Superbike model	Large Superbike Model	MOTO 2™



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V. DISCUSSION AND CONCLUSIONS

Despite the differences between the motorcycles, the rider position always influences the aerodynamic performances with the same trend. The effect is small in terms of C_x*S, ranging from 1% to 8%, but still has a non-negligible influence in terms of top speed, as will be shown later.
Tab.6 shows a similar general trend for all motorcycles: the central position – which incidentally is also the more comfortable position – always displays the lower C_x*S. The rider position has a genuinely significant effect for the large Superbike model and – on the contrary – a very limited effect on the close superbike model, but even this reduced effect must not be underestimated, as it still has an effect at top speed. Assuming a racing speed of 300Km/h, on the basis of Eq. 2 the effect on top speed of a variation of the drag area, C_x*S, can be evaluated; it can be clearly seen that an increase of 1% in the drag area will cause an increase of 1Km/h of the top speed. The relation between the variation in aerodynamic resistance and speed is not linear, but for small variations it can be linearized, and therefore a linear relation can be assumed (valid for speeds of around 300Km/h):

$$\Delta V = \Delta(C_x{*}S) \qquad [5]$$

Where ΔV = variation in speed (Km/h)
and $\Delta (C_x{*}S)$ = variation of the drag area (%)

The increase in speed due to an optimized rider position can therefore span from 2km/h to 8Km/h.
In order to understand the importance of these apparently small variations, one should evaluate the power increase required to reach the same goal. From Eq. 3, we can evaluate the extra power needed to increase the speed from 300 to 302Km/h as 2hp, while 16hp are necessary to increase from 300 to 308Km/h. From this point of view, it is clear that even small increments in top speed linked to rider position must not be disregarded, as they are completely free and comparable to a significant increase in engine power. This comparison clearly explains the importance of aerodynamic optimization, and that rider position is not an insignificant parameter.

The analysis of the tests shows a general trend for all motorcycles involved: the central position is the most convenient in order to reduce resistance; incidentally it is also the most comfortable seating position according to the riders. The effect is more relevant for the large superbike model, but the same tendency is found for all models tested.

The aim of the study was not a quantitative evaluation of the resistance induced by rider position, but rather a qualitative comparison between seating positions, in order to offer suggestions about the most convenient position. The rider's position on the saddle affects the posture of his entire body, as feet inclination, knee position and elbow span change every time he shifts his position on the saddle; the rider's position with respect to the saddle is therefore a parameter that defines the posture of the entire body.

In conclusion, the research has shown that the rider's position can be optimized in order to enhance the performance of a motorcycle and, as a "rule of thumb", the best position for the rider is the central position on the saddle. Further investigation is necessary in order to explore other aspects of the rider's position. In particular, a significant influence due to foot position was observed, and the frontal area effect also needs to be considered.

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Massimiliano Malerba obtained his degree in mechanical engineering at University of Perugia (Italy) in 2001 and received his PhD degree in Industrial Engineering at University of Perugia (Italy) in January 2015. Since 2007 up to now he is Assistant Professor at “Guglielmo Marconi” University, Rome (Italy). Currently, he is lecturer in Computer aided design at faculty of Science and Applied Technology University “Guglielmo Marconi” (Italy). His research interests includes motorcycle dynamics, Aerodynamics and design

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