



The Comparison of the Legislated New European Drive Cycle to Real World Application

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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1. Abbreviations & Nomenclature

1.1 Abbreviations

CO – Carbon Monoxide

CO₂ – Carbon Dioxide

EU - European Union

EUDC – Extra Urban Driving Cycle

ECU – *Electronic Control Unit*

GPS – Global Positioning

HC – Hydrocarbons

Km/h or Km/hr – Kilometres an hour

OB₂ – On-board Diagnostic

PEM – Portable Emissions Machine

RDE – Real Driving Emissions

MC₁ – Mumbles Cycle 1

MC₂- Mumbles Cycle 2

MPG – Miles per Gallon

M/s – Meters Per Second

MVEG (A/B) – Motor Vehicle Emissions Group

NO_x – Oxides of Nitrogen

NEDC – New European Drive Cycle

PM – Particulate Matter

Sec - Seconds

TWidth – Tyre Width

UDC –Urban Driving Cycle

VW – Volkswagen

WLTP – World Light Harmonised Test Procedure

1.2 Nomenclature

$Acc_{Wheel}(\text{rad/s/s})$ – Wheel Acceleration

$Acc_{Driveshaft}(\text{rad/s/s})$ – Driveline Acceleration

$A_{RATIO}(\%)$ – Aspect Ratio

$ATIT(Nm)$ – Actual Transmission Input Torque

AV – Average

$BMEP(N/m^2)$ or (Bar) – Brake Mean Effective Pressure

$\rho(ks/m^3)$ – Air Density

C – Carbon

cc/min – Cubic Centimetres per Minute

C_D – Drag Co-Efficient

D_{HEIGHT} – Depth Height

$E_{Idle}(RPM)$ – Engine Idle

$E_{Disp}(cc)$ – Engine Displacement

$E_{Inertia}(kgm^2)$ – Engine Inertia

$Extra_T(N/m)$ – Extra Torque

$F_{Flow}(gms/sec)$ – Fuel Flow

$F_{wheel}(N)$ – Wheel Force

$F_{Rolling}$ – Rolling Resistance

$F_{Area}(m)$ – Frontal Area

FD_{η} - Final Drive Efficiency

FD_R – Final Drive Ratio

g or gms = Grams

H – Hydrogen

$I_{wheel}(kgm^3)$ – Wheel Inertia

J/Sec - Joules Per Second

$g(m/s^2)$ – Gravity

(g/sec) - Grams per second

G_{η} - Gear Efficiency

G_R – Gear Ratio

rad/s or min - Radians per Second/Minute

$R_{DIAMETERCODE}(Inches)$ – Rim Diameter

(Rev/s) or min - Revolutions per second or minute

$R_{OUTRADIUS}$ – Rim Outer Radius

$R_{RESISTANCE}$ (N) – Rolling Resistance

n – Polytropic Index

P_n – Pressure

Power (Kw) – Engine Power

π - PI

Tor_{Wheel} (Nm) – Wheel Torque

$Tor_{DiffOUT}$ (Nm) – Differential Output Torque

$Tor_{DiffINT}$ (Nm) – Differential Input Torque

$Tor_{Driveline}$ (Nm) – Driveline Torque

$Tor_{EngineIN}$ (Nm) – Engine Internal Torque

$Tor_{EngineOUT}$ (Nm) - Engine Out Torque

T_{WIDTH} (mm) – Tyre Width

$V_n(cc)$ – Volume

Vel_n (m/s) – Velocity

$Vel_{TranOUT}$ – Transmissions Out Angular Velocity

Vel_{TranIN} (rev/s) – Transmissions Input Angular Velocity

V_{Mass} (kg) – Vehicle Mass

Vn_{Wheel} – Different Velocity Points

V_{Energy} (J/sec)(Kw/sec) – Vehicle Energy

Vel_{Engine} (rev/s)or (rpm)- Engine Angular Velocity

Vel_{Wheel} (rad/s) – Wheel Velocity

$Wheel_{RR}$ (m) – Wheel Rolling Radius

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3. Abstract

This report is presenting a comparison of 3 vehicles that have been tested by development of the New European Drive Cycle, *NEDC*. The vehicles that are being used are as follows; an Audi A3, Euro 3, Volkswagen Passat, Euro 4, and a Ford Fiesta Eco boost, Euro 5. The Volkswagen Passat and the Ford Fiesta data has been used to create the NEDC and by using interpretation of legislative requirements comparisons will be made of the two with CO₂ and fuel consumption being the predominant focus. A simple combustion model of the Ford Fiesta was also developed for an understanding of combustion. Excel was used for both the combustion model and the NEDC. To compare the NEDC to real world application On Board Diagnostics system has been used alongside an Audi A3 project car to enable testing of real world fuel consumption and CO₂ emittance in mixed driving conditions. Mixed driving conditions include Urban and Motorway to provide different miles per gallon, *MPG*, usage to investigate the closeness of real world to the NEDC. Research has been carried out into environmental influences of fuel consumption.

Using values researched for MPG, comparisons have been made between the measured and researched. The same has been completed for the CO₂ however, the CO₂ has been taken from the owner's logbook of the vehicle. Both of these tests had increased values, proving the speculation of how inaccurate the NEDC values are to Real World Driving Emissions.

A cold start procedure was also carried out compared to a warm start which showed the fuel increase of the cold start, this is due to the NEDC not including the start procedure and idling in the drive cycle since the year 2000.

A conclusion has been made to conclude the overall project and how true it is and further improvements.

4. Introduction

With growing technology in the Automotive Industry for emissions and overall performance, it generates stricter legislations for Carbon Dioxide, CO_2 , to compete with developments. Even though technology has advanced type approval tests for emissions have remained the same for nearly 30 years. As well as technology developing, more vehicles are now used on the road, a survey completed in 2014 found that there is 7 times more traffic on the road than there was in 1950 and 79% of road users were using a car (George & Kershaw, 2016). This expansion of car users also affects the total emissions output of cars as a whole. The NEDC was last updated in 1990, and before September 2017, there were no further changes in how emissions were regulated. With more car users, road traffic calming systems have been introduced as well as congestion increasing at peak times, resulting in an incomparable type approval test. As the type approval tests influences the tax band, fuel consumption value, CO_2 emissions value and overall efficiency of the vehicle, the values stated in the NEDC have been questioned by the government as to how accurate the speed profile is to real world driving. Now, after the loopholes of the NEDC have been exposed to the general public, the World Light Harmonised Test Procedure, *WLTP*, is being implemented officially in September 2018 to all manufacturers for passenger cars.

In this report the NEDC and the WLTP procedure will be discussed to provide understanding of the differences that have been made to the approval test. Real Driving Emissions, *RDE*, test procedure will also be discussed to enlighten how the *RDE* is so important to the new legislation. Certification for the legislations have been researched to interpret the restrictions that the light passenger vehicles in this report had to follow when released.

This report also analyses the impact of road conditions and how different routes on every day roads with the use of live testing, reflect the fuel consumption, MPG and CO_2 values. These will be compared to the manufacturer's specified values.

Conclusions will be made to gain validation of how relevant the NEDC is to real world application and a conclusion of the project focusing on improvements, anomalies and future work that could be carried out if the project is taken further.

4.1 Thanks and Acknowledgements

I would like to acknowledge the opportunity that UWTSD Swansea has given me to further my education and study this unique degree in a particular subject I have a great passion for. Thank you to all the lecturing staff for all their knowledge and enthusiasm and my peers that have helped myself along this challenging path.

A special acknowledgment has to be made to my supervisor Malcolm McDonald who dealt with our weekly meetings with such poise considering the tribulations of my projects. Your passion and dedication to us students never goes unnoticed, you have helped us remain calm and collected throughout a busy and important year.

And most of all, thank you to my loving family for supporting me emotionally and providing loving encouragement throughout these 4 years at University and being my motivational morning alarm clock in the later weeks leading up to the end.

Without the support of each and every one of you it wouldn't have felt achievable.

5. Project Planning

5.1 Aims

- ✧ To determine how accurate New European Drive Cycle, *NEDC*, is to real world applications.
- ✧ To produce the NEDC model on Excel to provide understanding of how the Carbon Dioxide and Fuel Consumption values are calculated and legislated for the industry.
- ✧ Research the impact of the automotive industry on global warming and how the government is regulating this growing problem to be able to provide recommendations from literature found.
- ✧ Values stated by industry of fuel consumption is always questioned therefore from carrying out an improvised RDE Step 2 test, analysis will be carried out on the effects of fuel consumption compared to the NEDC value stated from research.
- ✧ To produce understanding and conclusion of how accurate legislations are and why the World Light Harmonised Test Procedure is being implemented in September 2018.

5.2 Timing Plan

A timing plan was set at the beginning of the year, the author wanted to spend 4 hours a week on the project which would have been a total of 128 hours of work over 32 weeks. However, due to numerous University work commitments throughout the year and a troubled project at the beginning of the year, the final major project was not started till January. This resulted in a lot of loss time affecting the overall progress the author wanted from this project.

Figure 1 is the completed Gantt chart for the project, it is evident from the timings that a lot of the work that was carried out was from January 2018. If the project discussed in this report would have been started before January 2018 then most of the practical work would have been completed far earlier than the author wanted too, and would have provided varied results.

The first project that fell through will be discussed in section 5.3 Combustion Model.

[illegible]

Figure 1 Completed Timing Plan

5.3 Combustion Model

The author wanted to create a combustion model of a 2 stroke engine with fuel injection concentrating on reducing emissions, however due to commitments falling through with a manufacturer the author was unable to retrieve reliable and current data. While waiting for the manufacturer to decide on committing, a combustion model was started on CR500 and YZ125 2 stroke data from the University, as well as building a model on the 4 stroke Ford Fox engine that is being used in this project.

The initial step of the combustion model was to find the logarithm graphs for the cylinder pressure and volume, the differences of the 2 stroke and 4 stroke data can be seen in Graph 1 and Graph 3.

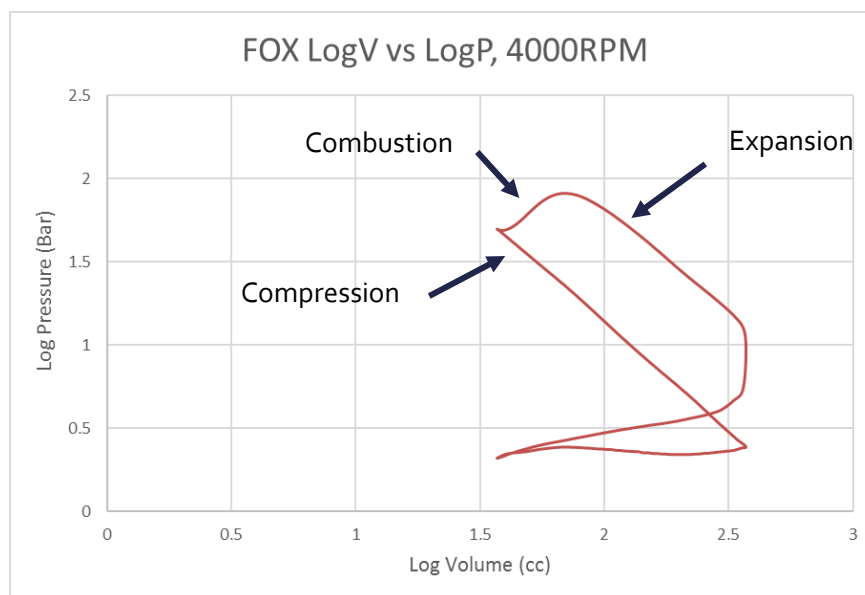
Log p versus *Log v* graphs can be used to check the quality of the cylinder pressure data. On *log p- log v* graphs the compression and expansion processes are straight lines on the slope, as labelled. These graphs need to be as smooth as possible to find the duration of combustion, which then can entail the characteristics of the combustion. Graph 3 presents an example of how *log p – log v* graphs can produce anomalies.

From many detailed studies it can be said that the compression and expansion processes are well fitted by a polytropic relation (Heywood, 1988):

$$pV^n = \text{constant}$$

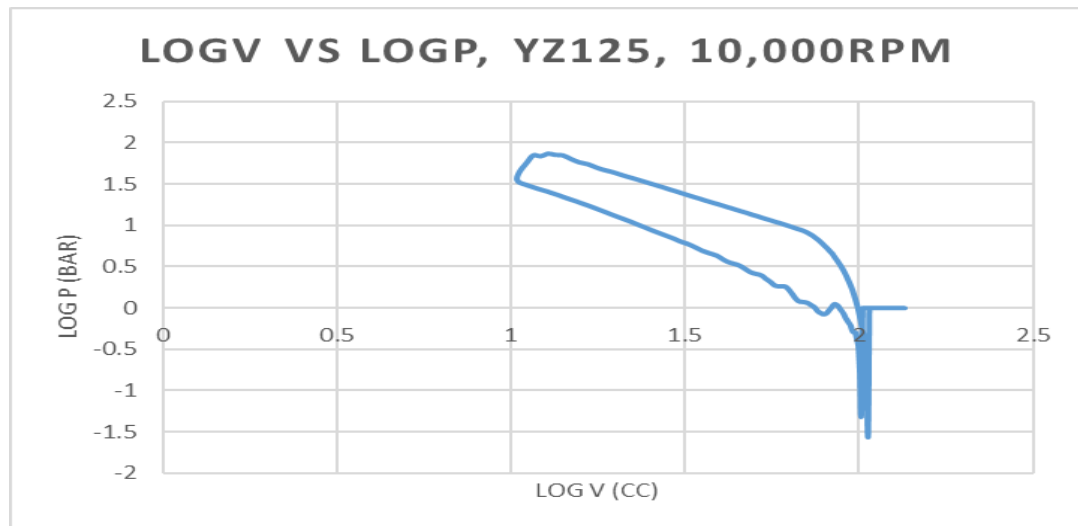
$$n = \frac{-P_2 - P_1}{V_2 - V_2}$$

Equation 1 Boltzmann Constant

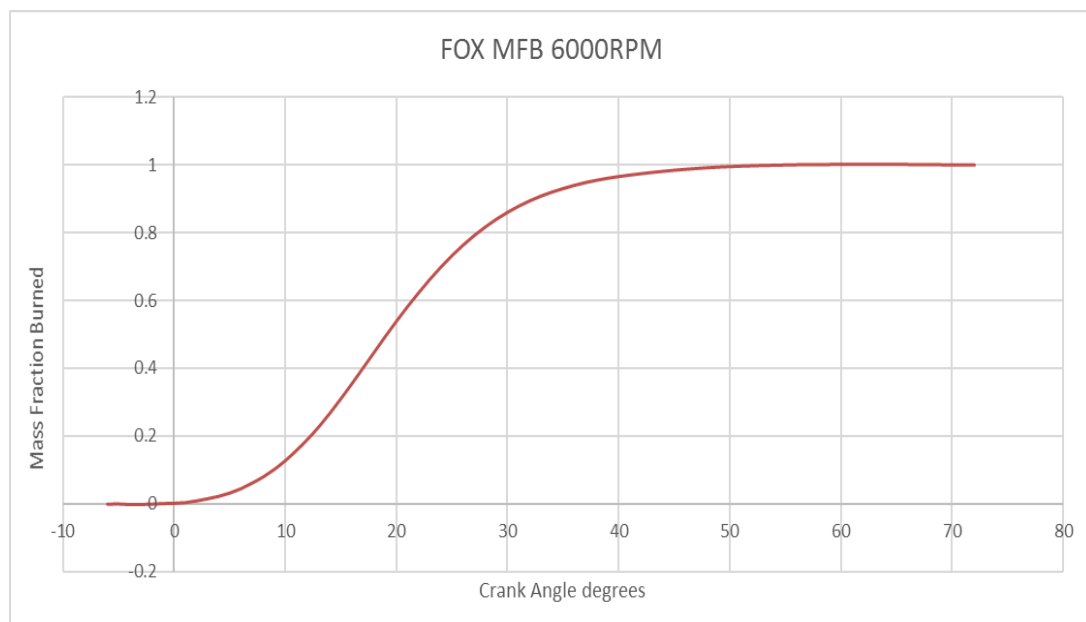


Graph 1 LogV vs LogP Graph

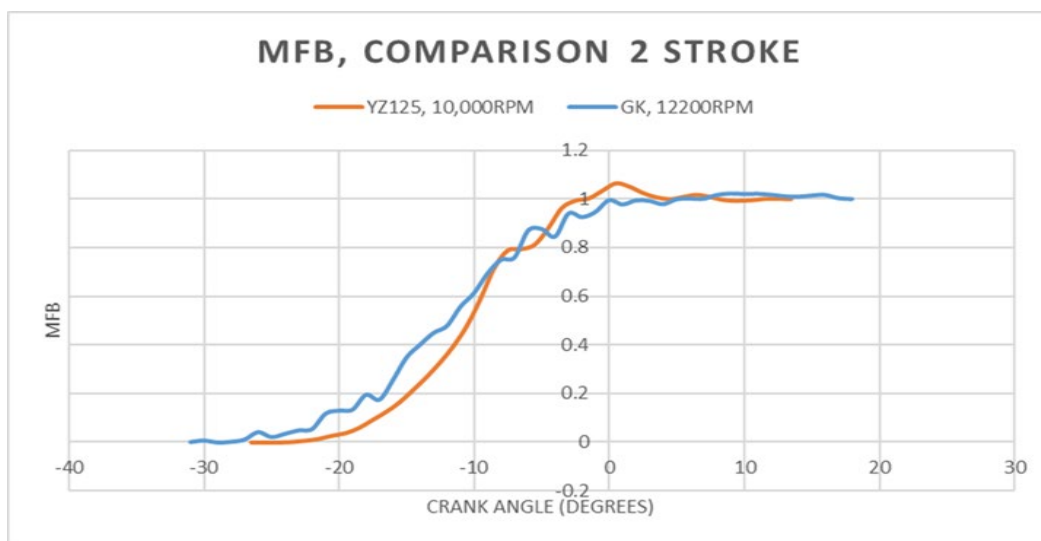
When using Equation 1 on the Ford Fox data, the polytropic index values ranged from 1.25-1.26, even though slightly lower than it should be, it didn't produce any anomalies. With conventional fuels the polytropic index should range between 1.25-1.35 (Heywood, 1988). Unlike the Ford, the YZ125 gave values ranging 1-1.8 which then proved it very difficult to calculate the mass fraction burned, therefore hindering the reliability of the data.



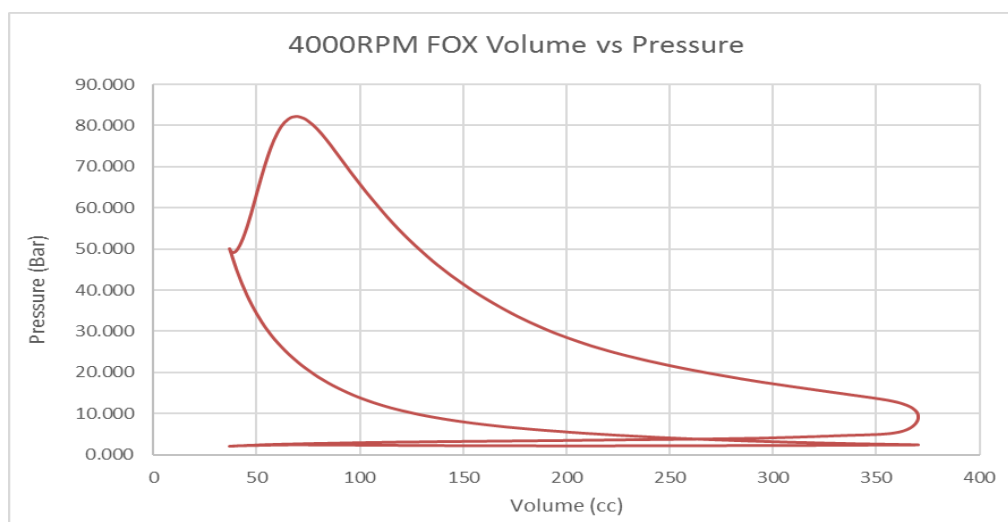
Graph 3 2 Stroke LogV vs LogP



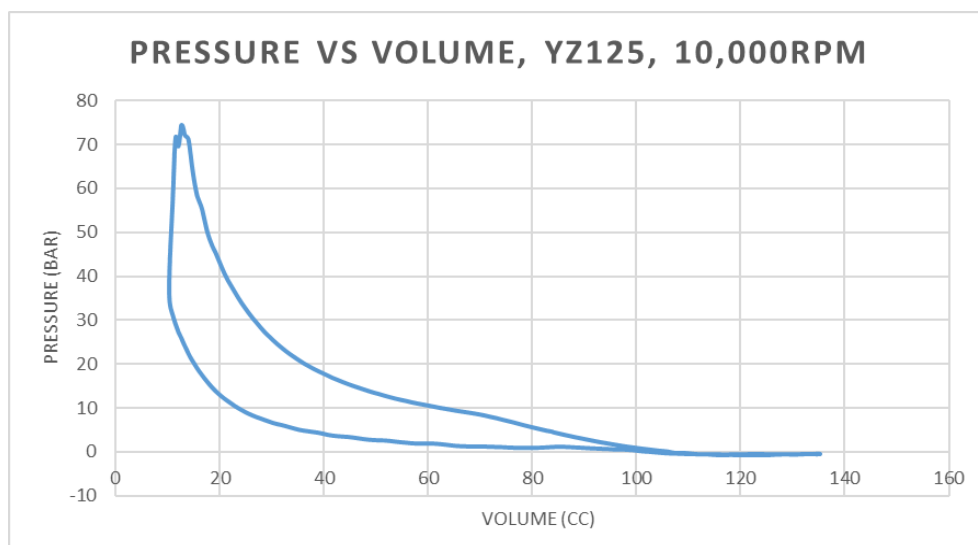
Graph 2 Ford Fox Mass Fraction Burn



Graph 4 2 Stroke Mass Fraction Burn

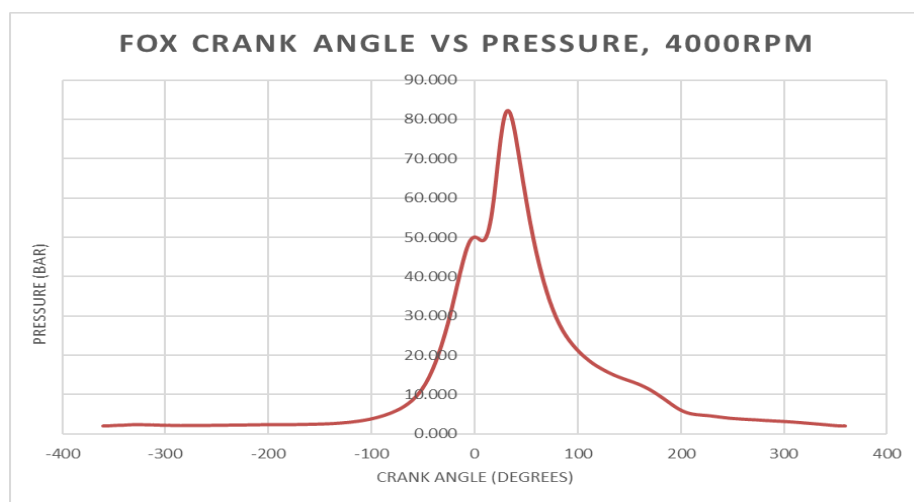


Graph 5 Fox Pressure vs Volume

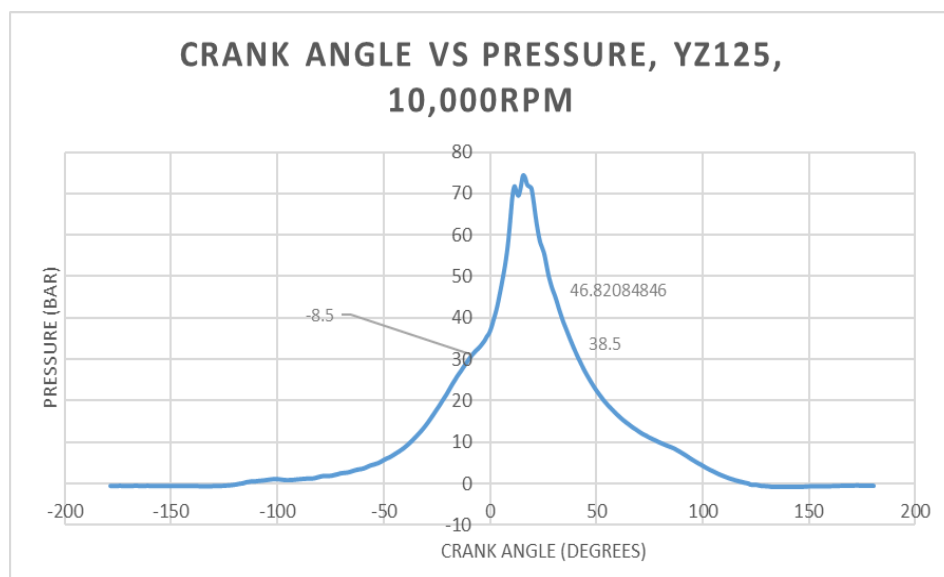


Graph 6 2 Stroke Pressure vs Volume

Only volume (cc) and pressure (Bar) and engine dimension data was received from a Go Kart Company for a 125cc 2 stroke engine, the same process was completed as before. Graph 4 presents the difficulties of the data when calculating the mass fraction burn, indicating the amount of fuel burned in the combustion process. Without accurate ignition timing, this also proved that the project would be difficult. The final issue was that pressure data was influenced by the pressure sensor and how the pressure would read a negative number. This had to be corrected by adding ambient pressure which influenced the peak pressure, the Fox data in Graph 7 proved to show a smooth increase in pressure and decrease in volume which is desirable for the combustion process. Compared to Graph 8 the pressure at Top Dead Centre, *TDC*, has decreased and increased, as a result of the lack of data from the manufacturer this could not be seen as reliable data, so due to these reasons, the decision was made to no longer work on this data.



Graph 7 Crank Angle vs Pressure



Graph 8 2 Stroke Crank Angle vs Pressure

6. Literature Review

The most relevant piece of literature to this project is from Georgios Fontaras, "Fuel consumption and CO₂ emissions from passenger cars in Europe vs laboratory versus real-world emissions".

This paper explains in great detail how altitude, resistive forces, air density, aerodynamics and weather as a few examples influence fuel consumption, but they're not at all considered in the NEDC type approval test. This paper is all theoretical, no tests were carried out by the individuals, and it was all researched.

Below is a graph taken from a report by T J Barlow, it includes all specifications for type approval tests. The graph was taken as it is representing how a real world driving test would look. It is displaying that there isn't a set speed or time to follow, however it is influenced a lot by traffic calming measures. Further into the report a graph created for the Audi RDE looks similar to this graph therefore the literature is relevant to the work being carried out.

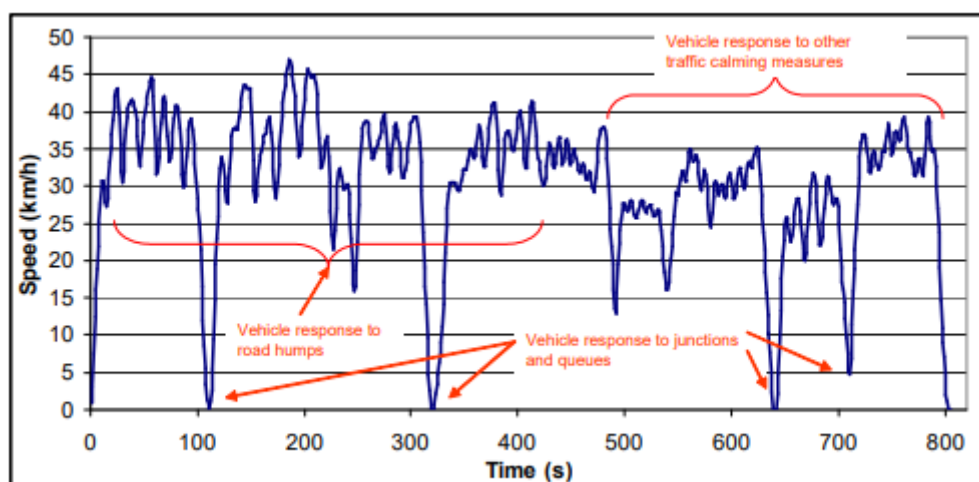


Figure 2 An Example of a Realistic Cycle (T J Barlow, 2009)

7. Emissions and Importance of Certifications

This section will explain the consequences of emissions from automotive vehicles and how they have been restricted throughout the different Euro Legislation generations.

7.1 Certification

The vehicles used in this report range from Euro 3 to Euro 5 legislations Table 1 is showing the legislation restriction differences between Euro 3 and Euro 5. In Figure 3 CO₂ has decreased enormously from 2007 to 2013 presenting how important emission certification is to the environment, by presenting to manufacturers CO₂ limits, it encourages manufacturers to develop emissions technology as it proves successful. The technologies include weight reduction by use of advanced materials, exhaust after treatment like three way catalytic convertors, advanced electronics to read emissions every millisecond which then can self-adjust, and most of all the development of fuel injection (George & Kershaw, 2016).

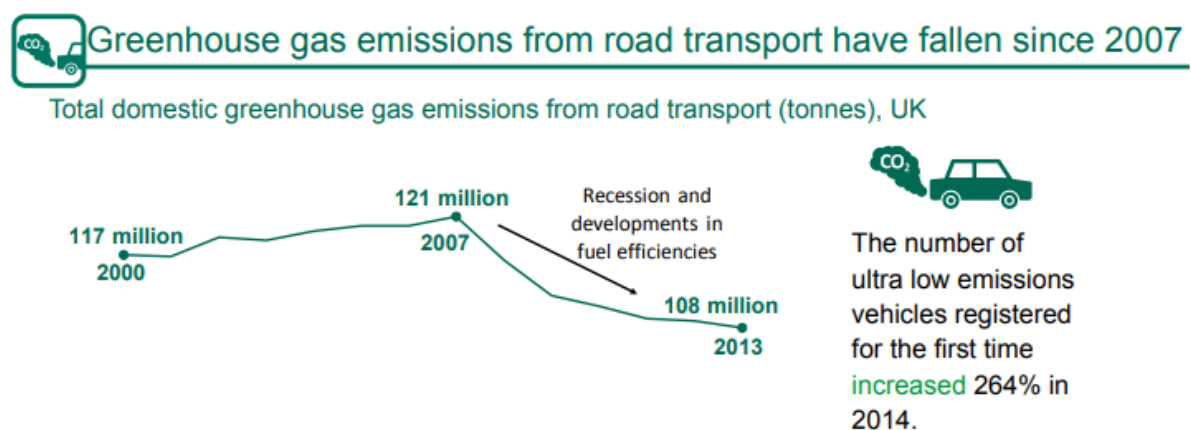


Figure 3 Greenhouse Gas Emissions (George & Kershaw, 2016)

Table 1 Euro Standards for Emissions (AA, 2017)

Emissions. All are measured in (g/km)	Euro 3, Audi A3 (January 2001)	Euro 4, VW Passat (January 2006)	Euro 5, Ford Focus (January 2011)	Current Euro Legislation, Euro 6 (September 2015)
Carbon Monoxide, CO	2.3	1	1	1
Hydrocarbons, HC	0.20	0.10	0.10	0.10
Oxides of Nitrogen, NOx	0.15	0.08	0.06	0.06
Particulate Matter, PM	No Limit	No Limit	0.005	0.005

The first European exhaust emissions standard for passenger cars was introduced in 1970, then in 1992 the Euro 1 standard was implemented with the fitting of catalytic convertors (AA, 2017).

From September 2017, the Euro 6 legislations are now considering the Road Driving Emissions, *RDE*, type test alongside the World Light Harmonised Test Procedure, *WLTP*. Legislations have become more stringent and the realistic tests are being used to certify new models against Euro 6 emission limits. The WLTP however will now be applied to all type vehicles from September 2018, therefore applying to new car registrations.

All type approval tests are explained in more detail in section Legislated Type Approval Tests.

The European Union, *EU*, hopes to achieve a cut to greenhouse gases by at least 20% below 1990 levels by 2020. In October 2014, the European Union leaders then agreed to a further 20% reduction by 2030.

The European Union has committed themselves to reducing the emissions by 80-95% of the 1990 levels by 2050, and CO₂ emissions will need to be 95g/km by 2020 (Bosch, 2014), as part of a collective effort from European Union Countries (EuropeanUnion, 2018).

"We have no choice but to adapt to climate change."

(EuropeanUnion, 2018)

This quotes defines how important greenhouse gases have become to our environment and how companies must surrender to the balance of the environment and desirable vehicles to eliminate dangerous levels of climate change.

7.2 Emissions from Combustion and their Impact on the Environment

Table 2 Emissions and Impact on Environment (Heywood, 1988)

Type of Product/Emission	Impact
1) Oxides of Nitrogen, <i>NO</i> and <i>N₂ or NO_x</i>	React in photochemical smog. <i>NO₂</i> is Toxic.
2) Carbon Monoxide, <i>CO</i>	Toxic
3) Unburned Hydrocarbons, <i>HC</i>	Reactant in photochemical smog
4) Particulates, (Soot and absorbed hydrocarbon compounds)	Reduces visibility; some of the HC compounds mutagenic.
5) Carbon Dioxide, <i>CO₂</i>	Greenhouse Gas

1) Nitrogen Oxides are formed by the reaction of nitrogen and oxygen, nitrogen is the most abundant gas in the equation. *NO_x* comprises of colourless nitric oxide, *NO*, and a very toxic and reactive nitrogen dioxide, *NO₂*. *NO_x* emissions cause harm to the environment as they lead to the formation of the secondary particulate matter and ground level ozone in the atmosphere. *NO_x* contributes to acidification and eutrophication of water and soils. (EEA, 2016).

2) Carbon Monoxide is a product of incomplete combustion, it is highly toxic and colourless. It occurs when the carbon in fuel is partially oxidised forming *CO* and not *CO₂*. Direct exposure to *CO* can reduce the flow of oxygen in the bloodstream and is dangerous to people's health, particularly heart disease. Carbon Monoxide also contributes to the formation of ground level ozone and smog (EEA, 2016).

3) Hydrocarbons are produced with incomplete combustion or partial combustion. *HC*'s contribute to the formation of ground level ozone and photochemical smog in the atmosphere. The ozone can irritate the eyes, cause damage to lungs and respiratory system (EEA, 2016).

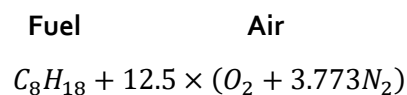
4) Particulate Matter, *PM*, is another product of incomplete combustion and can be split into primary and secondary *PM*'s. Primary is emitted directly into the atmosphere and secondary *PM* forms in the atmosphere following the release of gases like sulphur dioxide, nitrogen oxides and ammonia. Particulate matter is one of the most important emissions as it infiltrates into the respiratory system and can cause or make worse cardiovascular and lung diseases and even cancer (EEA, 2016).

7.2.1 Carbon Dioxide, CO

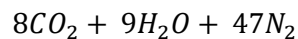
Carbon is the element that combines with oxygen to produce CO₂. For every one molecule of carbon there are two molecules of oxygen. Carbon on its own is not a greenhouse gas, but combined with oxygen it is damaging (thecarbonaccount, n.d.).

In a natural carbon cycle, carbon dioxide would be absorbed by plants and trees. Due to high intensity of burning fossil fuels, the effect of extra CO₂ in the atmosphere increases the overall temperature of the planet. As average global temperature increases, the day to day level of climate change is unpredictable. To reduce extreme weather and the implication fuelling has on the environment, certification legislations of emissions are implemented for the automotive industry (thecarbonaccount, n.d.).

The following equations and weights of species were used to calculate the amount of CO₂ produced for each value that has been calculated for CO₂ in this report. Automotive CO₂ is a product of the burning fuel in the combustion process of an engine. The fuel assumed to be used in this report is Isooctane, the species that make up this fuel are C₈H₁₈.



