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BSC Motorsport Engineering

M6X02206

Research Methods & Project

**Implementation of a Hybrid-Electric
System to a 'Classic' Vehicle - Main
Report**

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Abstracts

Non-technical:

For my individual project, I will be talking in-depth about hybrid-electric vehicles and what types of systems you would expect to find on a conventional road vehicle. I have chosen this topic because of the alarming rise in air pollution, especially in built-up areas such as cities, and the increase of hybrid vehicles being released into the automotive market. For this project, I will be using a vehicle that has no emission control system and I will be aiming to improve its emissions output and lower its fuel consumption by using a specific type of hybrid system. I will be discussing each system and will come to a decision on which system would be more suitable for my chosen vehicle. The use of a data logging device will help me to record the behaviour of the vehicle, such as speed and power output. I will then design a model of a component of the hybrid system attached to my chosen vehicle, using CAD software.

Technical:

For my individual project, I will be using the application of a hybrid-electric system to decrease the emissions output and lower the fuel consumption of a conventional road vehicle with an internal combustion engine. I have chosen this topic because of the alarming increase in air pollution, especially in urban environments such as cities, and the increase in hybrid-electric vehicles being released into the automotive market. I will be discussing in-detail the unique of each system, from series hybrids to parallel hybrids, and will come to a consensus on which system is appropriate for the vehicle of my choice. For this project, I have chosen a vehicle that has no emission control system. The primary aim is to be able to use the electric motor at lower speeds or in traffic, which will reduce the fuel consumption of the vehicle and decrease the levels of emissions being emitted from the vehicle. I will be using the data logger to collect data and record a drive cycle of my chosen vehicle and will then design the chosen hybrid system using CAD software and technical drawings and measurements of the vehicle.

1. Introduction

For my individual thesis, I will be exploring the technical aspects of a hybrid-electric system used to power a conventional road vehicle by theoretically installing a hybrid system onto a 'classic' vehicle of my choice. Through the assistance of online resources and books to collect necessary information, I will be discussing in-depth about the different types of hybrid systems you would expect to find installed onto a vehicle, which system would be ideal for the vehicle of my choice and justify why I chose the system over others. An elaboration on the different components of a hybrid-electric system is also provided in this report. The aim of this project is to highlight importance of reducing the fuel consumption and carbon emissions output from vehicles through the use of technologies such as hybrid-electric systems, especially in populated environments. Backed by credible research and testing methods, I will explain how a hybrid system is capable of reducing the fuel consumption and the emissions output from the internal combustion engine and how the employment of such systems will have a positive effect on the environment. In addition, I will discuss the drawbacks of a hybrid-electric system, ranging from its purchasing price to consumer convenience.

To justify my argument for hybrid-electric vehicles, I will be using a vehicle data-logging device that will allow me to create a drive cycle of the vehicle of my choice. Through the use of the Race Technology software and Microsoft Excel, I will compare XY line graphs of the standard vehicle to the 'hybridised' version of the vehicle to display the benefits of using a hybrid-electric vehicle in an urban environment and where it will be able reduce fuel consumption when the internal combustion engine is not necessary to propel the vehicle. Once I obtain the necessary data, I will display a series of calculations to solidify my claims that a hybrid-electric system will enhance the vehicle's efficiency by adapting a kinetic-energy recovery system. I will also consider the costs of purchasing and installing the hybrid system onto my chosen vehicle. There is no theoretical budget for this project, but I will attempt to create the system as cost effectively as possible. This is an important factor when promoting the sales of hybrid-electric vehicles, as many consumers are generally disinterested in spending thousands of pounds more to purchase a more environmentally-friendly vehicle.

I intend to combine my knowledge from other modules on this course to complete this investigation, using skills that I have learnt through different assignments I have been given throughout my time in university.

2. Literature Review

(2.1.)

(2.1.1.)

A vehicular hybrid system is propelled by a combination of a conventional internal combustion engine and an electric motor or other power sources (NDC, 1979). The first mass-produced hybrid-electric vehicle was introduced in 1997 as the Toyota Prius, which was launched to the Japanese automotive market (SAE, 2007). The Prius became an instant success in Japan since its release, as the vehicle inherited awards from Japanese automotive critics such as the 'Car of the Year' and the 'Automotive Researchers' and Journalists' Conference Car of the Year' in 1997 (Wikipedia, 2019). With the increasing demand of the Prius in the vehicle export markets, Toyota announced mass-production of the vehicle in western countries, starting production in the UK in August 2000 (Toyota, 2015).

The success of the Prius had captured the attention of other Japanese automotive manufacturers, which saw the development of vehicles that had adapted the hybrid-electric system principle. For example; Honda released the Insight hybrid-electric vehicle in November 1999, featuring its brand-new 'Integrated Motor Assist' system (Gooding, 2017). The Insight was primarily considered as a 'test' to see how Honda's hybrid-electric system would perform in the automotive market, in comparison to the Prius.

As the awareness of emissions output and overall efficiency is widely evolving within the automotive industry, vehicle manufacturers around the globe have been developing and releasing hybrid-electric vehicles more frequently to meet emissions regulations and improve the general quality of the systems. The system reduces fuel consumption by substituting battery energy for propulsion and, at the same, extending the electrical range of the vehicle (NDC, 1979). Therefore, manufacturers are increasing their interests in the hybrid-electric principle. Refer to section 2.3 in my analysis for the benefits and weaknesses of the hybrid-electric system.

(2.1.2.)

A typical hybrid-electric system comprises the use of different technologies to distribute the electric energy to the vehicle's final drive for propulsion and back into storage for future use. The use of specialised transmission systems, such CVT (Constantly Variable Transmission), are ideal for hybrid-electric vehicles as the single-speed automatic gearbox enables the driver to accelerate using the electrical energy without manually operating a clutch (Gibson, 2017). The CVT system can adjust continually to different road speeds, instead of relying on driver input (Cotta, 2019). As engines are more efficient when they maintain a set rotational speed, such as motorway driving when the driver remains at 70 mph, this helps reduce the consumption of fuel (Cotta, 2019). In this investigation, I will be using the original transmission system of my chosen vehicle, so I will not be choosing a CVT system. I have chosen this to reduce the costs of purchasing and installation, as I am trying to create the hybrid system as cost-efficiently as possible.

To create my hybrid-electric system, I need to research for the various components that will be installed onto my chosen vehicle. These components are:

(2.1.2.1.)

- **Electric Motor & Controller**

An electric motor is a device that converts the input of electrical energy into a rotational force. A typical motor will consist of an abundance of copper coils and steel laminations, otherwise known as a 'stator'. This allows a considerable amount of electrical energy to conduct through the motor (Hughes, 2013). The coils and laminations are situated within an electromagnetic field, which enables an output rotor (metal shaft) to rapidly rotate as the electrical current flows through the conducting material (Hughes, 2013). The rotational force of the output rotor will provide the mechanical torque to propel the vehicle.

Traditionally, hybrid-electric vehicle manufacturers will apply an 'AC' (alternating current) electric motor into its system for propulsion, as opposed to a 'DC' (direct current) motor. This is mainly due to the fundamental differentiation in control, power range and application between the two types (Niku, 2010). For example; the rotation speed of a DC motor can be controlled by altering the current flow through stator, while the rotation speed of an AC motor is controlled by the frequency of the supplied AC energy (Niku, 2010). Since the frequency of the AC power is constant, the rotational speed of an AC motor is generally constant. Since I will be implementing an AC induction motor into my hybrid system, I will elaborate on that particular type of motor.

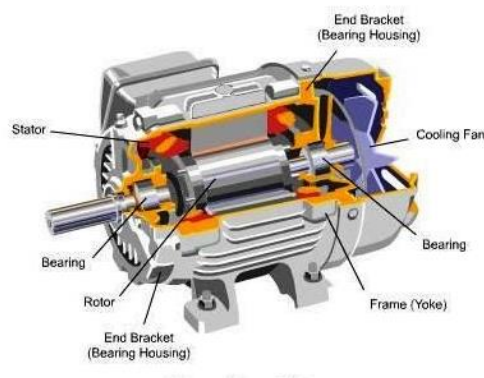


Figure 1 – Cutaway View of an AC induction motor (Poston, 2019)

The figure above displays the internal components within an AC induction motor. The electrical current from the storage device flows into the motor's electric terminals, which energises the electromagnet coils and laminations to produce magnetic field that will continuously rotate in the same direction (Woodford, 2018). The magnetic field is constantly fluctuating due to the rotation of the output rotor, so the magnetic field induces an electric current inside the stator (Woodford, 2018).

To maintain high performance and high efficiency from the electric motor, a controller is installed to primarily regulate the speed and direction of the output rotor by manipulating the voltage that is applied to the motor's terminals (4QD, n.d.). The voltage is manipulated according to the specific power requirements from the electric motor, which is regulated by manually operating the throttle in a hybrid-electric vehicle. The motor controller operates by using series of diodes as a form of an electricity rectifier, which is capable of converting a set frequency of alternating current (AC) into direct current (DC) and back into alternating current (AC) at a suitable frequency (David, 2017). A controller is vital to ensure the safety of the electric motor while it is in operation.

A stalled electric motor can take up to 20 times its normal operating current. If a sudden electrical charge is applied to the motor from the energy storage device, the motor can produce a very high initial current surge, which could seriously damage the motor and its internals if a controller is not installed (4QD, n.d.).

(2.1.2.2.)

- **Electricity Generator**

An electricity generator is a component that is capable of generating electrical energy while the vehicle is in motion. A hybrid-electric vehicle will employ a generator in order to process and regenerate a given fraction or, when available, the entire amount of traction power required by the vehicle wheels (Crescimbin, 2005). The electrical generators installed into a HEV vehicle is coupled onto a shaft from an internal-combustion engine (Crescimbin, 2005). In turn, this will convert mechanical energy from the shaft into electrical energy and redirect it back into the storage device.

In theory, a HEV's electricity generator adapts the same principle as an alternator that is installed to a vehicle with an internal combustion engine. As a hybrid system requires a sizeable amount of electrical current to sufficiently power its components, more electrical current is required to be send back into the storage device. Consequently, the generators that are applied to most hybrid-electric vehicles are generally larger in size and heavier in comparison to an alternator. A typical high-powered generator can be seen below:



Figure 2 – Electricity generator (Magtec, n.d.)

To effectively elaborate on the philosophy of an electricity generator, I will use an alternator as an example. The sole purpose of an electricity generator is to convert alternating current ('AC') from the mechanical energy, into direct current ('DC') for the storage device. To achieve this, a vehicle alternator is comprised of a voltage regulator and three main components; a rotor, a stator and a diode (Wright, 2018).

The rotor is an electromagnet that rotates through the use of mechanical torque, whether it be from an electric motor or an internal combustion engine (Auto Electro, n.d.). This is achieved by applying a pulley onto the alternator, as the use of a driven alternator belt provides the mechanical torque to the rotor (Weber, 2016). While the vehicle is in operation, the rotor is continuously rotating inside the stator, which consists of a series of fixed coils of tightly wound copper wire (Haynes, 2019).

As the rotor rotates, it generates an electromagnetic field and a small amount of electricity, which is amplified through the stator as the copper wire is eligible to conduct the energy (Haynes, 2019). The electrical charge from the stator is the form of alternating current (AC), which will need to be converted into direct current (DC) for its return into the storage device. The application of a diode is purposeful, as it will be able to rectify the electrical current and maintain the flow of electricity in one direction (Kuphaldt T. R., 2019).

A voltage regulator is applied to an electricity generator to maintain a suitable amount of voltage flow into the electromagnetic rotor from its mechanical power source (Britannica, n.d.). The sole purpose of this device is to refrain a substantial amount of voltage to flow through and prevent overcharging, which could cause significant damage to the energy storage device (Norman, 2015). Thus, increasing the life expectancy of the storage device.

(2.1.2.3.)

- **Energy Storage Device**

An energy storage device is implemented into a hybrid-electric system to store and supply electricity for the system's components to consume (Biradar, 1998). The application of an energy storage device within a hybrid system is to provide electrical power to components such as the motor, which rely on this energy to propel the vehicle. As the output of the battery increases, so too does the acceleration of the vehicle (Nissan, n.d.). Without it, the hybrid system will simply not be able to function. Throughout the evolution of hybrid-electric vehicles, numerous methods of storing energy have been trialled to explore the differentiation and effectiveness between them. These methods include the applications of components such as batteries, super-capacitors, and a flywheel (Sher, 2012). For this project, I will be adapting the use of a lithium-ion battery as an energy storage device.

