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Motorcycle Geometry Analysis and Dynamic Handling Investigation

ACHA 4003

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1 Introduction

This Essay will look at the handling concepts and the influence they have on a vehicles handling characteristics. Two motorcycles were chosen, a Kawasaki Ninja 400, and a Ducati Panigale. The centre of gravity (CoG) was calculated for both motorcycles. Further measurements were taken, such as the motorcycles geometry, for example, the rake and trail. Once these measurements had been completed, schematic diagrams were then made.

Secondly these were then compared to a further two motorcycles, a Moto 3 Honda NSF250R and a World Superbike Ducati Panigale to compare how a races ready model compares with road going counterparts.

Lastly, using the Kawasaki, gear ratios were used to calculate the motorcycles theoretical top speed. Using this information, the resistance to motion was needed, calculating the forces acting against the motorcycle, such as drag and rolling resistance. Resulting in enough data to see if the top speed was achievable.

2 Geometry Data

2.1 Kawasaki Ninja 400 2020

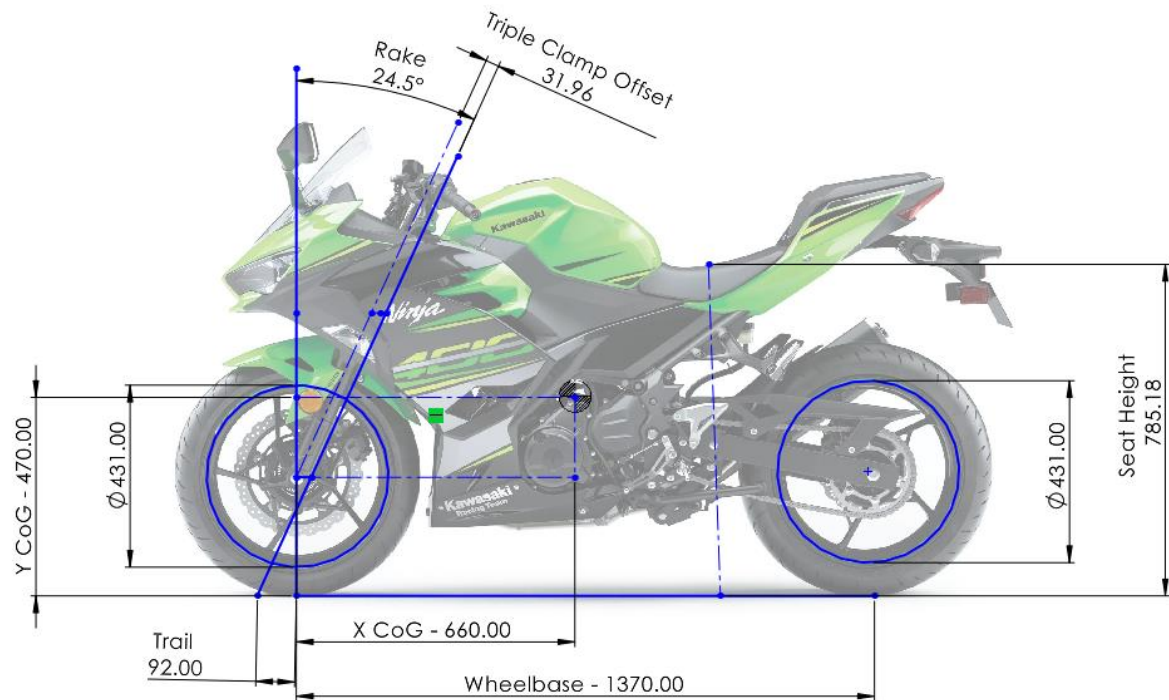


Figure 1 Kawasaki Ninja 400 Dimensions in mm (Vine, 2022)