Equation 2 Isooctane Fuel and Air Balance Equation



Equation 3 Stoichiometric Products from the Fuel and Air Balance Equation

Table 3 Calculating Mass of Fuel and CO₂ of Isooctane (Heywood, 1988)

1 Molecule of Isooctane = 8 Molecules of CO₂

Calculating molecular mass of Isooctane:
 $(8 \times 12 + 18 \times 1) = 114 \text{Kg Fuel}$
 (No of Molecules X Atomic Weight)

Calculating CO₂ in Isooctane:
 $8 \times (12 + 2 \times 16) = 352 \text{Kg CO}_2$
 (No of Molecules X Atomic Weight)

$$3.09 \text{ kg CO}_2 = \frac{\text{Total Kg of CO}_2}{\text{Total Kg of C}_8\text{H}_{18}} = \frac{352}{114}$$

$$\text{CO}_2 \text{ (g/km)} = \frac{\text{Total Fuel (g)} \times 3.09}{\text{Total Distance(km)}}$$

Equation 4 CO₂kg and CO₂g/km Calculations

The fuel mixes with air; oxygen and nitrogen, and depending on the lean or richness of the equation it influences the products. CO₂ along with water is the main product of fuel combustion. CO₂ is the most posing threat to the greenhouse gases and is a threat to public health and the environment in the long term (EEA, 2016) (EEA, 2016).

For this report, the CO₂ calculations have all been assumed to be from a stoichiometric combustion to provide reasonable comparisons and because a three way catalyst operates at lambda-1. If the balance equation is stoichiometric, then the total fuel used is proportional to the amount of CO₂ produced.

When the balance equation is stoichiometric, the carbon and oxygen will produce CO₂ as there is no excess carbon, (excess fuel) to produce CO or excess oxygen (excess air) to produce O₂. Excess O₂ can then react with nitrogen to form NO_x. With a more complex combustion model these species can be predicted, however for this report a simple prediction like Equation 4 of fuel consumption, can still predict relative CO₂ predictions (Mcdonald, 2017).

The Air:Fuel ratio that influences the amount of CO₂ emitted has been discussed further in the appendices in section 14.6.1.1 Air: Fuel Ratio

7.3 How CO₂ is Controlled in Automotive Industry

Table 4 CO₂ Tax Bands and Costs Over for a Year Payment (GOV.UK, n.d)

Tax Band	CO ₂ Emissions (g/km)	Single 12 Month Payment
A	Up to 100	£0
B	101-110	£20
C	111-120	£30
D	121-130	£120
E	131-140	£140
F	141-150	£155
G	151-165	£195
H	166-175	£230
I	176-185	£250
J	186-200	£290
K*	201-225	£315
L	226-255	£540
M	Over 255	£555

(*Includes cars with a CO₂ figure over 225g/km but were registered before 23rd March 2006)

Buying a vehicle with lower carbon footprint is a priority for consumers due to the tax payment, hence, manufacturers are always aiming for consumer needs however deceitful that solution is. The higher a CO₂ value the higher the tax band, Table 4 is showing the expense and correlating tax band. It is clear as to why car manufacturers attempt to reduce the emissions to provide an affordable model (Sandbag, 2011).

The vehicles that are being analysed, their tax bands can be found in Table 5.

Table 5 Tax Bands of Vehicles Used

Vehicle	Tax Band	Euro “.”	Researched CO ₂ Value
2003 Audi A3, 1.6L	H (£230)	Euro 3	170 g/km (V5C, 2017)
2010 Passat, 2L	I (£250)	Euro 4	185 g/km (carfolio, 2013)
2012 Ford Fox Sigma, 1L	C (£30)	Euro 5	114 g/km (FordMotorCompany, 2012)

The VW Passat has been assumed to be a 2010 model, the values found for CO₂ have been researched. It can't be assured that these are the absolute value due to the lack of information of the vehicle, however through research these values were used as they are the closest to the data provided. (ultimatespecs, 2009) And (carfolio, 2013) provided the same values of CO₂ emissions and the miles per gallon value, therefore these values have been used.

With the WLTP being introduced, manufacturers are now stating that the CO₂ values will be a lot higher (volkswagen, n.d.), than for the NEDC. Therefore the CO₂ tax bands will either decrease with the change or remain at the same and consumers will pay more.

A scheme has been introduced by the government to tackle CO₂ emissions without necessarily fining manufacturers. If manufacturers have exceeded the CO₂ limits, then the government can balance the carbon footprint by aiding environmental projects with carbon tokens, instead of administering fines to those who exceed. These schemes are called Emission Trading, this solution has been further discussed in 14.1 Carbon Offsetting (Sandbag, 2011).

8. Legislated Type Approval Tests

As road vehicles emit a range of atmospheric pollutants because of the combustion process they are regulated by the European Union, EU Directives. In the EU, type approval emission tests are required by law for all new light-duty vehicle models. The tests are completed under laboratory conditions. The light-duty vehicles are tested using a power-absorbing chassis dynamometer, for research and emission factor development. For chassis dynamometer tests, the vehicle drive wheels are positioned so that they are in contact with the rollers. The rollers are then adjusted to simulate friction losses and aerodynamic resistance replicating road conditions. The sampling of exhaust emissions is then performed at the maximum speed for each cycle (Bosch, 2014). Driving cycles are usually defined in terms of vehicle speed and gear selection as a function of time, a trained driver is employed to follow the drive cycle on the dynamometer (T J Barlow, 2009).

8.1 New European Drive Cycle, *NEDC*

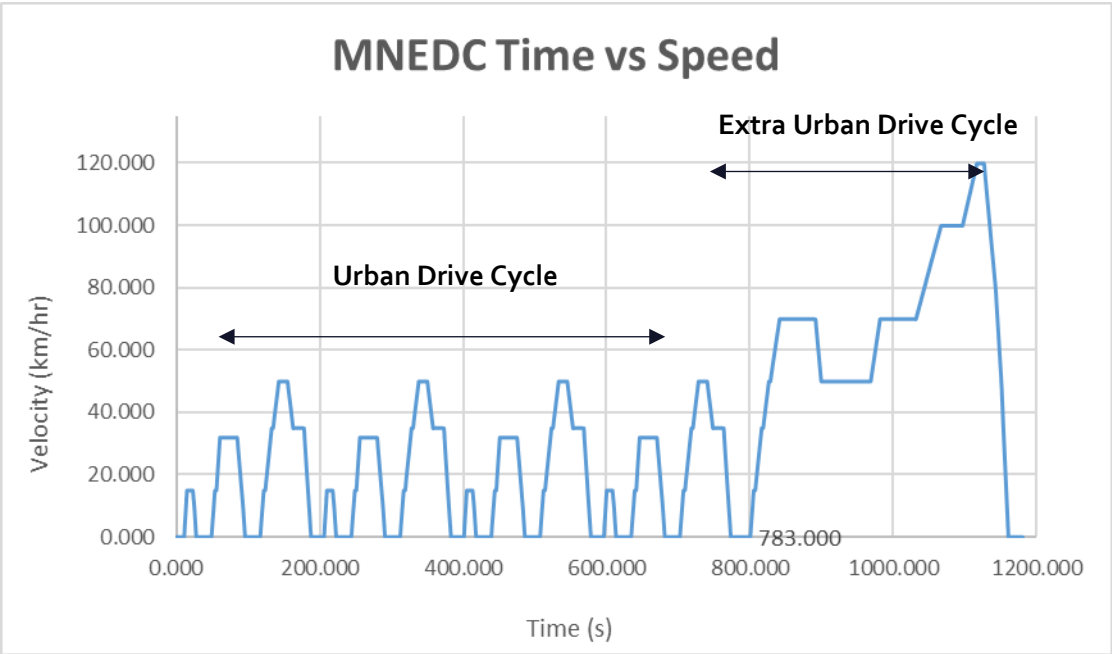
The Motor Vehicles Emissions Group, *MVEG-A*, cycle was introduced in 1970, it was created to assess the level of emissions from automotive vehicles and fuel economy in passenger cars. The cycle was created to represent a typical usage of a vehicle in Europe for that period, considering urban and motorway driving (DieselNet, 2013).

The modified cycle has now been as MNEDC (Bosch, 2014), which has been in force since Euro 3, compared to the Euro 2 NEDC, the MNEDC begins emission testing and includes cold starting. Prior to the test, the vehicle can soak for a minimum of 6 hours, to meet the requirements of the test temperature being, 20-30°C and then idled for 40's.

In the year 2000, the idling period was eliminated, and emissions sampling and the engine will start at 0 seconds (Bosch, 2014).

The MNEDC consists of two different cycles, an Urban, *UDC*, and an Extra Urban, *EUDC*. The UDC is repeated four times with no interruption and the EUDC is only carried out once. The NEDC was originally created regarding petrol vehicles, whereas with increasing technologies it now considers, diesel's, hybrid and battery electric vehicles all with different procedures (Bosch, 2014). The pollutants are collected in bags in the two phases of the NEDC, Urban and Extra Urban at max speed (Bosch, 2014). The MNEDC and the NEDC titles in this project are used as the same cycle to avoid any confusion.

Graph 9 has been taken from the Excel spreadsheet created by the author of the NEDC cycle, showing the time and speed profile of the whole cycle. The speed and time profile was provided by the University to create the model accurately.



Graph 9 Urban Drive Cycle and Extra Urban Drive Cycle

Table 6 is showing the measurements and the duration through the NEDC cycle.

Table 6 Duration of Cycles in NEDC

Measurements	Duration	Speed (km/h)
Urban Cycle	First 780s	Max: 50
Extra Urban Cycle	780s to 1180's	Max: 120
Overall (and Co ₂ emissions)	Complete Cycle	Average: 33.6km/h

The EUDC and UDC are combined for the fuel economy value, this is the total of the fuel consumption.

8.1.1 Urban Drive Cycle, UDC

The Urban Drive Cycle, was implemented by the United Nations in 1970 as part of the ECE Vehicle Regulations. More recent versions are defined as ECE R83, R84 and R101 (UnitedNations, 2013). The Urban Drive Cycle, represents typical driving conditions in European cities, it is categorised by low engine load (part load), low exhaust gas temperature and a maximum speed of 50km/h (DieselNet, 2013).

The cycle definitions is dependent on the type of vehicle, for this report all vehicles are manual therefore following the same specifications of cycle. The Urban Drive Cycle must reach, 15km/hr, 32km/hr, 50km/hr then back down to 32km/hr following the timings and it should end within 195 seconds completing 1Km. With the four cycles, the duration is 780 seconds and a theoretical distance of 4Km, with an average speed of 18.35km/hr (Bosch, 2014).

8.1.2 Extra Urban Drive Cycle, EUDC

The EUDC, was introduced in 1990 (UnitedNations, 2013), trying to represent the more aggressive and high-speed driving carried out. The maximum speed of the EUDC is 120km/hr and for lower engine sizes, it is limited to 90km/hr (DieselNet, 2013). The vehicle will then slowly accelerate to 70km/hr, back down to 50km/hr and then accelerates to 70km/hr, as mentioned previously, all within the time requirements. The vehicle cruises at 70km/hr, then accelerates slowly to 100km/hr and then further to 120km/hr, the vehicle then comes to a stop gradually. The whole duration is 400 seconds, with a theoretical distance of 6.9Km, and an average speed of 62.6km/hr. This section of the NEDC is representing motorway driving (Bosch, 2014).

8.2 World Light Harmonised Test Procedure, WLTP

In 2009 the World Forum for Harmonization of Vehicle Regulations initiated a new drive cycle, the Worldwide Harmonized Light Duty Test Procedure, WLTP. The introduction of the test procedure is dependent on specific country, the EU will be the first to introduce the WLTP, which was in 2017, and then followed by Japan. China, India, South Korea are also expected to implement this, the US are staying with their separate Federal Standards and California legislations (dieselnet, n.d). The WLTP addresses many limitations that the previous approval test had (Fontaras, et al., 2016). The whole cycle has been developed from data collected from many countries around the world to create an ideal cycle harmonised from collated speed and time profiles (Bosch, 2014).

Table 7 Changes Made for the WLTP (Fontaras, et al., 2016)

Modified
• Tyre Selection, Pressure and Tread Depth <i>Resistance force calculations changed, tyre characteristics are defined and boundary conditions for pressures.</i> • Vehicle Test Mass <i>Includes effect of optional equipment.</i> • Default Road Load Co-Efficient • Driving Cycle • Test Temperature <i>The test temperature has changed from a range of 20° -30°C to a more suited EU type temperature of 14°.</i> • Vehicle Inertia <i>Inertia classes have been removed.</i> • Pre-Conditioning
Corrected
• Gear Shift Strategy <i>The new speed and gear shifting calculation algorithm are the main changes. The WLTP addresses the issue of a more realistic drive cycle than the NEDC.</i>
Introduced
• Inertia of Rotating Parts

8.2.1 WLTP Steps

The WLTP has been split into 3 classes, defining the vehicles by their power-weight ratio, power in kW/Tonne.

- 1) Low powered vehicles ($\text{power} < 22$)
- 2) Medium powered vehicles ($22 > \text{power} \leq 34$)
- 3) High-power vehicles ($34 < \text{power}$)

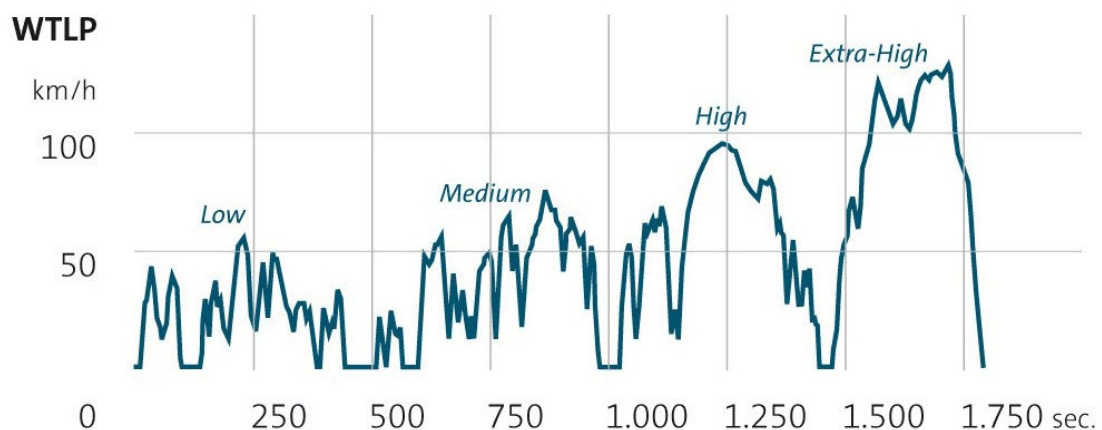


Figure 4 WLTP Graph Example (volkswagen, n.d.)

As seen in Figure 4 the WLTP consists of different types of driving, incorporating a real-world type cycle. Each class will be restricted as before due to the vehicles maximum speed, however the duration of each section is the exact same over the three classes (volkswagen, n.d.).

Class 3 will be discussed further due to it being mostly passenger cars. It has a maximum velocity of 135 km/h, has a duration of 1800 seconds and a total stop duration of 235 seconds. The complete distance is 23.27km, with the low cycle being 3095m with a maximum speed of 56.5km/h, medium distance of 4756m and speed 76.6km/h, high distance of 7162m and speed of 90km/h and the extra high distance of 8254m and maximum speed being 135km/h (Tutuianu, et al., 2013).

8.3 Real Driving Emissions, *RDE*

Real Driving Emissions, RDE measures pollutants emitted by cars while on the road using Portable Emissions Measuring System, *PEMS*. The RDE test lasts between 90 minutes to 120 minutes (ACEA, n.d). The RDE does not replace the WLTP laboratory test but complements it. Europe is the first region in the world to introduce this type of emissions testing, marking a major leap in the testing of car emissions (ACEA, n.d).

The process of the RDE is shown below in Figure 5.

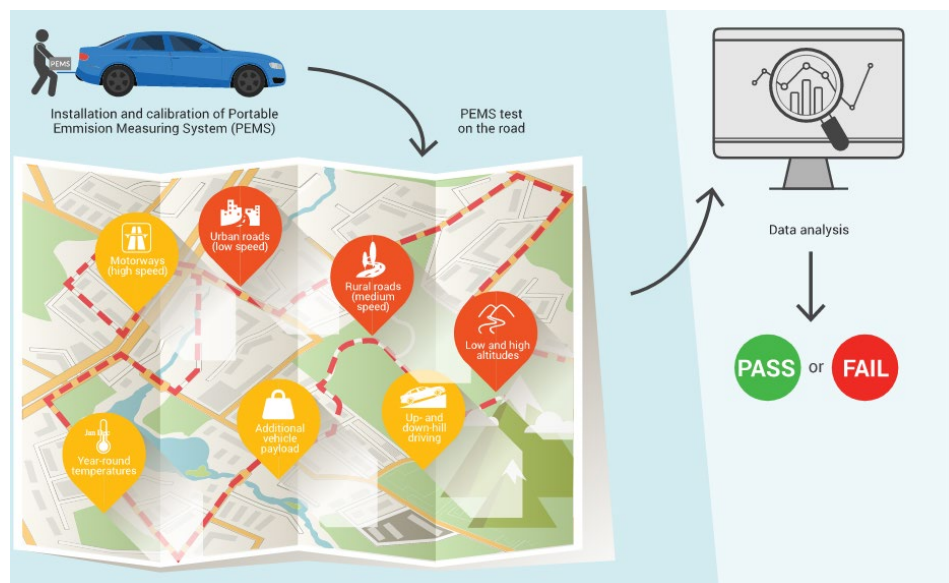


Figure 5 RDE Steps (ACEA, n.d)

Table 8 RDE Conditions

Conditions Covered in the RDE (ACEA, n.d)

Different Altitudes
Range in Temperatures
Additional Vehicle Payload (Weight)
Up-and-Down- Hill Driving
Urban Roads (low speed)
Rural Roads (medium speed)
Motorways (high speed)

PEMS provides a real-time monitoring of pollutants, with the inclusion of advanced gas analysers, exhaust mass flow meters, weather station, Global Position System, *GPS*, and a connection to the vehicle networks. Every manufacturer uses different suppliers for the PEMS equipment therefore the final results differ slightly (ACEA, n.d). To create accurate readings further development could mean that all manufacturers consider modelling vehicles to use the same PEMS.

RDE Step 1 (with NO_x conformity factor of 2.1)

RDE Step 1 applies to new type approvals from September 2017 and to all new registrations from September 2019. Cars type approved during this period are labelled as Euro 6d-temp (AA, 2017).

RDE Step 2 (with NO_x conformity factor of 1.0 plus an error margin of 0.5)

RDE Step 2 will be applied in January 2020 for new types. Then it will be applied to all new registrations in January 2021. Cars type approved during this period are labelled as Euro 6d-temp (AA, 2017).

In October 2015, the European Commission's Technical Committee on Motor Vehicles, *TCMV*, finalised the conformity factor applicable of the RDE Step 2. The conformity factor is the cap applied to vehicles to limit the NO_x emissions of real world driving.

The PEMS are installed on the back of the vehicle. The conformity factor is implemented because the PEMS have various inaccuracies. The repeatable accuracy of the PEMS does not compete with the same as the cyclic laboratory tests. The PEMS are also affected by altitude and the ambient temperature, therefore there is further development work needed to ensure accuracy of the technology (ACEA, n.d).

The International Council on Clean Transportation, *ICCT* completed a study finding that in Germany, the gap between type approval and the real-world application, fuel consumption and CO₂ values increased around 8% in 2001 to 21% in 2012, increasing greatly from 2007, indicating the importance of evolving technology to control this (Tietge, et al., 2017).

9. Creating the NEDC Model

9.1 Measurements

Table 9 and Table 10 Passat values were provided by the University and the Ford value were taken from (FordMotorCompany, 2012) assuming that the dimensions were for a Ford Focus, 5 door passenger car. These values were needed to find the necessary value for the NEDC model.

Table 9 Passat and Ford Values

Nomenclature	Passat	Ford
Air Density (kg/m ³)	1.2	1.2
Drag Co-Efficient	0.4	0.38
Engine Displacement (cc)	1984	999
Engine Idle (rpm)	800	800
Engine Inertia (kg/m ²)	0.15	0.15
Frontal Area (m ²)	2.235	2.7
Gravity (m/s ²)	9.81	9.81
Rolling Resistance Co-Efficient	0.015	0.015
Vehicle Mass (kg)	1650	1279
Wheel Inertia (kg/m ²)	0.8	1.6
Wheel Rolling Radius (m)	0.32	0.32

Table 10 Gear Ratios for Passat and Ford

		Passat	Ford
Gear	Efficiency %	Ratio	Ratio
1 st	0.94	3.36	3.727
2 nd	0.94	2.09	2.048
3 rd	0.95	1.47	1.357
4 th	0.97	1.1	1.032
5 th	0.97	0.87	0.821
6 th	0.96	0.73	0.690
Final Drive	0.94	3.94	4.07

The difference of the two vehicles is the idling rpm, vehicle mass and the frontal area. Through research it is a known fact that one of the keen progresses in industry is weight reduction to compliment power advantages. The frontal area is greater for the Ford due to the type of model, this doesn't prove fruitful for fuel consumption due to air resistance force.

9.2 Procedure for Creating the MNEDC

To compare the two models, like the MNEDC, the maximum speed values of both cycles have been compared, to then enable an accurate comparison to CO₂ (Bosch, 2014). All equations used were also provided during supervisor meetings. As the velocity and time are not set to change, the first calculation completed is converting velocity from km/hr to m/s, from this the acceleration is then calculated.

Acceleration is a measurement of how quickly the velocity changes in the vehicle. In this instance, acceleration in Equation 5 is the change in velocity from Vel₁ to Vel₂ in respect to time, the initial position was Vel₁.

$$Acceleration (m/s/s) = Vel_2 - Vel_1$$

Equation 5 Acceleration at the Wheels

The rolling force and aero force are needed as they are resistive forces acting on the vehicle which initiate the vehicles state in motion. Equation 6 and Equation 7 has been described in greater detail in section 10.4.1 Coast Down Test.

$$F_{Rolling} = \mu \times M \times G$$

Equation 6 Rolling Force

$$F_{Aero} = \frac{1}{2} \times \rho \times C_D \times F_{Area} \times V^2$$

Equation 7 Aero Force

If statements were used on Excel to eliminate any negative forces that derived from the deceleration of the vehicle. This is to ensure that the future calculations are not affected throughout the spreadsheet. Below is the function used for Equation 8:

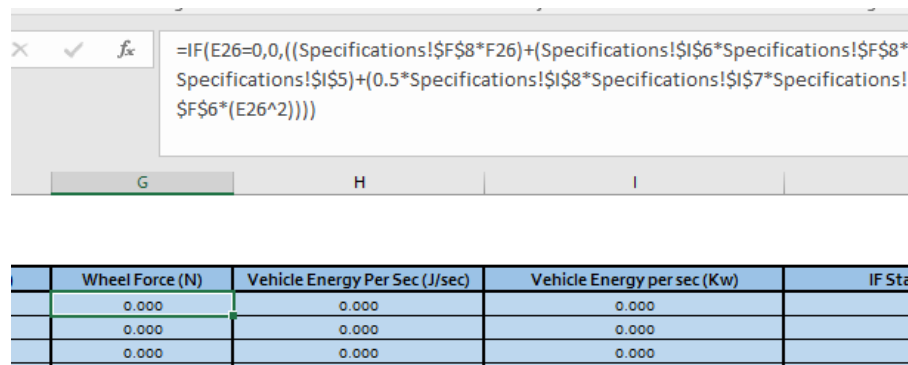


Figure 6 IF Function for Wheel Force

$$F_{wheel} (N) = M \times F_{Area} + F_{Rolling} + F_{Aero}$$

Equation 8 Wheel Force

The vehicle energy per second in both Joules and Kw was then calculated, averaging both negative and positive values over the cycle provide the assumption that this is the power driving the vehicle energy per/sec.

$$V_{Energy} (J/sec) = F_{Wheel} \times Vel (m/s)$$

$$V_{Energy} (Kw/sec) = \frac{V_{Energy} (J/sec)}{1000}$$

Equation 9 Vehicle Energy (J/sec & Kw)

$$Vel_{Wheel} (rad/s) = \frac{Vel (m/s)}{2\pi \times Wheel_{RR}}$$

$$Vel_{Wheel} (rad/min) = Vel_{Wheel} (rad/s) \times 60$$

$$Vel_{Wheel} (rad/s) = (Vel (rev/s) \times 360) \times \left(\frac{\pi}{180}\right)$$

Equation 10 Wheel Velocity (rev/s), (rev/min) & (rad/s)

A motor vehicles driveline is the portion of the vehicle that is delivers the power to the driving wheels. The drivetrain is coupled with the engine to produce mechanical power to rotate the axle. This includes physically linking components, at the opposite ends of the vehicle, so this requires a prop shaft or a drive shaft. The operating speed of the engine and the wheels are different, therefore gear ratios need to be used to ensure that vehicle speed changes remain efficient and no efficiency is lost through this process. The components that are included in a manual driveline are differentials, clutch, gearbox, rear axle and final drive. The following equations were used to provide the engine speed at different gear ratios, which then the fuel usage could be calculated by using the relevant speed and torque/BMEP. This is explained further in 9.3 Fuel Usage.

$$Tor_{Wheel} (Nm) = F_{wheel} \times Wheel_{RR} \times 2 (wheels)$$

Equation 11 Wheel Torque

$$Acc_{wheel} (rad/s/s) = V2_{wheel} (rad/s/s) - V1_{wheel} (rad/s/s)$$

Equation 12 Wheel Acceleration

$$Tor_{Driveline} (Nm) = Tor_{Wheel} + (I_{wheel} \times Acc_{Wheel})$$

Equation 13 Driveline Torque

$$Acc_{Driveshaft} ((rad / s) / s) = Acc_{Wheel} ((rad/s)/s)$$

Equation 14 Driveshaft Acceleration

$$Tor_{DiffOUT} (Nm) = Tor_{Driveline} (Nm)$$

Equation 15 Differential Output Torque (Nm)

$$Tor_{DiffIN} (Nm) = \frac{Tor_{DiffOUT}}{(FD_L \times FD_R)}$$

Equation 16 Differential Input Torque

Figure 7, Figure 8 and Figure 9 are presenting the IF functions used to calculate the correct engine speed with the correct gear ratio and gear efficiency in Excel. *IF (C26=1* < this function is an example of the author telling the software that if the gear is equal to 1 then use the efficiency and ratio for 1st gear. By doing this the engine RPM, which is a function of the final drive ratio and gear ratio, will be the correct and efficient range for the gear. The engine speed is then needed to calculate the engine internal torque and BMEP, which is then used in later calculations for the fuel usage.

iff. Input Torque (Nm)	Actual Transmission Input Torque (Nm)
0.000	0.000
0.000	0.000

Figure 7 IF Function for Gearing

$$ATIT (Nm) = \frac{Tor_{DiffIN}}{G\eta \times G_R}$$

Equation 17 Actual Transmission Input Torque

$$Engine(Rad/s/s) = Wheel Acc (rad/s/s) \times Final Drive Ratio \times Gear Ratio$$

Equation 18 Engine Acceleration

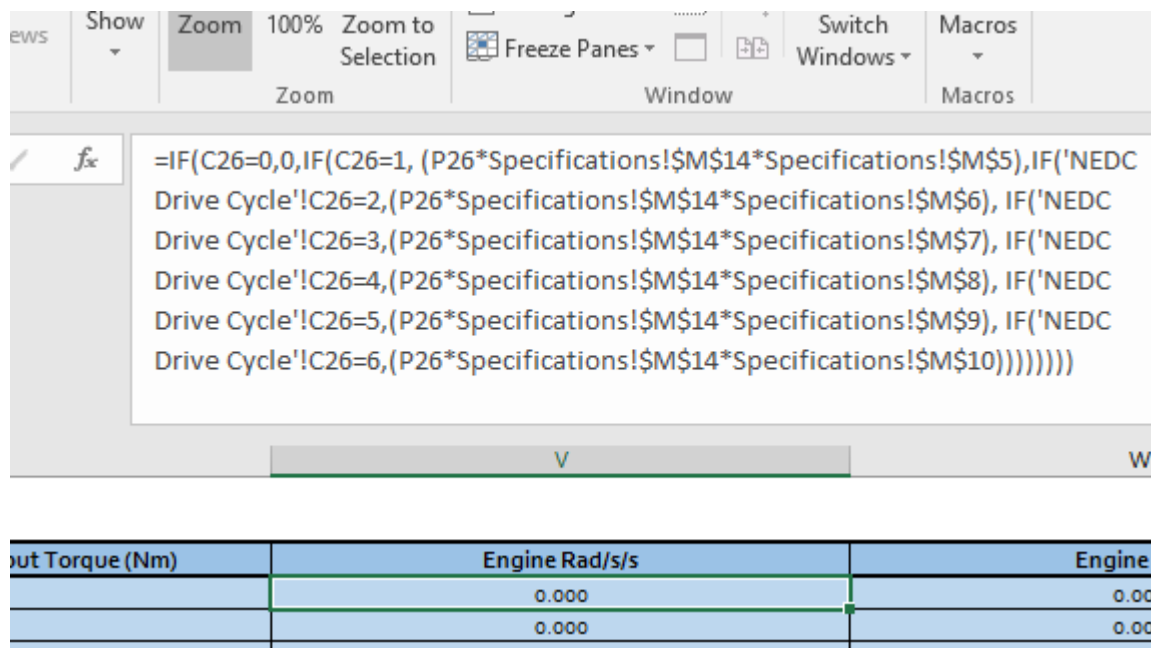


Figure 8 IF Function for correct Gear Ratio

$$\text{Engine(RPM)} = \text{Wheel Vel}(\text{rev/m}) \times \text{Final Drive Ratio} \times \text{Gear Ratio}$$

Equation 19 Engine RPM

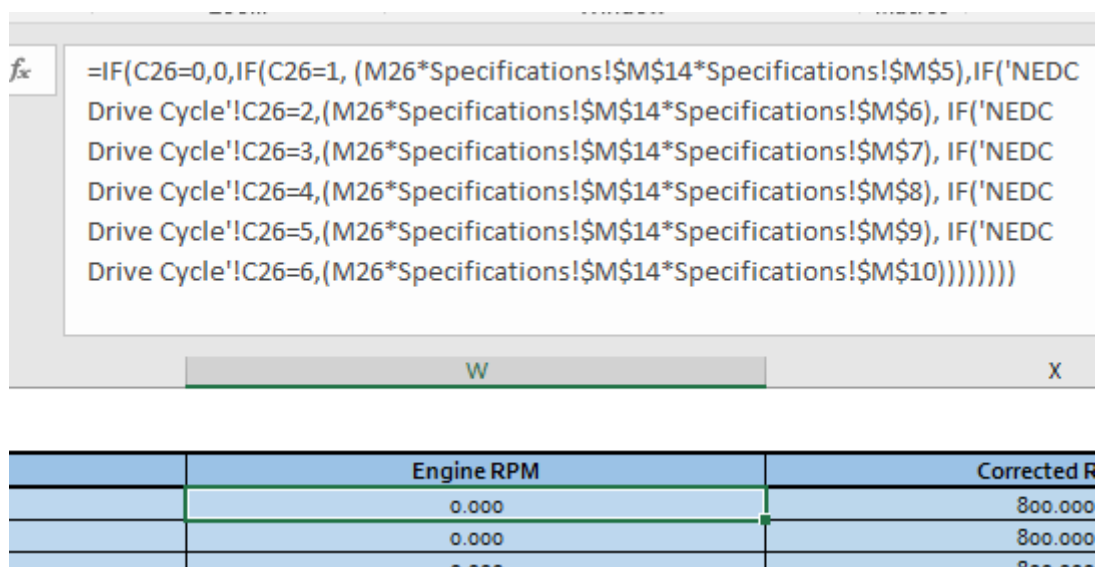


Figure 9 IF Function for Correct Gear Ratio (RPM)

$$Tor_{EngineINT} (Nm) = ATIT (Nm) + E_{Inertia} (kg/m^2) \times Engine \text{ Acceleration } (rad/s/s)$$

Equation 20 Engine Internal Torque

$$BMEP (N/m^2) = \frac{Tor_{EngineINT} \times 4\pi}{\left(\frac{Engine_{Disp}}{10^6}\right)}$$

$$BMEP (Bar) = BMEP (N/m^2) \times 10^5$$

Equation 21 BMEP (N/m²) & (Bar)

The following fuel equations were also used when calculating CO₂ and Fuel Usage in the RDE cycles.

$$Litres \text{ of Fuel to Gallons} = \frac{1 \text{ Litre}}{4.545} \text{ Gallons}$$

Equation 22 Fuel Conversion from Litre to Gallons

$$1 \text{ Litre of Fuel} = 750 \text{ gms (of fuel)}$$

Equation 23 Fuel Conversion Litre to gms of Fuel

$$Total \text{ Fuel (Litres)} = \frac{Total \text{ fuel gm/s}}{750}$$

Equation 24 Fuel Conversion from grams to Litre

$$MPG = \frac{Distance (miles)}{Fuel \text{ in Gallons}}$$

Equation 25 MPG

$$3.09 \text{ kg } CO_2 = \frac{Total \text{ Kg of } CO_2}{Total \text{ Kg of } C_8H_{18}} = \frac{352}{114}$$

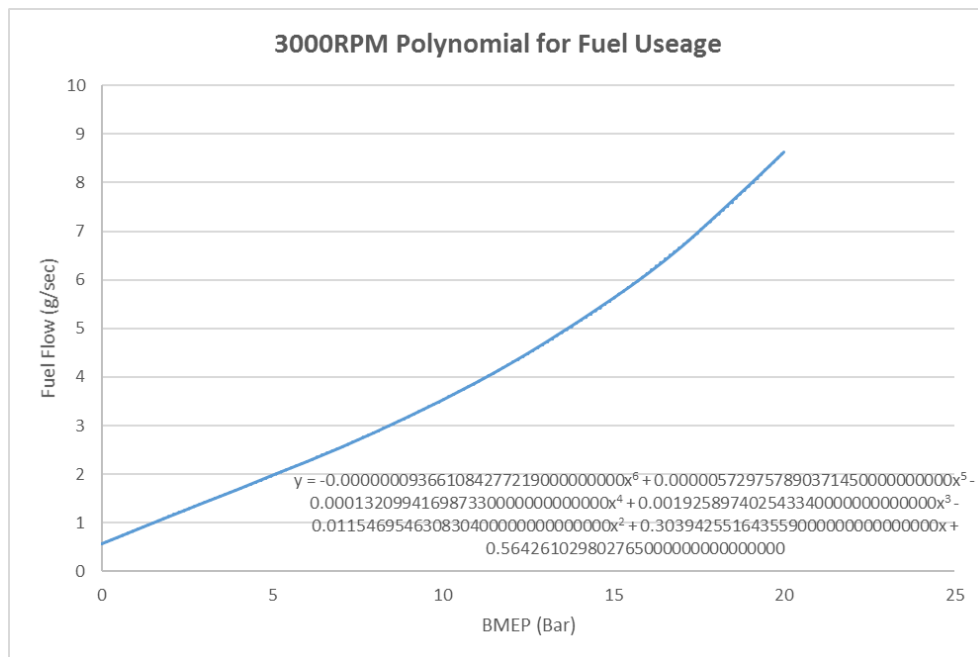
$$CO_2 (g/km) = \frac{Total \text{ Fuel (g)} \times 3.09}{Total \text{ Distance(km)}}$$

Equation 26 CO₂ Calculations

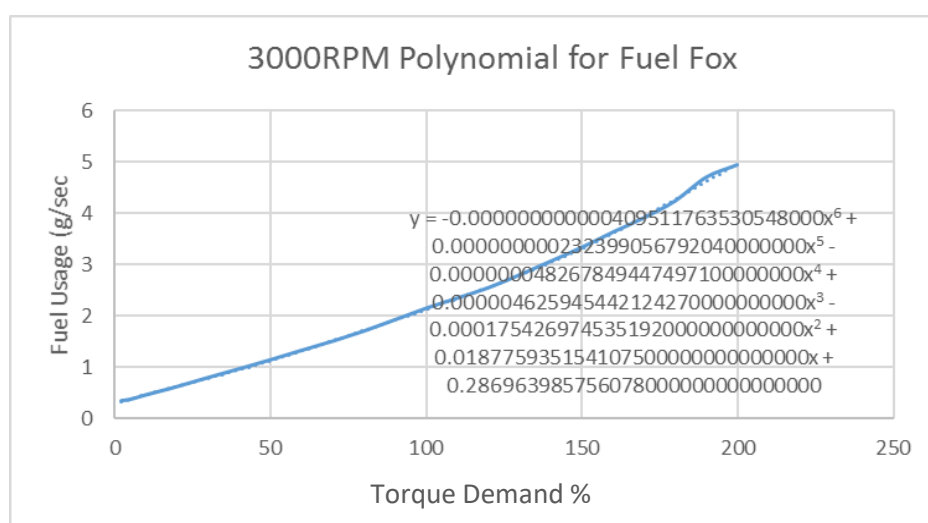
9.3 Fuel Usage

To find the fuel usage polynomial equations were used from the original data of the engines.

