

An Investigation into How Current Engines May Perform in the Future Proposed WLTP Drive Cycle

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1. Abstract

This paper researches and models how vehicles and engines will perform in the new and upcoming Worldwide Harmonized Light Vehicles Test Procedure (WLTP) compared to the current New European Drive Cycle (NEDC). A model will be created to calculate engine and vehicle performance throughout both cycles, these tests will vary in vehicle specifications to improve fuel consumption usage throughout the tests. These changes will be made on aerodynamic resistance, weight of the vehicle and gear ratios. With these changes being made, it will be shown that reduction in aero resistance and weight, as well as installing carefully selected gear ratios, will benefit the fuel consumption of the vehicle. The main outcome of this report is comparing a modern downsized 1.0 litre engine compared to a standard 2.0 litre engine and how these engines vary in fuel consumption changing from the NEDC to the WLTP. As the downsized engines were designed for the NEDC the larger 2.0 litre engine performs poorer in the NEDC cycle, however, even though the downsized engine still out performs in the WLTP, the fuel consumption did rise slightly where the 2.0 litre fuel consumption decreased.

2. Introduction

This report will consider the current drive cycle test and the future drive cycle test. A drive cycle is a compulsory test that is carried out on all production cars. It is used to measure the vehicles fuel consumption and exhaust emissions. It is these results that determine if the vehicle passes the regulations type approval for pollutant emissions and verify the manufacturers book data to determine their vehicle's fuel efficiencies and average emissions for road taxing purposes.

There are multiple drive cycles created for different country regulations. This report will be considering the European Drive Cycle (NEDC) and the future proposed Worldwide Harmonized Light Vehicles Test Procedure (WLTP). The USA and Japan also have their own cycles, the FTP 75 and 10-15 Mode respectively, but will also be replaced with the new WLTP. The NEDC is a combined test of two previously used test cycles, where the combined test was officially used from 1990 as a standardised test across Europe. The WLPT is currently under construction and was originally planned to be released in 2017 and used as a global harmonized test for all passenger cars and light commercial vehicles. The NEDC has come under a lot of criticism for it not representing a real-world driving cycle. Therefore, the WLTP was to be the new cycle, giving a more realistic drive cycle which in turn makes the test a more realistic outcome.

The purpose of this report will be to then create a computational model of both cycles and produce a series of fuel consumption predictions of how vehicles and varying engines will compare between the current and future cycle. Thus providing results to show how current downsized engines tuned for the NEDC will fair in the new WLTP along with how older, larger engines also vary between the two.

3. Background and Research of Drive Cycles

Drive cycle testing has been performed for many years to provide EU type approval in regard to emissions and fuel usage. The first European urban drive cycle test was first arranged back in 1958 when UNECE regulation 85 was composed. This was written for the proposal for the ECE 15 cycle that tested low speed urban driving with an average speed of only 18.35 kph (UNECE 1958). The test would be used later in 1970 for emissions testing when the UNECE released directive 70/220/EEC. The ECE 15 would also then go on to be part of the NEDC. There are also many other drive cycles that have been created throughout the world designed for their own emission laws. The current drive cycles being used to measure emissions from the exhaust, to type approve new vehicles to ensure they have met any current emissions regulations, which become harder to meet as they are updated. Therefore, all new vehicles are designed around current or future drive cycles to ensure their vehicles meet the regulations. This can be seen in current cars where most manufacturers are turning to smaller engines that have been fitted with forced induction to improve low load demand efficiency.

3.1 New European Drive Cycle (NEDC)

The NEDC is the current drive cycle being implemented throughout Europe to test new vehicles to ensure they meet the European emission regulations. The NEDC was the official test procedure from 1996 is made up of two types of drive cycles: the ECE 15 (as mentioned earlier) and the Extra Urban Drive Cycle (EUDC) which was created in 1990. The ECE 15 is repeated four times then directly followed by the EUDC as can be seen below in Figure 1 of the drive cycle's official speed trace. The full test procedure is defined in UN Regulation 101. The test is carried out under laboratory conditions with controlled room temperatures and on a rolling road.

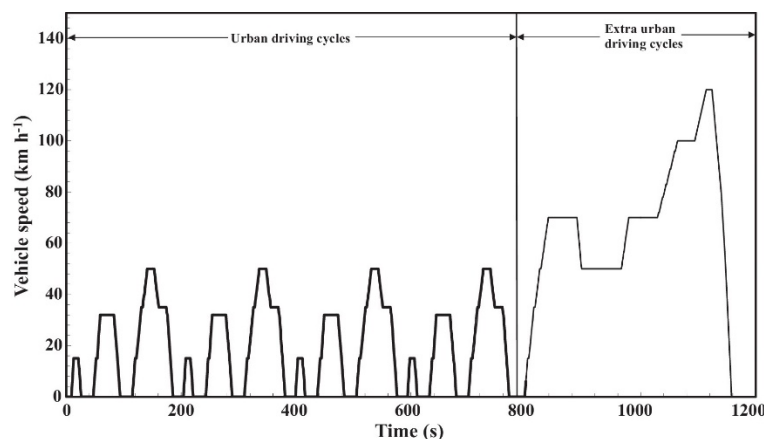


Figure 1: NEDC speed trace, highlighting the two phases (Robinson 2013)

During the NEDC test, the main results that are gathered for public advertisement are the urban fuel economy, extra urban fuel economy, overall fuel economy and CO emissions. Where the urban fuel economy is gathered from the four repetitive ECE 15 stage and the extra urban from the higher speed EUDC stage. In the following table shows the characteristics of the ECE 15, EUDC and NEDC.

Table 1: Characteristics of the phases throughout the NEDC (DieselNet 2017).

Characteristics	Unit	ECE 15	EUDC	NEDC†
Distance	km	0.9941	6.9549	10.9314
Total time	S	195	400	1180
Idle (standing) time	S	57	39	267
Average speed (incl. stops)	kph	18.35	62.59	33.35
Average driving speed (excl. stops)	kph	25.93	69.36	43.10
Maximum speed	kph	50	120	120
Average acceleration ¹	m/s ²	0.599	0.354	0.506
Maximum acceleration ¹	m/s ²	1.042	0.833	1.042
† Four repetitions of ECE 15 followed by one EUDC				
¹ Calculated using central difference method				

This cycle was originally designed to show an accurate representation of how the average light passenger vehicle was driven throughout Europe. However, this view has changed through recent years as the test has now been subject to criticism for being unrealistic and needs to be replaced. It is also described as being outdated as the last update on the test was made twenty years ago (1997). It can be seen straight from the table above; the vehicle must be stationary for 267 seconds during the test, that's almost 23% of the total test. This was promptly taken advantage of when manufacturers introduced stop/start technology, which turned the vehicle off during these stationary periods, therefore producing zero emissions during these stages through the test (Fonseca 2009).

Referring to the table and the speed trace, the maximum acceleration only extends to 1.042 ms⁻² and is performed in a linear manner. Acceleration and deceleration would rarely be performed linearly throughout a journey, the constant speeds are also an unnatural condition in the real world, all these conditions would naturally be inconsistent on the real road. However, the main speeds reached in the NEDC, being 30, 50, 70, 100 and 120 kph (18.6, 31, 43.5, 62.1 and 75 mph), are used from speed limits

around Europe. Although with many people using motorways now travelling at roughly the 120 kph target, during the NEDC it only reaches this speed for 12 seconds (1.02% of the test). Therefore, the target speeds are accurate to that of the speeds used on the road; however not reached in the same ways nor an accurate representation of maintaining a perfectly steady speed.

Another challenge for manufacturers is there is no longer a warm up period at the start of the cycle, this means all the tests must be carried out from a 'cold start'. To determine an accurate and even cold start for every vehicle, the regulations state that a vehicle must be kept in a temperature controlled room, between 20°C to 30°C, for at least 6 hours. This is to ensure that both the engine oil and coolant temperatures are within 2°C of the controlled room temperature. This challenge now requires the manufacturers to tune for an economical warm up phase in the engine; this is due to catalytic converters not being able to operate properly until they reach their operational temperatures at about 650°C (AA1 2017). Requiring manufacturers to come up with a special warm up strategy to get everything to working temperature as quickly as possible. Plus, due to a cold engine, the cold cylinder wall quenching will cause increased hydrocarbons due to inefficient flame speeds and temperatures (Flagan 1988).

Due to the test being a repetition and an unrealistic driving style, manufacturers have been known to cycle cheat. These cycle cheating claims have even gone to the point of programming vehicles to understand when they are on a drive cycle test and then running a completely different engine strategy to reduce emissions (Kageson 1998). One way of doing this was to increase the EGR percentages during the drive cycle then turn it off once out of the cycle. A simple cycle strategy can be seen below from Ford, where the area in which the engine is operating during the drive cycle has been highlighted. The EGR slowly drops off as the load increases, until its halfway into the drive cycle region, then the percentage drops down a lot quicker as it is no longer needed to reduce emissions. This strategy is done fairly, compared to some manufacturers that have turned it off completely once out of the drive cycle region.

Passat With Ford 999cc EcoBoost Engine EGR% Chart Showing The Area of the NEDC Operation																
RPM	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
Torque (Nm)																
200						0.8	0.8	1.0	1.4	1.8						
190						0.8	0.9	1.1	1.5	1.8						
180					0.4	0.9	0.9	1.1	1.5	1.9	2.2					
170				0.1	0.2	1.0	1.0	1.2	1.6	2.0	2.2	2.7				
160				0.2	0.2	1.1	1.1	1.3	1.7	2.0	2.2	2.6	3.0			
150				0.2	0.2	1.2	1.2	1.3	1.8	2.2	2.3	2.6	3.1	3.3		
140			0.2	0.2	0.3	1.0	1.2	1.3	2.1	2.4	2.6	2.7	3.1	3.4	3.6	
130			0.3	0.3	0.5	1.1	1.2	1.5	2.3	2.5	2.7	2.9	3.2	3.4	3.7	
120			0.3	0.5	0.8	1.2	1.4	1.7	2.5	2.7	2.9	3.0	3.2	3.5	3.8	4.2
110		0.6	0.5	0.8	1.0	1.3	1.5	1.9	2.6	3.0	3.1	3.1	3.2	3.7	3.9	4.3
100		1.1	0.9	1.1	1.4	1.6	1.8	2.1	2.8	3.4	3.4	3.3	3.3	3.7	4.1	4.5
90		1.8	1.5	1.8	2.1	2.5	2.5	2.8	3.4	3.8	3.6	3.6	3.4	3.7	4.2	4.5
80		3.5	3.0	3.2	3.3	3.2	3.5	4.7	4.9	4.6	4.3	4.1	3.6	3.8	4.4	4.6
70		5.7	5.4	6.0	6.0	5.7	6.5	6.9	6.7	6.2	5.6	5.4	4.2	4.2	4.6	4.8
60		9.7	9.9	10.0	9.9	10.3	10.4	9.4	9.0	8.5	8.0	7.6	5.5	4.6	5.0	5.1
50		14.1	14.7	14.7	14.4	14.6	14.2	12.9	11.5	11.1	10.3	9.6	7.3	5.1	5.4	5.6
40	18.6	18.1	18.4	18.6	19.8	19.5	17.0	15.2	15.1	14.3	12.7	11.2	8.9	5.7	5.9	6.0
30	19.9	19.3	18.6	20.7	21.7	21.3	18.6	16.5	17.7	17.1	14.2	12.5	10.6	6.7	6.7	6.7
20	20.6	19.0	19.0	20.1	19.8	19.5	18.5	17.4	18.0	17.2	15.5	13.1	11.4	8.6	8.3	8.2
10	25.6	24.7	23.4	23.1	21.9	21.3	21.4	21.8	19.9	17.9	16.5	14.5	13.3	11.7	10.8	10.4
5	28.0	27.8	26.1	25.7	23.9	23.8	23.7	24.0	21.7	19.7	17.2	16.1	14.9	13.4	12.8	12.1
2	33.3	29.1	27.3	27.6	26.2	25.8	25.2	25.3	23.1	21.3	18.3	17.3				

Figure 2: Image showing the area of where the NEDC operates in relation to the EGR%

Along with cycle cheating there are reasonably large tolerances, the regulation allowed that the operator can manipulate. During the test, the operator can deviate from the target trace by $\pm 2\text{ km/h}$ and $\pm 1\text{ s}$ as shown in figure 3. Although the test is carried out by an official, the manufacturer still needs to tune for the $\pm 2\text{ km/h}$ variant throughout the test.

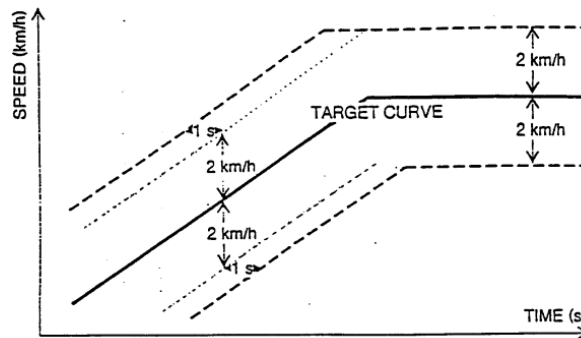


Figure 3: Displaying the tolerances allowed through the cycle (UNECE 2005)

Other tolerances from this regulation state the dynamometer being used to measure the vehicle can have a tolerance of 10% for speeds below 20kph and 5% for speeds above 20kph.

3.2 Worldwide Harmonized Light Vehicles Test Procedure (WLTP)

Due to the varying emissions laws across the world, manufacturers were required to create several variants of their vehicles to abide by varying regulations and to perform well in the different drive cycles. Therefore in 2007 the UNECE decided to start work on a new Worldwide drive cycle (known as the WLTP) for light vehicles (Tutuianu 2013). This new cycle has been designed to overcome the criticisms made towards the NEDC and make a more realistic test where stationary time has been majorly cut down and there are no extended periods of constant speed; the test is made up of constant fluctuating speeds throughout. The sections in the WLTP are made up of four sections: low, medium, high and extra high. Like the NEDC these sections are aimed at real world speed limits, however, the WLTP is based on real world collected data to give a more accurate representation of how the average vehicle is driven. This is necessary as once again the vehicle is tested in laboratory conditions on a rolling road. Below is a table of characteristics throughout the WLPT in comparison to the NEDC.

Table 2: Comparison of the characteristics between the cycles (Mast 2014)

Phase	WLTP - Class 3					NEDC		
	Low	Medium	High	Extra High	Total	Urban	Extra Urban	Total
Duration (s)	589	433	455	323	1800	780	400	1180
Stop Duration (s)	156	48	31	7	242	240	38	278
Stops (%)	26.5	11.1	6.8	2.2	13.4	30.77	9.55	23.6
Distance (km)	3.095	4.756	7.158	8.254	23.262	3.976	6.955	10.93
Max. Speed (kph)	56.5	76.6	97.4	131.3	131.1	50	120	120
Avg. Speed w/o Stops (kph)	25.7	44.5	60.8	94	53.8	25.93	69.36	43.1
Avg. Speed with Stops (kph)	18.9	39.5	56.6	92	46.5	18.35	62.59	33.35
Max. Acceleration (ms^{-2})	1.5	1.6	1.6	1	1.6	1.042	0.833	1.042
Avg. Acceleration (ms^{-2})	0.48	0.44	0.37	0.3	0.41	0.64	0.35	0.528

It is evident that the acceleration values are more accurate than of that found in the NEDC, in fact the WLTP maximum acceleration is 53.6% higher than that in the NEDC. The average speed throughout the entire test (including stops) is 39.4% higher in the WLTP. Below is the direct comparison of the two cycles, showing how the accelerations, decelerations and speeds are shown as a more realistic trace.

