

UWTSD

WISA



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Kinetic Energy Recovery Alternative Propulsion Systems (ACHA5010)

Finn Flye

2304833

November 2025

Contents

1	Introduction	v
1.1	Justification.....	v
2	Panigale S 1199 Dynamics Characteristics.....	vi
3	WLTP Cycle.....	viii
3.1	Forces Calculations.....	ix
3.2	Forces Graph	x
3.3	Power Against Time Graph	xi
4	Tractive and Braking over WLTP Cycle	xii
5	KERS.....	xiii
5.1	KER System	xiv
5.1.1	Mechanical Flywheel	xiv
5.1.2	Battery Based Systems	xiv
5.2	KERS Calculations.....	xv
6	System Overview.....	xvii
7	Conclusion	xix
8	References	xx

Figure 1 figure showing the overall dimensions of the bike which will be used to calculate the frontal area (F. Flye, 2024)	vii
Figure 2 Graph showing the Vehicle speed over the total elapsed time for the WLTP cycle of a class 3 vehicle (F. Flye, 2025)	viii
Figure 3 Graph showing the four forces the vehicle is subjected to (F. Flye, 2025)	x
Figure 4 Graph showing the Power accumulated over Total elapsed time (F. Flye, 2025)	xi
Figure 5 Graph Produced in MATLAB showing the cumulative tractive and braking energy in kWh (F. Flye, 2025)	xii
Figure 6 Graph Produced in MATLAB to convey the areas in which KERS is possible and the highest areas it can be captured (F. Flye, 2025)	xiii
Figure 7 Graph showing the cumulative energy recovered at the wheel against the total elapsed time (F. Flye, 2025)	xvi
Table 1 Abbreviations Table	iv
Table 2 Table showing the required data that enables the forces on the vehicle calculations (F. Flye, 2025)	vi
Table 3 Table showing the overall weights needed to calculate the test mass (F. Flye, 2025)	vii
Table 4 Table showing the calculated weight for each of the liquids (F. Flye, 2025)	vi
Table 5 Table showing the Calculated data required for the forces on the bike (F. Flye, 2025)	ix
Table 6 Pros and Cons Table of a Mechanical Flywheel (F. Flye, 2025)	xiv
Table 7 Pros and Cons table of a Battery Based System (F. Flye, 2025)	xiv
Table 8 Ideal Flywheel to store 0.21 kWh of energy (F. Flye, 2025)	xvi
Table 9 Table Showing Relative information regarding the calculations of KERS wheel lockout, all dimensions were personally measured and calculated (F. Flye, 2025)	xviii

Table 1 Abbreviations Table

Abbreviations	Meaning
BE	Braking Energy
BP	Braking Power
DF	Drag Force
ICE	Internal Combustion Engines
KE	Kinetic Energy
KERS	Kinetic Energy Recovery System
TE	Tractive Energy
TS	Time Step
XCoG	X axis Centre of Gravity
YCoG	Y axis Centre of Gravity

1 Introduction

This report will dissect the dynamic characteristics of the Panigale S 1199 that resides within the UWTSD Swansea IQ workshop to uncover key features that will enable calculations regarding its tractive and braking energy over the Worldwide harmonized light vehicle test procedures as this bike falls under class three in these cycles. From this calculated data the largest KERS areas can be obtained which enables research for a suitable system for the bike to be able to recover kinetic energy and store it more efficiently.

1.1 Justification

The selection of the vehicle was justified by its well-renowned reputation as a high-performing motorcycle that is widely used for racing, as well as having availability to the UWTSD Swansea's own personal one that regularly participates in track days and racing. Furthermore, this option was deemed most suitable as having worked on the motorcycle in previous years a vast amount of data was obtained through looking at dyno testing and looking at dynamic characteristics. This resulted in sufficient and reliable data as it was backed by multiple lecturers and technicians.

2 Panigale S 1199 Dynamics Characteristics

Table 2 Table showing the required data that enables the forces on the vehicle calculations (F. Flye, 2025)

Test Mass	270.89	kg
Frontal Area	0.9282	m ²
Rolling Resistance Coefficient	0.02	No unit
Aerodynamic Drag Coefficient	0.663	No unit

Table 3 Table showing the overall weights needed to calculate the test mass (F. Flye, 2025)

Dry weight	164	kg
Oil weight	3.045	kg
Coolant weight	2.507	kg
Fuel weight	12.835	kg
Rider weight	83	kg
leather weight	5.5	kg

Table 4 Table showing the calculated weight for each of the liquids (F. Flye, 2025)

	Oil capacity (l)	Coolant capacity (l)	Fuel capacity (l)	Oil density (kg/m ³)	Coolant density (kg/m ³)	Petrol density (kg/m ³)
	3.5	2.3	17	870	1090	755
@1l	1	1	1	870	1090	755
Mass (kg)	0.87	1.09	0.755	870	1090	755
Total Mass	3.045	1.962	12.835	870	1090	755

The tables above show the required elements that are needed for the calculations to be able to achieve tractive and braking energy results, to obtain the test mass the formula used was.

$$\text{Test Mass} = \text{Dry weight} + \text{oil weight} + \text{coolant weight} + \text{fuel weight} + \text{weight of the rider} + \text{leather weight}$$

The dry weight and the fuel capacity for the bike was obtained from (1000Ps,2025) whereas the oil capacity was sourced from (Ducati Forum, 2014). The coolant capacity was enclosed by (Oil-Finder, 2025). Finally, nominal values were obtained for the density of the liquids which were sourced from (Learn Metrics, 2025), (The Engineering Toolbox, 2003) and (Cosmo Motor oil, 2025).

