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Alternative Propulsion Systems

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Introduction

With the increased pressure on sustainability, awareness of environmental protection is increasing. This is causing vehicle owners to explore options for modifying their personal vehicles to strive for better energy usage to aid in a reduction of fuel consumption and therefore emissions. During braking events, a large quantity of kinetic energy is released into the atmosphere. This energy could be used to help power the vehicle.

Looking at the WLTP provides a good basis as it covers real world scenarios and is also standardised to compare across multiple vehicle types.

The purpose of this study is to evaluate the feasibility of adding a KERS system to a Volvo V70 SE Sport D5. The data from this test is taken at 1 second intervals and used to work out areas where energy is being lost and where it can be expended.

Vehicle Dynamic Characteristics

The Volvo V70 is an excellent base to implement a kinetic energy recovery system. Due to the large weight of the vehicle, it stores a large amount of kinetic energy during acceleration; however, subsequently it has large energy losses during deceleration. The engine is designed with long distance driving in mind. In traffic and city driving situations, there is an increased effect on the introduction of a KERS. Additionally, the large estate style body allows for the system to be added without the complete reduction of internal storage.



Figure 1 Shows the Test Vehicle used for this experiment.

Test Mass

The vehicle was weighed on the four corner scales in the MCR workshop and then compared to online data (Volvo, 2007). The weight taken in the workshop was 2056.93kg. To measure on these scales, it is essential to be done on a flat surface, i.e., on the same floor tile in 016. The vehicle was filled up with fuel fully on the way to weighing. According to Volvo, the fuel tank is 70L (Volvo, 2007), taking into account the density of fuel being 0.83 kg/L, it can be deduced that the fuel weight is 58.2kg (Paragon Scientific, 2025). Using the vehicle kerb weight from Volvo, the weight of passengers and luggage can be calculated. $2056.93 - 58.2 = 1998.73\text{kg}$ $1998.7 - 1815 = 183.7\text{kg}$ for

passengers and luggage. The driver weighed in at 82.4 kg with their baggage adding a further 30.5 kg, leaving 70kg mass of the passenger.

Frontal Area

This figure is supplied by Volvo at 2.37m^2 (Volvo, 2007).

Aerodynamic Drag Coefficient

This Figure is supplied by Volvo at 0.31 (Volvo, 2007).

Rolling Resistance Coefficient

To calculate the rolling resistance coefficient, data was taken on the rolling resistance of the tyre and then times by g and test mass. So for the Michelin Cross Climate + tyres, the C_{rr} is 0.014 (Michelin, 2025).

WLTP Selection

WLTP class 3 was selected because it aligns with the performance of the Volvo V70 and provides a realistic mix of driving conditions. The cycle includes low, medium, high, and extra high speed phases, each consisting of multiple areas of acceleration and deceleration. These are useful for analysing kinetic energy recovery. WLTP has a higher speed range and an improved correlation to real world scenarios compared to the NEDC test.

Spreadsheet Modelling Methodology

The spreadsheet was designed to allow all vehicle energy and forces figures to be calculated for every second throughout the duration of the WLTP for the Volvo V70. This allows figures such as Cumulative tractive energy, braking energy, and braking moments to be calculated with ease.

Fixed Data

$$Test\ Mass = 2056.93kg$$

$$Frontal\ Area = 2.37\ m^2$$

$$Cd = 0.31$$

$$Crr = 0.014$$

$$Air\ Density = 1.225\ kg/m^3$$

Remaining data

Vehicle speed in m/s

The WLTP supplied data is in km/h, so to convert to m/s, use the following formula:

$$V\left(\frac{m}{s}\right) = V\left(\frac{km}{h}\right) / 3.6$$

Acceleration in km/h

Acceleration was supplied in m/s, so to convert to km/h/s use:

$$\alpha\left(\frac{\frac{km}{h}}{s}\right) = \alpha\left(\frac{m}{s}\right) / \left(\frac{5}{18}\right)$$

Kinetic Energy

To calculate the kinetic energy, the vehicle speed and mass are used:

$$KE = 0.5 \times Mt \times \left(S\left(\frac{m}{s}\right)\right)^2$$

Change in KE

The change in KE is as simple as deducting the prior value from the current.

Acceleration Resistance

To calculate this value, multiply the acceleration by the test mass:

$$Ra = \alpha \times Mt$$

Rolling Resistance

This has been calculated to be a constant throughout the WLTP. Using the total rolling resistance of the four tyres and multiplying by gravity gets the rolling resistance force. Using Michelin's database, this is 7.2 per tyre.

$$RR = 28.8 \times 9.81$$

Alternatively, using the measured coefficient of rolling resistance multiplied by test mass and gravity, the total RR can be calculated.

$$RR = Crr \times Mt \times g$$

Aerodynamic Drag Resistance

This drag resistance will increase with speed and therefore is the dimensions of the car multiplied by speed in the formula.

$$Rad = 0.5 \times Air\ Density \times Cd \times Frontal\ Area \times (V)^2$$

Tractive Force

This is the combination of all resistances into one total resistive force.

