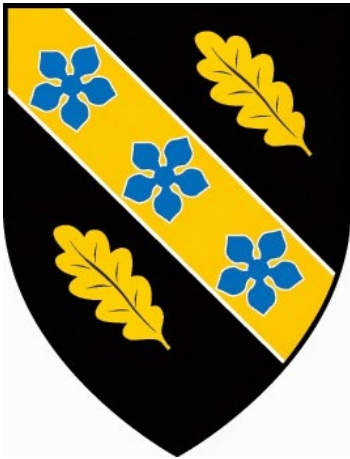




PRIFYSGOL CYMRU

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An Investigation into Fuel Mapping and Ignition Timing on a Turbocharged Engine

Jack Hazlewood | Main Project | 12/11/2018



Declaration of Authenticity

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

Signed:

Date:

Abstract

The project was taken on to find whether there were improvements that could be made on a Nissan 200sx. The Nissan spent 5 months of dynamometer testing with many improvements made to the engine. The engine wasn't opened up at any point and still uses the stock internals however external bolt-ons were added to support the increase in engine power. The exhaust temperatures were monitored to get a better understanding of what is happening in the combustion chamber. The project shows some benefits to changing the fuel and timing along with how an engine can be improved just by changing the quality of fuel that is put into the tank. The project sees a performance increase of 75% over standard engine power while still remaining safe and containing no engine detonation. The project shows how advancing the timing of a boosted engine can improve the performance and create more power. It will also show how an increase of octane rating can improve the power when having access to the timing tables but minimal effect with the same engine map. There will be the effects of how much fuel that is being injected into the cylinders and where the limit for max power and whether it can be achieved without causing too much heat.

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Abbreviations

Dyno- Dynamometer

AFR- Air Fuel Ratio

Knock- Detonation

RPM- Revs per Minute

ECU- Engine Control Unit

MAF- Mass Air Flow

OBD- On Board Diagnostics

CFM- Cubic Feet per Minute

BHP- Brake Horse Power

UK- United Kingdom

Nm- Newton Meters

°C- Degrees Celsius

L/s- Litres per Second

Kw- Kilowatts

Kg- Kilograms

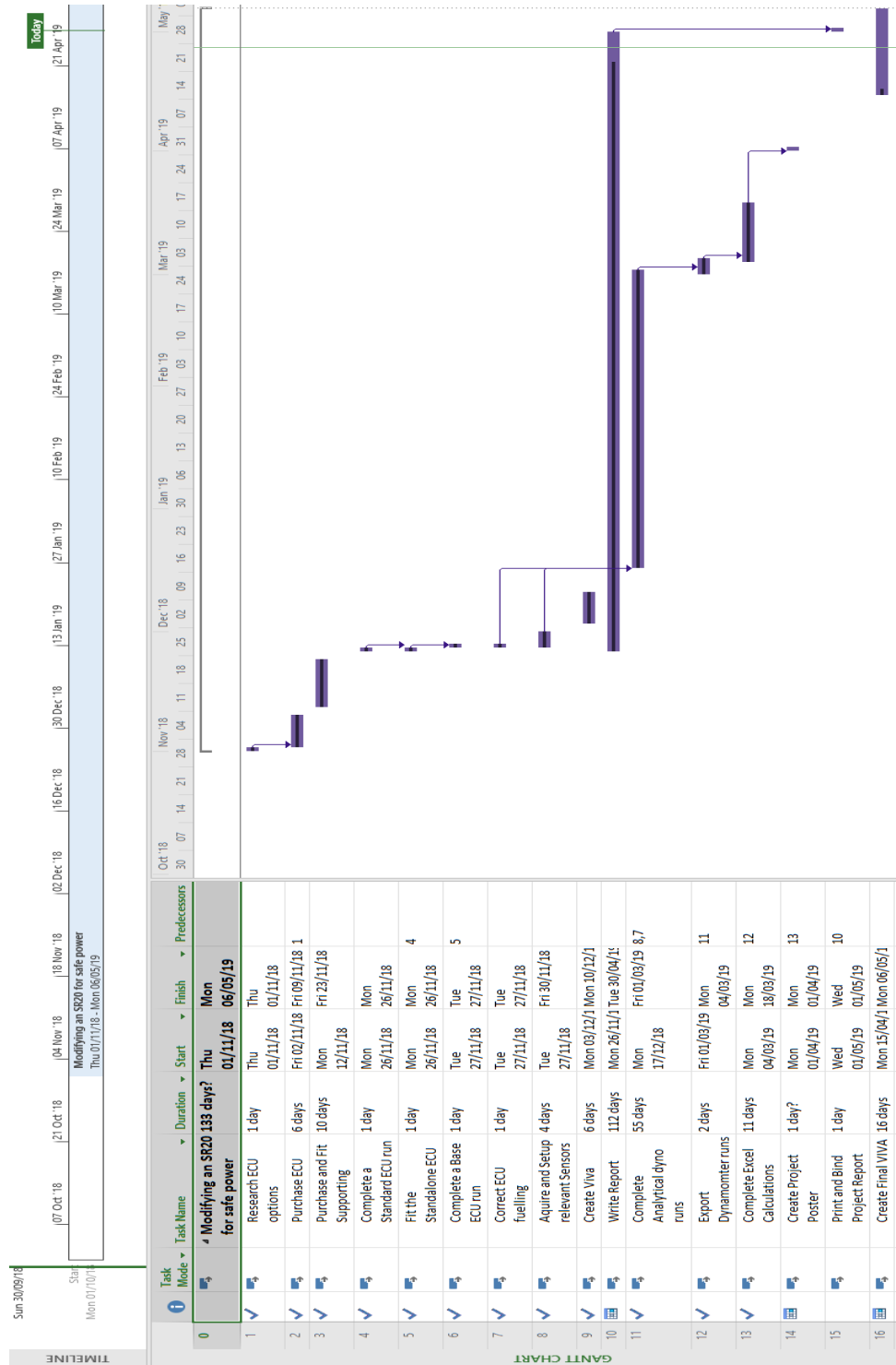
PSI- Pounds per Square Inch

1.0 Introduction

The project will consist of looking at some benefits of going to a standalone ECU by comparing some of the characteristics of engine tuning to compare the heat that is given out to the exhaust at each point. This will then allow a better understanding of engine combustion temperatures. Excessive engine temperatures can lead to the engine prematurely failing by having an excessive amount of knock leading to piston damage and eventually engine failure. There will be tests that involve looking at multiple load points this in turn will allow less air and fuel into the cylinder meaning there are less reactants to be ignited and combusted. There will also be a change of fuelling running it richer and also towards stoichiometric allowing more fuel to be added and therefore less oxygen resulting in a slower combustion. There will also be various timings tested to see how the exhaust temperatures change throughout and how the fuel can affect the amount of power and torque the engine can be produced and whether it effects internal combustion. The project will also consider some turbo efficiencies and whether a turbo can be made more efficient by changing the cars map.

The car that is being used is 2000 Nissan 200sx which consists of a two-litre turbocharged engine. The ECU that will be used is the link G4+ which is a straight plug and play with the standard Nissan loom and includes many features and will allow many other sensors to be added and monitored during the dynamometer runs. The turbo the car has is a Garrett T28, this is a standard unit for this car and tend to be able to run 17psi safely. It has an inlet size of 46.5mm and an outlet size of 60mm, therefore this a small turbo. However due to the turbo being old and using journal bearing system it is a fairly slow turbo to spool for its size with maximum pressure coming in at around 3500-4000 RPM, therefore the turbo is going to be an inefficient turbo to start with. (Turbo Charger kits, 2013)

2.0 Timing Plan



Gantt chart 1 - Project Timing

3.0.0 Research

3.1.0 DYNAMOMETER

A dynamometer is used to find an engine's characteristics such as power and torque. The dynamometer places a load on the engine and with a load applied to the vehicle then the engine doesn't have the ability to rev quickly and acts in a similar fashion to how the car would drive down the road. So placing the car in fourth gear and flooring it, the engine will take around a minute to get to red line, where less power means a longer run time. There is the ability to apply different loads to the vehicle so there is the possibility to keep the car at a certain RPM by applying the correct amount of load to the engine so it can no longer rev any higher. This is a useful feature when tuning a car as it allows the user to tune for each throttle position at each RPM point. A dynamometer uses the torque output to calculate the horsepower, the dynamometer will read the torque given out and complete an equation to calculate the horsepower at the wheels. A horsepower graph can be created using the RPM, power and torque registered from the dynamometer, this graph will show where the maximum torque and horsepower occurs, which can be used to find the best launch RPM, with a high grip coefficient tyre set up, the launch control can be set to maximum horsepower to get all of the available power to the tarmac. It is also a good indicator of where the optimum shifting time is. (Brain, n.d.)

3.1.1 Rolling Road

A chassis dyno is a more convenient dyno as you have the ability to drive the car straight onto the rollers and complete a run finding power and torque. There is an inertia type of dynamometer which uses a large drum that is spun using the vehicle's wheels. A bigger drum has more inertia than a smaller drum of the same weight, therefore requiring more torque. The dynamometer company knows how much inertia is created on each drum and uses that value to calculate the torque. There is also the brake type, which is much more useful, this makes use of a brake that is connected to the rollers. In the past, it used to be that most dynamometers were water type and therefore used hydraulics to put load on the wheel, however the newer eddy current brake is more commonly used and more user friendly. Applying electricity to the brake creates the load to resist the wheel's rotation. A strain gauge is used and it's used to calculate torque and further calculate horsepower. As

a constant load can be applied the eddy brake is more favourable for tuning an engines fuelling and ignition timing. (Bell, 2012)

A rolling road dynamometer can calculate the power to the wheels fairly easily, by completing a calculation using the torque figures, however some dynos have the ability to calculate the power to the engine of a vehicle. This is done during the coast down of the dyno run. So as the wheels are coming to a stop on the rollers it uses the amount of time taken to slow them down. It will know how long it takes for the rollers to slow down on their own with no car running, so therefore it can see how much quicker the car slows down and use a calculation to give a powertrain drag. As there are many moving components to a rear wheel drive car such as the flywheel, gearbox, prop shaft, differential, driveshaft and all of the lubricants. Therefore all these components play a part in slower the rollers down and the dynamometer will use the coast down after a run to calculate roughly how much loss there is through the drivetrain. This isn't always one hundred percent accurate and can be altered in the settings. The drivetrain loss is generally within five percent. (Fall, 2019)

3.1.2 Engine Cell

An engine dyno is a lot more accurate than the chassis dynos as they have the ability to read power and torque more accurately as it is the power coming directly from the engine with no drivetrain losses or changes. Therefore this means that every little change to the engine can be seen and noted and will allow the user to find the optimum fuelling and timing for that engine. There is the possibility of seeing how a spark plug gap, engine cam timing and cam profiling all effect the engine. Therefore engine dynamometers are great for fining tuning every characteristic of an engine to find the optimum power and torque. (Bell, 2012)

3.2.0 FUEL MAPPING

Fuel mapping is a vital part of allowing a car to run and drive smoothly. The fuelling is controlled by an electronic control unit sending information to electronic injectors, telling them when to open and for how long. The correct length of time the injector must spray is referred to as a pulse width and is generally found using extensive dynamometer testing. A road going car will take months of dynamometer testing to ensure the car is meeting the strict standard of government emissions, while obtaining engine performance, drivability

and economy. However a competition engine is less demanding as there isn't as many strict rules and creature comforts aren't a priority. The ECU will remember all of the RPM and load points and store it so it knows exactly what to do once subjected to different RPM and load points. The ECU must get a signal from an external sensor telling it how much air is flowing through the inlet or manifold. The two most common ways of doing this is using a mass air flow sensor or manifold pressure sensor. (Bell, 2012)

The chemical energy from fuel is converted into heat energy by burning the fuel. The energy that is released from the heat increases gas temperatures and therefore causes the pressure of the gases to increase. This pressure is then translated to the top of the piston to create mechanical force and the mechanical power. (Halderman, 2016)

As the engine is a high performance engine and adding performance to the engine is more of a priority than getting fuel consumption it is therefore important to prioritize getting the maximum amount of power from the engine. To get maximum power will mean getting the most amount of air into the cylinder that is possible and therefore means more fuel is needed. However it is most important to not compromise top end performance as this is where the peak performance is going to be achieved. However, fuel economy can be considered under low RPM and load points as this is likely when the driver isn't wanting the most from the vehicle. So under 3500RPM and around a 50% throttle position the maximum torque and power isn't necessary and therefore some fuel economy can be factored in. As this is a road car there is no need to squeeze every last horsepower from the engine so the few horsepower lost at top end can be compromised for some fuel economy when driving around towns and motorways. It is important to make the most of all the oxygen that is available, this includes the air that is left in the cylinder. Therefore it is good to run a rich mixture between 12 to 13.5 parts of air to fuel. This will mean there is more fuel which means it is more likely to get a bigger reaction due to using more of the available oxygen. However doing this will increase the amount of hydrocarbons and carbon monoxide and will ruin the catalyst quicker. (Thomas Leonard, 2012) Due to the research that has been carried out during this part of the experiment, it is clear that the fuel map should be set to get an AFR reading of around 13:1 to ensure maximum power is obtained from the engine and reactants being inserted, however there is also the consideration of engine temperatures, therefore this will also be a large factor as more fuel can lower the temperature in the engine due to a slower flame front allowing more heat to escape through the cylinder walls.

