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Vehicle selection

To analyse the effects of introducing a KERS to reduce vehicle fuel consumption, I have chosen the 2024 Ford Mustang GT V8¹. Due to its large engine, this vehicle consumes a significant amount of fuel, producing a large amount of power to accelerate. This acceleration generates substantial kinetic energy, which is normally lost as heat during braking. With a KERS, some of this energy can be recovered and used later to assist the car's acceleration, reducing fuel consumption.

It should be noted that the vehicle does not come equipped with a KERS from the factory. For the purposes of this assignment, a KERS has been conceptually added to the vehicle. An overall round-trip efficiency of 55% has been assumed, reflecting a typical value for a mechanical or battery-based KERS. All calculations of recovered energy in this report are based on this assumed system and efficiency.

A KERS (Kinetic Energy Recovery System) captures some of the vehicle's kinetic energy during braking and stores it for later use to assist acceleration. While it helps reduce energy lost as heat, KERS cannot fully replace friction brakes due to its limited energy storage capacity and power flow. Therefore, the vehicle's conventional braking system must still be used alongside the KERS.

Vehicle dynamic characteristics

Parameter	Value	Unit
Test mass	1949.3	kg
Frontal area	2.27	m ²
Rolling resistance coefficient	0.012	-
Aerodynamic drag coefficient ²	0.33	-

Test mass is used to determine how the mass of the vehicle affects the amount of kinetic energy generated. A heavier car produces more kinetic energy in motion, which means more energy can potentially be recovered during braking.

Frontal area measures the size of the vehicle as it moves through the air. A larger frontal area increases aerodynamic drag, requiring more engine power to maintain speed and thus more fuel. In the context of KERS, it affects the total energy lost during motion and the amount that can potentially be recovered.

Rolling resistance coefficient measures the force opposing the vehicle's motion due to tyre friction. A higher coefficient means more energy is lost to the tyres, increasing fuel

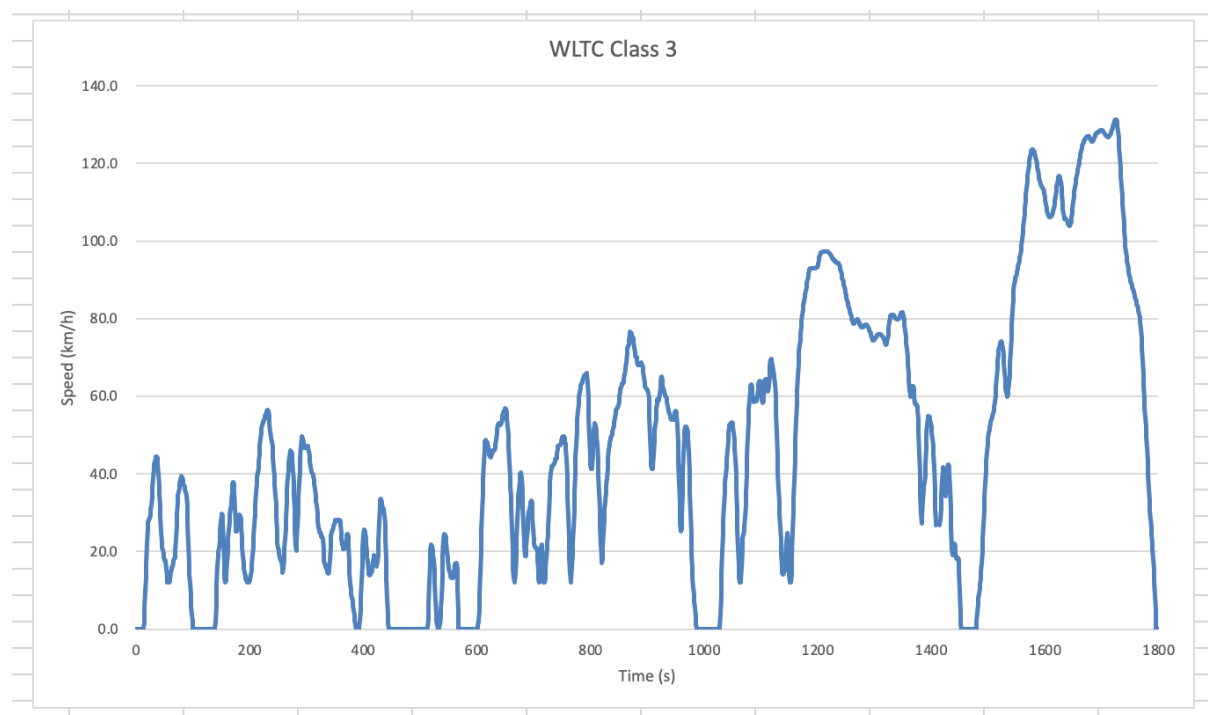
¹ <https://www.ford.co.uk/cars/mustang#exterior>