$$Ft = Ra + RR + Rad$$

Braking Force

To calculate this in Excel, the use of an IF function is necessary. This is displayed as =IF((α>0),0, Test mass × α) ×-1

Braking Energy

To find the braking energy, you must subtract the change in KE from the tractive energy.

$$Breaking\ Energy = \Delta KE - Tractive\ Energy$$

Braking Power

Is simply

$$Pb = Braking\ Force \times V$$

Power

$$P = Tractive\ Force \times V$$

Tractive Energy

$$\text{Tractive Energy} = \text{Tractive Force} \times V$$

Positive Cumulative Energy J

This uses another if statement to keep it positive. It is displayed as =cell above + IF(Tractive energy>0, ABS(Tractive Energy),0)

Cumulative Tractive Energy kWh

To convert to kWh, divide by 3,600,000

Cumulative Braking Energy J

Simply add the Braking energy to the cell above in Cumulative braking energy to get the total braking energy to that point.

Cumulative Braking Energy kWh

To convert to kWh, divide by 3,600,000

Identifying Braking Events

A conditional 'IF' formula was used in Excel to detect areas under braking. This is displayed as =IF(Acceleration<0, "YES", "NO")

Graphs

Tractive Forces against Time

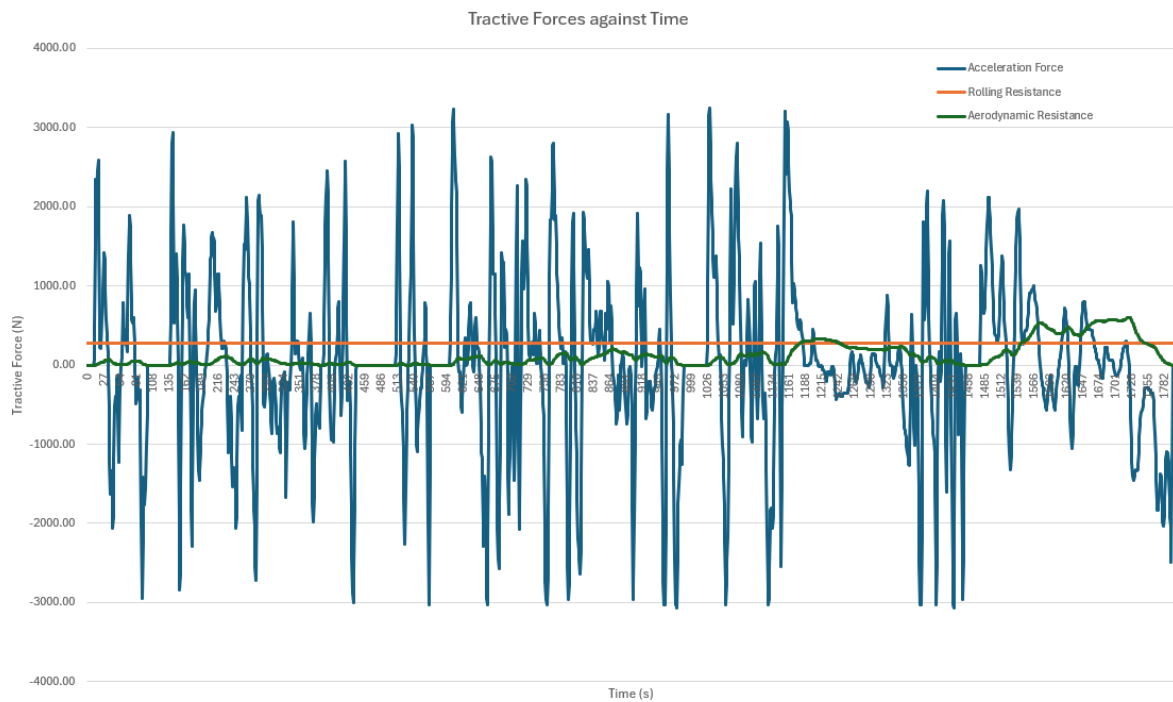


Figure 2 Shows the Tractive forces over time.