A hybrid-electric vehicle necessitates a battery/set of batteries that is capable of withstanding the copious amount of energy that is acquired to propel the vehicle. Therefore, specialised high-performance batteries are available on the automotive component market to suit the specific requirements of manufacturers. Throughout the evolution of hybrid-electric vehicles, numerous methods of storing energy have been trialled to explore the differentiation and effectiveness between them. These methods include the applications of components such as batteries, supercapacitors, and a flywheel (Sher, 2012). For this project, I will be adapting the use of a lithium-ion battery as an energy storage device.

A hybrid-electric vehicle necessitates a battery/set of batteries that is capable of withstanding the copious amount of energy that is acquired to propel the vehicle. Therefore, specialised high-performance batteries are available on the automotive component market to suit the specific requirements of manufacturers. There are three main types of rechargeable batteries that can be employed to a hybrid-electric vehicle; lead acid, nickel-metal-hydride (NiMH) or lithium-ion (Audet, 2019).



Figure 3 – Lithium-ion battery pack (Nissan, n.d.)

The reasoning for my choice of battery is the differentiation of capabilities the lithium-ion battery has in comparison to other alternatives. A lithium-ion battery is notoriously known for being able to hold a large quantity of electrical power as lithium is a highly reactive element, which deems it more practical in a hybrid vehicle application as opposed to other batteries (Audet, 2019). The weight of a typical lithium-ion battery is generally lighter than other alternatives of the same size, as the electrodes are made of lightweight lithium and carbon (Marshall, n.d.). Additionally, unlike other types of batteries that require a periodic discharge to prolong life expectancy, a lithium-ion battery does not require a periodic discharge and requires little to no maintenance throughout its life (Battery University, 2010). Therefore, making it a popular choice for hybrid-electric vehicle manufacturers.

Of course, a lithium-ion battery does have its drawbacks. Lithium, compared to other battery materials, is substantially more susceptible to permanent damage through excessive heat (Marshall, n.d.). It will need to operate in a suitable temperature to exploit the battery's life expectancy, otherwise the vehicle will suffer from a degradation of performance (Biradar, 1998). On the subject of life expectancy, the typical estimated life of a lithium-ion battery is about two to three years or 300 to 500 charge cycles (Tektronix, n.d.). Compared to other battery types, it is the most susceptible to ageing. Circumstantially, this makes it costly to maintain over a longer period of time as a lithium-ion battery is around 40 percent higher in cost than a battery constructed with nickel-metal-hydride (NiMH) (Battery University, 2010).

(2.1.2.4.)

- **Kinetic-Energy Recovery System**

A kinetic-energy recovery system, otherwise known as KERS, is primarily installed onto hybrid-electric vehicle to minimise the amount of kinetic-energy that is lost through heat and friction (Ehsani, 2010). The friction is created from the braking system (brake pads and discs) and the electric motor while the vehicle is slowing down in speed, which generates a certain amount of kinetic-energy and heat. The purpose of a KER system is to recover the kinetic-energy and convert it into electrical energy, which is redirected into the energy storage device for future use (Mathews, 2013). Effectively, the system recharges the energy storage device as the vehicle is in motion, extending the driving range of the hybrid-electric system. In terms of increasing vehicle efficiency, it is a significant development in the automotive industry.

The KER system principle has proved its effectiveness over a variety of different applications and configurations. The system had been adapted onto Formula 1 vehicles in 2009 to improve vehicle efficiency, which beneficially created around 80 hp of additional power for around six seconds per lap when the energy recovered from the KER system was being utilised (Formula 1, n.d.). Additional to the improvement of efficiency, the system actually provided the drivers with a boost in vehicle performance. The KER system in such applications as Formula 1 vehicles comprises the use of a lightweight flywheel, which was widely known as a 'Flybrid' system within the motorsport industry (Racecar Engineering, 2007). The flywheel is capable of storing and regulating energy by rotating continuously. In the instance of a Formula 1 vehicle, it can rotate up to an astronomical 64,500 RPM while in operation (Racecar Engineering, 2007). The amount of energy that a flywheel is capable of storing is dependent upon its weight and rotational speed (Mathews, 2013). Hence, the flywheel applied to a Formula 1 vehicle's KER system is considerably light in weight, so it can rotate at a faster speed.

Over recent years, kinetic-energy recovery systems have emerged into the automotive industry as an application to increase the efficiency of hybrid-electric vehicles. Due to extensive development, the system has generally improved in quality over time. The interests displayed from automotive manufacturers, such as Tesla and Volvo, demonstrates how manufacturers are keen to invest in developing a more efficient version of the system for their vehicles. For example; Toyota had introduced the regenerative-braking principle into the second-generation of the Prius and has since been applicated into each generation of the Prius ever since (Wikipedia, 2019). Of course, this type of KER system is completely different to the setup applicated onto a Formula 1 vehicle. The hybrid-electric system provides the majority of the braking by exploiting the principle of 'engine braking'. When the driver inputs pressure onto the brake pedal to slow the speed of the vehicle, the output rotor of the electric motor will reverse its rotation (Lampton, 2009). Thus, effectively slowing the speed of the vehicle's wheels. While rotating in reverse, the electric motor acts a form of electricity generator, as it produces electrical energy when the vehicle is slowing down in speed (Lampton, 2009). This electrical energy is then redirected into the energy storage device for future use. This type of kinetic-energy recovery system is most effective in stop-and-go situations, such as driving through city centres and congested areas.

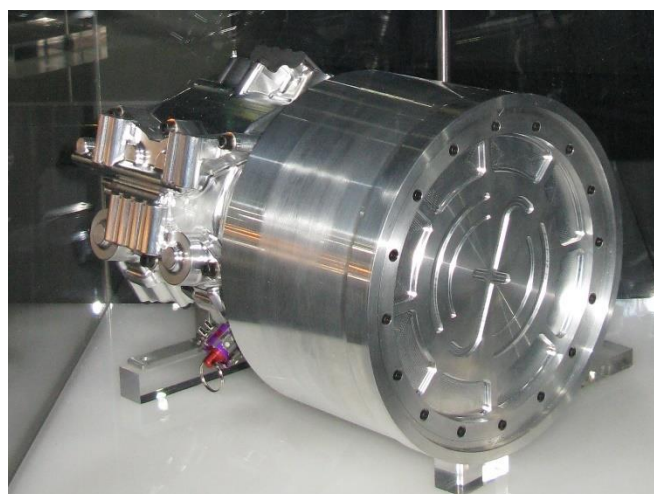


Figure 4 – 'Flybrid' kinetic-energy recovery system (Wikipedia, 2018)

(2.1.3.)

To select the appropriate hybrid-electric system for my chosen vehicle, I will need to explore the different types of systems and choose the most suitable system for my type of application. The power devices can be connected in series, in parallel or in series-parallel. I will need to consider which system is most suitable for my project.

(2.1.3.1.)

- **Series Hybrid-Electric Vehicles**

When the internal combustion engine and electric motor are connected in series, the electric motor is the only power provider to the vehicle wheels (Chris Mi, 2018). In this particular system, the ICE is the main energy converter that drives the electricity generator instead of directly driving the wheels, converting the mechanical power into electricity (Wroclaw University of Technology, n.d.). The ICE employed onto a series hybrid system is typically smaller than other system types, as it only has to meet certain power demands (UoCS, 2018). Hence, the ICE can run at optimum RPM and throttle input to consume the minimal amount of fuel and emit the minimal amount of pollutants (Fuhs, 2009). This system typically requires a single large motor or multiple small motors to match the performance of the ICE (Jordan, 2004). The electric motor/s provides torque to the final drive by using the electricity created by the generator, or electricity stored in the vehicle's energy storage device. An electronic control unit (ECU) can dictate how the electric motor can receive its electricity; from the engine, from the battery or from the electricity generator (Randall, n.d.). However, the components of this type of hybrid system will need to withstand the full amount of power required to propel the vehicle. Therefore, they are generally larger and heavier in comparison to other types of hybrid systems. The increase in weight has a negative effect on the vehicle's overall performance output, which will decrease due to the additional weight.

Since the electric motor is the only power provider to the wheels, I will not be using this type of hybrid system for my project. It does not comply with my system requirements.

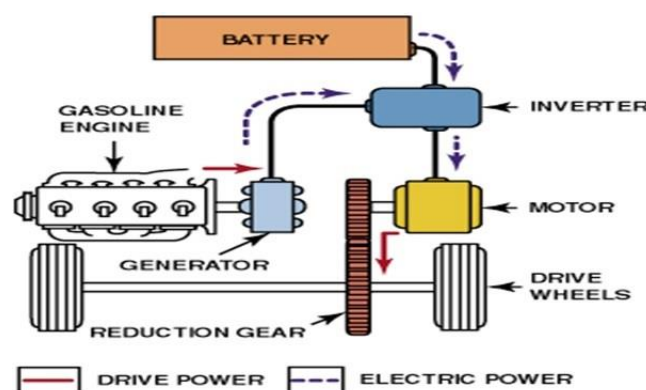


Figure 5 – Series hybrid system ('Praveen', 2015)

(2.1.3.2.)

- **Parallel Hybrid-Electric Vehicles**

When the internal combustion engine and electric motor are connected in parallel, both power devices work in unison to provide power to the vehicle wheels (Jordan, 2004). The ICE and electric motor are coupled together to provide torque to the final drive through mechanisms such as clutches, belts, pulleys and gears (Chris Mi, 2018). Both the ICE and the electric motor can be used provide power either separately or combined together, increasing the hybrid system's flexibility. For example; the Toyota Prius is employed with a parallel hybrid system, which is capable of only using the electric motor for power until the vehicle reaches 15 mph (Toyota, n.d.). Once the Prius overcomes that speed, the ICE will begin to provide power to the final drive in synchronisation with the electric motor. When the Prius is travelling at a high rate of speed, the electric motor will stop the production of power and the vehicle will only use the ICE for propulsion. In turn, the vehicle will be capable of redirecting and replacing electric energy back into the energy storage device. Furthermore, the electric motor can respond to the demand of instantaneous power and torque requirements, such as the power required to begin moving the vehicle from a stand-still, more effectively than an ICE (Fuhs, 2009). This is especially beneficial in densely populated environments. However, the overall efficiency of the system is at its highest while the vehicle is cruising at a high rate of speed, such as dual-carriageway or motorway driving (Wroclaw University of Technology, n.d.). This is one disadvantage of the parallel hybrid system, as the vehicle will not be capable of achieving its maximum effectivity at a lower rate of speed, such as congested and urban environments.

As I will be able to utilise both the ICE and the electric motor to produce power, I will be adapting this hybrid-electric system for this project. I plan to use the electric motor to propel the vehicle while only travelling in congested and urban areas, so this system is the most favourable for my type of application.

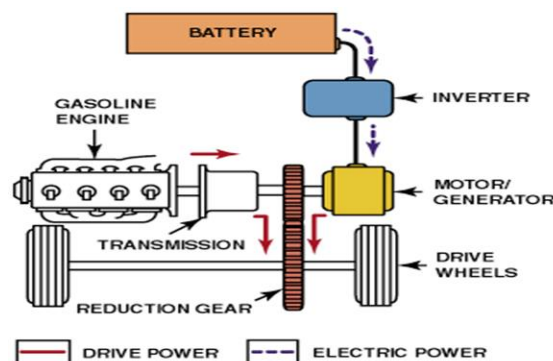


Figure 6 – Parallel hybrid system ('Praveen', 2015)

(2.1.3.3.)

- **Series-Parallel Hybrid-Electric Vehicles**

A series-parallel hybrid system incorporates the features from both series and parallel hybrid systems. Therefore, it can be operated as either a series or parallel system (Chris Mi, 2018). Alike the parallel system, this particular system uses an electric motor to drive the vehicle at a low speed and then an internal combustion engine when the speed increases (FAM, n.d.). Because of this, the fuel efficiency and driveability can be optimized based on the vehicle's operating condition, increasing the system's flexibility (Fuhs, 2009). Also, the electric motor and ICE can provide power individually, or in synchronisation, depending on the power required to drive the vehicle (FAM, n.d.). However, the additional components required to correctly develop this system affects the overall performance output of the vehicle it is applied to. A series-parallel is substantially heavier than other types of hybrid systems, due to the number of components it is required.

