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Motorcycle Geometry Analysis and Dynamic Handling Investigation

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1 Introduction

Scooters, Tourers, Naked, and Super-sport bikes are just some of the numerous motorcycle categories, each category has a distinct height and length specifically designed for its intended purpose of use, for example, a super-sport bike has a shorter wheelbase ranging from 1300mm to 1500mm with a rake angle ranging from 20° to 25° to achieve agility, the tourer motorbikes, on the other hand, has a longer wheelbase ranging from 1400mm to 1600mm and with rake angle range of 25° to 30° to achieve stability. In addition, aesthetic design, riding position, engine power, and the sound of the engine, etc., are all the aspects that give the motorcycle its unique “character”, which is also taken highly into consideration when designing a motorcycle to meet the customer demand without sacrificing performance (Gadola, *et al.* 2019).

1.1 Aims

The aim of this study is to gather motorcycle geometry data from four different motorcycles, two of which should be in the category of a normal commuting motorbike to a road-legal super-sport bike, which means it is being produced and sold to the public and the other two coming from a top-level range of motorcycles that are solely used for racing, examples of such motorcycles are: MotoGP, WSBK, and BSB) the data will then be used to compare the characteristics of the four motorcycles, and briefly discuss the similarities and differences of each motorcycle.

1.2 Objectives

At the end of this study, the author should be able to exhibit a thorough understanding of motorcycle geometry and how different adjustments and measurements affect the overall characteristics of the bike, (i.e. handling, driving stability, comfort, and resistance, etc.,) and the rider’s experience whenever the motorcycle is being used on either public roads or race tracks. In addition, the author should also include further work/study on how to improve such motorcycles utilising what has been learnt from this report’s contents.

2 Motorcycle Geometry

Topics such as handling, driving stability, and riding style are often talked about in the motorcycle industry, all of the mentioned topics can be determined by the main parameters of motorcycle geometry such as:

- Wheelbase
- Rake
- Trail/Castor
- Steering axis
- Centre of gravity position

Šmíraus and Richtář (2011) mentioned explained in their work that wheelbase measurements are taken from the centre point of the front wheel spindle to the centre point of the rear wheel spindle. The angle from the vertical axis or the steering axis where the front fork lies is called the rake or steering head angle, the angle varies from 24° to 30° to the ground depending on the motorcycle's riding style. The area where the ground intersection meets the steering axis is the trail which highly influences the handling and stability of a motorcycle. A stationary bike's perpendicular intersection to the ground is the steering axis or contact patch. Lastly, the centre of gravity consists of two determinants which are horizontal and vertical position, the centre of gravity changes relative to the mass of the rider or the pillion rider, the horizontal position can be measured from the contact point of the wheel to the ground going towards the centre of the bike, then the vertical position is measured from the end of the horizontal going upwards. These parameters are considered significantly synchronised where any adjustments done to one parameter can effectively affect the behaviour of the others (Šmíraus and Richtář, 2011).

Examples of rake, trail and wheelbase measurements are displayed in *Table 1* and *Figures 1-4*. However, *Figures 3* and *4* are theoretical values and inaccurate because pieces of information for top-level motorcycles such as MotoGP bikes are not widely available on the internet. *Figures 5-6*, and *Tables 2-3* illustrate the measurement of the horizontal (*X*) and vertical (*Y*) centre of gravity of the motorcycle.

Motorbike type	Racing <i>track racing only</i>	Sports <i>road-going motorbike, high power-to-weight ratio</i>	Touring <i>suitable for long- distance travelling</i>
<i>Handling requirements</i>	← <i>agile</i> <i>stable</i> →		
Caster angle	20°-25°		25°-30°
Normal trail ratio (front/rear)	5-7%	6-8%	7-9%
Front trail (on ground plane)	75-100 mm		90-130 mm
Wheelbase	1300-1500 mm		1400-1600 mm

Table 1. Geometry Measurements (Gadola, et al. 2019).