Tractive Forces against Time

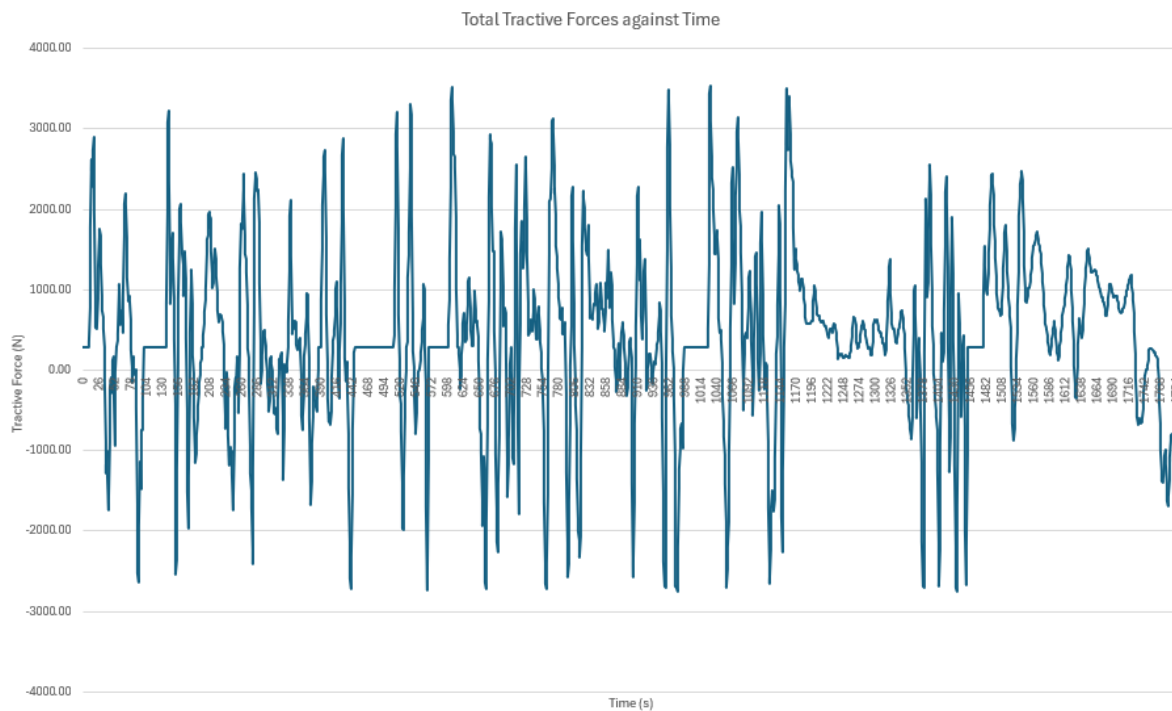


Figure 3 Showcases the total tractive forces against time.