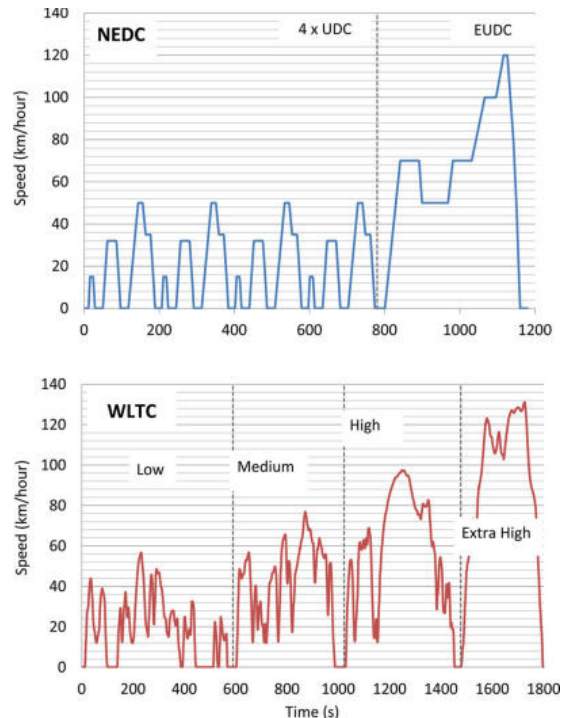


Figure 4: Comparison of the NEDC and WLTP (Marotta 2015)

To ensure the WLTP drive cycle was an accurate representation of real world driving, over 765000 km of data was collected from five different regions to process real world speed traces across urban, rural and motorway driving. Even to the point where the extreme acceleration in the extra high phase is used to represent acceleration up a slip road onto the motorway (Tutuianu 2013). The accelerations and top speeds have been designed to ensure all vehicles can reach these targets, however three groups have been produced, therefore vehicles that fall into the two first 'down scale procedure' sections will have a slower acceleration and decreased top speed to match the vehicle specifications, to be eligible for these test conditions the rules are as follows for the ratio between power and kerb mass (pmr) (Tutuianu 2013):

1. Class 1: $\text{pmr} \leq 22 \text{ W/kg}$,
2. Class 2: $22 \text{ W/kg} < \text{pmr} \leq 34 \text{ W/kg}$,
3. Class 3: $\text{pmr} > 34 \text{ W/kg}$.

This will then allow the manufacturers to enter their vehicles into the following WLTP versions:

Table 3: Comparing the class versions of the WLTP (Tutuianu 2013)

Vehicle Class	Cycle Version	Max. Velocity for Cycle Phase (kph)			
		Low	Medium	High	Extra High
1	2	49.1	64.4		
2	2	51.4	74.7	85.2	123.1
3	5.1/5.3	56.5	76.6	97.4	131.3

Where vehicles falling into class one will be eligible to be exempt from the high and extra high phases. For the purpose of this report, only the third vehicle class will be used as this is the class most European cars will be eligible for.

Like with the NEDC, the test vehicle must be stored in a temperature controlled room before the test, however this time the rules are stricter. The 'soak' room must be at a temperature of 23°C and must not deviate more than 3°C, the car is to be soaked in this room for a minimum of 6 hours and a maximum of 36 hours with the aim of the oil and coolant temperatures being within 2°C of the rooms set temperature. The test cell in which the cycle is carried out must also be at a temperature of 23°C and must not deviate by 5°C (UNECE 2014). This will again give the manufacturers the same issue with initial cold running procedures during the start of the cycle, however, due to the extended period of the test, the poor initial emissions due to the cold running issues will average out. General measuring equipment must also have tighter tolerances which is a substantial change compared to the wider

tolerances of the previous NEDC regulations. These range from tyre pressure monitoring to vehicle speed monitoring.

Due to the WLTP now requiring vehicle specifications and gear change strategies, several inputs are now required from manufacturers for the calculations:

- P_{rated} - rated engine power. The maximum power of the engine as declared by the manufacturer.
- s - rated engine speed. The engine speed at which an engine develops its maximum power. If the maximum power is developed over an engine speed range, s is determined by the mean of this range.
- n_{idle} - idling speed
- n_{min_drive} - minimum engine speed for short trips, and is used to define downshifts. The minimum value is determined by the following equation:

$$n_{min_drive} = n_{idle} + (0.125) \times (s - n_{idle})$$

Higher values can be used if requested by the manufacturer.

- $i = 1$ to ng_{max} determine the gear number
- ng_{max} - the number of gears
- ndv_i - a ratios determined by dividing n in min^{-1} by v in km/h for each gear i , $i = 1$ to ng_{max} .
- m_t - test mass of the vehicle in kg .
- f_0, f_1, f_2 , driving resistance coefficients.
- Full load power curve, normalized to rated power and (rated speed – idling speed).

(Tutuianu 2013)

The regulation then goes on to state how the calculations are to be carried out. These calculations will then be rewritten in the methodology from first principles for ease of understanding. There are three main calculations needed to determine gear strategies, these calculations are to identify the available power at any point of vehicle operation, the required power to overcome all forces on the car at any point of the cycle and the engine speeds.

The power required for every second (j) of the cycle is to be calculated with the regulations given equation:

$$P_{required,j} = \frac{f_0 \times v_j + f_1 \times (v_j)^2 + f_2 \times (v_j)^3}{3600} + \frac{(kr \times a_j) \times v_j \times m_t}{3600}$$

Where:

$P_{\text{required}, j}$ is the required power in kW at any second j

f_0 is the road load coefficient, N

f_1 is the road load parameter in relation to velocity, N/kph

f_2 is the road load parameter in relation to velocity², N/kph²

v_j is the vehicle velocity at any second j , kph

K_r is a factor taking the inertial resistances of the drivetrain during acceleration into account and is a value of 1.1

a_j is the vehicle acceleration at any second j , ms⁻²

m_t is the vehicle mass, kg

(Tutuianu 2013)

Determining engine speeds is the next step, to start with. For every moment, the velocity is less and equal to 1kph the gear lever is to be in the neutral position and the clutch to be engaged. When the vehicle velocity is greater than 1kph the engine speed is to be calculated with the equation:

$$n_{i,j} = n_d v_i \times v_j$$

(Tutuianu 2013)

When the regulation states; $n_{\min} \leq n_{i,j} \leq n_{\max}$, if a gear selection allows this to be met, it is a possible choice of gear to be used. Where:

$$\begin{aligned} n_{\min} &= n_{\min_drive} \text{ if } i \geq 3 \\ &= 1.25 \times n_{idle}, \text{ if } i = 2 \\ &= n_{idle}, \text{ if } i = 1 \\ n_{\max} &= 0.9 \times (s - n_{idle}) + n_{idle} \end{aligned}$$

(Tutuianu 2013)

If at any time the engine speed drops below the idle speed, it will be assumed the only possible gear for this to happen will be 1st and the clutch will be disengaged, only if the vehicle velocity is below or equal to 1kph.

The last step for the gear calculations is to work out the available power for every available gear at every vehicle velocity throughout the cycle trace. This equation given for this is:

$$P_{available,ij} = P_{norm_{wot}}(n_{norm_{i,j}}) \times P_n \times SM$$

Where:

$$n_{norm_{i,j}} = (ndv_i \times v_j - n_{idle}) / (s - n_{idle})$$

$P_{norm_{wot}}$ is a percentage of rated power available at $n_{norm_{i,j}}$ at full load from the full load power curve.

P_n is the rated power of the vehicle, kW.

SM is a safety margin to account for the difference between the full load conditions in a stationary situation and transient situation, this will be 0.9.

As stated the power calculations will be carried out from first principle in the methodology section, and will be carried out in different steps.

There is also a further section in the regulation that determines additional corrections and modifications that need to be carried out within the gear calculator. This determines the orders of gear sequences and stops the use of constant gear changing in a certain amount of time. These rules can be found in appendix 12.4 and will be implemented into the models gear calculator.

4. Aim of the Project

The aim of this project is to see how a downsized engine, which was designed for the NEDC, will perform in the new WLTP. And how a larger sized engine will perform in the WLTP. The results gathered will be the fuel consumption and the calculated BSFC values at each second of the test. The fuel consumption results will show how well the engine performs throughout the test. The BSFC values will also provide the information to show where the engine is running in a BSFC map to enable a better understanding of why the engines are using an increased or decreased amount of fuel.

A BSFC map can show where an engine is at its most efficient, as well as showing where it is least efficient. Pin pointing the BSFC values at each second from the cycles on the BSFC maps can be used to illustrate when and for how long the engines are operating at their peak efficiency and when they are running in their pumping loss region.

This now gives another main aim of the project of proving an engines inefficiency while running in the pumping loop region. While trying to show a larger engine will run better compared to a lower speed test as the throttle will be more open, therefore requiring a higher torque demand and running in an improved BSFC region.

5. Chosen Vehicle and Engines to be Used

The Volkswagen Passat will be the vehicle of choice, but the engine will be changed to show the varying effect the engine makes on the fuel consumption in the tests. The Volkswagen will then have a 10% change made to the specifications to show evidence how minor changes can also effect the fuel consumption throughout the tests.

5.1 Volkswagen Passat with 2.0 Litre Engine

This will be the base vehicle to test the accuracy of the model as all the data has been provided for this vehicle and its NEDC results (MAHLE 2017). Below is the following information needed from the vehicle to model the cycles.

Table 4: Vehicle Specifications for the Volkswagen Passat, with further data required for the calculation inputs.

Volkswagen Passat Vehicle Specifications	
Vehicle Mass (kg)	1650
Engine Displacement (cc)	1984
Wheel Rolling Radius (m)	0.318
Engine Idle (RPM)	800
Engine Inertia (kgm ²)	0.15
Frontal Area (m ²)	2.235
Wheel Inertia (kgm ²)	0.8
Rolling Resistance Coefficient	0.0145
Drag Coefficient	0.38
Gravity (ms ⁻²)	9.81
Air Density (kg/m ³)	1.2

Table 5: Volkswagen Passat 6 speed gearbox ratios and efficiencies.

Volkswagen Gear Specifications		
Gears	Efficiency	Ratio
1	94%	3.36
2	94%	2.09
3	95%	1.47
4	97%	1.1
5	97%	0.87
6	96%	0.73
Final Drive	94%	3.94

5.2 Volkswagen Passat with 1.0 Litre Ford Engine

For this setup, the vehicle data will be kept the same, except for the engine capacity, which is changed to 999cc. All the engines; power, BSFC and fuelling data has been extracted from a pdf file of the engines test data (Ford 2012). With the 1L engine installed to the Passat both the Passat gear ratios and ford gear ratios will be used for a comparison.

Table 6: Ford Fiesta 5 speed gearbox ratios and efficiencies (Ford 2012).

Ford Fiesta Gear Specifications		
Gears	Efficiency	Ratio
1	94%	3.582
2	94%	1.926
3	95%	1.281
4	97%	0.951
5	97%	0.756
Final Drive	94%	4.25

For the tests being carried out, these will be the base model specifications used for both tests, then changes will be made to lower the vehicle mass by 10%, extend the gear ratios by 10% and reduce the frontal area by 10%. This will then show how each main area of the vehicle specifications effect the overall out come on fuel usage.

6. Methodology

This section explains how the models were made to provide accurate predicted data of how a vehicle may perform in the drive cycles. All the cycles rules must be met and calculations followed, however, for simplicity the calculations will be shown from first principle to help understand the cycle regulations.

The NEDC will be the first to be modelled as this cycle stipulates what gear the vehicle must be in and when. Actual fuel consumption data from the NEDC has been provided by MAHLE Powertrain for the Volkswagen Passat 2.0 TDI. This will then allow the accuracy of the model to be calculated to ensure the calculations are working throughout.

Now the WLTP cycle can be modelled following the same calculations but with the extended time and new vehicle speed trace. The only other difference is the need of a gear calculator as this variable is now dependant on the vehicles power and is restricted to certain rules which will be discussed further.

6.1 Excel NEDC Model

For the model, each calculation will have its own column, therefore providing the calculations and results for every second of the cycle. This will also aid in analysis of the results to show how the performance throughout varies and where fuel is mainly used. The first three columns are: time in seconds, required gear and vehicle speed in kilometres per hour (kph), these three columns are stipulated by the NEDC regulations.

The following columns are then all the necessary calculations steps needed to calculate the fuel consumption. These steps are as follows, along with their calculations:

Vehicle speed conversion from kph to meters per second (ms^{-1}):

$$= kph \times \frac{1000}{3600}$$

Acceleration (ms^{-2}):

$$= \text{Vehicle speed at time}_i - \text{vehicle speed at time}_{i-1}$$

Wheel Velocity in revolutions per second (Revs/s):

$$= \frac{Vehicle\ Speed\ (ms^{-1})}{2 \times \pi \times Wheel\ Rolling\ Radius}$$

Wheel Velocity in revolutions per minute (RPM):

$$= Wheel\ Velocity\ (Revs/s) \times 60$$

Wheel Velocity in Radians/Second (Rads/s):

$$= (Wheel\ Velocity\ (Revs/s) \times 360) \times \left(\frac{\pi}{180}\right)$$

Wheel Acceleration (Rads/Sec²):

$$= Wheel\ Velocity\ (Rads/s)\ at\ time_i - Wheel\ Velocity\ (Rads/s)\ at\ time_{i-1}$$

Wheel Force in Newtons (N), this is the total of the main forces the vehicle must overcome to move; the mass of the vehicle, the frictional rolling resistance and the aerodynamic resistance. An 'IF' statement is used to say if the vehicle speed is 0 then so is the wheel force, if the vehicle speed is not 0 it is as follows:

$$\begin{aligned} &= (Vehicle\ Mass \times Acceleration) \\ &\quad + (Vehicle\ Mass \times Gravity \times Rolling\ Resistance\ Coefficient) \\ &\quad + \left(\frac{1}{2} \times Air\ Density \times Drag\ Coefficient \times Frontal\ Area \times Velocity^2\right) \end{aligned}$$

Wheel Torque in Newton Meters (Nm):

$$= Wheel\ Force \times Wheel\ Rolling\ Radius$$

Driveshaft Torque (Nm) for total of two shafts and wheel torque:

$$= Wheel\ Torque + (2 \times Wheel\ Inertia \times Wheel\ Acceleration)$$

Differential Acceleration (Rads/s²) is equal to the wheel acceleration as this is the acceleration to drive the wheel acceleration.

Differential Output Torque (Nm) equals the same as the Driveshaft Torque, ignoring any inertial forces throughout the driveline. The Differential Input Torque (Nm) is then as follows:

$$= \frac{\text{Differential Output Torque}}{(\text{Final Drive Ratio} \times \text{Final Drive Ratio Efficiency})}$$

Again, ignoring the inertia forces throughout the drivelines, the Transmission Output Torque will equal the same as the Differential Input Torque

Transmission Input Torque (Nm) will need a series of 'IF' statements again as the torque at this point is now dependant on what gear the vehicle is in. Therefore, if the required gear is at 0 then the input torque is also 0. Then when the vehicle is in gear it is calculated as follows (again ignoring inertia forces throughout the gearbox):

$$= \frac{\text{Transmission Output Torque}}{(\text{Required Gear Ratio} \times \text{Required Gear Efficiency})}$$

Engine Velocity (RPM) is now dependant on vehicle speed and selected gear so 'IF' statements are used again, if the vehicle speed is 0 then the engine velocity must be the engines idle speed. The engine velocity can then be calculated as:

$$= \text{Wheel Velocity} \times \text{Final Drive Gear Ratio} \times \text{Required Gear Ratio}$$

Engine Velocity (Corrected RPM), this new corrected velocity is to replicate clutch slip as the vehicle cannot drop below its engine idle speed. Therefore, an 'IF' statement can be used to stipulate if the engine velocity is below the idle RPM it should be the idle RPM and if it is above the idle RPM it remains the same.

Engine Output Torque (Nm) is equal to the Transmission Input Torque.

Engine Angular Velocity (Rads/s):

$$= \text{Engine Velocity (Corrected RPM)} \times \frac{2\pi}{60}$$

Engine Angular Acceleration (Rads/s²):

$$= \text{Engine Angular Velocity at time}_i - \text{Engine Angular Velocity at time}_{i-1}$$

Extra Torque to Accelerate Engine (Nm) this is to account for the largest inertia force in the powertrain, being the flywheel and rotational engine components:

$$= \text{Engine Angular Acceleration} \times \text{Engine Inertia (kgm}^2\text{)}$$

Measured Dyno Torque (Nm):

$$= \text{Engine Output Torque} + \text{Extra Torque to Accelerate Engine}$$

BMEP (Pa):

$$= \frac{(\text{Measured Dyno Torque} \times (4\pi))}{(\text{Engine Displacement (cc)} \times 10^{-3})} \times 10^3$$

BMEP (Bar):

$$= \text{BMEP (Pa)} \div 10^5$$

Due to deceleration, some values for BMEP will calculate to be negative values. A negative BMEP is not possible, therefore a corrected BMEP column is made to stipulate if the BMEP (Bar) is below 0 it must be 0.