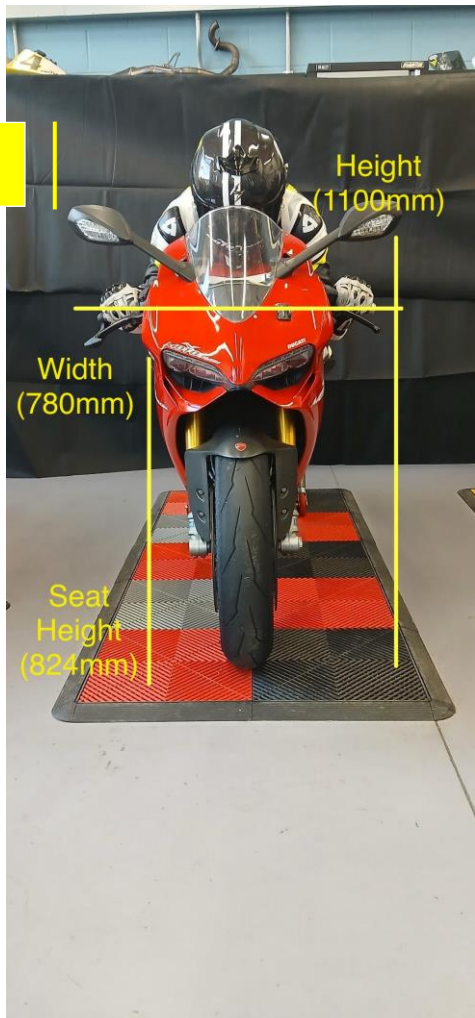


Figure 1 figure showing the overall dimensions of the bike which will be used to calculate the frontal area (F. Flye, 2024)

To obtain the frontal area of the motorcycle a simple equation is used.

$$\text{Area} = \text{Overall height} \times \text{Width}$$

To understand the actual frontal area of a motorcycle the unique shape of the bike needs to be considered so a correction factor must be installed, for this instance a correction factor of 0.85 was used, this is supported by (Altair, 2025) as stated in their report '0.4 to 0.9m² is overall range for motorcycles'. This then leads to the equation,

$$\text{Actual Frontal Area} = \text{Area} \times \text{Correction Factor}$$

Furthermore, this then enables the CDA to be calculated using the coefficient of drag as 0.663 which was ascertained by Mark Fall when conducting dyno testing on the Panigale.

$$\text{CDA} = \text{Coefficient of drag} \times \text{Frontal area}$$

Finally, to calculate the forces on the motorcycle the Rolling resistance coefficient was obtained from (x-Engineer, 2025).

3 WLTP Cycle

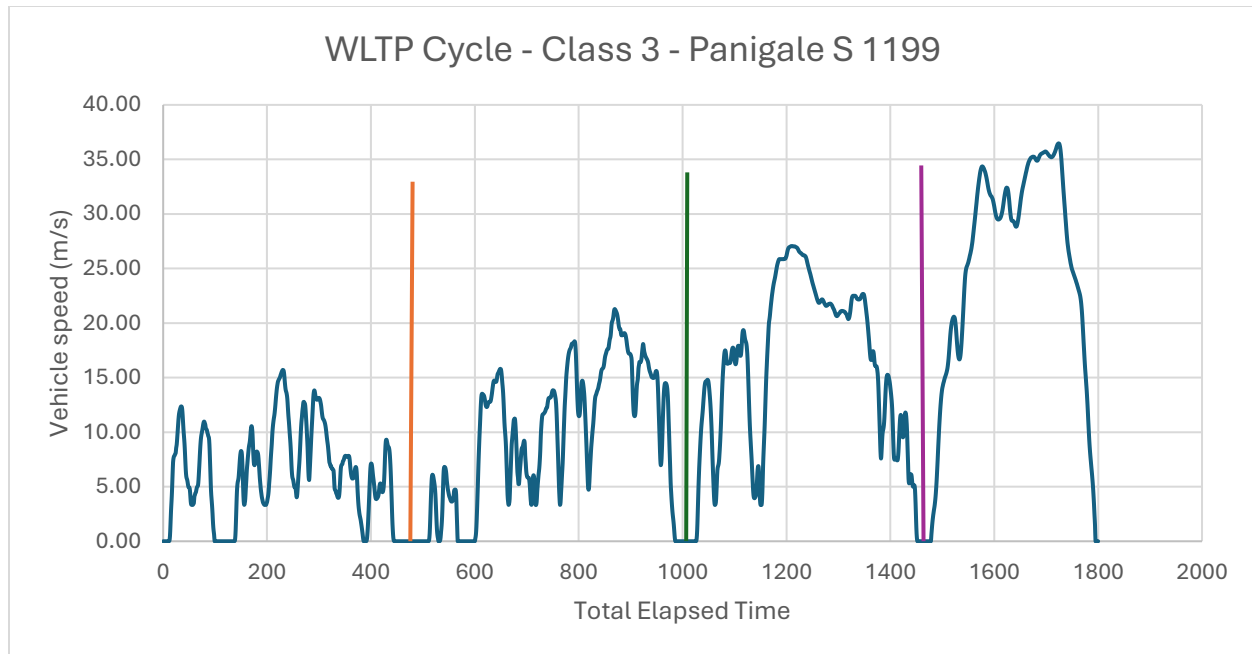


Figure 2 Graph showing the Vehicle speed over the total elapsed time for the WLTP cycle of a class 3 vehicle (F. Flye, 2025)

The lines on the graph indicate where the cycle changes from each section of the test from Low, medium, high to extra high.