RR against Time

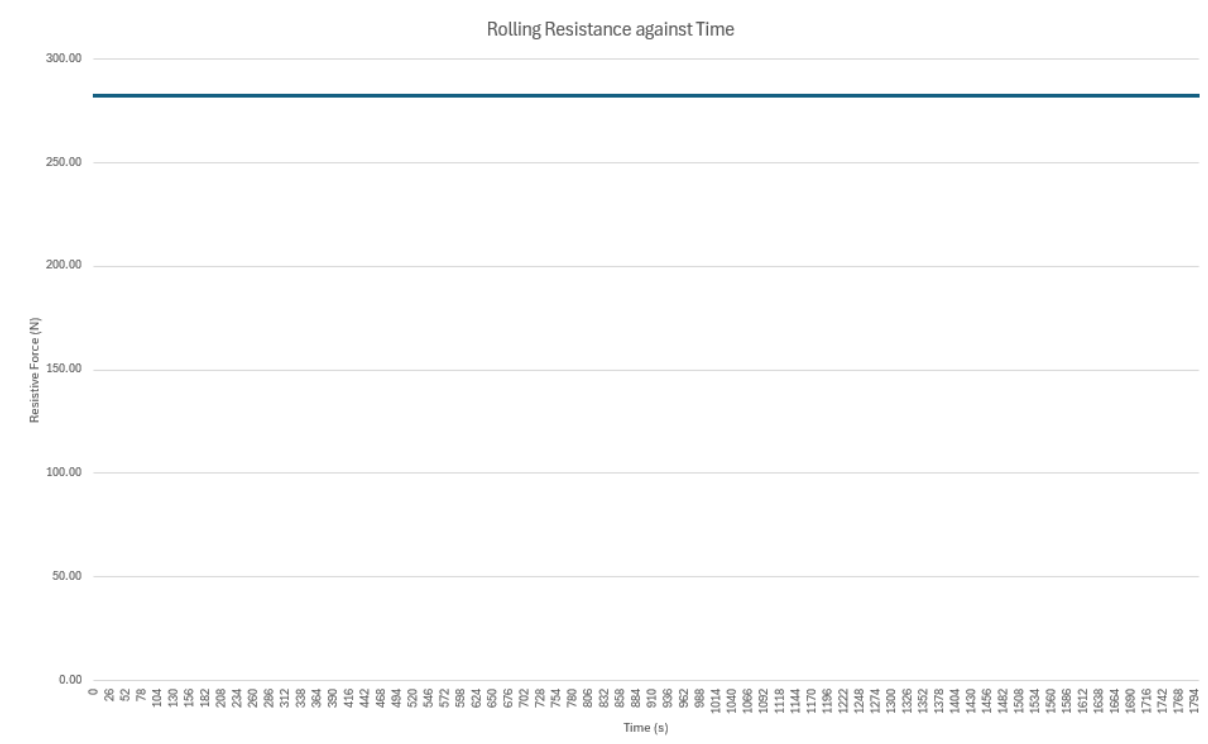


Figure 4 Shows the Rolling Resistance over Time

Accelerating Forces against Time

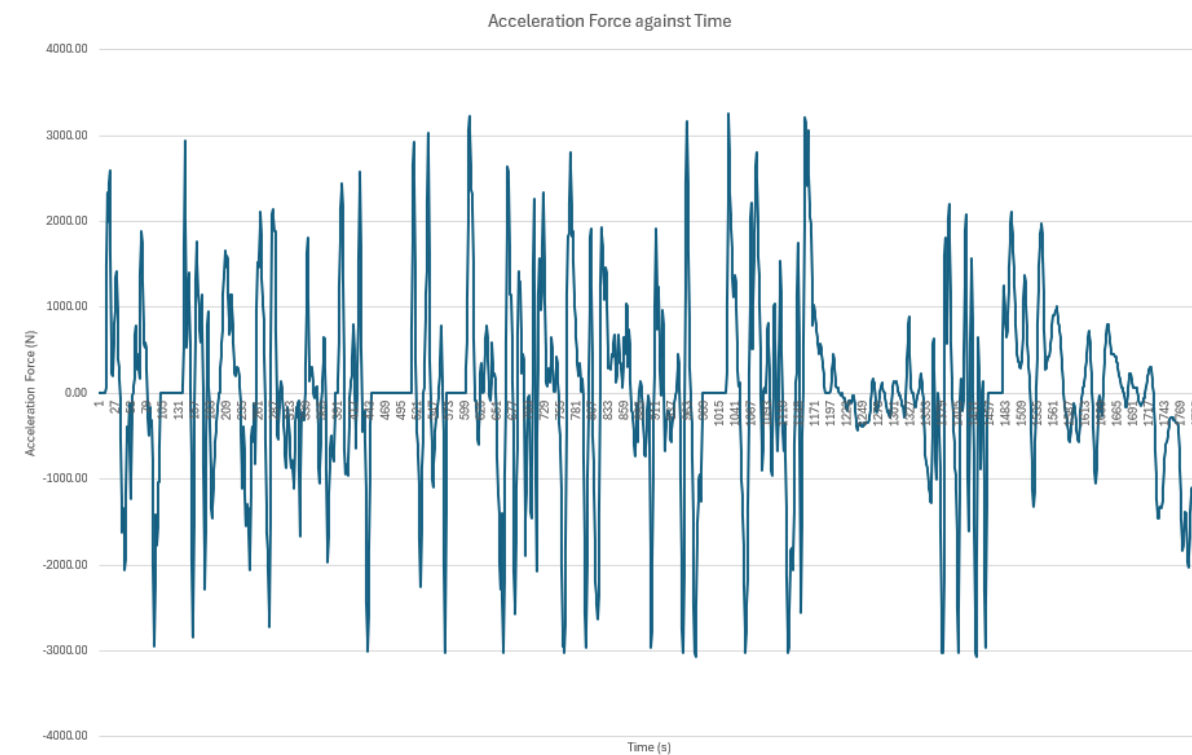


Figure 5 Acceleration Forces against Time

Aerodynamic Drag against Time

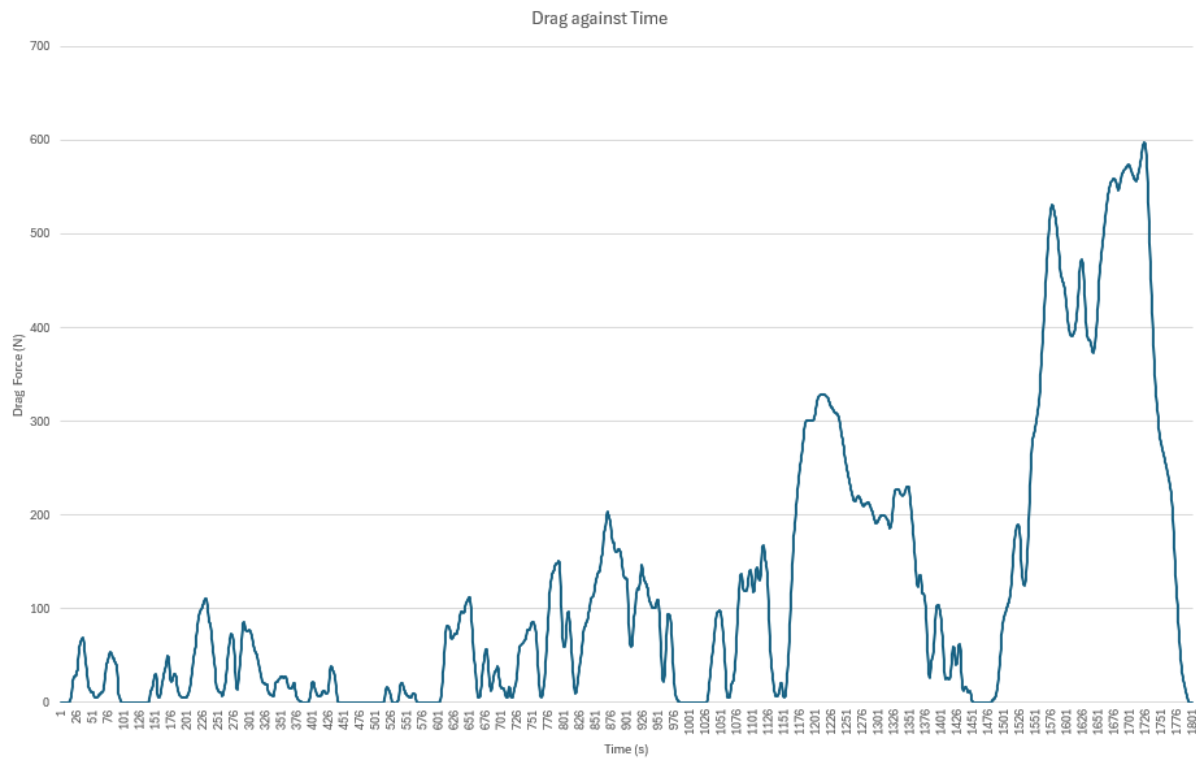


Figure 6 Showcases Drag over time

Tractive Energy against Time

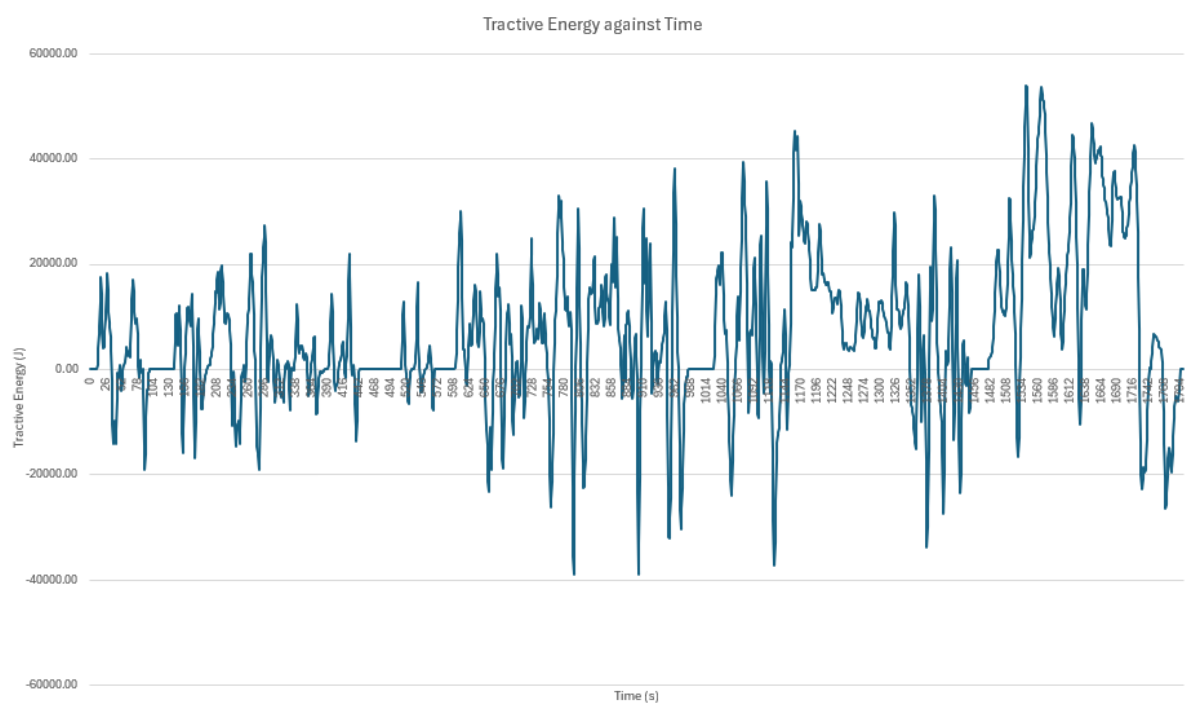


Figure 7 Tractive Energy over Time

Braking Energy against Time

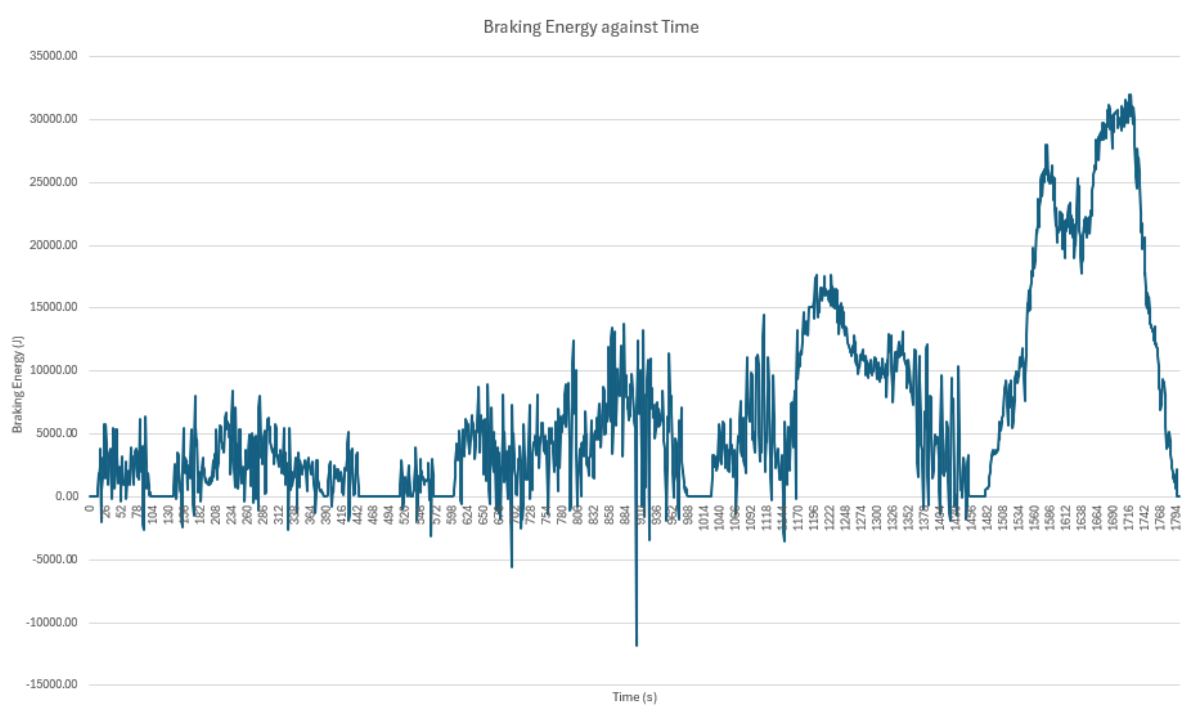