Fuel Usage (g/s), the fuel is calculated from fuel data retrieved by actual dynamometer testing. These tests were carried out by MAHLE Powertrain for the Passat 2.0L data and Ford Motor Company for the Ford 1.0L engine data. The MAHLE fuel data is provided as Fuel Flow (g/s) against BMEP (Bar) at certain RPM steps and the Ford fuel data is provided in Fuel Flow (Kg/hr) against Torque (Nm) at certain RPM

steps. However, for the model, the fuel usage needs to be known at every RPM instance, this means interpolation will be needed to calculate the exact fuel usage.

A polynomial will need to be created for each RPM step from the provided data (found in appendix 12.1 and 12.2), the polynomial can be calculated through excel by creating a graph for each RPM step with Fuel Flow against BMEP or Fuel Flow against Torque (seen in appendix 12.3). The polynomials can prove to calculate large errors; therefore, each polynomial will need to be checked individually to ensure the Fuel Flow numbers provided are calculated correctly when the BMEP or Torque is inputted. Sometimes the largest available order polynomial is not always the most accurate, so some trial and error will need to be used to ensure accuracy is kept.

Now the polynomials can be entered into an interpolation to calculate the fuel usage at any RPM, using an RPM between 1000 and 850 the interpolation will be as follows:

$$= \text{Polynomial at 850 RPM} + \frac{(\text{Engine Velocity} - 850)}{(1000 - 850)} \times \text{Polynomial at 1000 RPM} \\ - \text{Polynomial at 850 RPM}$$

This equation will need to be entered into 'IF' statements for each RPM step from the provided data. One large equation can then be used to calculate the fuel usage at any given second throughout the cycle. It is from these fuel calculations that can be used to check for the model's accuracy against the MAHLE NEDC for the Volkswagen Passat. The total fuel calculated is 730.63 grams compared to the actual fuel used being 715.9 grams, this gives an accuracy of 102.06% meaning the model over predicts by 2%. This wouldn't be accurate enough for real world testing, however the main accuracy issue will be from the estimated fuel calculation polynomials, in practice the fuel will be measured rather than calculated.

The accuracy cannot be measured when using different engines unless the total fuel consumption from an NEDC was obtained as the fuel data will be different for every vehicle. But as the model is within 2% accuracy it will be assumed that that the entire model is accurate and the only variable when changing vehicles will be the polynomial fuel calculations.

Now the final columns can be calculated to calculate power and BSFC.

Power (Watts):

$$= \text{BMEP (Bar)} \times 10^5 \times \text{Engine Displacement (cc)} \times 10^{-6} \times \frac{\text{Engine Velocity (RPM)}}{120}$$

Power (kW):

$$= Power (Watts) \times 10^{-3}$$

BSFC (g/kW.hr), with an 'IF' statement to stipulate if the power is 0 then BSFC is 0:

$$= \frac{Fuel\ Usage\ (g/s) \times 3600}{Power\ (kW)}$$

The remaining calculations will be the total fuel used during the Urban Cycle, Extra Urban Cycle, the total fuel used and average fuel used. The totals are simply calculated by taking the sum of the fuel used in the duration of each part of the test. These are stated previously as; Urban section 0-780 and Extra Urban 781-1180, then the total fuel used is the sum of the two. The Average fuel is then the total fuel used in grams divided by the total distance travelled to give the average grams per kilometre (g/km).

6.2 Excel WLTP Model

The WLTP model is designed in the same way to calculate the fuel usage and BSFC values, but has three major differences as stated earlier, the length of the test, the speed variances and the choice of gears. Therefore, the first changes to be made to the model are the new specified time and speed traces. The next step is to create the gear calculator, this is done by following the mentioned steps below:

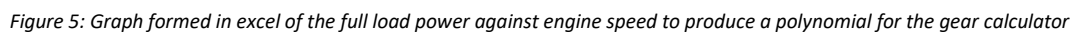
Keeping to official rules, the calculations will be carried out from first principle for ease of understanding. The first step to take is to calculate the Power Required (kW), this is the power that is needed to overcome the wheel forces to move the car at a certain velocity. In the model being built this is simply:

$$= \frac{Wheel\ Force\ (N) \times Velocity\ (ms^{-1})}{1000}$$

Where the wheel force calculations can be seen in 6.1.

Ford 1L Full Load Power Against Engine Speed

Engine Speed (RPM)	Engine Power (kW)
1000	15
1500	38
2000	50
2500	65
3000	78
3500	92
4000	105
4500	115
5000	125
5500	132
6000	135

$$y = -0.000000000000000083072941507x^6 + 0.0000000000000001893501002634240x^5 - 0.0000000000017622216199100200000x^4 + 0.000000084668623813945100000000x^3 - 0.000219691730030063000000000000x^2 + 0.31619526587641600000000000000x - 152.5611637068030000000000000000$$

$$\begin{aligned} s &= \text{Engine Speed at which maximum power is developed} \\ n_{idle} &= \text{Engines idle speed when in neutral} \\ n_{\min} = n_{\min_drive} &= \text{Minimum engine speed for gears } \geq 3 = n_{idle} + 0.125 \times (s - n_{idle}) \\ n_{\min} &= \text{Minimum engine speed for 2nd gear} = 1.25 \times n_{idle} \\ n_{\min} &= \text{Minimum engine speed for 1st gear} = n_{idle} \end{aligned}$$
$$n_{min} \leq Engine\ Speed \leq n_{max}$$
$$Power_{available} \geq Power_{required}$$

6.3 MATLAB NEDC Model

The main aim for transferring the calculator into MATLAB was to design the calculator model more user friendly and allow the user to be asked for all the input data necessary to predict the fuel usage. Therefore, the code starts by asking the user to enter the following information:

Vehicle Mass, Engine Displacement, Wheel Rolling Radius, Engine Idle RPM, Engine Inertia, Frontal Area, Wheel Inertia, Rolling Resistance Coefficient, Drag Coefficient, Air Density.

The user will also be told what units to enter the information in to save on calculation and user errors.

As the gear selection and vehicle velocity is set by NEDC these columns will be read from the excel file. Through the rest of the MATLAB model the same calculations are used from part 6.1.

The fuel polynomials can also be calculated within MATLAB's curve fitting tool, this is done by entering the same fuel data used in the excel model into a matrix in the MATLAB software, there is then a set tool in the software to create a polynomial or Gaussian fit line, depending on which gives a greater accuracy. It is then from these curve fit lines that a new equation is calculated and then used for the fuelling model using the same technique with the interpolation method. Although this method can be automated, the accuracy needs to be checked with each graph to ensure the best fit and will therefore create major inaccuracies if automated. In this instance, the fuel graphs will be used from the already checked models in the excel files, meaning the polynomial equations can be copied over into the MATLAB model. This will also mean, any engine that is entered, the MATLAB model will also need the corresponding fuel files added in. Although this adds time onto the method, it will retain its accuracy levels.

6.4 MATLAB WLTP Model

This model is replicated in the same way as how the NEDC MATLAB model works, however rather than reading the NEDC gear selections the calculator is also translated over into the MATLAB software. But as with the fuel files, it is an easier operation to carry out the gear calculator in the excel model, then read the final gear selection from the excel file or import the data into the MATLAB software. This provides a user-friendly model, and with a little knowledge in MATLAB will allow the user to easily swap around relevant codes to enable the input of any vehicle or any engine and any gear ratios. With the ease of changing each variable individually or all at once.

7. Results

7.1 NEDC

7.1.1 Volkswagen 2.0 Litre TSI Engine

As it was stated in the methodology, this combination of vehicle and engine was used to check for accuracy of the created model against a real word NEDC test. The main issue found was the error in the fuel equations. However, the result gave an accuracy of 2%, which following NEDC guidelines falls within the allowed tolerance window, this model can therefore be deemed as an ideal prediction calculator. This predication calculator will only be as accurate as the fuel equations, therefore if the new fuel equations for a new engine has a greater margin of error, this error will also follow through to the final fuel consumption results. The predicted and MAHLE test results can be seen below in table 7. The error margin can already be seen from the two phases of the cycle, yet total up accurately for a total result.

Table 7: Models predicted results compared to the actual measured data

Volkswagen Passat 2.0L TSI NEDC Results			
	Predicted	MAHLE Test	Accuracy
Urban	327.09	341.5	96%
Extra Urban	403.54	374.4	108%
Total	730.63	715.9	102%

7.1.2 Volkswagen 2.0 Litre TSI Engine with 10% Changes

The following results are to show how fuel consumption can be affected through the NEDC cycle with extreme changes. The changes have been made to the total vehicle mass, the frontal area of the car and gear ratios. Extreme gear ratio alterations will affect the driveability of the vehicle, and in the case of the NEDC the gear calculator has not been implemented, meaning it will be unknown if the vehicle will be able to cope with the gear ratio changes, therefore these will be used just to show the possible differences.

Table 8: Volkswagen 2.0L TSI results in the NEDC predictions

Volkswagen Passat 2.0L TSI NEDC Results with 10% Changes						
	Original	Lower Mass	Longer Ratios	Shorter Ratios	Improved Aero	Multiple
Urban (g)	327.09	315.40	294.46	367.18	326.06	281.25
Extra Urban (g)	403.54	387.01	376.57	437.64	393.18	349.10
Total (g)	730.63	702.41	671.03	804.82	719.24	630.35

The multiple changes made in this test was the use of; lower mass, improved aerodynamics and longer gear ratios.

7.1.3 Ford 1.0 Litre Engine

This is the same Volkswagen Passat vehicle, using a Ford 1.0 litre engine, therefore the only variants in the model will be the fuelling equations and the engine capacity. A comparison will also be used between the gear ratios used with the 2.0 litre TSI engine and the Ford gear ratios used in the Fiesta. The gear efficiencies were not available for the Ford gears so it will be assumed that gears follow the same efficiency from the Passat.

Table 9: NEDC predicted comparison of gear ratios

Volkswagen Passat 1.0L EcoBoost NEDC Results			
	Passat Ratios	Fiesta Ratios	Accuracy
Urban	232.05	230	101%
Extra Urban	331.81	330.77	100%
Total	563.86	560.77	101%

As it can be seen from table 9, there is only a 1% difference in the change of gear ratios, therefore throughout the rest of the testing, just the Passat gear ratios will be used.

7.1.4 Ford 1.0 Litre Engine with 10% Changes

The same areas will be changed for this vehicle-engine configuration.

Table 10: Volkswagen with Ford engine predicted NEDC results

Volkswagen Passat 1.0L EcoBoost NEDC Results with 10% Changes						
	Original	Lower Mass	Longer Ratios	Shorter Ratios	Improved Aero	Multiple
Urban	232.05	218.25	269.01	244.81	230.94	217.15
Extra Urban	331.81	314.04	335.51	342.51	320.72	303.16
Total	563.86	532.29	604.52	587.32	551.66	520.31

From these results, it can be instantly seen that altering the gear ratios either way has a negative effect on the fuel consumption outcome. This will be discussed further in the analysis. The multiple changes made in this test was the use of; lower mass and improved aerodynamics.

7.2 WLTP

7.2.1 Volkswagen 2.0 Litre Engine

The model was carried out utilizing the customized gear calculator with the Passat gear ratios, the results collected are as follows below, the NEDC results were also added in to show a representation of the phase they are being replaced by.

Table 11: WLTP results in comparison to previous NEDC.

Volkswagen Passat 2.0L TSI WLTP Results		
	NEDC	WLTP
Low (g)	302.55	243.32
Medium (g)		302.55
High (g)		425.95
Extra High (g)	425.95	569.13
Total (g)	569.13	1540.95

From the initial results, the extent of how different the tests compare can clearly be seen. It also shows the various phases the vehicles are tested at and the increasing fuel consumption these phases create due to the increasing speeds. Although so far, these results do not seem comparable, the average fuel consumption in grams per kilometre will be compared later.

7.2.2 Volkswagen 2.0 Litre Engine with 10% Changes

With the gear calculator being programmed to work with the original gear ratios, the change in ratios may produce an error in the results. This is due to the varying RPMs of the new ratios may not fall into line with the available power equations at those given moments. The issue will become more apparent with the 1.0L engine due to the smaller windows of available power.

Table 12: Volkswagen 2.0L TSI engine predicted WLTP results

Volkswagen Passat 2.0L TSI WLTP Results with 10% Changes						
	Original	Lower Mass	Longer Ratios	Shorter Ratios	Improved Aero	Multiple
Low (g)	243.32	233.40	220.55	270.89	242.69	209.63
Medium (g)	302.55	286.82	280.39	330.07	299.87	261.30
High (g)	425.95	407.55	396.24	465.7	416.72	367.6
Extra High (g)	569.13	549.52	537.55	612.49	546.11	493.33
Total (g)	1540.95	1477.29	1434.73	1679.15	1505.39	1331.86

The multiple changes made in this test was the use of; lower mass, improved aerodynamics and longer gear ratios.

7.2.3 Ford 1.0 Litre Engine

This model will again use the Passat gear ratios and the Passat vehicle specifications.

Table 13: WLTP results in comparison to previous NEDC.

Volkswagen Passat 1.0L EcoBoost WLTP Results		
	NEDC	WLTP
Low (g)	232.05	174.49
Medium (g)		242.79
High (g)		347.19
Extra High (g)	331.81	494.96
Total (g)	563.86	1259.43

Again, the average fuel consumptions will be looked at later for better comparisons.

7.2.4 Ford 1.0 Litre Engine with 10% Changes

As stated earlier, in regard to gear ratio changes, some results for this engine can be seen to be inaccurate and would require a reprogram of the gear calculator.

Table 14: Volkswagen with Ford engine predicted WLTP results.

Volkswagen Passat 1.0L EcoBoost WLTP Results with 10% Changes						
	Original	Lower Mass	Longer Ratios	Shorter Ratios	Improved Aero	Multiple
Low (g)	174.49	162.15	1089.48	176.58	173.70	161.38
Medium (g)	242.79	225.26	151.35	243.39	239.79	222.27
High (g)	347.19	326.55	7076.1	351.57	337.33	316.85
Extra High (g)	494.96	471.64	474.52	504.52	468.95	445.58
Total (g)	1259.43	1185.60	8791.45	1276.06	1219.77	1146.08

The multiple changes made in this test was the use of; lower mass and improved aerodynamics.

8. Analysis

On examination of the results, simple modifications to the vehicles can have effects on the measured fuel consumptions which is a well-known study with fuel saving technology (Fontara 2017), where reducing drive forces such as the mass of the vehicle and improving the aerodynamics will both always improve fuel consumption. However, as the results currently obtained are values of which cannot be compared with varying engines. To give a better comparison, the average fuel consumption of the tests will need to be calculated, simply by dividing the total fuel consumption by the total distance travelled throughout the test. Therefore, the following results were collected for better analysis between how the engines fared in each test.