In addition to the main parameters of a motorcycle geometry, other external factors also have to be considered relative to the equation of motorcycle motion such as:

- Driving force
- Rolling resistance
- Air resistance
- Road plane resistance

Rolling resistance remains constant ($0.02 * \text{mass } (m) * \text{gravity } (g)$) and is one of the resistances that secure linear stability. Road plane resistance $F_p = (m * g * \sin \theta)$ highly relies upon the character of the gradient of the road or track. Air resistance has a quadratic velocity (v^2) as its main element, derived from the motorcycle's top speed in (m/s). Furthermore, the density of air ρ is an additional external factor to consider driven by environmental conditions which can be seen in the equation as $\frac{1}{2} * \rho$ (Šmíraus and Richtář, 2011).

Drag force F_D equation = $\frac{1}{2} * \rho * \text{Coefficient of drag } C_D * \text{Frontal area } A * \text{Velocity } v^2$

Primarily, aerodynamics has a massive impact on designing the external body of a motorcycle, because it contributes significantly high in the total drag of a motorcycle, the frontal area which includes the body shape and position of the rider affects how the motorcycle behaves when in motion, rider influence is one of the visible features that makes the motorcycles' coefficient of drag go higher because the rider and potentially a pillion rider are directly exposed to the upcoming wind flow (Angeletti, *et al.* 2003).

2.1 Rake, Trail, and Wheelbase

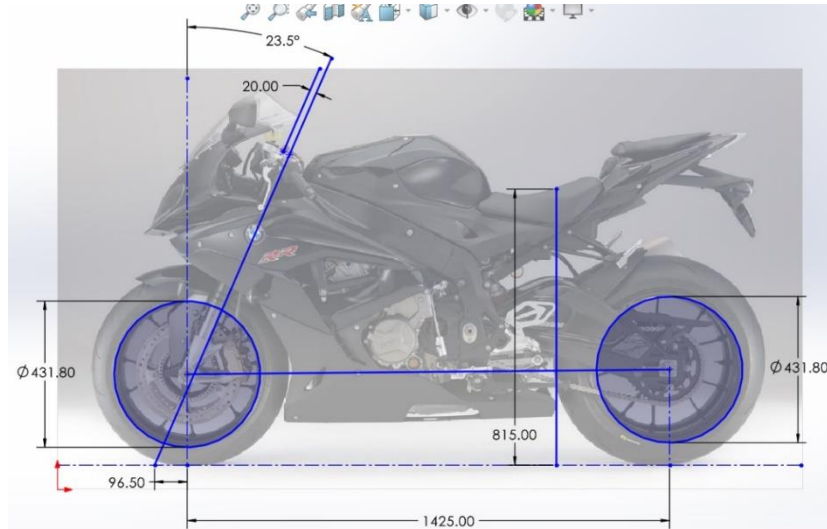


Figure 1. BMW S1000-RR Rake, Trail, and Wheelbase (Aganon, 2022a)

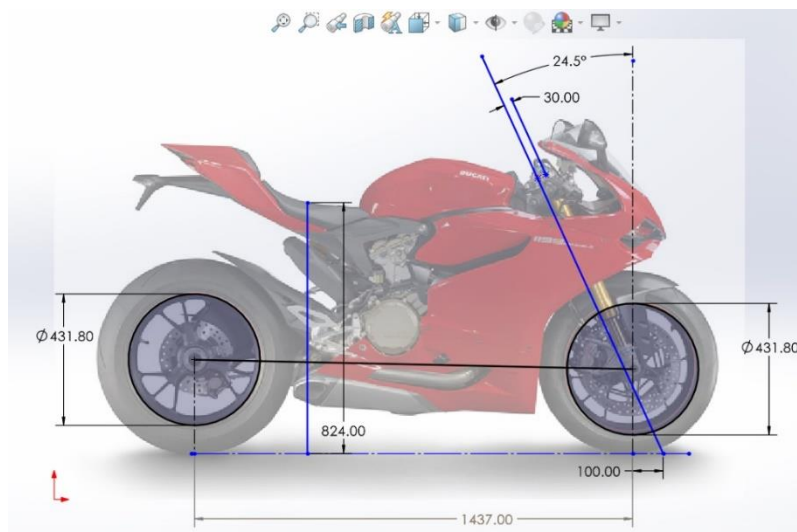


Figure 2. Ducati Panigale 1199-S Rake, Trail, and Wheelbase (Aganon, 2022a)