In Excel, graphs were created using fuel usage on the y axis and depending on the vehicle, BMEP or Torque demand on the x axis. Using the graph functions a polynomial trendline and equation was presented on the graph. Each RPM will have a different equation, only 3000RPM has been used for an example, the other graphs and equations used can be found in 13.5.1 Fuel Usage Graphs.



Graph 10 Polynomial Graph for 3000RPM



Graph 11 3000RPM Polynomial for Ford

The following figures are showing the accuracy of the polynomial equations to the original, to validate the equation before using in the model. The Ford Fox uses torque demand as a percentage for the reference points tested for fuel usage and the Passat uses BMEP in Bar.

	Passat															
B M E P (B A R)		500	850	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	6000	7000
	0.00	0.08	0.14	0.16	0.21	0.26	0.31	0.35	0.46	0.56	0.67	0.77	0.82	0.83	0.81	0.94
	0.50	0.10	0.18	0.21	0.27	0.33	0.40	0.46	0.59	0.71	0.83	0.93	1.04	1.15	1.28	1.24
	1.00	0.13	0.22	0.26	0.33	0.40	0.48	0.56	0.71	0.86	1.00	1.13	1.28	1.43	1.65	1.59
	1.50	0.15	0.26	0.30	0.38	0.47	0.55	0.64	0.82	1.00	1.17	1.34	1.51	1.69	1.95	1.97
	2.00	0.17	0.29	0.35	0.44	0.53	0.62	0.73	0.93	1.14	1.35	1.56	1.75	1.93	2.22	2.36
	3.00	0.21	0.37	0.43	0.54	0.65	0.77	0.89	1.14	1.41	1.71	1.99	2.22	2.41	2.74	3.15
	4.00	0.26	0.45	0.53	0.66	0.79	0.93	1.07	1.36	1.69	2.05	2.40	2.68	2.91	3.33	3.94
	5.00	0.32	0.54	0.63	0.78	0.94	1.10	1.26	1.59	1.97	2.37	2.77	3.12	3.44	4.01	4.75
	6.00	0.37	0.63	0.74	0.92	1.10	1.28	1.47	1.84	2.26	2.69	3.13	3.57	4.00	4.80	5.59
	7.00	0.43	0.73	0.85	1.06	1.27	1.47	1.69	2.11	2.55	3.02	3.51	4.03	4.59	5.65	6.53
	8.00	0.49	0.83	0.97	1.20	1.43	1.67	1.90	2.37	2.86	3.37	3.91	4.53	5.20	6.56	7.60
	9.00	0.55	0.92	1.08	1.34	1.60	1.86	2.12	2.64	3.19	3.76	4.38	5.07	5.84	7.48	8.85
	10.00	0.60	1.02	1.19	1.48	1.76	2.04	2.33	2.91	3.53	4.19	4.90	5.67	6.51	8.43	10.32
	11.00	0.65	1.10	1.29	1.60	1.92	2.23	2.54	3.19	3.90	4.66	5.48	6.33	7.24	9.43	12.01
	12.00	0.70	1.18	1.39	1.73	2.07	2.41	2.76	3.49	4.28	5.16	6.11	7.06	8.06	10.51	13.93
	13.00	0.74	1.26	1.48	1.85	2.23	2.61	2.99	3.80	4.70	5.69	6.76	7.85	8.99	11.75	16.06
	14.00	0.77	1.33	1.57	1.98	2.40	2.82	3.26	4.16	5.14	6.22	7.42	8.69	10.07	13.19	18.37
	15.00	0.81	1.41	1.67	2.12	2.59	3.06	3.56	4.56	5.62	6.77	8.07	9.60	11.30	14.91	20.82
	16.00	0.86	1.50	1.79	2.28	2.80	3.34	3.90	5.02	6.14	7.32	8.72	10.55	12.69	16.92	23.37
	17.00	0.90	1.60	1.91	2.46	3.03	3.64	4.28	5.52	6.70	7.91	9.38	11.56	14.19	19.19	26.01
	18.00	0.96	1.71	2.06	2.65	3.29	3.96	4.68	6.04	7.30	8.56	10.15	12.64	15.71	21.63	28.71
	19.00	1.03	1.84	2.21	2.86	3.55	4.28	5.06	6.55	7.95	9.37	11.15	13.81	17.11	24.00	31.52
	20.00	1.10	1.97	2.37	3.06	3.80	4.56	5.35	6.97	8.64	10.46	12.59	15.13	18.13	25.92	34.51

Figure 10 Original VW Passat Fuel Data

B M E P (B A R)	Passat															
		500	850	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	6000	7000
	0.00	0.08	0.14	0.16	0.21	0.26	0.31	0.35	0.46	0.56	0.67	0.77	0.82	0.83	0.81	0.94
	0.50	0.10	0.18	0.21	0.27	0.33	0.40	0.46	0.59	0.71	0.83	0.93	1.04	1.15	1.28	1.24
	1.00	0.13	0.22	0.26	0.33	0.40	0.48	0.56	0.71	0.86	1.00	1.13	1.28	1.43	1.65	1.59
	1.50	0.15	0.26	0.30	0.38	0.47	0.55	0.64	0.82	1.00	1.17	1.34	1.51	1.69	1.95	1.97
	2.00	0.17	0.29	0.35	0.44	0.53	0.62	0.73	0.93	1.14	1.35	1.56	1.75	1.93	2.22	2.36
	3.00	0.21	0.37	0.43	0.54	0.65	0.77	0.89	1.14	1.41	1.71	1.99	2.22	2.41	2.74	3.15
	4.00	0.26	0.45	0.53	0.66	0.79	0.93	1.07	1.36	1.69	2.05	2.40	2.68	2.91	3.33	3.94
	5.00	0.32	0.54	0.63	0.78	0.94	1.10	1.26	1.59	1.97	2.37	2.77	3.12	3.44	4.01	4.75
	6.00	0.37	0.63	0.74	0.92	1.10	1.28	1.47	1.84	2.26	2.69	3.13	3.57	4.00	4.80	5.59
	7.00	0.43	0.73	0.85	1.06	1.27	1.47	1.69	2.11	2.55	3.02	3.51	4.03	4.59	5.65	6.53
	8.00	0.49	0.83	0.97	1.20	1.43	1.67	1.90	2.37	2.86	3.37	3.91	4.53	5.20	6.56	7.60
	9.00	0.55	0.92	1.08	1.34	1.60	1.86	2.12	2.64	3.19	3.76	4.38	5.07	5.84	7.48	8.85
	10.00	0.60	1.02	1.19	1.48	1.76	2.04	2.33	2.91	3.53	4.19	4.90	5.67	6.51	8.43	10.32
	11.00	0.65	1.10	1.29	1.60	1.92	2.23	2.54	3.19	3.90	4.66	5.48	6.33	7.24	9.43	12.01
	12.00	0.70	1.18	1.39	1.73	2.07	2.41	2.76	3.49	4.28	5.16	6.11	7.06	8.06	10.51	13.93
	13.00	0.74	1.26	1.48	1.85	2.23	2.61	2.99	3.80	4.70	5.69	6.76	7.85	8.99	11.75	16.06
	14.00	0.77	1.33	1.57	1.98	2.40	2.82	3.26	4.16	5.14	6.22	7.42	8.69	10.07	13.19	18.37
	15.00	0.81	1.41	1.67	2.12	2.59	3.06	3.56	4.56	5.62	6.77	8.07	9.60	11.30	14.91	20.82
	16.00	0.86	1.50	1.79	2.28	2.80	3.34	3.90	5.02	6.14	7.32	8.72	10.55	12.69	16.92	23.37
	17.00	0.90	1.60	1.91	2.46	3.03	3.64	4.28	5.52	6.70	7.91	9.38	11.56	14.19	19.19	26.01
	18.00	0.96	1.71	2.06	2.65	3.29	3.96	4.68	6.04	7.30	8.56	10.15	12.64	15.71	21.63	28.71
	19.00	1.03	1.84	2.21	2.86	3.55	4.28	5.06	6.55	7.95	9.37	11.15	13.81	17.11	24.00	31.52
20.00	1.10	1.97	2.37	3.06	3.80	4.56	5.35	6.97	8.64	10.46	12.59	15.13	18.13	25.92	34.51	

Figure 11 Polynomial VW Passat Fuel Data

New Fuel Usage From Polynomials (g/s)	Fox																
	RPM	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
	FL																
	200						3.1605	3.6012	3.9613	4.963	5.3804						
	190						2.97	3.3445	3.7115	4.6262	5.2067						
	180					2.5397	2.7898	3.1229	3.4802	4.2766	4.932	5.7307					
	170				2.0899934	2.4139	2.6155	2.9199	3.2574	3.9352	4.6072	5.2432	5.958				
	160				1.9620025	2.2518	2.4439	2.7251	3.0375	3.6136	4.2659	4.8432	5.4738	6.5577			
	150				1.8185409	2.0769	2.2735	2.5331	2.8188	3.3164	3.9288	4.4922	5.042	5.8731	6.7684		
	140			1.439	1.670449	1.903	2.1035	2.3417	2.6016	3.0438	3.6064	4.1655	4.6503	5.2652	6.0856	7.0846	
	130			1.3229	1.5242842	1.7364	1.934	2.151	2.3877	2.7927	3.3029	3.8493	4.2876	4.7716	5.4544	6.4168	
	120			1.2021	1.3835115	1.5792	1.7659	1.9626	2.1792	2.5588	3.0177	3.537	3.9446	4.3785	4.9388	5.7018	6.4442
	110		0.8952	1.0787	1.2495146	1.4305	1.6005	1.7788	1.9783	2.3372	2.7481	3.2273	3.614	4.0475	4.5268	5.1035	5.9096
	100		0.8217	0.9572	1.1224266	1.2886	1.4392	1.6018	1.7865	2.1239	2.4907	2.9221	3.2911	3.7358	4.1714	4.6349	5.2336
	90		0.7152	0.8421	1.0017814	1.1518	1.2837	1.433	1.6044	1.916	2.2427	2.6244	2.9736	3.411	3.8226	4.2387	4.6874
	80		0.6113	0.7369	0.8869857	1.0194	1.1355	1.2735	1.4315	1.7119	2.0023	2.3374	2.6615	3.0594	3.4477	3.8474	4.2608
	70		0.5231	0.6427	0.7776097	0.8917	0.9957	1.1232	1.2667	1.5119	1.7691	2.0632	2.3563	2.6883	3.0418	3.4207	3.8499
	60		0.45	0.5586	0.6734999	0.77	0.8649	0.981	1.1082	1.3172	1.5442	1.8028	2.0607	2.3219	2.6282	2.9634	3.3799
	50		0.3861	0.4817	0.5747106	0.6564	0.743	0.8453	0.9537	1.13	1.3293	1.5556	1.7778	1.9917	2.247	2.5201	2.863
	40	0.29	0.3247	0.4076	0.4812565	0.5523	0.6288	0.714	0.8016	0.9519	1.1257	1.3197	1.5095	1.7207	1.935	2.1502	2.3908
	30	0.25	0.2623	0.3328	0.3926851	0.457	0.5202	0.5852	0.6514	0.7835	0.9326	1.0929	1.2559	1.5006	1.6938	1.8804	2.0624
	20	0.17	0.2002	0.2558	0.3074694	0.3667	0.4135	0.4577	0.5048	0.6223	0.7456	0.8734	1.0133	1.2644	1.4479	1.6368	1.8474
	10	0.12	0.1433	0.1804	0.2222206	0.271	0.3035	0.3321	0.3667	0.4613	0.5539	0.6618	0.7725	0.8518	0.9929	1.1547	1.3832
	5	0.1	0.119	0.1465	0.1777817	0.2157	0.2451	0.2708	0.3036	0.377	0.4505	0.5601	0.6481	0.494	0.5723	0.6626	0.7894
	2	0.09	0.1062	0.1288	0.1499434	0.1783	0.2085	0.235	0.2686	0.3239	0.3841	0.501	0.5706	0.2029	0.2199	0.2304	0.215

Figure 13 Polynomial Values for the Fuel (g/sec)

Fox																
RPM	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
FL		3.24	5.22	7.52	9.39	11.35	12.92	14.34	18.08	18.92	21.54	22.34	25.55	26.61	27.62	25.11
200						11.34	12.96	14.25	17.78	19.47						
190						10.77	12.04	13.39	16.91	18.46						
180					9.11	10.05	11.26	12.52	15.24	17.76	20.61					
170				7.51	8.77	9.38	10.52	11.72	14.06	17.14	18.91	21.41				
160				7.1	8.08	8.74	9.77	10.88	13.05	15.06	17.46	19.8	23.68			
150				6.52	7.46	8.17	9.12	10.19	11.98	14	16.18	18.15	20.99	24.47		
140			5.19	6.04	6.84	7.63	8.45	9.44	11.01	12.93	14.87	16.65	18.92	21.63	25.58	
130			4.73	5.46	6.16	6.96	7.73	8.55	10.05	11.89	13.84	15.4	17.3	19.71	22.93	
120			4.35	4.93	5.75	6.39	7.07	7.79	9.15	10.95	12.86	14.24	15.88	18	20.45	23.3
110		3.22	3.91	4.52	5.24	5.78	6.43	7.13	8.42	9.97	11.65	13.06	14.58	16.31	18.66	20.9
100		2.97	3.43	4.13	4.66	5.2	5.78	6.48	7.71	9.03	10.53	11.88	13.38	15	16.78	19.21
90		2.56	3	3.6	4.11	4.55	5.13	5.77	6.9	8.05	9.36	10.7	12.11	13.59	15.15	16.95
80		2.2	2.66	3.15	3.59	4.05	4.55	5.13	6.11	7.13	8.39	9.56	10.95	12.32	13.64	15.25
70		1.89	2.33	2.77	3.21	3.6	4.07	4.56	5.4	6.32	7.45	8.44	9.71	10.92	12.18	13.69
60		1.63	2.02	2.42	2.78	3.12	3.54	4.02	4.75	5.54	6.5	7.39	8.51	9.6	10.76	12.04
50		1.38	1.73	2.08	2.38	2.7	3.03	3.41	4.09	4.8	5.6	6.41	7.31	8.25	9.33	10.42
40	1.04	1.16	1.46	1.76	2.01	2.28	2.57	2.87	3.46	4.1	4.77	5.48	6.27	7.1	7.94	8.92
30	0.89	0.95	1.19	1.42	1.67	1.88	2.13	2.36	2.85	3.41	3.94	4.55	5.21	5.94	6.62	7.51
20	0.61	0.73	0.93	1.1	1.3	1.48	1.65	1.84	2.21	2.67	3.13	3.64	4.18	4.76	5.37	6.08
10	0.44	0.51	0.65	0.78	0.93	1.05	1.16	1.29	1.63	1.92	2.38	2.72	3.18	3.64	4.18	4.79
5	0.36	0.42	0.53	0.63	0.79	0.88	0.98	1.09	1.32	1.6	1.99	2.33	2.73	3.14	3.56	4.08
2	0.32	0.39	0.46	0.56	0.66	0.78	0.86	0.98	1.22	1.44	1.83	2.09				

Figure 12 Ford Fox Fuel Values (kg/h) (FordMotorCompany, 2012)

The following section will explain how the polynomials were retrieved and then calculated for each vehicle.

$$F_{Flow}(gms/sec) = \text{polynomial equations}$$

Equation 27 Fuel Flow Equation From Polynomials

$$y = y + \left(\frac{x - x_1}{x_2 - x_1} \right) \times (y_2 - y_1)$$

Equation 28 Interpolation Equation for Polynomials

An IF statement in Excel and Equation 28 was used to find the estimating values between the known data points of the BMEP/Torque Demand. Circle 1, is the IF statement asking the software that if the RPM selected *CellY22*, is greater than 300 but smaller than 850, use the following equation. Circle 2, is showing the use of the interpolation equation, where (*CellY22*) is the RPM calculated at that data section and using interpolation to give the estimated value using the polynomial. Circle 3 is showing the repetition in the formula to ensure that no data points have been left out.

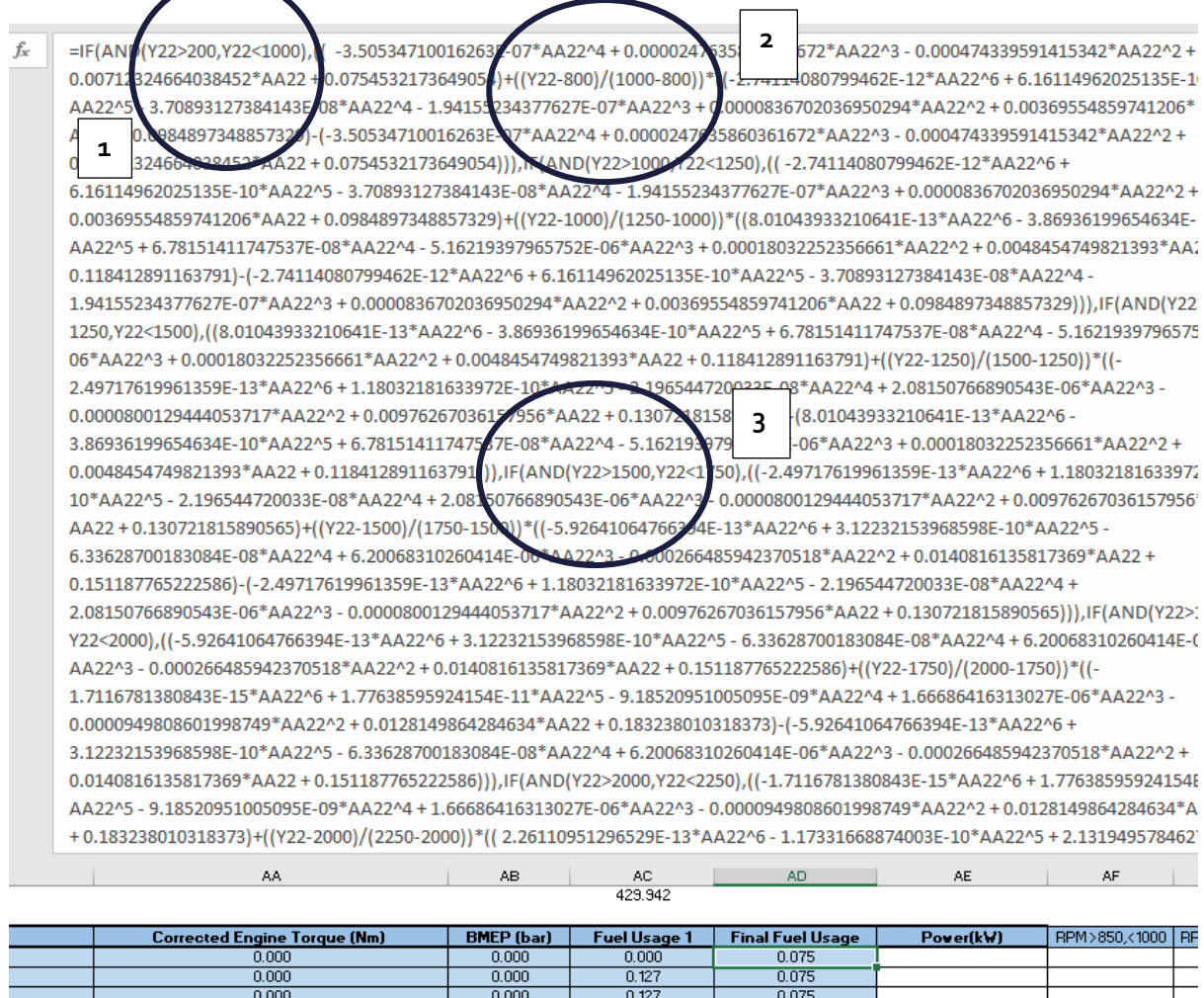
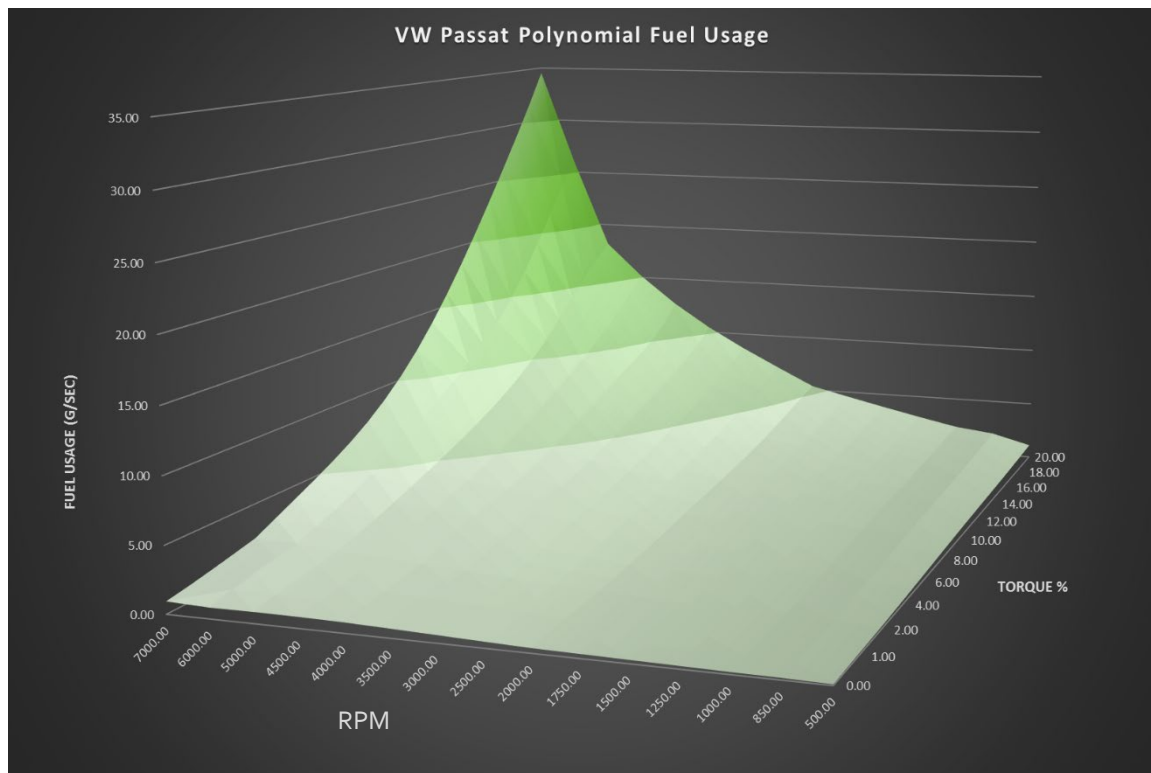


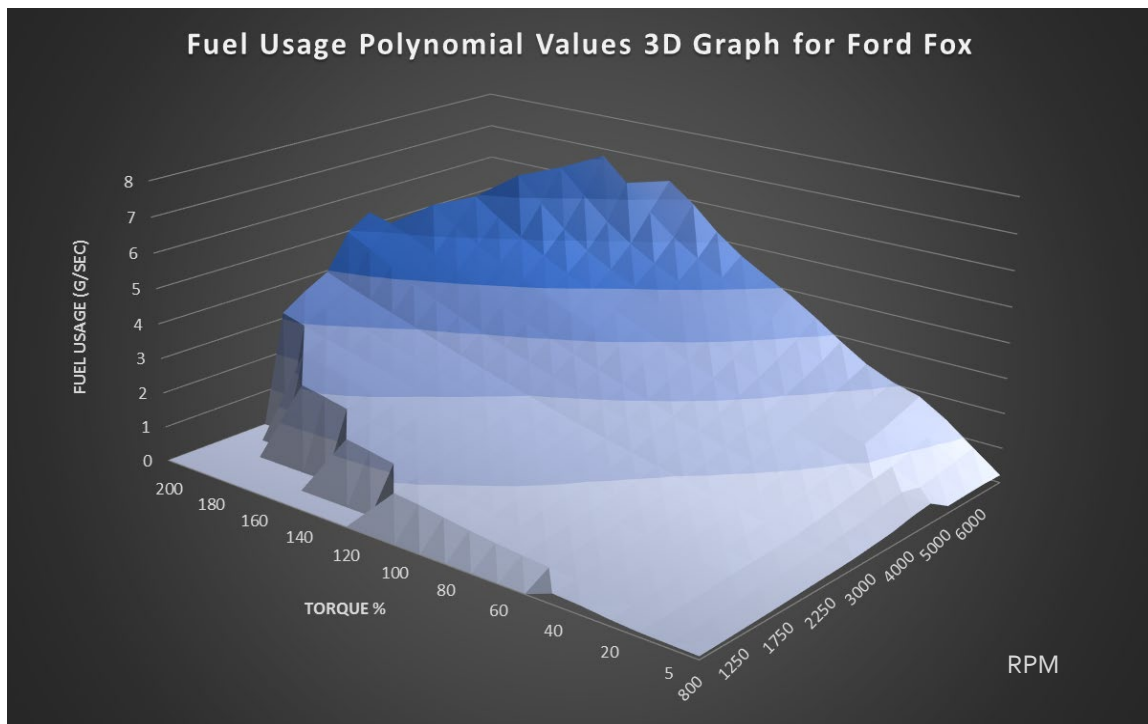
Figure 14 If Function, Polynomial and Interpolation Example

3D graphs have been formed to create a physical representation of the fuel usage. The VW Passat shows a very high value for high BMEP and high RPM, 34.51(g/sec), this can be due to the cooling effect of excess fuel at high temperatures in the engine, caused by very high pressures as it is supercharged and turbocharged. The Passat is also a stratified fuel injection which is a forced aspiration, and the fuel is injected straight into the combustion chamber to create a stratified charge, this increases the torque and power of the engine with a higher compression ratio. TSFI can help reduce emissions and is 15% more economical due to the fuel distribution in the chamber (Audi, 2009).



Graph 12 VW Passat Polynomial Fuel Usage

The Ford being a 1L compared to the 2L Passat cannot achieve the same torque at the higher RPM's therefore the fuel data does not consider this. There is a gradual fuel increase, and doesn't peak with extreme fuel usage, producing less fuel than the Passat. The turbochargers still increases fuel efficiency but not increasing power, the turbo recovers waste energy in the exhaust and feeds it back into the engine intake (Cummins, n.d.). The wasted energy increases the mass of air, and it becomes easier for all the fuel to be combusted by the spark plug.



Graph 13 Ford Fox Fuel Usage from Polynomials

9.4 Values Calculated

Table 11 Max Speed of UDC and EUDC Driving Cycle Data

	VW Passat		Ford Focus	
Measurement	UDC. Max Speed 50(km/hr)	EUDC. Max Speed 120(km/hr)	UDC. Max Speed 50(km/hr)	EUDC. Max Speed 120(km/hr)
Velocity (m/s)	13.9	33.33	13.9	33.33
Acceleration (m/s/s)	0	0	0	0
Wheel Force (N)	346.270	838.8	306.96	872.205
Vehicle Energy Per Sec (J/sec)	4809.3	27959.9	4263.26	29073.5
Vehicle Energy per sec (Kw)	4.81	27.96	4.263	29.07
Wheel Velocity (rev/s)	6.91	16.58	6.9	16.6
Wheel Velocity (rev/m)	414.47	994.72	414.47	994.72
Wheel Velocity (rad/s)	43.403	104.17	43.403	104.17
Wheel Torque (Nm)	110.81	268.42	98.226	279.12
Wheel Acceleration (rad/s/s)	0	0	0	0
Driveline Torque (Nm)	110.8	268.42	98.23	279.12
Driveshaft. Acceleration (rad/s/s)	0	0	0	0
Diff. Out Torque (Nm)	110.81	268.42	98.23	279.12
Diff. Input Torque (Nm)	29.92	72.5	25.68	72.95
Actual Transmission Input Torque (Nm)	28	85.9	19.92	91.61
Engine Rad/s/s	0	0	0	0
Engine RPM	1796	3409	2289	3323
Engine Torque (Nm)	28	85.9	19.916	91.61
BMEP (bar)	1.762	5.396	1.251	5.756

Table 12 Fuel and CO₂ Consumption on UDC and NEDC

	VW Passat		Ford Focus	
Measurement	UDC. Max Speed 50(km/hr)	EUDC. Max Speed 120(km/hr)	UDC. Max Speed 50(km/hr)	EUDC. Max Speed 120(km/hr)
Final Fuel Usage (g/sec)	0.68	2.424	0.464	2.165
Fuel Usage (g)	320.2	407.4	207.6	320.4
Total Fuel (g)	727.6		528	
MPG	26	34	40	44
Combined (MPG)	30		42	
CO ₂ Emissions (g/Sec)	0.002	0.007	0.001	0.007
CO ₂ Emissions (g/km)	89.71	114.15	58.33	90
Total CO ₂ (g/km)	203.87		148.33	

Table 13 Actual Stated Values Found From Research

	VW Passat (ultimatespecs, 2009)		Ford Focus (FordMotorCompany, 2012)	
Measurement	UDC. Max Speed 50(km/hr)	EUDC. Max Speed 120(km/hr)	UDC. Max Speed 50(km/hr)	EUDC. Max Speed 120(km/hr)
MPG	26	46	47.8	68.8
Combined (MPG)	36		58.5	
Total CO ₂ (g/km)	183		109	

10. Real Driving Emissions on an Audi A3

The NEDC CO₂ and MPG are obtained when the vehicles are type approved in the NEDC cycle, for this section the MPG used from research are those for the Audi A3.

Carbon dioxide and MPG values that are obtained under the WLTP may be higher than those that are obtained under the NEDC cycle. There is still anticipation that the taxation and the registration of the fleet emissions will remain on the NEDC values till 2020/2021 (volkswagen, n.d.). This is due to the lack of testing of the new drive cycle to present accurate values to go by. By keeping to the NEDC values there won't be an influx in vehicles exceeding the CO₂ limit. In line with the Government guidance the NEDC figures will still be stated even for type approved WLTP (volkswagen, n.d.).

Due to this literature, the RDE carried out on the Audi A3 will be compared to the NEDC legislations that were in place for Euro 3.

10.1 On-board Diagnostics, OBD

OBD refers to a vehicles self-diagnosing and reporting capability, it was first introduced in the 1980's. OBD systems give the vehicle owner or repair technician access to the status of various subsystems within the ECU. Modern systems now use standardized digital communications point to provide real time data in addition to standardized series of diagnostic trouble codes, these allow rapid identification and remedy malfunctions (ARB, 2015).

OBD has had many improvements and different adjustments. OBD2 is an improvement in both capability and standardization on the first generation, OBD1. The OBD2 standard specifies the type of connector and pins for the connection, electrical signalling protocols available and messaging format (ARB, 2015).

To retrieve real-live testing data for this report, an XTRONS ELM327 OBD2 Car Bluetooth Scanner was purchased. The connector was connected to a port underneath the steering wheel. There is a pin in the connector that provides power for the scan tool from the vehicle battery, which eliminates a separate power source. The OBD2 provides a list of standardized diagnostic trouble codes, a single device can query the on-board computers for these parameters in any vehicle.

Standardization was prompted to simplify diagnosis of an increasingly complicated emissions equipment, most manufacturers have made the OBD2 data link connector the main connector in the vehicle through which all systems are diagnosed and reprogrammed (EuropeanCommunities, 1998). OBD2 is the common definition for the system, however there is an EOBD system that is used for the European OBD. The EOBD applies to all passenger cars of category M1, the Audi falling into this category (V5C, 2017), those which are first registered within the EU member states since January 2001 for petrol cars.



Figure 15 XTRONS OBD2 Bluetooth Scanner

Literature from The European Parliament and of the Council stated in 1998 that new provisions for the OBD should be introduced with a view of permitting an intermediate detection of failure of anti-pollution vehicle equipment and thus allowing a significant upgrading of the maintenance of initial emissions performance from 2001-2005. The paper also stated that OBD systems offer unrestricted and standardized access: information must be provided for diagnosis by suppliers of vehicle parts and repairs, to not create any disadvantage throughout the industry. (EuropeanCommunities, 1998)

10.2 OBD Data Available

OBD2 provides access to data from the ECU and offers a valuable source of information for trouble shooting. Certain manufacturers will allows access to their specified information.

Table 14 Variables Chosen for the RDE Cycle

Variables Chosen for the RDE Cycle	
GPS Time	Intake Air Temperature (°C)
Device Time	Intake Manifold Pressure (psi)
Longitude	Mass Air Flow Rate (g/s)
Latitude	Miles Per Gallon (Long Term Average)(mpg)
GPS Speed (Meters/second)	Relative Throttle Position (%)
Altitude (m)	Speed (GPS)(mph)
Air Fuel Ratio (Measured)(:1)	Throttle Position (Manifold)(%)
Engine Coolant Temperature (°C)	Timing Advance (°)
Engine kW (At the wheels)(kW)	Torque (Nm)
Engine Load (%)	Trip average MPG (mpg)
Engine RPM (rpm)	Trip Distance (miles)
Fuel flow rate/minute (cc/min)	Trip distance (stored in vehicle profile)(miles)
Fuel used (trip)(l)	Trip Time (Since journey start)(s)
Horsepower (At the wheels)(hp)	Voltage (OBD Adapter)(V)

10.3 Specification Sheet

The specification sheet was created by the author before using the OBD2 adapter so the data that would be recorded was unknown. To the authors advantage a lot of variables were recorded which made the collation of data easier. The variables that endorsed the report were device time, date, and longitude/latitude position of every trip.

Creating specification sheets allows the user to record and document the trips accordingly, ambient pressure could not be recorded due to lack of equipment however the temperature used in this report was always taken from the vehicles own reading on the dashboard. The importance to record fuelling ensures the weight of the vehicle and to clarify that the fuel usage in response to those recorded from OBD2.

Real Driving Emissions Specification Sheet



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

Vehicle Data		Measured Values		Miscellaneous	
Manufacturer		Fuel In		Pressure	
Model		Fuel Out		Temperature	
Engine Size		Mileage Before		Max Power	
Tyre Size		Mileage After		Max Torque	
Vehicle Weight		Start Location		Max Power Calc.	
Length		End Location		Max Torque Calc.	
Height		Tyre Pressure F		Added Weight	
Width		Tyre Pressure R			
Fuel Tank Cap		Test Data		Cold Start	
Drag Co-Eff		Vehicle Class		Warm Start	
Frontal Area		Vehicle Legislation		Wet	
CdA		Year		Dry	
Bore		Gearing Ratio		CatConverter	
Stroke		First			
Compression Ratio		Second			
Carbon Dioxide Em		Third			
Fuel Consump..		Fourth			
Engine Type NA/T		Fifth			
Final Drive		Sixth			

Notes:

Date:
Time:
Name:

Figure 16 RDE Specification Sheet

10.4 Steps to the RDE Cycles

10.4.1 Coast Down Test

The vehicle start speed was recorded to be 60mph, the engine was disconnected from the wheels with the clutch engaged. The vehicle slowed down to a stop gradually over 119 seconds over a distance of 1475m. The reason for carrying out this test was to calculate the resistive forces acting on the vehicle, the vehicle will slow down if these forces are greater than the vehicles forward motion.

These are showing in Figure 17.

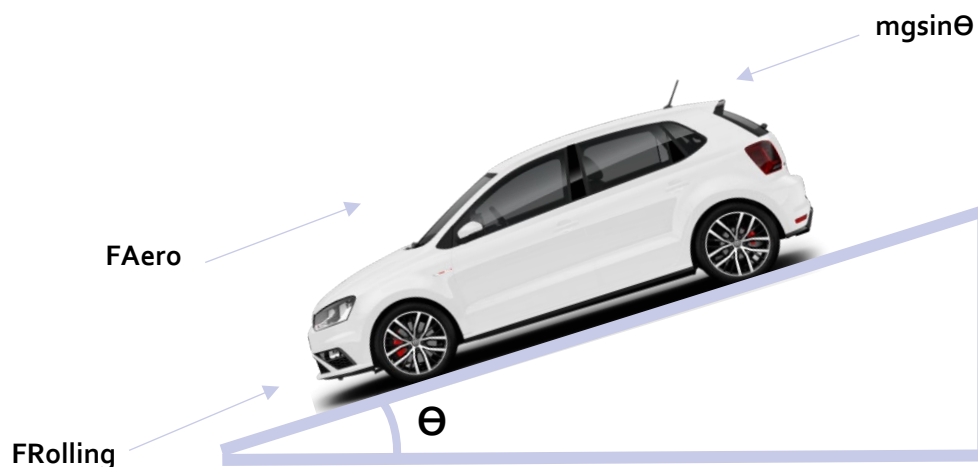


Figure 17 Resistance to Motion Test Annotation with an Angle

10.4.1.1 Aerodynamic Force/Drag

When the vehicle is travelling through the air, there is a resistance due to the molecules of air colliding with the vehicle. If the air is denser, the resistance is greater, and if the air is lighter, the resistance is lessened (Sengerandu, 2013).

