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Effect of Rider Position on the Energy Consumption of an Electric Motorcycle

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***Abstract*— Unlike other transport vehicles, the rider of a motorcycle contributes to the change of frontal area and drag coefficient during riding as their position changes, and therefore, rider position can directly affect energy consumption. This manuscript systematically investigates the effects of variations in combined drag coefficient and frontal area on electric motorcycle (EM) range over the World Motorcycle Test Cycle (WMTC) 3.2 standard drive cycle. The combined drag coefficient and frontal area (CdA) values were measured in a full-scale wind tunnel using a rider who was fully kitted in separate leathers as opposed to single piece race suits. A vehicle longitudinal backwards-facing model was used to estimate the effect of different riding position on motorcycle energy consumption. A decrease of 30% in the product of drag coefficient (Cd) and frontal area (A) through changing from an upright to a tucked-in position leads to a decrease of up to 19% in terms of energy consumption.**

Keywords—electric motorcycle, vehicle range, energy consumption, rider position, rider posture

I. Introduction

Electric Vehicles (EV) are demonstrating considerable (17-30%) CO_2 emissions savings compared to conventional vehicles across multiple transport sectors [1]. This is also true for the Electric Motorcycle (EM) sector, despite being in its infancy compared to electric passenger cars [2]. The EM segment tends to suffer with negative publicity around the differences between published and actual range achieved by users. This is partly contributed by the differences in how a user actually uses the motorcycle in comparison to standardised drive-cycles that are used to publish range such as the Worldwide harmonised Motorcycle Test Cycle (WMTC).

One of the other contributions is more unique to the EM sector in comparison to other transportation products; the effective frontal area (A) and drag coefficient (Cd) can change quite significantly depending on the rider's position or lean angle. This has an effect on the combined motorcycle/rider drag coefficient and frontal area product (CdA) which in turn has an impact on energy consumption, particularly at higher speeds where the aerodynamic drag dominates resistance to motion forces. This makes accurate prediction of EM range challenging as even for the same speed-time profile, riders who are more upright will generate a higher energy consumption than those who are more tucked-in. Furthermore, the tendency of a rider to lean during turning can also contribute to this and overall range achieved by a vehicle.

Although there has been a significant amount of study undertaken around motorcycle aerodynamics [3,4], these are largely focused on the fundamentals of motorcycle design (bodywork, windshield) or performance improvement in a computational environment [5,6]. In the previous studies, the motorcycle and rider are not considered together while evaluating aerodynamics, and the fundamental output of improving aerodynamic behaviour in commercially available vehicles are not evaluated.

This manuscript reports measurements of 4 motorcycles (2 conventional and 2 electric) combined with powertrain simulations to determine the magnitudes of the effects of rider position on energy consumption in Wh/km for WMTC3.2 standard drive cycle.

II. Measurements of Frontal Area and Drag Coefficient

For this study four motorcycles and three rider positions were considered. These motorcycles were considered as they covered a suitable range of performance and rider positions (ergonomics) across different powertrain categories, considering electric and conventional internal combustion engines. The motorcycles measured were Ducati V4S, Triumph Street Triple, which are petrol motorcycles, and Harley Davidson (HD) LiveWire and Energica Ego+RS, which are electric motorcycles. Depending on ergonomics of the motorcycle, the rider can usually be sat in one of three fundamental positions (upright, fully tucked-in or something in the middle). These positions are shown in Figure 1. An average rider, riding on real-world roads would typically only transition between upright or 'mid' positions according to their preferred riding behaviour. In contrast, the tucked-in is an extreme position that is specific to sports bikes or high-performance use-cases such as track days.

The CdA values were measured in a full-scale wind tunnel using a rider who was fully kitted in separate leathers (as opposed to single piece race suits). The motorcycle under test was arranged such that there was zero yaw angle and the wind speeds used were in the range of 17-35m/s, which is equivalent to up to 126 km/h vehicle speed, to match the maximum speed of the WMTC drive cycle. Figure 1 shows the rider positions during the testing for the Energica Ego+RS.

Fig. 1. Rider Positions for Wind Tunnel Testing, from Left to Right; Upright, Mid-position, Tucked-in.