2.2 Ducati Panigale 2012

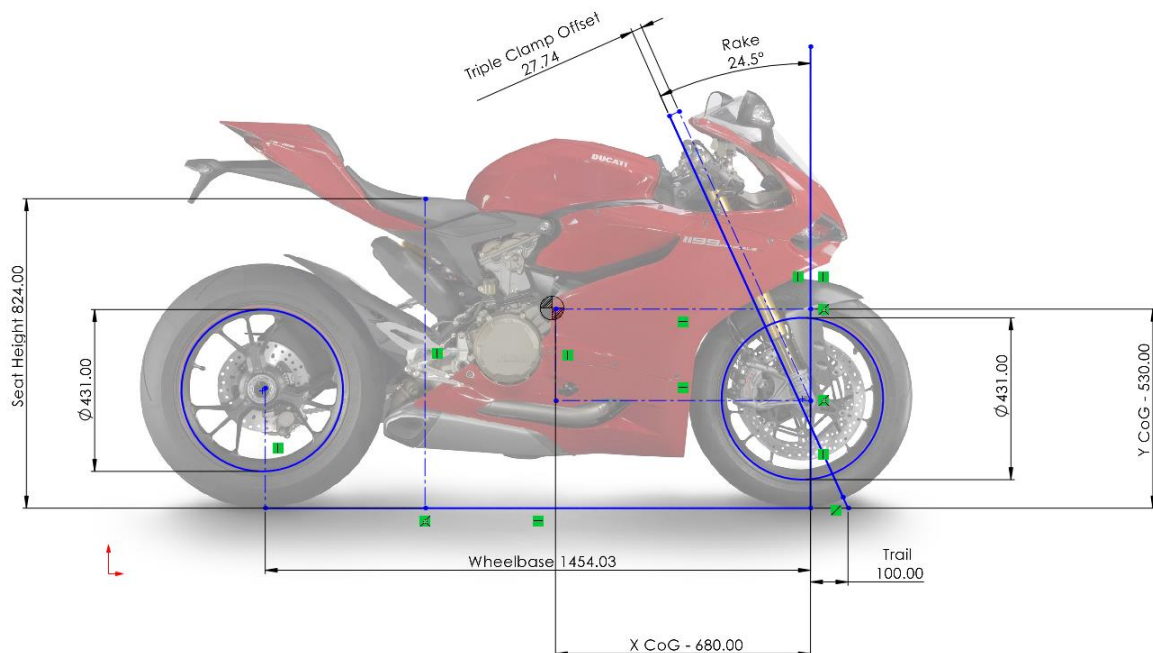


Figure 2 Ducati Panigale 2012 Dimensions in mm (Vine, 2022)

2.3 Centre of Gravity

The CoG was measured for both motorcycles, the CoG in *figure 1* and *figure 2* is without a rider.

The X CoG was calculated using

$$X_{CoG} = \frac{(W_r \times L)}{W_t}$$

In which

Wr – Load on the rear wheel

Wt – The total mass of the motorcycle

L = Wheelbase

The Y CoG was then calculated using

$$Y_{CoG} = \frac{L \times (W_r - W_{lifted})}{W_t \times \tan\theta} + R_{av}$$

In which

Rav = Average wheel radius

Wrlifted = The load on the rear wheel when elevated on a stand

θ = The angle of the bike whilst on the stand.

(Harrison, 2022)

Tables 1 to 4 are calculated using the above method, with and without the rider. The percentage load was also calculated.

Kawasaki Ninja 400 (Without Rider)							
Wr	79.68kg					X CoG	.66m
Wf	86.32kg			Fwr	.31m	Y CoG	.47m
Wt	166.kg			Rwr	.32m		
Rav	.32m			Rav	.315m	% Load F	52.
θ	14.26°					% Load R	48.
Wb	1.38m			Wheelbase	1.38m		
Wr-Lifted	74.2kg			Elevation	.34m		

Table 1 Ninja CoG without rider (Vine, 2022)

Kawasaki Ninja 400 (With Rider)							
Wr	122.5kg					X CoG	.72m
Wf	111.5kg			Fwr	.31m	Y CoG	.67m
Wt	234.kg			Rwr	.32m		
Rav	.32m			Rav	.315m	% Load F	47.65
θ	14.26°					% Load R	52.35
Wb	1.38m			Wheelbase	1.38m		
Wr-Lifted	104.8kg			Elevation	.34m		

Table 2 - Ninja 400 CoG with rider (Vine, 2022)

Ducati Panigale (Without Rider)							
Wr	87.7kg					X CoG	.68m
Wf	99.2kg			Fwr	.31m	Y CoG	.53m
Wt	186.9kg			Rwr	.32m		
Rav	.32m			Rav	.315m	% Load F	53.08
Θ	13.56°					% Load R	46.92
Wb	1.45m			Wheelbase	1.45m		
Wr-Lifted	81.kg			Elevation	.34m		

Table 3 - Ducati CoG without rider (Vine, 2022)