3.3.0 IGNITION TIMING

There are many factors that can improve performance within an engine however without proper set up then they aren't as effective. It is important to make use of the performance by squeezing every drop of energy from the fuel and air. Therefore, it is important to get the exact spark timing to ensure the flame is keeping up with the engine, if the speed is too slow then the engine pressure will increase too slowly and therefore will not give the crankshaft the push round needed, while if the speed of the flame is too quick then it can become explosive and cause detonation eventually causing engine damage. The ignition timing is effectively the time at which the spark plug is being fired at and is generally compared to the crank position in degrees. The spark plug is generally fired before top dead centre to allow the combustion time to start and spread. There are many factors that can influence the flame speed during combustion, things such as: fuel quality, mixture quality, the amount of turbulence and the space of combustion. (Bell, 2012) Using this piece of research the vehicle will be advanced to knock limit to obtain maximum power from the engine, the timing will be advanced and using the information obtained the highest octane rating will be used to extract the most from the engine.

4.0 Dyno Setup

4.1 STRAPPING THE CAR

Using the Nissan 200sx as the example car to tie down. There are 2 tow hooks mounted to the chassis at the front of the car that are more than adequate to hold the car from the front. The two front straps are thick ratchet straps and work in the same way as any other ratcheting straps. Thread the strap through the mounting eye in the floor trying to ensure the ratchet is facing upwards at the top of the strap to make it easier to tighten. Use the protector on the straps to sit in the eye of the mount and thread the other side through the tow hook loop and pull back though. Ensure all the straps are straight and not twisted to make tightening easier and to keep everything looking tidy and professional. Again, use the protector and place it through the tow eye. Pull the strap through the ratchet as tight as possible and use the ratchet until the straps are tight and are not touching the floor. Fold the excess up and tuck under the car or straps to reduce tripping hazards. Repeat

for the other side of the car. At the back of the car the straps have to be crossed over and, on the Nissan, there is only one tow eye that can be used on the right-hand side. For the left-hand side of the car there is a hole in the sub frame that the hook is able to go through and lock on to, ensure the chain goes above exhaust to avoid it fouling on the exhaust when tightened. To tighten the chains, they need to be pulled as tight as can be and placed in the locking tool attached, ensure the bar is pulled over to avoid the chain popping out. Use the bar to tighten fully by turning the middle around while the outer parts are not moving. See below for attached images.

4.2



Figure 1 - Strapping the Car to the Dynamometer

4.2 CONNECTING SENSORS

The two thermocouples need to be screwed into the exhaust manifold and downpipe, ensuring they do not leak and are fully tightened to stop them coming loose. Ensure the exhaust has cooled down. These need to be plugged into the dynos sensor box, it is easier to read the results if the higher temperature is set to temperature one. The MAF sensor needs to be plugged in and attached to an external battery to stop the alternator from interfering with the signal that is given out from the MAF. The signal wire from the MAF then needs to be connected to the dyno sensor box to allow the dynameters program to record what is happening and another ground needs to come from the signal box to the negative side of the battery for the program to pick up the correct voltages. There is also the option to setup an additional lambda that slots into the back of the exhaust and logs it on the dyno, this will allow you to download the lambda data with the power and torque data and keep everything together. The lambda also has an external battery pack with a

wire and plug that has been adapted to connect straight onto the lambda plug. There is an external module that connects between the sensors and a signal is sent to the dyno.

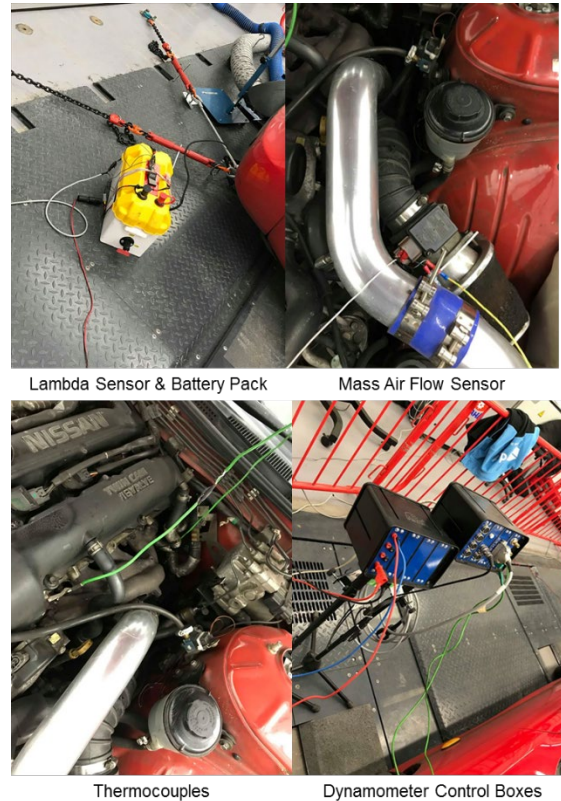


Figure 2 - Connecting the Sensors before a Run

4.3 SETTING UP THE DYNO

Ensure the switch is on at the side of the machine to power everything up. With the switch on turn the computer and monitor on and load up the dyno program. With the car all strapped down, ensure the handbrake is removed and move the bed of the dyno so the roller is directly under the driven wheels, ensure the car both sides on the car. With car and dyno bed all set up the non-driven wheel rollers should be locked to ensure there is no movement. Recheck all of the tie downs to ensure they are all still tight and haven't become loose. The settings of the car should be inputted into the dyno so the dyno knows exactly what it is expecting. Ensure the driven wheels are selected, the engine configuration is selected for example whether the vehicle is naturally aspirated or turbocharged and ensure the rough power output is set. This will help the dynamometer computer to get a better idea of what's being used. Next check that all the sensors are

working and that they are calibrated correctly in the service menu of the dyno program. The temperature sensors should be calibrated before inserting them into the exhaust. Use a thermometer to get the room temperature and leave the sensors hang in the air for roughly five minutes and if the sensor and thermometer read the same then proceed with the set-up, otherwise they can be changed and calibrated within the setting menu. The dyno has the option to plug straight into the OBD allowing the dyno to retrieve the ECU data, this is particularly useful for getting the correct RPM. However with the Nissan being a late nighties car does not have an OBD two port and therefore the RPM needs to be set up separately before the runs can begin. This is a simple procedure that takes a couple of minutes to complete, select run vehicle, it will bring up the car setup again, double check it to ensure everything is correct and continue, this will then bring up the RPM setting, set the new RPM and select the desired RPM, around 3000 RPM is good number, drive the car to the desired gear, which should be the gear with the closest ratio to 1:1, with the car in the correct gear drive the car to the chosen RPM, once happy signal the operator to click enter and the RPM should change ensure the RPM on screen is similar to the RPM read by the car.

5.0.0 Completing a Run

With the dyno and car all set up, ensure the exhaust extraction system is on. Plug the ECU into a laptop and turn the vehicle ignition on. Start the car and allow the car to idle for a couple of minutes to allow all the fluids to get around the engine. Proceed from the RPM page on the dyno and the dyno is ready to go, it can be useful to upload some previous data, this is easily achievable by clicking load and selecting background 1. The program has the possibility to insert up to three graphs into the background. It is recommended to complete a short run say up to 4000 RPM to warm all of the drivetrain components up and to check that everything is working correctly such as the external sensors. Once everything is all in check, proceed to complete a run. The car is cycled through the gears until the correct gear is selected in this case fourth gear, with a car that has no OBD plugged in then the dyno will start to measure power when the RPM indicates 1500 on the computer screen, this means by 1500 RPM the car should be in the correct gear and ready to proceed to maximum RPM. The on board RPM uses the speed of the

rollers to figure out what RPM the car is at based on what it was previously set at during the RPM trial. Proceed with the run to maximum RPM, ensure there is someone checking for leaks and that the vehicle operator is keeping an eye on the gauges such as lambda, boost and knock while keeping an eye on the screen of the dyno and the external operator in case the run needs to be ended early. Ensure all the in car sensors are recording between the limits the user is happy to run at, otherwise end the run and make changes.



Figure 3 - End of Dyno Run

6.0 MAF setup

To know exactly the amount of air that is going into the engine, the mass air flow sensor (MAF) has to be calibrated so the voltage output that is given from the signal wire can be

Voltage	Flow (cfm)	lpm
0.5	0	0
0.75	1	28.3
1	2.5	70.75
1.5	10	283
2	27.5	778.25
2.5	56	1584.8
3	89	2518.7

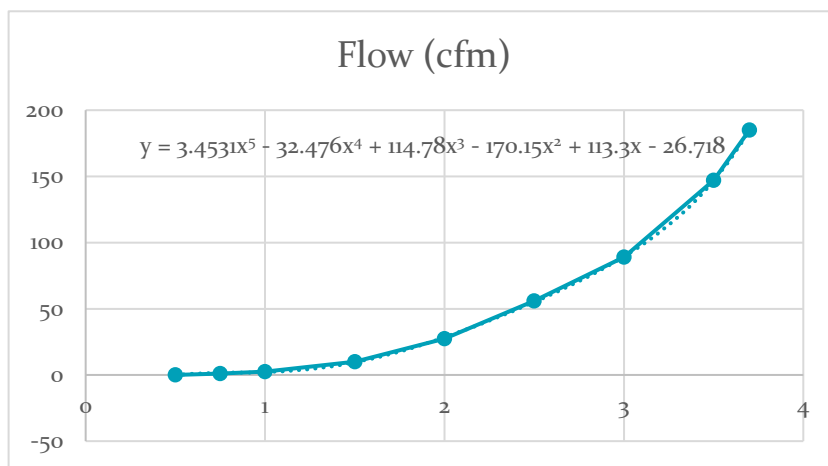
Table 1 - Table of Airflow obtained from Flow Bench

converted into the actually amount of airflow.

This is achieved using the flow bench with a car battery and voltmeter to power the MAF sensor and get the voltage supplied from the MAF's signal wire. The MAF needs to be seated on the flow bench the correct way with the sensor facing the air filter point down of the flow bench. The flow bench needs to be set to exhaust to ensure it's giving out air and not creating a

vacuum. Ensure a good seal is created, blue tack can be used to make a seal. Connect the MAF to the battery and voltmeter using wire, do a quick test with the machine to ensure the signal wire is giving different voltages as the air flow is increased. Use the voltmeter on the signal wire to determine the voltage when there is no air flowing and add to a spreadsheet.

Table 1 shows the table created when flowing the MAF. The voltmeter was used to go up in multiples of 0.5 volts. Then using the graph displayed on the machine to get the flow rate in cfm. This was then converted to litres per minute by multiplying by 28.3. The machine only went to 185 cfm which equated to 3.7 volts. Therefore, a line graph was created with a polynomial being utilized to get the values right the way to 5 volts which is the maximum output of the signal wire.



Graph 1 - Increase in Voltage with Polynomial

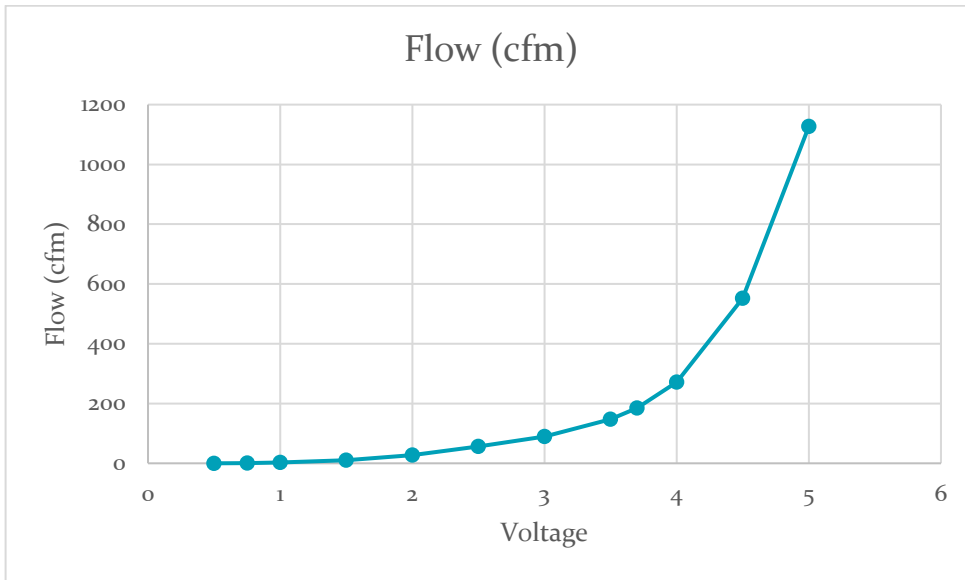
Graph one is the polynomial equation and line graph from the results gained from the flow bench.

3.7	185	5235.3					200
4	$= (3.453 * A11^5) - (32.476 * A11^4) + (114.78 * A11^3) - (170.15 * A11^2) + (113.3 * A11) - 26.718$						
4.5	551.4884	15607.12					150
5	1126.657	31884.39					

Table 2 - Polynomial Equation

Table 2 shows how the polynomial was used within spreadsheet to get the corresponding values for the final voltages. While graph 2 shows the new graph that has been created

using the figures obtained from the polynomials. As shown it is a good curve with a steady increase that is a similar shape to other MAF reading graphs.