The test itself was repeated on each vehicle and in each position to understand the possible variability. Figure 2 shows the result variability from the Energica Ego+RS. The tests also had certain limitations such as the absence of a rolling road. A rolling road might lead to the build-up of a large boundary layer at the tunnel floor in front of the bike. Also, rotating

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wheels on a two-wheeler application can contribute to the overall drag [7], which cannot be observed in the test. In addition, as the bikes were stationary and the engine is not running, any effect caused by moving chains or heat from engine is also not accounted for.

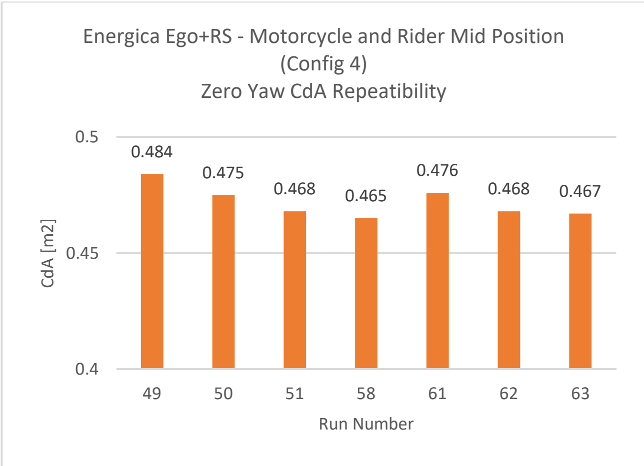

Fig. 2. Energica Ego Zero Yaw Mid Repeatability

Figure 3 shows the rider position angle β, measured between knee, hip and shoulder. Table 1 shows the actual measured angle β for each tested vehicle and rider positions upright, mid and tucked-in. Table 2 shows the drag coefficient and frontal area (CdA) values for the relevant rider positions. Figure 4 shows the effect of CdA for each rider position for Energica and Ducati for different windspeeds.

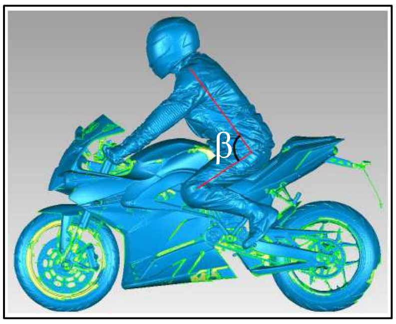

Fig. 3. Rider Position Angle, Measured Between Knee, Hip and Shoulder for Each Tested Vehicle

TABLE I. RIDER POSITION ANGLE, MEASURED BETWEEN KNEE, HIP AND SHOULDER FOR EACH TESTED VEHICLE

	Angle of Rider Position (deg)		
Motorcycle	**Upright**	**Mid**	**Tucked-In**
Energica Ego+RS	88	68	51
Street Triple	97	87	48
H-D LiveWire	95	69	42
Ducati V4S	77	-	44

TABLE II. C_DA (m^2) VALUES FOR THE 4 MOTORCYLES AND 3 RIDER POSITIONS

Motorcycle	**Bare Bike**	**Bike + Upright**	**Bike + Mid**	**Bike + Tucked-In**
Energica Ego+RS	0.297	0.500	0.472	0.347
Street Triple	0.269	0.590	0.578	0.425
H-D LiveWire	0.259	0.569	0.504	0.423
Ducati V4S	0.308	0.499	Not Measured	0.325

Although the combined CdA for all four tested vehicles (bare bike) is quite similar, there is a notable difference in the measured values when the addition of the rider. The Ducati V4S and Energica Ego+RS are similar as the two sports bikes, and Triumph Speed Triple and H-D LiveWire are similar as two street bikes. This is an expected observation due to the ergonomic style of the two categories of motorcycles tested, the sports bike aside from being fully faired also offer more 'aggressive' rider position. As a result, the combined drag (motorcycle and rider together) is reduced while keeping the frontal area comparatively small.

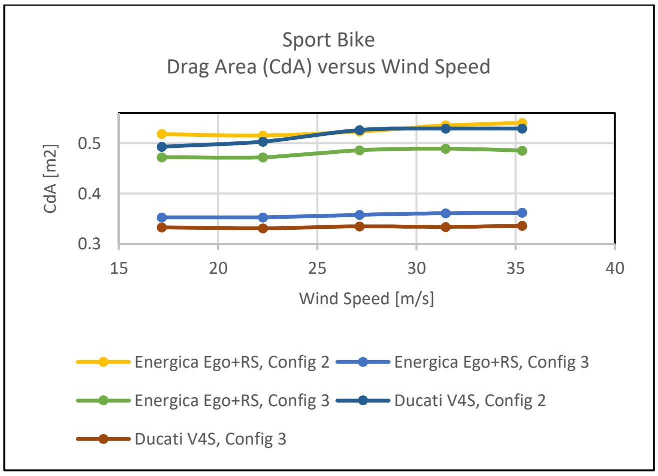

Fig. 4. Variation of CdA on Windspeed for Sports Bikes Energica Ego+RS and Ducati V4S