3.1 Forces Calculations

Table 5 Table showing the Calculated data required for the forces on the bike (F. Flye, 2025)

Mass (kg)	Air Density (Kg/m ³)	CD	Area (m ²)	RR Coefficient	Correction Factor	CDA
270.89	1.167	0.663	0.9282	0.02	0.85	0.6153966

To understand the forces acting on the vehicle, the relevant test conditions and parameters must be considered. For this instance, the test was conducted on a flat road, thus gradient-based forces can be excluded. Therefore, the primary forces acting on the vehicle are Aerodynamic drag, Rolling resistance, and Acceleration resistance. These primary forces enable total force acting on the vehicle to be determined. Determining these forces on the vehicle required a series of equations that were sourced from (Sandford, 2025) these are...

$$\text{Aerodynamic Drag Force (N)} = \frac{1}{2} \times \text{Air Density} \times \text{CDA} \times \text{Velocity}^2 \text{ (m/s)}$$

$$\text{Rolling Resistance Force (N)} = \text{Mass} \times \text{Gravity} \times \text{Rolling Resistance Coefficient}$$

$$\text{Acceleration Resistance Force (N)} = \text{Acceleration} \times \text{Mass}$$

$$\text{Total Resistive Force (N)} = \text{Aerodynamic DF} + \text{Rolling RF} + \text{Acceleration RF}$$

After calculating the forces, a graph can be produced that plots the forces against the overall elapsed time of the cycle to convey all four forces that the vehicle is subjected to.

3.2 Forces Graph

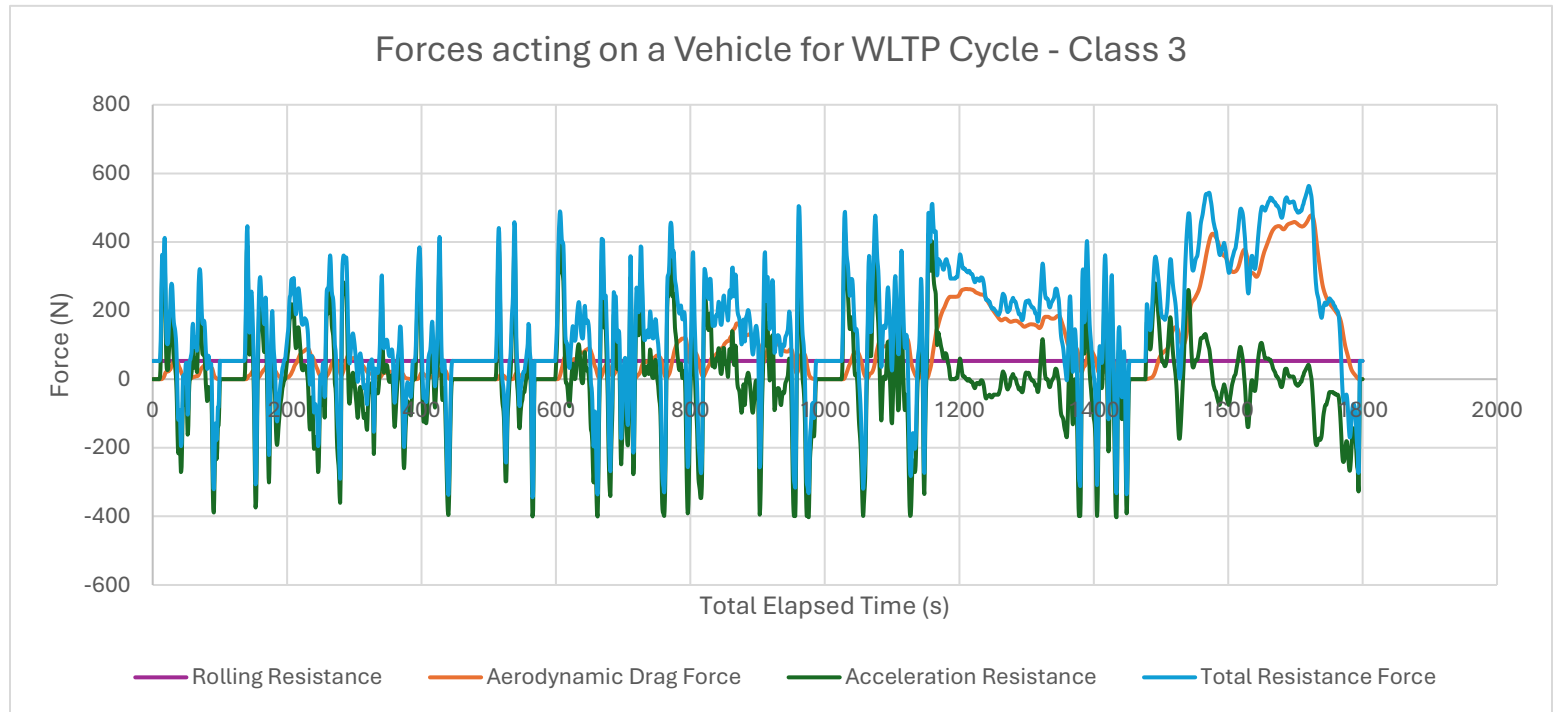


Figure 3 Graph showing the four forces the vehicle is subjected to (F. Flye, 2025)

The graph above illustrates the relationship between the forces and the total elapsed time over the WLTP cycle. From this data the tractive power can be Determined, thus enabling the tractive energy in kWh to be calculated which is necessary to identify the cumulative tractive and braking energy.