Table 15: Comparison of average fuel consumptions from all predicted cycles

Average Fuel Consumption			
		NEDC (g)	WLTP (g)
2.0L TSI Engine	Original	66.24	66.22
	Aero	65.21	64.96
	Mass	63.81	63.48
	Low Ratio	72.97	72.16
	High Ratio	60.84	61.66
1.0L EcoBoost	Original	51.12	54.12
	Aero	50.01	52.42
	Mass	48.26	50.95
	Low Ratio	53.25	54.84
	High Ratio	54.81	377.80

As from the results section 7.2.4 the high ratios used for the 1L EcoBoost in the WLTP can be ignored due to the gear calculator not yet being automated. However, for the results found in the NEDC this engine has a very small window of operation with gear ratios. This will be due to the gear ratios causing the engine to operate outside of it's ideal BSFC map during the drive cycles. Examining of the vehicles BFSC maps will be the best way to analyse where the engines are in operation throughout the tests and therefore giving a reason as to why the fuel consumption has increased or decreased. This will be achieved by taking the BSFC result from every second throughout the tests and creating graphs to show how often through the cycle the engine runs in the best possible BSFC region. Below are the BSFC maps for each engine:

Passat With Ford 999cc EcoBoost Engine BSFC Chart Showing the Best Possible BSFC Running Area																
RPM	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
Torque (Nm)																
200						273.7	274.8	271.9	282.5	269.3						
190						270.5	268.8	268.6	283.9	266.5						
180					276.2	266.7	265.2	256.7	269.8	270.1	273.2					
170				285.5	281.6	263.9	263.0	263.0	273.7	265.6	267.3					
160				282.1	275.6	260.9	259.1	259.8	259.6	256.7	260.7	262.8				
150				277.5	271.2	259.7	258.0	259.6	254.3	254.5	256.7	256.8	267.1	283.2		
140			284.6	275.6	266.6	258.8	256.3	257.5	250.5	251.9	254.7	252.2	257.9	268.4	290.8	
130			278.2	266.7	258.4	255.4	252.3	251.2	246.0	249.4	253.8	251.2	254.1	263.2	280.4	
120			276.7	262.2	261.7	255.7	250.2	247.8	242.6	249.0	255.1	251.7	252.5	260.6	271.2	285.1
110		288.5	271.5	261.0	260.2	251.0	247.9	247.4	243.5	247.4	254.0	251.9	252.9	257.4	269.7	279.0
100		287.4	261.8	263.0	254.1	246.9	245.0	247.3	245.5	246.5	250.1	251.8	255.1	260.3	266.6	282.0
90		273.2	254.6	255.0	249.1	242.7	242.1	245.1	244.3	243.9	249.3	252.3	256.4	262.2	267.8	276.5
80		263.4	253.8	249.6	245.2	241.1	241.1	244.7	243.2	243.2	250.4	253.7	261.5	267.3	271.0	279.9
70		259.2	253.0	252.7	250.4	246.0	246.4	248.6	245.4	246.3	252.8	255.9	265.1	270.9	277.0	287.0
60		259.8	256.6	255.6	252.6	249.4	250.6	255.8	251.8	251.8	259.2	261.1	271.0	277.9	285.2	294.6
50		265.0	264.0	265.7	260.2	257.6	257.3	260.4	260.0	262.0	268.1	271.8	279.2	286.4	296.8	306.6
40	300.4	282.6	278.3	278.0	274.2	271.7	273.2	273.8	275.8	279.8	284.1	290.9	299.1	307.4	316.4	328.3
30	314.7	310.6	305.0	305.3	303.0	300.9	300.5	300.5	302.1	308.9	313.8	321.5	331.5	342.7	350.8	367.4
20	362.4	370.0	356.0	364.4	355.0	355.5	350.8	353.8	352.0	363.7	373.7	386.5	399.4	413.6	424.2	448.2
10	489.7	558.9	519.8	515.4	509.1	515.7	509.8	512.1	493.5	525.8	570.2	599.7	613.2	611.1	626.9	657.6
5	763.3	956.7	858.1	868.2	730.5	826.4	880.8	843.4	963.8	882.6	958.0	997.8	1069.5	976.4	1076.5	1088.2
2	1805.3	1462.4	3652.6	1772.2	1990.7	1617.0	1794.6	1779.4	1766.0	1988.3	2175.9	2188.9				

Figure 6: Ford 1L EcoBoost BSFC map

From the 1.0L BSFC map, the ideal running area is the white shaded area, and below is where the engine runs during the NEDC.

Passat With Ford 999cc GTDI Engine BSFC Chart Showing the Area of the NEDC Drive Cycle Operation																
RPM	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
Torque (Nm)																
200						273.7	274.8	271.9	282.5	269.3						
190						270.5	268.8	268.6	283.9	266.5						
180					276.2	266.7	265.2	256.7	269.8	270.1	273.2					
170				285.5	281.6	263.9	263.0	263.0	273.7	265.6	267.3					
160				282.1	275.6	260.9	259.1	259.8	259.6	256.7	260.7	262.8	282.5			
150				277.5	271.2	259.7	258.0	259.6	254.3	254.5	256.7	256.8	267.1	283.2		
140			284.6	275.6	266.6	258.8	256.3	257.5	250.5	251.9	254.7	252.2	257.9	268.4	290.8	
130			278.2	266.7	258.4	255.4	252.3	251.2	246.0	249.4	253.8	251.2	254.1	263.2	280.4	
120			276.7	262.2	261.7	255.7	250.2	247.8	242.6	249.0	255.1	251.7	252.5	260.6	271.2	285.1
110		288.5	271.5	261.0	260.2	251.0	247.9	247.4	243.5	247.4	254.0	251.9	252.9	257.4	269.7	279.0
100		287.4	261.8	263.0	254.1	246.9	245.0	247.3	245.5	246.5	250.1	251.8	255.1	260.3	266.6	282.0
90		273.2	254.6	255.0	249.1	242.7	242.1	245.1	244.3	243.9	249.3	252.3	256.4	262.2	267.8	276.5
80		263.4	253.8	249.6	245.2	241.1	241.1	244.7	243.2	243.2	250.4	253.7	261.5	267.3	271.0	279.9
70		259.2	253.0	252.7	250.4	246.0	246.4	248.6	245.4	246.3	252.8	255.9	265.1	270.9	277.0	287.0
60		259.8	256.6	255.6	252.6	249.4	250.6	255.8	251.8	251.8	259.2	261.1	271.0	277.9	285.2	294.6
50		265.0	264.0	265.7	260.2	257.6	257.3	260.4	260.0	262.0	268.1	271.8	279.2	286.4	296.8	306.6
40	300.4	282.6	278.3	278.0	274.2	271.7	273.2	273.8	275.8	279.8	284.1	290.9	299.1	307.4	316.4	328.3
30	314.7	310.6	305.0	305.3	303.0	300.9	300.5	300.5	302.1	308.9	313.8	321.5	331.5	342.7	350.8	367.4
20	362.4	370.0	356.0	364.4	355.0	355.5	350.8	353.8	352.0	363.7	373.7	386.5	399.4	413.6	424.2	448.2
10	489.7	558.9	519.8	515.4	509.1	515.7	509.8	512.1	493.5	525.8	570.2	599.7	613.2	611.1	626.9	657.6
5	763.3	956.7	858.1	868.2	730.5	826.4	880.8	843.4	963.8	882.6	958.0	997.8	1069.5	976.4	1076.5	1088.2
2	1805.3	1462.4	3652.6	1772.2	1990.7	1617.0	1794.6	1779.4	1766.0	1988.3	2175.9	2188.9				

Figure 7: Ford 1L EcoBoost BSFC map with highlighted area of where the engine operates through NEDC cycle

It can be seen clearly that this engine has been optimized for running in this cycle as most time is spent within the best possible BSFC numbers. This is then emphasized in the following graph.

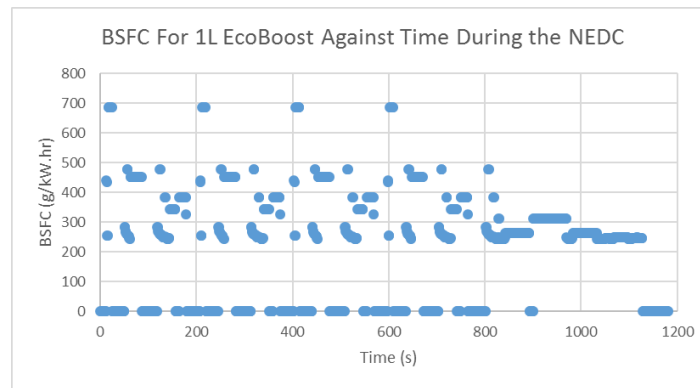


Figure 8: How the BSFC values vary throughout the NEDC.

The zero BSFC values are there due to the calculator being unable to calculate accurate values for deceleration and idle, it is also unknown if the vehicle would be using a fuel cut off strategy on deceleration so these values can be ignored for this analysis (Zhao 2009).

Another issue with the 1L engine is accuracy with the calculations such as the engine inertia, the engine inertia was used from the 2L engine as this value was not available to calculate the engines extra torque. Of course, this value would be different due to the ford engine having less weight and less parts. Also with no real-world data for the 1L engine, an accuracy comparison of fuel consumption cannot be carried out.

Looking now at the following 2L TSI BSFC map below, the ideal BSFC values occur at lower RPM and higher torque loads, this already, knowing from the low torque demands in the NEDC could prove a disadvantage for the larger engine. Comparing this with where the engine operates during the drive cycle it confirms that the engine is unable to perform at its best due to the low torque demand of the NEDC. The reason for the 2L engine having poor BSFC values at the low loads is due to the pumping losses (Mechadyne 2017). The larger engine is producing more friction and trying to draw in more air, yet the throttle is barely open due to the low torque demand and therefore not allowing the air to draw in, this in turn then creates a vacuum inside the intake manifold and causes air flow to be poor into the cylinders (Mechadyne 2017).

Passat 2.0L BSFC Chart Showing The Area OF the Drive Cycle Operation															
RPM	500	850	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	6000	7000
Torque (Nm)															
320	274	288	294	304	313	322	329	343	358	376	395	411	431	503	573
310	231	244	249	258	267	275	284	295	301	309	324	352	388	461	523
300	217	228	233	242	250	259	268	277	280	282	295	329	371	440	499
290	218	229	234	242	250	259	267	277	278	279	291	325	368	430	490
280	226	237	241	249	257	265	274	283	285	286	298	330	369	423	486
270	236	246	250	257	265	272	280	289	293	296	307	336	370	416	482
260	244	253	257	263	270	276	283	292	297	303	314	339	367	407	476
250	249	256	260	265	271	276	282	290	297	304	316	337	360	394	465
240	250	256	259	263	267	272	276	284	292	300	313	329	348	379	449
230	248	252	254	257	261	264	267	274	282	292	304	318	333	362	430
220	244	247	248	250	252	255	257	262	270	280	292	304	316	345	409
210	240	242	242	243	244	245	246	251	258	268	279	289	300	329	387
200	238	237	237	237	237	237	238	241	247	256	266	276	286	315	366
190	237	236	235	234	233	233	232	235	240	248	257	266	276	304	348
180	239	237	236	234	233	232	231	233	236	243	251	260	270	298	333
170	244	242	240	239	237	235	234	235	238	243	251	259	269	295	322
160	252	249	248	246	244	243	241	242	244	248	255	263	272	296	315
150	262	259	258	256	254	252	252	251	253	257	263	270	279	300	311
140	272	269	268	267	265	264	263	263	265	269	273	280	288	305	310
130	281	279	278	277	275	274	274	274	277	280	285	291	298	309	311
120	288	286	286	284	283	283	283	283	287	291	295	300	305	313	311
110	291	290	289	288	287	287	288	288	293	298	302	306	310	313	310
100	289	288	288	287	286	287	287	289	294	300	305	308	310	310	306
90	283	282	281	281	280	281	282	283	290	297	302	305	306	303	300
80	273	272	271	271	270	271	273	275	282	290	296	298	298	293	291
70	264	262	261	260	260	261	263	266	274	283	289	291	290	285	283
60	259	258	257	256	256	258	260	263	272	282	288	289	288	282	279
50	269	268	267	267	267	270	273	277	286	296	302	303	302	293	286
40	304	305	306	306	308	312	316	322	331	340	345	346	343	331	314
30	382	387	389	392	396	402	407	417	427	435	438	437	432	409	376
20	524	536	540	549	557	565	574	589	600	606	606	601	590	549	492
10	758	780	790	806	821	834	847	869	884	888	883	870	849	777	685
5	920	949	962	983	1003	1020	1035	1063	1080	1083	1076	1057	1029	934	819
2	1034	1069	1084	1109	1132	1151	1168	1200	1219	1222	1212	1189	1155	1044	913

Figure 9: Volkswagen Passat 2L TSI calculated BSFC map

Passat 2.0L BSFC Chart Showing The Area OF the Drive Cycle Operation															
RPM	500	850	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	6000	7000
Torque (Nm)															
320	274	288	294	304	313	322	329	343	358	376	395	411	431	503	573
310	231	244	249	258	267	275	284	295	301	309	324	352	388	461	523
300	217	228	233	242	250	259	268	277	280	282	295	329	371	440	499
290	218	229	234	242	250	259	267	277	278	279	291	325	368	430	490
280	226	237	241	249	257	265	274	283	285	286	298	330	369	423	486
270	236	246	250	257	265	272	280	289	293	296	307	336	370	416	482
260	244	253	257	263	270	276	283	292	297	303	314	339	367	407	476
250	249	256	260	265	271	276	282	290	297	304	316	337	360	394	465
240	250	256	259	263	267	272	276	284	292	300	313	329	348	379	449
230	248	252	254	257	261	264	267	274	282	292	304	318	333	362	430
220	244	247	248	250	252	255	257	262	270	280	292	304	316	345	409
210	240	242	242	243	244	245	246	251	258	268	279	289	300	329	387
200	238	237	237	237	237	237	238	241	247	256	266	276	286	315	366
190	237	236	235	234	233	233	232	235	240	248	257	266	276	304	348
180	239	237	236	234	233	232	231	233	236	243	251	260	270	298	333
170	244	242	240	239	237	235	234	235	238	243	251	259	269	295	322
160	252	249	248	246	244	243	241	242	244	248	255	263	272	296	315
150	262	259	258	256	254	252	252	251	253	257	263	270	279	300	311
140	272	269	268	267	265	264	263	263	265	269	273	280	288	305	310
130	281	279	278	277	275	274	274	274	277	280	285	291	298	309	311
120	288	286	286	284	283	283	283	283	287	291	295	300	305	313	311
110	291	290	289	288	287	287	288	288	293	298	302	306	310	313	310
100	289	288	288	287	286	287	287	289	294	300	305	308	310	310	306
90	283	282	281	281	280	281	282	283	290	297	302	305	306	303	300
80	273	272	271	271	270	271	273	275	282	290	296	298	298	293	291
70	264	262	261	260	260	261	263	266	274	283	289	291	290	285	283
60	259	258	257	256	256	258	260	263	272	282	288	289	288	282	279
50	269	268	267	267	267	270	273	277	286	296	302	303	302	293	286
40	304	305	306	306	308	312	316	322	331	340	345	346	343	331	314
30	382	387	389	392	396	402	407	417	427	435	438	437	432	409	376
20	524	536	540	549	557	565	574	589	600	606	606	601	590	549	492
10	758	780	790	806	821	834	847	869	884	888	883	870	849	777	685
5	920	949	962	983	1003	1020	1035	1063	1080	1083	1076	1057	1029	934	819
2	1034	1069	1084	1109	1132	1151	1168	1200	1219	1222	1212	1189	1155	1044	913

Figure 10: Volkswagen Passat 2L TSI calculated BSFC map with highlighted area of where the engine operates through NEDC cycle

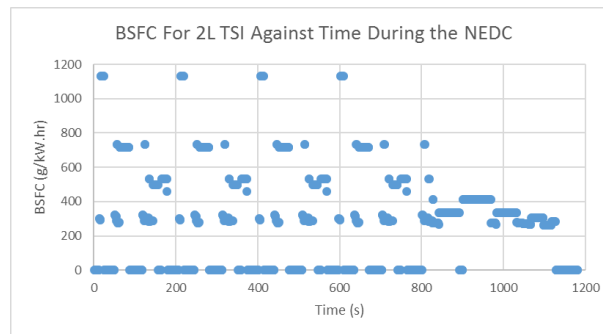


Figure 11: How the BSFC values vary throughout the NEDC.

Subsequently the BSFC stays constant at a reasonable level in the higher speed part of the test due to running in the best BSFC regions. However, the BSFC for the 2L engine does vary around a lot more in the slower urban phase due to the pumping losses at lower speeds.

On examination of how the engines perform in the WLTP, it can be seen from the average consumption, that the bigger engine performs slightly better whereas the downsized 1.0L engine has decreased in efficiency. This was to be expected following on from previous research carried out on current tests conducted by Ricardo to compare the tests as seen below (Mock 2014).