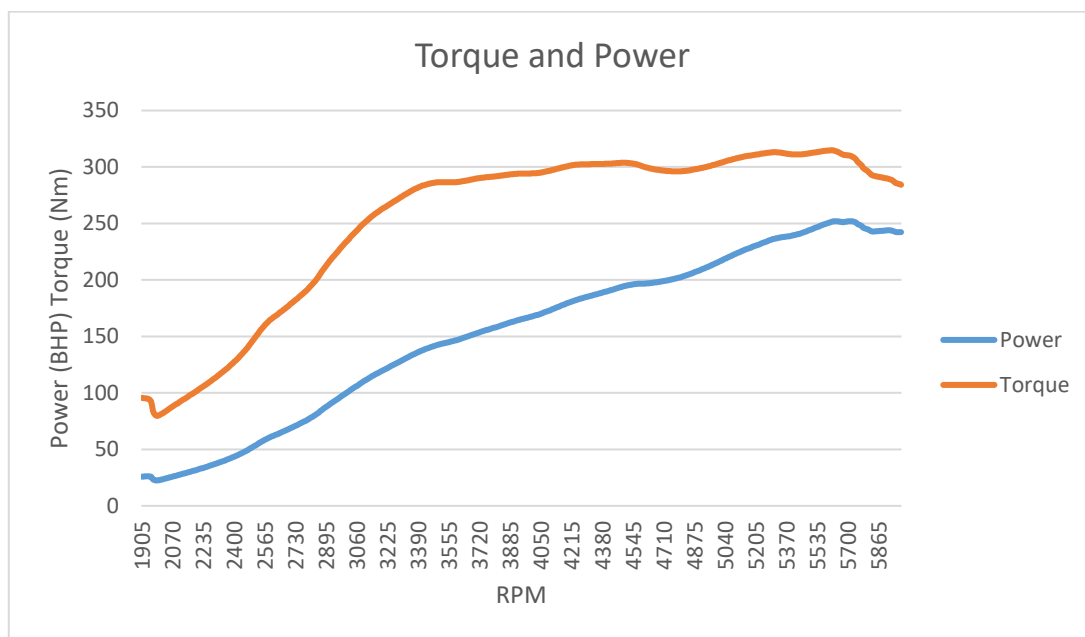


Graph 2 - Graph of Flow to 5v

An additional sheet was created with the flow for each voltage being shown on. This was created using the polynomial equation that was given from the graph, it increases in voltage by 0.01 to allow an accurate reading of air flow. A VLOOKUP equation was added in place to allow the user to easily find the flow rate at the required voltage.

7.0 Base run

A base run was completed using the standard ECU this was adding too much fuel into the combustion chamber affecting the maximum output of the engine. The car ran uneasy and had breakups under high amount of load as boost peaked during mid-range acceleration. The dynamometer struggled when we tried to cycle the car through the gears as it started the run early which meant the car was set off in fourth gear at a low RPM and full throttle was applied until the horsepower on screen started to drop off and indicate the end of the run as peak horsepower is found.



Graph 3 - Base Power and Torque graph

The torque curve is good indicator of how the fuelling of the car is. The torque curve shows that with the standard ECU the low RPM is not bad and has a good gradual increase, however as the manifold pressure increases then the curve drops off and does the opposite of what it should do. The curve also shows a lot of bumps throughout, this shows that the fuelling is inconsistent. However with the standard ECU it made 250 BHP, this is 50 BHP more than the car had from factory which would suggest it has been remapped or had a chip installed.

8.0 Setting up the new ECU.

The new ECU that is being added to the car is the link g4+ xtreme. This ECU is a straight plug in to the Nissan using the factory ECU casing. The ECU has many features that can be used for many different applications including some motorsport applications such as launch control and flat foot shifting to allow the user to maintain boost pressure during launch and gear changes. However, the main features that will be used are the fuel table, timings table and AFR table to make changes to the running of the engine to see the effects that will incur on the exhaust temperature.

8.1 INSTALLING THE ECU

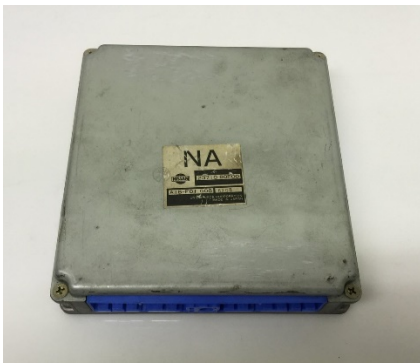


Figure 4 - 200sx ECU

(Suspicious Garage, n.d.)

To install the new ECU disconnect the old ECU from the passenger side foot well. There are three bolts holding the ECU in place and one bolt holding the wiring harness connector in the ECU. Once removed place onto a clear work surface, remove the ECU bracket and covers, to reveal the ECU board. AT this point the antistatic band should be attached to the work bench and to the wrist of the technician. Next the ECU grounds need to be disconnected from the casing, this will then release the ECU board. With the standard board removed, place the new ECU into the ECU casing and screw it into place. Ensure all the ECU switches are set to match the car, these can be found to the front of the ECU board. The two settings are dependent of the origin of the car, with a UK car the switches should be set to New Zealand Domestic market. A vacuum line needs to be added into

the ECU to allow the ECU to get manifold pressure, therefore attach the ECU to the inlet manifold. With the SR20DET engine it is best to take the vacuum line from the fuel rail regulator. Reinstall all the covers onto the ECU, a slot will need to be made for the vacuum line and additional sensor wiring to go through the car, it is best to ensure the hole is as small as possible to try and prevent water ingress. Any additional sensors need an extra loom, this needs to be plugged in to the left of the ECU board. It is labelled, so the input name can be matched with the colour of wire. Therefore it is worth taking a picture of the plug with the loom plugged in for future reference.

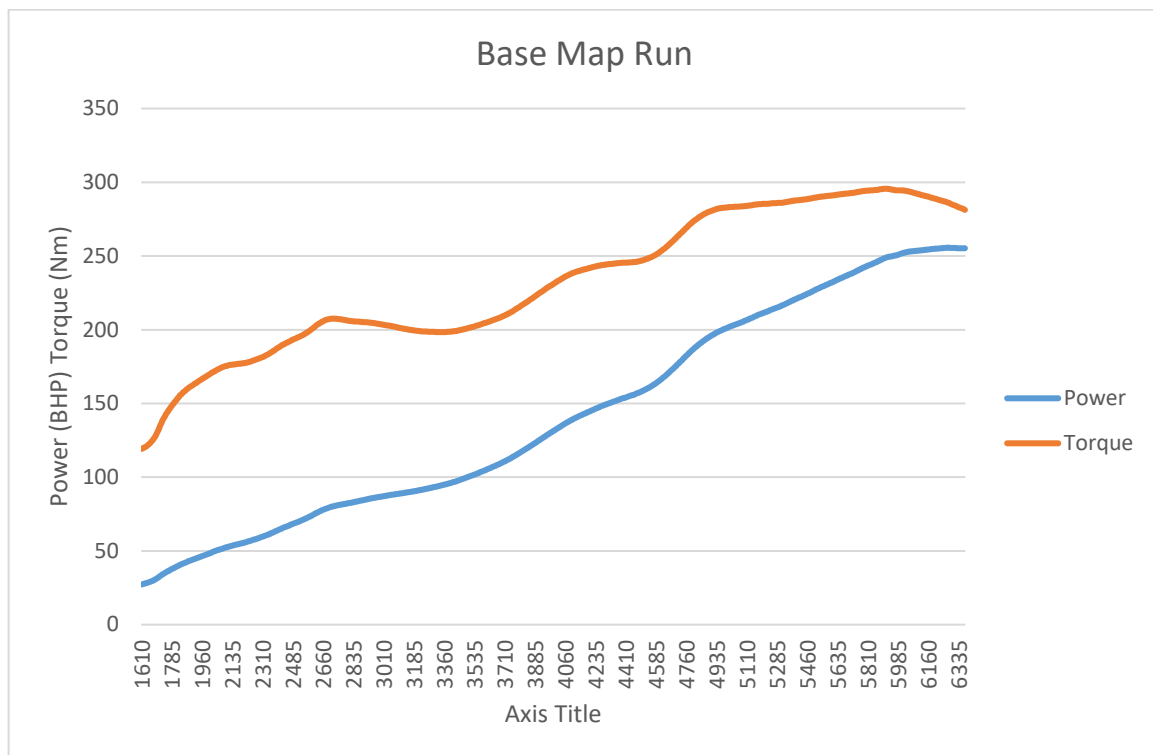


(Brands Hatch Performance, 2019)

Figure 5 - New ECU Board

8.2 BASE MAP RUN.

The tuning program that is provided with the ECU comes with a base map for the Nissan 200, this map will be set up for a standard Nissan 200sx and therefore will not allow the car to run at its peak performance. The base map is set up to be very safe to prevent engine damage, it is also recommended to not be driven a far distance on, it is mainly to get the car to a tuner to put a proper map on the car. For this reason the map will not get the highest potential torque and power for the engine.



Graph 4 - The Power and Torque with a Base Map

Again looking at the torque map, it shows that the vehicles map is not very consistent and the fuelling is all over the place with very rich spikes in the run. This shows that the map isn't safe to be driven on every day as it will cause additional wear to the engine. However the map is safe to be used for a short distance as the increase of the torque is very steady and there are no steep sections where there is large increase in torque. Comparing the base map to the original map on the ECU shows that the performance is very similar with the standard ECU making slightly more torque. The differences also shows how the torque increase is different as with the base map it is very gradual while the standard ECU gains quickly but then falls off at higher RPM's

9.0 Tuning Program

With the ECU installed in the car the corresponding program was downloaded to the laptops and the tuning fun begins. The program is very user friendly and everything is laid out allowing easy access to the vital parts of the program with the option to make a new page displaying the information that matters to the user. Some of the useful areas are listed below.

9.1 CUSTOM PAGE

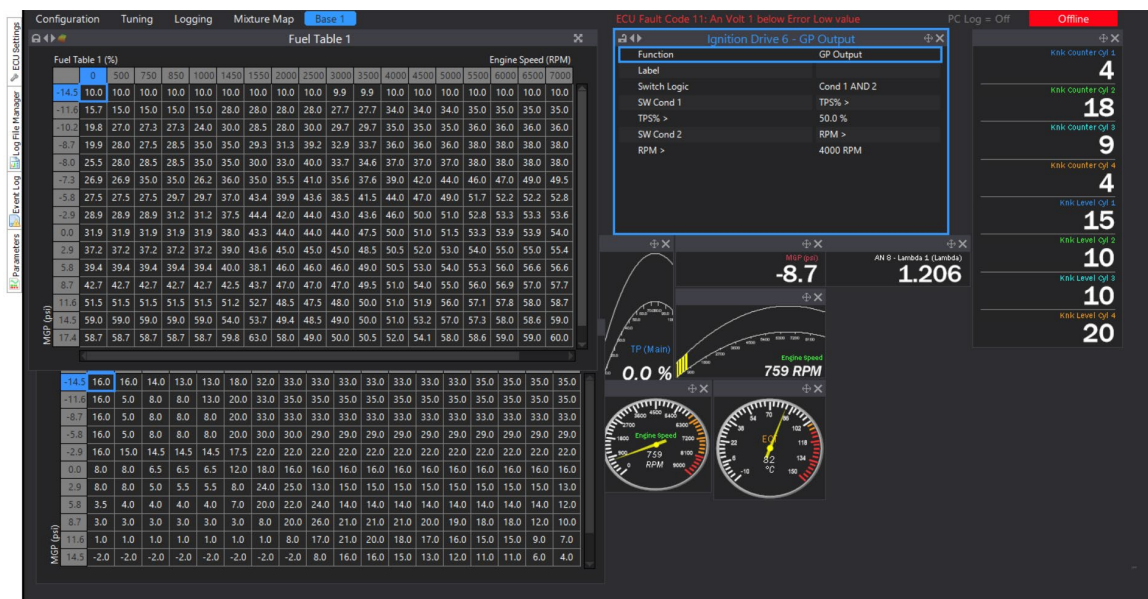


Figure 6 - Custom ECU Program Page

Figure 6 is the main page that was used when tuning in this particular project, the page is custom made up showing all the tables and information that is needed when completing dyno runs. Starting from the left side, the ECU settings is a vital tab that is worth getting to know as this is where all the vehicle sensors and electronics are found. This is where sensors can be added and calibrated, previous sensors can be changed and the variables can be set, all the engine safety parameters can be set up, where the motorsport features can be found such as flat shifting and where all the fuel, ignition and boost can be set up from. There is a search bar at the top to make it easier to find the setting that is required. Along the top are different tabs that are open and have been set up to help the user tune the vehicle, along with any errors that the ECU has picked up with any failing sensors or

problems with the car and finally its where the ECU can be connected and disconnect from the laptop. The page layout for the runs that were completed for this project are the fuel table, ignition table, throttle position, RPM, gauge boost pressure, lambda, engine coolant temperature, knock counts and knock levels for each cylinder and finally the methanol setup.