Due to the additional components and increased complexity, this system is generally more expensive than a series or parallel hybrid system. Thus, I will not be using this system for my project. The additional weight of the components will likely decrease the performance of my chosen vehicle as it is relatively light. In addition, I do not require the function of a series hybrid system for this project. The increased flexibility of this system is only beneficial when it is correctly applied for its intended purpose.

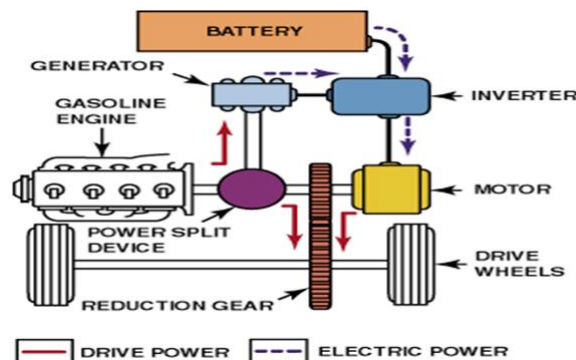


Figure 7 – Series-parallel hybrid system ('Praveen', 2015)

(2.2.)

While vehicle manufacturers are continuously investing into the hybrid-electrification of vehicles, there are some weaknesses that cannot be solved simply. Regardless, the hybrid-electric principle has generally improved in quality since the introduction of the Toyota Prius over 20 years ago. This is credited to large investments of time and money from vehicle manufacturers, whom have adapted technologies that were originally developed for motorsport applications, such as Formula One and LMP1 racing vehicles. For example; after extensive development, Porsche released the 918 Spyder hybrid-electric hypercar as a limited edition consumer product in 2014 (Berman, 2016). This vehicle, along with the Ferrari LaFerrari and the McLaren P1, is considered as the first generation of commercially available hybrid-electric hypercars. This signifies the evolvement of hybrid-electric technology as an alternative method of vehicle propulsion.

The continuous strengthening of emissions standards, such as the up-coming Euro 7 and its predecessors, is placing a constant strain on vehicle manufacturers to produce more environmentally friendly vehicles. Inevitably, the enforcement of stricter emission standards could lead vehicle manufacturers might consider abandoning the ICE principle and invest into only producing hybrid-electric or all-electric vehicles in the distant future. The BBC claims that we could be seeing this revolutionary change in vehicle production as close as 2032 (BBC, 2018). Listed below are the benefits and weaknesses of a hybrid-electric vehicle:

(2.2.1.)

Benefits

- **Reduced vehicle emissions**

Hybrid-electric vehicles are widely known for their cleanliness in operation. They are capable of emitting considerably less emissions at all ranges of speed in comparison to other conventional vehicles (AFDC, n.d.). Since the electric motor is not reliant on the combustion of fuel and air mixture for vehicle propulsion, it cannot produce and emit harmful greenhouse gases, such as CO₂, into the atmosphere (Hannan, 2017). Hence, automotive manufacturers particularly highlight the 'zero emissions' output when selling their hybrid-electric vehicles. Especially for the basis of this project, which is revolved around improving the emissions output of vehicles in urban environments, the system is extremely beneficial.

The issue of extensive vehicle pollution stems from the amount non-electrical vehicles that are being utilised on a daily basis. ICE-powered vehicles significantly contribute to air pollution in comparison with other types of cars (Al-Rousan, 2015). Newer ICE-powered vehicles are being installed with technologies such as 'stop/start', which enables the vehicle to completely cut off the ICE without the driver's input when it is at idle (Haynes, n.d.). This prevents the vehicle from emitting pollutants when the ICE is not required. However, at present, all conventional vehicles rely on the combustion of hydrocarbon (HC) fuels inside the cylinder of an internal combustion engine to derive the energy that is necessary for their propulsion (Ehsani, 2010). The combustion of the hydrocarbon fuels results in the production of mainly carbon dioxide, water and heat (Afework, 2018). Consequently, these combustion products contain a certain percentage of different pollutants, such as; carbon monoxide (CO), fine dust particles, nitrogen oxides (NO_x) and unburnt hydrocarbons (NetRegs, n.d.). The pollutants are then emitted from vehicle via the exhaust system and into the atmosphere. Especially in densely populated and congested areas, the greenhouse gases that are produced by ICE-powered vehicles can be damaging to humans and other forms of life as they are toxic to inhale (Ehsani, 2010). Inhaling the gases can contribute towards developing illnesses such as carbon monoxide poisoning, which has been the cause of around 60 deaths in the United Kingdom each year (NHS, n.d.). Furthermore, it can cause respiratory problems and side effects such as dizziness and nausea (NHS, n.d.).

The release of pollutants from non-electrical vehicles can also contribute to the ever-increasing issue of 'smog'. 'Smog' is an accumulation of smoke, gases, and chemicals that can be seen in the atmosphere (Cambridge Dictionary, n.d.). As the name suggests, a 'smog' cloud identifies like a typical patch of fog. It is more susceptible to develop in cities, where thousands of ICE-powered vehicles are emitting greenhouse gases within the same area, even if they are at idle due to traffic.

Alike carbon monoxide poisoning, 'smog' is exceptionally dangerous to human health, as it can cause respiratory problems if inhaled for a period of time (Healthline, n.d.). It is a worsening issue in cities around the globe, such as Tokyo and Bangkok, where vehicle emissions standards are disproportionately lower to other countries. Citizens who live in, or travel into, these cities are forced to wear pollution masks to prevent the inhalation of 'smog'.

To summarise, the daily utilisation of non-electrical vehicles is a large contribution to the global warming (Hannan, 2017). This is an issue on a global scale. By cutting down on the amount of pollutants we emit into atmosphere through the deployment of hybrid-electric vehicles, we can lower the effects of global warming over time. Especially in densely populated areas such as cities, the quality of air in the atmosphere will increase as more hybrid-electric vehicles are being utilised.



Figure 8 – 'Smog' cloud over Bangkok (The Independent, 2019)

- **Quieter environment**

Considered as 'noise pollution', the employment of more hybrid-electric systems will drastically lower the level of noise being emitted from vehicles. Noise pollution remains a major environmental health problem around the globe, with the transport sector playing a major role in this issue (EEA, 2017). Hybrid-electric vehicles are predominantly beneficial in densely populated areas, where non-electrical vehicles are continuously running and producing noise when the ICE is required to propel the vehicle. Even at idle engine speed, an ICE-powered vehicle can produce a level of noise. In congested environments, such as cities centres and traffic lights, this is amplified due to the number of vehicles in the area. As previously mentioned, newer ICE-powered vehicles are being installed with 'stop/start' technology. In turn, this prevents the vehicle from producing noise while the ICE is not required. However, the electric motor from a hybrid vehicle produces very little noise while in operation and when the vehicle encounters traffic, the electric motor will not produce noise when the vehicle is at idle. If every vehicle were to be installed with a hybrid-electric system, the noise pollution from within an urban environment will drastically decrease as a result.

Noise pollution is a continuous battle for citizens who live in areas such as city centres and regularly congested roads.

According to the European Environment Agency, road traffic noise is the dominant source of noise pollution, affecting human exposure above the EU's threshold of 55 decibels (dB) for daily exposure and 50 dB for night exposure (EEA, 2017). Citizens that are subjected to noise pollution are more susceptible to health risks that could affect their quality of life. These health risks include such instances as: sleep disturbance (which can lead to chronic fatigue), hearing impairment, cardiovascular disease and general wellbeing (Singh, 2004). By increasing the utilisation of hybrid-electric vehicles, we can lower the level of noise pollution from vehicle transportation, which will benefit the wellbeing of citizens.

- **Fuel economy**

Since the electric motor dismisses the requirement of ignitable fuel for propulsion, a consumer of a hybrid-electric vehicle will recognise a financial saving in fuel costs. Alike the environmental benefits, automotive manufacturers adapt the fuel economy ratings of their hybrid-electric vehicles as a marketing strategy to attract consumers. Many consumers are interested in vehicles with low fuel consumption, as the overall running costs of a vehicle are reduced if the requirement of fuel is reduced. This is particularly important as the purchasing cost of petrol and diesel fuels will gradually increase over time, due to the decrease of reserves (Taymaz, 2014). Consequently, it will increase the running costs of a hybrid-electric or ICE-powered vehicle.

Conventional ICE-powered vehicles are predominantly known for wasting fuel. The ICE is allowed to consistently run while the vehicle is utilised to provide the requirement of power when necessary. In situations such as traffic, when the vehicle requires little to no power for propulsion, the ICE is still burning fuel unnecessarily. Thus, reducing the miles-per-gallon (MPG) average of the vehicle. The fuel consumption of an ICE-powered vehicle at idle differentiates according to a range of different factors, such as: driving behaviour, idling speed, combustion efficiency, ignition timing and engine temperature (Ferreira, 1982). Automotive manufacturers heavily invest into the development of fuel systems for their vehicles to improve fuel economy. For example; manufacturers have adapted the use of specialised fuelling systems to process alternative fuels, such as hydrogen, as a solution to decrease fuel consumption (Lajunen, 2014). Additionally, newer ICE-powered vehicles are equipped with technology has as 'stop-start' to reduce the amount of wasted fuel in congested environments, but a large majority of vehicles being utilised today do not employ this type of technology.

A hybrid-electric vehicle achieves its low fuel consumption rating as the electric motor is primarily used in situations such as traffic and low-speed travel. Therefore, reducing the amount of fuel consumed by the internal combustion engine and increasing the vehicle's fuel efficiency (Taymaz, 2014). In fact, depending on the type of driving environment, the fuel economy improvements that are achievable with a hybrid-electric vehicle can be as great as 33% in comparison to a conventional ICE-powered vehicle (Manzie, 2007).

I have previously stated that I will be installing the hybrid-electric system onto my chosen vehicle to provide propulsion power in urban environments, where traffic and low-speed travel is a common occurrence. Thus, the lesser requirement of fuel to operate the vehicle is extremely beneficial.

- **Energy recovery**

As previously discussed in this report, a hybrid-electric vehicle is capable of recharging its energy storage device while in operation through the employment of an electricity generator and, in some vehicles, a kinetic-energy recovery (KER) system. The KER system is beneficial as it converts kinetic-energy into electrical energy, which is then redirected into the energy storage device for future use (Mathews, 2013). Effectively, the installation of an electricity generator and a KER system increases the driving range of the electric motor and improves the overall efficiency of the vehicle. Additionally, in relation to plug-in hybrid-electric vehicles, the implementation of these technologies reduces the requirement of charging the vehicle in the form of a plug-in adapter. Refer to sections 2.1.2.2 and 2.1.2.4 of my literature review for more information about electricity generators and kinetic-energy recovery systems.

(2.2.2.)

Weaknesses

- **Charge time (plug-in hybrid-electric vehicles)**

With the increase of plug-in hybrid-electric vehicles available on the automotive market, the emergent issue of charge time has deterred consumers from purchasing them.

Fundamentally, a plug-in hybrid-electric vehicle accommodates a plug socket to enable the energy storage device to recharge while the vehicle is not in operation. This form of electrical recharge is required more frequently when the vehicle is not eligible to recharge the energy storage device while it is in operation. In situations such as inner-city driving and traffic congestion, the electric motor is continuously utilised to provide vehicle propulsion, which obtains its energy supply from the energy storage device. The vehicle is not capable of recharging the energy storage device while the electric motor is in operation. Thus, utilising a hybrid-electric vehicle in these environments will increase the requirement of plug-in charging.

The time taken to completely recharge a plug-in hybrid-electric vehicle is dependent on the type of charging station that is used. For convenience, a consumer can use a 3-pin plug and plug socket to recharge their vehicle, which allows for home charging. However, the wide-spread installation of 'rapid charging' stations at locations such as motorway services allows for the vehicle to charge at a quicker rate. The amount of electrical charge that is supplied from a 'rapid charging' station is significantly higher than the electrical charge from a typical 3-pin plug and plug socket and in most cases, completes its charging phase more than twice as quickly. For example; if I were to charge a Toyota Prius Prime with a 3-pin plug and plug socket at home, it will take less than 5 hours and 30 minutes (Toyota, n.d.). If I were to charge the vehicle using a 'rapid charging' station, it will take approximately 2 hours and 10 minutes (Toyota, n.d.). Of course, the consumer could easily unplug the vehicle mid-charge and drive. However, to ensure the maximum sustainability and lifespan of the energy storage device, this is not advisable.