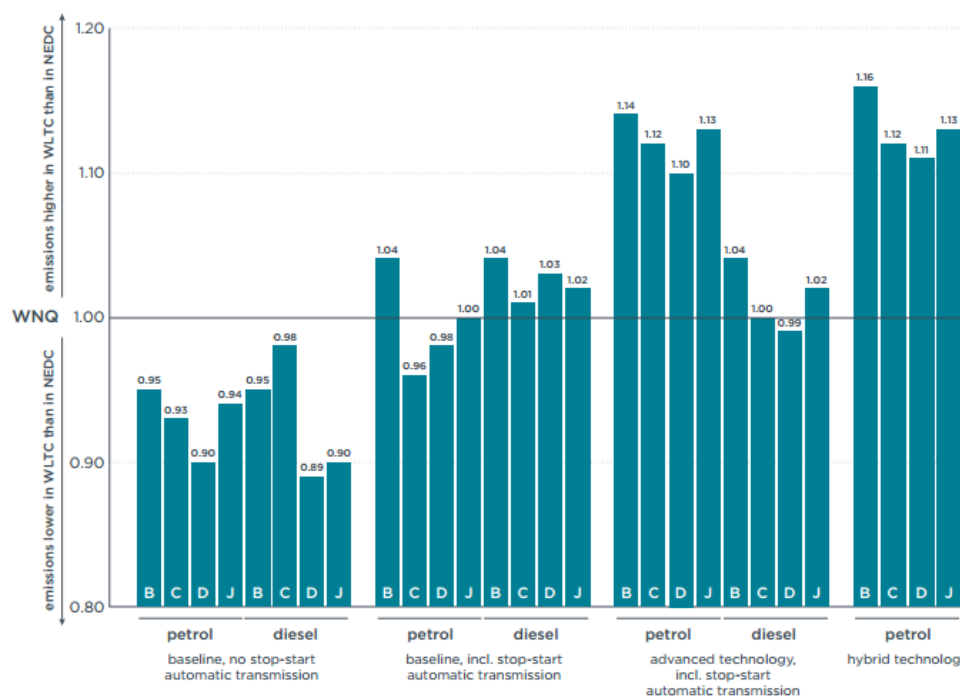


Figure 12: Ricardo test data for how current vehicles compare in the new WLTP (Mock 2014)

Although the fuel consumptions have only minor changes, the engines are tuned to operate within the NEDC regulations, both engines would run better again once optimized, however the 2.0L engine

would perform better again due to the higher torque demands throughout the cycle. Below are the new BSFC maps with where the engine operates in the WLTP.

Passat 2.0L BSFC Chart Showing The Area OF the WLTP Operation															
RPM	500	850	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	6000	7000
Torque (Nm)															
320	274	288	294	304	313	322	329	343	358	376	395	411	431	503	573
310	231	244	249	258	267	275	284	295	301	309	324	352	388	461	523
300	217	228	233	242	250	259	268	277	280	282	295	329	371	440	499
290	218	229	234	242	250	259	267	277	278	279	291	325	368	430	490
280	226	237	241	249	257	265	274	283	285	286	298	330	369	423	486
270	236	246	250	257	265	272	280	289	293	296	307	336	370	416	482
260	244	253	257	263	270	276	283	292	297	303	314	339	367	407	476
250	249	256	260	265	271	276	282	290	297	304	316	337	360	394	465
240	250	256	259	263	267	272	276	284	292	300	313	329	348	379	449
230	248	252	254	257	261	264	267	274	282	292	304	318	333	362	430
220	244	247	248	250	252	255	257	262	270	280	292	304	316	345	409
210	240	242	242	243	244	245	246	251	258	268	279	289	300	329	387
200	238	237	237	237	237	237	238	241	247	256	266	276	286	315	366
190	237	236	235	234	233	233	232	235	240	248	257	266	276	304	348
180	239	237	236	234	233	232	231	233	236	243	251	260	270	298	333
170	244	242	240	239	237	235	234	235	238	243	251	259	269	295	322
160	252	249	248	246	244	243	241	242	244	248	255	263	272	296	315
150	262	259	258	256	254	252	252	251	253	257	263	270	279	300	311
140	272	269	268	267	265	264	263	263	265	269	273	280	288	305	310
130	281	279	278	277	275	274	274	274	277	280	285	291	298	309	311
120	288	286	286	284	283	283	283	283	287	291	295	300	305	313	311
110	291	290	289	288	287	287	288	288	293	298	302	306	310	313	310
100	289	288	288	287	286	287	287	289	294	300	305	308	310	310	306
90	283	282	281	281	280	281	282	283	290	297	302	305	306	303	300
80	273	272	271	271	270	271	273	275	282	290	296	298	298	293	291
70	264	262	261	260	260	261	263	266	274	283	289	291	290	285	283
60	259	258	257	256	256	258	260	263	272	282	288	289	288	282	279
50	269	268	267	267	267	270	273	277	286	296	302	303	302	293	286
40	304	305	306	306	308	312	316	322	331	340	345	346	343	331	314
30	382	387	389	392	396	402	407	417	427	435	438	437	432	409	376
20	524	536	540	549	557	565	574	589	600	606	606	601	590	549	492
10	758	780	790	806	821	834	847	869	884	888	883	870	849	777	685
5	920	949	962	983	1003	1020	1035	1063	1080	1083	1076	1057	1029	934	819
2	1034	1069	1084	1109	1132	1151	1168	1200	1219	1222	1212	1189	1155	1044	913

Figure 13: Volkswagen Passat 2L TSI calculated BSFC map with highlighted area of where the engine operates through WLTP cycle

Passat With Ford 999cc GTDI Engine BSFC Chart Showing the Area of the WLTP Drive Cycle Operation																
RPM	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
Torque (Nm)																
200						273.7	274.8	271.9	282.5	269.3						
190						270.5	268.8	268.6	283.9	266.5						
180					276.2	266.7	265.2	256.7	269.8	270.1	273.2					
170				285.5	281.6	263.9	263.0	263.0	263.0	273.7	265.6	267.3				
160				282.1	275.6	260.9	259.1	259.8	259.6	256.7	260.7	262.8	282.5			
150				277.5	271.2	259.7	258.0	259.6	254.3	254.5	256.7	256.8	267.1	283.2		
140			284.6	275.6	266.6	258.8	256.3	257.5	250.5	251.9	254.7	252.2	257.9	268.4	290.8	
130			278.2	266.7	258.4	255.4	252.3	251.2	246.0	249.4	253.8	251.2	254.1	263.2	280.4	
120			276.7	262.2	261.7	255.7	250.2	247.8	242.6	249.0	255.1	251.7	252.5	260.6	271.2	285.1
110		288.5	271.5	261.0	260.2	251.0	247.9	247.4	243.5	247.4	254.0	251.9	252.9	257.4	269.7	279.0
100		287.4	261.8	263.0	254.1	246.9	245.0	247.3	245.5	246.5	250.1	251.8	255.1	260.3	266.6	282.0
90		273.2	254.6	255.0	249.1	242.7	242.1	245.1	244.3	243.9	249.3	252.3	256.4	262.2	267.8	276.5
80		263.4	253.8	249.6	245.2	241.1	241.1	244.7	243.2	243.2	250.4	253.7	261.5	267.3	271.0	279.9
70		259.2	253.0	252.7	250.4	246.0	246.4	248.6	245.4	246.3	252.8	255.9	265.1	270.9	277.0	287.0
60		259.8	256.6	255.6	252.6	249.4	250.6	255.8	251.8	251.8	259.2	261.1	271.0	277.9	285.2	294.6
50		265.0	264.0	265.7	260.2	257.6	257.3	260.4	260.0	262.0	268.1	271.8	279.2	286.4	296.8	306.6
40	300.4	282.6	278.3	278.0	274.2	271.7	273.2	273.8	275.8	279.8	284.1	290.9	299.1	307.4	316.4	328.3
30	314.7	310.6	305.0	305.3	303.0	300.9	300.5	300.5	302.1	308.9	313.8	321.5	331.5	342.7	350.8	367.4
20	362.4	370.0	356.0	364.4	355.0	355.5	350.8	353.8	352.0	363.7	373.7	386.5	399.4	413.6	424.2	448.2
10	489.7	558.9	519.8	515.4	509.1	515.7	509.8	512.1	493.5	525.8	570.2	599.7	613.2	611.1	626.9	657.6
5	763.3	956.7	858.1	868.2	730.5	826.4	880.8	843.4	963.8	882.6	958.0	997.8	1069.5	976.4	1076.5	1088.2
2	1805.3	1462.4	3652.6	1772.2	1990.7	1617.0	1794.6	1779.4	1766.0	1988.3	2175.9	2188.9				

Figure 14: Ford 1L EcoBoost BSFC map with highlighted area of where the engine operates through WLTP cycle

Both Engines can be seen operating further out of their ideal regions, however they spend more of the running time in and around these regions, thus still producing reasonably similar fuel consumption figures to those produced in the NEDC.

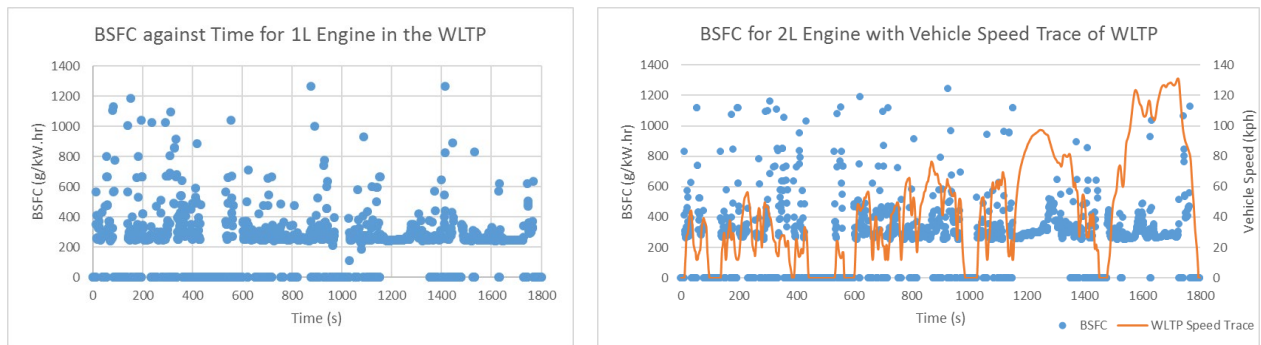


Figure 15 & 16: (Left) How the BSFC values for the 1L EcoBoost vary throughout the WLTP, (Right) How the BSFC values for the 2.0L TSI vary throughout the WLTP

From examination of the two graphs above it can be seen that the 1L engine still runs very efficiently in the WLTP keeping the BSFC values to a minimum mainly between 200 and 400, whereas with the 2L engine varies a lot more throughout the cycle. Although most of the values are found in the ideal region, the BSFC still spikes on slow speed phases of the test as well as in certain acceleration points. It is still these slow speeds that cause a problem for the larger engines, yet with the increased speeds further through the test, it really helps to bring the averages down. Comparing the results to the NEDC, the minimalizing of stop points throughout the tests also allows for less instances of the engine having to accelerate from standstill, helping minimize more spikes in the BSFC.

As this analysis was carried out mainly on the original outcomes of the vehicles fuel consumption without modifications, one modification needs highlighting. The 1L engine with modified gear ratios in the WLTP faired poorer on fuel consumption with both shorter and longer ratios. This result was down to the small area available of low BSFC values, with the gear ratios changed, this forced the running of the car out of this operational window, with the low ratio gears causing the engine to run higher in the RPM range and the high ratio performing the opposite. Although the high ratio gear change shows an error with an abnormal figure, when the errors were eliminated within the data, the average fuel consumption was still above that of the original fuel consumption.

9. Conclusion

In conclusion, the aim of this project was to create an accurate drive cycle model for the current NEDC and future WLTP. The initial model for the NEDC had actual data to compare accuracies and a model with 2% accuracy was produced. It was quickly evidenced that errors within fuel interpolation equations could produce errors throughout the models, but with careful checks made, these errors were kept to a minimum to produce accurate models for both cycles.

With both the models providing a thorough understanding of how the vehicles perform in the cycles a greater understanding of how they reacted to the varying test conditions was gained. From these clear results, it was evidenced that due to the increased speeds and load demand through the future test, larger engines have been given a lifeline to still produce results with less fuel consumption meeting the regulation requirements. Although with the new freedom of gear selection from the manufacturers, better results can easily be achieved by varying the gear calculator to suit different strategies to enable the vehicles to run with greater consistency in their best BSFC regions.

The models created proved to be useful tools in predicting the relevant data. This study would benefit from a greater number of engines being used for comparison, however, this would mean collecting the engine data from manufacturers. With further work carried out to ensure accurate fuel data interpolations to eliminate any errors, these models would be very accurate and enable any user to predict how a vehicle would perform in a drive cycle with any vehicle and engine configuration.

10. Future Work

For future work in these models, it would be ideal to fully automate the gear calculator to run off inputted data entered into MATLAB. This would save time and any user errors in calculations as it is a timely method currently. With this calculator finalised, it would be easy to see in the data where the engine was performing poorly through the test and a simple gear ratio change could be made to automatically recalibrate the gear strategy. However as of now, the whole calculator would need reprogramming to work accurately with altered gear ratios. Further work could also be carried out to measure more accurate fuel usage data to narrow the errors found in the fuel usage polynomial equations.