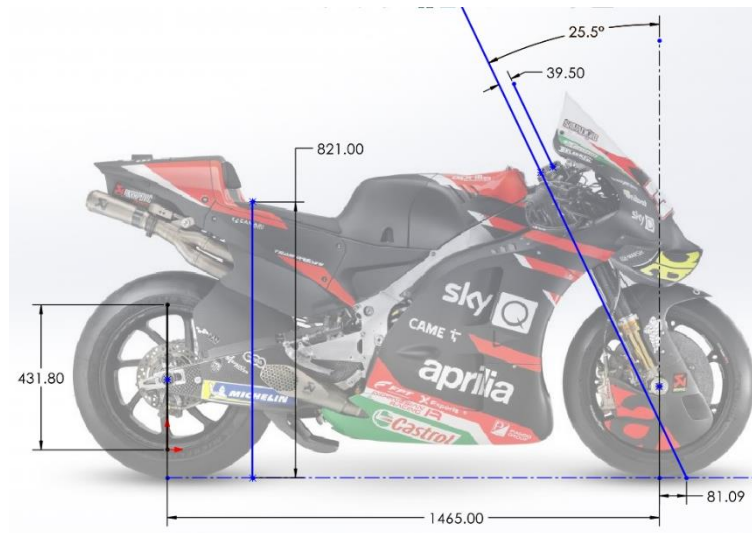


Figure 3. Aprilia RS-GP 2022 Theoretical Rake, Trail, and Wheelbase (Aganon, 2022a)

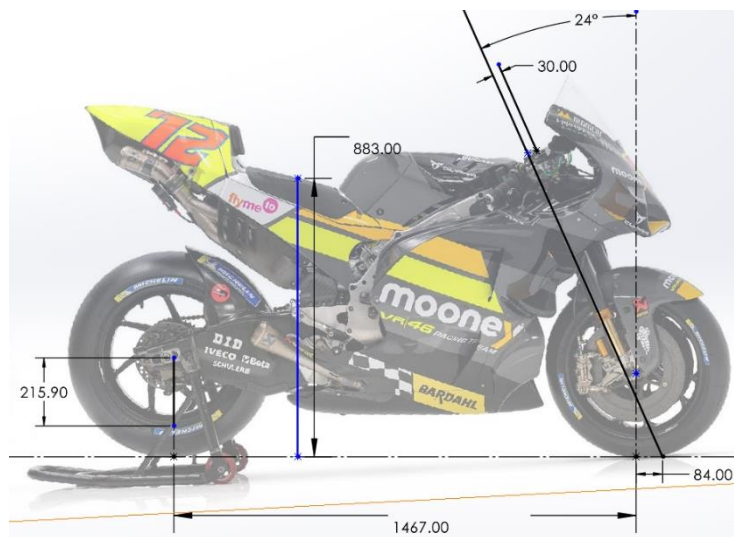


Figure 4. Ducati Mooney 2022 Desmosedici Theoretical Rake, Trail, and Wheelbase (Aganon, 2022a)