Ducati Panigale (With Rider)							
Wr	129.1kg					X CoG	.72m
Wf	130.75kg			Fwr	.31m	Y CoG	.64m
Wt	259.85kg			Rwr	.32m		
Rav	.32m			Rav	.315m	% Load F	50.32
Θ	13.56°					% Load R	49.68
Wb	1.45m			Wheelbase	1.45m		
Wr-Lifted	115.kg			Elevation	.34m		

Table 4 - Ducati CoG with rider (Vine, 2022)

3 Handling Characteristics

3.1 Rake and Trail

The rake angle is taken by drawing two lines, the first line being vertical and passing through the centre of the front wheel, and the second line passing through the centre of the steering yoke, as seen in *figure 1* and *2*. The rake angle for both road and racing motorcycles will sit between 22 and 29 degrees (Bradley, p110, 1996). The rake value depicts the speed in which the motorcycle will respond to the movement of the front wheel. The smaller the rake angle, the more immediate the reaction (Berry, 2020). Taking this into account along with the earlier range of 22-29. The Kawasaki and the Ducati both sit with a low rake angle of 24.5 degrees. You would expect both motorcycles to be very agile before looking at both trail and wheelbase, which will lead to one motorcycle having a handling advantage over the other, as arguable trail has more influence on steering behaviour.

The value of trail is related to the rake value, an increase in rake should result in an increase of trail. The value of trail is also dependant on the wheelbase. Ranges of trail can sit between 90-100mm in touring and sports motorcycles (Cossalter, p5, 2006). To measure the trail, a line must be drawn through the horizontal distance from the point in which the tyre contacts the road, to the point where a line drawn down through the steering axis would contact the road, this can be seen in *figure 1* and *2*. A larger trail value tends to mean more stability, looking at the Kawasaki with a trail value of 92mm, and the Ducati with a value of 100mm. Without looking into suspension set up and the loads on the motorcycle, the rake and trail figures alone are not sufficient to determine the optimal stability of the motorcycle.

3.2 CoG

When the Ducati has a rider onboard, the CoG nearly sits at a perfect 50/50 bias, compared with its unladen weigh bias of 53.08% front and 46.52% rear. Whilst the Kawasaki's unladen CoG sits 52% on the front and 48% on the rear, once the rider is placed onto the bike the weight bias switches and goes to the rear, at 47.65% on the front and 52.35% on the rear. The CoG can cause and resolve certain limiting conditions, such as front wheel lift on acceleration or rear wheel lift when braking. Looking at the Kawasaki, the rear end bias is compensated by the lack of power available, a negative to this is that the motorcycle will also not handle as well, compared to having a more lightweight rider and a more central CoG location.

3.3 Wheelbase

Firstly, looking at wheelbase and its importance in how a motorcycle handles. With different capacity motorcycles, once the wheelbase exceeds a certain length, it changes the handling dramatically. For example, once a 125cc exceeds 1310mm it would start to feel more like a 250cc then over 1250mm a 250cc motorcycle would resemble the handling characteristics of a 500cc (Bradley, p109, 1996). So, looking firstly at the Kawasaki, with its 400cc engine and its relatively short wheelbase of 1370mm. it can be assumed a wheelbase of this length, along with its seat height of 785.18mm, has been chosen so the motorcycle can accommodate larger riders. With this wheelbase and its ground clearance of 140mm (Sorap, 2022), it should be quite a nimble motorcycle and capable of some respectable lean angles. The Ducati, with its wheelbase of 1454mm, fits in with which would be expected from a sports bike, as the average wheelbase for a sports bike sits at 1444mm (sportbikeplanet.com, 2022) giving the Ducati the manoeuvrability that would be expected off a motorcycle of this calibre. It must be noted that the wheelbase is liable to change when considering chain tension and sprocket variations. This could be anything from 20-40mm (Bradley, p104, 1996).