3.3 Power Against Time Graph

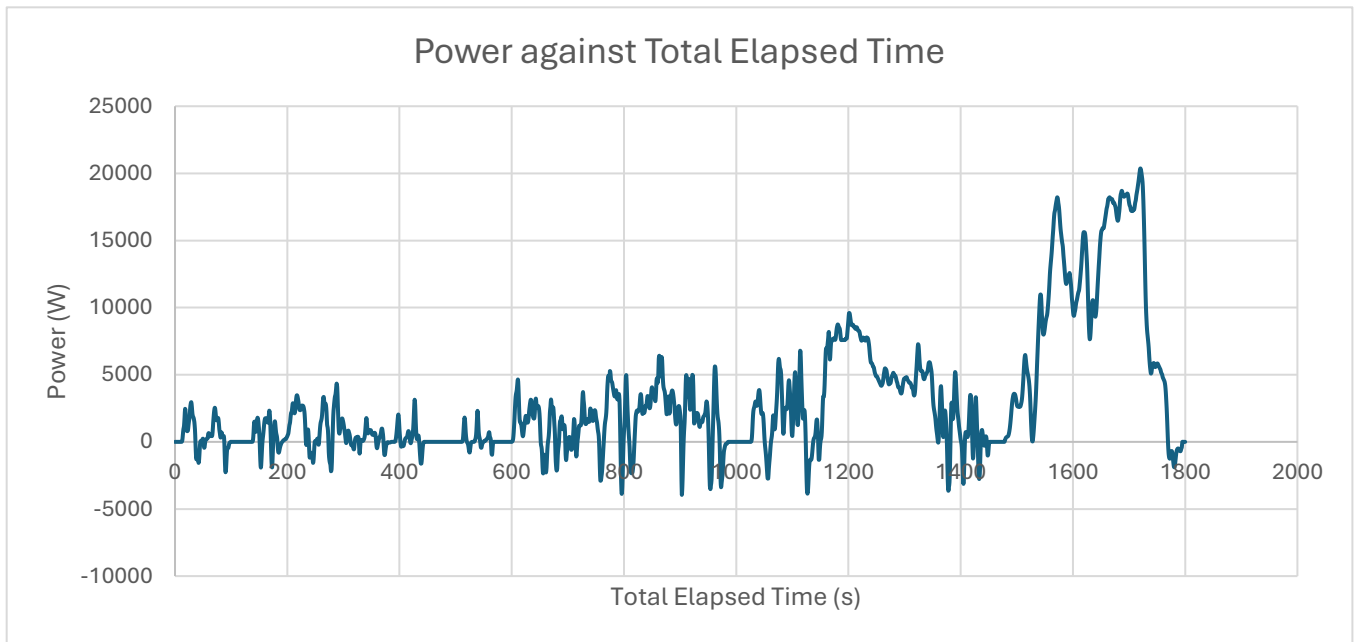


Figure 4 Graph showing the Power accumulated over Total elapsed time (F. Flye, 2025)

From the graph above that displays the accumulated Power over the whole cycle it can be depicted that the KER power is at 3.2kW which is required to understand the Wheel locking system within the KERS.