10.4.1.2 Rolling Force

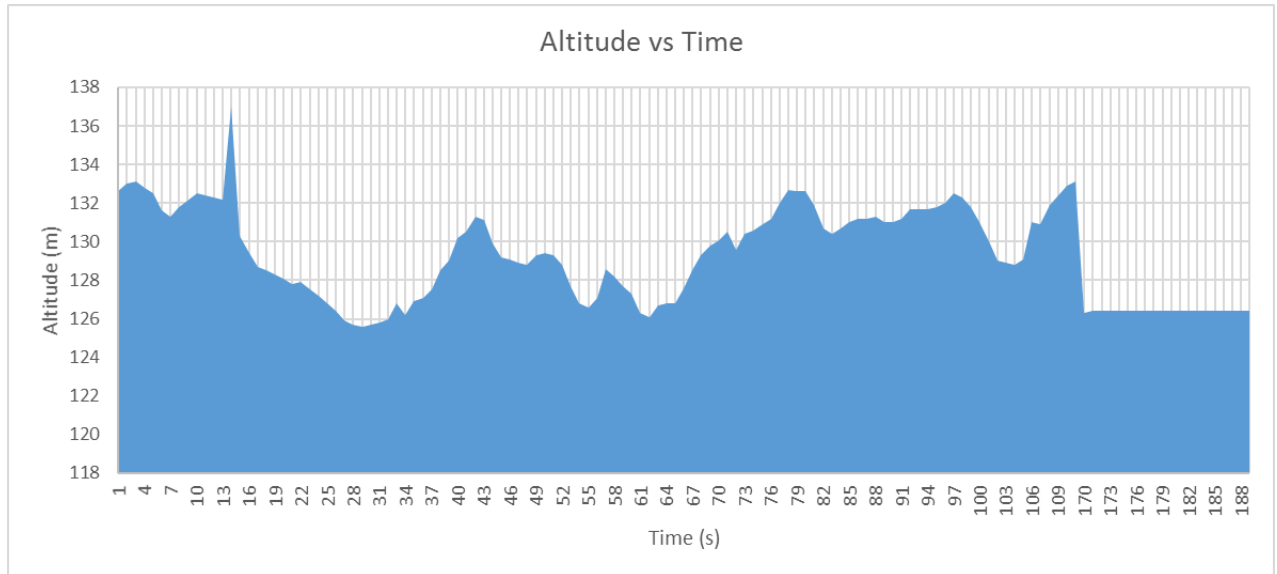
When the vehicle is in motion, and the tyres are rolling over the contact surface, the relative motion of the two surfaces produces friction. For this coast down it is assumed that the tyre is a constant radius and a very small patch of tyre, therefore no energy loss will be generated by slip (Sengerandu, 2013).

“For the coast down test will be assumed a road not too bumpy” (Preda, et al., n.d)

Literature states that to complete the test effectively the road cannot be too bumpy. 10.4.1.3 Altitude explains how this proved to be true. Calculations used to find the values of these are presented in 10.4.1.4 Drag Co-Efficient and 10.4.1.5 Rolling Resistance.

10.4.1.3 Altitude

The altitude is measured by using the phones own GPS and the units are in m. Initially it was thought that the vehicle was either going up or downhill. Graph 14 is showing the altitude changes over 1475 metres. When conducting the calculations over this time frame there were inaccuracies. Figure 18 is presenting the incorrect data for the overall altitude throughout the journey.



Graph 14 Altitude vs Time for Coast Down

Average Rolling Resistance											
362.3788185											
μ											
0.030655384											
Average pcda											
0.310206731											

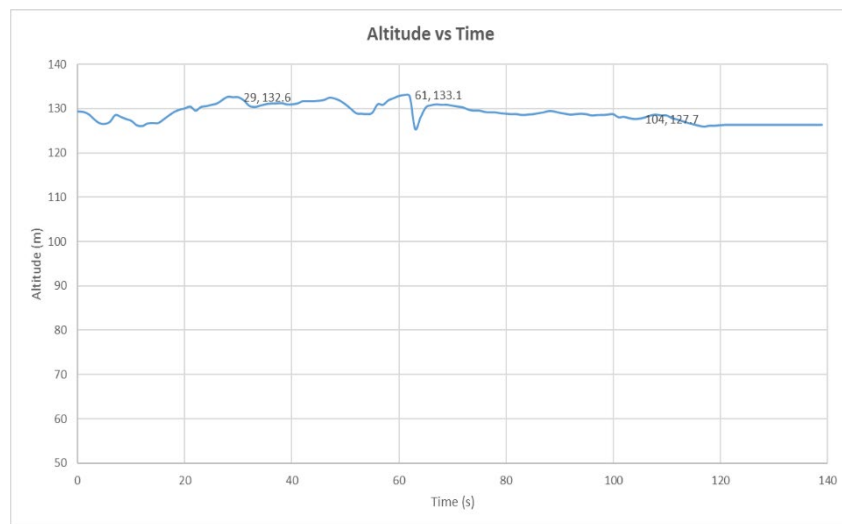
Altitude Difference	SinTheta	Radians	(ABS) of Angle	Change In Angle	Degrees	Speed (Polynomial)	Acceleration		Rolling Resistance	dacc/dt	pcda	FAERO
0.5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0	#VALUE!	0	0	0	0	0
0.1	0.00374055	0.00374056	0.003740559	#DIV/0!	0.214318262	26.7340321	26.7340321	321.618813	32536.12753	27.021654	45.55856586	13.51083
-0.1	-0.00378123	-0.00378124	-0.003781241	4.06812E-05	-0.21664912	26.4464103	-0.28761187	314.735677	-31.84868117	0.002701658	-0.427985204	-0.12421
-0.5	-0.01911501	-0.01911717	-0.019117174	0.018335933	-1.09533338	26.1560867	-0.29032353	307.863393	-41.97646313	0.002368464	-0.375836418	-0.10669
-1.1	-0.04253115	-0.04254399	-0.042543986	0.023426812	-2.43759084	25.8633947	-0.292692	301.011834	-51.68202109	0.002048491	-0.326080478	-0.09051
-0.9	-0.03519935	-0.03520662	-0.035206622	-0.00737364	-2.01719087	25.5686542	-0.29474049	294.1902136	-60.97205335	0.00174148	-0.278456868	-0.07554
-0.2	-0.00791384	-0.00791393	-0.007913925	-0.027292697	-0.45343453	25.2721723	-0.29648197	287.407211	-69.85355978	0.001474714	-0.232737785	-0.06168
0.5	0.02002053	0.02002196	0.020021954	0.012108039	1.147174061	24.9742431	-0.29792914	280.670769	-78.33384639	0.001165317	-0.188723395	-0.04884
1.5	0.06078991	0.06082741	0.06082741	0.040805446	3.48515389	24.6751487	-0.29909446	273.988333	-86.42048923	0.000895656	-0.146237921	-0.03695
-0.4	-0.01641015	-0.01641089	-0.016410886	-0.044416524	-0.94007522	24.3751586	-0.29999011	267.36676	-94.12132763	0.000637939	-0.1051264	-0.02592
-0.5	-0.02076884	-0.02077033	-0.02077033	0.004359444	-1.19005327	24.0745305	-0.30061805	260.812359	-104.1444453	0.000391917	-0.065251983	-0.01569
-0.4	-0.01681545	-0.01681624	-0.016816243	-0.0039444087	-0.96407273	23.7735105	-0.30101997	254.330911	-108.3981222	0.000157242	-0.026493669	-0.00621
-1	-0.04260335	-0.04261635	-0.042616247	0.025790004	-2.4417311	23.473332	-0.30117731	247.927692	-114.9909681	-6.60328E-05	0.011355586	0.002573
-0.2	-0.0086314	-0.0086315	-0.008631504	-0.033984744	-0.49454872	23.172239	-0.30111118	241.607487	-121.2316039	-0.00027845	0.048090476	0.001714
0.6	0.02623148	0.02623781	0.026237807	0.017606303	1.503315585	22.8703891	-0.30083183	235.374614	-127.1189437	-0.000480154	0.084094694	0.018152
0.1	0.00443065	0.00443067	0.004430668	-0.021807139	0.253858549	22.570034	-0.300351267	229.212945	-132.6920274	-0.000671383	0.119342078	0.025226
0	0	0	0	-0.004430668	0	22.2703552	-0.29968129	223.185923	-137.9300329	-0.000852377	0.153897587	0.031672
0.8	0.03641076	0.03641881	0.036418811	0.036418811	2.086644191	21.9715262	-0.29881891	217.236584	-141.8121258	-0.001023371	0.187818128	0.037612
0.9	0.04152494	0.04153689	0.041536885	0.005118074	2.379888218	21.6737207	-0.29780554	211.387576	-147.4681038	-0.001184602	0.221153266	0.043107
0.8	0.03742322	0.03743197	0.037431965	-0.00410492	2.144693616	21.3770998	-0.29661094	205.641177	-151.7870568	-0.001336302	0.253945619	0.048153
0.5	0.0237712	0.02371935	0.023719347	-0.013712618	1.359018473	21.081811	-0.29518464	199.999318	-155.8186723	-0.001478702	0.28623279	0.051786
0.3	0.0144314	0.0144319	0.014431897	-0.00928745	0.826886808	20.7880092	-0.29380594	194.463596	-159.5775581	-0.001612031	0.318043752	0.057029
-0.3	-0.01951618	-0.01951742	-0.019517418	0.005085521	1.118265686	20.4958153	-0.29219391	189.0353	-163.0583581	-0.00173516	0.349405328	0.060904
-0.9	-0.04454264	-0.04455738	-0.044557383	0.02039965	-2.55295	20.2053579	-0.29045739	183.715419	-166.2857366	-0.001852384	0.380337405	0.06443
0.8	0.04016719	0.0401978	0.040197999	-0.004379384	2.302029772	19.9167529	-0.28865011	178.50467	-169.264353	-0.001959857	0.410855464	0.067615
0.2	0.01018843	0.01018961	0.010189607	-0.029989392	0.583764202	19.6301077	-0.28664515	173.403508	-172.0093973	-0.002059158	0.440970402	0.070508
0.3	0.01507746	0.0150809	0.01508087	0.005319479	0.888547908	19.3455217	-0.28458599	168.412145	-174.513375	-0.002150506	0.470688733	0.073093
0.3	0.01577322	0.01577371	0.01577371	0.000229784	0.901713563	19.0630862	-0.28243549	163.530566	-176.8044942	-0.00223412	0.50001276	0.075396
0.8	0.04259197	0.04260485	0.042604854	0.026866984	2.441078341	18.788849	-0.2802037	158.758544	-178.8844101	-0.002310216	0.528940724	0.077421
0.7	0.03781753	0.03783665	0.037836654	-0.0047682	2.167980599	18.5049937	-0.27789115	154.095557	-180.7531786	-0.002379007	0.557466932	0.07911
-0.1	-0.00548862	-0.005488647	-0.005488647	-0.032351007	-0.314304423	18.2294899	-0.27591243	149.541298	-182.4508325	-0.002440707	0.585881871	0.08074567
0	0	0	0	-0.005488647	0	17.95641015	-0.273071436	145.0946995	-183.9563806	0.002440707	-0.599800699	-0.080247
-0.7	-0.039578639	-0.039595004	-0.039595004	0.039595004	-2.26834223	17.68503424	-0.27057591	140.7548298	-185.2890415	0.002495626	-0.628397523	-0.0819584
-1.2	-0.06889503	-0.06894964	-0.068949649	0.029359609	-3.9505239	17.4178802	-0.26803214	135.520922	-186.4579235	0.002543673	-0.656550171	-0.08285

Figure 18 Altitude Anomalies

The altitude difference was a simple calculation of subtracting the second altitude value by the first. However, the altitude difference values were jumping from negative to positives, this is because of slight bumps in the road, making it difficult to achieve the change in angle every second.

Referring to the earlier statement made of road surface affecting coast down test (Preda, et al., n.d) the data was then cut down to approximately 20seconds.

Graph 15 is evidence of the slightly uneven surface, however the change in altitude was taken from two data points, 29 – 61. The calculations have been discussed further into the report.



Graph 15 Altitude vs Time

10.4.1.4 Drag Co-Efficient

The following equations were used to find the values for co-efficient of drag and the rolling resistance.

$$F_{Rolling} = \mu \times M \times G$$

Equation 29 Rolling Resistance

$$F_{Aero} = \frac{1}{2} \times \rho \times C_D \times F_{Area} \times V^2$$

Equation 30 Aero Force

$$F_{Wheel} - F_{Aero} - R_{RESISTANCE} + M \times \sin\theta = M \times Acceleration$$

$$F_{Aero} + R_{RESISTANCE} - M \times g \times \sin\theta = M \times Deceleration$$

On the coast down test due to the clutch being disengaged, the wheel force becomes o.

$$\rho C_D F_{Area} (Av) = \mathbf{0.88}$$

Equation 31 $\rho C_D F_{Area}$

As the air density value is stated to be **1.2Kg/m²** and the frontal area is **2m²** the equation can be rearranged to find the drag co-efficient.

$$C_D(Av) = \frac{\rho C_D F_{Area}}{\rho}$$

$$C_D A(Av) = \frac{0.88}{1.2} = \mathbf{0.73}$$

Equation 32 $C_D(Av)$

$$C_D = \frac{C_D A}{A}$$

$$C_D = \frac{0.73}{2} = \mathbf{0.365}$$

Equation 33 C_D

												Average Rolling Resistance			
												-188 1260686			
												II		Average pcda	
												-0.015914497		-0.883792823	

10.4.1.5 Rolling Resistance

Tyre rolling resistance can be defined as the force required to maintain the forward movement of a loaded tyre in a straight line. The tyre losses can be from, friction or scrubbing between tyre and road way, aerodynamic drag of wheels and losses of tyres due to constant cyclic stresses. Friction or scrubbing losses occur due to slippage at the tyre to road, due to tangential forces and difference in the radius of the tyre and the contact to the surface (Varghese, 2013).

$$R_{RESISTANCE} (N) = \mu \times V_{Mass} \times g = V_{Mass} \times Deceleration - F_{Aero}$$

Equation 34 Rolling Resistance

As the vehicle was slowing down, the acceleration turns into deceleration.

10.4.4.6 Rolling Resistance Co-Efficient

The rolling resistance co-efficient is a dimensionless value that is considered to be constant or proportional to engine

$$R_{RESISTANCE}(Av) = 188N$$

$$\mu = \frac{R_{RESISTANCE}(Av)(N)}{V_{Mass} (kg) \times g}$$

$$\mu = \frac{188}{1205 \times 9.81} = \mathbf{0.015914497}$$

Equation 35 Rolling Resistance Co-Efficient

From literature (Bosch, 2014) states that the standard rolling resistance co-efficient is 0.012, an increase in rolling resistance can increase fuel temperature. However, if the rolling resistance was to go the opposite affect towards 0.006 then the tyres will have no grip and be dangerous for car users.

The efficiency of a tyre can improve fuel consumption by 7% for motorway type driving and 4% for urban style driving. A 10% reduction in rolling resistance can improve fuel economy by 4%, larger tyres have higher rolling resistance forces but a lower rolling resistance co-efficient as the load is higher requiring more effort to turn due to physics. The reason can be down to the tyre tread bending and stretching and can recover simply (Varghese, 2013). The rolling resistance of a vehicle is also dependent on the temperature of the surroundings such as the ambient air temperature and the contact surface (Ejsmont, 2017).

Rolling resistance of tyres from NEDC conditions can account for 20-25% of the total vehicle energy loss, 5-30% reduction in rolling resistance can lead to 13.5% improvements to fuel consumption. Due to the energy inefficiency tyres can have on a vehicle, the NEDC have classes for rolling resistance ranging from A-G. Vehicles tested on the NEDC dynamometer can have different tyres on than those sold for customers (Fontaras, et al., 2016). This variation in the rolling resistance co-efficient can reach up to 90%, increasing fuel consumption by 7.5%.

The WLTP is now introducing that the tests will be conducted with a tyre in class A and class G, to then advertise fuel efficiency with no discrepancy (Fontaras, et al., 2016).

10.4.2 Wheel Rolling Radius

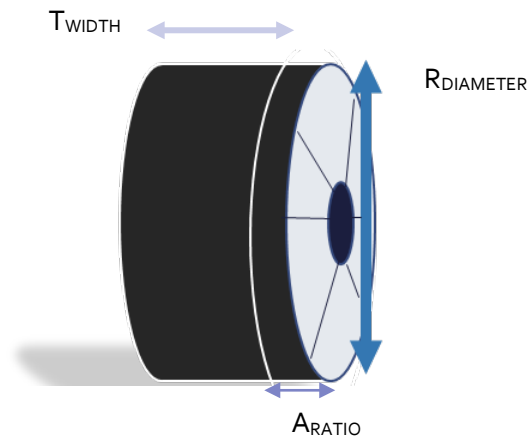


Figure 20 Wheel Dimensions

The values for the Audi A3 tyre dimensions were retrieved physically from the author's vehicle. Equations from (Shibashis Ghosh, 2012) were used to find the correct rolling radius for the RDE project vehicle.

Table 15 Nomenclature Used for Tyre Dimensions

Nomenclature	Definition	Values
$R_{DIAMETERCODE}$	Rim Diameter (Inches)	17
T_{WIDTH}	Tyre Width (mm)	225
A_{RATIO}	Aspect Ratio (%)	45
	Inches to mm conversion	25.4

$$D = A_{RATIO} \times T_{WIDTH}$$

$$D_{HEIGHT} = 0.45 \times 225 = \mathbf{101.5mm}$$

Equation 36 Depth Height of the Tyres

$$R_{OUTRADIUS} = \frac{(17 \times 25.4)}{2} = \mathbf{215.9mm}$$

Equation 37 Rim Outer Radius

$$Wheel_{RR} = R_{OUTRADIUS} + \left(\frac{A_{RATIO} \times T_{WIDTH}}{1000} \right)$$

$$Wheel_{RR} = 215.9 + \left(\frac{0.45 \times 225}{1000} \right) = \mathbf{0.31715m}$$

Equation 38 Wheel Rolling Radius for Audi

11. RDE Cycles Conducted

This section will explain the cycles completed to gain data for the RDE section of this report.

Table 16 Audi A3 MPG and Fuel Consumption Data (ultimatespecs, n.d)

Fuel Consumption - Economy - Combined:	7 L/100km	40 mpg UK
Fuel Consumption - Economy - Extra Urban:	5.5 L/100km	51 mpg UK
Fuel Consumption - Economy - City:	9.6 L/100km	29 mpg UK

11.3.1 Briton Ferry

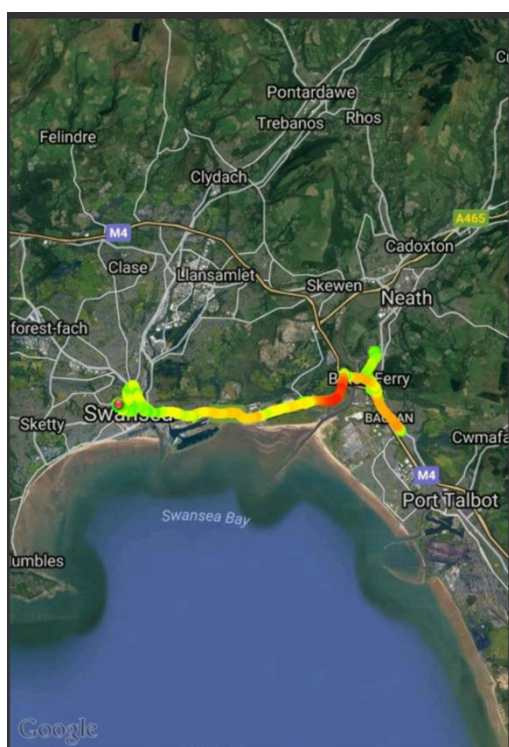


Table 17 Briton Ferry Drive Cycle

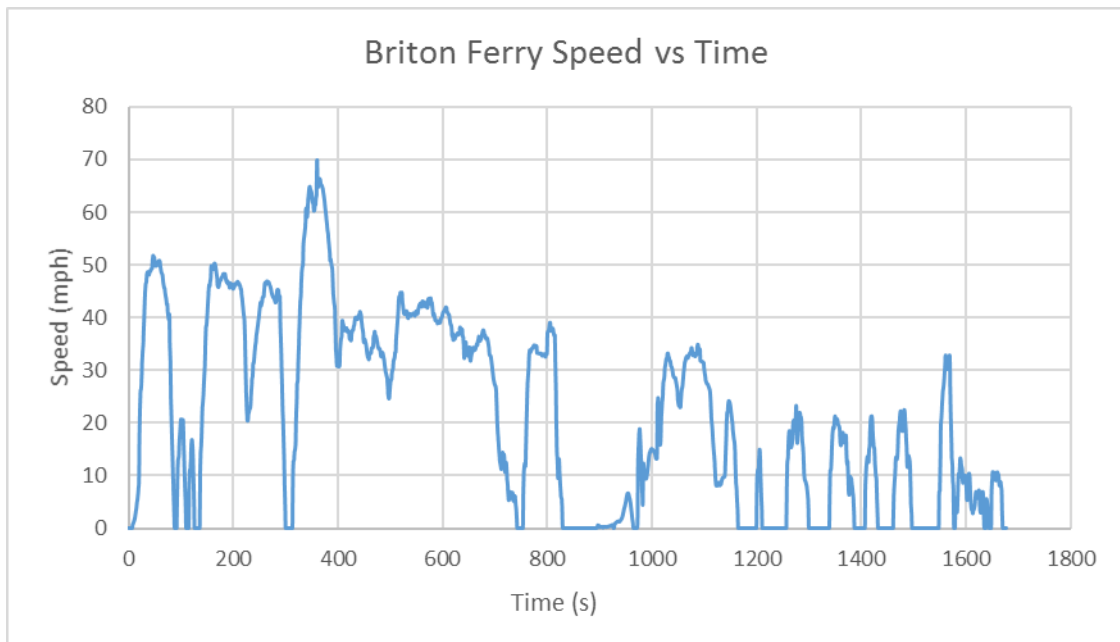
Measurements	Values	Units
Total Distance	15951.122	m
Total Distance	15.951	Km
Total Distance	9.570673101	miles
Total Fuel Used	1279.565	g
Total Fuel Used	1.706	L
Miles Per Gallon	25.494	MPG
Total CO2 Emitted	247.8732633	g/km

Figure 21 Briton Ferry Drive Cycle

Figure 21 has been taken from the Torque app used on the author's phone to record the data, for every route carried out the GPS records the location. The GPS also records the speed, then produces a photo showing the route. The definition for the colours in the picture can be found below.

Table 18 Speed Range Key for RDE

	Maximum Speed
	High Speed
	Mid Speed
	Low Speed



Graph 16 Briton Ferry Speed vs Time

This trip was the first carried out, for this report it was used as a test trip.

This section will explain the steps taken to calculate CO₂, MPG and the total fuel used for the RDE. The OBD2 adapter measures the fuel every second in cc/min this value was then converted to g/sec.

$$\text{Fuel cc/min to g/sec} = \text{Fuel Flow (cc)} \times \frac{0.75}{60}$$

Equation 39 Fuel Conversion cc/min to g/sec

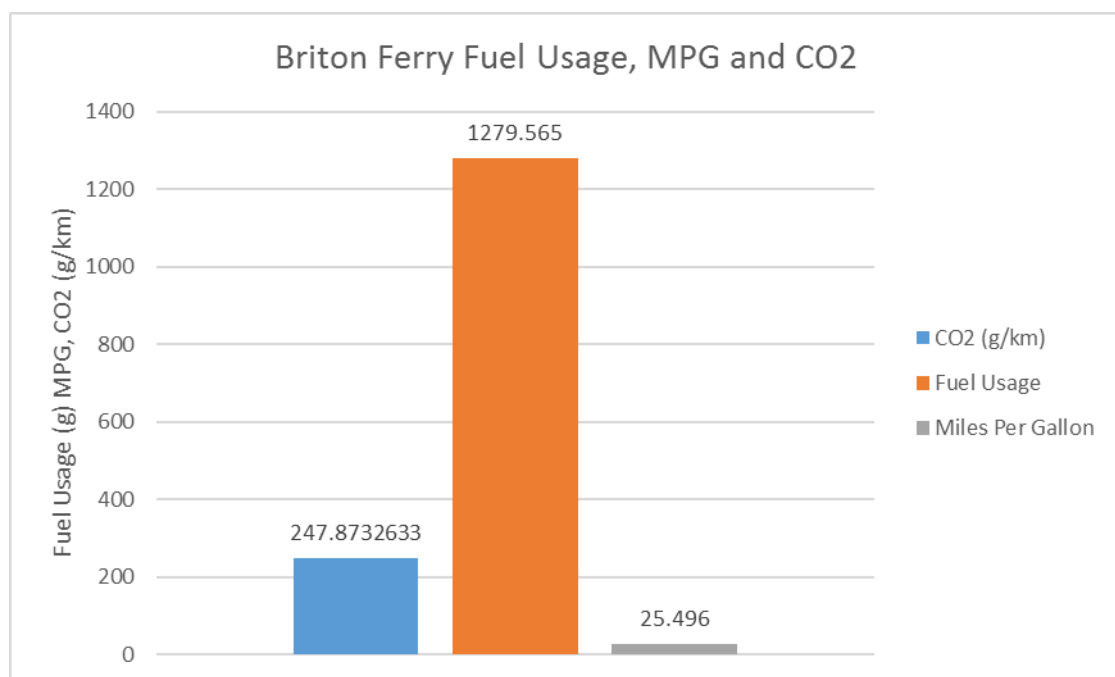
Equation 4 CO₂kg and CO₂g/km Calculations and Equation 25 MPG were used to calculate the CO₂ emissions, assuming that the Audi is operating at stoichiometric.

This test was conducted over 27 minutes, with 15km covered. The test consists of numerous stops as seen in Graph 16. The speeds range from 70mph to very low speeds through the town, with an average speed of 27mph. This cycle is a representation of urban driving and extra urban, with a likeliness to the WLTP speed profile seen in Figure 4 WLTP Graph Example (volkswagen, n.d.).

Over the 15km covered, 1279 g's of fuel was used, producing 247 g/km of CO₂ and a MPG of 25. When comparing the combined NEDC MPG, to the MPG calculated there is a 37.5% decrease of the value stated from manufacturers. It can be argued that the distance covered is longer than the NEDC, however the values advertised are not accurate.

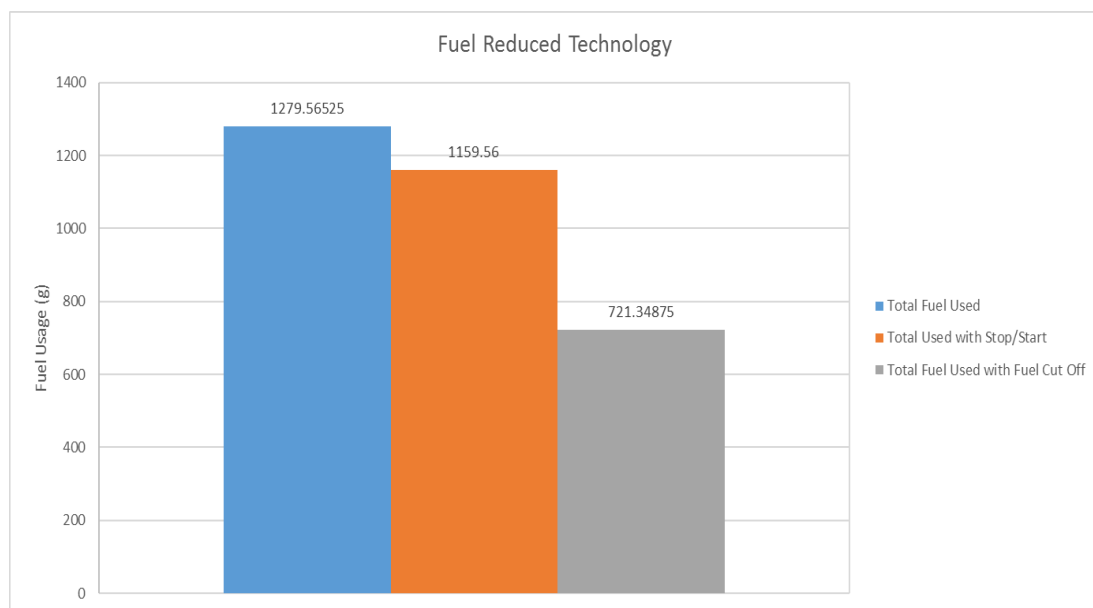
The 170g/kmCO₂ figure for the combined drive cycle has now increased by 45% in this particular cycle.

Without having values to compare % increase the only assumptions for these values is the cycle is more of a reflection to real world figures of fuel consumption and CO₂ than the NEDC. (Fontaras, et al., 2016) Stated in 2016 that there is a 30-40% increase in official values of the NEDC to the real world type approval tests. According to this statement the calculations can be proved true.

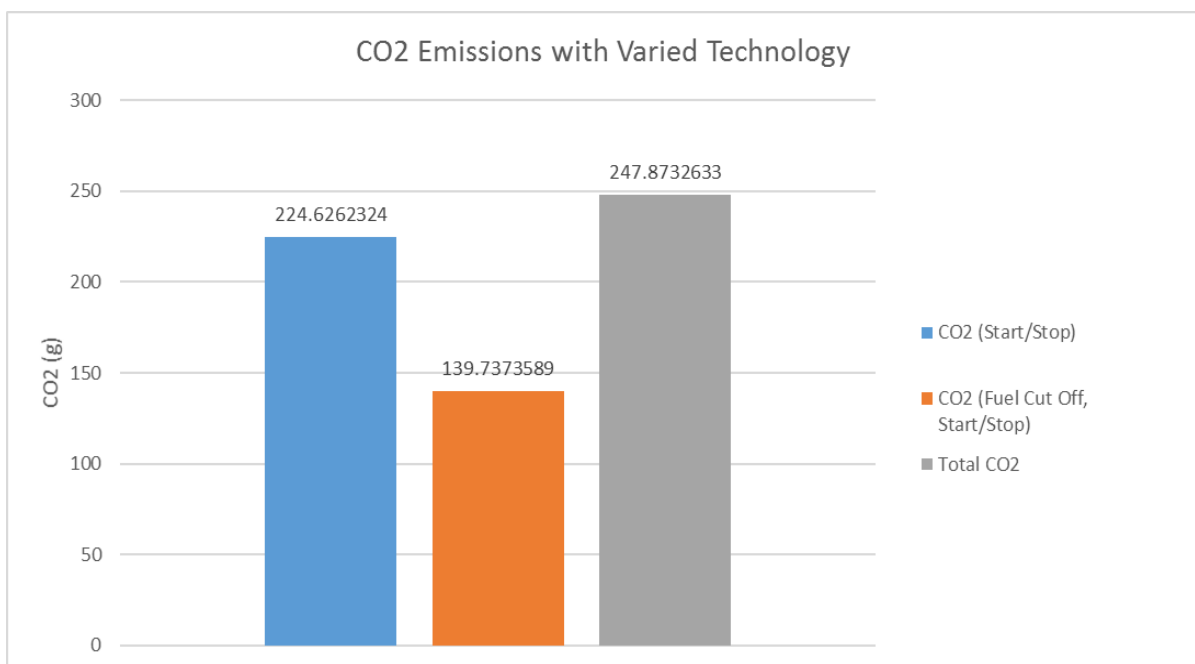


Graph 17 Briton Ferry Data

The start/stop technology values were calculated with the assumption that fuel usage is zero when the velocity is zero. The fuel cut off assumes that the acceleration is less than 0, indicating deceleration and fuel injectors are cut. With a combination of the two technologies the fuel consumption and CO₂ emissions over the whole route has been reduced by 43%. This means that the CO₂ emissions can be cut by half by using these technologies, improving the carbon footprint of automotive vehicles. It is important to mention that the vehicle is a 2003 A3 Audi, 1.6, therefore the emissions equipment on there today are nowhere near advanced as 2018. It is also relevant that the equipment may not be working to the same standard as they would have upon release due to rust, dirt from roads and wear and tear of the vehicle.

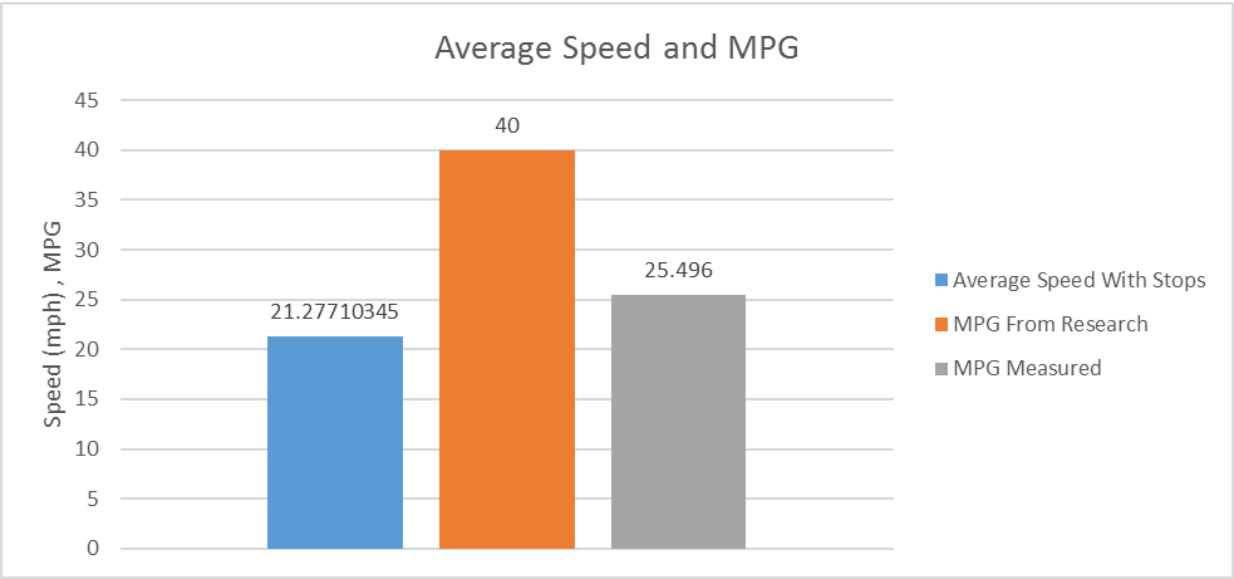


Graph 18 Briton Ferry, Fuel Technology



Graph 19 Briton Ferry CO₂ with Technology

Graph 20 is showing the difference of the two MPG with the average speed of the Briton Ferry route.



Graph 20 Average Speed, MPG

11.3.2 Motorway, M25 and M4

Table 19 Motorway Drive Cycle Data



Figure 22 Motorway Type Driving, M25,M4 19th March

Measurements	Values	Units
Total Distance	35005.764	m
Total Distance	35.006	Km
Total Distance	21.0034582	miles
Average Positive Kw coming from vehicle	8.62013699	Kw
Total Energy Used Driving	10171761.649	Joules
Average Negative Kw coming from vehicle	-1.446038516	Kw
Total Energy Used Slowing Down	1706325.449	Joules
Total Fuel Used	2081.221	g
Total Fuel Used	2.775	L
Miles Per Gallon	34.401	MPG
Total CO2 Emitted	183.7117855	g/km

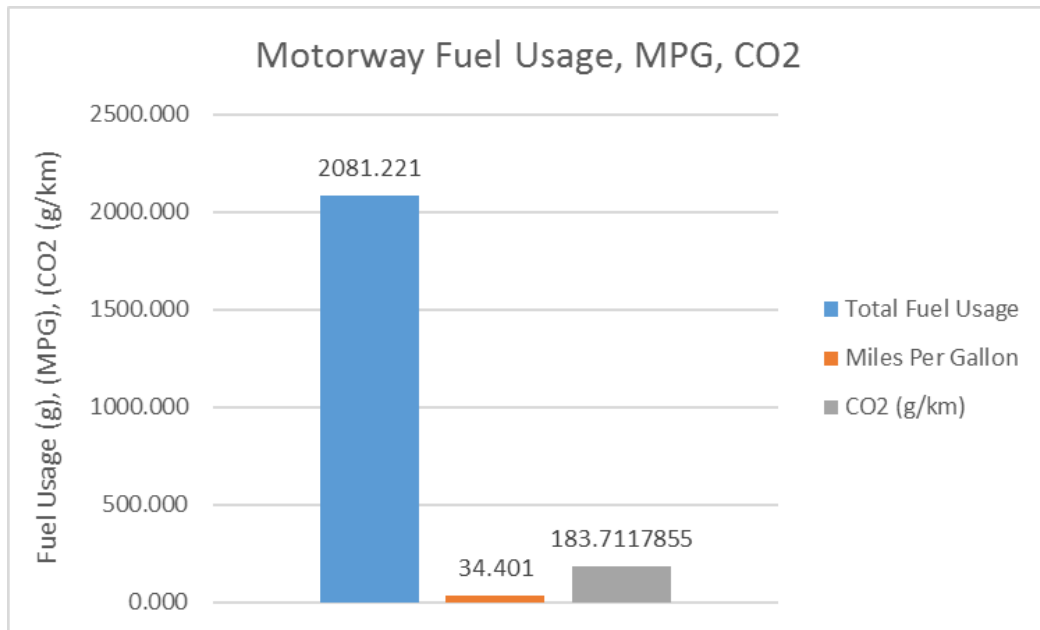
The motorway route was conducted over 35km even though the whole route was a distance of 395km, the total distance could not be used as there was traffic and variable speed limits along the route hindering the average speed and the fuel consumption.