9.2 LOGGING PAGE



Figure 7 - ECU Program Logging Page

The logging page is used for when a run has been recorded using the ECU's logging feature, this will record a run that has taken place and record all the relevant data that goes along with that run, it will show all the information from all the sensors that are available. Figure 7 shows the logging page that was set up on the program already, for this project purpose a knock counter has been added to show the knock level the sensor is picking up. This page has the engine speed, the manifold air pressure and engine coolant temperature shown as a graph with a slider that can be moved to find the part of the run that the user is looking for. All the information is the shown for that point of the log file on the right-hand side as a list with the option to add additional sensors in to the list if a new sensor is added. There is also a slider at the bottom of the screen that is based primarily on engine speed. There is also a list of knock values to ensure that the knock isn't showing too high in order to protect the engine. This page is useful to have as it can help the user find where a fault is in the run and make it easier to find the fault and make relevant changes.

9.3 MIXTURE MAP

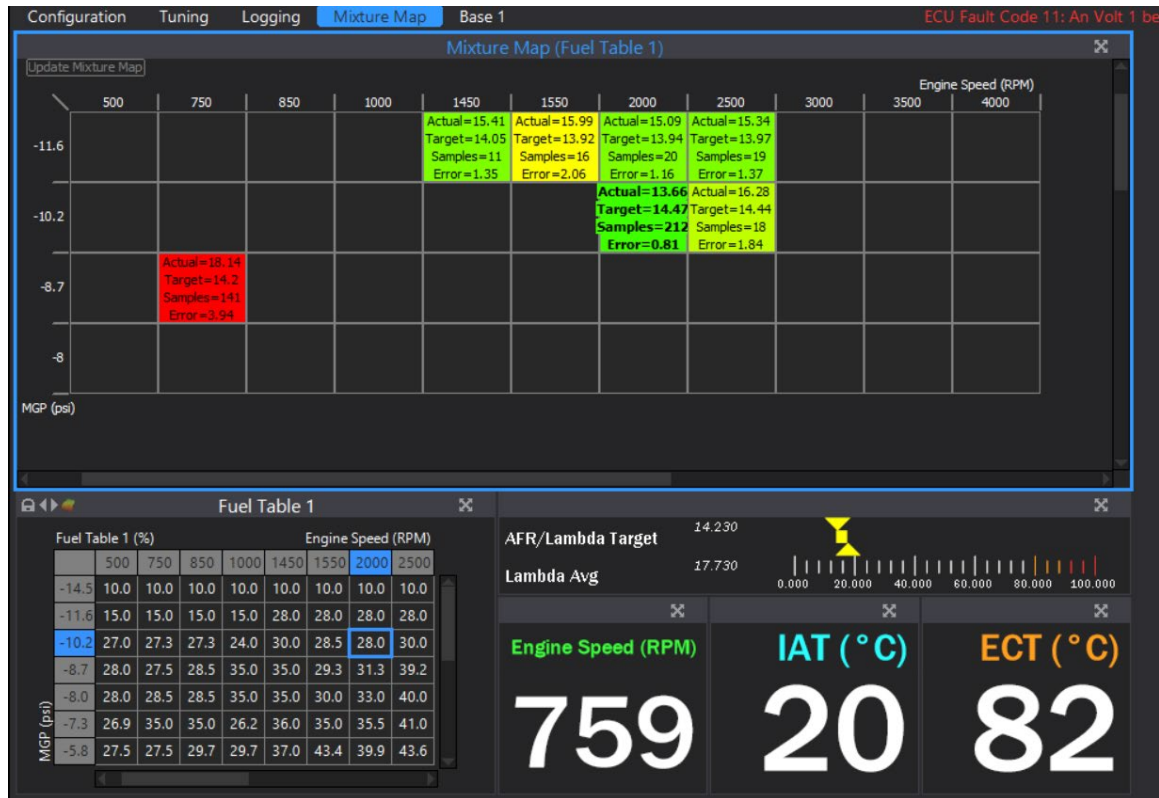


Figure 8 - ECU Program Mixture Map

The mixture map is a great aid for a beginner tuner assuming the car has a lambda that is wired to the ECU it will determine the engines air fuel mix and allow the user to set the AFR targets for each RPM and load point, a run needs to be completed while using the logging feature and the log file saved. With the log file open it can be inserted into the mixture map table and the program will compare the actual AFR to the target set in the table and give the user the option to change the fuelling at each point that is out from the target to allow a smoother and linear lambda and power curve. By double clicking the boxes highlighted in red, green or yellow, the program will calculate how much the fuel should be changed and automatically change it within the fuel table.

10.0.0 Practical Work

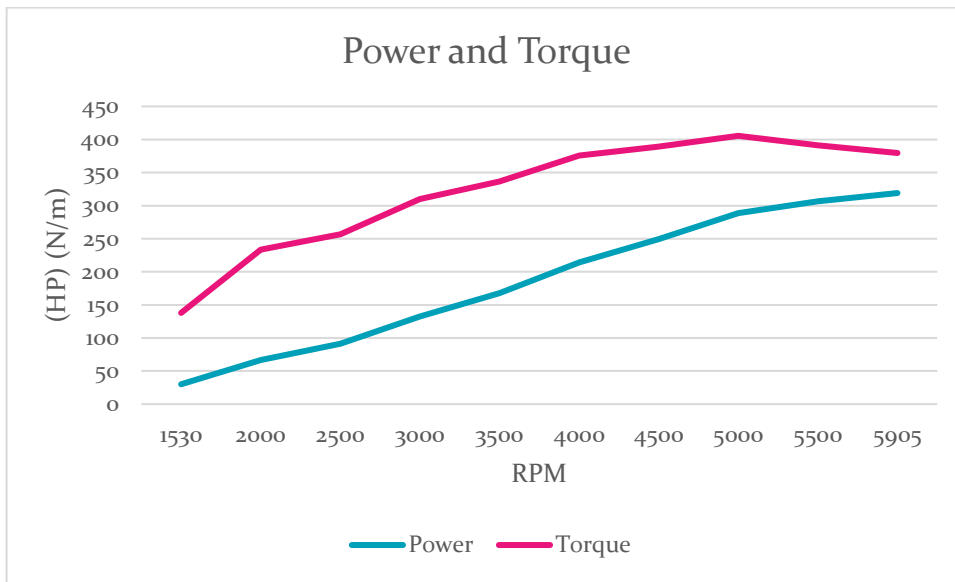
During this project, the following changes will be made to the vehicle's engine: the type of fuel being used, the amount of fuel being used, timing changes and the amount of throttle position being applied thus effecting the amount of boost being created. Also look at how efficient the turbo on this engine is, this is a T28 turbo which was designed and made in the 1990s and therefore has old parts. The parts that have been logged are the horsepower, torque, lambda, mass air flow, manifold pressure, manifold temperature and downpipe temperature, with the ability to use the ECU to find the amount of fuel being added to the engine.

10.1.0 FUEL TYPES

During this experiment, three different fuels will be used that are all available from supermarket petrol stations, the first having an octane rating of 95, the second an octane rating of 97 and finally an octane rating of 99. All will be tested at different ignition timings, where the car has been taken to the knock limit and backed off to get a full safe run. As well as a straight comparison between 95 octane and 99 octane using the exact same map to see whether better quality fuel has the potential to get more power and torque from the engine and how it effects the combustion of the engine by looking at the exhaust temperatures.

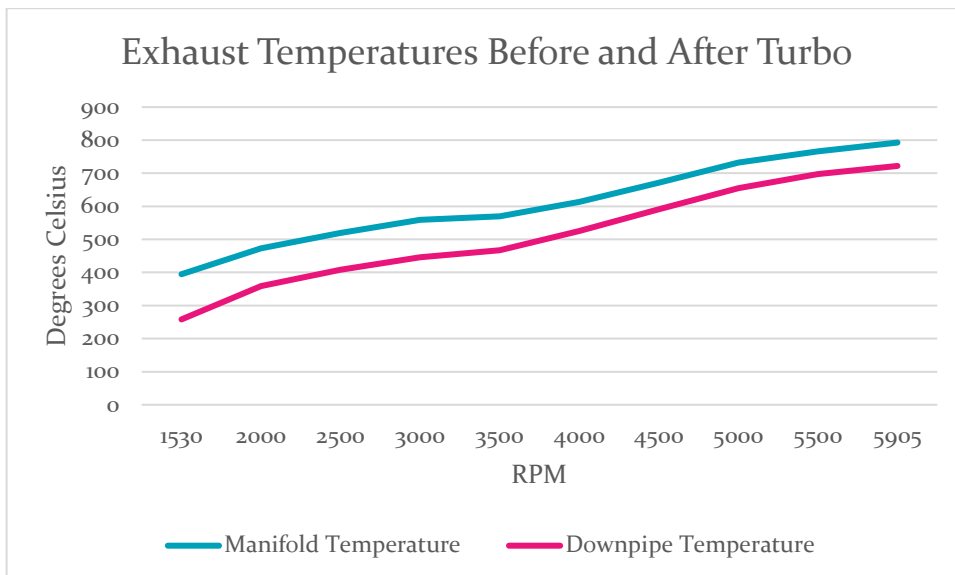
10.1.1 99 Octane

The first runs were done on Tesco momentum with an octane rating of 99, the car was using 99 octane throughout the project and is therefore already set up to extract maximum power from the vehicle using this fuel. With a couple of warm up runs being completed to ensure all the drivetrain is up to temperature and that all runs are started with similar temperatures throughout the experiment to try rule out heat soak. The car did two back to back runs using the 99 octane fuel ensuring the knock count is noted to get similar knock counts for other octane ratings. As the two runs were very similar the second run was chosen and the data recorded.



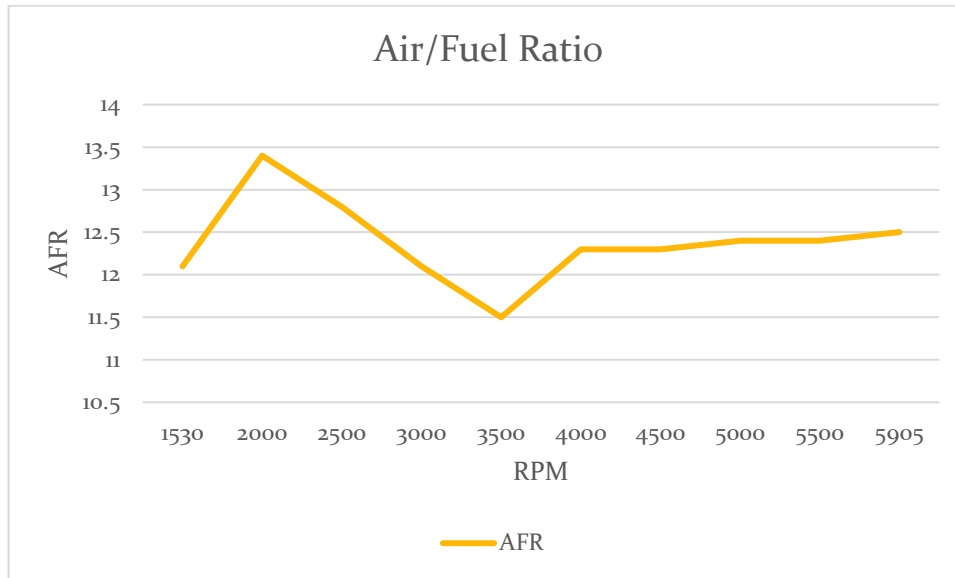
Graph 5 - Power and Torque (99 Octane)

The dynamometer gives out power and torque figures using the rollers and some behind the scene calculations within the program. As shown the torque isn't one hundred percent smooth therefore meaning there are improvements that can be made to the fuel table. However the fuel table was kept the same throughout the experiment to ensure the amount of fuel is effecting the results.



Graph 6 - Exhaust Temperatures (99 Octane)

Using the thermocouples previously installed into the exhaust system, the dynamometer program is able to log the temperature increase as the RPM increases.



Graph 7 - AFR (99 Octane)

The AFR is taken from a lambda that is installed in the de-cat pipe. This is wired into the ECU, this means the log files can be used to get the exact lambda at each RPM point. As previously stated the fuelling can be changed to make a smoother power delivery. As seen there is a correlation between the drops in lambda to the drop in torque, this means if there is some fuel removed at 3500RPM then the torque delivery will become smoother with a more consistent lambda line.