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12. Appendix

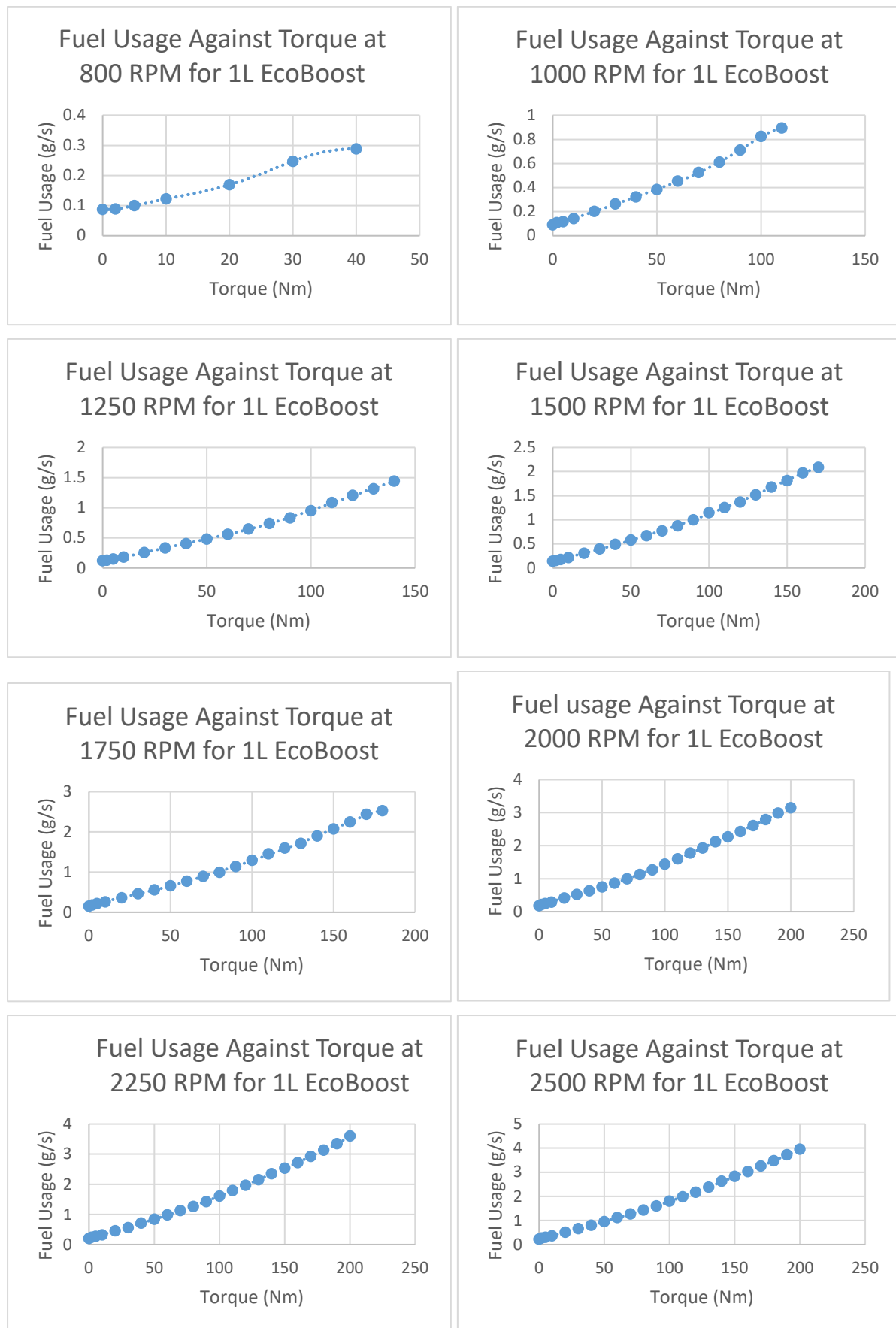
12.1 Volkswagen Passat 2.0L Fuel Data

500 RPM	850 RPM		1000 RPM		1250 RPM		1500 RPM		1750 RPM		2000 RPM		2500 RPM		3000 RPM		3500 RPM		4000 RPM		4500 RPM		5000 RPM		6000 RPM		7000 RPM		
	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	BMP (Bar)	Fuel Flow (g/s)	
0	0.07638411	0	0.13942504	0	0.166916921	0	0.214656586	0	0.26438017	0	0.335709412	0	0.366390216	0	0.47019583	0	0.569066588	0	0.6600005	0	0.74330102	0	0.8138646	0	0.87014556	0	0.92591423	0	0.8949398
0.5	0.101228531	0.5	0.17751138	0.5	0.211588779	0.5	0.27009467	0.5	0.334089258	0.5	0.391326304	0.5	0.455472444	0.5	0.584187056	0.5	0.71742177	0.5	0.833230409	0.5	0.945630589	0.5	1.046500336	0.5	1.133225972	0.5	1.240179422	0.5	1.263507895
1	0.124132989	1	0.225715689	1	0.256210833	1	0.325422879	1	0.396716006	1	0.469476396	1	0.54388108	1	0.63828656	1	0.854551981	1	1.00640762	1	1.150105813	1	1.28142443	1	1.36624715	1	1.554407731	1	1.629087321
1.5	0.147182096	1.5	0.25407007	1.5	0.300917648	1.5	0.386513369	1.5	0.462654354	1.5	0.56440275	1.5	0.62452105	1.5	0.821592789	1.5	0.996469401	1.5	1.179306518	1.5	1.354915972	1.5	1.51576718	1.5	1.65891272	1.5	1.868807027	1.5	1.996862354
2	0.170386672	2	0.292735141	2	0.345907001	2	0.435553082	2	0.527139227	2	0.623135684	2	0.721759428	2	0.927100021	2	1.138434456	2	1.352101988	2	1.559640016	2	1.750368335	2	1.921049257	2	2.18286513	2	2.365810623
3	0.217515907	3	0.371757985	3	0.430610836	3	0.549639305	3	0.664047539	3	0.780351977	3	0.910231013	3	1.1539174021	3	1.41784354	3	1.6980405	3	1.917086813	3	2.217086813	3	2.420715666	3	2.81304306	3	3.11236468
4	0.265943604	4	0.45230451	4	0.532893812	4	0.667934418	4	0.80630129	4	0.946831057	4	1.094016635	4	1.363116917	4	1.69159976	4	2.01787893	4	2.371530343	4	2.6764972	4	2.956615389	4	3.45397546	4	3.888916336
5	0.31748471	5	0.536832945	5	0.621953276	5	0.781614921	5	0.932963136	5	1.092519401	5	1.257951757	5	1.59917852	5	1.979359302	5	2.370053638	5	2.751784305	5	3.11806673	5	3.4700361655	5	4.117653467	5	4.712767119
6	0.371885381	6	0.625910277	6	0.733317324	6	0.91046571	6	1.087547113	6	1.266938384	6	1.453889352	6	1.832666244	6	2.255306334	6	2.6957716	6	3.127245483	6	3.59343336	6	3.99535238	6	4.839139475	6	5.60133859
7	0.428979309	7	0.722771939	7	0.847172986	7	1.052380515	7	1.25788966	7	1.462739178	7	1.689215367	7	2.094454518	7	2.549619775	7	3.029467339	7	3.524158946	7	4.028306909	7	4.594040635	7	5.576159895	7	6.577582994
8	0.488919405	8	0.824099582	8	0.946119844	8	1.200770634	8	1.433523998	8	1.665142694	8	1.896543979	8	2.36671406	8	2.861242498	8	3.39191369	8	3.94774919	8	4.53656982	8	5.148017555	8	6.408461937	8	7.665798054
9	0.549393881	9	0.92516376	9	1.083071154	9	1.348032299	9	1.608102571	9	1.866248059	9	2.12349549	9	2.64486949	9	3.188271817	9	3.77423893	9	4.406744	9	5.08472851	9	5.802395327	9	7.349516703	9	8.895116892
10	0.616346478	10	1.02746601	10	1.198891933	10	1.489053956	10	1.775517517	10	2.059590878	10	2.342970875	10	2.919219547	10	3.539310376	10	4.191203481	10	4.93734788	10	5.683323691	10	6.517443999	10	8.366427985	10	10.3101137
11	0.653935758	11	1.08971688	11	1.300116863	11	1.616756614	11	1.93940872	11	2.240439515	11	2.55429554	11	3.1998939	11	3.89431596	11	4.64656529	11	5.45997108	11	6.35691091	11	7.29717677	11	9.9493924	11	11.92185325
12	0.696539955	12	1.17880796	12	1.38249475	12	1.72553947	12	2.07111922	12	2.41163944	12	2.76146038	12	3.495452307	12	4.283551292	12	5.139999356	12	6.05739483	12	7.049566106	12	8.12583396	12	10.3805241	12	13.08002159
13	0.73730536	13	1.247665146	13	1.468017359	13	1.83963211	13	2.208631782	13	2.593189942	13	2.994274561	13	3.810519434	13	4.70377392	13	5.679398086	13	6.714210148	13	7.821407654	13	9.024538814	13	12.0047188	13	16.09405158
14	0.77127752	14	1.324891611	14	1.565782719	14	1.97242428	14	2.38690711	14	2.8113998	14	3.246794053	14	4.16973387	14	5.15338407	14	6.238812748	14	7.417102568	14	8.676374669	14	10.0239334	14	13.268882	14	18.5688936
15	0.81161244	15	1.41348201	15	1.676206136	15	2.127843327	15	2.59144477	15	3.06631198	15	3.55477312	15	4.55407354	15	5.62338958	15	6.80495766	15	8.13193073	15	9.61797931	15	11.26572836	15	14.4930829	15	20.8791633
16	0.85388949	16	1.504324215	16	1.79503978	16	2.294054329	16	2.815910502	16	3.35110379	16	3.896301399	16	5.00138924	16	6.124176585	16	7.34631414	16	8.80045498	16	10.38038882	16	12.65105494	16	16.6380005	16	23.3943899
17	0.90473398	17	1.602771002	17	1.9185776	17	2.467680394	17	3.04856896	17	3.65105936	17	4.27451081	17	5.514681178	17	6.681334514	17	7.87844015	17	9.384215368	17	11.56413499	17	14.2340666	17	19.3955669	17	25.9204949
18	0.96243336	18	1.711496204	18	2.05142481	18	2.64940389	18	3.27113306	18	3.946159135	18	4.69554146	18	6.069516486	18	7.313723884	18	8.513745001	18	9.983747131	18	12.59975642	18	15.845624	18	21.8845624	18	28.7073792
19	1.02717542	19	1.83164907	19	2.206597085	19	2.857471789	19	3.54679462	19	4.279071954	19	5.043370315	19	6.55651039	19	7.9591691	19	9.427374331	19	11.2544631	19	13.8277646	19	16.99889206	19	23.9410572	19	31.53215556
20	1.049671114	20	1.97959699	20	2.36951057	20	3.166989075	20	3.80917986	20	4.55375941	20	5.351819495	20	6.9797091	20	8.62986164	20	10.4455555	20	12.5564004	20	15.1451468	20	18.15527763	20	25.8611754	20	34.0952071

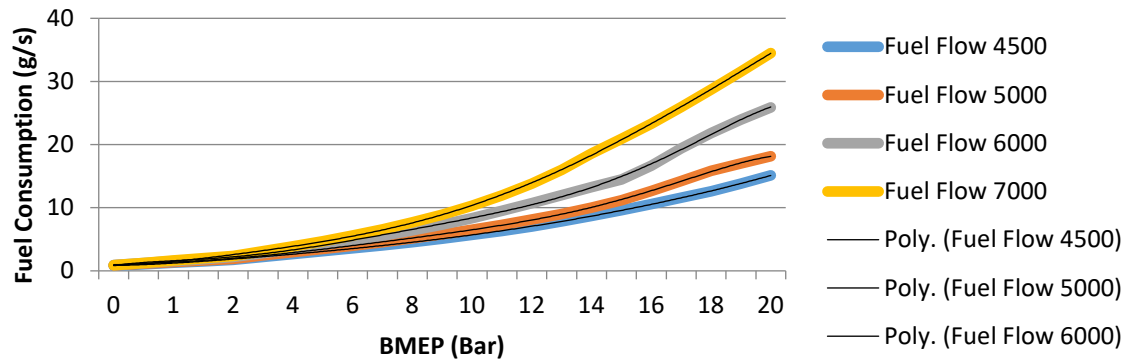
12.2 Ford 1.0L Fuel Data

FUELMASS kg/h																
	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	28.11
200						11.34	12.96	14.25	17.78	19.47						
190								13.39	16.91	18.46						
180						10.77	12.04	13.39	15.24	17.76	20.61					
170					9.11	10.05	11.26	12.52	14.06	17.14	18.91	21.41				
160				7.51	8.77	9.38	10.52	11.72	13.05	15.06	17.46	19.80	23.68			
150				6.52	7.46	8.17	9.12	10.19	11.98	14.00	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	15.40	17.30	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	15.98	18.00	20.45	23.30
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	20.90
100		2.97	3.43	4.13	4.66	5.20	5.78	6.48	7.71	9.03	10.53	11.88	13.38	15.00	16.78	19.21
90		2.56	3.00	3.60	4.11	4.55	5.13	5.77	6.90	8.05	9.36	10.70	12.11	13.59	15.15	16.95
80		2.20	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	3.60	4.07	4.56	5.40	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	6.50	7.39	8.51	9.60	10.76	12.04
50		1.38	1.73	2.08	2.38	2.70	3.03	3.41	4.09	4.80	5.60	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	4.10	4.77	5.48	6.27	7.10	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	1.10	1.30	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	3.19	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	1.60	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				

12.3 Fuel Graphs with Trendlines



Passat 2.0L TSI Fuel Usage Against BMEP



12.4 Corrections and Modifications of gear use

5.4. Additional requirements for corrections and/or modifications of gear use

The initial gear use shall be checked and modified in order to avoid too frequent gearshifts and to ensure drivability and conformity with practical use. The requirements are described below and summarized in Table 5-3.

Corrections/modifications are made depending on the following requirements:

- First gear shall be selected 1 second before the beginning of an acceleration phase from standstill. Vehicle speeds below 1 km/h imply that the vehicle is standing still.
- Skipping of gears during acceleration phases is not permitted. Gears used during accelerations and decelerations must be used for a period of at least 3 seconds.
E.g. a gear sequence 1, 1, 2, 2, 3, 3, 3, 3 is replaced by 1, 1, 1, 2, 2, 2, 3, 3, 3
- Skipping of gears during deceleration phases is permitted. For the last phases of a deceleration down to a stop, the clutch may be either disengaged or the gear lever in neutral position and the clutch engaged.
- There shall be no gearshift during the transition from an acceleration phase to a deceleration phase. E.g., if $v_j < v_{j+1} > v_{j+2}$ and the gear for the time sequence j and $j+1$ is i , gear i is also kept for the time $j+2$, even if the initial gear for $j+2$ would be $i+1$.
- If a gear i is used for a time sequence of 1 to 5 s and the gear before this sequence is the same as the gear after this sequence, e.g. $i-1$, the gear use for this sequence is corrected to $i-1$.

That means:

- a gear sequence $i-1, i, i-1$ is replaced by $i-1, i-1, i-1$
- a gear sequence $i-1, i, i, i-1$ is replaced by $i-1, i-1, i-1, i-1$
- a gear sequence $i-1, i, i, i, i-1$ is replaced by $i-1, i-1, i-1, i-1, i-1$
- a gear sequence $i-1, i, i, i, i, i-1$ is replaced by $i-1, i-1, i-1, i-1, i-1, i-1$
- a gear sequence $i-1, i, i, i, i, i, i-1$ is replaced by $i-1, i-1, i-1, i-1, i-1, i-1, i-1$

for all cases (1) to (5), $g_{min} \leq i$ must be fulfilled.

- a gear sequence $i, i-1, i$ is replaced by i, i, i , if the following conditions are fulfilled:

- the engine speed does not drop below n_{min} and
- These corrections do not occur more often than 4 times each for the low, medium and high speed cycle parts and not more than 3 times for the extra high speed part.

The requirement (2) is necessary, because the available power will drop below the required power, when the gear $i-1$ is replaced by i . And this should not occur too frequently.

- If during an acceleration phase a lower gear is required at a higher vehicle speed, the higher gears before are corrected to the lower gear, if the lower gear is required for at least 2 s.

Example: $v_j < v_{j+1} < v_{j+2} < v_{j+3} < v_{j+4} < v_{j+5} < v_{j+6}$. The originally calculated gear use is 2, 3, 3, 3, 2, 2, 3. In this case the gear use will be corrected to 2, 2, 2, 2, 2, 2, 3.

Since the above modifications may create new gear use sequences which are in conflict with these requirements, the gear sequences shall be checked twice.

12.5 Excel Model Calculator Image

Time (s)	Required Gear	Velocity (km/h)	Velocity (m/s ²)	Acceleration (m/s ²)	Wheel Velocity (rev/s)	Wheel Velocity (RPM)	Wheel Velocity (rad/s)	Wheel Acceleration (rad/s ²)	Wheel Force (N)	Wheel Torque Driveline Torque (Nm)	Differential Acceleration (rad/s ²)	Differential Output Torque (Nm)	Differential Input Torque (Nm)	Transmission output Torque (Nm)	Transmission Input Torque (Nm)	Engine Velocity (Calculated)	Engine Velocity (Corrected RPM)	Engine Output Torque (Nm)	Engine Angular Velocity (rad/s)	Engine Angular Acceleration (rad/s ²)	Extra Torque to Accelerate Engine (Nm)	Measured Drive Torque (Nm)	BMEP (bar)	Fuel Usage (g/s)	Power (Watts)	Power (kW)	BSFC (g/kWh)	
0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
1	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
2	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
3	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
4	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
5	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
6	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
7	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
8	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
9	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
10	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
11	1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	800.000	800.000	0.000	83.773	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0
12	1	3.75	1.047	1.047	0.5213	31.285	3.757	3.757	1594.072	621.3743	626.154	3.757	626.154	161.199	53.565	414.1031	800.000	53.565	83.773	0.000	0.000	0.000	0.000	53.565	6.7316	0.0899995	4.4071740	4683.7158
13	1	7.5	2.083	1.047	1.047	62.590	6.514	3.757	1555.660	621.910	627.1429	3.757	627.1429	161.333	53.616	828.1263	828.1263	53.616	86.726	2.938	0.461	0.000	53.565	6.7316	0.0899995	4.683114	494.0814	
14	1	11.25	3.129	1.047	1.540	93.844	9.820	3.757	1598.496	627.789	630.0220	3.757	630.0220	161.370	53.688	1242.394	1242.394	53.688	130.949	43.348	6.597	0.195	0.000	6.750	0.0899995	4.683114	738.0336	256.00708
15	1	15	4.167	1.047	2.084	125.128	13.107	3.757	1602.311	630.018	632.5238	3.757	632.5238	161.930	53.790	1556.426	1556.426	53.790	173.491	43.348	6.597	0.287	0.000	7.574	0.0899995	10.4595646	1045.9564	535.81072
16	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
17	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
18	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
19	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
20	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
21	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
22	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653
23	1	15	4.167	0.000	2.084	125.128	13.107	0.000	243.511	77.493	77.493	0.000	77.493	20.919	6.620	1556.426	1556.426	6.620	173.491	0.000	0.000	0.000	6.620	0.8320	0.2086769	1.148179	1.14819551	686.371653