4 Theoretical v Calculated Top Speed

4.1 Theoretical Top Speed Calculations

RPM	Power (hp)	Torque (nm)	Power (kw)
3000	10	21.69	7.46
3500	12	21.02	8.95
4000	13	22.37	9.69
4500	17	25.76	12.68
5000	20	29.83	14.91
5500	22	29.15	16.41
6000	24	28.47	17.90
6500	26	29.83	19.39
7000	30	30.51	22.37
7500	34	31.18	25.35
8000	36	33.90	26.85
8500	40	33.90	29.83
9000	41	33.22	30.57
9500	42	31.86	31.32
10000	44	31.18	32.81
10500	43	29.83	32.07
11000	42	28.47	31.32
12000	41	21.69	30.57
12500	36	20.34	26.85

Table 5 - Power and Torque (Vine, 2022)

Table 6 - Road speed through the gears (Vine, 2022)

Road Speed (km/h)					
1st gear	2nd gear	3rd gear	4th gear	5th gear	6th gear
18.18	25.90	32.89	39.93	46.14	51.34
21.21	30.22	38.37	46.59	53.84	59.90
24.24	34.54	43.85	53.24	61.53	68.46
27.27	38.85	49.33	59.90	69.22	77.01
30.30	43.17	54.81	66.55	76.91	85.57
33.33	47.49	60.29	73.21	84.60	94.13
36.36	51.80	65.77	79.87	92.29	102.68
39.39	56.12	71.25	86.52	99.98	111.24
42.42	60.44	76.73	93.18	107.67	119.80
45.45	64.76	82.21	99.83	115.36	128.36
48.48	69.07	87.70	106.49	123.05	136.91
51.51	73.39	93.18	113.14	130.74	145.47
54.54	77.71	98.66	119.80	138.43	154.03
57.57	82.02	104.14	126.45	146.12	162.58
60.60	86.34	109.62	133.11	153.81	171.14
63.63	90.66	115.10	139.76	161.51	179.70
66.66	94.98	120.58	146.42	169.20	188.25
72.72	103.61	131.54	159.73	184.58	205.37
75.75	107.93	137.02	166.39	192.27	213.93

Driving Force (Nm)						
1st	2nd	3rd	4th	5th	6th	
	1477	1036	816	672	582	523
	1519	1066	840	691	598	538
	1440	1010	796	655	567	510
	1673	1175	925	762	659	593
	1772	1244	980	807	698	627
	1772	1244	980	807	698	627
	1772	1244	980	807	698	627
	1772	1244	980	807	698	627
	1898	1333	1050	864	748	672
	2008	1410	1110	914	791	711
	1993	1399	1102	908	785	706
	2085	1463	1152	949	821	738
	2018	1416	1116	919	795	715
	1958	1375	1083	892	772	693
	1949	1368	1078	887	768	690
	1814	1273	1003	826	715	642
	1691	1187	935	770	666	599
	1513	1062	837	689	596	536
	1276	895	705	581	503	452

Table 7 - Driving force throughout the gears (Vine, 2022)

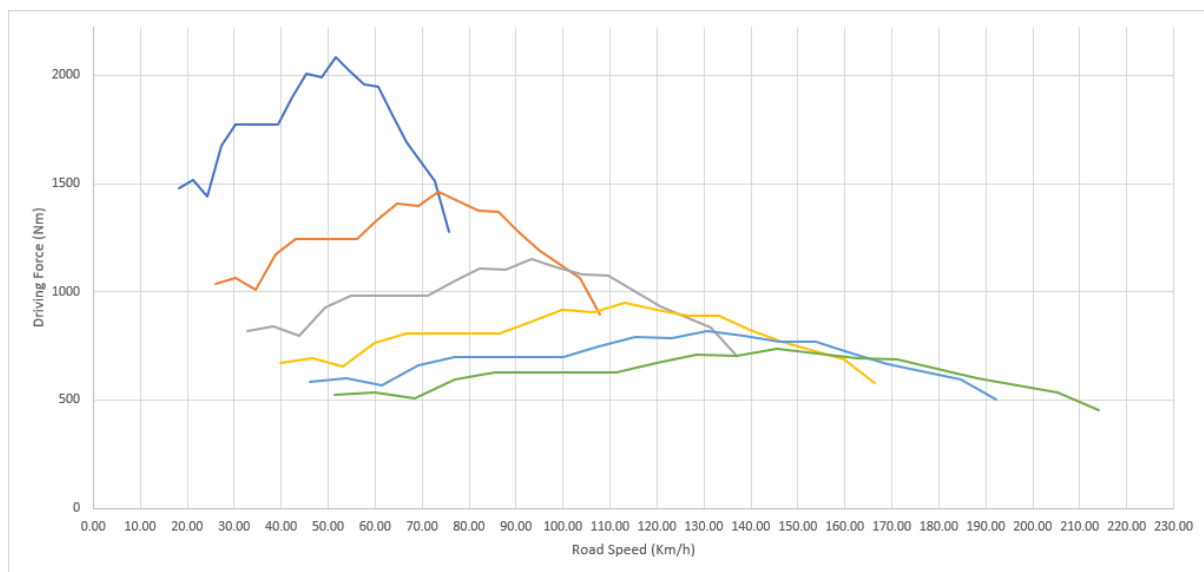


Figure 3 - Driving Force v Road Speed (Vine,2022)