If this issue were to be eliminated through the employment of purchasable 'rapid charging' stations for home usage, we would be seeing more of an interest from consumers regarding plug-in hybrid-electric vehicles.

As the current accessibility to a 'rapid charging' station is strictly limited, a wide-spread installation of these stations in public areas could also improve the consumer's perception on these vehicles.



Figure 9 – Toyota Prius Prime in charging phase (ChargePoint, 2018)

- **Purchasing price**

The primary disadvantage of the installation of a hybrid-electric system is the initial cost to purchase the vehicle. Astonishingly, some hybrid-electric vehicles can be as much as 70% more expensive to purchase than an ICE-powered equivalent (Manzie, 2007). This is due to the manufacturing costs of the vehicle and its components. Since the components are required to withstand a large amount of electricity, they are manufactured with specialised materials that are costly to obtain from suppliers. Thus, increasing the purchasing prices of the components. The additional manufacturing processes to assemble the components onto the vehicle also increases its purchasing price.

To provide evidence of the deafferentation in purchasing costs, I will use the 2019 Toyota Corolla Hatchback as an example. Along with their ICE-powered variants, Toyota offer a hybrid-electric version of the Corolla to consumers. According to their website, the typical ICE-powered version of the 'Design' edition will cost from £23,375 (Toyota, 2018). The hybridised version of the 'Design' edition will cost from £25,825 for the 1.8L variant or £27,550 for the 2.0L variant (Toyota, 2018). To summarise, the hybridised versions are £2,450 and £4,175 more expensive to purchase than the ICE-powered version. This is unattractive for the marketing aspect of hybrid-electric vehicles, as the average consumer is disinterested in spend thousands of pounds more for a hybrid-electric version of a given vehicle.

- **Hidden environmental impacts**

The main criteria for the production of hybrid-electric vehicles is to reduce the level of impact we are having on the global environment. However, producing materials for the components of the hybrid-electric system are uncovering new issues involving the environment.

For example; nickel is a form of steel that is adapted into components such as nickel–metal hydride (NiMH) battery packs to ensure the efficient conductivity of electricity. Sharing the same the conductive properties of nickel, copper is a form of steel that is adapted into components such as electric motors and electrical wiring (CDA, n.d.).

To obtain nickel and copper, they are mined from open pits or underground mines in a way that can lead to further environmental degradation (Williams, n.d.). The mining and processing of these materials can generate high levels of dust in the atmosphere, which contain high concentrations of potentially toxic metals and sulfuric acid (Oprey, 2017). Although this type of material extraction is environmentally damaging and dangerous to human health, it is a rarely discussed topic.



Figure 10 – Dust created by copper mining (Tunatazama, 2018)

(2.3.)

I have chosen to use a 1987 Austin Mini Advantage as the basis of my project. This particular Mini is a 2-door saloon vehicle that was produced in 1987. The vehicle uses an A-Series Plus 998cc internal combustion engine, which produces around 30kW (40bhp) of power (Automobile-Catalog, n.d.). It is important that I consider the power of the vehicle while researching for an electric motor. I would not want to select a motor that equals the power of the engine as I am planning to use the electric motor for urban and congested environments only. The vehicle is front-wheel drive, which could become an issue when designing the hybrid system as I have limited space to install the components. The vehicle weighs 640kg without a driver, but I will have to add the weight of myself and another person to give me the total weight of the vehicle while undertaking the DL1 test (Automobile-Catalog, n.d.).

I have chosen this particular vehicle for my project because of the lack of emission control this vehicle has. There is no catalytic converter installed onto the exhaust system and the vehicle does not use an engine control unit (ECU) to monitor the exhaust gases, meaning there are no lambda sensors present. I will be attempting to 'modernise' the Mini in relation to its emissions levels and fuel consumption. Retrieved from the Automobile-Catalog website, I will be using the following values for my calculations within Microsoft Excel:

- **Coefficient of Drag (Cd) = 0.48**
- **Frontal Area = 1.58 m²**
- **Vehicle Mass = 640 kg**
Including Driver (+63.5 kg/10 stone) = 703.5 kg
- **Gear Ratios:**
1st = 3.647
2nd = 2.185
3rd = 1.425
4th = 1
Final Drive = 3.105

(Automobile-Catalog, n.d.)



Figure 11 – Austin Mini Advantage (Prewett, 2019)

(2.4.)

To construct a hybrid-electric system that is suitable for my chosen vehicle, I will need to research for the necessary components in relation to the power output I would like the system to produce. For example; a 20 kW electric motor would be too powerful for the intended purpose of the hybrid system as I plan to utilise it while driving in congested and city environments. Due to this factor, I would need the system to produce enough power to achieve a maximum speed of around 30 mph, depending of the road conditions and gradient. I plan to use the relevant specifications, such as the efficiency, of each component to calculate the torque and power produced at the wheels of my chosen vehicle while the hybrid system is operating. With careful consideration, I have chosen the following components:

(2.4.1.)

The electric motor is a critical component for propulsion, so I will need to consider how much power is necessary for my hybrid system.

With the current specifications taken into consideration, I have chosen a 12 kW motor for my hybrid system. Specifically, the 'AC9' AC induction motor from the Electric Motorsport website. The primary reason for my choice is the motor's power output, which will produce a suitable overall power output figure when combined with the hybrid system's supplementary components, such as the motor controller. The specifications of the motor are provided on the website and after inspection, I decided it would be most suitable for this type of application. I believe that I will have a sufficient amount of power to achieve the desired top speed, according to the specified mass of the vehicle. The specifications are:

- **Application = Golf buggy (around 426 kg ('Chris', 2018))**
- **Component Weight = 46 lbs (20.9 kg)**
- **Operating Voltage = 48 V**
- **Operating Current = 650 Amps**
- **Maximum Power Output = 18 hp (13.42 kW)**
- **Maximum Torque Output = 81 ft/lbs**
- **Maximum RPM = 7500**
- **Maximum Efficiency = 89%**

(Electric Motorsport, n.d.)

Since these specifications are relevant to a golf buggy, I could expect a dissimilar performance output from the electric motor as my chosen vehicle will be heavier.



Figure 12 – AC-9 induction motor (Electric Motorsport, n.d.)

The motor controller is also available from the Electric Motorsport webpage, specifying a range of different controllers to suit the motor's purpose. I chose the 'Curtis 1236E-5621 (48V 550A)' AC controller from the drop-down box.

I researched this particular controller and found its specifications on a different website. The specifications most critical for this project are:

- **Component Weight = 9 lbs (4.1 kg)**
- **Operating Voltage = 36-60 V**
- **Operating Current = 550 Amps**
- **Maximum Power Output = 27 hp (20.13 kW)**
- **Maximum Torque Output = 70 ft-lbs.**
- **Maximum Efficiency = 92%**

(EV West, n.d.)



Figure 13 - Curtis 1236e-5621 AC controller (EV West, n.d.)

(2.4.2.)

As previously stated, the purpose of an electricity generator is to recharge the energy storage device and extend the driving-range of the hybrid-electric system while the vehicle is in motion. Throughout my research, I struggled to find an HEV generator within my power limitation. The smallest HEV generator I could find would produce a power output of 80 kW, which is too powerful for my energy storage device (Magtec, n.d.). An alternator from a conventional petrol/diesel powered car adapts the same principle as an HEV generator, as it redirects electrical energy back into the battery for storage.

I have decided to use a 48V 100A DC generator from the Aurora Generators website, simply because I could not find an HEV generator that will be suitable for my setup. The alternator will be able to operate adequately as it is compatible with my energy storage device, using a 48-volt charge for its operation. It will also be able to produce up to 4.8 kW of power, which is sufficient enough to recharge the battery effectively (Aurora Generators, n.d.). The website that displays the alternator does not specify its efficiency, so I researched for the average efficiency percentage of an alternator. From my findings, I have decided to use the efficiency value of 80% for this component (Wikipedia, 2018).



Figure 14 – 48-volt DC generator (Aurora Generators, n.d.)

(2.4.3.)

As previously mentioned, an energy storage device is necessary to provide electrical energy to the components of the hybrid-electric system. The battery will be able to provide the necessary amount of energy when required and will be capable of recharging itself while the hybrid system is operating. I will need to consider the amount of the batteries I would need to install onto the vehicle, as I do not want to affect the performance and handling capabilities by adapting a set of batteries that are moderately heavy if combined together, as opposed to one battery.

For this project, I will employ a lithium-ion battery into the system. Specifically, the 'Powerbrick+ 48V – 61Ah – 3.12kWh Lithium-ion Battery Pack' from the PowerTech Systems website. I have chosen this particular battery as it will be capable of storing a suitable amount of electricity and will provide enough energy to sufficiently power the components I have chosen for my hybrid system. The company that supplies the battery have displayed the specifications on their website:

- **Nominal Voltage = 51.2 V**
- **Stored Energy = 3.12 kWh**
- **Continuous Discharge Current = 80 Amps (4.1 kW)**
- **Maximum Discharge Current (< 30s) = 120 Amps (6.1 kW)**
- **Maximum Continuous Charge Current = 60 Amps (3.05 kW)**
- **Weight = 31.6 Kg**

(PowerTech Systems, n.d.)

I opted not to use multiple batteries for this project as I need to take the characteristics of my chosen vehicle into consideration. Although the battery I have chosen is slightly heavier than other alternatives, I have limited space to install multiple batteries. To a certain degree, I do not want to affect practicality of the vehicle by occupying too much space. Refer to section 4.8.1 of my analysis to view where I will be installing the battery.



Figure 15 - Powerbrick+ lithium-ion battery pack (PowerTech Systems, n.d.)

(2.4.4.)

The components of a hybrid-electric system are particularly heavy. As they are required to withstand large amounts of electrical energy, the components are generally larger in size and heavier in weight than their low-powered variants. Hence, a hybrid-electric version of a given vehicle will be typically larger in weight than its ICE-powered counterpart. For this reason, it is important that I recognise the overall weight of the components I have chosen for my hybrid-electric system. Although I am only calculating the weight of the basic components, I need to consider the overall weight of the hybrid-electric system once it has installed onto the vehicle. I could expect the weight of the system to increase when installing items such as electrical wiring, among other necessities.

Unfortunately, the webpage that supplies my choice of electricity generator does not provide information regarding its weight. Therefore, I have estimated the weight of component to be 5 kg. The overall weight of the components and the vehicle are as follows:

- **Electric Motor = 20.9 kg (Electric Motorsport, n.d.)**
- **Motor Controller = 4.1 kg (EV West, n.d.)**
- **Electricity Generator = 5 kg**
- **Energy Storage Device = 31.6 kg (PowerTech Systems, n.d.)**

Overall Weight of Components = 61.6 kg

- **Vehicle Mass (Without Driver) = 640 kg**
- **Overall Weight of Components = 61.6 kg**

Vehicle Mass with Hybrid-Electric System = 701.6 kg+

The additional weight from installing a hybrid system will have more of an effect on lightweight vehicles, such as the Austin Mini Advantage. Consequently, due to this reason, I am expecting a slight decrease in overall vehicle performance output.

(2.4.5.)

Although I have no theoretical budget in place for this project, I would like to remain aware of how much I would have to spend in order to obtain my chosen components. It is widely-known that a hybrid-electric vehicle is generally more expensive to purchase than an ICE-powered vehicle. This is partly due to the cost of manufacturing and purchasing the hybrid system components. Refer to section 2.2.2 of my literature review for more information.

The prices of the components I have chosen are displayed in USD (\$) and Euro (€) on their supplier websites, which has been converted to GBP (£) for my convenience. Since my components seem to be available in foreign countries, I would also need to consider the additional costs of shipping. The overall cost to purchase the components are as follows:

- **Electric Motor = £1,077.87 (Electric Motorsport, n.d.)**
- **Motor Controller = £841.79 (EV West, n.d.)**
- **Electricity Generator = £1,159.78 (Aurora Generators, n.d.)**
- **Energy Storage Device = £2,477.66 (Wattuneed, n.d.)**

Total Cost (Without Shipping Fees) = £5,571.10

To install the hybrid-electric system onto my chosen vehicle, I would expect to spend a large amount of money on items such as electrical wiring and other necessities, so the system will be able to function correctly.