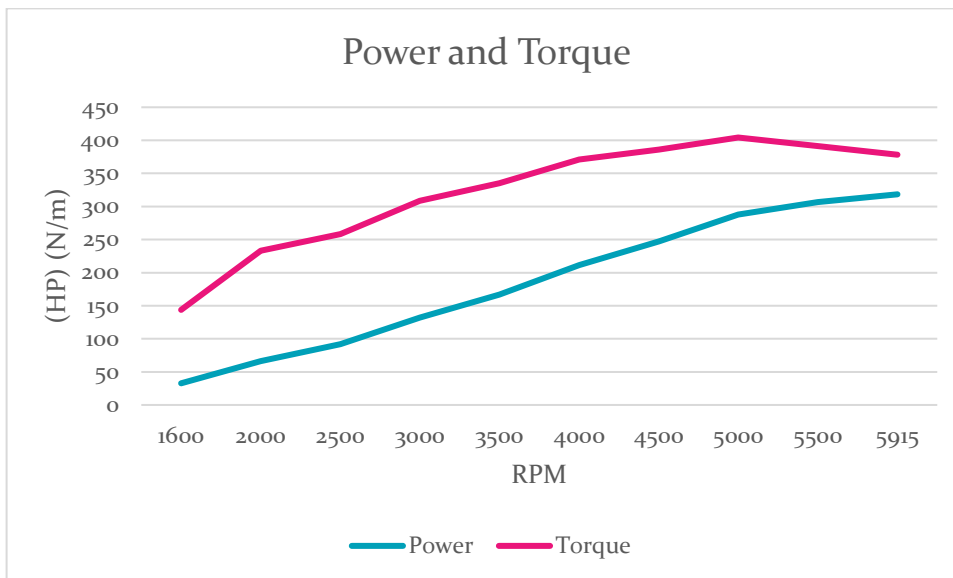
n (rpm)	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	AFR	Boost (psi)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1530	30.038	137.885	12.92	17.745	258.1	394.7	12.1	0.4	4648.888	1.30098	1.13616	138.8005	33.49331	20.7		144.8	34.630874	21.0	26.1%
2000	66.527	233.619	44.486	23.431	358.505	473.286	13.4	3	4881.952	2.15352	0.59354	125.547	38.88545	21.8	35.2%	305.4			
2500	91.411	256.802	63.691	29.629	408.442	519.842	12.8	5.2	4774.384	1.76004	0.84398	131.664	36.26188	21.3	32.4%	429.1			
3000	132.491	310.173	99.236	36.022	446.025	558.988	12.1	9.6	4648.888	1.30098	1.13616	138.8005	33.49331	20.7	27.2%	638.7			
3500	167.625	336.365	128.58	42.542	466.741	569.96	11.5	12.2	4541.32	0.9075	1.3866	144.9175	31.33728	20.3	25.4%	827.2			
4000	213.992	375.731	169.189	49.288	524.975	613.68	12.3	13.2	4684.744	1.43214	1.05268	136.7615	34.25485	20.9	23.0%	1023.7			
4500	249.536	389.458	198.471	56.295	591.263	671.302	12.3	13.8	4684.744	1.43214	1.05268	136.7615	34.25485	20.9	22.6%	1193.7			
5000	288.729	405.565	231.359	63.431	654.744	732.479	12.4	14.6	4702.672	1.49772	1.01094	135.742	34.64419	21.0	22.0%	1375.9			
5500	306.51	391.402	242.111	70.834	697.9	766	12.4	14.8	4702.672	1.49772	1.01094	135.742	34.64419	21.0	23.1%	1460.6			
5905	319.073	379.498	248.701	77.102	722.043	792.704	12.5	14.4	4720.6	1.5633	0.9692	134.7225	35.03943	21.1	24.2%	1514.7			

Table 3 - Figures for 99 Octane

Listed above is all of the information obtained for the engine and vehicle when the car doing a full power run using 99 Octane.

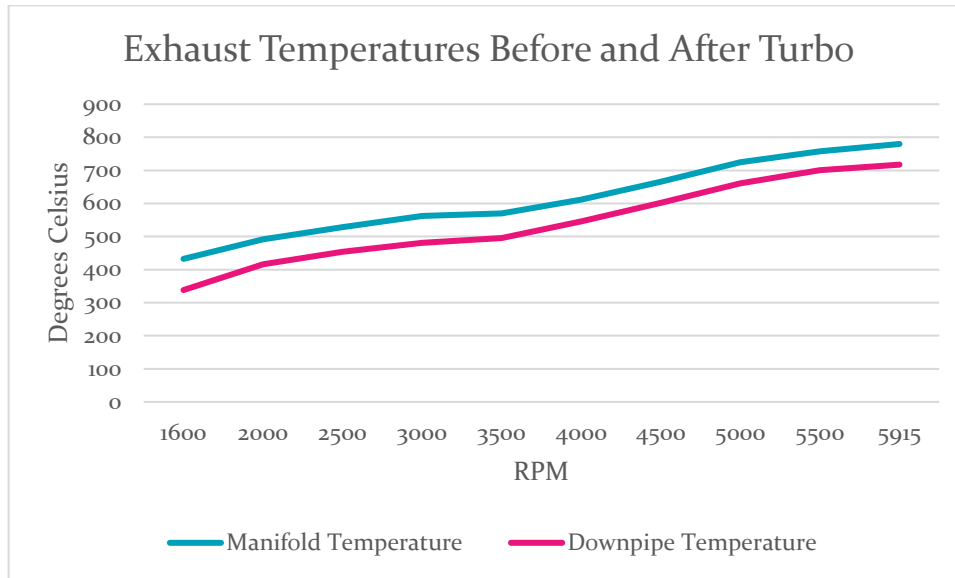
10.1.2 97 Octane

During this part of the experiment the fuel tank was drained of all the 99 fuel, this was achieved by pulling the inlet to the fuel filter in the engine bay off and using a larger diameter rubber pipe to put around the cars fuel line to extend the line to a fuel jug. With the line secure and in the jerry can the fuel pump is turned on using the ECU. Within the ECU there is the ability to test sensors and operators that are on the car, therefore putting the fuel pump into test on will allow the fuel pump to be constantly active and pump all the fuel out of the tank and into the jug. Ensure there are no leaks between the extensions and that the jug doesn't overfill. With the tank being empty, fill it with 97 octane fuel. This fuel is the supreme fuel from Sainsbury with a stated octane rating of around 97. With this fuel being a lower octane rating is expected that the car will knock before 99 and therefore the ignition map needs to be changed before completing a run to ensure there is no damage done to the engine internals. Start by retarding the ignition by around 5 degrees and complete a maximum power run, ensuring the engine isn't knocking when completing the run. If there is too much knock, stop the run and make further changes to the ignition table. If it isn't knocking at all then advance the engine by one degree each run until the engines knock count becomes too high. And take the highest advanced run that was possible. Two back to back runs were also completed with the 97 octane fuel, to get a similar starting temperature, and to validate between the two runs. Again take the second dynamometer run.



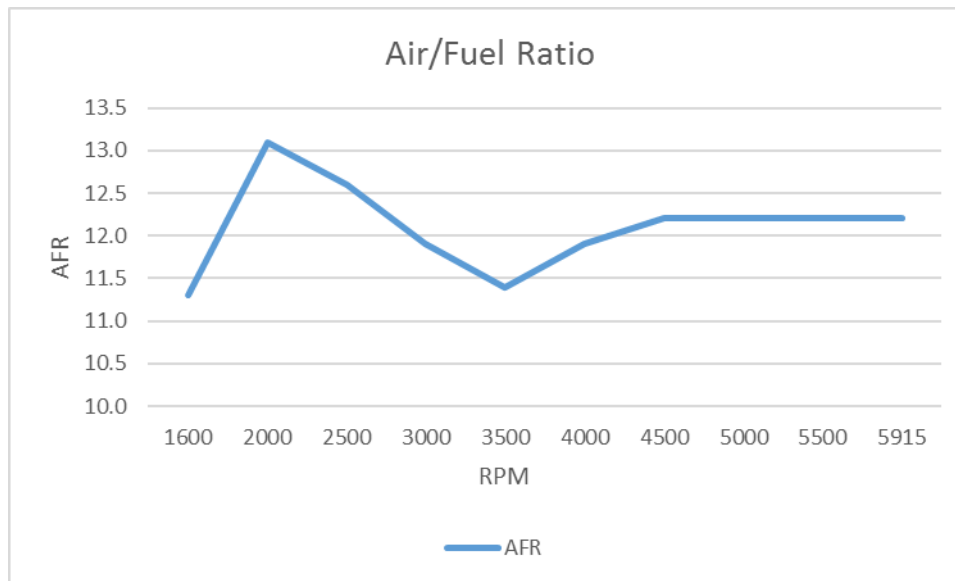
Graph 8 - Power and Torque (97 Octane)

The power and torque curves for the vehicle using 97 octane, it is worth noting that these results were taken with the knock count being a little bit higher than other results due to a different vehicle operator.



Graph 9 - Exhaust Temperature (97 Octane)

The exhaust temperatures taken during a full power run with 97 octane.

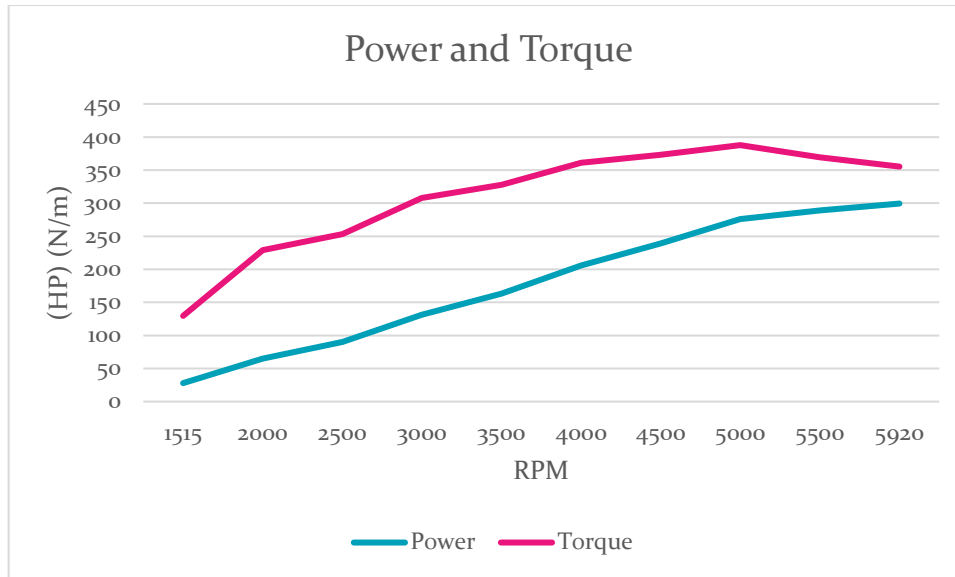


Graph 10 - AFR (97 Octane)

The amount of air to fuel taken from the ECU log file.

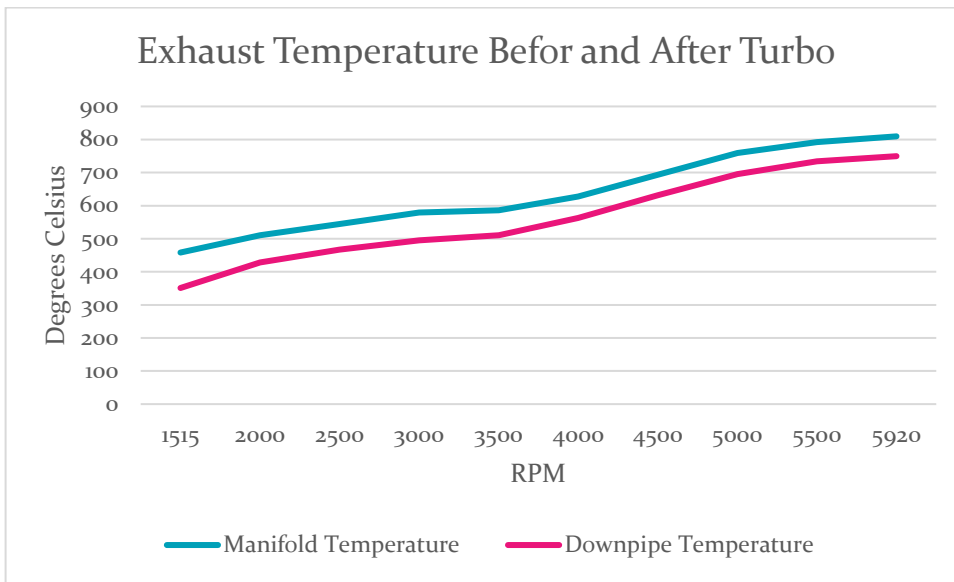
10.1.3 95 Octane

The tank again needs to be emptied of all the 97-octane fuel. Using the fuel pump is a good way of getting the other fuel out as it will pick up most of the fuel in the tank and clear all the lines of the old fuel. This means it's not going to be mixed together giving it a higher-octane rating than previously stated. This also had two runs completed on the car and the second run being used to get the results.



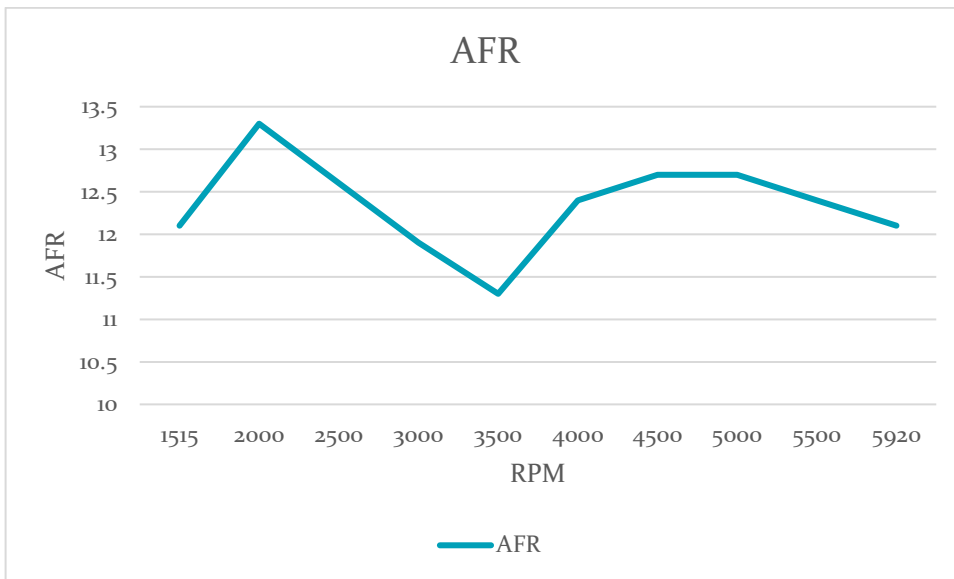
Graph 11 - Power and Torque (95 Octane)

The power and curve torque obtained using a full power run with the fuel having an octane rating of 95.