2.2 Centre of Gravity

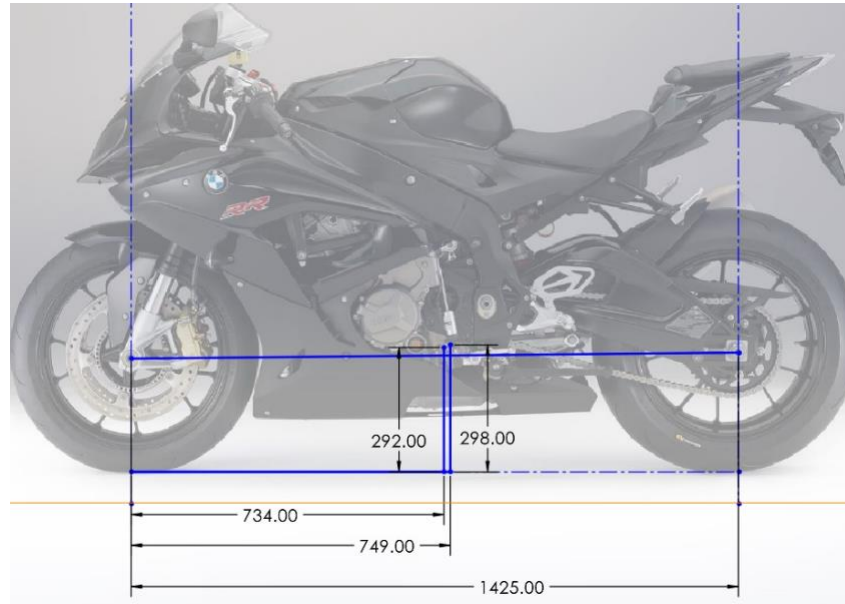


Figure 5. BMW S1000-RR CoG (Aganon, 2022a)

Center of Gravity		Xcog
	Level W/out Rider (<i>m</i>)	0.734
	Level With Rider (<i>m</i>)	0.749
	Ycog	
	Level W/out Rider (<i>m</i>)	0.292
	Level With Rider (<i>m</i>)	0.298
	% of Front	% of Rear
W/out rider	48.48%	51.52%
With rider	49.11%	50.89%

Table 2. BMW S1000-RR CoG Calculation (Aganon, 2022b)

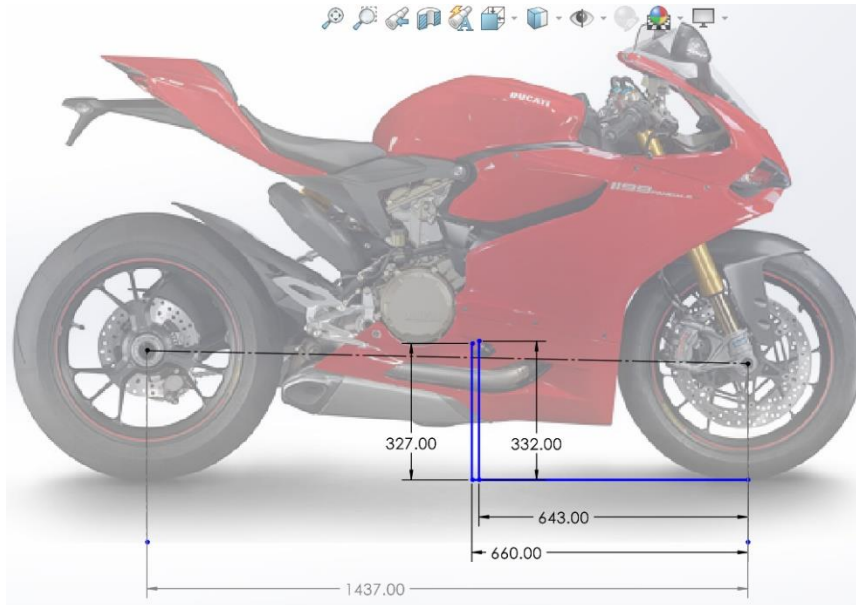


Figure 6. Ducati Panigale 1199-S CoG (Aganon, 2022a)

Center of Gravity		Xcog	
	Level W/out Rider (<i>m</i>)	0.643	
	Level With Rider (<i>m</i>)	0.660	
		Ycog	
	W/out Rider (<i>m</i>)	0.332	
	With Rider (<i>m</i>)	0.327	
		% of Front	% of Rear
	W/out rider	53.08%	46.92%
	With rider	51.72%	48.14%

Table 3. Ducati Panigale 1199-S CoG Calculation (Aganon, 2022b)