4 Tractive and Braking over WLTP Cycle

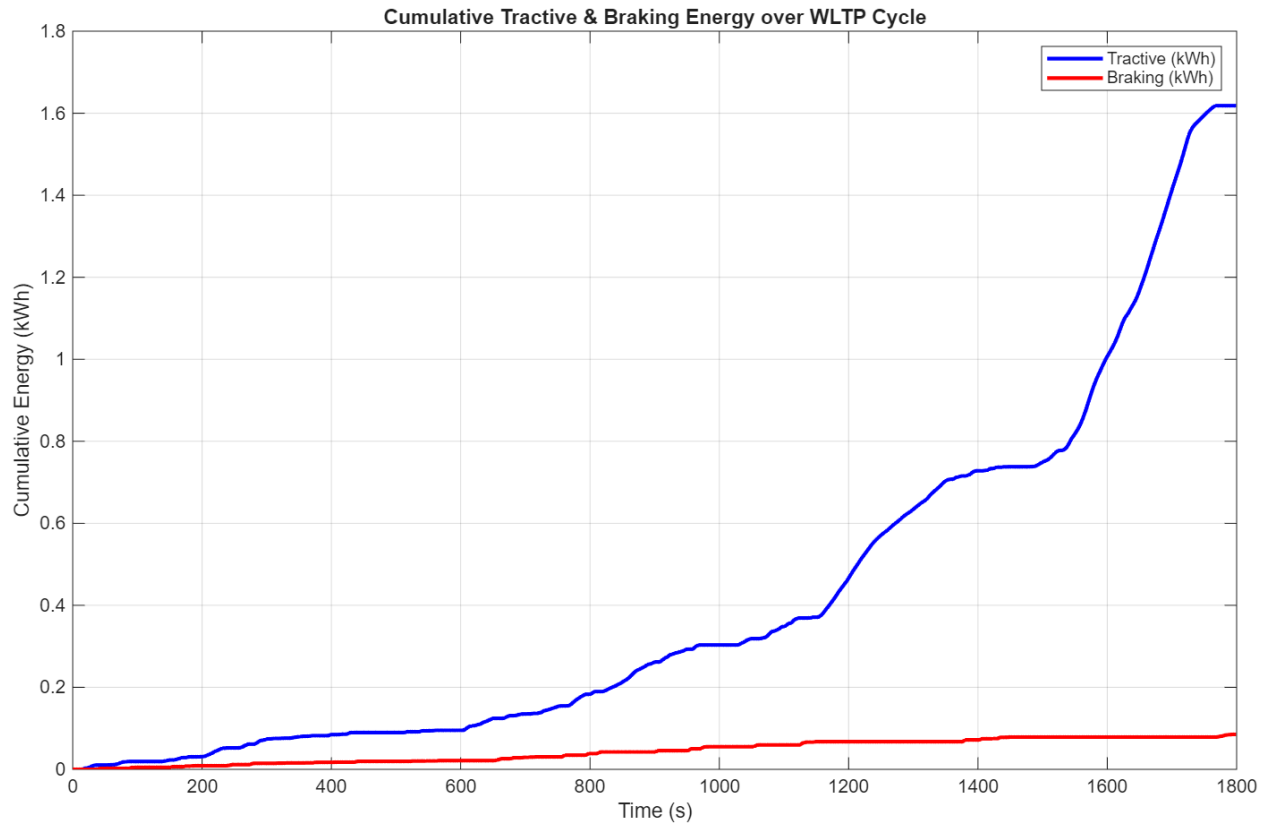


Figure 5 Graph Produced in MATLAB showing the cumulative tractive and braking energy in kWh (F. Flye, 2025)

$$\text{Tractive Power} = \text{Total Resistance Forces} \times \text{Velocity}$$

To determine the tractive power to initialize the calculations for tractive energy the formula above was used, hence creating the power in the unit of watts.

The graph above uses a script created in MATLAB to read the power outputs calculated on the excel file and convert them into a cumulative progression between the tractive and braking energies, the braking energies being the slow progression to 0 and the negative power outputs. The calculations done in MATLAB were done with the equations below,

$$\text{Tractive Power} = \max(\text{Power}, 0)$$

$$\text{Braking Power} = -\min(\text{Power}, 0)$$

$$\text{Cumulative TE (J)} = \text{cumsum}(\text{Tractive Power} \times \text{TS between consecutive Measurements})$$

$$\text{Cumulative BE (J)} = \text{cumsum}(\text{Braking Power} \times \text{TS between consecutive Measurements})$$