Graph 12 - Exhaust Temperature (95 Octane)

The exhaust temperatures before and after the turbo using 95 octane fuel.

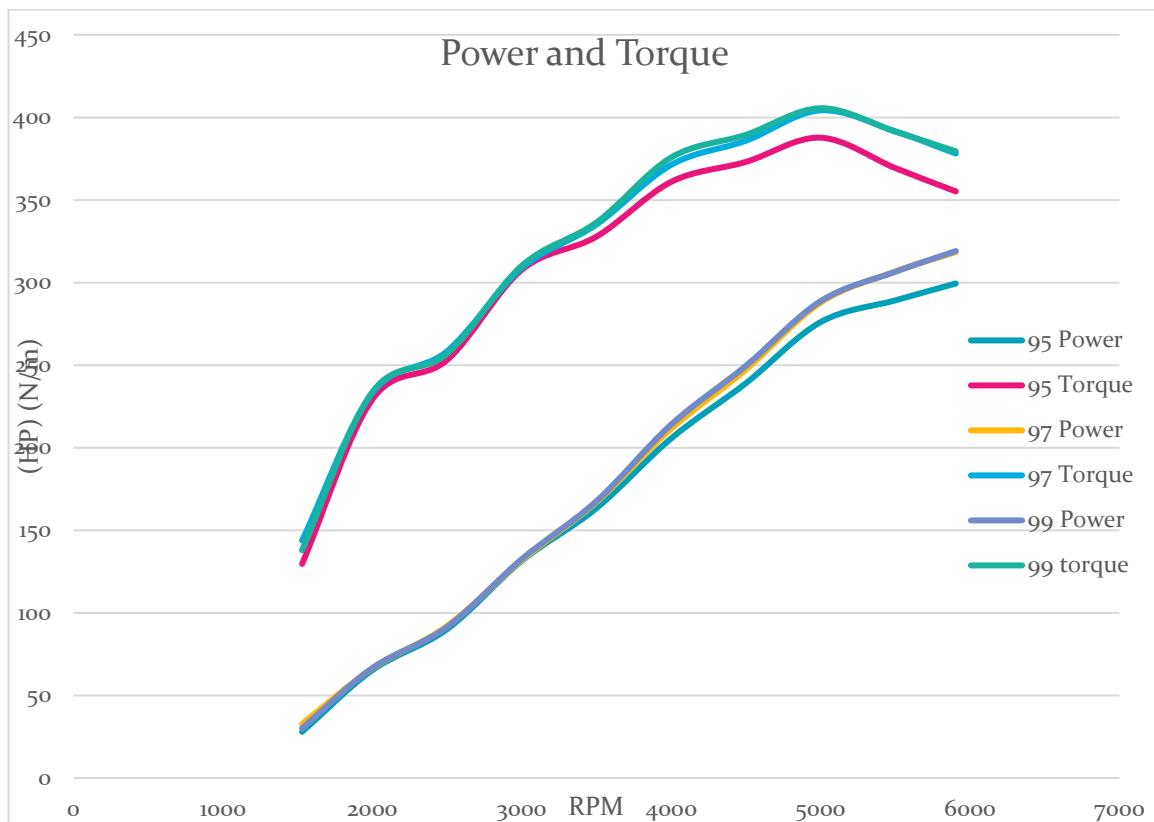


Graph 13 - AFR (95 Octane)

The AFR of the vehicle, again taken from the ECU log file.

10.1.4 Results

Comparing all three types of fuel and the output benefits of each while changing the timing within the map to get maximum power while staying within a safe amount of knock. Each fuel was taken to the maximum amount of advance the engine can take until the knock count increases rapidly. At this point the timing is then backed off a couple degrees and a full power run is attempted ensuring there is no knock happening during the run. The injector duty cycles were all kept the same to ensure the amount of fuel being inputted is kept the same. And that the boost levels are all kept the same, this means the only changes that occur are the type of fuel being used and the timing.



Graph 14 - Comparison of Power and Torque

RPM	Power	Torque
2000	1.264	4.438
2500	1.33	3.736
3000	1.055	2.469
3500	4.263	8.554
4000	8.415	14.774
4500	10.514	16.41
5000	12.694	17.831
5500	17.297	22.089

Table 4- Differences in Power and Torque

To the left is the maximum difference between the fuels. The sum is taking away the power obtained with 99 octane fuel by the amount of power obtained from the 95 octane fuel. As the table shows there is potential to draw a fair amount more power from the engine by simply adding a higher octane fuel. More performance can be drawn from the engine as having a higher octane means the reactants within the chamber has more time to burn making more use of the reactants being inputted into the engine. There is also the consideration of bottom end

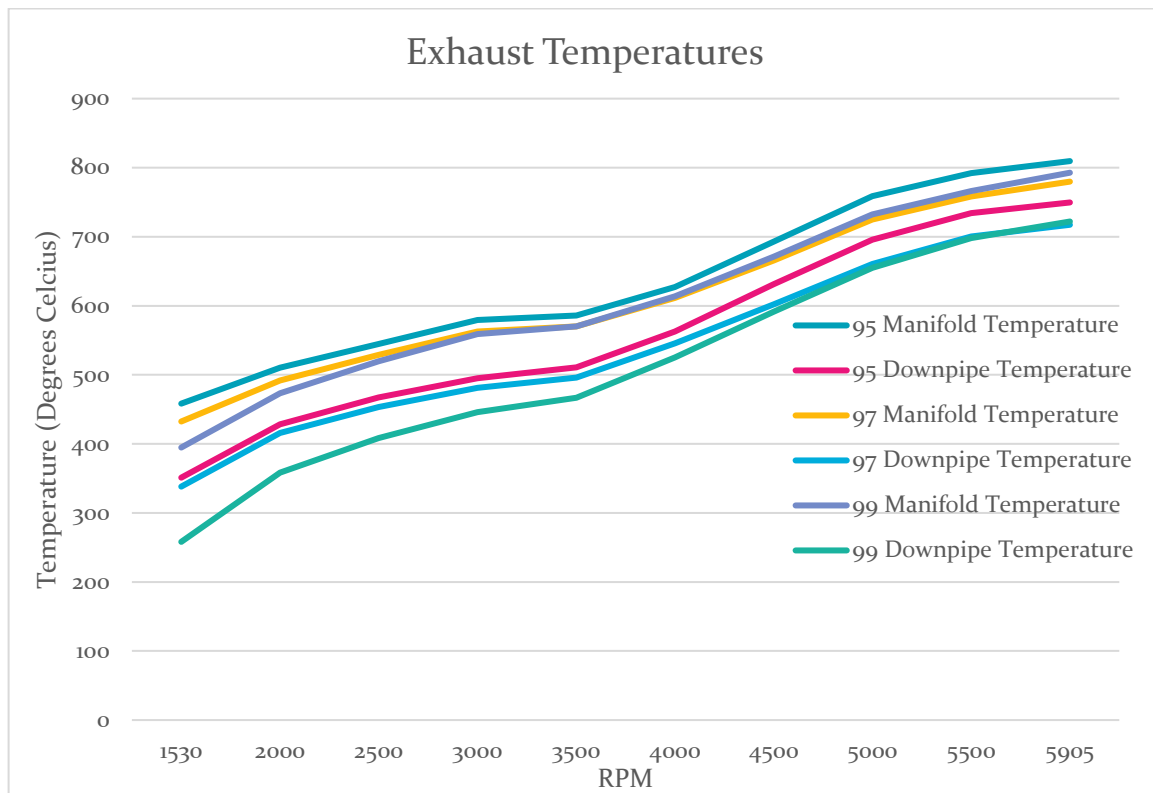
fatigue of the engine such as the main bearing and crank bearing as there will only be a certain amount of force they are able to take until they spin around the crank causing a bottom end failure. Therefore adding a super high octane fuel such as aero fuel may seem like a good idea at first but it will be increasing the internal pressures as it will allow a lot higher advance, therefore causing conrod or bearing failure.

95 price	99 price	mpg	amount of fuel (gallons)	Total Miles	£/mile (95)	£/mile (99)
£ 1.24	£ 1.29	15	5	75	£ 0.38	£ 0.39
95 Price/Gallon	99 Price/Gallon	95 price per 5 gallons	99 Price per 5 Gallons			
£ 5.63	£ 5.86	£ 28.15	£ 29.28			

Table 5 - Comparison in Price

(RAC, 2019) Over 1000 miles that's a £10 differences. So roughly over 3 to 4 months an extra £10 will be spent on fuel to get a power and torque increase of approximately twenty horsepower or 22Nm.

The table to the left shows the price per litre of both the 95 octane and 99 octane. Using the Nissan real life MPGs and the current fuel prices, it shows a 1p difference per mile. (RAC,

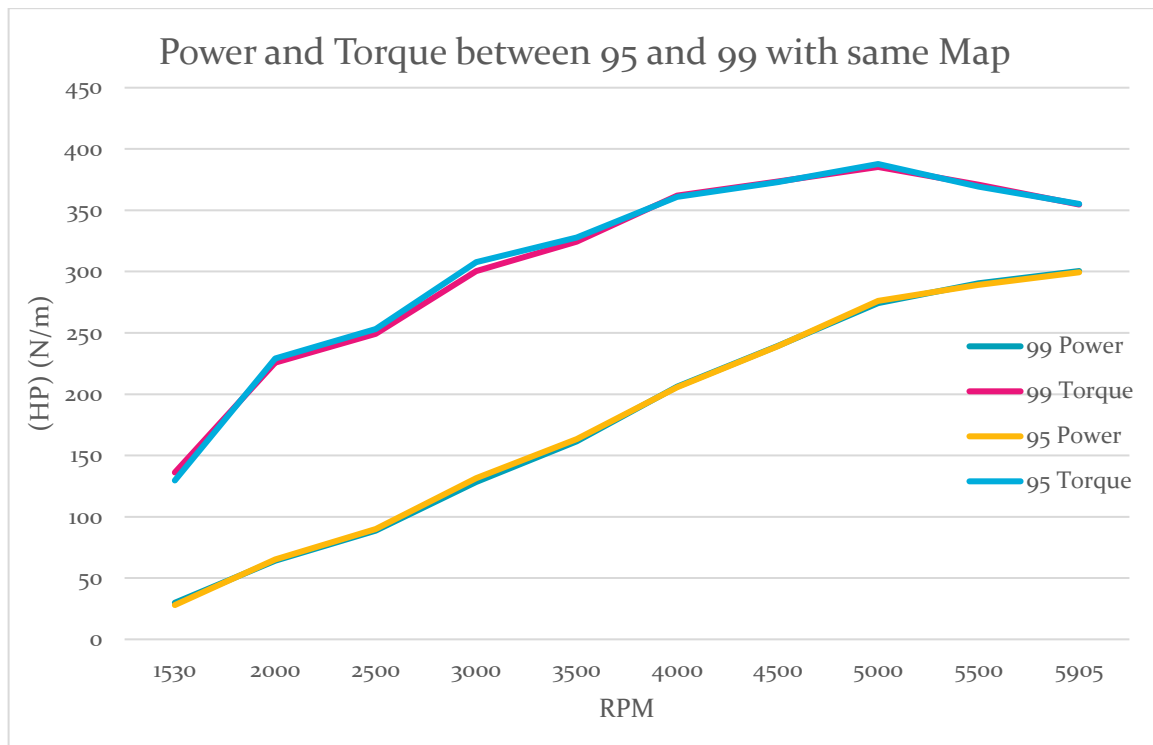


Graph 15 - Comparison of Exhaust Temperatures due to Octane

Running a higher octane fuel also causes a lower exhaust temperature and therefore a lower combustion temperature. This could be beneficial to the car's engine as a cooler engine effectively means there is less pressure, this means the engine isn't being worked as hard and there's less stress on engine internals. As the fuel goes through further processing it is able to get a higher octane rating which is effectively a knock prevention method. Knock generally happens when cylinder pressures get higher due to higher RPM

speeds or increase in manifold pressure using a compressor. As a higher octane rating burns slower it means the combustion temperature will be lower as heat has more time to escape through cylinder walls. Therefore causing a cooler exhaust and combustion temperature. (O'Clair, 2014)