(2.5.)

For this project, I will be utilising a vehicle data logger to record the characteristics of the Austin Mini Advantage while it undergoes the specific tests. The device is called 'DL1 Club', which is developed and produced by Race Technology Ltd. The device uses GPS signals to track the location of the vehicle geographically and records the data onto an SD card by using a built-in 3-axis accelerometer (Race Technology, n.d.). I will be using the software that is provided on the Race Technology website to analyse the recorded data sets and transfer them onto a spreadsheet created within Microsoft Excel.



Figure 16 – DL1 Club device (Competition Supplies, n.d.)

3. Methodology

(3.1.)

To ensure a fair test while gathering data with the DL1 device, a route consisting of different driving conditions in a city environment is imperative to this project. A route has been created within the Swansea area, that will be used to create my drive cycle. The route has been chosen for the following conditions:

- **Variant changes in speed**

The route consists of a series of different speed limits, ranging from 30 mph in congested areas to 60 mph on a single carriageway. Recording the data as the vehicle travels at different speeds is essential towards my investigation as I will be able to analyse the vehicle's behaviour under different speeds, which will arise any issues that could be resolved with the installation of a hybrid system. It will also provide me with information regarding the power output the vehicle requires to reach these speeds, which will become useful when justifying my choice of electric motor. The electric motor should provide enough power to propel the vehicle up to 30 mph, so recording the power output of the vehicle at 30 mph is imperative.

- **Congestion 'hot spots'**

I have chosen this particular route because I would like to investigate how the vehicle behaves in traffic. The route consists of traffic lights and generally busy roads, which will allow me to produce an accurate drive cycle of a typical journey through a city. I plan to record the drive cycle at around 1:00 pm, so I will expect to be caught up in traffic for the majority of the cycle. Not only will it highlight the benefits of a hybrid system in relation to fuel consumption, it will also justify my argument against non-electrical vehicles in congested areas.

- **Gradient changes**

The route consists of uphill gradients, which will provide me with essential information about the power output needed to propel the vehicle up a gradient at a consistent speed. The electric motor I have chosen should be able to provide enough power for the vehicle to maintain a specific speed while climbing up gradients or climb up significant gradients without losing too much speed.

Once I have completed this test, I will create a drive cycle from the data set to display how my vehicle performed during the test. This will strengthen my justification as to why a hybrid-electric system will be beneficial for my chosen vehicle, such as highlighting the duration of time I will spend in congested areas and how fast I will be travelling through the city. The route can be seen below, highlighted in red:



Figure 17 – Urban driving test location (Google Maps, 2019)

(3.2.)

The coastdown test will be undertaken on the A4217 road within the Swansea area. The 1.4-mile-long road provides plenty of straight-lined road for me to successfully run the test (Google Maps, 2019). I am planning to undertake the test in the early hours of the morning to avoid disturbing other road users. I chose this road in particular because it does not feature any sort of gradient or cornering, allowing me to run the test as accurately as possible.

From this set of data, I will be able to determine how much kinetic-energy the vehicle is producing. The energy will be eligible for conversion into electrical energy, which could be directed into the energy storage device if my vehicle were to be fitted with a kinetic-energy recovery (KER) system. The road can be seen in the image below, highlighted in red:



Figure 18 – Coastdown test location (Google Maps, 2019)

(3.3.)

In addition to the previous tests I have mentioned, I will be recording data of the vehicle travelling down a gradient. Specifically, the Mount Pleasant road within the Swansea area. I chose this specific road because it provides a steep gradient to test the vehicle. I plan to provide an example of when the hybrid-electric system will be able to recover 'wasted' energy back into the storage device through the use of braking, which is frequently required in order to maintain speed and control of the vehicle. In addition, the electric motor will provide 'wasted' energy while the vehicle is travelling down the gradient. Therefore, this specific road is a perfect location to for this investigation.

Alike the coastdown test, a kinetic-energy equation will be created within Microsoft Excel to display the amount of 'wasted' energy that will be eligible for recovery into the energy storage device if my vehicle were to be fitted with a KER system. The road can be seen in the image below, highlighted in red:

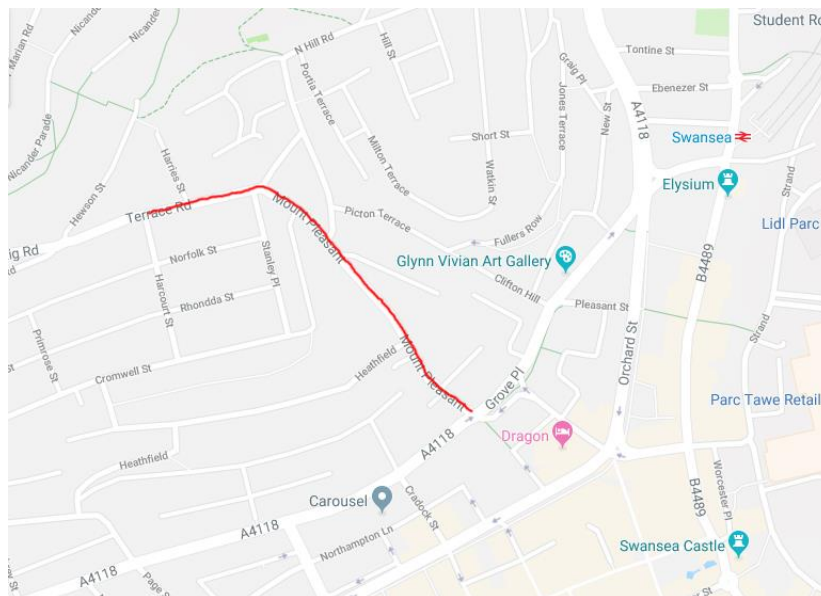


Figure 19 – Recoverable energy test location (Google Maps, 2019)

(3.4.)

Before carrying out the road tests on my vehicle, the requirement of the Race Technology software is necessary to view the data that is recorded from the DL1 Club device. Upon opening the application, a series of setup requirements were displayed to ensure that the data logging is calculated as accurately as possible, according to the vehicle specifications.

After conducting research in other online sources, I decided that the Automobile-Catalog website would be the primary source of this information. The website displays all of the relevant data I need to setup the software. To maintain accuracy, I also used an online tyre-circumference calculator to acquire the tyre circumference of the vehicle. The website required me to input the size of the wheels and provided me with a calculation in millimetres, which I had to convert to meters for the software.

The software setup required the following values:

- **Gear Ratios & Tyre Circumference**

To acquire the tyre circumference of the Austin Mini, I had to multiply the radius of tyre by $2 \times \pi$. Since the vehicles uses 12 inch wheels and I require the result to be in metres, the equation is as follows:

$$(0.305 \div 2) \times (2 \times \pi) = 0.9582 \text{ m}$$

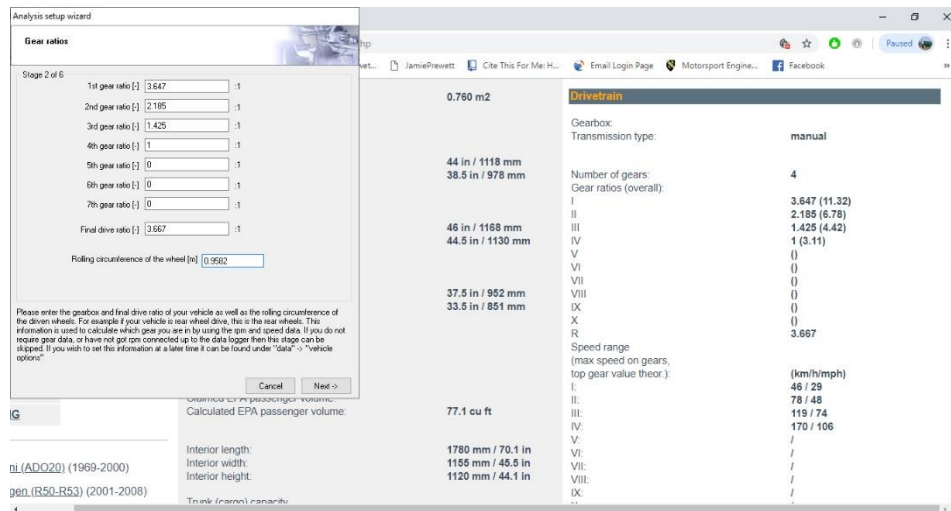


Figure 20 – Inserting gear ratios into Race Technology software (Prewett, 2019)

- **Coefficient of Drag, Rolling Resistance & Vehicle Mass**

The rolling resistance could not be found through the Automobile-Catalog website and upon further online research, I could not find a definitive value for my vehicle. Therefore, I had used the default value of 0.017. I inserted the mass of 703.5 kg to include the weight of myself, as only I will be performing the tests.

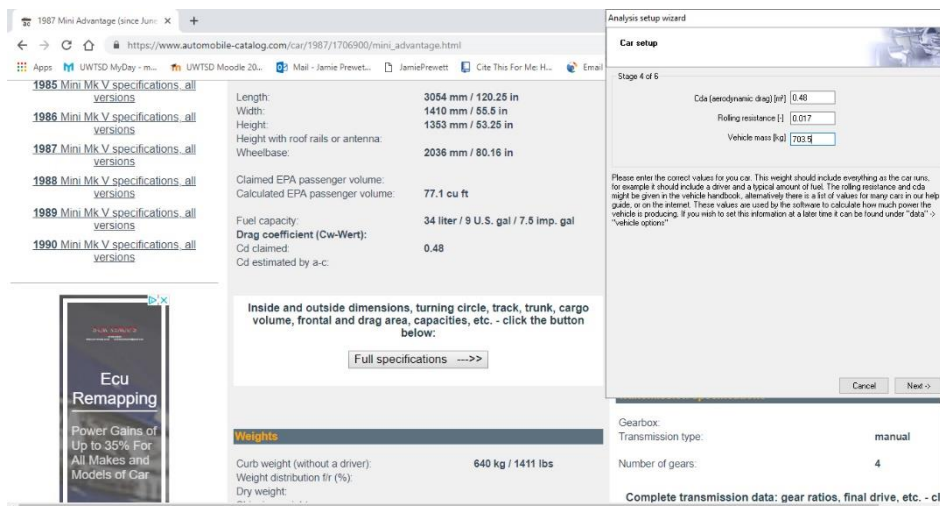


Figure 21 – Inserting coefficient of drag, rolling resistance & vehicle mass into Race Technology software (Prewett, 2019)

- **Cornering Grip & Maximum Power**

As I am unaware of the cornering forces experienced by the vehicle, I used the default values of 1.1 g for the setup. Alike the rolling resistance value, I could not find a definitive value through the use of online research.

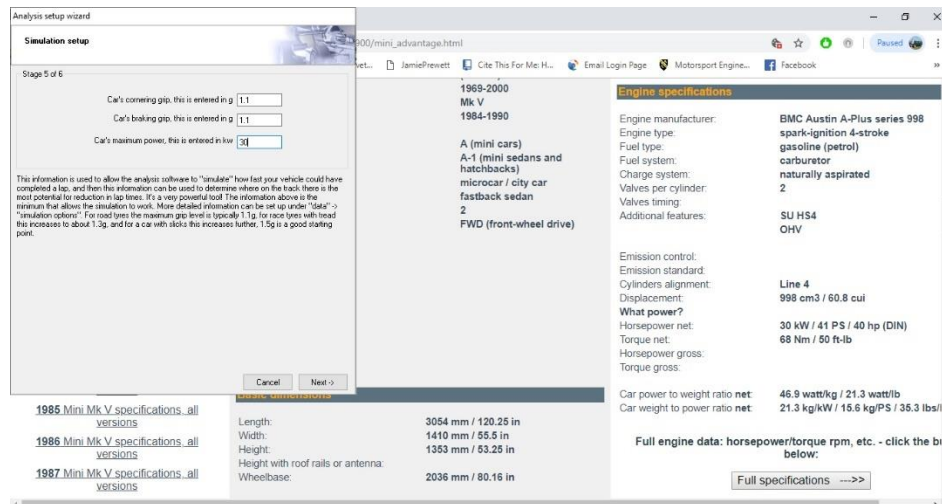


Figure 22 – Inserting cornering grip & maximum power into Race Technology software (Prewett, 2019)

(3.5.)