$$\text{Cumulative TE (kWh)} = \text{Cumulative TE (J)} / 3.6 \times 10^6$$

$$\text{Cumulative BE (kWh)} = \text{Cumulative BE (J)} / 3.6 \times 10^6$$

5 KERS

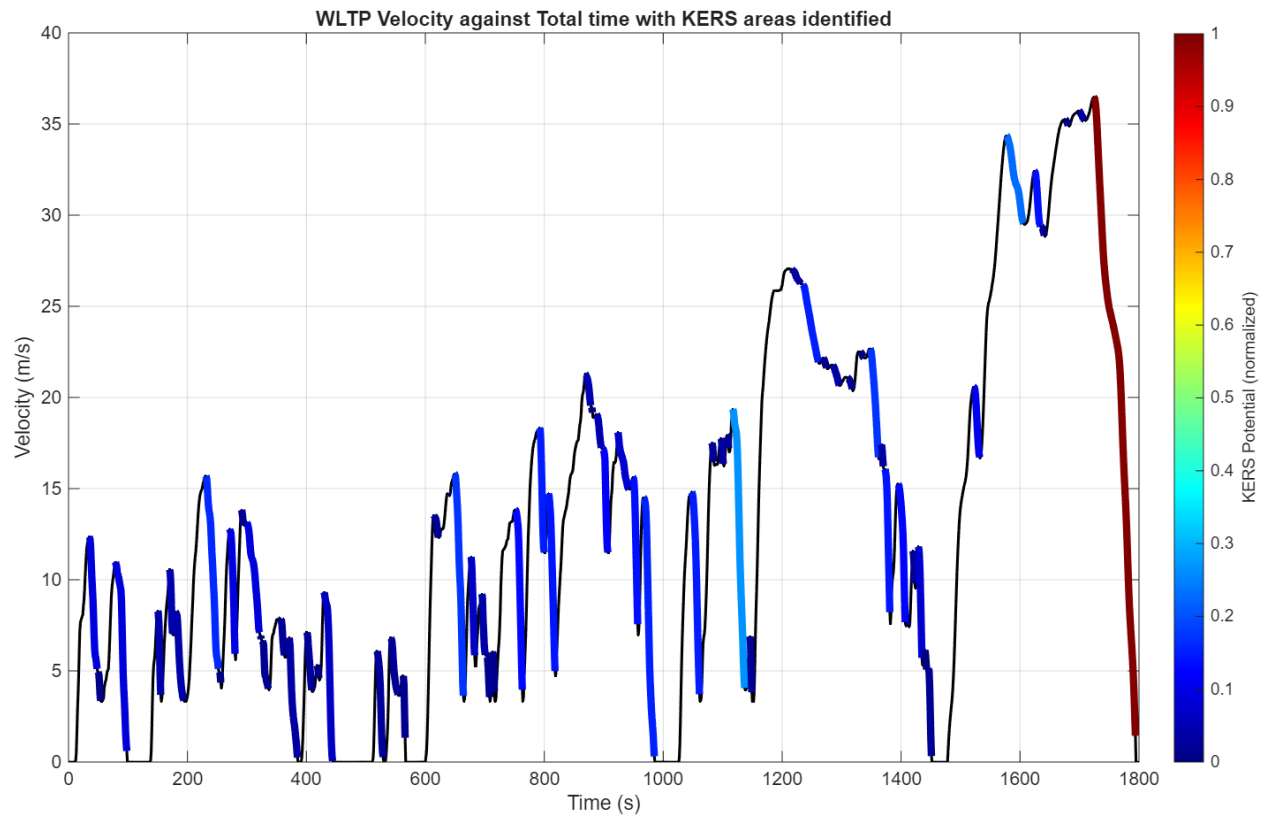


Figure 6 Graph Produced in MATLAB to convey the areas in which KERS is possible and the highest areas it can be captured (F. Flye, 2025)

The graph above conveys the areas within the cycle where KERS events occur, using the scale on the side this indicates the magnitude and potential of these events. In the data above, the highest KERS event takes place in the extra-high-speed region of the cycle, when the bike returns to rest from its maximum velocity. The KERS events help identify the natural coast down of the vehicle. As Stated by Emtage (1983), ‘the coast down is used to determine the aerodynamic drag coefficient and the static rolling resistance coefficient’. During natural coast down, deceleration is caused solely by resistive forces, enabling the calculation of these coefficients. This occurrence is also reflected by the graph, where the velocity line returns to black after deceleration, indicating no KERS potential during natural coast down.

Furthermore, using this graph can help determine the actual amount of Kinetic energy recovered from these events using KERS efficiency which is determined by the selected KER system.

5.1 KER System

5.1.1 Mechanical Flywheel

Table 6 Pros and Cons Table of a Mechanical Flywheel (F. Flye, 2025)

Pros	Cons
Smooth power delivery as flywheels can absorb and release energy relatively quickly	Flywheels can cause gyroscopic problems within the bike as it is a relatively free moving rotational part, which can cause issues with cornering
High Efficiency as the bike is battery based so there are quick charge and discharges, seeing up to 85% efficiency	Flywheels have a short lifespan as they wear easily due to how fast they rotate for constant periods of time
Rapid Torque delivery to the drivetrain which helps with acceleration	Limited on how fast they can spin, which reduces the amount of energy stored

5.1.2 Battery Based Systems

Table 7 Pros and Cons table of a Battery Based System (F. Flye, 2025)

Pros	Cons
Longer and higher storage capacity than that of a flywheel	They have a lower efficiency compared to the mechanical flywheel
Can place anywhere without affecting centre of gravity due to their convenient and compact size	Additional mass due to the electrical systems that come in addition to them
Battery based systems have a high charge and discharge rate that vastly improves their efficiency	Battery decay after constant use over cycles in a race

The chosen system for the vehicle selected is the flywheel due to the high efficiency and rapid burst of energy that can be applied to the drivetrain which vastly improves the acceleration and boost moments when traversing a track. In regard to the efficiency of the flywheel as stated by (Chauhan and Saini, 2014) 'efficiency of flywheel modules varies from 80% to 85%' which is significantly higher than the output efficiency of battery-based systems.

5.2 KERS Calculations

This section covers the code used to identify the total energy recovered at the wheel when in contact with the road using the efficiency previously identified in the section above.

$$KE = 0.5 \times mass \times velocity^2$$

$$\Delta KE \text{ between time steps}(TS) = -diff(KE);$$

$$\Delta KE \text{ between time steps } (\Delta KE \text{ between time steps } < 0) = 0$$

$$BP = \Delta KE \text{ between time steps} / TS \text{ between consecutive Measurements}$$

$$Power \text{ Captured} = \text{minimum}(BP, P_{max})$$

$$Actual \text{ Power Captured} = Power \text{ Captured} \times Kers \text{ efficiency}$$

$$Energy \text{ Captured} / TS = Actual \text{ Power Captured} \times TS \text{ between consecutive Measurements}$$

$$Energy \text{ captured} = \text{sum}(Energy \text{ Captured} / TS)$$

$$Energy \text{ captured (kWh)} = Energy \text{ captured} / 3.6e6$$

From this code using the data found in the excel the total energy captured by the KERS was 0.2 kWh across the whole cycle using the KERS power at 3.2kW. Using this code a graph was produced to illustrate the cumulative kinetic energy recovered when the wheel was in contact with the road against the total elapsed time.