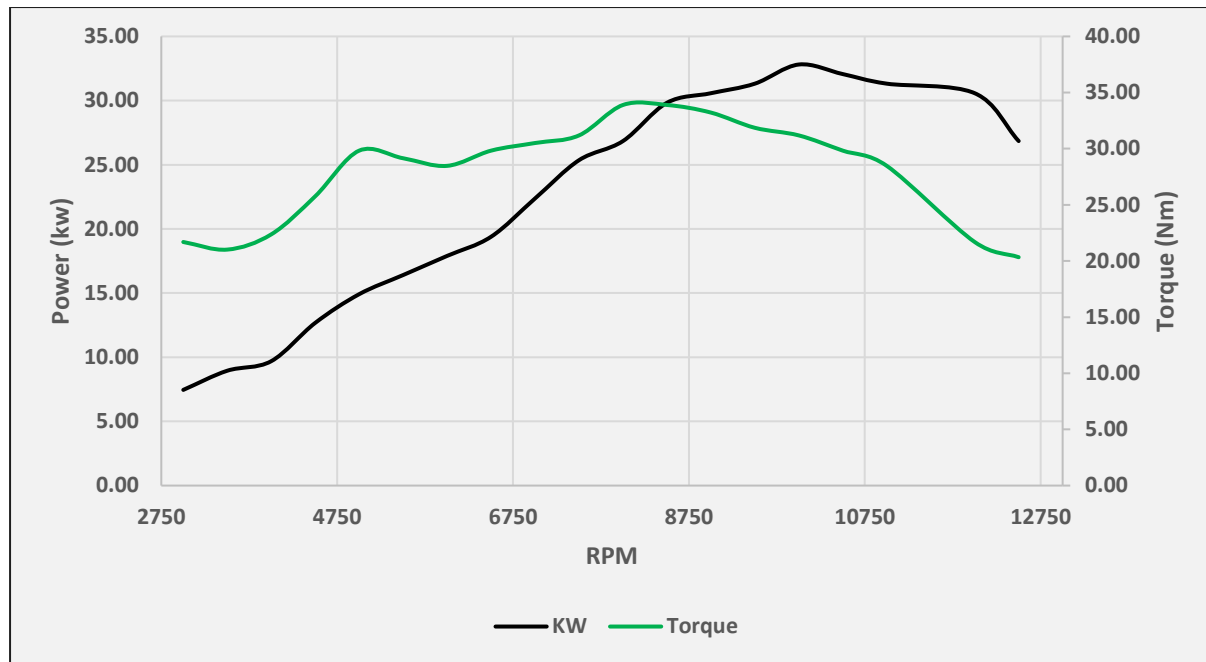


Figure 4 - Power curve, using torque and KW against rpm (Vine,2022)

4.2 Resistance to Motion

To calculate the forces acting against the motorcycle, first the specific resistances must be considered. The aerodynamic drag of the vehicle was calculated using

$$F_D = \frac{1}{2} \rho \times C_D \times A \times V^2$$

$$\rho = 1.167 \text{ kg/m}^3 \quad C_D = 0.6 \quad A = 0.59 \text{ m}^2 \quad V = 59 \text{ m/s}$$

(Harrison, 2022)

The air density (ρ) 1.167 kg/m^3 was used. As sporting motorcycles have a drag coefficient around 0.4-0.6, the value of 0.5 was chosen (Cossalter, p76, 2006). The frontal area with a rider was then measured, giving the value of 0.59 m^2 for A and lastly, the velocity is the top speed of 213 km/h as seen in table 6, converted into m/s . The resulting aerodynamic drag is 607.86 N .

The Rolling resistance was then calculated using

$$F_W = 0.02 \times m \times g$$

0.02 as the number for rolling resistance for general asphalt (x-engineer.org, 2022), multiplied by mg , the combined weight of motorcycle and rider, 234 kg and gravity at 9.81 m/s^2 . Giving a total rolling resistance of 45.91 N . Combining the aerodynamic drag and the rolling resistance brings to total resistance to 653.77 N .