² https://www.automobile-catalog.com/car/2024/3314480/ford_mustang_fastback_gt_automatic.html

consumption. This parameter also impacts the total energy available for recovery by the KERS.

Coefficient of aerodynamic drag indicates how easily the vehicle moves through the air. A higher value increases energy losses to drag, while a lower value reduces them. This affects the amount of kinetic energy that could potentially be captured by the KERS.

WLTP cycle selection



The Worldwide Harmonised Light Vehicle Test Procedure (WLTP) is a standardised framework designed to provide consumers with a realistic and reliable indication of a vehicle's energy consumption, CO₂ emissions, and electric range. Unlike previous testing methods, WLTP assesses each individual model variant, meaning that differences in engines, motors, battery sizes, and even wheel sizes can influence the results. The full test cycle lasts 30 minutes³ and is divided into four phases: low, middle, high, and extra-high.

The 2024 Ford Mustang GT V8 falls into Class 3, which applies to vehicles with a test mass greater than 1,760kg. With a test mass of 1,949.3 kg, the Mustang follows the most demanding speed trace, involving higher accelerations and higher maximum speeds, reflecting the higher performance expected from this category of vehicle⁴.

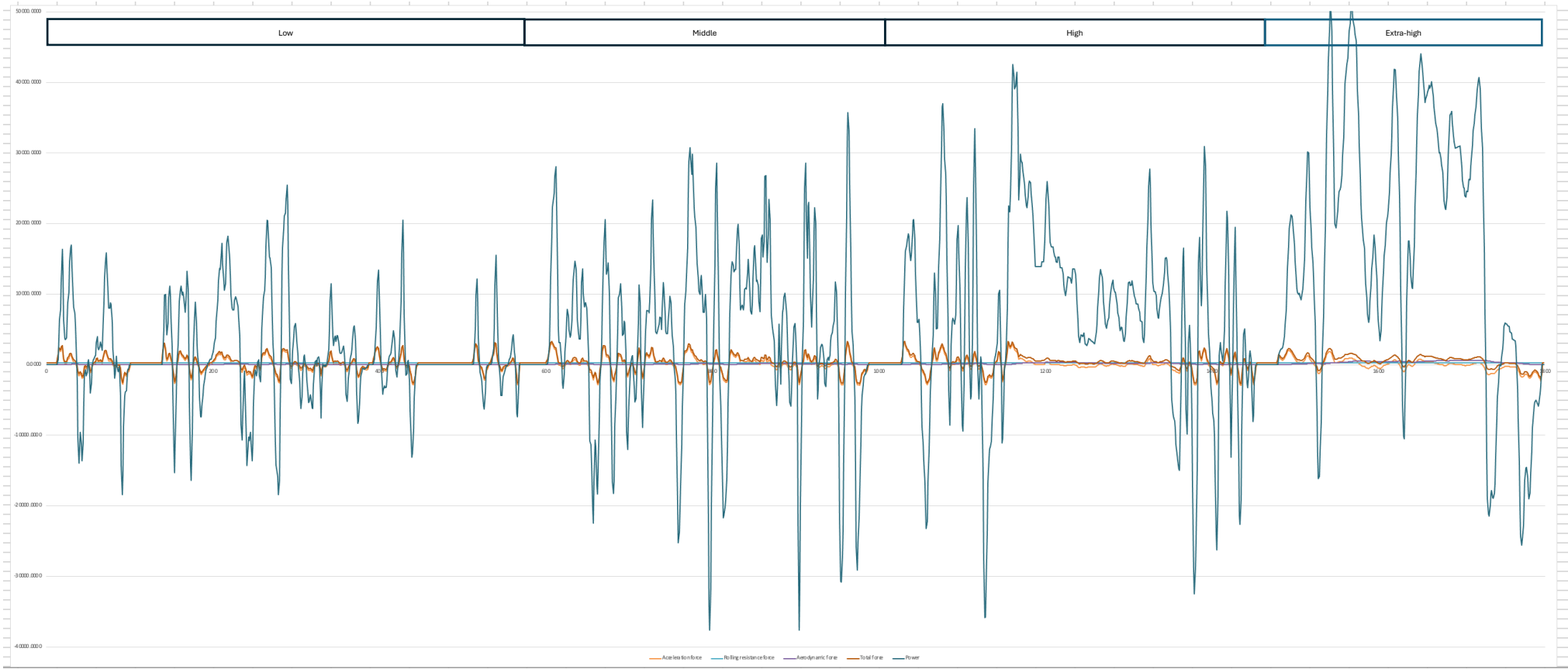
WLTP is particularly useful for analysing the performance of a KERS because it includes a wide range of driving conditions, with multiple acceleration and deceleration phases. This allows assessment of how the KERS captures energy during braking and how the recovered energy can be reused to assist acceleration under real-world conditions.