Figure 8 Energy of braking over Time

Identification of KERS Requirements

To determine which KER System to use for the Volvo V70, the maximum power input and energy storage requirements must be considered. To do this, a graph can be plotted to showcase the brake power exerted.

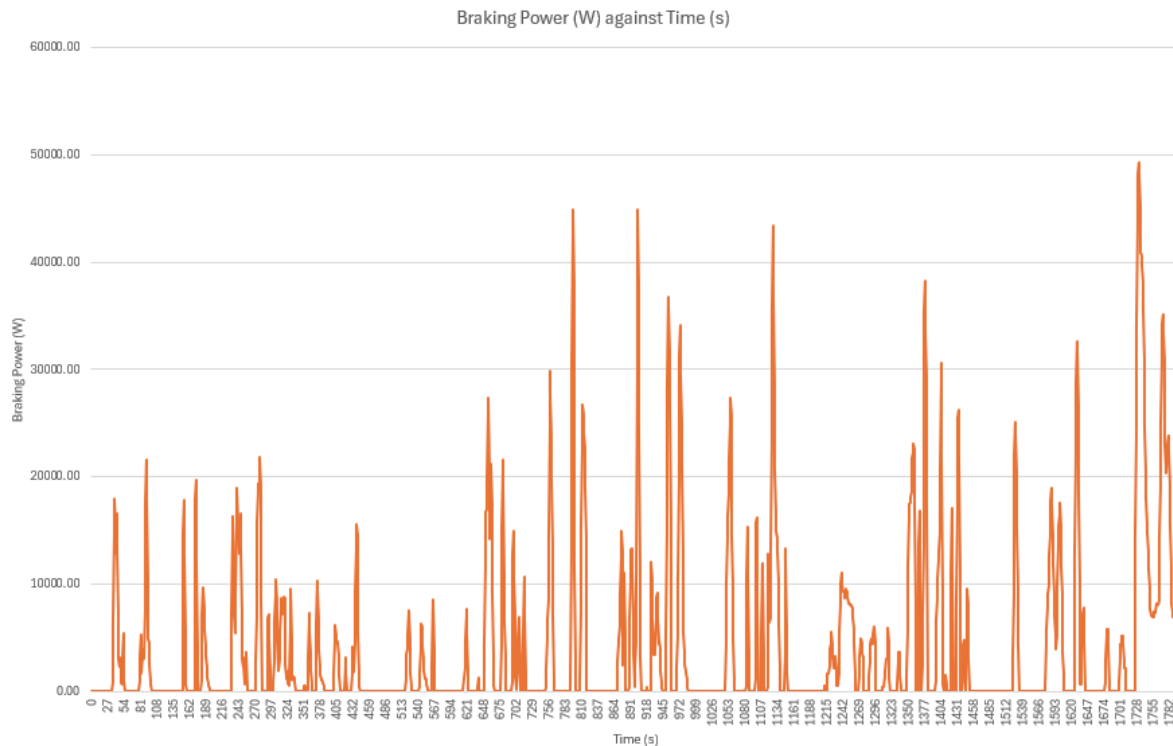


Figure 9 Braking power against times

Looking at Figure 9, the high points signify areas of harsh braking, and the low points show areas of coasting or acceleration. There are multiple significant deceleration points throughout the WLTP. Looking at the largest deceleration period, the energy storage system must be able to withstand this before the next braking event occurs. A safety margin of 25% is commonly used. The largest braking energy event was found using integration of braking power over time. This resulted in a total of 887700J, which showcases the highest energy packet that the KERS must store before the next braking event. When applying the 25% margin, the minimum storage requirement reaches 1.11mJ or 0.31kWh.