The motorway fuel consumption calculated the MPG to be 34, to prove the accuracy of this, cross checking was carried out.

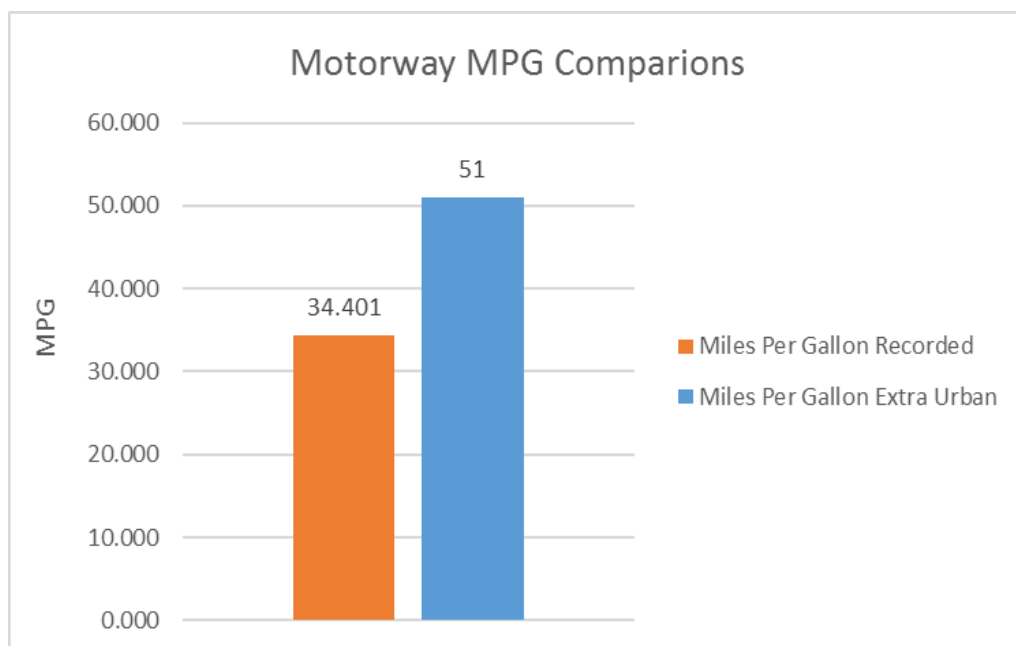
$$395 \text{ km} = 237 \text{ miles}$$

$$\frac{237 \text{ miles}}{34 \text{ MPG}} \times 4.545 = 31.7 \text{ Liters of fuel used}$$

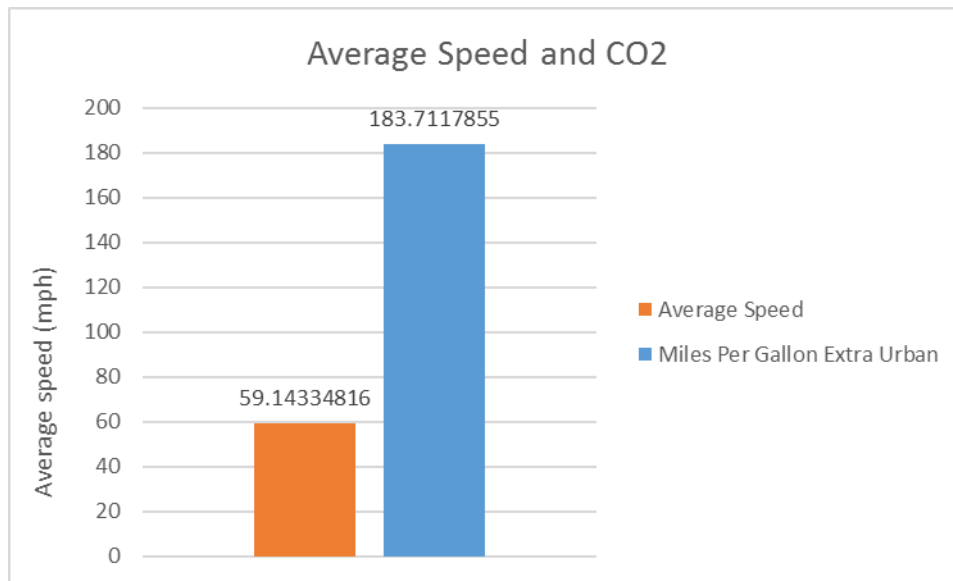
This is a very close estimate, since the journey has been completed before the author knows that the vehicle uses just over half a tank, 27.5 litres. Providing the figure to be 31.7liters, this can be seen as validation of the data.



Graph 22 Motorway Data



Graph 21 Motorway MPG Comparisons



Graph 23 Average Speed and CO₂ for Motorway

The extra-urban part of the NEDC, lasts for only 400seconds and the highest speed of 120km/hr only lasts for 80's. Comparing the MPG found from the motorway with the NEDC values is impracticable as one speed is not measured for a constant times.

The overall CO₂ value is lower because when on the motorway there are no inefficiency gear changing which means inefficient engine speeds. With inefficient engine speeds the fuel may not burn fully, therefore not providing as much power. Whereas on the motorway an engine can work at its optimum at a constant speed, with the perfect volumetric efficiency of the intake and the throttle opening, which in turn creates cleaner combustion if the temperature isn't too hot.

11.3.3 Mumbles

The first Mumbles Cycle was carried out on the 7th of March, also referred to as *MC1*. This route was chosen to represent an urban type drive test, with speeds varying from 10-40mph. The test was carried out again on the 12th of March, named as *MC2*, the time chosen was during “rush hour” for Swansea, Wales, therefore the test has shown the fuel consumption and CO₂ for a city at its busiest time.

The calculations that have carried out in this section are: Acceleration, Wheel Force, CO₂, MPG, Vehicle Energy and an estimate of fuel usage when using fuel saving strategies such as Stop and Start and Fuel Cut off Technologies. These technologies have been explained further into the appendices in section

This section has been split into 2 separate parts, and then an analysis will be completed at the end of the results.

11.3.3.1 MC1 Data

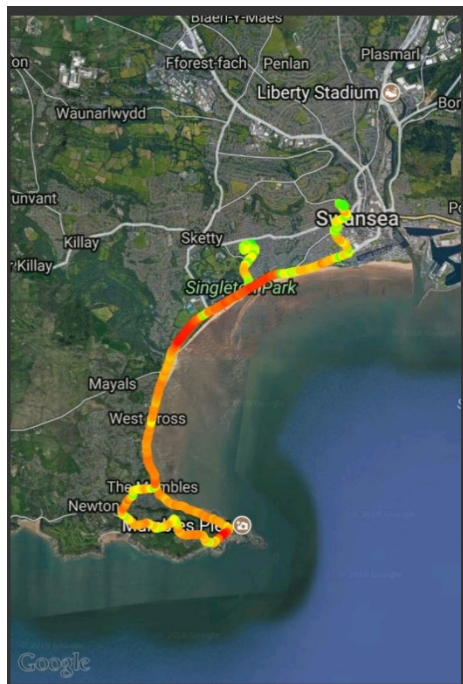


Figure 23 Urban Type Driving Mumbles 7th March

Table 20 7th March Mumbles Data

Measurements	Values	Units
Total Distance	19000.066	m
Total Distance	19.000	Km
Total Distance	11.400	miles
Average Positive Kw coming from vehicle	0.88746281	Kw
Total Energy Used Driving	1047206.116	Joules
Average Negative Kw coming from vehicle	-1.646088976	Kw
Total Energy Used Slowing Down	1942384.991	Joules
Total Fuel Used	1564.754	g
Total Fuel Used	2.086	L
Miles Per Gallon	24.834	MPG
CO2	254.4775711	g/km

10.3.3.2 MC2 Data

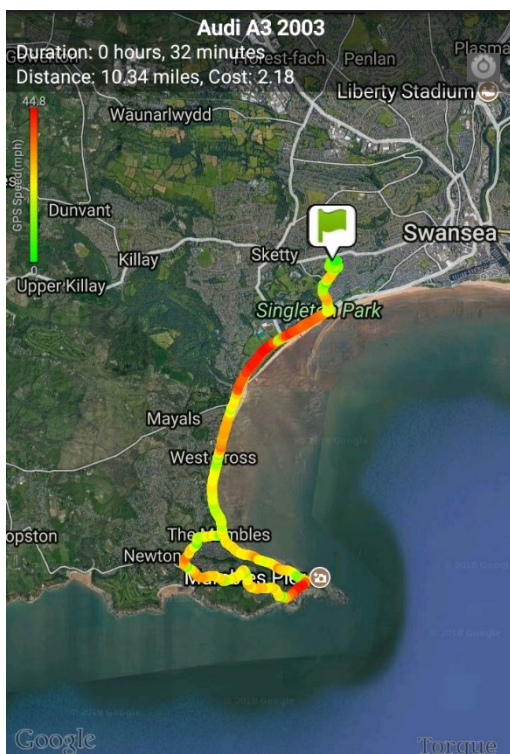


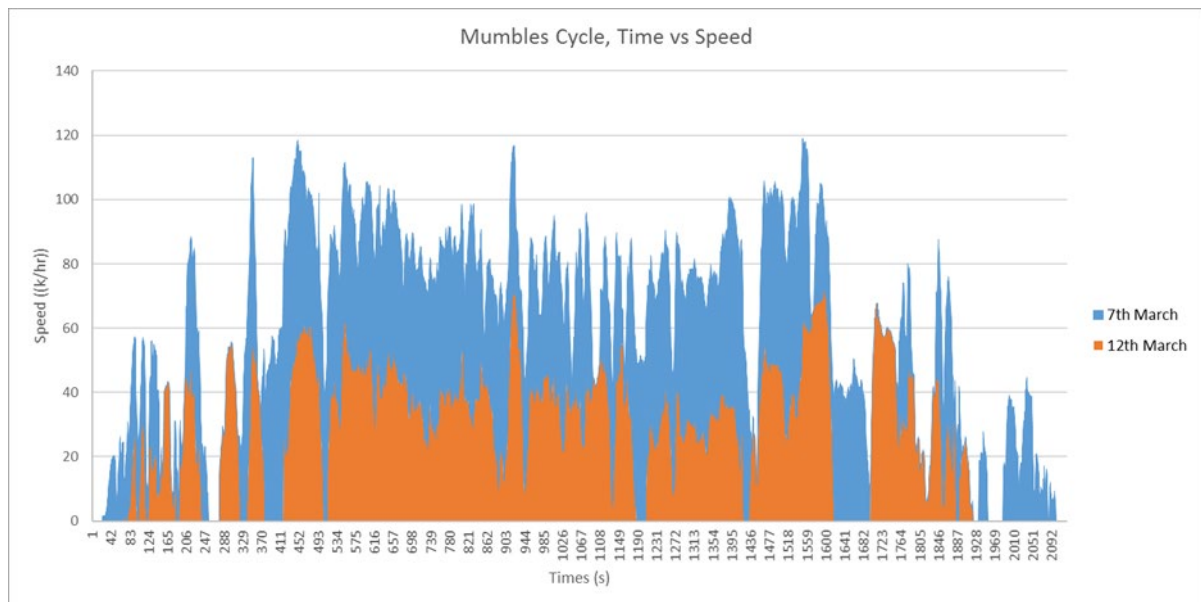
Figure 24 Mumbles 12th Drive Cycle

Table 21 Mumbles 12th Values

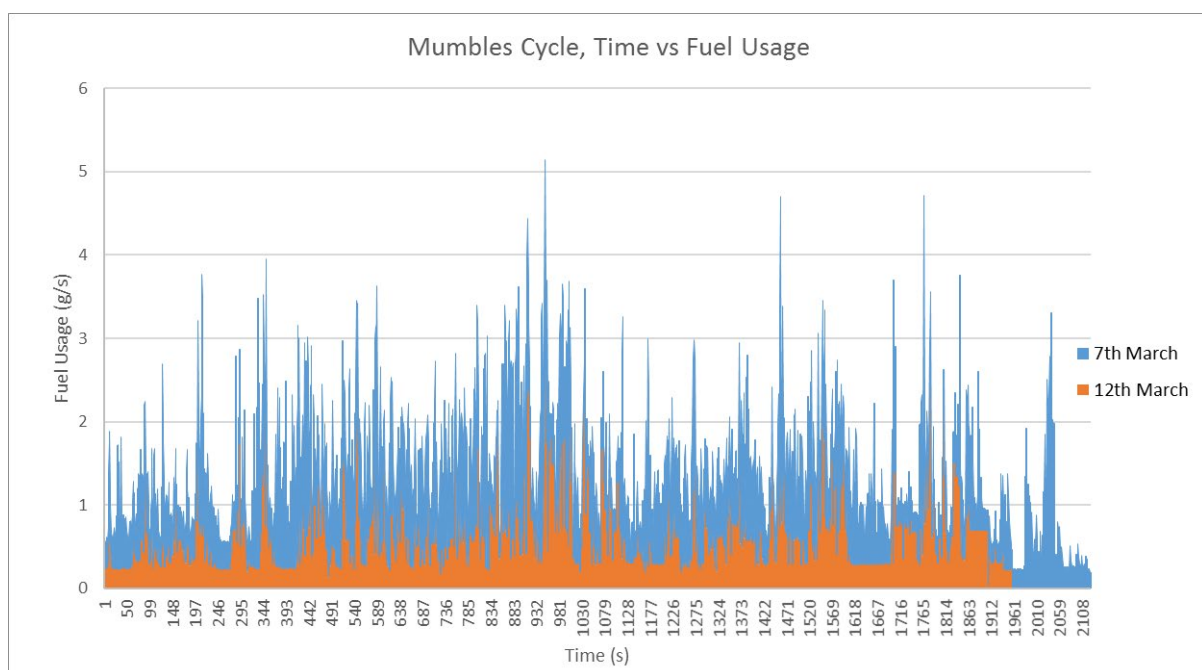
Measurements	Values	Units
Total Distance	16547.597	m
Total Distance	16.548	Km
Total Distance	9.929	miles
Average Positive Kw coming from vehicle	0.88056484	Kw
Total Energy Used Driving	1039066.512	Joules
Average Negative Kw coming from vehicle	-2.055009904	Kw
Total Energy Used Slowing Down	2424911.687	Joules
Total Fuel Used	1395.841	g
Total Fuel Used	1.861	L
Miles Per Gallon	24.246	MPG
CO2	260.65	g/km

11.4 Comparison of Both Trips

Graph 24 and Graph 25 can show that the lower the average speed on this trip, the lower the fuel consumption. The MC2 had an average speed with stops of 18mph and 22 mph without stops. The MC1 however had an average speed of 19mph with stops and 24mph without stops. Even though 2mph slower, the MC2 produced less fuel.

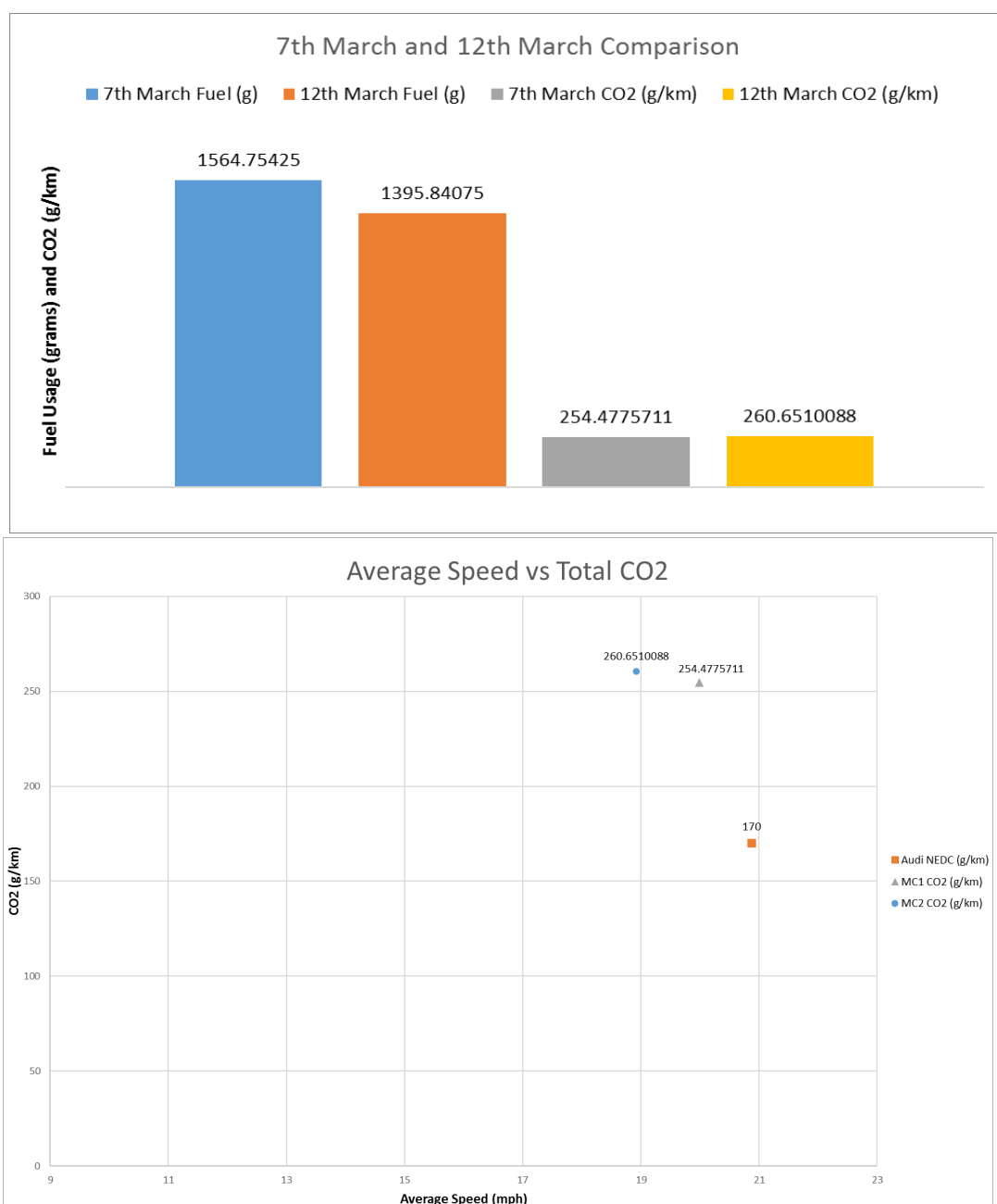


Graph 24 Speed Comparison



Graph 25 Fuel Usage and Time Comparison

The total fuel for the MC1 is 1564kg and MC2 1385g, when using the CO₂ calculations, Equation 4 the general trend would be the higher the fuel the higher the CO₂. However these calculations are a function of distance. The MC1 duration was 19km and the MC2 test was 16km. With a lower distance and lower fuel consumption further calculations were carried out. An IF statement was made to see which cycle was under 10mph the longest, indicating congestion. The MC1 test had a duration of 958 seconds and the MC2 was 1059 seconds, indicating that the MC2 was influenced a lot by other road users. The author can also state that the driving was influenced by a slow moving bus and other car users. The following two sections explain in detail the reason for the increase in CO₂. Graph 35 further into the document is presenting that carrying out the same route in congestion the fuel consumption will increase by 2%.



Graph 27 Average Speed over Mumbles Drive Cycles

11.4.1 Driver and Style

Drivers differ from one person to the next, whether they are heavy on the throttle, using higher rpm's or late braking. All of which will have an impact on fuel consumption. The more aggressive a drive is on the throttle, the higher the acceleration speeds and the deceleration for braking, as well as higher RPM operations.

The laws of physics state that to get a vehicle moving, it requires more effort than to keep it rolling. A driver harsher on the brake during traffic, due to restlessness, by braking sharply and accelerating fast, means the vehicle is having to use more power to accelerate the vehicle from standstill (Pyefinch, 2015).

Drivers will also use different gears during congestion, some drivers will remain in 1st while others will get the most out of 2nd gear, and gears are in place to make sure that the engine is operating efficiently at that part of rpm range of the vehicle.

When in traffic the throttle position is partly closed, and as mentioned before, throttle opening is highly reliable to fuel consumption and the applicable load.

11.4.2. Congestion and Traffic Calming Solutions

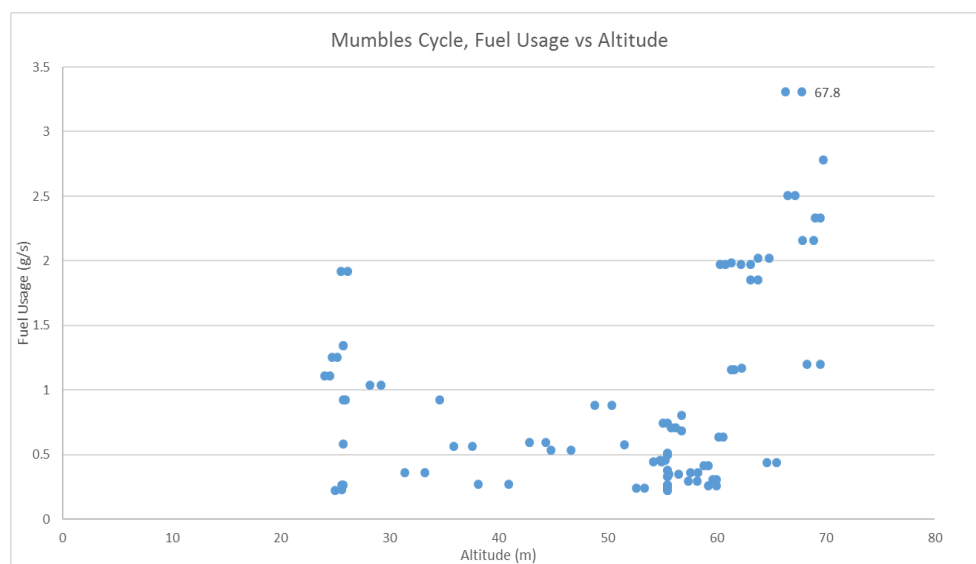
The time of both tests differ hugely, one test was conducted at 7:09am with minimal traffic, however the second was carried out at 17:00pm during rush hours.

Congestion has an influence on consumption due to frequent start and stop and acceleration in urban situations. Increased traffic affects the speed profile of each trip and influences how drivers handle the car. Increased traffic, means increase in CO₂ this may be severe under low speed urban driving conditions in heavy traffic.

Idle fuel consumption is such a large part of our city fuel consumption that car makers developed the start/stop procedure which stops the car engine, therefore the fuel usage when stopped or decelerating for fuel usage.

11.4.3 Altitude

The NEDC type approval test doesn't take into consideration the altitude, as it is tested on a chassis dynamometer the test has never considered the load on the engine with mass and gravity acting down including an angle. Graph 28 is presenting that at a higher altitude the fuel consumption became much greater than those at low. This particular instance the vehicle was travelling up a very steep gradient. This is also another factor that the new RDE drive cycle is considering.



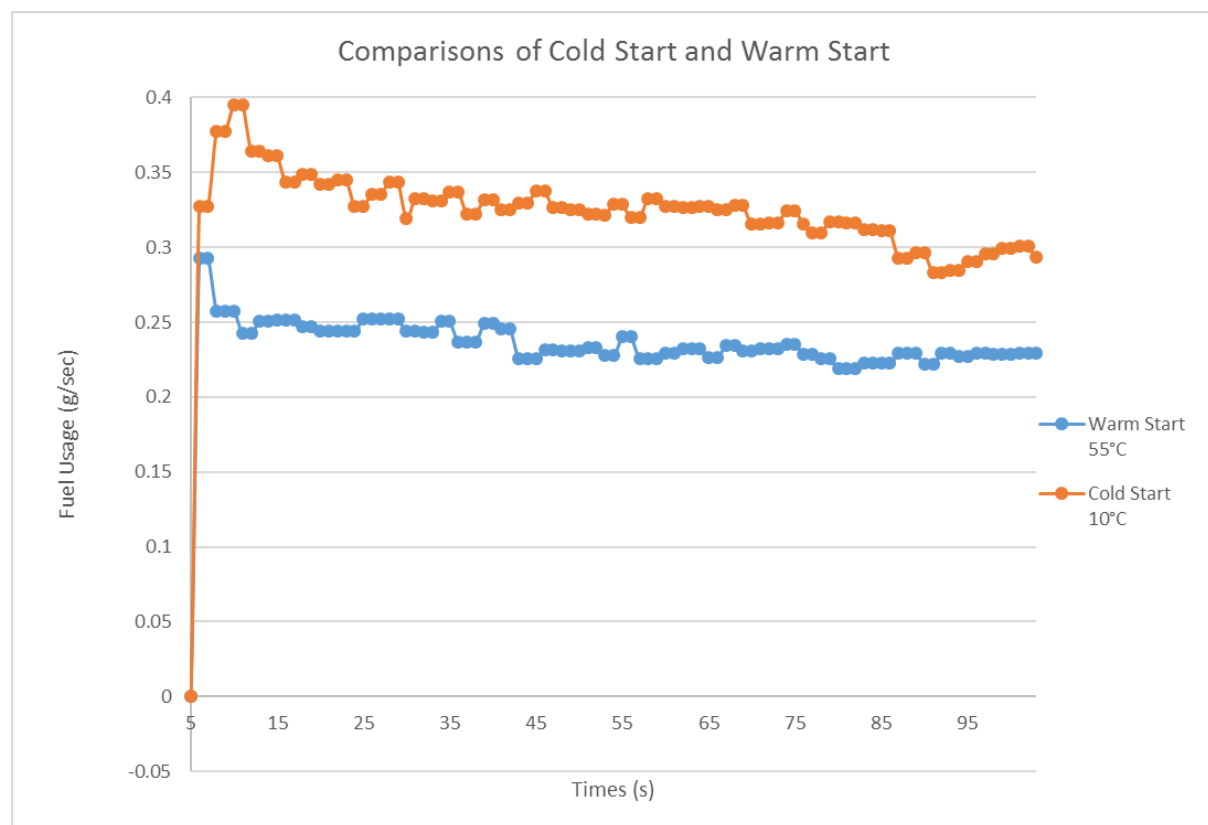
Graph 28 7th March Mumbles, Altitude vs Fuel Usage

12. Cold Starting

Ambient temperatures determine the temperatures of the vehicle when left for long enough for a cold start state, this then affects the components when starting. Literature found from U.S Environmental Protection Agency stated that a drop in temperature from 24°C to 7°C can increase the fuel consumption in urban commutes by 17-28% (Canada, 2014).

Cold starts last until all components are at their working temperature (Fontaras, et al., 2016), the duration chosen for the test was 120seconds. This duration was chosen as the idling period was the same for both cycles, however the two cycle routes differed therefore it wouldn't have been feasible to compare fuel consumption over a longer period.

The reason for cold starts influencing fuel consumption is that the lubrication systems take longer to get to their efficiency operating temperature, transmission, engine components and exhaust after treatment all function differently. Exhaust after treatment does not work properly until it has reached above 2000K.



Graph 29 Warm and Cold Start Comparison

The ambient temperature for the warm start test was 12°C, however, once the air is inducted into the engine the actual temperature will change due to heat transfer through the intake and cylinder head. 55°C was taken from the dial gauge of the vehicle and the temperature values were measured from the OBD2.

The NEDC test has a starting temperature of 20-30°C, mostly 25°C, as seen by the tests carried out the English weather during this period does not fall into that category, and therefore this highlights how irrelevant that temperature is to real world application. Another piece of literature also stated that for every 10% decrease in air temperature there can be a 23% increase of fuel consumption (Fontaras, et al., 2016).

Cold start for urban cycles increased 15% and 20% for conventional vehicles for 8 petrol cars (Fontaras, et al., 2016).

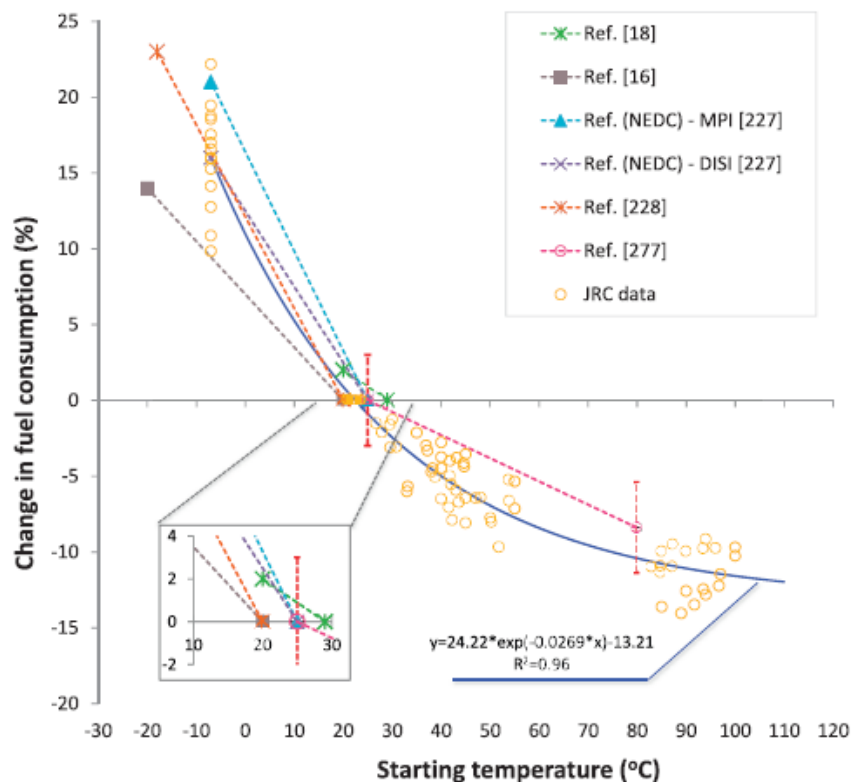
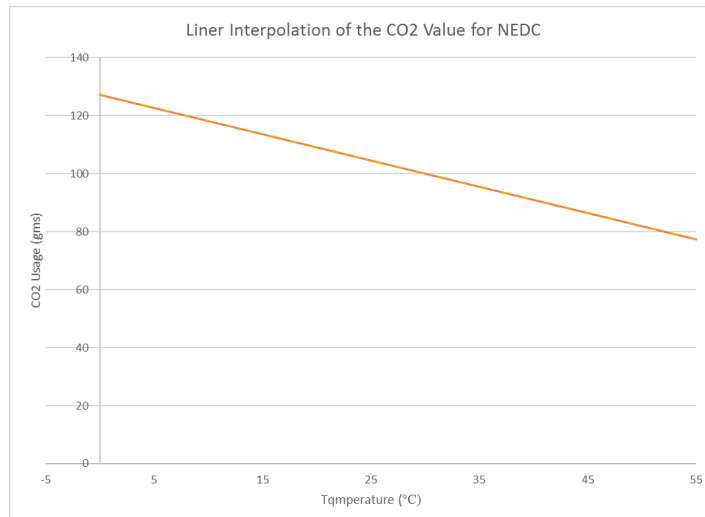


Figure 25 Percentage increase in fuel consumption related to starting temperature (Fontaras, et al., 2016)



Graph 30 Linear Interpolation for NEDC CO₂

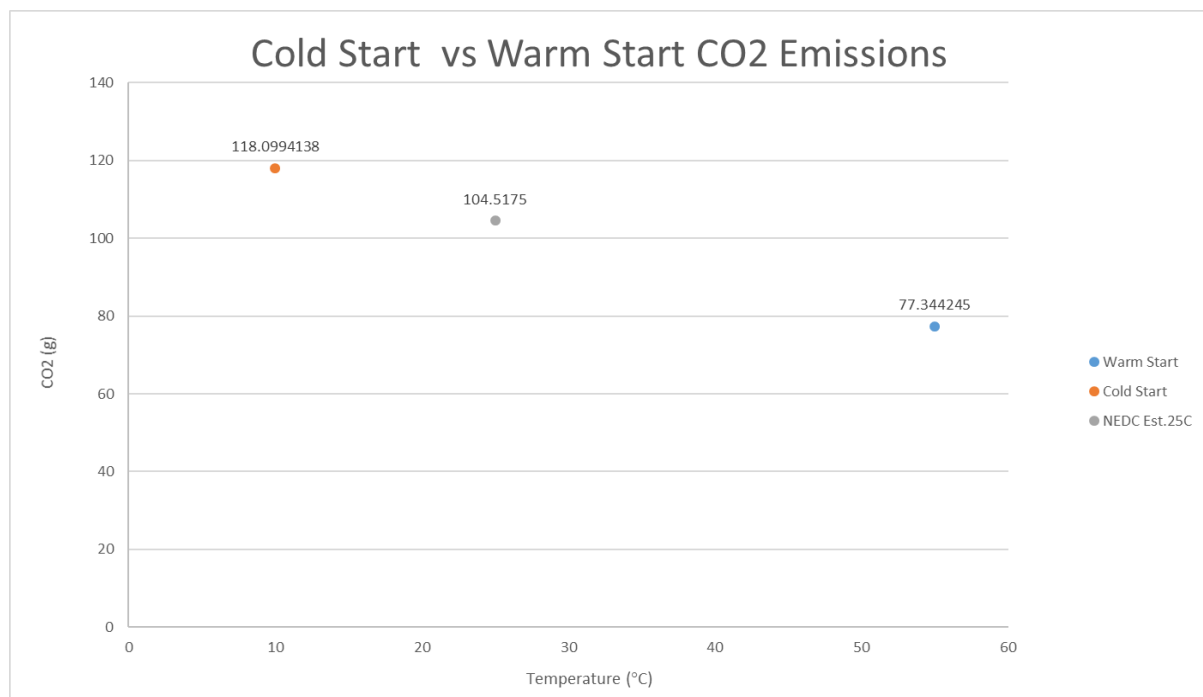
$$y = 0.9057 \times X + 127.16$$

$$y = 0.9057 \times 25 + 127.16$$

$$y = 104.5175 \text{ (gms)}$$

Equation 40 Interpolation of CO₂ for NEDC

From literature, the author decided to interpolate between the two points on the graph from the warm and cold start to suit the NEDC temperature which is 25°C.