10.1.4.0 Differences between the Quality of Fuels with the same Map



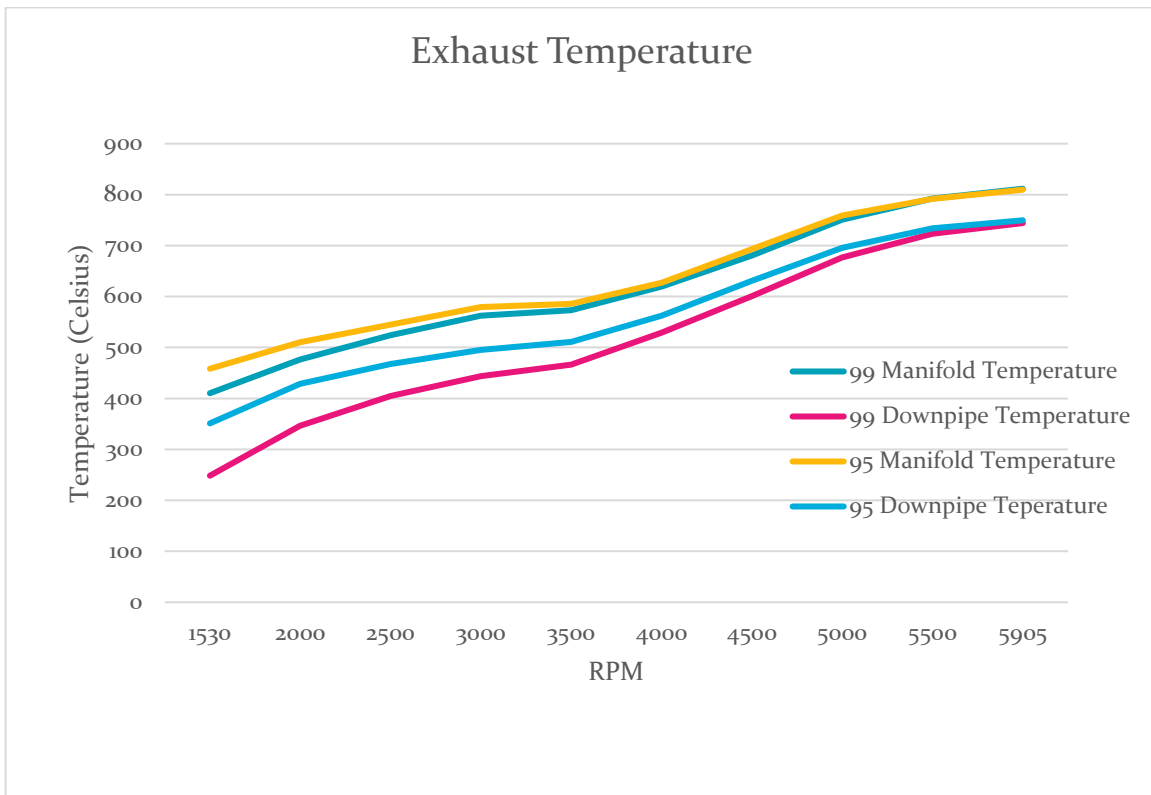
Graph 16 - Difference in Power and Torque between 99 and 95 Octane

This is the comparison between running a 99 octane fuel to a 95 octane fuel when nothing is changed in the map. Therefore keeping everything exactly the same, it is possible to see the difference just swapping for a higher octane fuel can do for the engine and whether it has any benefits.

RPM	Difference in Power	Difference in Torque
2000	-1.011	-3.551
2500	-1.347	-3.784
3000	-3.106	-7.272
3500	-1.749	-3.51
4000	0.586	1.027
4500	0.183	0.285
5000	-1.715	-2.408
5500	1.127	1.439

To the left were the power and torque figures taken away from each other. The 95 octane being taken away from the 99 octane. As shown the differences are negligible and the numbers shown could be due to a higher room temperature. Therefore it shows that there is no gain in using 99 octane fuel when running on a standard ECU and will be a waste of money.

Table 6 - Differences in Power and Torque with the same map.



Graph 17 - Difference in Exhaust Temperatures with same map.

Above shows the differences in temperatures between the two runs and would suggest that the 99 octane fuel was done while the room was hotter or with a hotter engine as the temperatures are more or less the same. The higher octane fuel would have burnt slower

and therefore have a lower temperature. However this graph would suggest a lower temperature during lower RPM's.

RPM	Difference in Manifold Temperature	Difference in Downpipe Temperature
2000	-33.506	-81.766
2500	-20.623	-62.758
3000	-16.598	-51.298
3500	-12.6	-44.537
4000	-7.39	-33.386
4500	-12.581	-30.533
5000	-8.008	-19.233
5500	0.668	-10.998

Table 7 - Differences in exhaust Temperatures with the same map.

As shown the temperature difference is a fair amount cooler during low RPM but as the RPM increases then the temperature difference becomes less. Therefore it will not do much in helping engine pressures when under full load. However as higher octane fuels help to prevent knock then it may help the timing of the engine with a standard ECU. A standard ECU will retard the engine if knock is detected and therefore reducing power. With knock being less likely it will mean the ECU won't

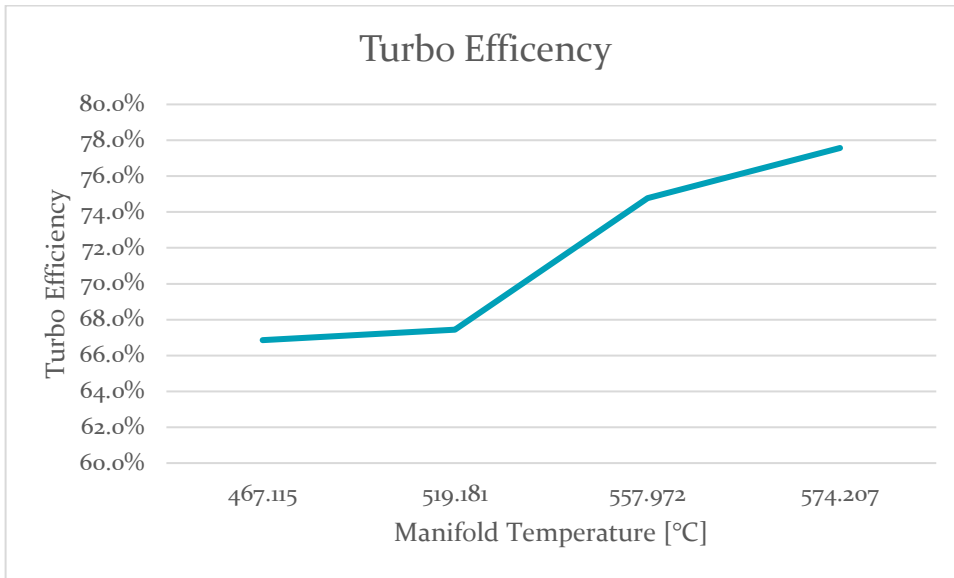
be making changes and will leave the engine to reach full power. However it is not worth spending the extra money on a higher octane fuel.

10.2.0 TURBO EFFICIENCY

The car has an electronic boost solenoid wired into the ECU and plumbed into the waste gate to allow more control over the amount of pressure the manifold is subjected to at various RPM points. It also allows control over how quickly the turbo is going to spool up as all the pressure created will go straight to the intake manifold quicker rather than allowing some of the pressure to escape quicker. As the stock wastegate has a 0.5 bar spring in it means that the wastegate is going to start open around 2700 RPM and gradually open further throughout the rev range. However with the boost solenoid in place it means the wastegate can be fully closed until the desired 1 Bar is reached and then allow the wastegate to open slowly to keep the pressure as best it can. However with the internal wastegate the car will experience boost creep at the high RPMs, this needs to be considered when creating the wastegate table to ensure the boost doesn't spike too high.

To get the turbo efficiency for this instance without knowing how much of the air would be flowing through the wastegate and how much through the turbo, the wastegate had to remain fully shut until the boost becomes too high and will cause the manifold pressure

limiter to come in as there is no more table for the ECU to read or if the tables are in place then stop the run when the pressure becomes dangerous for either the turbo or engine. Getting the wastegate to stay shut is simple task when there is a boost solenoid in place as the wastegate table can all be set to 100% meaning none of the pressure will reach the wastegate to open it.



Graph 18 - Turbo Efficiency regarding Exhaust Temperatures

This graph shows how the temperature of the manifold can affect the efficiency of the turbo. As shown the efficiency of the turbo increases as the temperature of the exhaust increase, this is likely due to having more pressure coming out of the exhaust and therefore having more pressure to spin up the turbine. However, as the temperature increase there will be a maximum efficiency for that turbo and the curve will start to flatten out.

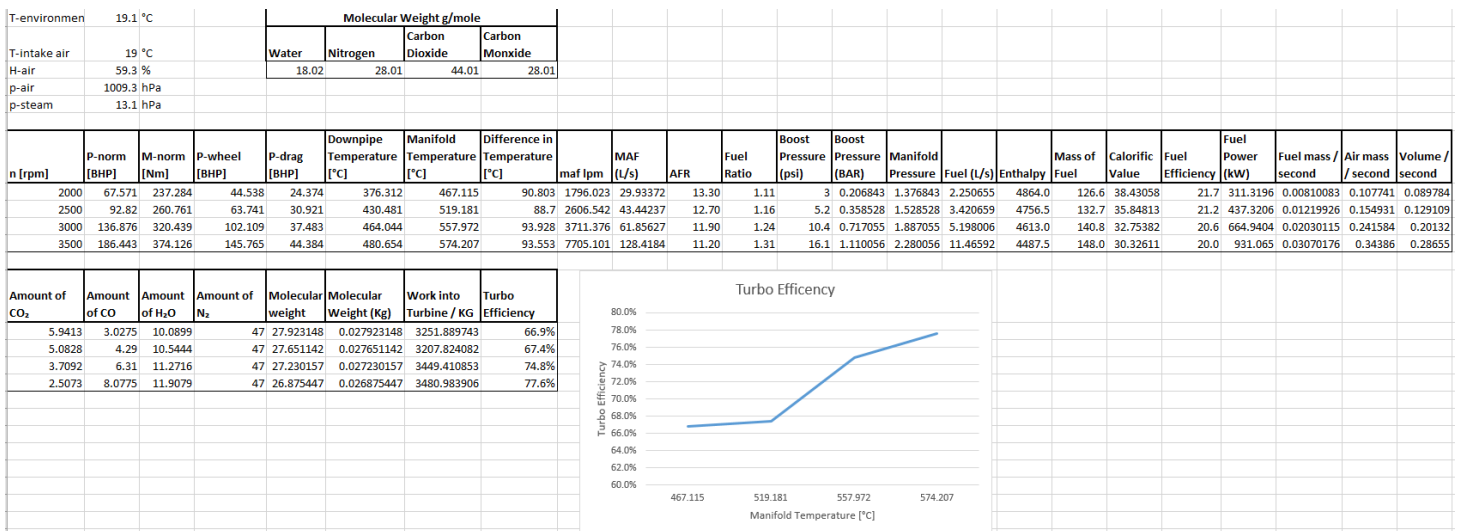


Figure 9 - Turbo Efficiencies

The turbo efficiency can be worked out using the temperatures acquired from the dynamometer using the thermocouples attached to the exhaust. The temperature differences is the enthalpy that the turbo takes up. Using the fuel ratio it is also possible to acquire the products that are being released into the exhaust, from there the molecular weights of the products can be calculated using the weight of each product multiplied by the amount of each product there is available once the fuel and air has been burnt in the combustion chamber. There is a problem that with this method there is the assumptions that all of the fuel is being burnt in the chamber where this may not be accurate and therefore will make the turbo efficiency a little better than it actually is. Using the molecular weight that comes from the engine into the exhaust, it is possible to get the amount of work done by the compressor per kilogram of products. This is achieved by using the difference in temperature between the compressors and dividing this figure by the molecular weight previously calculated. The enthalpy of the exhaust is also needed and this can be calculated using the amount of each product of the exhaust multiplied by the enthalpy needed by each product to get to zero. Then all of the enthalpies are added together to get the total enthalpy into the exhaust. Once both the work done of the compressor and enthalpy of exhaust are calculated then the turbo efficiency can be calculated. This is done by dividing the work done by the exhaust enthalpy.