12.6 NEDC MATLAB Code

```
clc
clear all
VehicleMass=input('Enter Vehicle Mass in kg: ');
EngineDisplacement=input('Enter Engine Displacement in cubic centimeters: ');
WRollingRadius=input('Enter Wheel Rolling Radius in meters: ');
EngineIdle=input('Enter Engine idle RPM: ');
EngineInertia=input('Enter Engine Inertia in kgm2: ');
FrontalArea=input('Enter Vehicles Frontal Area in m2: ');
WheelInertia=input('Enter Wheel Inertia in kgm2: ');
RollingResistanceC=input('Enter Rolling Resistance Coefficient: ');
DragC=input('Enter Drag Coefficient: ');
AirDensity=input('Enter Air Density in kg/m3: ');
time=[0:1180];
RequiredGear=xlsread('Drive Cycle','Drive Cycle NEDC','C2:C1182');
Velocitykmh=xlsread('Drive Cycle','Drive Cycle NEDC','D2:D1182');

Velocityms=(1000/3600)*Velocitykmh;

Acceleration=zeros(1181,1);
for i=2:1181
    Acceleration(i)=Velocityms(i)-Velocityms(i-1);
end

WVelocityRev=zeros(1181,1);
for i=1:1181
    WVelocityRev(i)=Velocityms(i)/(2*pi*WRollingRadius);
end

WVelocityRPM=60*WVelocityRev;

WVelocityRad=zeros(1181,1);
for i=1:1181
    WVelocityRad(i)=(WVelocityRev(i)*360)*(pi/180);
end

WAcceleration=zeros(1181,1);
for i=2:1181
    WAcceleration(i)=WVelocityRad(i)-WVelocityRad(i-1);
end

WForce=zeros(1181,1);
% Need an if 0 then 0????
for i=1:1181
    if Velocityms(i)==0
        WForce(i)=0;
    else

WForce(i)=(VehicleMass*Acceleration(i))+(VehicleMass*9.81*RollingResistanceC)+(0.5*AirDensity*DragC*FrontalArea*Velocityms(i)^2);
    end
end

WTorque=WForce*WRollingRadius;

DlTorque=zeros(1181,1);
```

```

for i=1:1181
    DlTorque(i)=WTorque(i)+(2*WheelInertia*WAcceleration(i));
end

DiffAcceleration=WAcceleration;

Diff_Output_Torque=DlTorque;

FDEfficiency=0.94;

FDRatio=3.94;

Diff_Input_Torque=zeros(1181,1);
for i=1:1181
    Diff_Input_Torque(i)=Diff_Output_Torque(i)/(FDRatio*FDEfficiency);
end

Trans_Output_Torque=Diff_Input_Torque;

GEfficiency=[0.94 0.94 0.95 0.97 0.97 0.96]';

GRatio=[3.36 2.09 1.47 1.1 0.87 0.73]';

Trans_Input_Torque=zeros(1181,1);
for i=1:1181
    p=RequiredGear(i);
    if RequiredGear(i)==0
        Trans_Input_Torque(i)=0;
    else
        Trans_Input_Torque(i)=Trans_Output_Torque(i)/(GEfficiency(p)*GRatio(p));
    end
end

EVelocity=zeros(1181,1);
for i=1:1181
    p=RequiredGear(i);
    if Velocityms(i)==0
        EVelocity(i)=800;
    else
        EVelocity(i)=WVelocityRPM(i)*(FDRatio*GRatio(p));
    end
end

CorrEVelocity=zeros(1181,1);
for i=1:1181
    if EVelocity(i)<800
        CorrEVelocity(i)=800;
    else
        CorrEVelocity(i)=EVelocity(i);
    end
end

Eng_Output_Torque=Trans_Input_Torque;

Eng_Angular_Velocity=CorrEVelocity*(2*pi/60);

Eng_Angular_Acceleration=zeros(1181,1);

```

```

for i=2:1181
    Eng_Angular_Acceleration(i)=Eng_Angular_Velocity(i)-
    Eng_Angular_Velocity(i-1);
end

Extra_Torque_Engine=Eng_Angular_Acceleration*EngineInertia;

DynoTorque=Eng_Output_Torque+Extra_Torque_Engine;

BMEPPa=zeros(1181,1);
for i=1:1181
    BMEPPa(i)=(DynoTorque(i)*(4*pi/(EngineDisplacement*0.001)))*1000;
end

BMEPB=zeros(1181,1);
for i=1:1181
    BMEPB(i)=BMEPPa(i)/100000;
end

BMEP=zeros(1181,1);
for i=1:1181
    if BMEPB(i)<0
        BMEP(i)=0;
    else
        BMEP(i)=BMEPB(i);
    end
end

PowerW=zeros(1181,1);
for i=1:1181
    PowerW(i)=BMEP(i)*100000*EngineDisplacement*0.000001*3000/120;
end

PowerkW=zeros(1181,1);
for i=1:1181
    PowerkW(i)=PowerW(i)*0.001;
end

FuelUsage=zeros(1181,1);
for i=1:1181
    if CorrEVelocity(i)<850
        FuelUsage(i)=(0.00000079653*BMEP(i)^5-0.000025193*BMEP(i)^4 +
        0.0001313*BMEP(i)^3 + 0.0016997*BMEP(i)^2 + 0.038719*BMEP(i)
        +0.082001)+(CorrEVelocity(i)-500)/(850-500)*(( 0.00000078449*BMEP(i)^5 -
        0.000018557*BMEP(i)^4 - 0.000085777*BMEP(i)^3 + 0.0043539*BMEP(i)^2 +
        0.061814*BMEP(i)+ 0.14636)-( 0.00000079653*BMEP(i)^5 -
        0.000025193*BMEP(i)^4 + 0.0001313*BMEP(i)^3 + 0.0016997*BMEP(i)^2 +
        0.038719*BMEP(i) +0.082001));
    elseif CorrEVelocity(i)<1000
        FuelUsage(i)=(0.00000078449*BMEP(i)^5-0.000018557*BMEP(i)^4 -
        0.000085777*BMEP(i)^3 + 0.0043539*BMEP(i)^2 + 0.061814*BMEP(i)+
        0.14636)+(CorrEVelocity(i)-850)/(1000-850)*(( 0.00000061499*BMEP(i)^5 -
        0.0000086811*BMEP(i)^4 - 0.00027016*BMEP(i)^3 +0.0059349*BMEP(i)^2 +
        0.070584*BMEP(i) + 0.1757)-( 0.00000078449*BMEP(i)^5 -
        0.000018557*BMEP(i)^4 - 0.000085777*BMEP(i)^3 + 0.0043539*BMEP(i)^2 +
        0.061814*BMEP(i)+ 0.14636));
    elseif CorrEVelocity(i)<1250
        FuelUsage(i)=(0.00000061499*BMEP(i)^5-0.0000086811*BMEP(i)^4 -
        0.00027016*BMEP(i)^3 +0.0059349*BMEP(i)^2 + 0.070584*BMEP(i) +

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0.1757)+(CorrEVelocity(i)-1000)/(1250-1000)*((0.000000084359*BMEP(i)^5 +
0.00001834*BMEP(i)^4 - 0.00071424*BMEP(i)^3 + 0.0092148*BMEP(i)^2
+0.083751*BMEP(i)+ 0.22686)-( 0.00000061499*BMEP(i)^5 -
0.0000086811*BMEP(i)^4 - 0.00027016*BMEP(i)^3 +0.0059349*BMEP(i)^2 +
0.070584*BMEP(i) + 0.1757));
elseif CorrEVelocity(i)<1500
    FuelUsage(i)=(0.000000084359*BMEP(i)^5+0.00001834*BMEP(i)^4 -
0.00071424*BMEP(i)^3 + 0.0092148*BMEP(i)^2 +0.083751*BMEP(i)+
0.22686)+(CorrEVelocity(i)-1250)/(1500-1250)*((-0.00000082274*BMEP(i)^5 +
0.000061243*BMEP(i)^4 - 0.0013628*BMEP(i)^3 + 0.013401*BMEP(i)^2
+0.095572*BMEP(i)+ 0.28042)-( 0.000000084359*BMEP(i)^5 +
0.00001834*BMEP(i)^4 - 0.00071424*BMEP(i)^3 + 0.0092148*BMEP(i)^2
+0.083751*BMEP(i)+ 0.22686));
elseif CorrEVelocity(i)<1750
    FuelUsage(i)=(-0.00000082274*BMEP(i)^5+0.000061243*BMEP(i)^4 -
0.0013628*BMEP(i)^3 + 0.013401*BMEP(i)^2 +0.095572*BMEP(i)+
0.28042)+(CorrEVelocity(i)-1500)/(1750-1500)*((-0.0000022305*BMEP(i)^5 +
0.00012508*BMEP(i)^4 - 0.0022781*BMEP(i)^3 + 0.018643*BMEP(i)^2 +
0.10723*BMEP(i) + 0.33537)-( - 0.00000082274*BMEP(i)^5 +
0.000061243*BMEP(i)^4 - 0.0013628*BMEP(i)^3 + 0.013401*BMEP(i)^2
+0.095572*BMEP(i)+ 0.28042));
elseif CorrEVelocity(i)<2000
    FuelUsage(i)=(-0.0000022305*BMEP(i)^5+0.00012508*BMEP(i)^4 -
0.0022781*BMEP(i)^3 + 0.018643*BMEP(i)^2 + 0.10723*BMEP(i) +
0.33537)+(CorrEVelocity(i)-1750)/(2000-1750)*((-0.0000044863*BMEP(i)^5 +
0.00022681*BMEP(i)^4 - 0.0037523*BMEP(i)^3 + 0.027024*BMEP(i)^2 +
0.11353*BMEP(i)+ 0.39352)-( - 0.0000022305*BMEP(i)^5 + 0.00012508*BMEP(i)^4
- 0.0022781*BMEP(i)^3 + 0.018643*BMEP(i)^2 + 0.10723*BMEP(i) + 0.33537));
elseif CorrEVelocity(i)<2500
    FuelUsage(i)=(-0.0000044863*BMEP(i)^5+0.00022681*BMEP(i)^4 -
0.0037523*BMEP(i)^3 + 0.027024*BMEP(i)^2 + 0.11353*BMEP(i)+
0.39352)+(CorrEVelocity(i)-2000)/(2500-2000)*((-0.0000050694*BMEP(i)^5 +
0.00024692*BMEP(i)^4 - 0.0037971*BMEP(i)^3 + 0.025796*BMEP(i)^2 +
0.16397*BMEP(i) + 0.49813)-( - 0.0000044863*BMEP(i)^5 +
0.00022681*BMEP(i)^4 - 0.0037523*BMEP(i)^3 + 0.027024*BMEP(i)^2 +
0.11353*BMEP(i)+ 0.39352));
elseif CorrEVelocity(i)<3000
    FuelUsage(i)=(-0.0000050694*BMEP(i)^5+0.00024692*BMEP(i)^4 -
0.0037971*BMEP(i)^3 + 0.025796*BMEP(i)^2 + 0.16397*BMEP(i) +
0.49813)+(CorrEVelocity(i)-2500)/(3000-2500)*((0.00000014371*BMEP(i)^5 -
0.0000070983*BMEP(i)^4 + 0.00063422*BMEP(i)^3 - 0.0054834*BMEP(i)^2 +
0.29336*BMEP(i) + 0.5677)-( - 0.0000050694*BMEP(i)^5 + 0.00024692*BMEP(i)^4
- 0.0037971*BMEP(i)^3 + 0.025796*BMEP(i)^2 + 0.16397*BMEP(i) + 0.49813));
elseif CorrEVelocity(i)<3500
    FuelUsage(i)=(0.00000014371*BMEP(i)^5-0.0000070983*BMEP(i)^4 +
0.00063422*BMEP(i)^3 - 0.0054834*BMEP(i)^2 + 0.29336*BMEP(i) +
0.5677)+(CorrEVelocity(i)-3000)/(3500-3000)*((0.0000099835*BMEP(i)^5 -
0.0004789*BMEP(i)^4 + 0.0085932*BMEP(i)^3 - 0.059672*BMEP(i)^2 +
0.47972*BMEP(i) + 0.6086)-( 0.00000014371*BMEP(i)^5 -
0.0000070983*BMEP(i)^4 + 0.00063422*BMEP(i)^3 - 0.0054834*BMEP(i)^2 +
0.29336*BMEP(i) + 0.5677));
elseif CorrEVelocity(i)<4000
    FuelUsage(i)=(0.0000099835*BMEP(i)^5-0.0004789*BMEP(i)^4 +
0.0085932*BMEP(i)^3 - 0.059672*BMEP(i)^2 + 0.47972*BMEP(i) +
0.6086)+(CorrEVelocity(i)-3500)/(4000-3500)*(( 0.000016528*BMEP(i)^5 -
0.00079771*BMEP(i)^4 + 0.014138*BMEP(i)^3 - 0.097772*BMEP(i)^2 +
0.62938*BMEP(i) + 0.65513)-( 0.0000099835*BMEP(i)^5 - 0.0004789*BMEP(i)^4 +
0.0085932*BMEP(i)^3 - 0.059672*BMEP(i)^2 + 0.47972*BMEP(i) + 0.6086));
elseif CorrEVelocity(i)<4500
    FuelUsage(i)=(0.000016528*BMEP(i)^5-0.00079771*BMEP(i)^4 +
0.014138*BMEP(i)^3 - 0.097772*BMEP(i)^2 + 0.62938*BMEP(i) +

```

```

0.65513)+(CorrEVelocity(i)-4000)/(4500-4000)*(( 0.0000011737*BMEP(i)^5 -
0.000097067*BMEP(i)^4 + 0.0034715*BMEP(i)^3 - 0.031395*BMEP(i)^2 +
0.54363*BMEP(i)+ 0.78326)-( 0.000016528*BMEP(i)^5 - 0.00079771*BMEP(i)^4 +
0.014138*BMEP(i)^3 - 0.097772*BMEP(i)^2 + 0.62938*BMEP(i) + 0.65513));
elseif CorrEVelocity(i)<5000
    FuelUsage(i)=(0.0000011737*BMEP(i)^5-0.000097067*BMEP(i)^4 +
0.0034715*BMEP(i)^3 - 0.031395*BMEP(i)^2 + 0.54363*BMEP(i)+
0.78326)+(CorrEVelocity(i)-4500)/(5000-4500)*((-0.000023555*BMEP(i)^5 +
0.0010484*BMEP(i)^4 - 0.014389*BMEP(i)^3 + 0.082709*BMEP(i)^2
+0.34748*BMEP(i)+ 0.94136)-( 0.0000011737*BMEP(i)^5 - 0.000097067*BMEP(i)^4
+ 0.0034715*BMEP(i)^3 - 0.031395*BMEP(i)^2 + 0.54363*BMEP(i)+ 0.78326));
elseif CorrEVelocity(i)<6000
    FuelUsage(i)=(-0.000023555*BMEP(i)^5+0.0010484*BMEP(i)^4 -
0.014389*BMEP(i)^3 + 0.082709*BMEP(i)^2 +0.34748*BMEP(i)+
0.94136)+(CorrEVelocity(i)-5000)/(6000-5000)*(( - 0.000024333*BMEP(i)^5 +
0.0011791*BMEP(i)^4 - 0.017593*BMEP(i)^3 + 0.12086*BMEP(i)^2 +
0.3345*BMEP(i)+ 1.0532)-(- 0.000023555*BMEP(i)^5 + 0.0010484*BMEP(i)^4 -
0.014389*BMEP(i)^3 + 0.082709*BMEP(i)^2 +0.34748*BMEP(i)+ 0.94136));
else CorrEVelocity(i)<7000
    FuelUsage(i)=(-0.000024333*BMEP(i)^5+0.0011791*BMEP(i)^4 -
0.017593*BMEP(i)^3 + 0.12086*BMEP(i)^2 + 0.3345*BMEP(i)+
1.0532)+(CorrEVelocity(i)-6000)/(7000-6000)*(( - 0.0000032483*BMEP(i)^5 -
0.000095355*BMEP(i)^4 + 0.0084331*BMEP(i)^3 - 0.065338*BMEP(i)^2 +
0.89555*BMEP(i)+ 0.82541)-(- 0.000024333*BMEP(i)^5 + 0.0011791*BMEP(i)^4 -
0.017593*BMEP(i)^3 + 0.12086*BMEP(i)^2 + 0.3345*BMEP(i)+ 1.0532));
end
end
FuelUsage;
UrbanFU=sum(FuelUsage(1:781,1))
ExtraUrbanFU=sum(FuelUsage(782:1181))
FU=sum(FuelUsage)