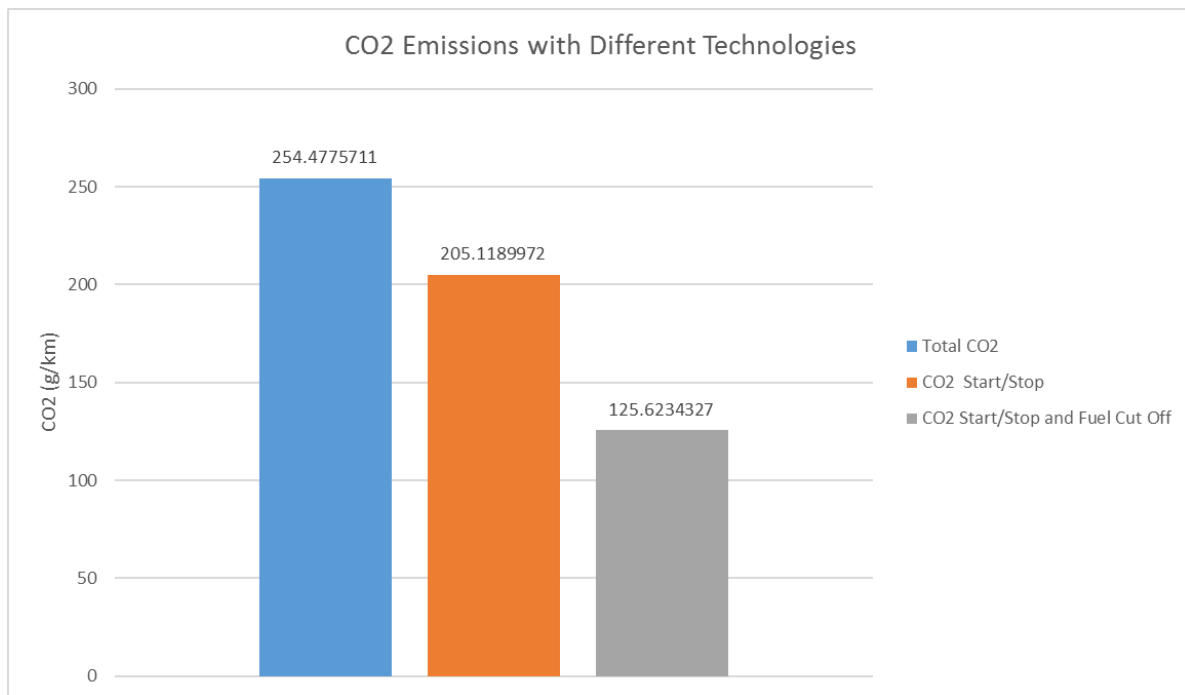


Graph 31 Cold Start vs Warm Start CO₂ Emissions

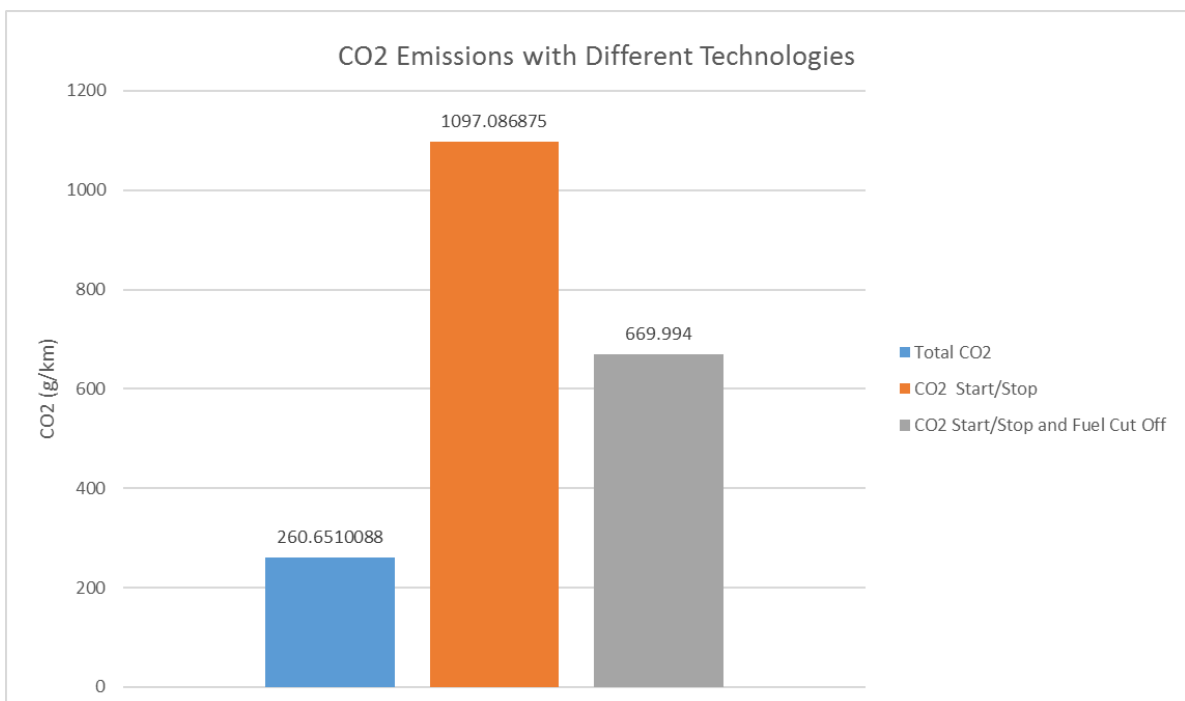
Assuming that the NEDC start temperature is 25°C, at 55°C there is a 25% decrease of CO₂ emissions when the start temperature is higher. For the cold start however, there is a 13% increase of CO₂ due to the increase of fuel needed preventing the engine from stalling through the warm up phase.

12.1 Relevant Graphs Created From RDE

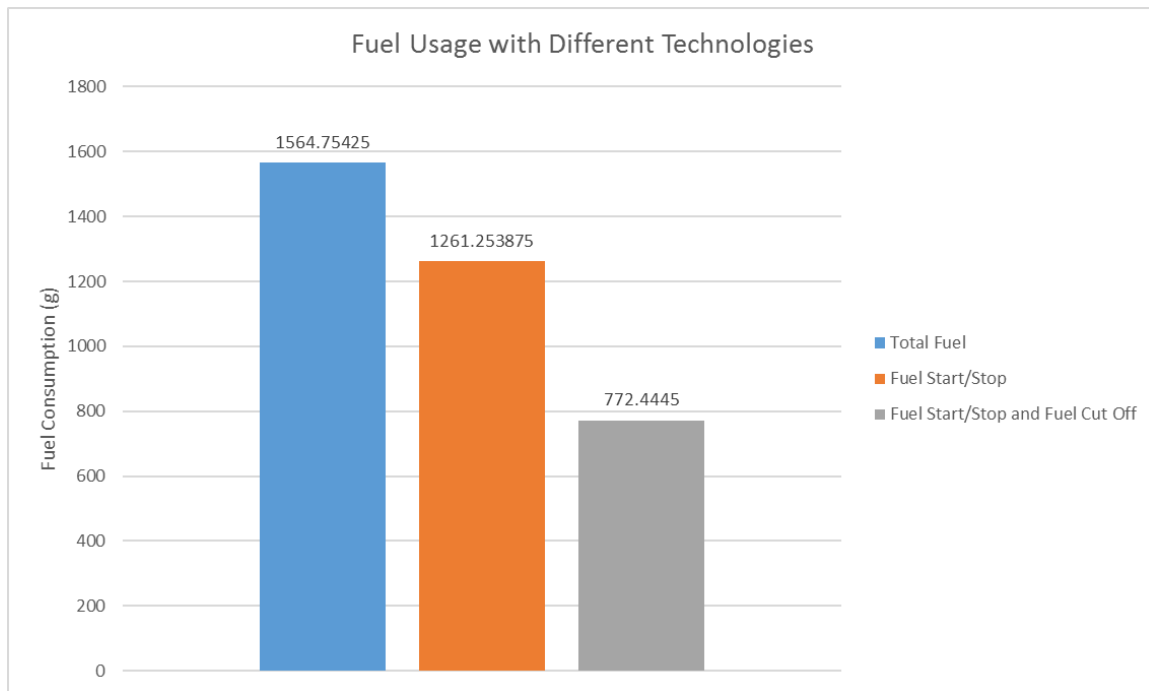
The graphs attached after this is just further comparisons made but not elaborated.



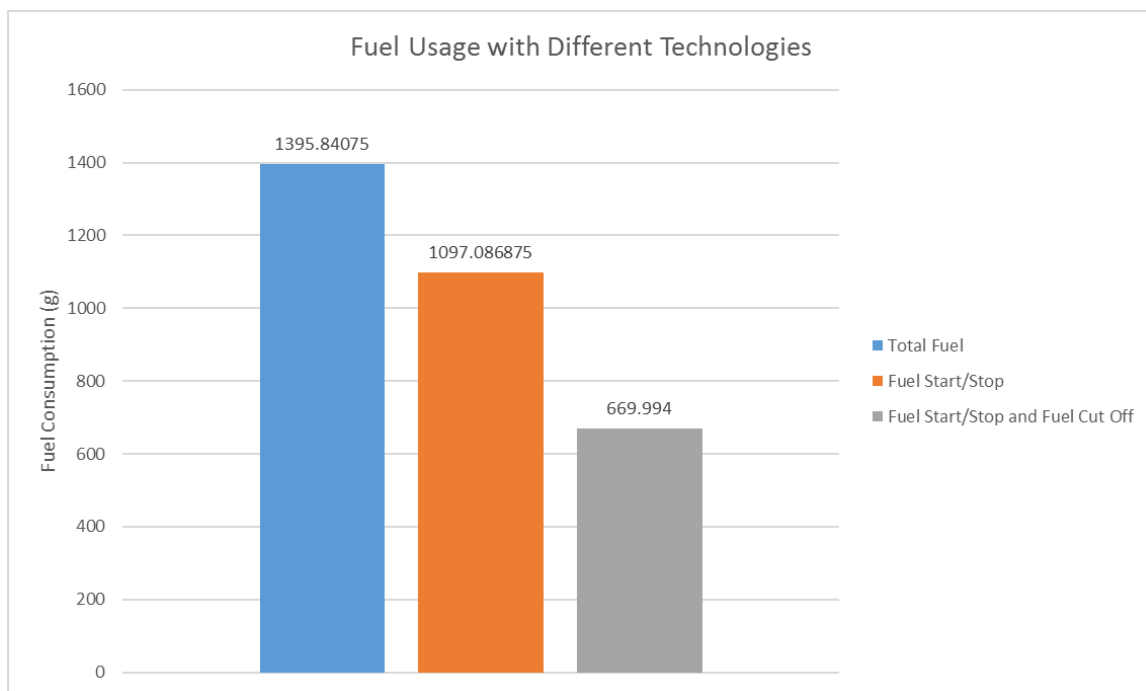
Graph 32 Mumbles 7th CO2 Emissions with Fuel Technology



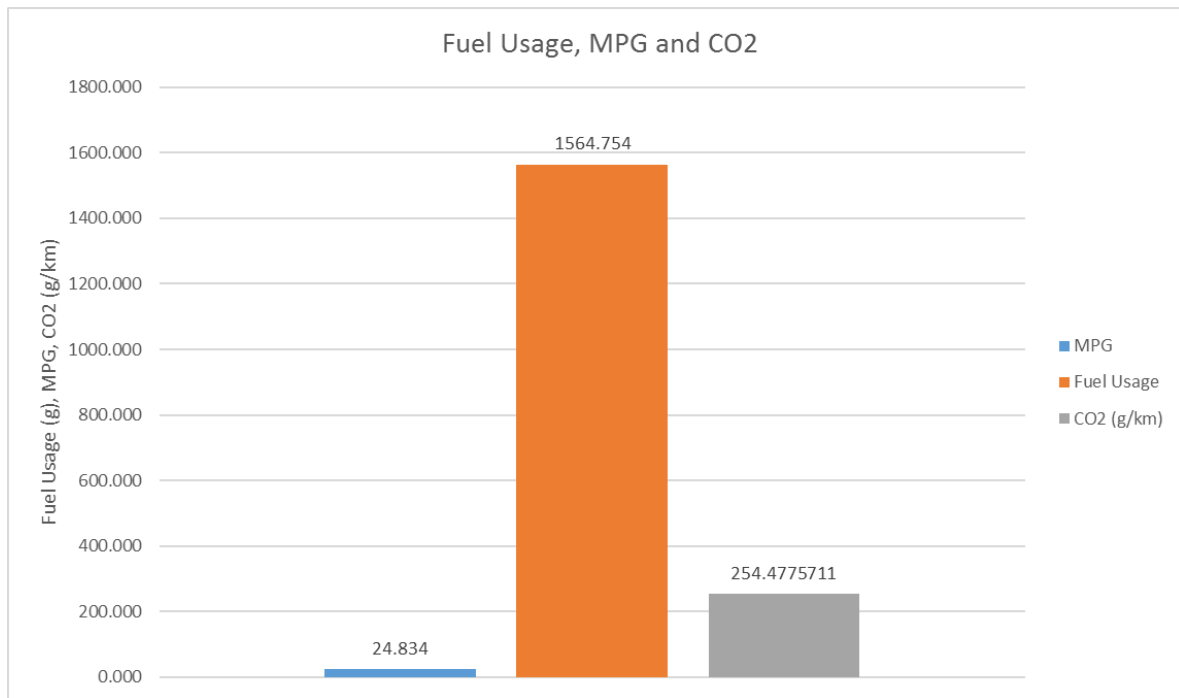
Graph 33 12th March CO2 Emissions with Fuel Technology



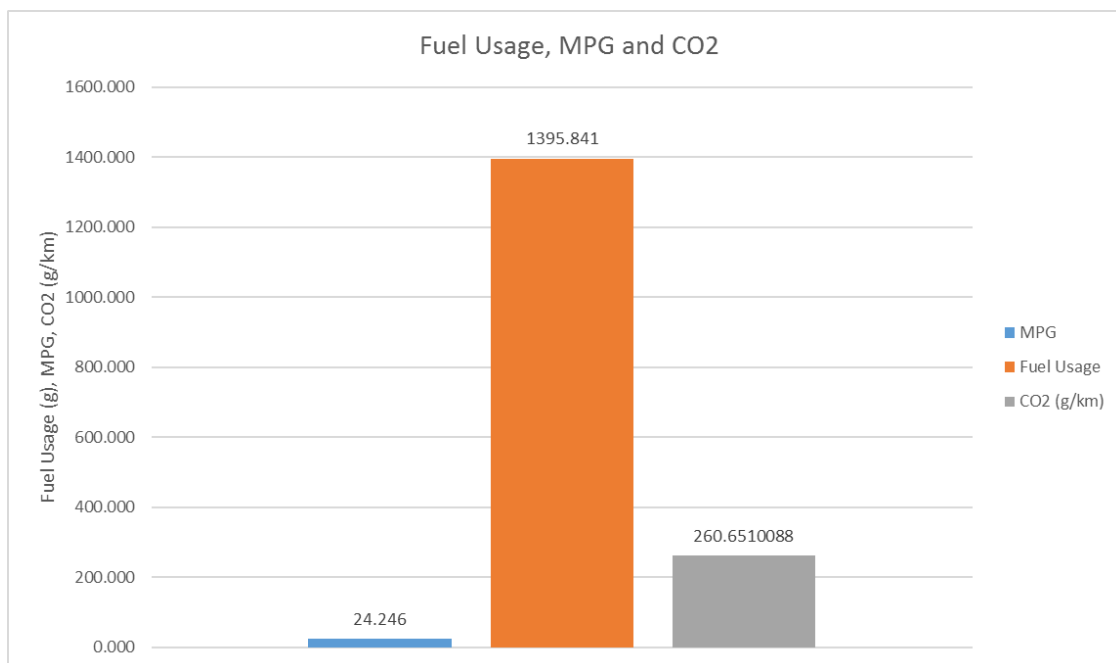
Graph 34 Mumbles 7th Fuel Usage with Different Technologies



Graph 35 Mumbles 12th Fuel Usage with Different Technologies



Graph 36 Mumbles 7th Fuel Usage, CO₂ and MPG



Graph 37 Mumbles 12th Fuel Usage, CO₂ and MPG

13. Conclusions

The NEDC values for the Passat proved to be in range with the MPG researched, however the extra urban was slightly over. This was also the same for the Ford, the Ford CO₂ values were 148g/km from the model whereas researched values were 109 g/km. the only reason the author can give is that the polynomial equations may not have been accurate enough at higher BMEP and Torque. This will be future work to see if the data is incorrect or the values researched are. Overall the NEDC proved to help the understanding of this report, it created a platform for the author to produce and understand their own RDE and have a reference point on values created by the NEDC. If the NEDC was to be carried out again, more time would be spent on being able to apply the Audi to the NEDC model created to compare the model and the RDE. It was also attempted to insert the fuel (g/sec) for every second into the Mumbles speed profile, however the fuel consumption values were becoming negative, and this may also be because of the polynomial equations.

Other than the altitude values creating problems with the OBD2 data, overall the tool was very helpful and easy to use, and surprisingly provided varied and important data. The fact the OBD2 was easily accessible is because the European Union made this a legislation for all manufacturers to access the OBD.

Researching the impact of CO₂ and how the government have strict legislations not just in the automotive industry, makes the seriousness of global warming become more apparent. It is important for all industries emitting billions of CO₂ to be cautious of this and be confident enough to tackle the problem.

The RDE proved how unreliable the NEDC values can be, the only difference is that the CO₂ is taken at a maximum speed of the two cycles (Bosch, 2014), the argument against this is that vehicle isn't doing this speed all the time therefore this way of measuring is unreliable. This can be one of the reasons as to why the CO₂ values were greater than those stated in the logbook for the Audi. The vehicle is always changing air: fuel ratio which affects CO₂ emittance a Co₂ model was attempted using the measured air: fuel ratio however due to time this was unfinished. A picture has been added into the appendices presenting the first steps, this would be an area where the author would like to expand on after. The aim of the project was to find whether the NEDC was accurate to real world driving emissions. From research carried out and values calculated the project seems reliable enough to say that it isn't. It can be seen how important the WLTP and RDE legislation is to the environment for reducing global warming.

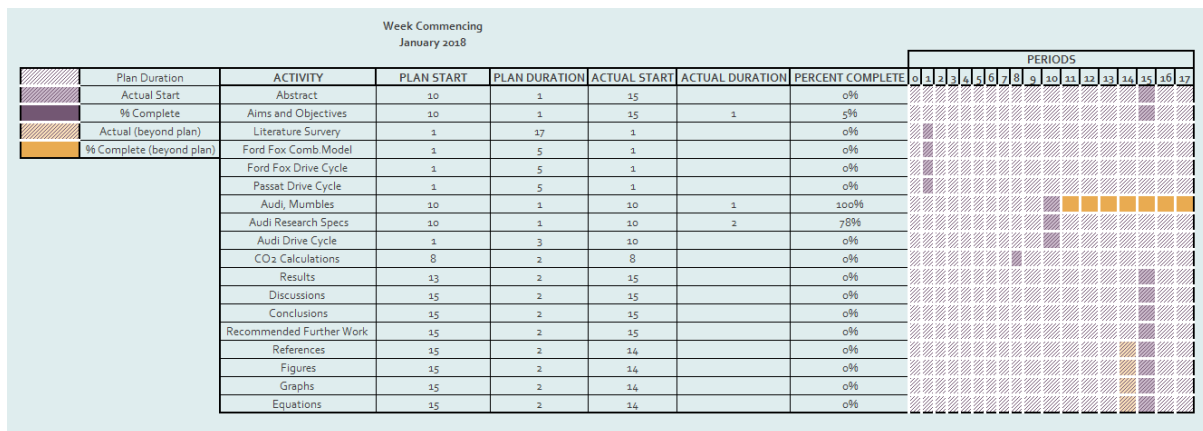
14. Appendices

14.1 Carbon Offsetting

Carbon offset schemes allow companies to invest in environmental project in order to balance out their own carbon footprints. This can involve rolling out clean energy technologies or purchasing and ripping up carbon credits from an emissions trading scheme (Sandbag, 2011).

Emissions trading is a market based approach to controlling pollution, by creating tradeable pollution permits it attempts to add the profit motive as an incentive for good performance unlike traditional environmental regulation, which is based solely on the threat of penalties. Setting a limit on pollution and allowing the market to decide how to stay within that limit is ideally suited to reducing carbon emissions (Sandbag, 2011).

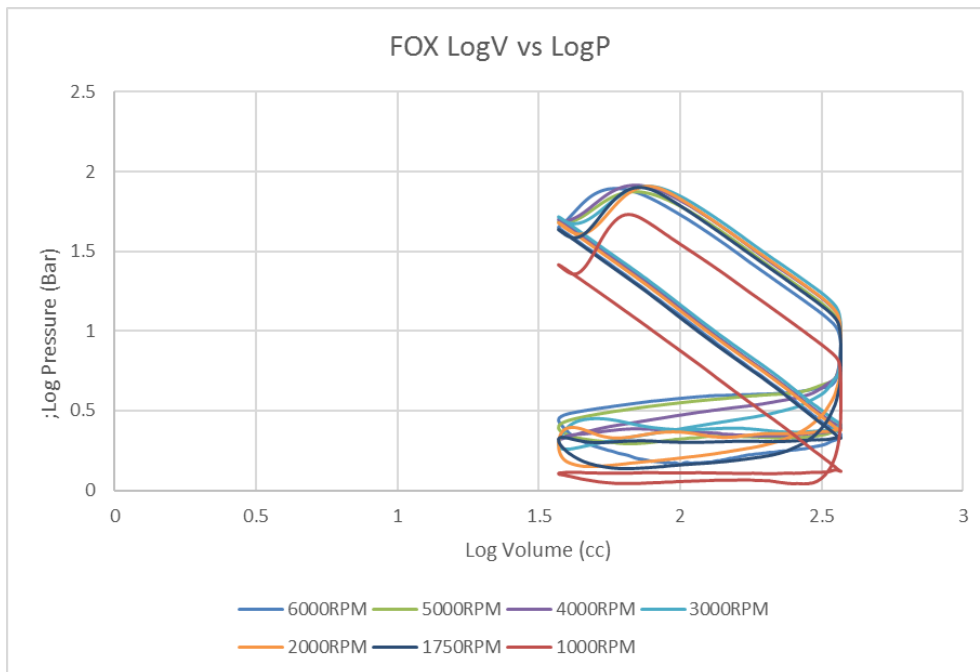
14.2 Planning



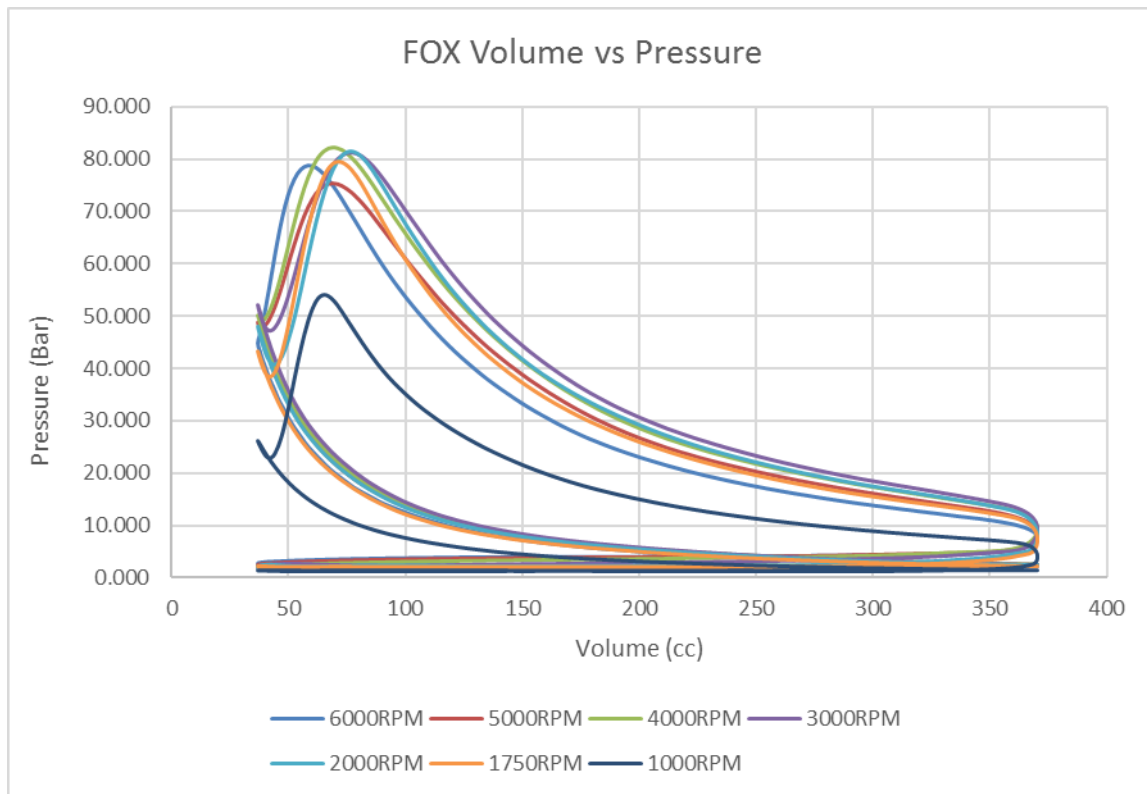
Appendices Figure 1 Chart Screenshot on April 11th 2018

14.3 Combustion Model

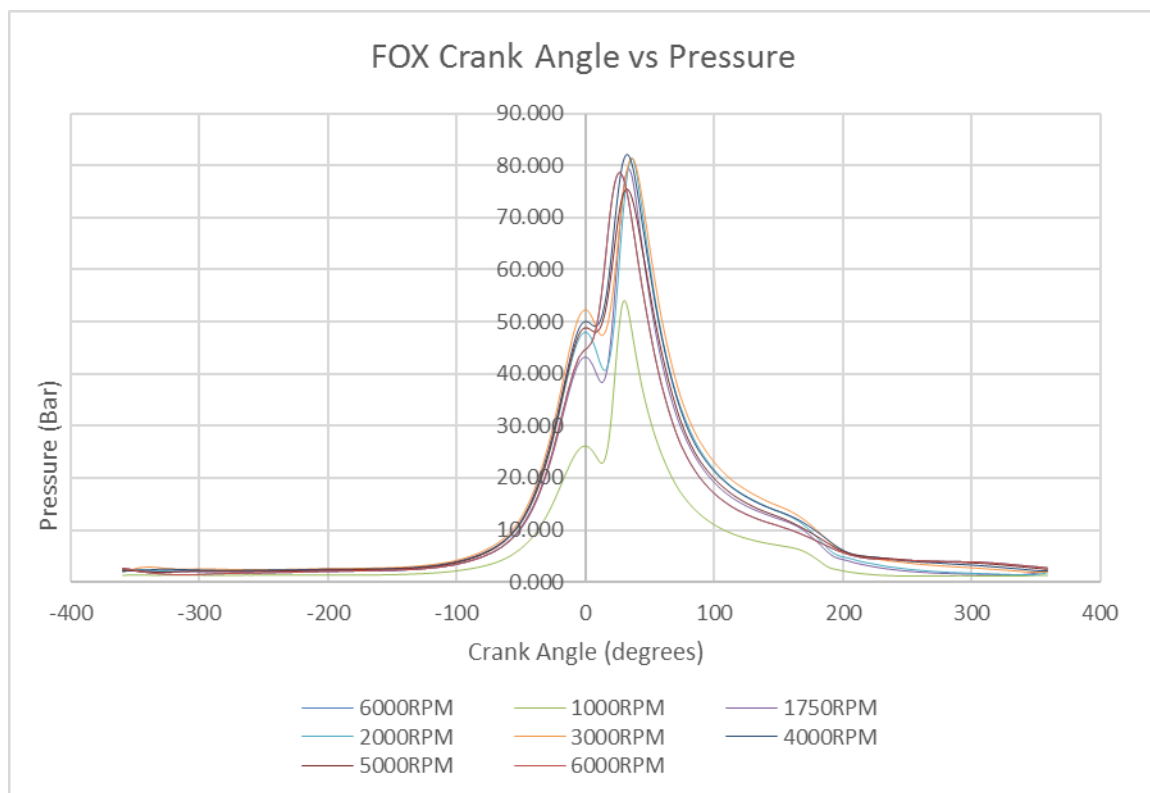
This section includes the graphs created for the combustion model that was going to be completed for the first project.



Appendices Graph 1 FOX LogV vs LogP



Appendices Graph 3 FOX Volume vs Pressure

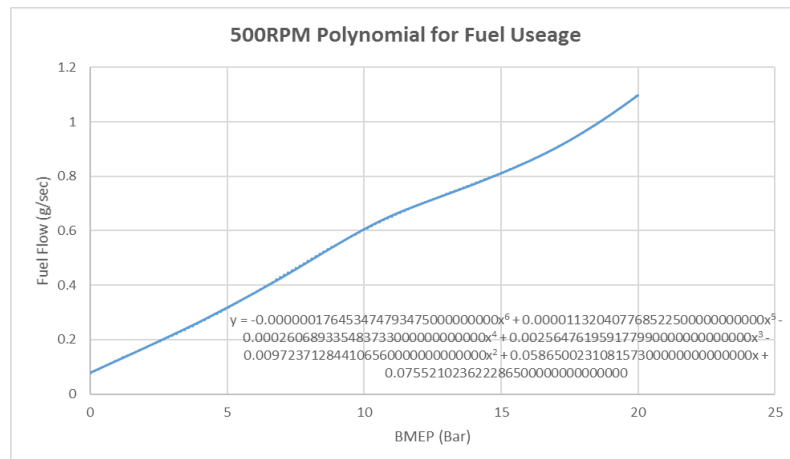


Appendices Graph 2 Ford FOX Crank Angle vs Pressure

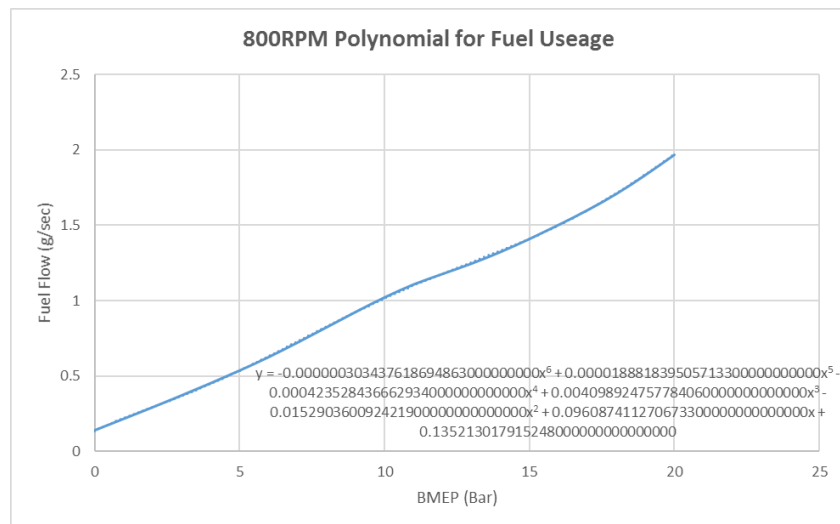
14.4 Drive Cycle

14.4.1 Passat

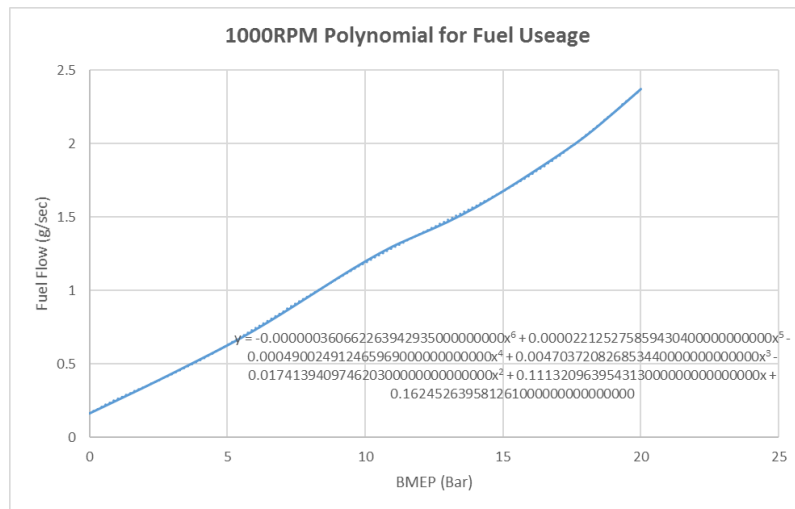
14.4.1.1 Fuel Usage Graphs



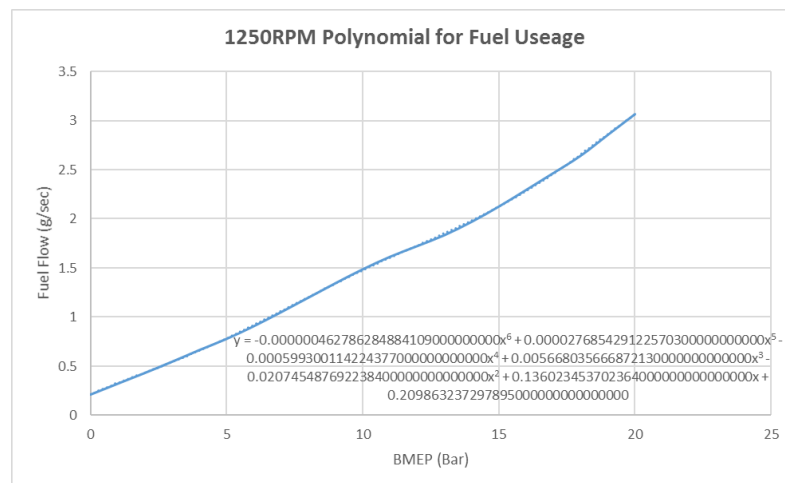
Appendices Graph 4 500RPM Polynomial, Passat



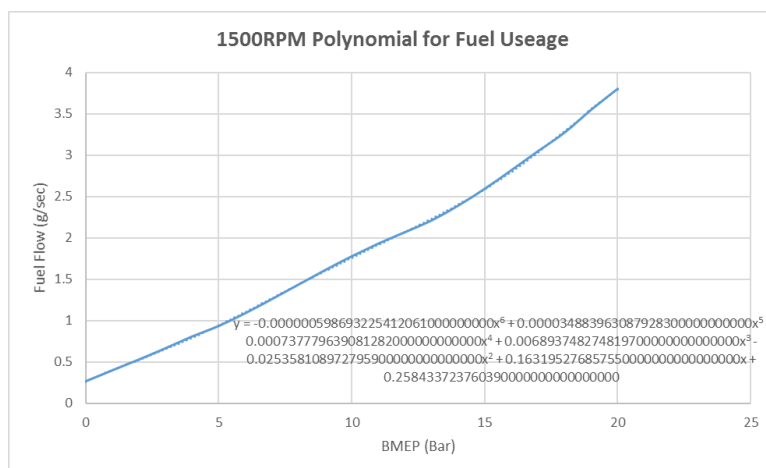
Appendices Graph 5 800RPM Polynomial, Passat



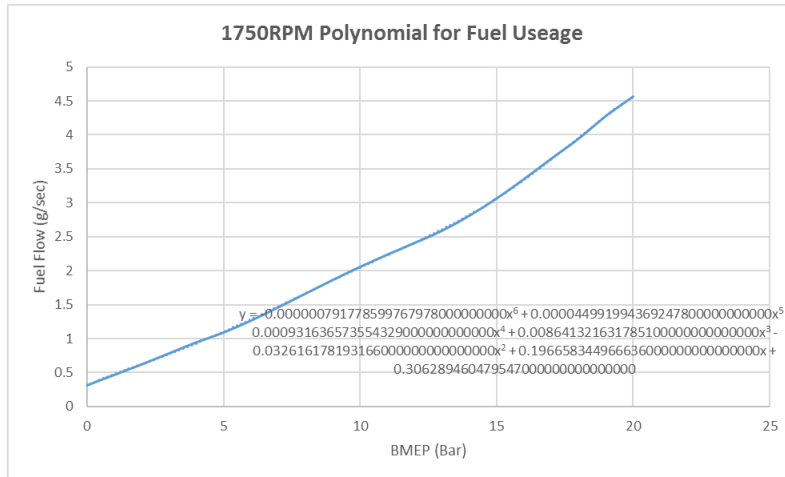
Appendices Graph 6 1000RPM Polynomial, Passat



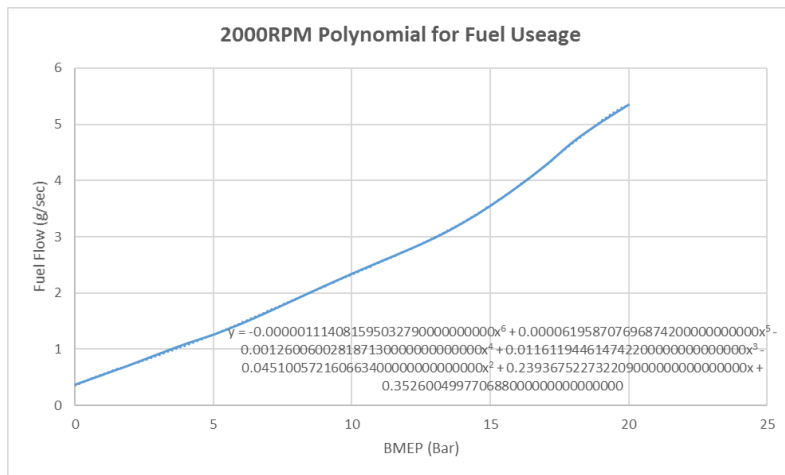
Appendices Graph 7 1250RPM Polynomial, Passat