III. Model Development

As defined by [8], the total force that is required to be overcome by a vehicle can be split into four categories, which are acceleration, aerodynamic drag, slope and rolling friction. The slope and frictional components are largely defined by the road elevation or friction; acceleration by the mass and actual rate of acceleration; the drag component is the only one that contains a variable which is fundamental, and can be controlled by the motorcycle design i.e. frontal area and drag coefficient.

Utilising the vehicle longitudinal backwards-facing model tool from [8], the WMTC3.2 drive cycle can easily be represented as the portion of each of these four force components as shown in Figure 5. It is evident that a large portion of the force required to meet the drive cycle is associated with the aerodynamic effect of the vehicle, which will only increase with real-world use-cases that operate at much higher speed. The maximum vehicle speed in WMTC3.2 is 125 km/h.

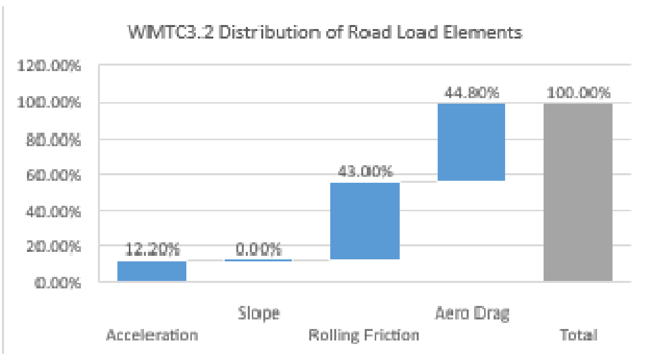

Fig. 5. WMTC3.2 Average Distribution Across the Four Road Load Components

IV. Range Sensitivity

The model was used to estimate the energy consumption in Wh/km of all four motorcycles over the standard WMTC 3.2 drive cycle. This was calculated at the wheel so was independent of powertrain efficiency for the purposes of this study.

Table 3 shows the estimated energy consumption obtained from the published range figures and the percentage effect on range for different rider positions; a negative percentage represents a reduction in energy consumption.

The energy consumption for the electric motorcycles was estimated based on the published range figures and the usable battery capacity in kWh. The measured CdA values in each rider position were then used to understand how the consumption changed. Interestingly, the Energica Ego+RS matched the published consumption in 'Upright' condition. However, the H-D LiveWire showed a predicted range close to the real-world range with a rider position between mid and tucked.

The conventional ICE motorcycles Ducati V4S and Triumph Street Triple had their baseline energy consumption calculated by using published specification of vehicle weight and measured CdA value in upright condition. These calculations were done using the model referenced above [8]. As a result, the upright condition for the ICE vehicles is represented as 0.0% as the default or baseline.

TABLE III. Estimated Energy Consumption in Wh/km for the WMTC3.2 Drive Cycle and percentage differences for Different Rider Positions

Motorcycle Model	Estimated Published	Upright	Mid	Tucked-In
Energica Ego+RS	105.0	0.0%	-4.16%	-18.77%
Street Triple	106.7	0.0%	-1.42%	-19.5%
H-D LiveWire	98.0	+12.16%	+5.3%	-4.66%
Ducati V4S	96.3	0.0%		-22.47%

The tucked-in position clearly represents the optimum riding position for improving energy consumption, by approximately 20%, however this potentially comes at the expense of rider comfort. One conclusion from this study is that when testing, particularly electric, motorcycles for range and energy certification, a standardised rider position is recommended to be used to ensure representative results across different motorcycle types.

V. Conclusions

This study demonstrates that rider position can have a relatively large (~20%) effect on energy consumption of motorcycles over the standard WMTC3.2 drive cycle. The work reported here is currently limited to the WMTC3.2 drive cycle. As a further study it is suggested to investigate the effects of rider position on energy efficiency for other drive cycles including higher speeds to discuss the wider significance of the results.

Acknowledgements

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