KERS Options

KERS Type	Pros	Cons
Super Capacitors	Flexible Torque High power efficiency	Risk of overheating Heavy

Flywheel	High energy density Fast response time	Limited energy storage Large packaging
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The peak braking power calculated for the Volvo suggests that the KERS must absorb energy rapidly over short timeframes, which favours high power density systems over higher energy dense systems.

Based on the WLTP proven power and energy demands, a super capacitor based KERS is chosen as the most appropriate for the Volvo. This is due to the moderate braking energy sections that show that high energy density is not needed, and instead, the strong braking power peaks require rapid energy absorption. A super capacitor can respond instantly to this power influx as well as improve trip efficiency. A flywheel based system will also add in large packaging constraints, given the already cramped engine bay.

KERS System Specification

System overview

A super capacitor based KERS is decided for the D5 engine in the Volvo. The system consists of a motor generator unit (MGU) that is connected to the driveline, an inverter, and a supercapacitor storage pack. When the vehicle experiences braking, the MGU works similarly to a standard generator, turning kinetic energy into electrical energy (EIA, 2023). This energy is then stored in the supercapacitors. Under acceleration, the system works in reverse, expending the stored energy back into kinetic energy and aiding the engine, reducing fuel consumption and strain on the engine.

Supercapacitors are best suited for this scenario due to the short bursts of braking in the WLTP that require large power levels. Super capacitors offer very high power density and rapid charging compared to lithium ion batteries.

Requirements and Sizing

Power Requirements

From the braking power calculations, the maximum instantaneous braking power during the cycle is

$$P_{brake\ peak} = 49.3kW$$

This value determines the minimum regenerative power that the KERS must be able to absorb, in the event that all braking energy is to be used. To avoid saturation and the risks of ageing, a margin of 25% is allowed. Bringing the total to 62.5kW for the target MGU rating.

The largest braking event lasts around 69s and contains 887,700J of energy. Equalling an average of 12.9kW over the event. This confirms that the 62.5 kW is safely sufficient to deal with peak and sustained demands.

Storage Requirements

The largest braking packet from the WLTP is

$$E_{packet\ max} = 887700J = 887.7\ kJ$$

This shows the maximum amount of energy that must be stored if all the braking energy is to be recovered from a single event. Adding on the same 25% safety margin brings this storage requirement to 1.11mJ; this is equivalent to 0.31 kWh.

Sizing Summary

The Excel proves that for a sufficient KERS system, the MGU and inverter rating is 62.5 kW, and the supercapacitor minimum storage is 1.11mJ or 0.31kWh.

This shows that a supercapacitor design is feasible for a Volvo V70, and the storage capacity is modest.

Kinetic Energy Returned to the Wheels

Energy Recovery

When looking at the Excel, it can be seen that the total available braking energy is 3.31 kWh. This represents a maximum energy for recovery if all events were captured perfectly. However, due to components in the KERS requiring some energy to be powered, there are some losses that take place from start to finish.

Energy Loss		
	Energy Capture system	80%
	Super Capacitor Bank	98%
	Energy after Capacitor	98%
	MGU	90%
	Energy post Generator	90%
	Controller	94%
	Energy Post Controller	94%

Figure 10 shows a screen grab from the spreadsheet showcasing the various efficiencies of the components (Zhong, 2007)

The overall trip efficiency of the KERS system is calculated to be 54.9%, based on losses throughout the entire system. This aligns with the range reported for experimental KERS in passenger vehicles (Chat GPT, 2024). After conversion and storage losses, the final usable traction energy is

$$3.318 \text{ kWh} \times 0.549 = 1.82 \text{ kWh}$$

Fuel Saving Estimate

To convert recovered energy into fuel savings, a theoretical energy content of diesel must be used. Diesel contains approximately 10kWh of energy per litre (Sustainability Exchange, n.d.), but a diesel engine only has an efficiency of 35% (Chat GPT, 2024). Therefore, only 3.5kWh is usable at the wheels.

$$\text{Fuel Saved per Cycle} = \text{Energy Recovered} / 3.5$$

Limitations

The key limitations of this model are due to a lack of data being supplied.

Limitation	Effects
Lack of Friction Braking	May reduce KERS capture
Environmental conditions were not stated	Will affect Cd, RR, Air Density

No Gradient	Descents will increase energy, and climbs will decrease available energy
No thermal modelling	A hot Capacitor is less efficient
WLTP does not simulate traffic	Start stop traffic will have different requirements from motorway driving.