2.3 Motion Resistance

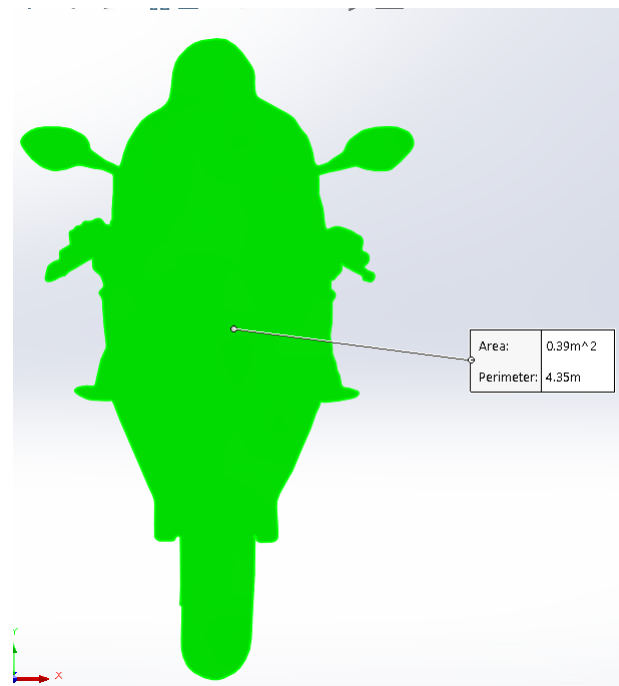


Figure 7. BMW S1000-RR Frontal Area (Aganon, 2022a)

Resistance to Motion				
Coefficient of Drag C_D	0.31		<i>Formula</i>	<i>Total Force Needed</i>
Frontal Area A (m^2)	0.39		$F = FD + FW$	563.32
Top speed in m/s V (m/s)	83.61			
Rho ρ	1.17			
Rolling resistance ($0.02 \cdot m \cdot g$)	0.02		<i>Fomula</i>	<i>Total Power Needed</i>
Mass m	351.15		$P = F \cdot V$	47099.07
Gravity g	9.81			
	0.5			

Table 4. BMW S1000-RR Resistance Calculation (Aganon, 2022b)

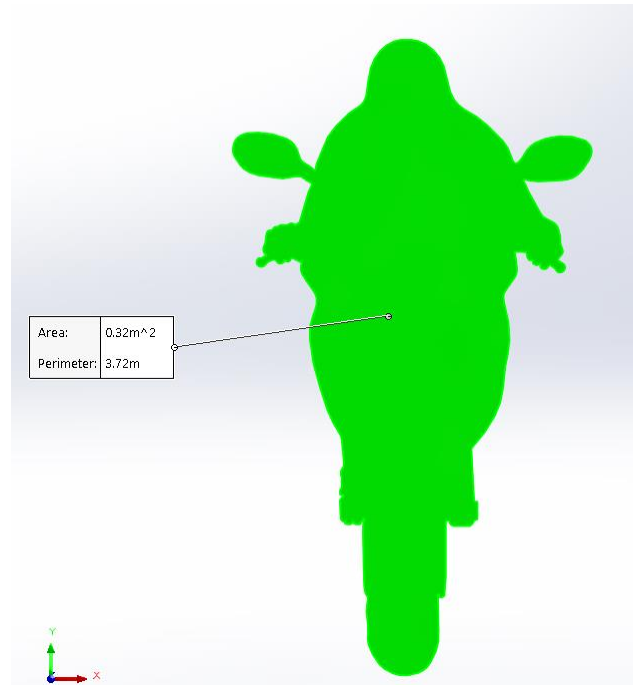


Figure 8. Ducati Panigale 1199-S Frontal Area (Aganon, 2022a)

Resistance to Motion				
Coefficient of Drag C_D	0.26		Formula	Total Force Needed
Frontal Area A (m^2)	0.32		$F = F_D + F_W$	475.58
Top speed in m/s V (m/s)	91.67			
Rho ρ	1.17			
Rolling resistance ($0.02 \cdot m \cdot g$)	0.02		Formula	Total Power Needed
Mass m	333.5		$P = F \cdot V$	43596.69
Gravity g	9.981			
	0.5			

Table 5. Ducati Panigale 1199-S Resistance Calculation (Aganon, 2022b)