³ <https://www.whatcar.com/advice/buying/wltp-meaning-official-economy-emissions/n1223>

⁴ <https://www.rac.co.uk/drive/advice/emissions/new-worldwide-fuel-consumption-test-explained/>

WLTP energy analysis

Resistance forces



The tractive forces graph shows the acceleration force, rolling resistance force, aerodynamic drag, total tractive force, and power throughout the WLTP Class 3 cycle.

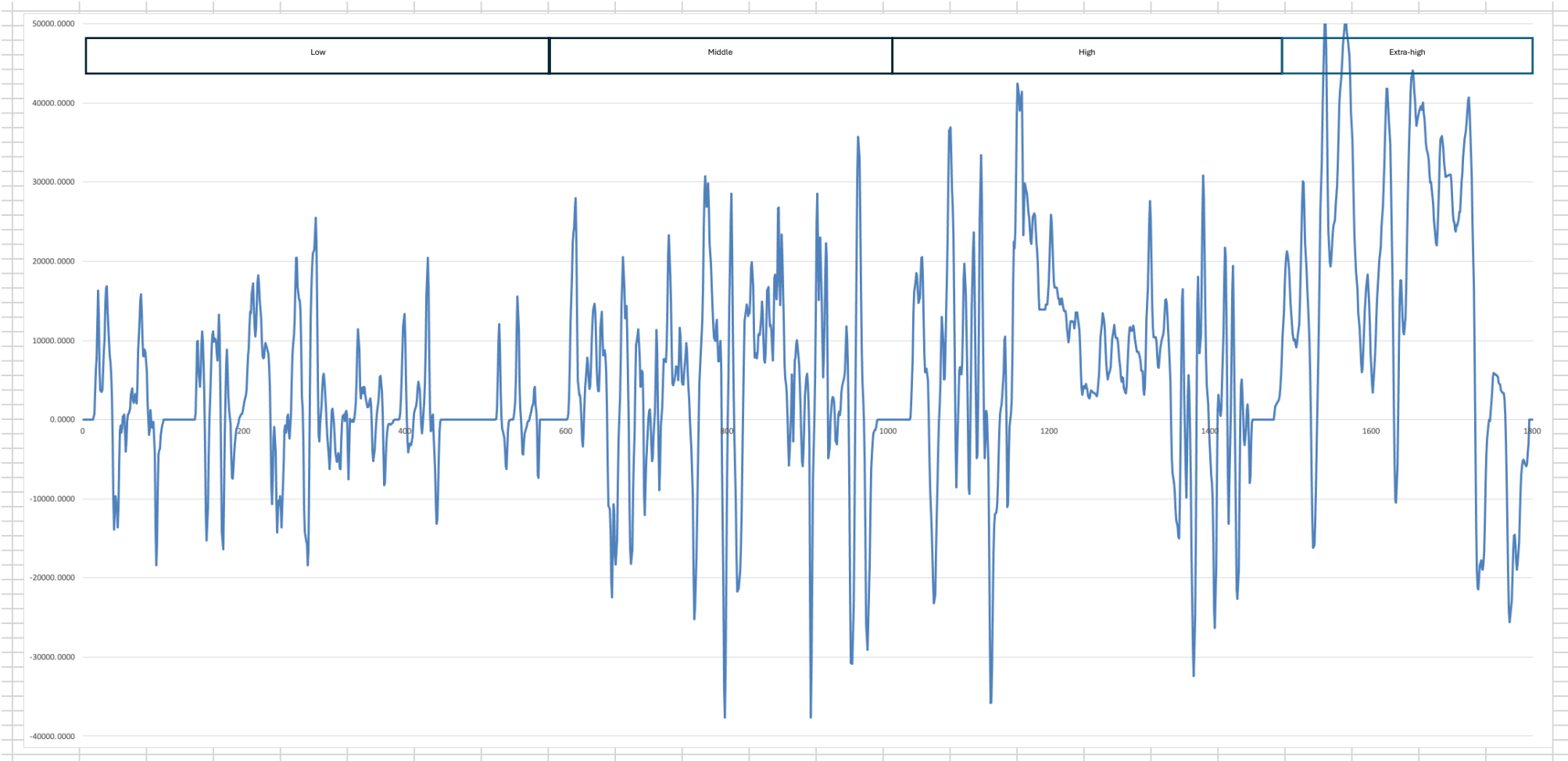
During the low phase, the vehicle experiences frequent acceleration and braking. Rolling resistance and acceleration are the main contributors to the total tractive force, while aerodynamic drag is minimal due to the low speeds. Peaks in total tractive force correspond to strong acceleration events.