This lack of data means the simulation represents a best case scenario rather than a practical demonstration of day to day driving.

KE Returned to Wheels

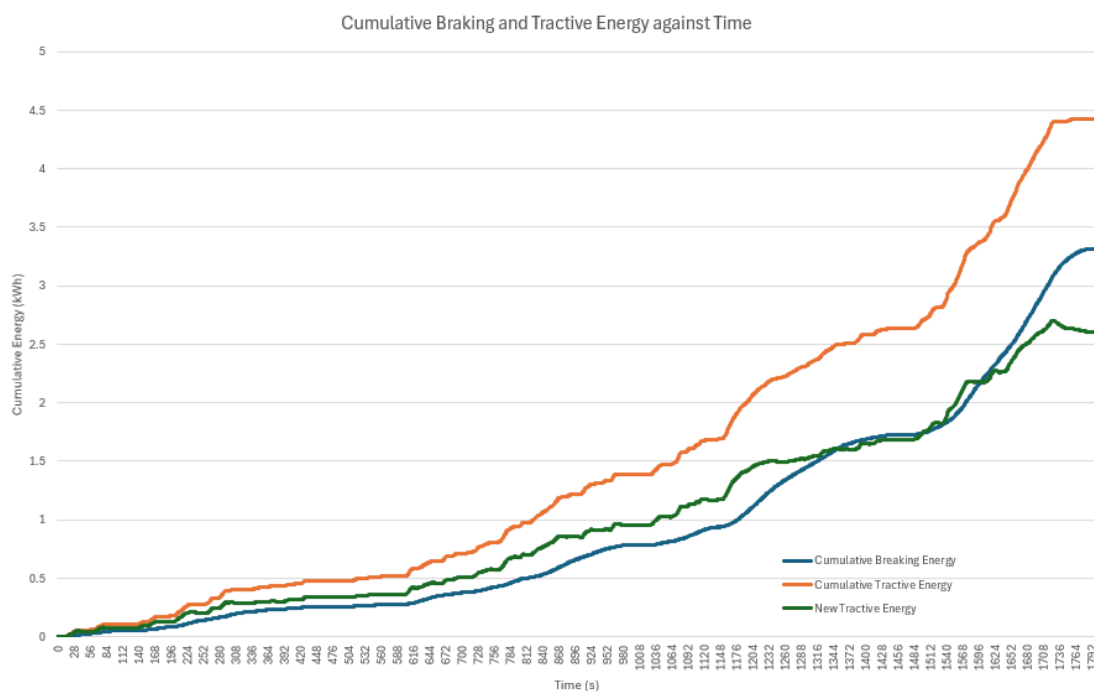


Figure 11 shows the comparison between Cumulative Tractive, Braking Energy, and the newly calculated tractive energy after adding a KERS.

Figure 11 shows that the new implementation of a KERS to this vehicle is very effective in the low, mid, and high phases of the WLTP; however is not as effective in the Extra High phase. This could be due to the engine selected being already optimised for high speed driving, and therefore, the need for a KERS is not as much.

Overall, the modelling confirms that the addition of a KERS system is feasible for the Volvo V70 and that super capacitors are an appropriate choice based on power demands and charge acceptance. Due to the body style of the V70, it is also a choice that can be fitted with little to no effect on the driver.

Driver Experience

Brake Feel

In a perfect implementation, the driver should not detect a change in brake feel. This is due to the regenerative braking coming into effect first, then the traditional braking is blended in when required. This subsequently means that there is a reduction in brake wear. However, improper calibration between the systems can cause safety concerns with unpredictability between braking responses and braking speed.

Noise, Vibration, and Harshness

There will be a need for insulation around the motor to help the reduction of noise whilst under rapid change and use scenarios. However, in casual driving, it will remain quiet.

Packaging and Maintenance

The V70 offers a practical platform to implement a KERS due to the large available boot space and equally large under boot floor storage. Supercapacitor packs are smaller than full hybrid systems and are easier to house (Muller Energy, 2023). Due to the larger mass of the vehicle, the added mass will be less significant to the overall driver's feel. The maintenance cost of the KERS system is offset by the reduction in maintenance of braking systems.

A KERS would not significantly alter driver operation, but would require extensive work in the calibration and addition into the system to preserve an OEM feel.

Conclusion

The WLTP simulation showcased that the Volvo V70 generates significant braking energy, with a peak braking power of 49.3kW and the largest braking energy event of 887.7kJ. It is proven that regeneration is practical and well suited towards a supercapacitor based KERS rather than a flywheel based system. Following an in depth efficiency analysis, a realistic total of 1.82kWh of usable energy shows the system is 55% efficient. When applied to repeated urban cycles, the potential energy savings are magnified. Reduced brake wear, reduced fuel consumption, and lower engine strain are also positive side effects.

Overall, the modelling and analysis have led to the decision that the introduction of a KERS will be beneficial. With further optimisation, the v70 could exploit a large portion of its braking energy into improvements in sustainability.

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