```

12.7 WLTP MATLAB Code

```
clc
clear all
VehicleMass=input('Enter Vehicle Mass in kg: ');
EngineDisplacement=input('Enter Engine Displacement in cubic centimeters: ');
WRollingRadius=input('Enter Wheel Rolling Radius in meters: ');
EngineIdle=input('Enter Engine idle RPM: ');
EngineInertia=input('Enter Engine Inertia in kgm2: ');
FrontalArea=input('Enter Vehicles Frontal Area in m2: ');
WheelInertia=input('Enter Wheel Inertia in kgm2: ');
RollingResistanceC=input('Enter Rolling Resistance Coefficient: ');
DragC=input('Enter Drag Coefficient: ');
AirDensity=input('Enter Air Density in kg/m3: ');
Time=[0:1800];
RequiredGear=xlsread('Drive Cycle','WLTC','C2:C1802');
Velocitykmh=xlsread('Drive Cycle','WLTC','D2:D1802');

Velocityms=(1000/3600)*Velocitykmh;

Acceleration=zeros(1801,1);
for i=2:1801
    Acceleration(i)=Velocityms(i)-Velocityms(i-1);
end

WVelocityRev=zeros(1801,1);
for i=1:1801
    WVelocityRev(i)=Velocityms(i)/(2*pi*WRollingRadius);
end

WVelocityRPM=60*WVelocityRev;

WVelocityRad=zeros(1801,1);
for i=1:1801
    WVelocityRad(i)=(WVelocityRev(i)*360)*(pi/180);
end

WAcceleration=zeros(1801,1);
for i=2:1801
    WAcceleration(i)=WVelocityRad(i)-WVelocityRad(i-1);
end

WForce=zeros(1801,1);
% Need an if 0 then 0????
for i=1:1801
    if Velocityms (i)==0;
        WForce (i)=0;
    else

WForce(i)=(VehicleMass*Acceleration(i))+(VehicleMass*9.81*RollingResistance
C)+(0.5*AirDensity*DragC*FrontalArea*Velocityms(i)^2);
    end
end

WTorque=WForce*WRollingRadius;

DlTorque=zeros(1801,1);
```

```

for i=1:1801
    DlTorque(i)=WTorque(i)+(2*WheelInertia*WAcceleration(i));
end

DiffAcceleration=WAcceleration;

Diff_Output_Torque=DlTorque;

FDEfficiency=0.94;

FDRatio=3.94;

Diff_Input_Torque=zeros(1801,1);
for i=1:1801
    Diff_Input_Torque(i)=Diff_Output_Torque(i)/(FDRatio*FDEfficiency);
end

Trans_Output_Torque=Diff_Input_Torque;

GEfficiency=[0.94 0.94 0.95 0.97 0.97 0.96]';

GRatio=[3.36 2.09 1.47 1.1 0.87 0.73]';

Trans_Input_Torque=zeros(1801,1);
for i=1:1801
    p=RequiredGear(i);
    if RequiredGear(i)==0
        Trans_Input_Torque(i)=0;
    else
        Trans_Input_Torque(i)=Trans_Output_Torque(i)/(GEfficiency(p)*GRatio(p));
    end
end

EVelocity=zeros(1801,1);
for i=1:1801
    p=RequiredGear(i);
    if Velocityms(i)==0
        EVelocity(i)=800;
    else
        EVelocity(i)=WVelocityRPM(i)*(FDRatio*GRatio(p));
    end
end

CorrEVelocity=zeros(1801,1);
for i=1:1801
    if EVelocity(i)<800;
        CorrEVelocity(i)=800;
    else
        CorrEVelocity(i)=EVelocity(i);
    end
end

Eng_Output_Torque=Trans_Input_Torque;

Eng_Angular_Velocity=CorrEVelocity*(2*pi/60);

Eng_Angular_Acceleration=zeros(1801,1);

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for i=2:1801
    Eng_Angular_Acceleration(i)=Eng_Angular_Velocity(i)-
    Eng_Angular_Velocity(i-1);
end

Extra_Torque_Engine=Eng_Angular_Acceleration*EngineInertia;

DynoTorque=Eng_Output_Torque+Extra_Torque_Engine;

BMEPPa=zeros(1801,1);
for i=1:1801
    BMEPPa(i)=(DynoTorque(i)*(4*pi/(EngineDisplacement*0.001)))*1000;
end

BMEPB=zeros(1801,1);
for i=1:1801
    BMEPB(i)=BMEPPa(i)/100000;
end

BMEP=zeros(1801,1);
for i=1:1801
    if BMEPB(i)<0;
        BMEP(i)=0;
    else
        BMEP(i)=BMEPB(i);
    end
end

PowerW=zeros(1801,1);
for i=1:1801
    PowerW(i)=BMEP(i)*100000*EngineDisplacement*0.000001*3000/120;
end

PowerkW=zeros(1801,1);
for i=1:1801
    PowerkW(i)=PowerW(i)*0.001;
end

FuelUsage=zeros(1801,1);
for i=1:1801
    if CorrEVelocity(i)<850
        FuelUsage(i)=(0.00000079653*BMEP(i)^5-0.000025193*BMEP(i)^4 +
0.0001313*BMEP(i)^3 + 0.0016997*BMEP(i)^2 + 0.038719*BMEP(i)
+0.082001)+(CorrEVelocity(i)-500)/(850-500)*(( 0.00000078449*BMEP(i)^5 -
0.000018557*BMEP(i)^4 - 0.000085777*BMEP(i)^3 + 0.0043539*BMEP(i)^2 +
0.061814*BMEP(i)+ 0.14636)-( 0.00000079653*BMEP(i)^5 -
0.000025193*BMEP(i)^4 + 0.0001313*BMEP(i)^3 + 0.0016997*BMEP(i)^2 +
0.038719*BMEP(i) +0.082001));
    elseif CorrEVelocity(i)<1000
        FuelUsage(i)=(0.00000078449*BMEP(i)^5-0.000018557*BMEP(i)^4 -
0.000085777*BMEP(i)^3 + 0.0043539*BMEP(i)^2 + 0.061814*BMEP(i)+
0.14636)+(CorrEVelocity(i)-850)/(1000-850)*(( 0.00000061499*BMEP(i)^5 -
0.0000086811*BMEP(i)^4 - 0.00027016*BMEP(i)^3 +0.0059349*BMEP(i)^2 +
0.070584*BMEP(i) + 0.1757)-( 0.00000078449*BMEP(i)^5 -
0.000018557*BMEP(i)^4 - 0.000085777*BMEP(i)^3 + 0.0043539*BMEP(i)^2 +
0.061814*BMEP(i)+ 0.14636));
    elseif CorrEVelocity(i)<1250
        FuelUsage(i)=(0.00000061499*BMEP(i)^5-0.0000086811*BMEP(i)^4 -
0.00027016*BMEP(i)^3 +0.0059349*BMEP(i)^2 + 0.070584*BMEP(i) +

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0.1757)+(CorrEVelocity(i)-1000)/(1250-1000)*((0.000000084359*BMEP(i)^5 +
0.00001834*BMEP(i)^4 - 0.00071424*BMEP(i)^3 + 0.0092148*BMEP(i)^2
+0.083751*BMEP(i)+ 0.22686)-( 0.00000061499*BMEP(i)^5 -
0.0000086811*BMEP(i)^4 - 0.00027016*BMEP(i)^3 +0.0059349*BMEP(i)^2 +
0.070584*BMEP(i) + 0.1757));
elseif CorrEVelocity(i)<1500
    FuelUsage(i)=(0.000000084359*BMEP(i)^5+0.00001834*BMEP(i)^4 -
0.00071424*BMEP(i)^3 + 0.0092148*BMEP(i)^2 +0.083751*BMEP(i)+
0.22686)+(CorrEVelocity(i)-1250)/(1500-1250)*((-0.00000082274*BMEP(i)^5 +
0.000061243*BMEP(i)^4 - 0.0013628*BMEP(i)^3 + 0.013401*BMEP(i)^2
+0.095572*BMEP(i)+ 0.28042)-( 0.000000084359*BMEP(i)^5 +
0.00001834*BMEP(i)^4 - 0.00071424*BMEP(i)^3 + 0.0092148*BMEP(i)^2
+0.083751*BMEP(i)+ 0.22686));
elseif CorrEVelocity(i)<1750
    FuelUsage(i)=(-0.00000082274*BMEP(i)^5+0.000061243*BMEP(i)^4 -
0.0013628*BMEP(i)^3 + 0.013401*BMEP(i)^2 +0.095572*BMEP(i)+
0.28042)+(CorrEVelocity(i)-1500)/(1750-1500)*((-0.0000022305*BMEP(i)^5 +
0.00012508*BMEP(i)^4 - 0.0022781*BMEP(i)^3 + 0.018643*BMEP(i)^2 +
0.10723*BMEP(i) + 0.33537)-( - 0.00000082274*BMEP(i)^5 +
0.000061243*BMEP(i)^4 - 0.0013628*BMEP(i)^3 + 0.013401*BMEP(i)^2
+0.095572*BMEP(i)+ 0.28042));
elseif CorrEVelocity(i)<2000
    FuelUsage(i)=(-0.0000022305*BMEP(i)^5+0.00012508*BMEP(i)^4 -
0.0022781*BMEP(i)^3 + 0.018643*BMEP(i)^2 + 0.10723*BMEP(i) +
0.33537)+(CorrEVelocity(i)-1750)/(2000-1750)*((-0.0000044863*BMEP(i)^5 +
0.00022681*BMEP(i)^4 - 0.0037523*BMEP(i)^3 + 0.027024*BMEP(i)^2 +
0.11353*BMEP(i)+ 0.39352)-( - 0.0000022305*BMEP(i)^5 + 0.00012508*BMEP(i)^4
- 0.0022781*BMEP(i)^3 + 0.018643*BMEP(i)^2 + 0.10723*BMEP(i) + 0.33537));
elseif CorrEVelocity(i)<2500
    FuelUsage(i)=(-0.0000044863*BMEP(i)^5+0.00022681*BMEP(i)^4 -
0.0037523*BMEP(i)^3 + 0.027024*BMEP(i)^2 + 0.11353*BMEP(i)+
0.39352)+(CorrEVelocity(i)-2000)/(2500-2000)*((-0.0000050694*BMEP(i)^5 +
0.00024692*BMEP(i)^4 - 0.0037971*BMEP(i)^3 + 0.025796*BMEP(i)^2 +
0.16397*BMEP(i) + 0.49813)-( - 0.0000044863*BMEP(i)^5 +
0.00022681*BMEP(i)^4 - 0.0037523*BMEP(i)^3 + 0.027024*BMEP(i)^2 +
0.11353*BMEP(i)+ 0.39352));
elseif CorrEVelocity(i)<3000
    FuelUsage(i)=(-0.0000050694*BMEP(i)^5+0.00024692*BMEP(i)^4 -
0.0037971*BMEP(i)^3 + 0.025796*BMEP(i)^2 + 0.16397*BMEP(i) +
0.49813)+(CorrEVelocity(i)-2500)/(3000-2500)*((0.00000014371*BMEP(i)^5 -
0.0000070983*BMEP(i)^4 + 0.00063422*BMEP(i)^3 - 0.0054834*BMEP(i)^2 +
0.29336*BMEP(i) + 0.5677)-( - 0.0000050694*BMEP(i)^5 + 0.00024692*BMEP(i)^4
- 0.0037971*BMEP(i)^3 + 0.025796*BMEP(i)^2 + 0.16397*BMEP(i) + 0.49813));
elseif CorrEVelocity(i)<3500
    FuelUsage(i)=(0.00000014371*BMEP(i)^5-0.0000070983*BMEP(i)^4 +
0.00063422*BMEP(i)^3 - 0.0054834*BMEP(i)^2 + 0.29336*BMEP(i) +
0.5677)+(CorrEVelocity(i)-3000)/(3500-3000)*((0.0000099835*BMEP(i)^5 -
0.0004789*BMEP(i)^4 + 0.0085932*BMEP(i)^3 - 0.059672*BMEP(i)^2 +
0.47972*BMEP(i) + 0.6086)-( 0.00000014371*BMEP(i)^5 -
0.0000070983*BMEP(i)^4 + 0.00063422*BMEP(i)^3 - 0.0054834*BMEP(i)^2 +
0.29336*BMEP(i) + 0.5677));
elseif CorrEVelocity(i)<4000
    FuelUsage(i)=(0.0000099835*BMEP(i)^5-0.0004789*BMEP(i)^4 +
0.0085932*BMEP(i)^3 - 0.059672*BMEP(i)^2 + 0.47972*BMEP(i) +
0.6086)+(CorrEVelocity(i)-3500)/(4000-3500)*(( 0.000016528*BMEP(i)^5 -
0.00079771*BMEP(i)^4 + 0.014138*BMEP(i)^3 - 0.097772*BMEP(i)^2 +
0.62938*BMEP(i) + 0.65513)-( 0.0000099835*BMEP(i)^5 - 0.0004789*BMEP(i)^4 +
0.0085932*BMEP(i)^3 - 0.059672*BMEP(i)^2 + 0.47972*BMEP(i) + 0.6086));
elseif CorrEVelocity(i)<4500
    FuelUsage(i)=(0.000016528*BMEP(i)^5-0.00079771*BMEP(i)^4 +
0.014138*BMEP(i)^3 - 0.097772*BMEP(i)^2 + 0.62938*BMEP(i) +

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0.65513)+(CorrEVelocity(i)-4000)/(4500-4000)*(( 0.0000011737*BMEP(i)^5 -
0.000097067*BMEP(i)^4 + 0.0034715*BMEP(i)^3 - 0.031395*BMEP(i)^2 +
0.54363*BMEP(i)+ 0.78326)-( 0.000016528*BMEP(i)^5 - 0.00079771*BMEP(i)^4 +
0.014138*BMEP(i)^3 - 0.097772*BMEP(i)^2 + 0.62938*BMEP(i) + 0.65513));
elseif CorrEVelocity(i)<5000
    FuelUsage(i)=(0.0000011737*BMEP(i)^5-0.000097067*BMEP(i)^4 +
0.0034715*BMEP(i)^3 - 0.031395*BMEP(i)^2 + 0.54363*BMEP(i)+
0.78326)+(CorrEVelocity(i)-4500)/(5000-4500)*((-0.000023555*BMEP(i)^5 +
0.0010484*BMEP(i)^4 - 0.014389*BMEP(i)^3 + 0.082709*BMEP(i)^2
+0.34748*BMEP(i)+ 0.94136)-( 0.0000011737*BMEP(i)^5 - 0.000097067*BMEP(i)^4
+ 0.0034715*BMEP(i)^3 - 0.031395*BMEP(i)^2 + 0.54363*BMEP(i)+ 0.78326));
elseif CorrEVelocity(i)<6000
    FuelUsage(i)=(-0.000023555*BMEP(i)^5+0.0010484*BMEP(i)^4 -
0.014389*BMEP(i)^3 + 0.082709*BMEP(i)^2 +0.34748*BMEP(i)+
0.94136)+(CorrEVelocity(i)-5000)/(6000-5000)*(( - 0.000024333*BMEP(i)^5 +
0.0011791*BMEP(i)^4 - 0.017593*BMEP(i)^3 + 0.12086*BMEP(i)^2 +
0.3345*BMEP(i)+ 1.0532)-( - 0.000023555*BMEP(i)^5 + 0.0010484*BMEP(i)^4 -
0.014389*BMEP(i)^3 + 0.082709*BMEP(i)^2 +0.34748*BMEP(i)+ 0.94136));
else CorrEVelocity(i)<7000
    FuelUsage(i)=(-0.000024333*BMEP(i)^5+0.0011791*BMEP(i)^4 -
0.017593*BMEP(i)^3 + 0.12086*BMEP(i)^2 + 0.3345*BMEP(i)+
1.0532)+(CorrEVelocity(i)-6000)/(7000-6000)*(( - 0.0000032483*BMEP(i)^5 -
0.000095355*BMEP(i)^4 + 0.0084331*BMEP(i)^3 - 0.065338*BMEP(i)^2 +
0.89555*BMEP(i)+ 0.82541)-( - 0.000024333*BMEP(i)^5 + 0.0011791*BMEP(i)^4 -
0.017593*BMEP(i)^3 + 0.12086*BMEP(i)^2 + 0.3345*BMEP(i)+ 1.0532));
end
end
FuelUsage;
LowFU=sum(FuelUsage(1:590,1))
MediumFU=sum(FuelUsage(591:1023,1))
HighFU=sum(FuelUsage(1024:1478,1))
ExtraHighFU=sum(FuelUsage(1479:1801,1))
FU=sum(FuelUsage)

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