In the middle and high phases, aerodynamic drag becomes more significant as speed increases, and while acceleration still contributes noticeable peaks, rolling resistance is comparatively smaller.

During the extra-high phase, aerodynamic drag dominates the total tractive force due to high speeds. Acceleration forces are smaller because strong acceleration events are less frequent, while rolling resistance contributes with a small impact.

Overall, the graph shows how the different resistive forces contribute to the total force the vehicle must overcome. It highlights the way vehicle speed and driving conditions affect wheel demand and sets the stage for understanding how this translates into power and energy requirements.

Tractive power



The tractive power graph shows the power required at the wheels to overcome all resistive forces and produce acceleration. Power is calculated by multiplying the total tractive force by the vehicle velocity, which explains why power rises sharply at higher speeds, since both drag force and vehicle velocity increase.

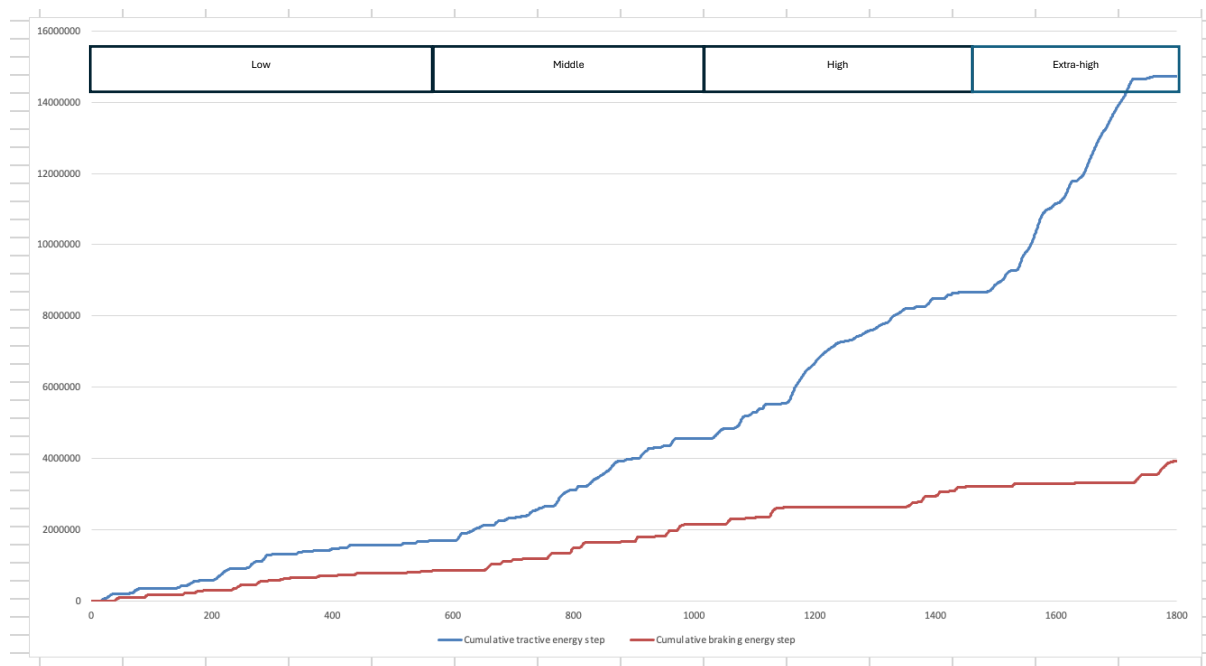
During the low phase, speeds are low, so even during strong accelerations the power required remains fairly modest. Negative power values correspond to braking events, which represent opportunities for the KERS to recover kinetic energy.

In the middle and high phases, aerodynamic drag increases, leading to higher power requirements. Acceleration events produce larger peaks in power, while braking events continue to appear as negative power, though they are less frequent than in low-speed phase.

During the extra-high phase, aerodynamic drag is the dominant factor, resulting in the largest power peaks. There are fewer braking events, which limits the potential for energy recovery by the KERS.

Overall, the graph highlights the moments of high energy demand and where energy can potentially be recovered. Positive power peaks indicate high fuel consumption, while negative power shows when the KERS could capture energy to assist the vehicle during subsequent acceleration.

Cumulative energy



The cumulative energy graph shows the cumulative tractive energy and the cumulative braking energy over the WLTP Class 3 cycle. The cumulative tractive energy represents the total energy the vehicle requires to overcome resistive forces and accelerate, while the cumulative braking energy shows the total kinetic energy available for recovery. The gap between the two lines represent energy lost throughout the cycle, including aerodynamic drag, tyre losses, and heat from braking.