The installation of the DL1 device proved to be fairly simplistic. The GPS antenna was mounted into the glove-box of the vehicle via magnetic force to prevent the antenna from moving while the vehicle is in motion, which could disrupt my results and provide an inaccurate set of data. The electricity to power the device was provided by the vehicle's cigarette lighter. Before I began each test, I waited for the device to lock onto a GPS signal. Without a GPS lock, my results will become inadequate as the device could incorrectly measure the speed of the vehicle and where the vehicle is geographically.

Once I had travelled to the location of each test, I was able to press the red button to start and stop the data logging. The data from each test was recorded onto an SD card, which I will be able to analyse within the Race Technology software and export into Microsoft Excel as a spreadsheet for further calculations. Refer to sections 4.1 and 4.2 of my analysis to view my results and calculations.



Figure 23 – Installation of the DL1 Club device (Prewett, 2019)

4. Analysis

(4.1.)

(4.1.1.)

Once I had retrieved my test results from the DL1 Club device, the Race Technology software allowed me to view the individual test runs from the raw data files. Initially, I transferred the raw data files onto my hard-drive from the DL1 Club's SD card. By clicking '**Analysis**' on the software's opening display, I was able to create a blank session from the menu displayed and open each test run by clicking **File > Load logged data**. To ensure my test results were sufficiently recorded, I inspected each run before extracting the data on Microsoft Excel. This required using features within the software, such as '**Track map**' to display where the vehicle travelled geographically and '**XY graph**' to display the speed of the vehicle.

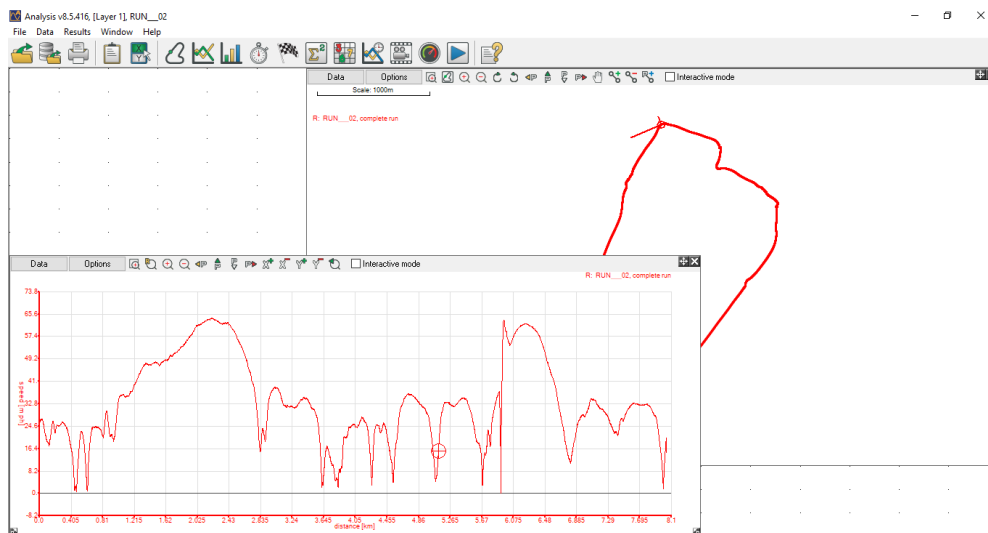


Figure 24 – Urban driving test results displayed in Race Technology software (Prewett, 2019)

To export the data onto Microsoft Excel, I clicked on **File > Export as data...** and selected the '**Spreadsheet .Csv file**' option. Once I had clicked the '**Export entire run**' option on the menu, I was able to save the data onto my internal hard-drive in a Microsoft Excel format. This process was undertaken to export the remaining two test runs.

(4.1.2.)

For my convenience, I have imported the three sets of data into one complete workbook within Microsoft Excel. To achieve this, I clicked on **Data > Get Data > From Workbook** in a newly-created workbook and chose each individual data set to import into the workbook. This created three separate spreadsheets in the workbook, which will simplify my analysis of data sets.

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8
0	-0.78125	0.16796875	0.799102663993835	0.265625	26.3796291351318	0	0
0.01	-0.70703125	0.0625	0.70978832244873	0.265625	26.1696853637695	1.17458213935606E-04	0
0.02	-0.71484375	0.19921875	0.742084681987762	0.2421875	25.9597415924072	2.33977916650474E-04	0
0.03	-0.8046875	-0.05078125	0.806288242340088	0.3046875	25.7695064544678	3.49603127688169E-04	0
0.04	-0.92578125	0.2109375	0.84950807094574	0.65625	25.7665233612061	4.64796437881887E-04	0
0.05	-0.94140625	0.0234375	0.941697955131531	0.7265625	25.7626819610596	5.79978497668445E-04	0
0.06	-0.96875	0.21875	0.993140518665314	0.42578125	25.7297058105469	6.95070310030133E-04	0
0.07	-0.8359375	0.10546875	0.842564642429352	0.4375	25.7387180328369	8.10112513136119E-04	0
0.08	-0.69921875	0.3515625	0.782625734806061	0.6015625	25.7460174560547	9.25191212445498E-04	0
0.09	-0.796875	0.3828125	0.884056091308594	0.734375	25.7610282897949	1.04031979572028E-03	0
0.1	-1.0078125	-0.015625	1.00793361663818	0.32421875	25.749475479126	1.1554560624063E-03	0
0.11	-1.00390625	-0.10546875	1.00943124294281	0.47265625	25.7850513458252	1.27064599655569E-03	0
0.12	-0.8203125	0.01953125	0.82054495814624	0.546875	25.7897796630859	1.38592603616416E-03	0
0.13	-0.86328125	0.33203125	0.924932062625885	0.4921875	25.8056468963623	1.50125217624009E-03	0
0.14	-0.844270825386047	0.118749998509884	0.862793207168579	0.30078125	25.8043766021729	1.61661091260612E-03	0
0.15	-0.841796875	0.122656248509884	0.860854685306543	0.5078125	25.8159399304199	1.73195269920588E-03	0

Figure 25 – Data imported into Microsoft Excel (Prewett, 2019)

As I only require the speed of the vehicle from the DL1 Club device, I deleted the unnecessary columns of data that were provided in the three spreadsheets, most of which were inaccurate. The vehicle speed is vital for my project, as I will be using the values to create the additional calculations. To maintain a suitable format, I reduced the vehicle speed values to 4 decimal places. This required me to remove the spaces that were included in the numeral cells, by using the ‘Find and Replace’ feature within Excel.

Time [s]	Speed [mph]
0	26.3796
0.01	26.1697
0.02	25.9597
0.03	25.7695
0.04	25.7665
0.05	25.7627
0.06	25.7297
0.07	25.7387
0.08	25.7460
0.09	25.7610
0.1	25.7495
0.11	25.7851
0.12	25.7898
0.13	25.8056
0.14	25.8044
0.15	25.8160
0.16	25.8018
0.17	25.8177

Figure 26 – Organised data within Microsoft Excel (Prewett, 2019)

(4.2.)

(4.2.1.)

The additional calculations are essential for this project. They will provide me with specific specifications of the vehicle that were not recorded from the DL1 Club device. Utilising the values that are created from these calculations, I will be capable of displaying the behaviour of each specification through the use of an XY line graph, created within Microsoft Excel. Before I could begin calculating the specifications of the vehicle, it is essential that I insert a set of values that are required for the calculations in the spreadsheets. These values are:

- **Vehicle Mass (Including Driver) [kg] = 703.5 (Automobile-Catalog, n.d.)**
- **Gravity [m/s^2] = 9.81 (Engineering ToolBox, 2003)**
- **Air Density [kg/m^3] = 1.293 (Cutnell, 1995)**
- **Rolling Resistance Coefficient (Asphalt) = 0.02 (Engineering ToolBox, 2008)**
- **Frontal Area [m^2] = 1.58 (Automobile-Catalog, n.d.)**

Once the values were implemented into Excel, I applied the following equations into their respective columns in the three spreadsheets:

- **Velocity [m/s]**

Speed [mph] ÷ 2.237

- **Change in Acceleration [m/s]**

Velocity [m/s] ÷ Vehicle Mass (Including Driver) [kg]

(Final Velocity – Initial Velocity)

- **Change in Acceleration [N]**

Vehicle Mass (Including Driver) [kg] × Change in Acceleration [N]

- **Aerodynamic Force [N]**

$0.5 \times \text{Air Density [kg/m}^3] \times 0.5 \times \text{Frontal Area [m}^2] \times \text{Velocity [m/s]}^2$

- **Rolling Resistance [N]**

Vehicle Mass (Including Driver) [kg] × Gravity [m/s²] × Rolling Resistance Coefficient (Asphalt)

- **Total Resistive Forces [N]**

Change in Acceleration [N] + Aerodynamic Force [N] + Rolling Resistance [N]

- **Maximum Power [kW]**

(Velocity [m/s] × Total Resistive Forces [N]) ÷ 1000

- **Average Power [kW]**

=AVERAGE Function within Microsoft Excel

- **Kinetic-energy**

(Vehicle Mass (Including Driver) [kg] ÷ 2) × Velocity [m/s]²

To maintain a suitable format throughout the spreadsheets, alike the vehicle speed values, I reduced the calculated values to 4 decimal places. The results are displayed in the figure below:

	C	D	E	F	G	H	I	J
	Velocity [m/s]	Change in Acceleration [m/s]	Change in Acceleration [N]	Aerodynamic Force [N]	Rolling Resistance [N]	Total Resistive Forces [N]	Maximum Power Output [kW]	Average Power Output [kW]
7	11.7924	0.0168	11.7924	71.0233	138.0267	220.8424	2.6043	2.6043
9	11.6986	-0.0939	-66.0239	69.8973	138.0267	141.9002	1.6600	2.1321
10	11.6047	-0.0939	-66.0239	68.7804	138.0267	140.7832	1.6337	1.9660
11	11.5197	-0.0850	-59.8258	67.7760	138.0267	145.9768	1.6816	1.8949
12	11.5183	-0.0013	-0.9381	67.7603	138.0267	204.8489	2.3595	1.9878
13	11.5166	-0.0017	-1.2081	67.7401	138.0267	204.5387	2.3558	2.0492
14	11.5019	-0.0147	-10.3705	67.5668	138.0267	195.2230	2.2454	2.0772
15	11.5059	0.0040	2.8342	67.6141	138.0267	208.4750	2.3987	2.1174
16	11.5092	0.0033	2.2955	67.6525	138.0267	207.9747	2.3936	2.1481
17	11.5159	0.0067	4.7207	67.7314	138.0267	210.4788	2.4238	2.1757
18	11.5107	-0.0052	-3.6312	67.6707	138.0267	202.9642	2.3259	2.1893
19	11.5266	0.0159	11.1880	67.8578	138.0267	217.0725	2.5021	2.2154
20	11.5287	0.0021	1.4870	67.8827	138.0267	207.3963	2.3910	2.2289
21	11.5358	0.0071	4.9960	67.9662	138.0267	210.9829	2.4339	2.2435
22	11.5353	-0.0005	-0.3995	67.9595	138.0267	205.5867	2.3715	2.2521
23	11.5404	0.0052	3.6428	68.0206	138.0267	209.6900	2.4199	2.2626
24	11.5341	-0.0063	-4.4411	67.9462	138.0267	201.5317	2.3245	2.2662
25	11.5412	0.0071	4.9900	68.0298	138.0267	211.0464	2.4357	2.2756
26	11.5556	0.0144	10.1101	68.1993	138.0267	216.3361	2.4999	2.2874
27	11.5692	0.0136	9.5715	68.3600	138.0267	215.9582	2.4985	2.2980
28	11.5740	0.0048	3.3734	68.4167	138.0267	209.8168	2.4284	2.3042
29	11.5666	-0.0071	-4.9804	68.3130	138.0267	201.3763	2.3783	2.3053

Figure 27 – Derived specifications within Microsoft Excel (Prewett, 2019)

(4.2.2.)