Lastly using $P = F \times V$ to find out the power needed in Watts. Power needed to reach the theoretical top speed is 38850.14 W .

4.3 Is the top speed achievable?

With the maximum power needed being 38 kW to reach the theoretical top speed of 213.93 km/h as seen in table 6 and looking at table 5, the maximum kW produced by the motorcycle was 32.81 . The Kawasaki would not reach the theoretical top speed.

5 Further Research on Geometry

5.1 Moto 3 Honda NSF250R

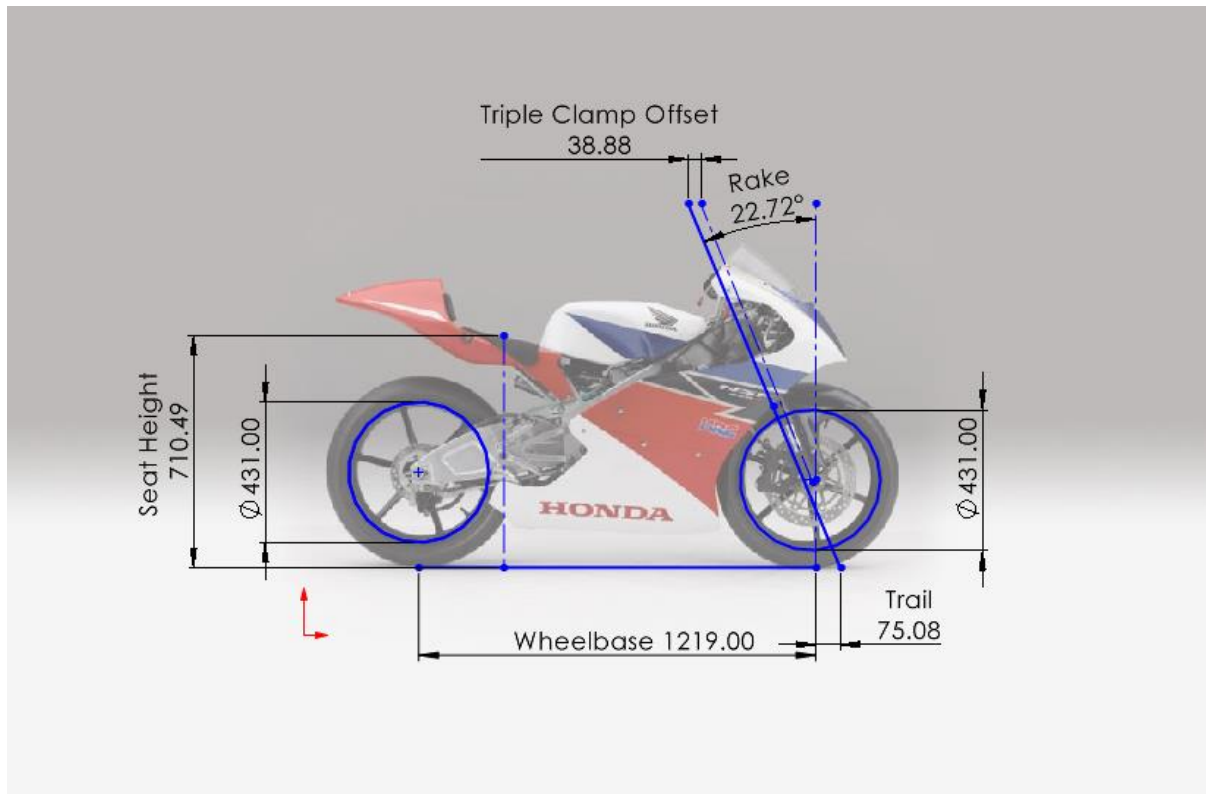


Figure 5 - Honda NSF250R Moto 3 dimensions in mm (Vine, 2022)

A motorcycle that was built for rookie classes and heavily influenced by a Honda 125 chassis to help keep the dimensions small, suiting more lightweight riders. As seen in *figure 5* its short wheelbase and trail of 75.08mm will make for an incredibly nimble motorcycle. The low seat height designed for a tucked in rider is then complimented by the lightweight 86kg (motorcyclespecs.co.za, 2022), resulting in a motorcycle that is very much track ready. Honda also changed the angle of the cylinder by inclining it 15 degrees to the rear to aid the concentration of mass (padgettsmotorcycles.com, 2022).