The tractive energy line rises smoothly over the cycle, with steep increases corresponding to periods of high-power demand and flatter sections where power demand is low. These step increases typically occur during acceleration events. In contrast, the braking energy line increases more gradually, with long flat sections indicating periods with no braking.

During the low phase, both tractive and braking energy increase gradually, with tractive energy rising slightly faster due to acceleration events seen at low speeds. In the middle and high phases, higher vehicle speeds result in much larger increases in tractive energy, while the braking energy continues to increase but remains gradual, reflecting fewer braking events. In the extra-high phase, tractive energy rises most sharply due to high speeds and aerodynamic drag dominating energy demand. Braking events are rare in this phase, limiting the amount of energy the KERS could recover.

The total tractive energy over the WLTP cycle is approximately 14,732,613 J, while the total braking energy available for recovery is around 3,922,001 J. If we calculate the percentage of tractive energy by dividing the braking energy by the tractive energy, we

find that around 26.6% of the wheel energy could theoretically be recovered by a KERS. The remaining 73.4% is effectively lost to aerodynamic drag, rolling resistance, and braking events where energy cannot be captured.

From the graph, it is clear that KERS would be most effective during the low and middle phases, where frequent braking provides opportunities to recover energy. In contrast, in the extra-high phase, KERS would have limited impact due to the low availability of braking energy relative to the high tractive energy demand.

Largest possible KERS power input

The largest peak braking power observed in the WLTP cycle is 37,623.067 W, meaning the KERS must be capable of absorbing approximately 37.6 kW instantaneously. This value represents the highest negative power point in the cycle and therefore defines the minimum power rating of the motor-generator unit. If the KERS cannot absorb this level of power, the excess energy will be dissipated as heat in the friction brakes, reducing the overall energy-recovery potential. The peak braking power therefore directly determines the maximum charging power the system must safely handle.