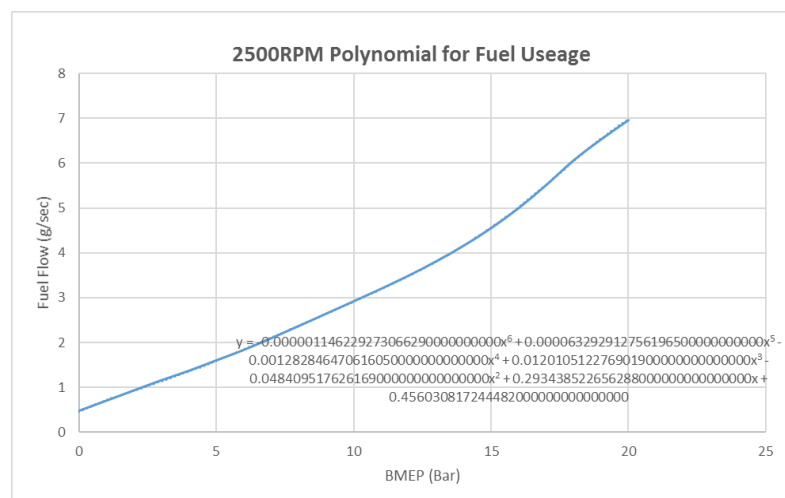
Appendices Graph 8 1500RPM Polynomial, Passat



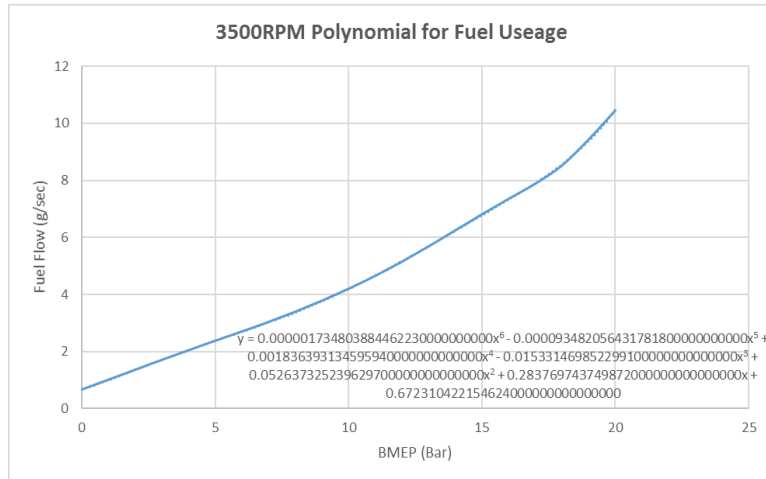
Appendices Graph 9 1750RPM Polynomial, Passat



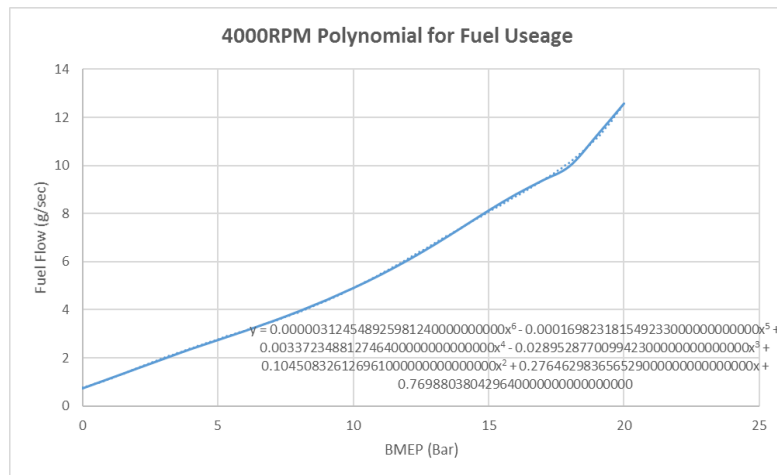
Appendices Graph 10 2000RPM Polynomial, Passat



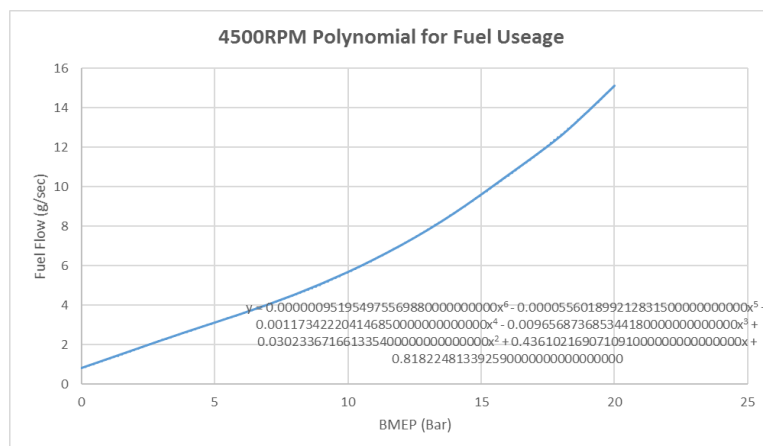
Appendices Graph 11 2500RPM Polynomial, Passat



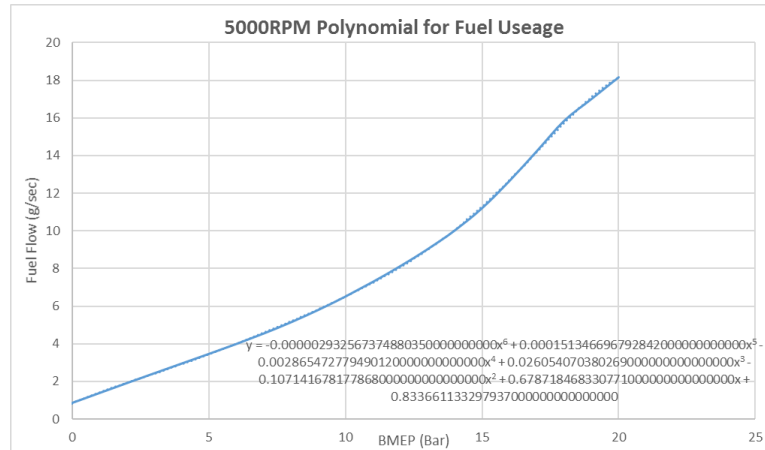
Appendices Graph 12 3500RPM Polynomial, Passat



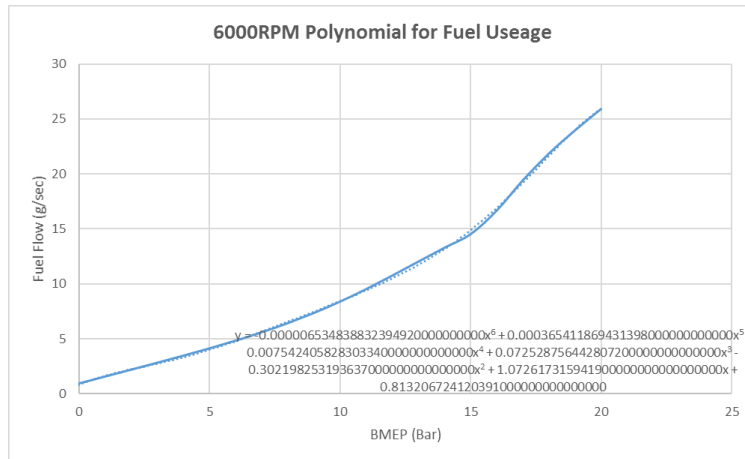
Appendices Graph 13 4000RPM Polynomial, Passat



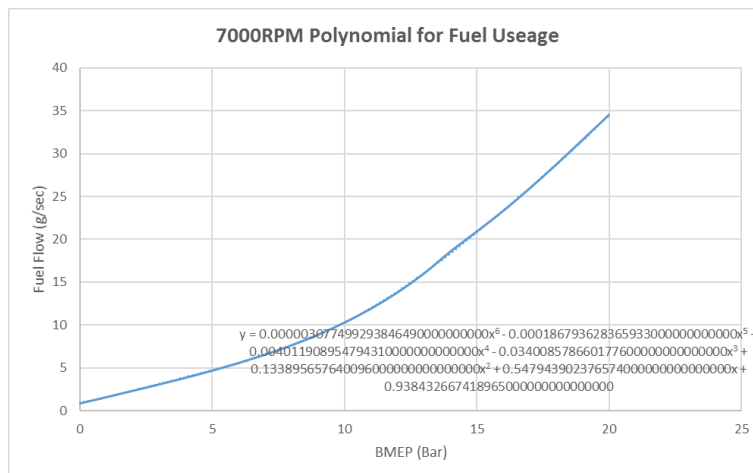
Appendices Graph 14 4500RPM Polynomial, Passat



Appendices Graph 15 5000RPM Polynomial, Passat



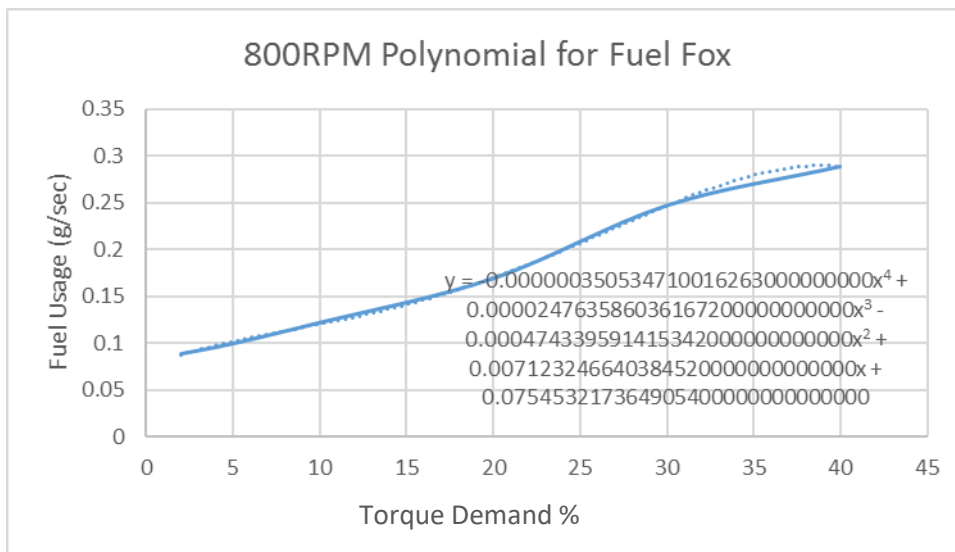
Appendices Graph 16 6000RPM Polynomial, Passat



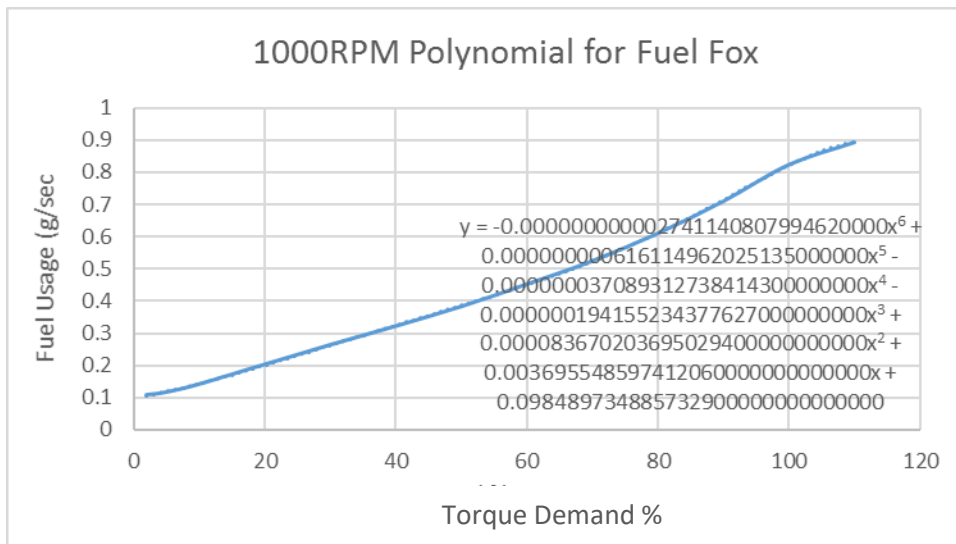
Appendices Graph 17 7000RPM Polynomial, Passat

13.5 Drive Cycle Ford

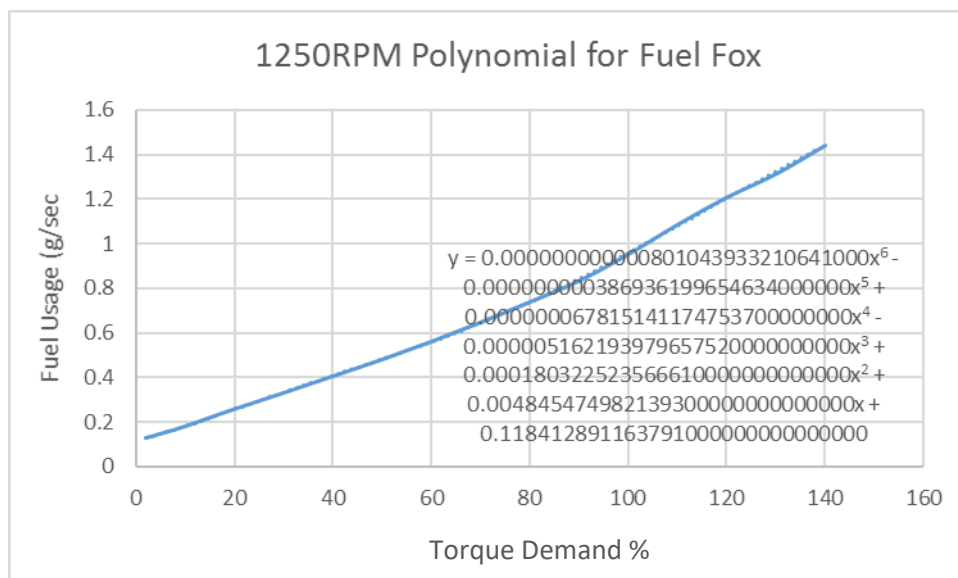
13.5.1 Fuel Usage Graphs



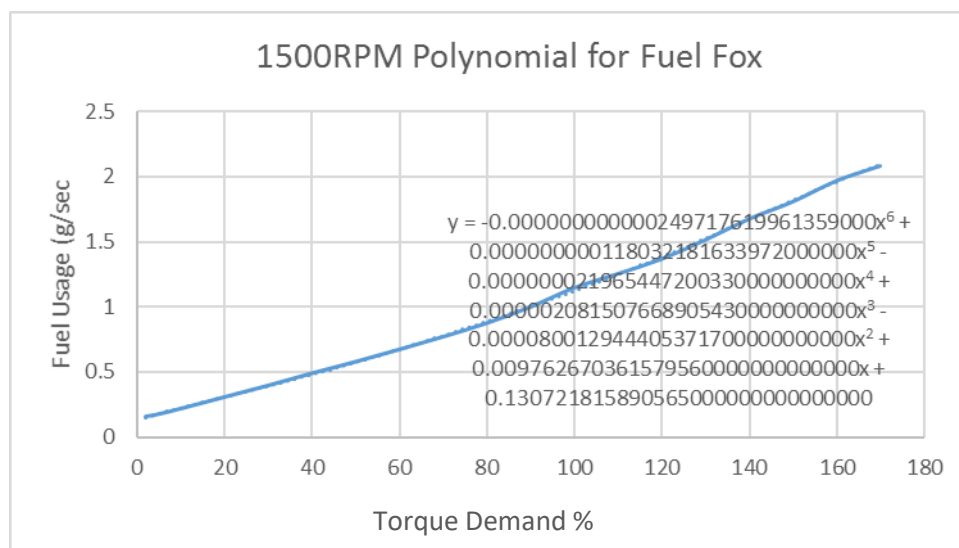
Appendices Graph 18 800RPM Polynomial



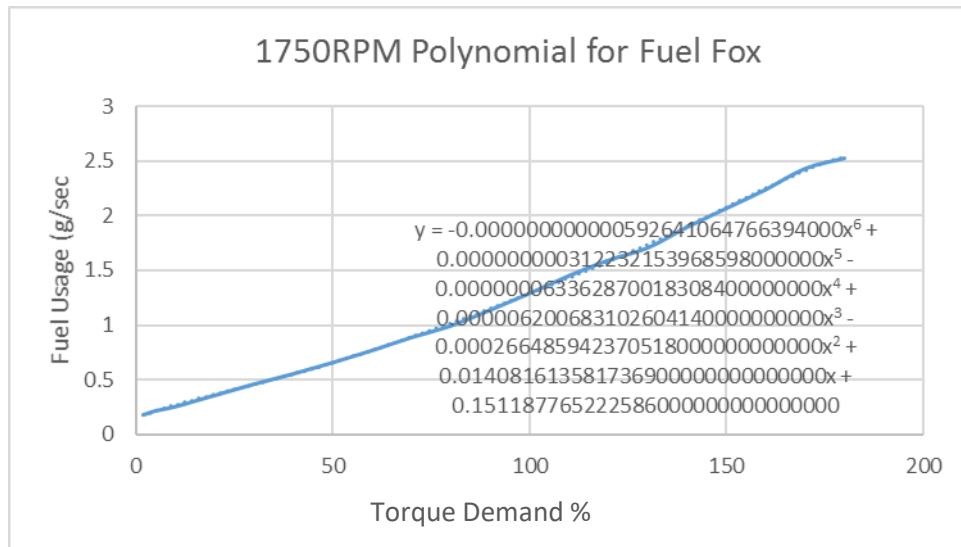
Appendices Graph 19 1000RPM Polynomial



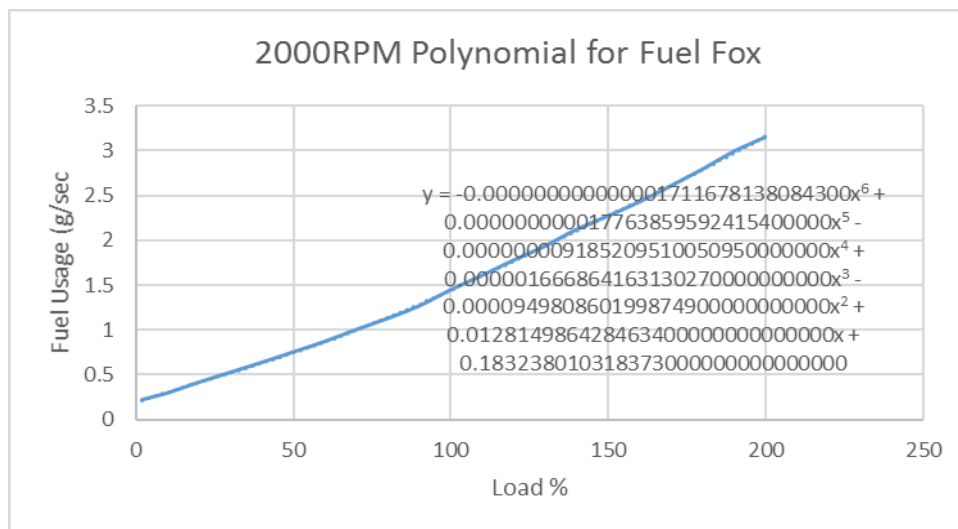
Appendices Graph 20 1250RPM Polynomial



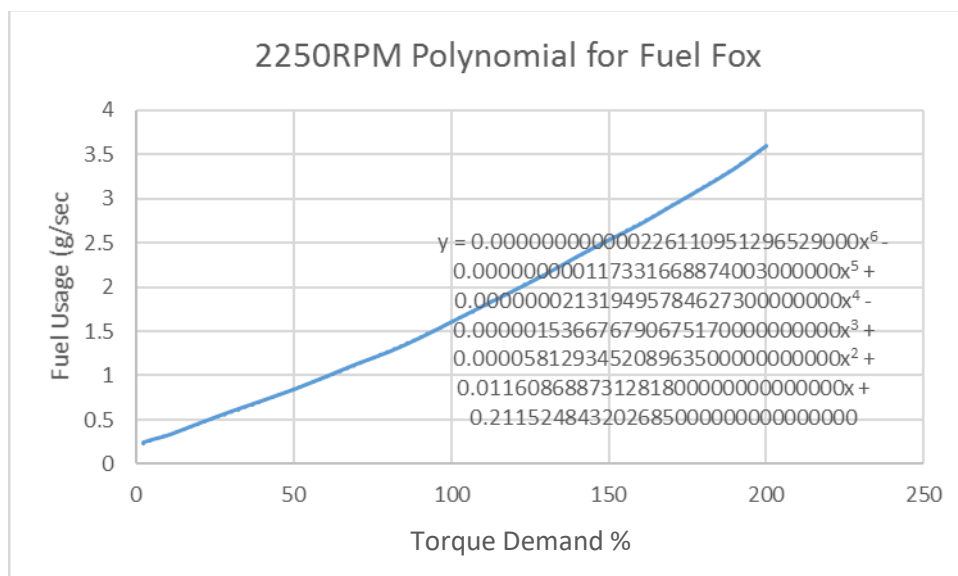
Appendices Graph 21 1500RPM Polynomial



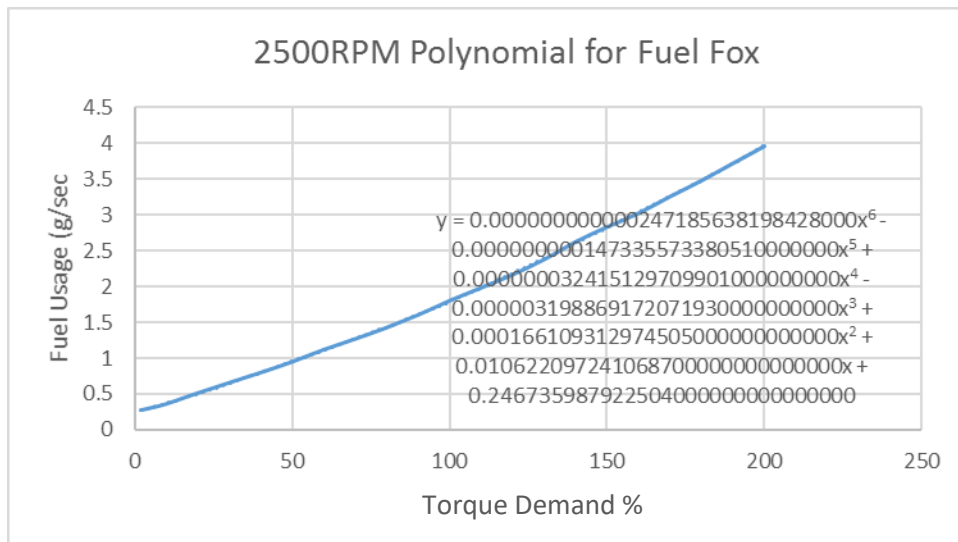
Appendices Graph 23 1750RPM Polynomial



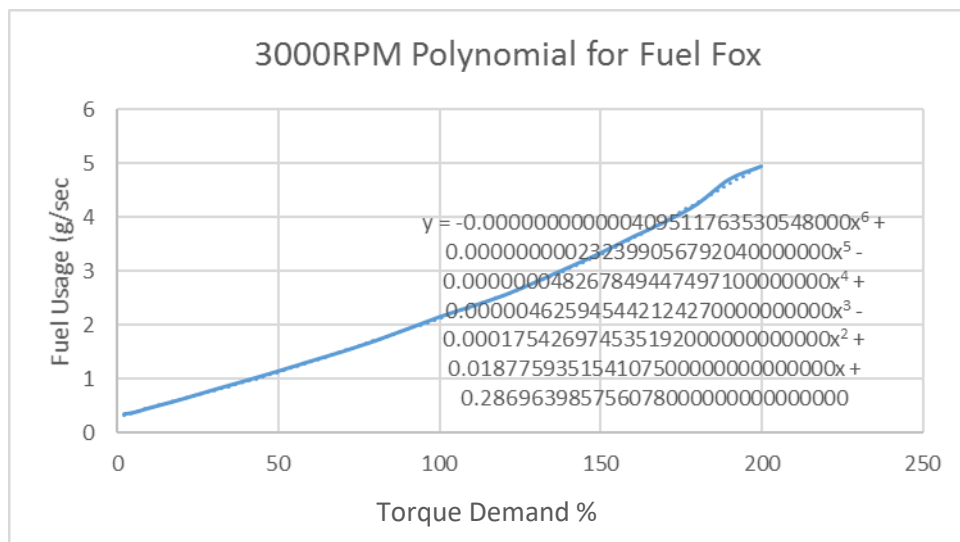
Appendices Graph 22 2000RPM Polynomial



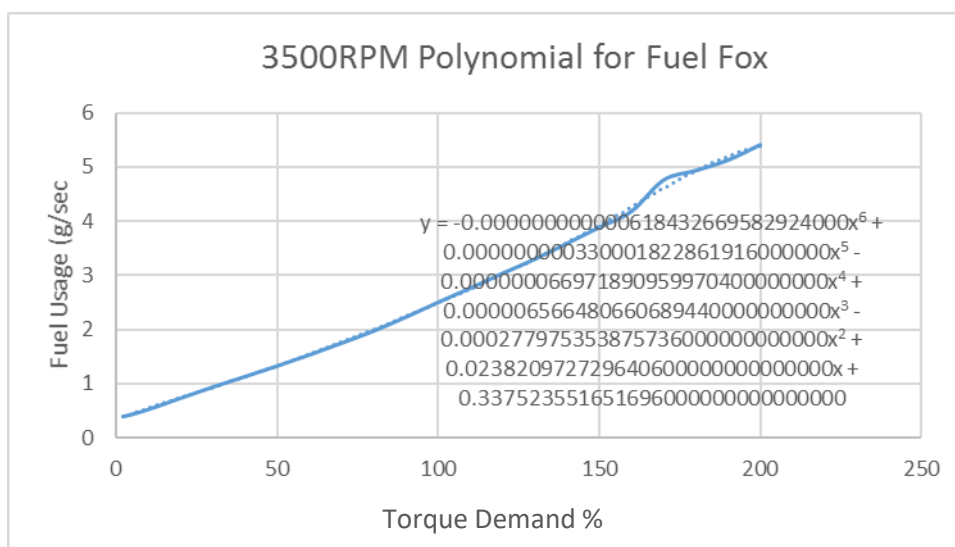
Appendices Graph 24 2250RPM Polynomial



Appendices Graph 25 2500RPM Polynomial



Appendices Graph 26 3000RPM Polynomial



Appendices Graph 27 3500RPM Polynomial

14.6 Real Driving Emissions Section

14.6.1 Fuel Usage

The OBD2 diagnostic equipment collates the Air: Fuel ratio of the engine for every second.

14.6.1.1 Air: Fuel Ratio

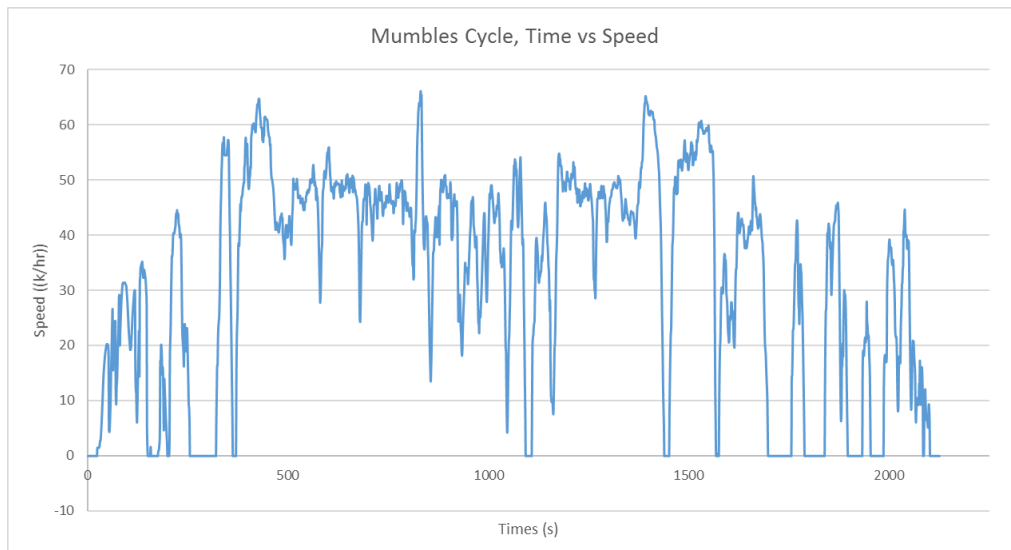
For engines the Air: Fuel ratio is crucial for how lean, rich or stoichiometric the fuel usage is. When the fuel and air composition is stoichiometric, it means that the structure has the correct amount of air and fuel to produce a chemically complete combustion in the chamber. For petrol engines, the stoichiometric Air: Fuel ratio is 14.7:1, 14.7 parts of air to one part of fuel (turbobygarrett, n.d.).

Appendices Table 1 Air: Fuel Ratio

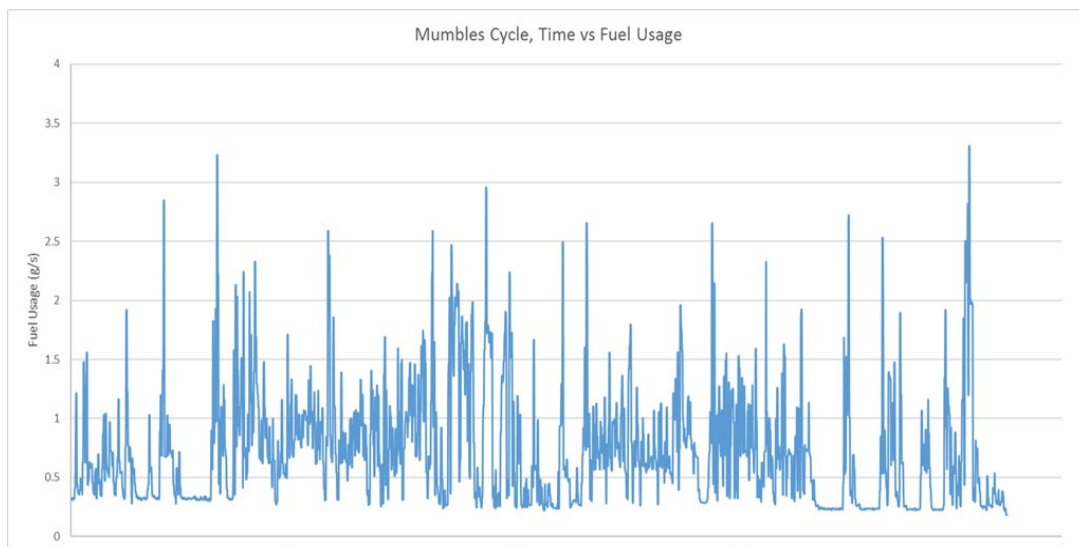
Lean	Stoichiometric	Rich
Greater than 14.7	14.7: 1	Less than 14.7
With excess air, the products of the Equation 2 Isooctane Fuel and Air Balance Equation generates more O ₂ .		There is insufficient oxygen to oxidize fully the fuel C and H to CO ₂ and H ₂ O. The products are a mixture of H ₂ O and CO ₂ with CO, H ₂ and N ₂ .

The air: fuel ratio determines how combustible the mixture is, the higher the ratio the more air that has been added to one part of fuel. The ratio is part of the feedback system of the vehicle to ensure a controlled level of emissions (Heywood, 1988). The ratio is measured by a lambda sensor in the exhaust system that measures the oxygen level of the exhaust gas. Signals are sent to the ECU in a closed loop control system, which enables the fuel injectors to change the levels of fuel used. This type of system allows tight tolerances to be used for fuelling, improving the emissions.