Through the use of Microsoft Excel, I was capable of creating a drive cycle of the urban driving test. On a separate spreadsheet to the test data, I clicked on **Insert > Insert line or area chart > Line** within Excel and inserted the necessary values into the graph. In this instance, I plotted the velocity values onto the X axis and the time values onto the Y axis. The result is displayed in the figure below:

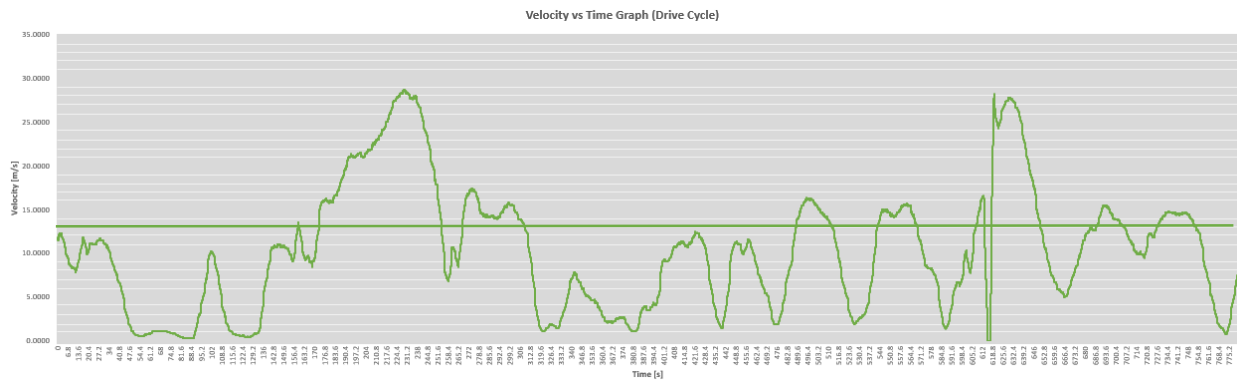


Figure 28 – Velocity vs time graph (drive cycle) (Prewett, 2019)

The graph displays a significant period of time in which the vehicle remained at or below 30 mph. To put it into perspective, I have highlighted where 30 mph is on the graph, which is the equivalent to 13.4 m/s. The vehicle encountered traffic several times throughout the test and as I was abiding to the speed limits of the route, the vehicle was occasionally allowed to surpass 30 mph. In an urban environment such as cities, this is a common occurrence.

This is vital evidence to my argument for hybrid-electric vehicles. The requirements of my hybrid-electric system specify that the electric motor should be able provide power to vehicle wheels until the vehicle surpasses 30 mph. Essentially, as data trace drops below the line I have implemented, the electric motor will become the main power provider to the vehicle wheels. Beneficially, this will reduce the fuel consumption of the internal combustion engine and the vehicle will not be emitting pollutants into the atmosphere. In an instance where I require to surpass 30 mph, the electric motor will stop providing power and internal combustion engine will become the main power provider to the vehicle wheels. Judging by the results from the drive cycle, the electric motor will be regularly utilised as a form of vehicle propulsion while driving through an urban environment. Thus, the implementation of a hybrid-electric system will be incredibly beneficial for the Austin Mini.

(4.3.)

(4.3.1.)

The torque output calculations are included in this report to display the maximum torque figure achieved by the Austin Mini at each test session. The results derived from these calculations will provide me with the differentiation in torque output from the internal combustion engine to the vehicle wheels. From this, I will be able to measure the amount of torque that is lost through the transmission of the vehicle. This will be important for my analysis, as I would need to reconsider my choice of transmission if the torque losses are substantial. The efficiency of the vehicle's final drive needs to be high, in order to ensure an effective power output from my chosen electric motor. To begin the derivation, I implemented these values into Excel for my calculations:

- **Tyre Radius [m] = 0.1525 m**

Wheel Size [in] = 12 (Automobile-Catalog, n.d.)

$$0.305 \text{ m} \div 2 = 0.1525 \text{ m}$$

- **Wheel Circumference [m]**

$$\text{Tyre Radius [m]} \times (2 \times \text{PI})$$

- **Final Drive Ratio = 3.105:1**

Transmission = 3.105 (Automobile-Catalog, n.d.)

Wheels = 1

(4.3.1.1.)

- **Maximum Torque (ICE) [Nm]**

$$\text{Maximum Total Resistive Force [N]} \times \text{Tyre Radius [m]}$$

- **Maximum Torque (Wheels) [Nm]**

$$\text{Final Drive (Transmission)} \div \text{Maximum Torque (ICE) [Nm]}$$

- **Torque Loss [%]**

$$(\text{Maximum Torque (ICE) [Nm]} - \text{Maximum Torque (Wheels) [Nm]}) \div 100$$

- **Wheel Speed at Maximum Torque [RPS]**

$$\text{Velocity of Maximum Total Resistive Forces [m/s]} \times \text{Wheel Circumference [m]}$$

- **Wheel Speed at Maximum Torque (RPM)**

$$\text{Wheel Speed [RPS]} \times 60$$

M	N	O	P	Q	R
Vehicle Mass (Including Driver) [kg] = 703.5			Torque Calculations:		
Gravity [m/s ²] = 9.81			Maximum Torque (ICE) [Nm] = 93.4368		
Air Density [kg/m ³] = 1.293			Maximum Torque (Wheels) [Nm] = 30.0924		
Rolling Resistance Coefficient (Asphalt) = 0.02			Torque Loss [%] = 63.34%		
Frontal Area [m ²] = 1.58					
			Wheel Speed at Maximum Torque [RPS] = 29.3755		
			Wheel Speed at Maximum Torque [RPM] = 1762.5305		
Tyre Radius [m] = 0.1525					
Wheel Circumference [m] = 0.9582					
Final Drive Ratio (Transmission) = 3.105					
Final Drive Ratio (Wheels) = 1					
Maximum Power Output [kW] = 17.2458					
Maximum Total Resistive Forces [N] = 612.7001					
Overall Average Power Output [kW] = 2.8486					
Component Efficiencies					
Final Drive = 0.94					
Electric Motor = 0.89					
Motor Controller = 0.92					
Electricity Generator = 0.80					

Figure 29 – Torque calculations inserted into Microsoft Excel (Prewett, 2019)

(4.3.1.2.)

The primary purpose of the following calculations is to display the power output of the vehicle if a hybrid-electric system were to be installed. Essentially, I will be analysing the average power and cumulative power output through the use of XY line graphs. The graphs will be able to display where the electric motor will be capable of driving the vehicle wheels and where electrical energy could be salvaged for redirection into the energy storage device. Additionally, I will be analysing the kinetic energy that is produced by the vehicle, which will be eligible for conversion into electrical energy if I were to install a KER system.

To derive the results, the following calculations were inserted into Microsoft Excel. I have also included additional information about the behaviour of the supposed hybrid-electric system during each test:

Component Power Output using Efficiency Values [kW]

- **Electric Motor**

Electric Motor Efficiency × Motor Controller Power Output [kW]

- **Motor Controller**

Motor Controller Efficiency × Electricity Generator Power Output [kW]

- **Electricity Generator**

Electricity Generator Efficiency × Maximum Power Output [kW]

Hybrid-Electric System Power Output using Efficiency Values [kW]

- **Electric Motor**

Overall Average Power Output [kW] ÷ Final Drive Efficiency

- **Motor Controller**

Electric Motor Efficiency ÷ Electric Motor Power Output [kW]

- **Electricity Generator**

Motor Controller Efficiency ÷ Motor Controller Power Output [kW]

- ICE

Electricity Generator Efficiency ÷ Electricity Generator Power Output [kW]

- Overall

Electric Motor Power Output [kW] + Motor Controller Power Output [kW] + Electricity Generator Power Output [kW] + ICE Power Output [kW]

Battery Output Calculations using Maximum Power Values [kW]

- Electric Motor

Final Drive Efficiency ÷ Maximum Power Output [kW]

- Motor Controller

Electric Motor Efficiency ÷ Electric Motor Power Input [kW]

- Electricity Generator

Motor Controller Efficiency ÷ Motor Controller Power Input [kW]

- Battery

Electricity Generator Power Input [kW] – Electricity Generator Power Output [kW]

- Average Power Output for Duty Cycle [kW]

Overall Average Power Output [kW] – Maximum Power Output (Data Set) [kW]

- Cumulative Power Output [kW]

Final Average Power for Duty Cycle Value [kW] – Initial Cumulative Power Output Value [kW]

S	T	U	V	W	X
Power Calculations:			Average Power Output for Duty Cycle [kW]	Cumulative Power Output [kW]	
Component Power Output using Efficiency Values [kW]					
Electric Motor = 11.2967					
Motor Controller = 12.6929					
Electricity Generator = 13.7966					
Hybrid-Electric System Power Output using Efficiency Values [kW]			Average Power Output for Duty Cycle [kW]	Cumulative Power Output [kW]	
Electric Motor = 3.0305			0.2444	0.2444	
Motor Controller = 3.4050			1.1886	0.9442	
Electricity Generator (Battery Input) = 3.7011			1.2149	0.2706	
ICE = 4.6264			1.1670	0.8964	
Overall = 14.7629			0.4891	-0.4073	
			0.4928	0.9001	
Battery Power Output using Maximum Power Values [kW]			0.6032	-0.2969	
Electric Motor = 18.3466			0.4499	0.7468	
Motor Controller = 20.6141			0.4550	-0.2918	
Electricity Generator = 22.4067			0.4248	0.7166	
Battery = 18.7056			0.5227	-0.1939	
			0.3465	0.5404	
			0.4576	-0.0828	
			0.4148	0.4975	
			0.4771	-0.0204	
			0.4787	0.4491	

Figure 30 - Power calculations inserted into Microsoft Excel (Prewett, 2019)

(4.3.2.)

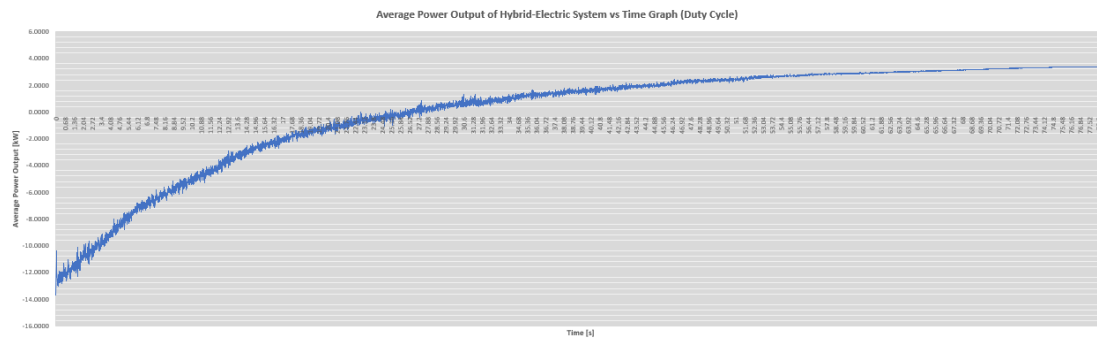


Figure 31 – Average power output from hybrid-electric system vs time graph (Prewett, 2019)

The figure above displays the average power output of the supposed hybrid-electric system while the vehicle is performing the coastdown test. The minus power values indicate that the electric motor is not being utilised. Due to the speed of the vehicle, the internal combustion engine is the primary source of vehicle power. When the vehicle gradually decreases in speed, the electric motor will activate and will then become the primary source of vehicle power. When this occurs, the average power data trace will increase over zero and will gradually rise until peak power is achieved. This particular graph displays this operation.

(4.3.3.)