The largest braking event energy during the cycle is 121,371.81 J, which sets the minimum required energy-storage capacity for the KERS. This means the energy storage unit must store at least 121 kJ. If the storage capacity is lower than this value, the system will fill prematurely during heavy braking, causing the remaining energy to be wasted through the friction brakes.

These two values combined create the minimum size requirements for the KERS system.

It is assumed that all recovered energy is discharged before the next braking event. This means that the system only needs to store enough energy for a single braking event at a time, rather than accumulating energy over multiple events. This simplifies the system design and ensures the storage device is correctly sized for the most demanding recovery period.

Chosen KERS technology

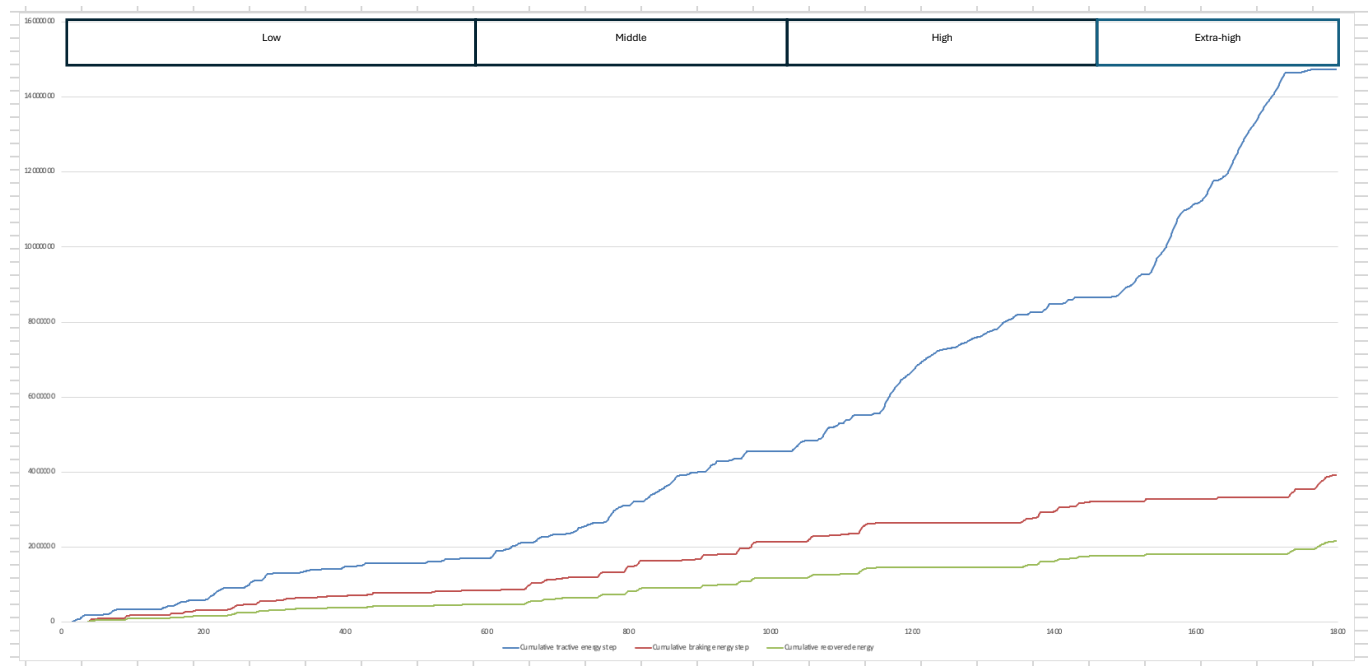
For this vehicle, a flywheel-based KERS has been selected. Flywheel systems are well suited to the short, high-power braking events seen in the WLTP cycle because they can absorb and release power very rapidly. They also tolerate frequent charge-discharge cycles with minimal degradation and have fast response times, which makes them appropriate for a high-performance vehicle such as the Mustang GT.