14.6.2 Mumbles, MC1



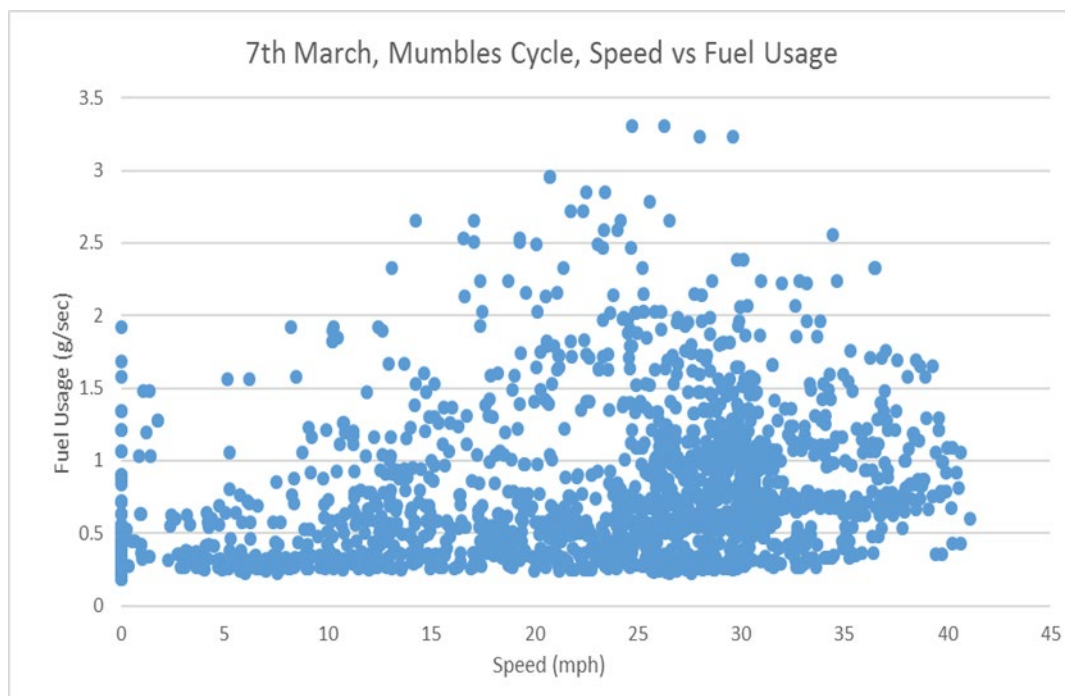
Appendices Graph 29 7th March Mumbles Cycle



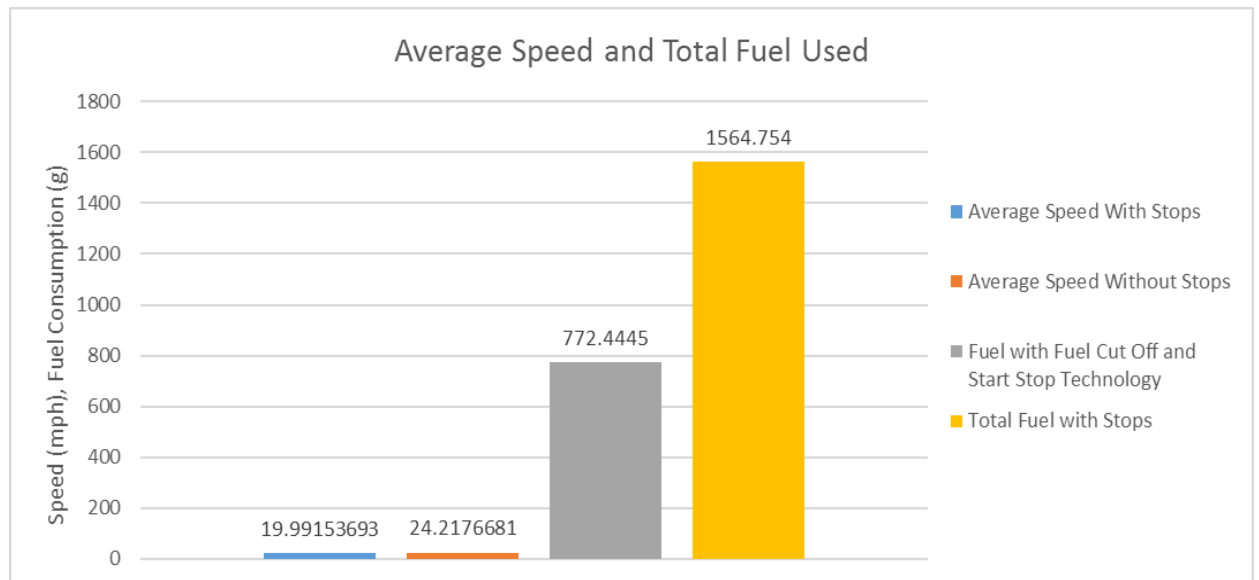
Appendices Graph 28 7th March Mumbles Fuel Usage



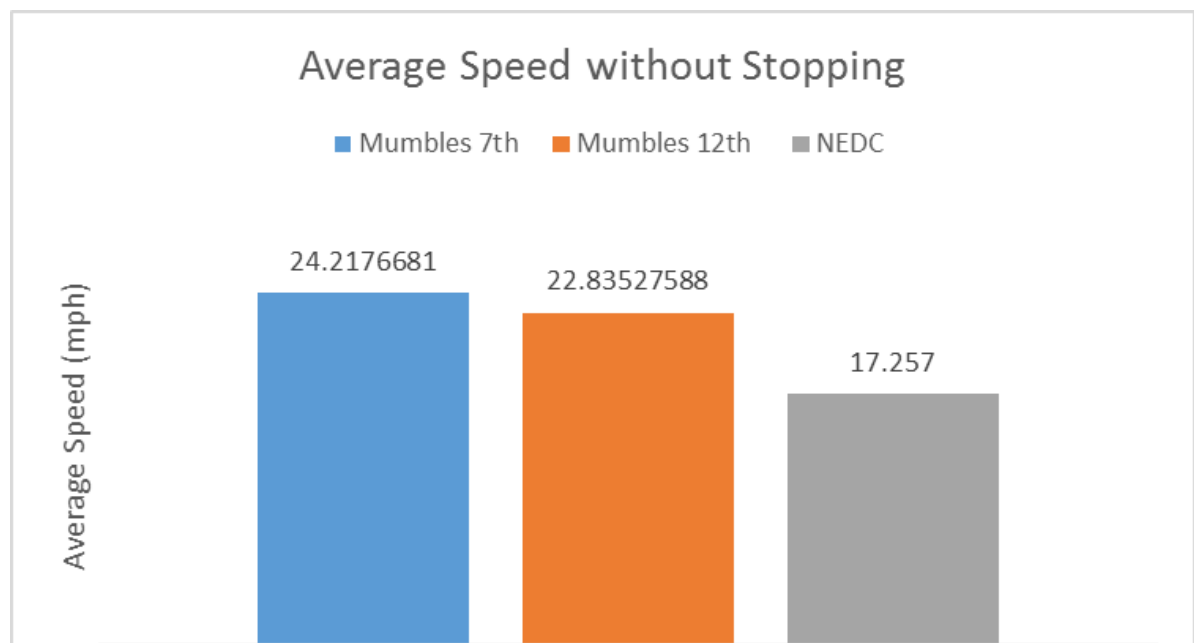
Appendices Figure 2 7th March Mumbles Google Earth



Appendices Graph 30 Speed vs Fuel, 7th of March

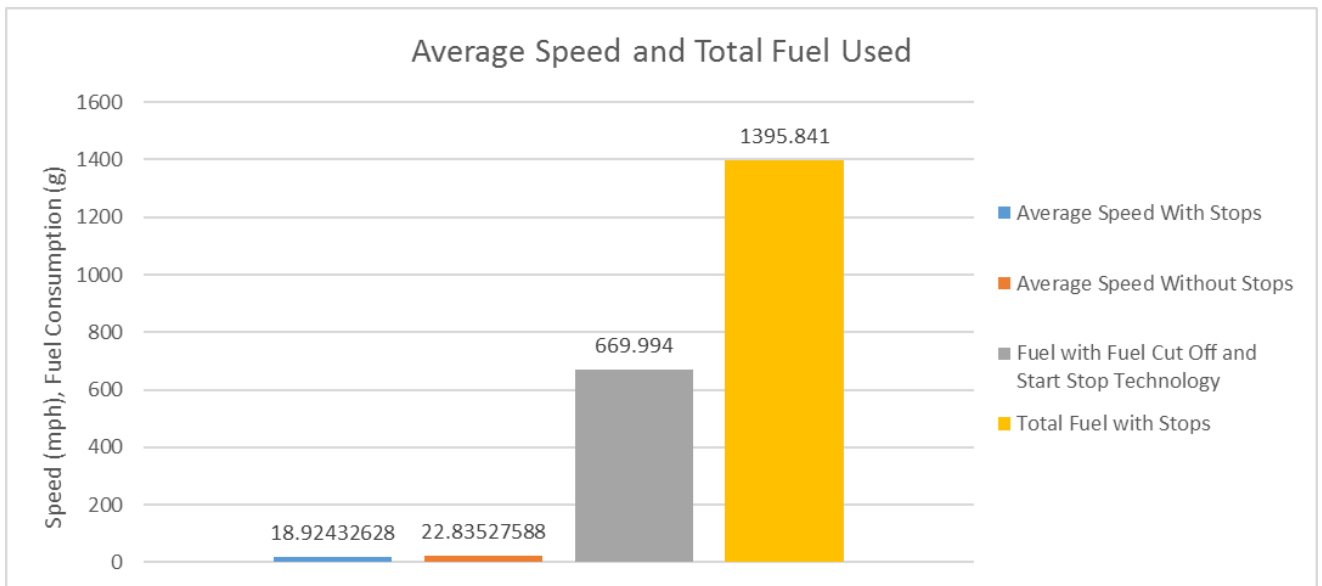


Appendices Graph 31 MC1 Average Speed and Total Fuel Used

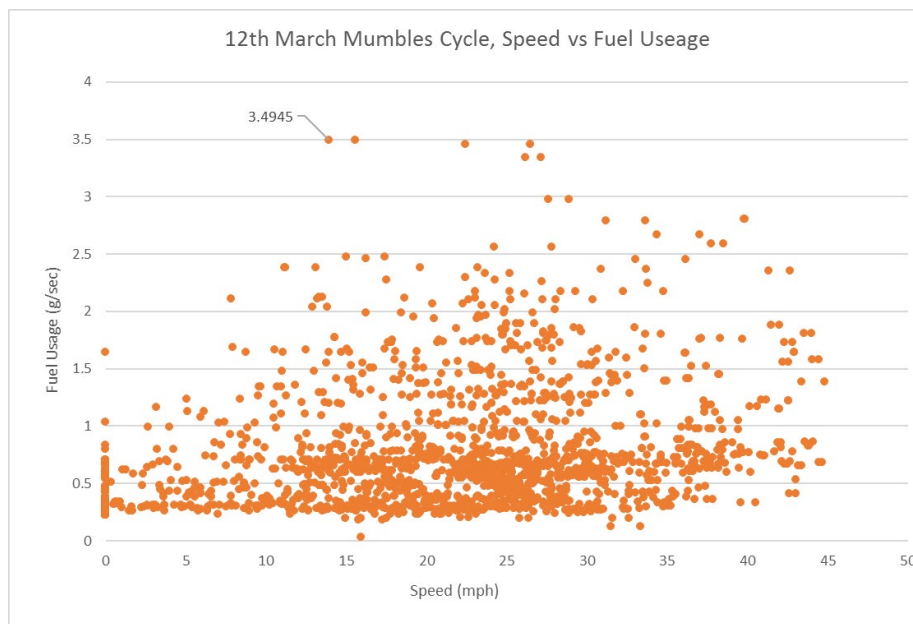


Appendices Graph 32 MC1 Average Speed without Stopping

14.6.3 Mumbles MC2



Appendices Graph 33 MC2 Average Speed and Total Fuel Used



Appendices Graph 34 MC2 Speed and Fuel Usage, 12th March

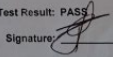
14.6.4 MOT and Proof of Data V5C

(B.1) Date of first registration in the UK	11 09 2003
D.1 Make	AUDI
D.2 Type	
Variant	LBGUF1
Version	FMSAF006R8P60M
D.3 Model	A3 SPORT
D.5 Body type	3 DOOR HATCHBACK
(N) Taxation class	PETROL CAR
(D.6) Suspension Type	
(T) Revenue weight	1316.0 KG UNLADEN
P.1 Cylinder capacity (cc)	1595 CC
V.7 CO ₂ (g/km)	170 G/KM
P.3 Type of fuel	PETROL
S.1 Number of seats, including driver	
S.2 Number of standing places (where appropriate)	
(D.4) Wheelplan	2-AXLE-RIGID BODY
J Vehicle category	M1
K Type approval number	e1*2001/116*0217*00 *
P.2 Max. net power (kW)	
E VIN/Chassis/Frame No.	WAUZZZ8P14A024100
P.5 Engine number	BGU 008706
F.1 Max. permissible mass (exc. m/c)	
G Mass in service	1391
Q Power/Weight ratio (kW/kg) (only for motorcycles)	
R Colour	BLACK
O Technical permissible maximum towable mass of the trailer:	
Q.1 braked (kg)	
Q.2 unbraked (kg)	
U Sound level:	
U.1 stationary (dB(A))	
U.2 engine speed (min-1)	
U.3 drive-by (dB(A))	
V Exhaust Emissions:	
V.1 CO (g/km or g/kWh)	0.644
V.2 HC (g/km or g/kWh)	0.060
V.3 NOx (g/km or g/kWh)	0.030
V.4 HC+NOx (g/km)	
V.5 particulates (g/km or g/kWh)	

Appendices Figure 3 Audi A3 V5C Logbook

Basic Emissions Test for Catalyst equipped vehicles
 Test Station : CRAY CAR CARE Tel:01689 830506 Station No: 19274
 Unit 5, Crayfields Ind/Park, Main Rd, St Pauls Cray, Kent BR5 3HP
 Software release : Ver 11.1 Database release : August 2014
 Date of Test: Fri Sep 09 2016 Time of Test: 12:38
Vehicle Details
 Vehicle Registration: X2RNB

Engine speed measurement was by-passed

DESCRIPTION	Limits	Reading	
Engine temp		Temp gauge showed warm	
Fast idle test			PASS
Engine Speed	2500-3000 rpm	--	Not Checked
CO	Max 0.20%	0.08%	PASS
HC	Max 200 ppm	49 ppm	PASS
Lambda	0.97-1.03	1.00	PASS
Natural idle test:			PASS
Engine Speed	450-1500 rpm	--	Not Checked
CO	Max 0.30%	0.00%	PASS
Overall Result:	Basic Emission Test Result: PASS		
Tested By: Tony Faccini	Signature: 		

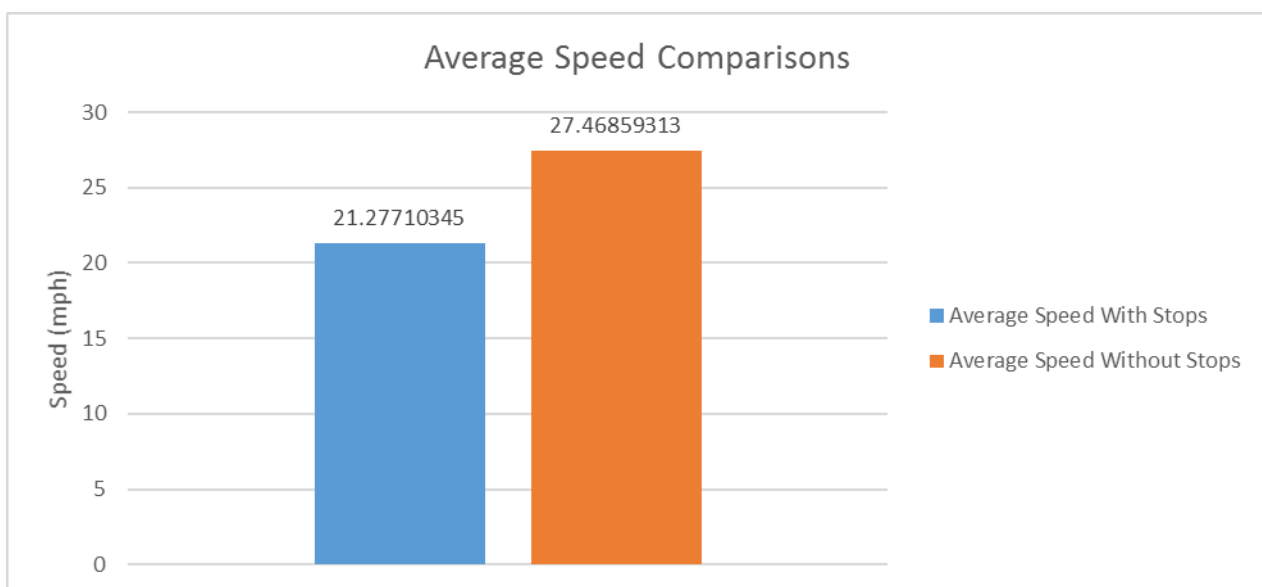
Manufactured by: Premier Diagnostics Ltd, Banbury, England
 Tel: +44(0)870 1125070. email: info@premierdiagnostics.ltd.uk

Appendices Figure 4 Basic Emissions test Completed in 2016 on the Audi A3

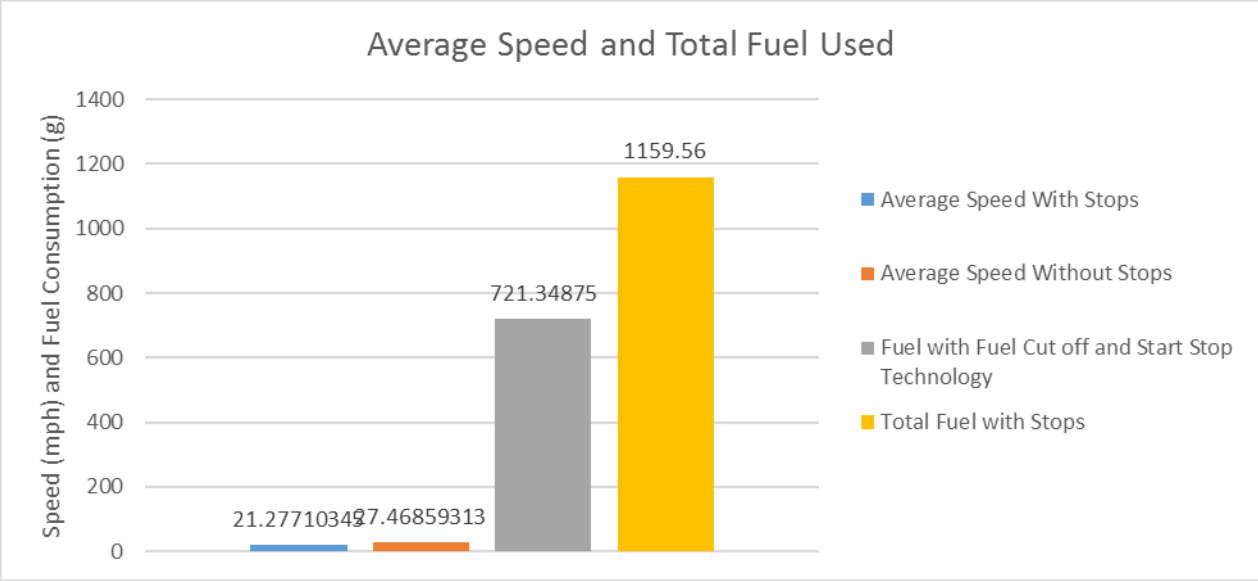
14.6.5 Rolling Resistance Co-Efficient

Due to the design of the vehicle, the aerodynamic drag from the wheels can vary due to the hub or the size, finally, most of the tyre losses can be from the tyre rubber element. Rubber has both viscous and elastic response to deformation, viscous is proportional to the rate of deformation and the elastic response is proportional to the amount of deformation. Visco-elastic material also has a property of hysteresis which means the material relaxation takes more time than material compression time.

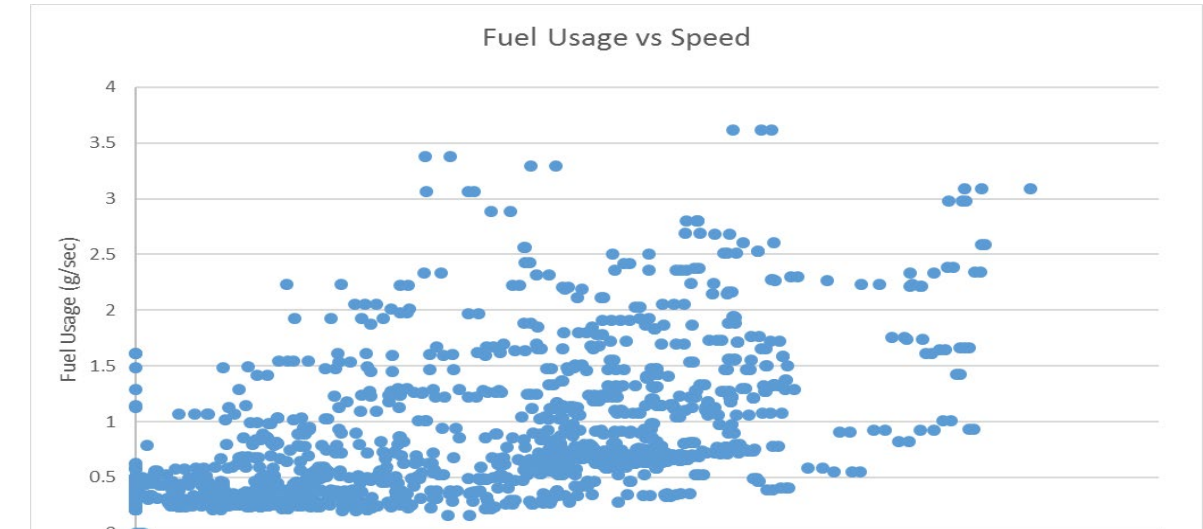
14.6.6 Briton Ferry



Appendices Graph 35 Briton Ferry Average Speed



Appendices Graph 36 Briton Ferry Average Speed and Total Fuel Used



Appendices Graph 37 Briton Ferry Fuel Usage vs Speed

14.6.7 Resistance to Motion

The total resistance to motion is the sum of rolling resistance, aerodynamic drag and climbing resistance. In order to overcome this resistance a sufficient amount of motive force needs to be applied to the wheels.

14.6.8 Drag Co-Efficient Derivation

$$F_{Aero} + \mu \times V_{Mass} \times g \times \cos\theta - V_{Mass} \times g \times \sin\theta = V_{Mass} \times Deceleration$$

The incline is $M \times g \times \sin\theta$ and the rolling resistance is the $\mu \times mass \times g \times \cos\theta$

Due to the altitude implications, we are assuming that the slope is therefore $\sin\theta$ becomes 0.

$$Approx: \cos\theta \text{ is } 1. F_{Aero} + \mu \times V_{Mass} \times g \times \cos\theta = V_{Mass} \times deceleration$$

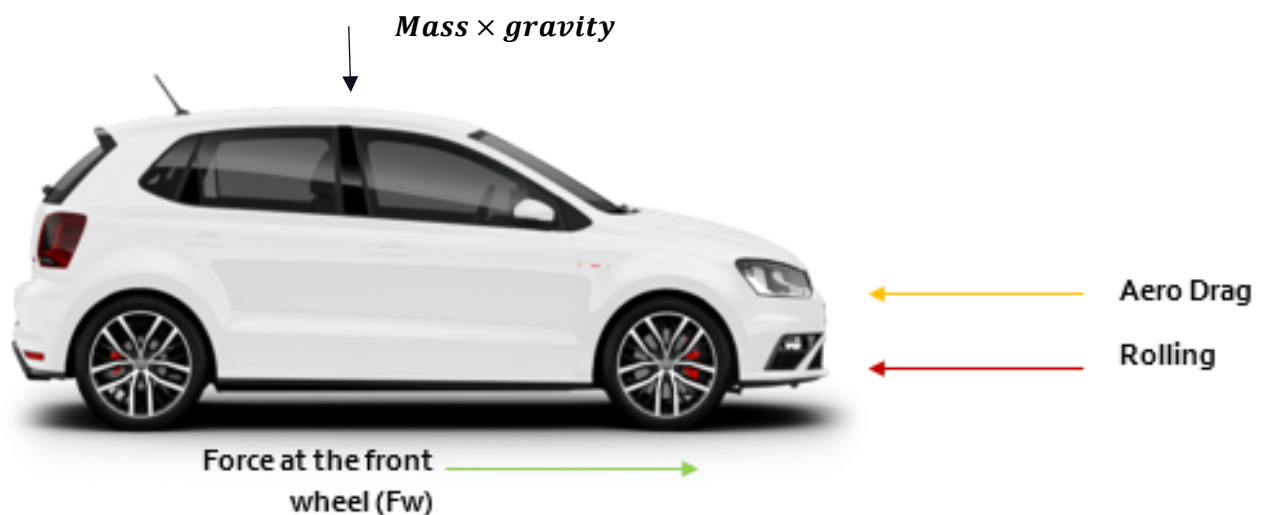
$$F_{Aero} + \mu \times V_{Mass} \times g = M \times deceleration$$

$$\frac{1}{2} \rho C_D F_{Aera} V^2 + \mu \times V_{Mass} \times g = V_{Mass} \times deceleration$$

The drag co-efficient needed to be calculated for every second.

$$\frac{1}{2} \rho C_D F_{Aera} V \frac{dv}{dt} + 0 = V_{Mass} \times \frac{d}{dt} (dec)$$

$$\rho C_D F_{Aera} = \frac{V_{Mass} \times \frac{d}{dt} (dec)}{V \frac{dv}{dt}}$$



$$Fw - Rolling Resistance - Aero Drag = Mass \times Acceleration$$

Appendices Figure 5 Force at the Wheel Diagram

14.6.9 Stop/Start and Fuel Cut Off Technology

When the car comes to a stop, the ECU will cut off supply to the spark and the fuel injectors. There is a sensor on the brake or clutch pedal that tells the ECU when the driver has let off the pedal, which then allows the engine to fire back up. A bigger battery is required to start the engine instantly and with an increase of on and off cycling. The stop and start system is there to reduce the amount of time the engine is idling, therefore aiding the reduction in fuel consumption. Stop and start technology has become more common due to stricter fuel economy and emissions regulations.

14.6.10 Other Factors Affecting Fuel Consumption

14.6.9.10.1 Vehicle Mass

The mass of vehicles is one of the main factor that manufacturers concentrate on for aiding decrease of fuel consumption, especially under low velocity loads.

The operating mass of a vehicle is defined in the NEDC of an empty vehicle. There have been many deceitful methods in testing to reduce the weight of vehicles, such as disabling of auxiliary systems (Stenner & Lienkamp, 2014). Some manufacturers disabled units like air conditioning and other heating elements that reduced the fuel consumption by around 0.5 – 1 litre of fuel (Stenner & Lienkamp, 2014).

For a given mass value for the NEDC it then gives an inertia value therefore setting a class for the vehicle. More power is needed to accelerate the vehicle through the acceleration phases during the drive cycle and rolling resistance is increased proportionally. The average weight for passenger cars is 1340-1400kg. In general weight reduction is meant to reduce fuel consumption by 5-10%.

The NEDC reports a linear relationship between mass reduction and fuel consumption, decrease in vehicle weight can lead to 8-6% of fuel decrease.

An additional 100kg increases fuel consumption by an average of 57% for a medium sized car of 1500kg. Weight reduction can also be linked to powertrain characteristics such as engine power. With lighter vehicles and component efficiency improvements the peak power could further be reduced over time leading to fuel consumption improvements.

A 10% weight reduction can improve fuel economy by 48% depending on engine downsized to maintain engine performance. Load carrying vehicles can add up to 5.6% increase with a 50% of the mass equal.

14.6.9.10.2 Aerodynamic Resistance

As aerodynamic resistance is linear dependent, the tests are performed in lighter air, therefore suiting a higher altitude and higher temperature.

14.6.11 Air: Fuel Ratio

Below is the beginning of a CO₂ calculator. The author wanted to calculate the CO₂ when the air: fuel ratio was lean and when rich to provide accurate data. However due to time this couldn't be achieved.

										If stoich and lean, 114kg of fuel produces 352kgCO ₂ kg. When the ratio is lean or stoich, you burn the fuel fully to		kg/sec				Total g	Total km	Total g/km of CO ₂ (lean)
										1956	37.93 Lean	1708.4	18.3165313	93.27169164		1708.4	18.3165313	93.27169164
										1214.00	62.0524 Rich	1708.4	18.3165313	93.27169164		1708.4	18.3165313	93.27169164
										742.00		1708.4	18.3165313	93.27169164		1708.4	18.3165313	93.27169164
										Lean								
Air/Fuel Ratio	Fuel Equiv	Fuel Equiv Lean		CO ₂	H ₂ O	N ₂	O ₂	1 kg of CO ₂	Fuel flow rate(gm/sec)	Fuel flow rate(kg/sec)	CO ₂ /sec	GPS Speed m/s	Throttle Position/Manifold(%)	Fuel Equiv Ric				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.324375	0.000324375	0.001	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.324375	0.000324375	0.001	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.31275	0.00031275	0.001	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.31275	0.00031275	0.001	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.329125	0.000329125	0.001	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.329125	0.000329125	0.001	0	4.31	0.00	0.00				
14.92	0.98	0.98	1.00	7.88	8.86	47.00	3.087719298	0.3215	0.0003215	0.001	0	4.31	0.00	0.00				
14.92	0.98	0.98	1.00	7.88	8.86	47.00	3.087719298	0.3215	0.0003215	0.001	0	11.75	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.444875	0.000444875	0.003	0	11.75	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.444875	0.000444875	0.003	0	13.73	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.8395	0.0008395	0.0036	0	13.73	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	1.214125	0.001214125	0.0037	0	9.02	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.88	47.00	3.087719298	1.214125	0.001214125	0.0037	0	5.88	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.443375	0.000443375	0.0014	0	5.88	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.443375	0.000443375	0.0014	0	4.71	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.376625	0.000376625	0.0012	0	4.71	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.376625	0.000376625	0.0012	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.376625	0.000376625	0.0012	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.392125	0.000392125	0.0012	0	8.63	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.88	47.00	3.087719298	0.392125	0.000392125	0.0012	0	8.63	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.493	0.000493	0.0015	0	7.06	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.493	0.000493	0.0015	0	7.06	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.88	47.00	3.087719298	0.4155	0.0004155	0.0013	0	4.71	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.88	47.00	3.087719298	0.4155	0.0004155	0.0013	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.88	47.00	3.087719298	0.361375	0.000361375	0.0011	0	4.31	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.63375	0.00063375	0.002	0	11.94	0.00	0.00				
14.92	0.99	0.99	1.00	7.88	8.87	47.00	3.087719298	0.63375	0.00063375	0.002	0	11.94	0.00	0.00				
14.92	0.98	0.98	1.00	7.88	8.86	47.00	3.087719298	1.480125	0.001480125	0.0046	0	11.94	0.00	0.00				
14.92	0.98	0.98	1.00	7.88	8.86	47.00	3.087719298	1.480125	0.001480125	0.0046	0	10.2	0.00	0.00				
15.15	0.97	0.97	1.00	7.76	8.73	47.00	3.087719298	1.27975	0.00127975	0.0039	0	10.2	0.00	0.00				
15.15	0.97	0.97	1.00	7.76	8.73	47.00	3.087719298	1.27975	0.00127975	0.0039	0	9.41	0.00	0.00				
15.45	0.95	0.95	1.00	7.61	8.56	47.00	3.087719298	0.627	0.000627	0.0019	0	9.41	0.00	0.00				
15.45	0.95	0.95	1.00	7.61	8.56	47.00	3.087719298	0.627	0.000627	0.0019	0	12.94	0.00	0.00				
15.01	0.92	0.92	1.00	7.35	8.36	47.00	3.087719298	0.64375	0.00064375	0.002	0	12.94	0.00	0.00				
14.23	1.03	0.00	0.00	0.00	0.00	47.00	0	1.559375	0.001559375	0	2.88455	10.59	0.00	1.03				
14.23	1.03	0.00	0.00	0.00	0.00	47.00	0	1.559375	0.001559375	0	2.88455	7.06	0.00	1.03				

Appendices Figure 6 CO₂ Calculations from Air:Fuel Ratio from OBD₂ Data

15. References

- AA, 2017. *Limits to improve air quality and health*. [Online]
Available at: <https://www.theaa.com/driving-advice/fuels-environment/euro-emissions-standards>
[Accessed 18 April 2018].
- ACEA, n.d. *What is the real driving emissions (RDE) test?*. [Online]
Available at: <http://www.caremissionstestingfacts.eu/rde-real-driving-emissions-test/>
[Accessed 12 04 2018].
- ARB, 2015. *On-Board Diagnostic II (OBD II) Systems - Fact Sheet / FAQs*. [Online]
Available at: <https://www.arb.ca.gov/msprog/obdprog/obdfaq.htm>
[Accessed 14 04 2018].
- Audi, 2009. *FSI*. [Online]
Available at:
https://web.archive.org/web/20090428151335/http://www.audi.co.uk/audi/uk/en2/tools/glossary/engine_driveline/fsi.html
[Accessed 4 2018].
- Bell, J., Treshow, M. & Colville, R., 2002. *Air Pollution and Plant Life*. Second Edition ed. Chichester: John Wiley & Sons Ltd.
- Bosch, 2014. *Automotive Handbook*. 9th ed. Germany: Robert Bosch GmbH.
- BrakeControl, 2014. *Baic Principles of Vehicle Dynamics*. s.l.:Springer.
- Canada, N. R., 2014. *Learn the facts: Cold weather effects on fuel efficiency*, Canada: Natural Resources Canada.
- carfolio, 2013. *Volkswagen Passat Variant 2.0 FSI Turbo, 2010*. [Online]
Available at: <https://www.carfolio.com/specifications/models/car/?car=218658>
[Accessed 14 04 2018].
- Contag, M. & Li, G., n.d. *How They Did It: An Analysis of Emission Defeat Devices in Modern Automobiles*, Germany: s.n.
- Cummins, n.d. *Turbo Technologies*. [Online]
Available at: <https://www.cummins.com/components/turbo-technologies/turbochargers/how-a-turbocharger-works>
[Accessed 4 2018].
- DieselNet, 2013. *ECE 15 + EUDC / NEDC*. [Online]
Available at: https://www.dieselnet.com/standards/cycles/ece_eudc.php
- dieselnet, n.d. *Emissions Standards United States*. [Online]
Available at: <https://www.dieselnet.com/standards/us/index.php>
[Accessed 12 04 2018].
- Docherty, I. & Shaw, J., 2008. *Traffic Jam. Ten years of "sustainable transport in the UK"*. Bristol: The Policy Press.

- EEA, 2016. *Explaining road transport emissions*. [Online]
Available at: <https://www.eea.europa.eu/publications/explaining-road-transport-emissions/file>
[Accessed 14 04 2018].
- Ejsmont, J., 2017. *Influence of temperature on the tyre rolling resistance*, s.l.: SpringerLink.
- EuropeanCommunities, 1998. *DIRECTIVE 98/69/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC*. [Online]
Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31998L0069:EN:HTML>
[Accessed 14 04 2018].
- EuropeanUnion, 2018. *Climate action*. [Online]
Available at: https://europa.eu/european-union/topics/climate-action_en
[Accessed 04 2018].
- Fontaras, G., Georgios Zacharof, N. & Ciuffo, B., 2016. *Fuel consumption and CO₂ emissions from passenger cars in Europe - Laboratory versus real-world emissions*. s.l.:Elsevier Ltd.
- FordMotorCompany, 2012. *125PS_C344_TJ01A_o2_Non_PATS_200Nm_CM13929*, s.l.: Ford.
- FordMotorCompany, 2012. *FORD FOCUS 1.0-LITRE ECOBOOST SPECIFICATIONS*. [Online]
Available at:
https://media.ford.com/content/dam/fordmedia/Europe/en/2013/Features/The%20Ecoboost%20Engine/Focus1.0-litre%20EcoBoost_TechSpecs_EU.pdf
- George, N. & Kershaw, K., 2016. *Road Use Statistics Great Britain 2016*, s.l.: Department For Transport.
- GOV.UK, n.d. *Vehicle tax rates*. [Online]
Available at: <https://www.gov.uk/vehicle-tax-rate-tables/rates-for-cars-registered-on-or-after-1-march-2001>
[Accessed 14 04 2018].
- Heywood, J. B., 1988. *Internal Combustion Engine Fundamentals*. USA: McGraw-Hill Inc.
- Manahan, S. E., 2010. *Environmental Chemistry*. 9th Edition ed. USA: Taylor and Francis Group.
- Mcdonald, M., 2017. *Lecture Notes*. s.l.:s.n.
- McDonald, M., 2018. *Lecture Notes*. Swansea: s.n.
- peugeotlogic, n.d. *www.peugeotlogic.com*. [Online]
Available at: <http://www.peugeotlogic.com/info/info1.htm>
- Powers, J. M., 2014. [Online]
Available at: <https://www3.nd.edu/~powers/ame.60636/notes.pdf>
- Preda, I., Covaciu, D. & Ciolan, G., n.d. *COAST DOWN TEST– THEORETICAL AND EXPERIMENTAL APPROACH*, Romania: Transilvania University of Brasov.
- Pyefinch, J., 2015. *Fuel efficiency ratings | what do they tell you?*. [Online]
Available at: <https://www.carsguide.com.au/car-advice/fuel-efficiency-ratings-what-do-they-tell-you-31319>
[Accessed 04 2018].

- Pyefinch, J., 2015. *Fuel efficiency ratings | what do they tell you?*. [Online]
Available at: <https://www.carsguide.com.au/car-advice/fuel-efficiency-ratings-what-do-they-tell-you-31319>
[Accessed 4 2018].
- Sandbag, 2011. *What is emissions trading?*. s.l.:The Guardian.
- Sengerandu, 2013. *Resistance to motion*. [Online]
Available at: <https://sengerandu.wordpress.com/tutorials/automobile-engineering/resistance-to-motion/>
[Accessed 4 2018].
- Shibashis Ghosh, 2012. *Tire Rolling Circumference Calculation Example*. [Online]
Available at: <https://mechguru.com/vehicle-design/tire-rolling-circumference-calculation-example/>
[Accessed 11 04 2018].
- Stenner, P. & Lienkamp, M., 2014. *100 Tips to Beat the New European Driving Cycle (NEDC)*. [Online]
Available at: <file:///C:/Users/p141311/Downloads/100tipstobeattheNewEuropeanDrivingCycle.pdf>
[Accessed 12th April 2018].
- T J Barlow, E. a., 2009. *A Reference Book of Driving Cycles for Use in The Measurement of Road Vehicle Emissions*, s.l.: TRL Limited.
- thecarbonaccount, n.d. *What are carbon emissions?*. [Online]
Available at: <http://www.thecarbonaccount.com/carbonexplained/>
[Accessed 14 04 2018].
- Tietge, U., Díaz, S., Yang, Z. & Mock, P., 2017. *A COMPARISON OF OFFICIAL AND REAL-WORLD FUEL CONSUMPTION AND CO₂ VALUES FOR PASSENGER CARS IN EUROPE, THE UNITED STATES, CHINA, AND JAPAN*. [Online]
Available at: https://www.theicct.org/sites/default/files/publications/Lab-to-road-intl_ICCT-white-paper_06112017_vF.pdf
[Accessed 4 2018].
- turbobygarrett, n.d. *Air/Fuel Ratio tuning:Rich vs Lean*. [Online]
Available at: https://www.turbobygarrett.com/turbobygarrett/airfuel_ratio_tuning_rich_vs_lean
[Accessed 16 04 2018].
- Tutuianu, M. et al., 2013. *Development of a Worldwide harmonized Light duty driving Test Cycle (WLTC)*, s.l.: WLTP DHC Chair.
- ultimatespecs, 2009. *Volkswagen Passat CC CC R-Line 2.0 TSI 200HP Specs*. [Online]
Available at: <https://www.ultimatespecs.com/car-specs/Volkswagen/10448/Volkswagen-Passat-CC-CC-R-Line-20-TSI-200HP.html>
[Accessed 2018].
- ultimatespecs, n.d. *Audi A3 (8P) 1.6 Specs (2003)*. [Online]
Available at: [https://www.ultimatespecs.com/car-specs/Audi/686/Audi-A3-\(8P\)-16.html](https://www.ultimatespecs.com/car-specs/Audi/686/Audi-A3-(8P)-16.html)
[Accessed 14 04 2018].
- UnitedNations, 2013. *Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be fitted and/or be used on Wheeled Vehicles and the*

Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescript, s.l.:
UNITED NATIONS.

V5C, 2017. *UK Registration Certificate*. Swansea : DVLA.

Varghese, A., 2013. *Influence of Tyre Inflation Pressure on Fuel Consumption, Vehicle Handling and Ride Quality*, Sweden: CHALMERS UNIVERSITY OF TECHNOLOGY.

volkswagen, n.d. *WLTP New standards for consumption values*. [Online]
Available at: <http://www.volkswagen.co.uk/owners/wltp>
[Accessed 16 04 2018].