3 Analysis

All four bikes are equipped with the same wheel rim diameter of 431.8mm and exhibited relatively similar wheelbase measurements that fall around the 14xx-mm mark with an average of 1448.5mm . An evaluation of rake and trail can only be done properly to the three motorcycles which are the BMW S1000-RR, Ducati Panigale 1199-S, and the MotoGP bike Aprilia RSGP, the S1000-RR has a slightly shorter trail value of 96.5mm and lower rake angle 23.5° compared to the Panigale 1199-S that has a total of 100mm trail with a rake angle 24.5° . The Aprilia RSGP has given the shortest trail with a value of 81.09mm and rake angle of 24° , however, these RSGP values are only theoretical and inaccurate as there were no pieces of information were acquired and the image was only dimensioned using approximation by measuring the wheel rim diameters as MotoGP bikes follow certain regulations one of which is running a 17inch or 431.8mm wheels. In addition, the reason why the chosen two road-legal motorcycle exhibits almost identical wheelbase and rake angle is that super-sports motorcycles are right in the middle in the category of racing and a sports bike as shown in *Table 1*. The reason why the other MotoGP bike was not evaluated and given measurements properly is that the acquired image of the Ducati Desmosedici MOONEY bike has a slightly tilted handlebar angle and it is a difficult task to exhibit an approximate geometry measurement from an image.

For the weight distribution calculation of the two road-legal sports-bike, the results have given a completely different set of values for the front and rear weight distribution. The S1000-RR has a front percentage of 48.48% without the rider with a rear percentage of 51.52%, the other calculation is with the rider having a front percentage of 49.11%, and a rear percentage of 50.89%. The Panigale 1199-S, on the other hand, has a front percentage of 53.08% without a rider and the rear has 46.92%, next value is the front with a total of 51.72% with the rider and the rear has 48.14%. These percentages show that the S1000-RR weight distribution is leaning more towards the rear of the bike and the Panigale 1199-S is the complete opposite with its weight being distributed more towards the front.

The wheelbase and centre of gravity play a primary role during the acceleration and the braking because both are accountable for the large mass transfer between the front and the rear wheels. By changing the wheelbase and the mass distribution it is possible to influence its maximum acceleration and maximum deceleration. When the optimum acceleration is desired the mass should be moved from the rear towards the front, due to the high torque output of such powerful super-sport bike engines the front end of the bikes tend to be lifted up into the air also known as “wheelie” typically undesirable in a racing perspective the ideal launch is when both wheels stay planted into the ground, therefore wheelie could decrease the linear acceleration and momentum of the launch. Similarly, with the pursuit of optimum deceleration, the opposite is required, the mass should be moved from the

front towards the rear as the rear end of the bike tends to shift most of its weight towards the front during an extreme braking situation where the rear wheel disengages from the ground that results to losing stability and control. Therefore, incorrect positioning of the centre of gravity could weaken the advantages of the wheelbase.

4 Conclusion

Extensive work on aerodynamics and creating an improved fairing for the BMW S1000-RR to improve the flow around the motorcycle and lessen the exposure of the rider and/or pillion rider to the wind flow with regards to the riding position and riding style of the motorcycle as it currently has a $C_D = 0.31$ and $A = 0.39$ including the rider, compared to the Ducati Panigale 1199-S that has a much lower $C_D = 0.26$ and $A = 0.32$ with the rider. By doing so, a decrease in drag should be achieved giving better aerodynamic performance and resulting in more fuel efficiency and an increased top speed.

5 References

- Aganon, M.C. (2022a). *Rake, Trail, and Wheelbase*. Dassault Systemes: Solidworks
- Aganon, M.C. (2022a). *Centre of Gravity*. Dassault Systemes: Solidworks
- Aganon, M.C. (2022a). *Frontal Area*. Dassault Systemes: Solidworks
- Aganon, M.C. (2022b). *Centre of Gravity Calculations*. Microsoft: Excel
- Aganon, M.C. (2022b). *Resistance Calculations*. Microsoft: Excel
- Angeletti, M. *et al.* (2003). *The Role of CFD on the Aerodynamic Investigation of Motorcycles*. Available at: <https://doi.org/10.4271/2003-01-0997>.
- Gadola, M. *et al.* (2019). The Design of A Motorcycle Featuring Fully Independent Adjustability for Front Suspension and Steering Geometry. *IOP Conference Series. Materials Science and Engineering*, 538(1), 12064–. <https://doi.org/10.1088/1757-899X/538/1/012064>
- Jakub Šmiraus , Richtář, M. (2011). ‘DESIGN OF MOTORCYCLE ACTIVE CHASSIS GEOMETRY CHANGE SYSTEM’ (2011) *Perner’s contacts*, 6(4).