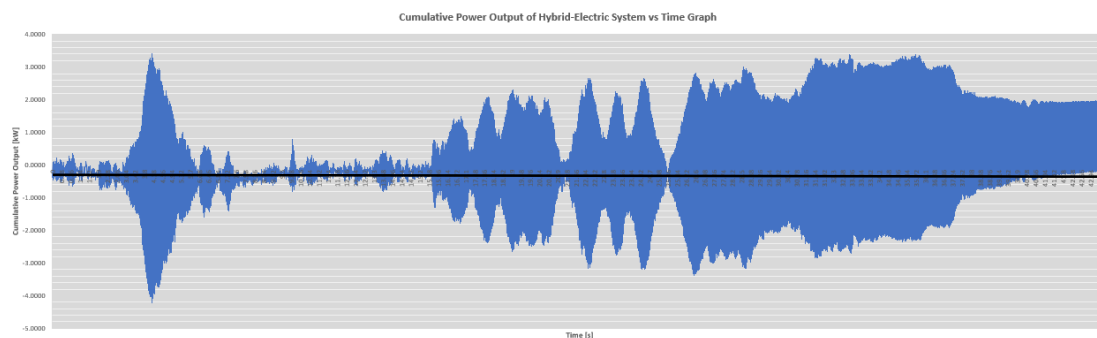


Figure 32 – Cumulative power output vs time graph (Prewett, 2019)

The figure above displays the cumulative power output from the supposed hybrid-electric system while the vehicle is performing the recoverable energy test. As the vehicle is travelling down the Mount Pleasant gradient, it will gather an accumulation of electrical energy. Rather than waste this energy, the utilisation of the electricity generator will make it eligible for the energy to be redirected into the energy storage device. The minus values in this data set indicate the phases of energy regeneration. Beneficially, this means that the vehicle will be capable of effectively recharging itself while travelling down the gradient. In turn, this will increase the driving range of the electric motor.

(4.4.)

To maintain a high level of detail, I will be discussing about the ideal locations to install the components of my hybrid-electric system. As it is belt driven, the electricity generator I have chosen will need to be installed within the engine compartment. Unfortunately, it is too complex for me to explain through this report. However, I have chosen the installation locations of the energy storage device and the electric motor.

(4.4.1.)

Logically, I have decided to mount the lithium-ion battery into the boot of the Austin Mini Advantage. I chose this particular location due to the size of battery. According to the PowerTech Systems website, the Powerbrick+ lithium-ion battery has the following measurements:

- **Length = 500 mm**
- **Height = 280 mm**
- **Width = 217 mm**

(PowerTech Systems, n.d.)

I would like to maintain the practicality of the vehicle, so mounting a large battery inside of the vehicle is not ideal. Although I will be compromising the practicality of the boot, it is a suitable location for a battery of this size. To ensure that the boot can accommodate the lithium-ion battery, I have conducted measurements of the boot. These measurements are:

- **Length = 735 mm**
- **Height = 470 mm**
- **Width = 225 mm**



Figures 33, 34 & 35– Austin Mini Advantage boot length, height & width (Prewett, 2019)

The measurements taken of the boot has solidified my choice of location for the battery.

Since the boot already accommodates the vehicle's standard 12-volt battery, there is an electrical wiring system that runs from battery to the electrical components at the front of the vehicle, such as the alternator. This is ideal for my type of fitment, as I will not need to create space at the rear of the vehicle for the installation of the hybrid-electric system. Of course, a smooth surface would be required to support the lithium-ion battery in place and provide a level of sturdiness. The figure below displays how the lithium-ion battery would be mounted into the boot.



Figure 36 – Lithium-ion battery installation (Prewett, 2019)

(4.4.2.)

As a contribution to my analysis, I will include a 3D model of the Austin Mini's gearbox casing and the proposed choice of electric motor to elaborate on how I intend to install the electric motor onto the vehicle's final drive. Since the differential is imbedded into the gearbox of an Austin Mini, I will need to modify the gearbox casing to allow the rotational shaft of the electric motor to provide mechanical torque to the differential. The CAD modelling will be undertaken using Solidworks software, where I will be using the features within Solidworks to demonstrate how the electric motor will be coupled onto the gearbox casing through minor modifications.

Throughout my research for this project, I could not find the size specifications of my chosen electric motor. Although I would like to create the model individually, I am unaware of the vital measurements needed to sufficiently create the motor, such as its length and width. To maintain a level of accuracy through this process, I have acquired a pre-modelled 'AC-9' electric motor from the EV West website. I trust that the model is sized accordingly and will credit the creators when applicable.

(4.4.2.1.)

To begin the modelling process, I required the specific measurements of the gearbox casing. I was unable to find these measurements through online research, so I have manually acquired the measurements from my own vehicle. I would like to maintain a level of accuracy throughout this process, so it was important that I recorded the measurements to the best of my ability. The measurements I have acquired are as follows:

- Length = 350 mm
- Height = 225 mm
- Width = 260 mm



Figures 37, 38 & 39 – Austin Mini Advantage gearbox length, height & width (Prewett, 2019)

Equipped with the relevant measurements, I could begin the modelling process. By utilising the wide range of features provided by the Solidworks software, I was capable of modelling the gearbox casing as accurately as possible. The completed gearbox can be seen in the figure below:

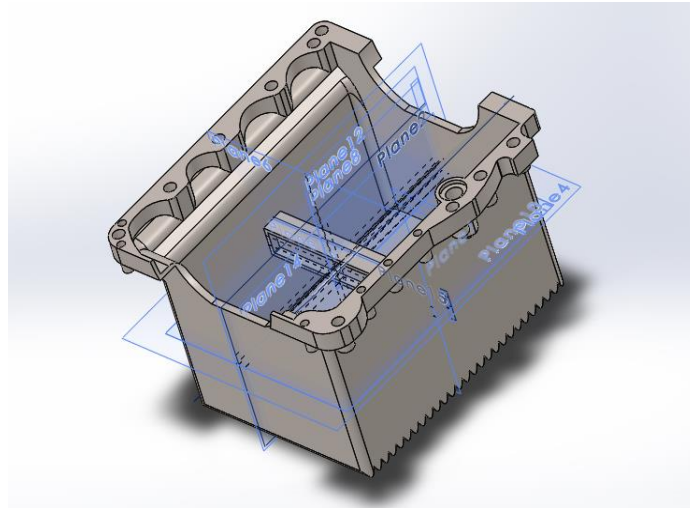
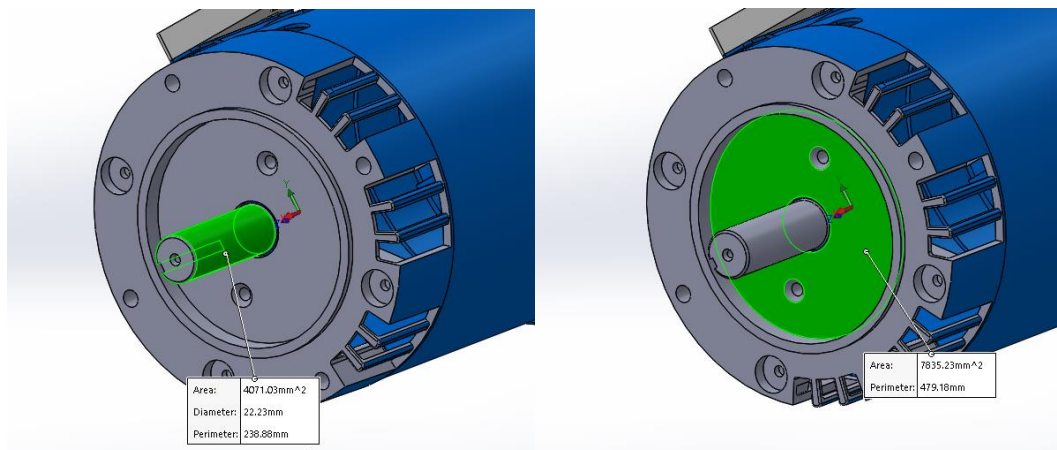


Figure 40 – Austin Mini gearbox casing within CAD software (Prewett, 2019)

(4.4.2.2.)

The CAD model of the AC-9 induction motor, provided by EV West, allows me to take a closer inspection of the component's measurements. Specifically, I need to acquire the diameter of the rotational shaft to begin performing the modifications to my gearbox casing. This was easily distinguishable by using the 'measure' feature within Solidworks. Including the rotational shaft, I measured the diameter of the inner surface.



Figures 41 & 42 – Diameters of the rotational shaft & inner surface (Prewett, 2019)

As the rotational shaft enters into the gearbox casing during installation, it will become sealed. This is to avoid exposure of the shaft.

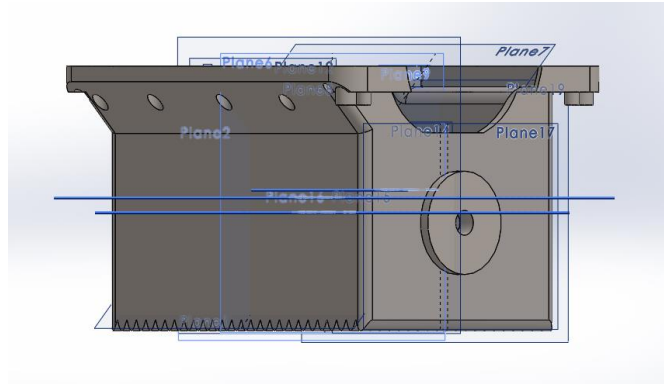


Figure 43 – Modified Austin Mini gearbox casing (Prewett, 2019)

(4.4.2.3.)

After modifying the gearbox casing to accompany the electric motor, I have created an assembly model to display how the electric motor will attach onto the gearbox of the Austin Mini Advantage. I have installed the motor into the side of the gearbox where the differential is situated. In theory, through the employment of a gear that is situated at the end of the rotational shaft, the electric motor will be able to drive the differential gear when it is in operation.

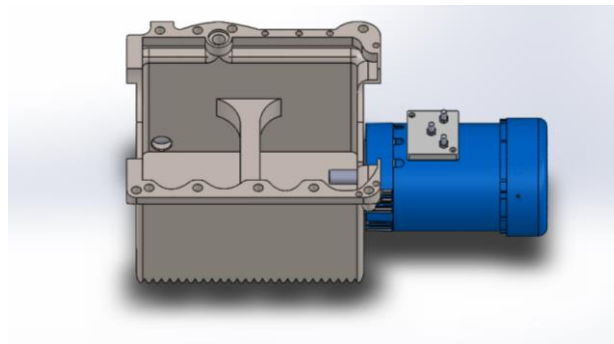


Figure 44 – Complete assembly of electric motor & gearbox casing (Prewett, 2019)

5. Conclusion

Through this report, I have demonstrated my knowledge and understanding of hybrid-electric systems by discussing in-detail about the different types of systems and choosing which system will be more suitable for my specific requirements. Through the use of online resources and books, I have collected a sufficient amount of research to elaborate on different topics, such as the benefits and weaknesses of hybrid systems, to coherently justify my argument for hybrid-electric vehicles and how the environment, particularly air pollution, would improve in densely populated areas if more vehicles are adapted with the system. To analyse my test data effectively, I have used the Race Technology software to transfer my results onto Microsoft Excel, where I was able to sufficiently display my results and provide additional data sets of my theoretical instalment of a hybrid-electric system. From this, I have displayed where the vehicle will be capable of recovering and redirecting 'wasted' energy into the energy storage device through the employment of a KER (kinetic-energy recovery) system, through the use of an XY graph. I can conclude that a hybrid-electric system will be environmentally and financially beneficial for the Austin Mini

Advantage, but the increase in weight will have a negative effect on the vehicle's overall performance output.

I believe that I could have shown a better understanding of the mathematical aspect of this report. Although I have displayed a series of calculations to determine the amount of kinetic-energy that could be recovered from the system, I believe I could have provided more formulas to calculate other aspects of the hybrid system, such as how much power the electric motor would need to produce to propel the vehicle up a gradient. I also struggled to collect a sufficient amount research on particular sections of this report, such as information regarding the series-parallel hybrid system.

Conclusively, hybrid-electric systems are becoming increasingly popular within the automotive industry as an alternative to using a conventional internal combustion engine due to the enforcement of stricter emissions standards. As hybrid-electric vehicles are becoming more widely available on the automotive market, they are evolving to become more convenient and beneficial for consumers. Additionally, the widespread utilisation of hybrid-electric vehicles will have a positive effect on the environment. However, due to the expense of the system and its manufacturing processes, the purchasing price of a vehicle with a hybrid-electric system is generally higher than a typical ICE powered vehicle. This is deterring consumers, as many are disinterested in spending thousands of pounds more for a hybrid vehicle. I believe that consumers will be more interested in purchasing a hybrid-electric vehicle if they were more affordable, thus increasing the number of hybrid vehicles being utilised and slowly improving the quality of the environment.

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