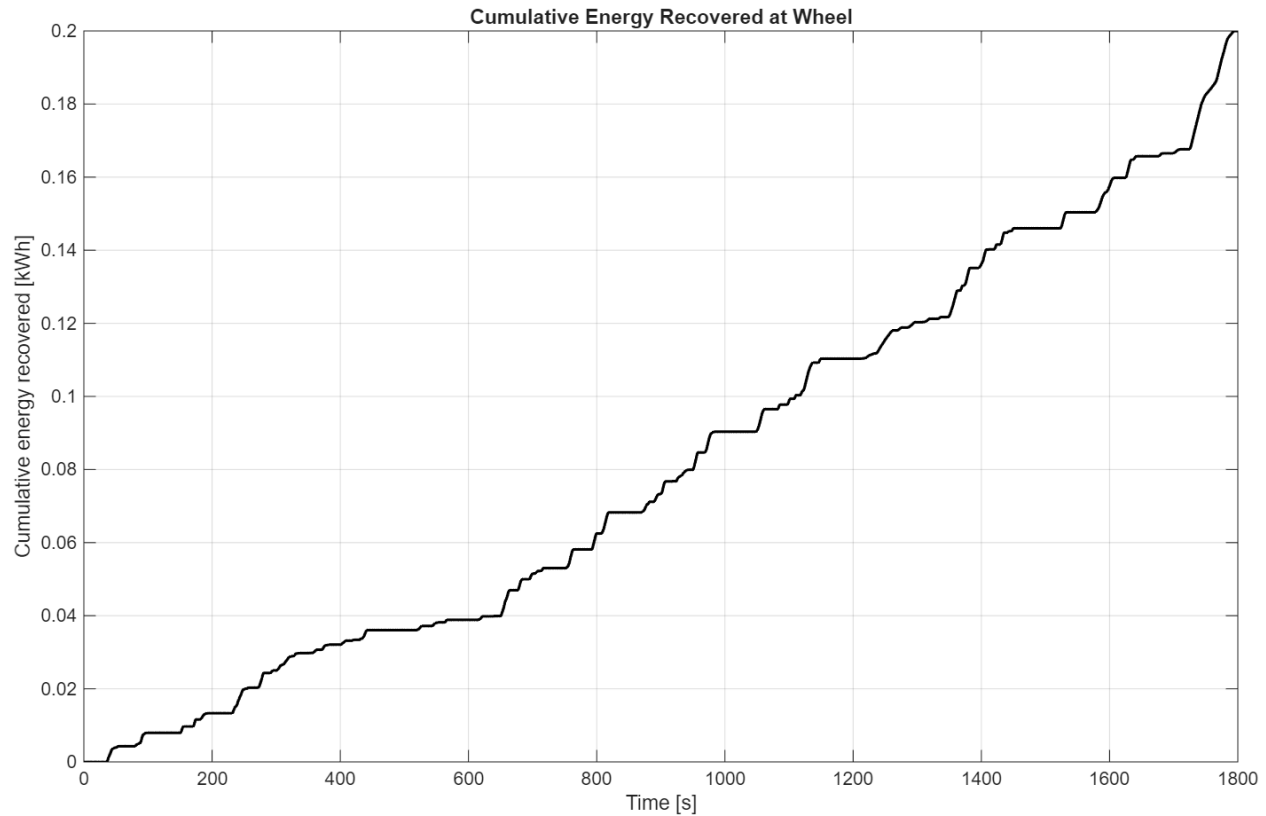


Figure 7 Graph showing the cumulative energy recovered at the wheel against the total elapsed time (F. Flye, 2025)

Table 8 Ideal Flywheel to store 0.21 kWh of energy (F. Flye, 2025)

Dimensions/Characteristics	Value	Unit
Radius	0.21	m
Mass	16	kg
RPM	2,094	rad/s
Moment of Inertia	0.3528	kg/m ²

Finally, using the data above for a flywheel with a KERS efficiency of 85% and using a generalized Drivetrain efficiency of 95% as remarked by (Zhang, Tak, 2020) '97 and 99% efficiency' is where they encounter frictional losses. The maximum energy required for storage can be calculated to store a maximum of 0.21 kWh of energy.

$$\text{Rotational Kinetic Energy} = \frac{1}{2} \times \text{Moment of inertia} \times \omega^2$$

$$\text{Max Energy Stored(kWh)} = \text{Rotational Kinetic Energy}/3.6 \times 10^6$$

Which correlates ideally to the kinetic energy recovered at the wheel over the whole cycle.

6 System Overview

This section of the report contains how the flywheel operates within the vehicle and how it generates energy to be able to apply it back to the drivetrain. ‘A flywheel is an old way of storing energy and smoothing out power variations (Hedlund *et al*, 2015)’ this simply describes what a flywheel is but in the basis of a motorcycle it is connected straight to the crankshaft as stated by (Motorcycle Guidelines, 2025) ‘A flywheel is a mechanical device that stores rotational energy. In a motorcycle, it is typically a large, heavy disc connected to the engine’s crankshaft’ with the flywheel attached these create smooth power transitions on delivery, which in turn helps the engine keep a consistent speed.

Furthermore, The rider is significantly effected with the addition of a flywheel to the motorcycle for this instance the use of a lightweight Ducati flywheel was chosen as stated by (Liu, 2025) ‘A lighter flywheel can improve acceleration’, this conveys that the lighter version can improve acceleration as it can rotate faster meaning the response time vastly improves which perfectly ties in with motorcycle racing when accelerating out of a turn. Another key factor that the rider will experience compared to conventional braking is a smoother deceleration as remarked by (English Electric Motors, 2024) ‘When you release the throttle, the regen braking system gradually slows the motorcycle, creating a smooth and controlled deceleration’ which describes a more enhanced version of engine braking, thus meaning the brake lever isn’t required as often whereas in ICE engine braking and lever action are only applicable which can cause harsher jolts during braking.