5.2 World Superbike Ducati Panigale V4 R

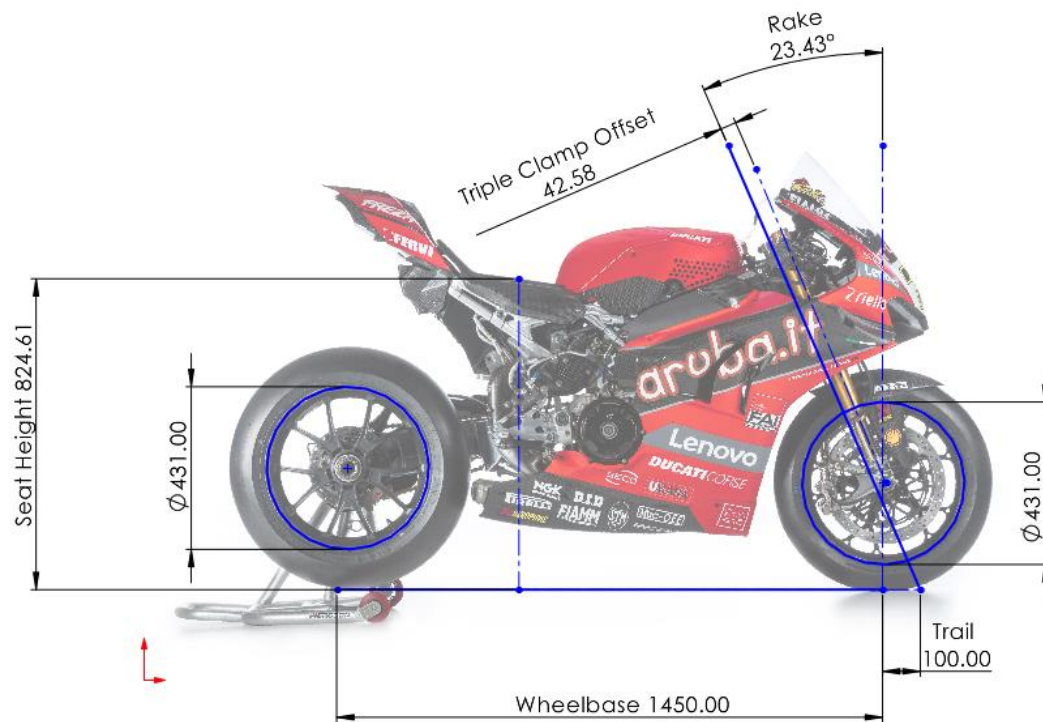


Figure 6 - WSBK Ducati Panigale dimensions in mm (Vine, 2022)

With dimensions not too dissimilar as seen in *figure 2* with the road going Panigale, a slight difference in rake and triple clamp offset can be seen. The difference when it comes to racing, will be the amount of adjustability on the V4 R in comparison to the road going version. If the geometry was to be looked at over a race weekend the differences may be more obvious.

6 Improving Handling Characteristics

Taking into account the topics covered in this essay, improvements that would be considered on the Kawasaki would be to aim for a better weight balance, as to minimise front wheel lift on acceleration and also front wheel locking upon braking. Also, a CoG which is too far back could cause the characteristic of understeer.

Looking at making the Kawasaki more track focused, changes could include extending the wheelbase to increase stability at higher speeds, this could be achieved by extending the swingarm marginally, thus bringing some of the weight forward. Trail would be something that would be increased. To avoid making drastic changes to the suspension and ride height, an adjustable triple clamp would be installed, to make adjustment in small increments. Lastly, after calculating the top speed, aerodynamics could be looked at to lower the drag coefficient, closing the gap on the theoretical top speed.

7 Conclusion

To conclude, looking at the basic geometry of a motorcycle, it has shown that the relationship between parts of the vehicle and how changing one aspect can directly affect the handling characteristics. Meaning that when making changes to the motorcycle, care must be taken to aware of the geometry changes that could happen as a result of even the smallest change elsewhere on the motorcycle.

7.1 Further Work

Improvements to the CoG calculations could have been made by considering more aspects of the motorcycle, such as a tank of fuel and a full radiator. Looking at individual CoG location of each major item could also improve the accuracy.

Word Count: 1547

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