From the earlier analysis, the peak braking power during the WLTP cycle is approximately 37.6 kW, meaning the KERS must be capable of absorbing at least this level of power instantaneously. The largest single braking event corresponds to around 121 kJ of energy, so the flywheel must be sized to store at least this amount without saturating. This ensures the system can recover the full braking event without relying on friction brakes for excess dissipation.

In a flywheel KERS, the recovered energy is stored mechanically as rotational kinetic energy. Because the flywheel operates at very high rotational speeds, it requires a vacuum housing to minimise aerodynamic drag and limit heat generation. The rotor must be constructed from high-strength composite materials to withstand the stresses associated with high-speed rotation, and the containment structure must be capable of safely containing the rotor in the event of failure⁵.

⁵ <https://www.sciencedirect.com/science/article/abs/pii/S0360319925017197>

Kinetic Energy Recovered



This graph shows the cumulative kinetic energy recovered by the KERS over the WLTP cycle. A round-trip efficiency of 55% has been assumed.

The recovered energy curve follows the same general pattern as the cumulative braking energy graph because the KERS can only recover energy during deceleration. At low speeds early in the cycle, the amount of energy recovered per braking event is small. When braking occurs, the recovered energy line rises in discrete steps, and during coasting or acceleration, it remains flat as no energy can be captured in these periods.

In the low phase, the frequent braking events cause the steepest increases in recovered energy, making this the most effective region for KERS operation. In the middle and high phases, braking still occurs but less frequently, producing more gradual increases. In the extra-high phase, braking is minimal, which is reflected by the long flat sections of the curve and the limited energy recovery capability at high speeds.

The total braking energy available across the cycle is approximately 3,922,001 J. Applying the assumed efficiency of 55%, it gives a total recovered energy of around 2,157,101 J. This is the usable energy that can assist the vehicle during subsequent acceleration events, reducing the load on the engine and, in principle, lowering fuel consumption. The actual reduction in fuel depends on the engine efficiency and driving conditions.

System operation compared to the conventional ICE

Several assumptions have been made in this analysis. Firstly, a round-trip efficiency of 55% is assumed, meaning that 55% of the braking energy recovered by the flywheel can later be delivered back to the wheels as useful tractive energy. It has also been assumed that the system can absorb the peak braking power of 37.6 kW and store at least 121 kJ during the largest braking event. Another assumption is that energy transfer occurs ideally, with no delays, control losses, or safety cut-outs limiting the system's use.

A flywheel KERS changes the way the vehicle feels compared to a conventional ICE and friction-brake system. Because the flywheel harvests energy during braking, the initial braking feel can be smoother, as the system absorbs part of the deceleration before the friction brakes take over. In contrast, a normal ICE vehicle relies entirely on friction brakes, which gives a more predictable and consistent feel. During acceleration, a flywheel KERS can provide a short power boost, making the car feel more responsive at low and medium speeds, whereas a conventional ICE vehicle relies only on engine torque. However, the flywheel can 'run out' of stored energy, meaning the boost is not always available. The addition of a KERS system also adds some weight and complexity, which may slightly affect handling, although this depends on placement and design.

Conclusion

The aim of this analysis was to investigate how introducing a KERS could reduce the fuel consumption of a 2024 Ford Mustang GT. The analysis used the WLTP Class 3 cycle to determine the tractive force, tractive power, and cumulative energy requirements of the vehicle. The results showed that the vehicle requires around 14.7 MJ of tractive energy over the cycle, with approximately 3.9 MJ of braking energy available for recovery.

A flywheel KERS was selected due to its high-power capability and suitability for frequent charged and discharged cycles. From the data, the system would need to absorb a peak braking power of 37.6 kW and be able to store at least 121 kJ during the largest braking event. With an assumed efficiency of 55%, the system could return around 2.16 MJ of useful energy to the wheels.

Overall, the analysis suggests that a KERS could reduce fuel consumption by lowering the load on the engine during acceleration, especially in the low and middle phases of the WLTP cycle where frequent braking occurs. However, the benefit is smaller at higher speeds, where braking opportunities are limited, and aerodynamic drag dominates.

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