Table 9 Table Showing Relative information regarding the calculations of KERS wheel lockout, all dimensions were personally measured and calculated (F. Flye, 2025)

KERS Power	3200	W
Rear Wheel load (static)	1342.493476	N
wheelbase	1.445	m
XCoG	0.73	m
YCoG	0.33	m
Deceleration	1.4	m/s
Gravity	9.81	m/s ²
total weight (mg)	2657.40147	kg
Fraction on Rear wheel	0.505190311	
Δ Weight	86.60885398	N
Actual Rear Wheel Load	1255.884622	N
Speed to Lock out Wheel	2.58004764	m/s
Speed to Lock out wheel	9.172817149	km/h
Friction Coefficient	1	

From the data recorded in the table above this can be used to establish the wheel lockout speed at the max KERS power. From the data the max KERS power recorded was 3kW using this and equation below the WLS can be determined.

$$\text{Wheel Lockout Speed} = \text{KERS Power} / \text{Wheel Lock Force (Rear Wheel Load in dry)}$$

To understand the Wheel lock force first the load on the Rear wheel has to be calculated, using the equations below.

$$\text{Static Rear Wheel Load} = \text{Mass} \times \text{Gravity} \times \frac{\text{XCoG}}{\text{Wheelbase}}$$

$$\Delta \text{Weight during braking} = \text{Mass} \times \text{Deceleration} \times \frac{\text{YCoG}}{\text{Wheelbase}}$$

$$\text{Actual Rear Wheel Load} = \text{Static} + \Delta \text{Weight}$$

$$\text{Wheel Lock Force} = \text{Actual Rear Wheel Load} \times \text{Friction Coefficient}$$

So, at a KERS power of 3.2kW the speed required to overcome the forces to instigate the KERS wheel lockout is 2.6m/s or 9.2 km/h which correlates to figure 5 when there are no longer any KERS events happening.

7 Conclusion

To conclude the system chosen was a Mechanical flywheel as they are renowned for having high efficiencies in Kinetic Energy recovery and produce fast and efficient power delivery back into the system making them idea for racing scenarios and energy recovery. However, in regard to KER and ICE, ICE is the more proficient category as there are few scenarios in which a motorcycle can recover Kinetic Energy during braking as they are in use of conventional braking alongside the KER systems as sole kinetic energy braking wouldn't produce enough braking power to stop the vehicle rapidly.

8 References

Abrahamsson, J. Bernhoff, H. Hedlund, M. Lundin, J. Santiago, D. J. 2015, 'Flywheel Energy Storage for Automotive Applications', *Energies*, vol. 8(10), p. 1

Altair Engineering (2025) *Aerodynamics of Two-Wheelers*. Available at: [Aerodynamics for Two-Wheelers](#) (Accessed 17th November)

Chauhan, A. Saini, R. P. 2014, 'A review on Integrated Renewable Energy System based power generation for stand-alone applications: Configurations, storage options, sizing methodologies and control', *Renewable and Sustainable Energy Reviews*, vol. 38, pp.99-120

Cosmo Motor Oil (2025) *Product Data Sheet 10 – 30w*. Available at: [TDS - 10W-30.pdf.aOsgBA3bb44JWLEyZv4ZbDYvdh1VYFj](#) (Accessed 17th November)

Ducati Forum (2014) *1199 Oil Change*. Available at: [1199 Oil change | Ducati Motorcycle Forum](#) (Accessed 17th of November)

Emtage, A.L., 1983. 'The vehicle coast-down test', Doctoral dissertation, Loughborough University. p.7

English Electric Motor (2024) *What is Regenerative Braking, and how does it work in electric motorcycles*. Available at: [What Is Regenerative Braking, and How Does It Work in Electric Motorcycles? | English Electric Motor Co](#) (Accessed 27th of November)

Learn Metrics (2025) *Gasoline Density*. Available at: [Gasoline Density In kg/m3, lb/gal, kg/L, lb/ft3 \(+ Chart\) - LearnMetrics](#) (Accessed 17th of November)

Liu, S. (2025) *How does a Flywheel Affect the Performance of a Motorcycle Engine*. Available at: [How does a flywheel affect the performance of a motorcycle engine? - Blog](#) (Accessed 27th November)

Motorcycle Guidelines (2025) *What is a Flywheel on a Motorcycle*. Available at: [What is a Flywheel on a Motorcycle](#) (Accessed 27th November)

Oil-Filter (2025) *Ducati 1199 Panigale 2012-2015 fluids type and filling capacities*. Available at: [Capacity of oils and fluids for DUCATI 1199 Panigale 2012-2015](#) (Accessed 17th November)

Sandford, M. 2025 'School of Engineering', *Alternative Powertrain Kinetic Energy Recovery*, p. 3

Tak, T. Zhang, S. 2020, 'Efficiency Estimation of Roller Chain Power Transmission Systems', *Applied Sciences*, vol. 10(21), p. 1

The Engineering Toolbox (2003). *Ethylene Glycol Heat-Transfer Fluid Properties: Density, Data & Charts*. Available at: [Ethylene Glycol Heat-Transfer Fluid Properties: Density, Data & Charts](#) (Accessed 17th of November)

X-Engineer (2025) *How to calculate Rolling Resistance*. Available at: [How to calculate rolling resistance – x-engineer.org](#) (Accessed 17th of November)

1000Ps (2025) *Ducati Panigale 1199 S*. Available at: [Ducati 1199 Panigale S - technical data, prices, reviews](#) (Accessed 17th November)