10.3.0 TIMING CHANGES

During this section of the project the engines spark plug timing will be changed. There will be a variety of changes from retarded well away from the knock limit to reaching the knock limit under the circumstances the car is under. There will be 6 different tests increasing the timing of the vehicle by 2.5 each time. There will be an evaluation of the power and torque the engine makes and evaluate how it effects the exhaust temperatures and then investigate the reasons behind this to get a better idea of what the engine is doing.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	Mass Air Flow [lpm]	AFR	Boost (PSI)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power (BHP)	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1570	29.035	129.885	12.125	17.381	461.8	354.5	1440.731	11.9	0.6	4613.032	1.16982	1.21964	140.8395	32.75382	20.584703	13.4%	630.9782	34.48357	20.93137	14.2%
2000	58.536	205.555	37.079	22.408	496.984	402.705	1781.015	13.4	3	4881.952	2.15352	0.59354	125.547	38.88545	21.784703	10.9%	943.5749			
2500	85.081	239.019	58.048	28.406	552.709	472.641	2330.065	12.7	5.8	4756.456	1.69446	0.88572	132.6835	35.84813	21.224703	11.9%	1126.136			
3000	126.37	295.843	93.831	34.566	593.129	507.6	3599.485	11.9	11.3	4613.032	1.16982	1.21964	140.8395	32.75382	20.584703	11.7%	1437.198			
3500	156.986	315.016	118.558	40.917	614.7	532.703	4955.457	11.3	13.3	4505.464	0.77634	1.47008	146.9565	30.65849	20.104703	13.0%	1566.877			
4000	194.623	341.723	150.316	47.417	640.995	573.592	6908.826	12.4	13.5	4702.672	1.49772	1.01094	135.742	34.64419	20.984703	13.9%	1628.439			
4500	226.427	353.391	176.154	53.897	703.754	646.954	9011.227	12.3	14.5	4684.744	1.43214	1.05268	136.7615	34.25485	20.904703	15.3%	1690.486			
5000	258.927	363.703	202.048	60.991	773.123	710.475	13838.82	12.9	15.4	4792.312	1.82562	0.80224	130.6445	36.68208	21.384703	16.8%	1700.762			
5480	266.562	341.632	202.982	67.813	825.571	763.771	16473.99	12.2	15.7	4666.816	1.36656	1.09442	137.781	33.87126	20.824703	19.8%	1640.513			

Table 8 - 10 Degree Retard

This is the table for a 10-degree retard map from the standard running map. This was a full run with no hiccups

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	Mass Air Flow [lpm]	AFR	Boost (PSI)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power (BHP)	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1575	28.462	126.918	12.631	16.223	449.2	354.5	1413.278	13.7	0.6	4935.736	2.35026	0.46832	122.4885	40.29551	22.0247	57.0%	576.2529	35.27441	21.0887	0.2562589
2000	61.054	214.398	41.051	20.844	501.065	421.32	1766.149	13.3	3.3	4864.024	2.08794	0.63528	126.5665	38.43058	21.7047	34.1%	987.7951			
2500	83.93	235.786	58.544	26.535	546.561	470.648	2576.512	12.8	5.5	4774.384	1.76004	0.84398	131.664	36.26188	21.3047	31.6%	1106.732			
3000	126.108	295.231	95.529	32.306	585.287	501.596	3564.005	12	10.7	4630.96	1.2354	1.1779	139.82	33.12087	20.6647	25.6%	1428.673			
3500	156.72	314.482	120.63	38.22	597.6	519.9	4766.392	11.4	12.8	4523.392	0.84192	1.42834	145.937	30.99551	20.1847	24.4%	1558.021			
4000	194.417	341.362	152.725	44.335	623.833	559.222	6637.091	12.2	13.1	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	22.8%	1639.217			
4500	227.781	355.505	180.213	50.663	685.22	627.927	8794.467	12.5	13.9	4720.6	1.5633	0.9692	134.7225	35.03943	21.0647	22.2%	1687.681			
5000	263.43	370.029	210.013	57.005	748.096	687.57	13421.07	12.6	15.1	4738.528	1.62888	0.92746	133.703	35.4407	21.1447	21.6%	1749.984			
5500	273.54	349.3	213.656	63.609	805.599	748.558	16152.28	12.4	15.2	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	23.3%	1664.546			
6000	281.831	329.896	215.381	70.267	828.011	771.811	18665.18	12.4	14.4	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	24.9%	1572.078			

Table 9 - 7.5 Degree Retard

This is the table for the 7.5 degree retard map. Also a full run.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	Mass Air Flow [lpm]	AFR	Boost (PSI)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power (BHP)	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1550	26.159	118.53	10.235	16.267	459.861	397.481	1333.467	13.6	0.9	4917.808	2.28468	0.51006	123.508	39.81773	21.9447	62%	540.1303	35.27597	21.0887	25.5%
2000	61.815	217.073	41.434	21.185	502.992	449.192	1749.648	13.5	3	4899.88	2.2191	0.5518	124.5275	39.34777	21.8647	34%	992.801			
2500	85.133	239.164	59.242	26.982	549.494	496.528	2345.251	12.9	5.4	4792.312	1.82562	0.80224	130.6445	36.68208	21.3847	32%	1118.388			
3000	126.868	297.01	95.606	32.893	584.334	520.769	3426.421	12	10.3	4630.96	1.2354	1.1779	139.82	33.12087	20.6647	26%	1437.282			
3500	157.507	316.061	120.576	38.901	594.774	532.974	4631.292	11.5	12.5	4541.32	0.9075	1.3866	144.9175	31.33728	20.2647	25%	1559.663			
4000	196.255	344.588	153.69	45.007	621.26	567.99	6557.73	12.3	13.3	4684.744	1.43214	1.05268	136.7615	34.25485	20.9047	23%	1648.375			
4500	233.368	364.224	184.984	51.317	684.827	633.871	8682.322	12.2	14.1	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	22%	1749			
5000	271.084	380.78	216.708	57.736	748.365	691.904	12713.66	12.5	14.9	4720.6	1.5633	0.9692	134.7225	35.03943	21.0647	21%	1807.668			
5500	284.617	363.444	223.31	64.813	790.5	739.672	13241.69	12.4	14.9	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	23%	1731.947			
6000	296.313	346.848	228.171	71.762	811.548	758.1	17202.11	12.4	14.2	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	24%	1652.861			

Table 10 - 5 Degree Retard

This is the table to show a 5 degree retard.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	Mass Air Flow (lpm)	AFR	Boost (PSI)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power (BHP)	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1540	25.581	116.665	9.495	16.389	423.608	335.715	1343.399	12.3	0.6	4684.744	1.43214	1.05268	136.7615	34.25485	20.9047	64.1%	558.0802	34.99533	21.0407	25.7%
2000	57.328	201.315	36.543	21.472	453.005	369.607	897.681	13.5	2.8	4899.88	2.2191	0.5518	124.5275	39.34777	21.8647	37.5%	920.7305			
2500	85.855	241.194	59.631	27.251	526.906	452.467	2296.519	12.8	5.2	4774.384	1.76004	0.84398	131.664	36.26188	21.3047	31.7%	1132.116			
3000	127.25	297.905	95.53	33.245	566.452	484.352	3387.485	12.2	9.9	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	26.1%	1430.537			
3500	158.654	318.363	121.35	39.206	580	500.441	4660.121	11.5	12.2	4541.32	0.9075	1.3866	144.9175	31.33728	20.2647	24.7%	1571.022			
4000	199.736	350.701	156.786	45.345	607.9	537.9	6484.858	12.2	12.9	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	22.7%	1684.062			
4500	237.241	370.268	187.969	52.066	667	603.7	8506.464	12.4	13.8	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	21.9%	1764.466			
5000	276.977	389.058	221.757	58.455	723.156	660.841	12777.26	12.7	14.5	4756.456	1.69446	0.88572	132.6835	35.84813	21.2247	21.1%	1833.043			
5500	294.158	375.628	232.183	65.428	776.37	717.71	15486.86	12.8	14.6	4774.384	1.76004	0.84398	131.664	36.26188	21.3047	22.2%	1763.122			
6000	309.153	361.878	240.041	72.74	798.139	736.953	9802.427	12.3	14.1	4684.744	1.43214	1.05268	136.7615	34.25485	20.9047	23.5%	1731.084			

Table 11 - 2.5 Degree Retard

This is a 2.5 degree retard.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	Mass Air Flow (lpm)	AFR	Boost (PSI)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power (BHP)	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1565	30.444	136.623	13.437	17.341	410.261	316.451	1347.256	12.9	0.4	4792.312	1.82562	0.80224	130.6445	36.68208	21.3847	57.0%	638.8819	35.15227	21.0727	26.0%
2000	63.986	224.696	42.307	22.38	470.622	388.485	1719.636	13.4	2.9	4881.952	2.15352	0.59354	125.547	38.88545	21.7847	35.0%	1031.439			
2500	86.641	243.402	59.157	28.451	520.497	440.839	2281.067	12.9	5.1	4792.312	1.82562	0.80224	130.6445	36.68208	21.3847	32.8%	1138.206			
3000	127.564	298.638	94.429	34.558	559.371	473.15	2020.452	12.1	9.6	4648.888	1.30098	1.13616	138.8005	33.49331	20.7447	27.1%	1439.587			
3500	157.702	316.453	118.731	40.758	571.2	487.9	4560.517	11.5	11.7	4541.32	0.9075	1.3866	144.9175	31.33728	20.2647	25.8%	1561.597			
4000	201.82	354.36	156.98	47.128	599.1	525.5	6419.619	12.2	12.8	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	23.4%	1701.633			
4500	239.821	374.295	188.974	53.602	657.767	592.38	8716.538	12.5	13.5	4720.6	1.5633	0.9692	134.7225	35.03943	21.0647	22.4%	1776.882			
5000	281.498	395.408	224.42	60.277	707.526	642.964	12480.41	12.7	14.4	4756.456	1.69446	0.88572	132.6835	35.84813	21.2247	21.4%	1862.961			
5500	301.82	385.412	237.753	67.606	762.159	699.876	14893.63	12.5	14.6	4720.6	1.5633	0.9692	134.7225	35.03943	21.0647	22.4%	1829.658			
6000	317.769	371.963	246.716	74.75	781.9	719	17391.24	12.4	13.6	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	23.5%	1772.544			

Table 12 - Running Map

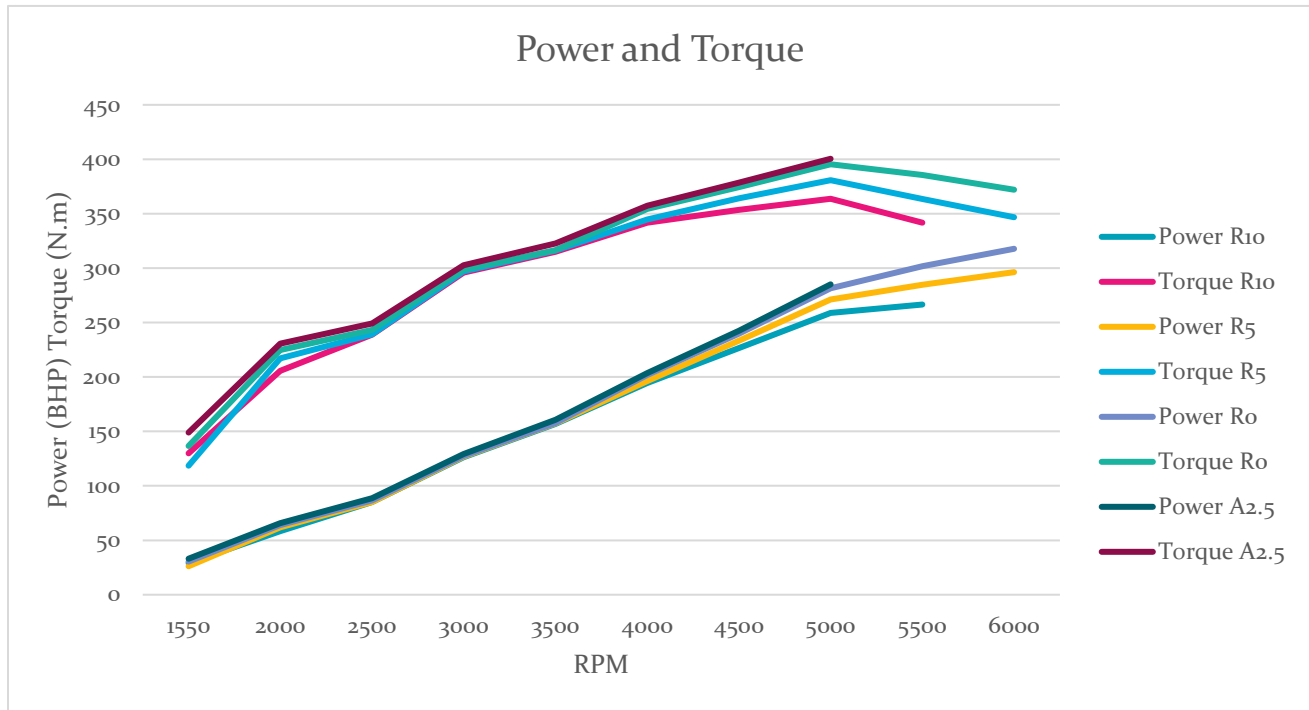
This is the standard running map.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	Mass Air Flow (lpm)	AFR	Boost (PSI)	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power (BHP)	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1560	33.09	148.973	14.689	18.855	431.9	355.6	1327	11.7	0.3	4577.176	1.03866	1.30312	142.8785	32.03544	20.4247	57.0%	729.3766	34.42379	20.9247	28.6%
2000	65.719	230.783	42.19	24.432	478.747	413.771	1719.505	13.2	2.8	4846.096	2.02236	0.67702	127.586	37.98298	21.6247	37.2%	1067.219			
2500	88.737	249.289	59.044	30.882	522.764	461.185	2313.624	12.8	4.9	4774.384	1.76004	0.84398	131.664	36.26188	21.3047	34.8%	1170.113			
3000	129.302	302.707	93.582	37.445	559.652	488.135	3253.234	12.2	9	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	29.0%	1453.596			
3500	160.828	322.726	118.869	44.077	570.768	499.4	4494.705	11.6	11.6	4559.248	0.97308	1.34486	143.898	31.68389	20.3447	27.4%	1586.29			
4000	203.57	357.431	155.3	50.925	600.041	535.255	6347.446	12.2	12.6	4666.816	1.36656	1.09442	137.781	33.87126	20.8247	25.0%	1716.38			
4500	242.473	378.434	187.293	58.338	656.293	598.786	8107.079	12.4	13.3	4702.672	1.49772	1.01094	135.742	34.64419	20.9847	24.1%	1803.38			
5000	285.087	400.449	223.037	65.712	694.342	645.278	12078.35	12.5	13.8	4720.6	1.5633	0.9692	134.7225	35.03943	21.0647	23.0%	1901.043			

Table 13 - 2.5 Degree Advance

This run is an attempted run with a 2.5 degree advance on the running map. It was not able to complete the run due to the engine being knock limited and the map causing the car to surpass the knock limit.

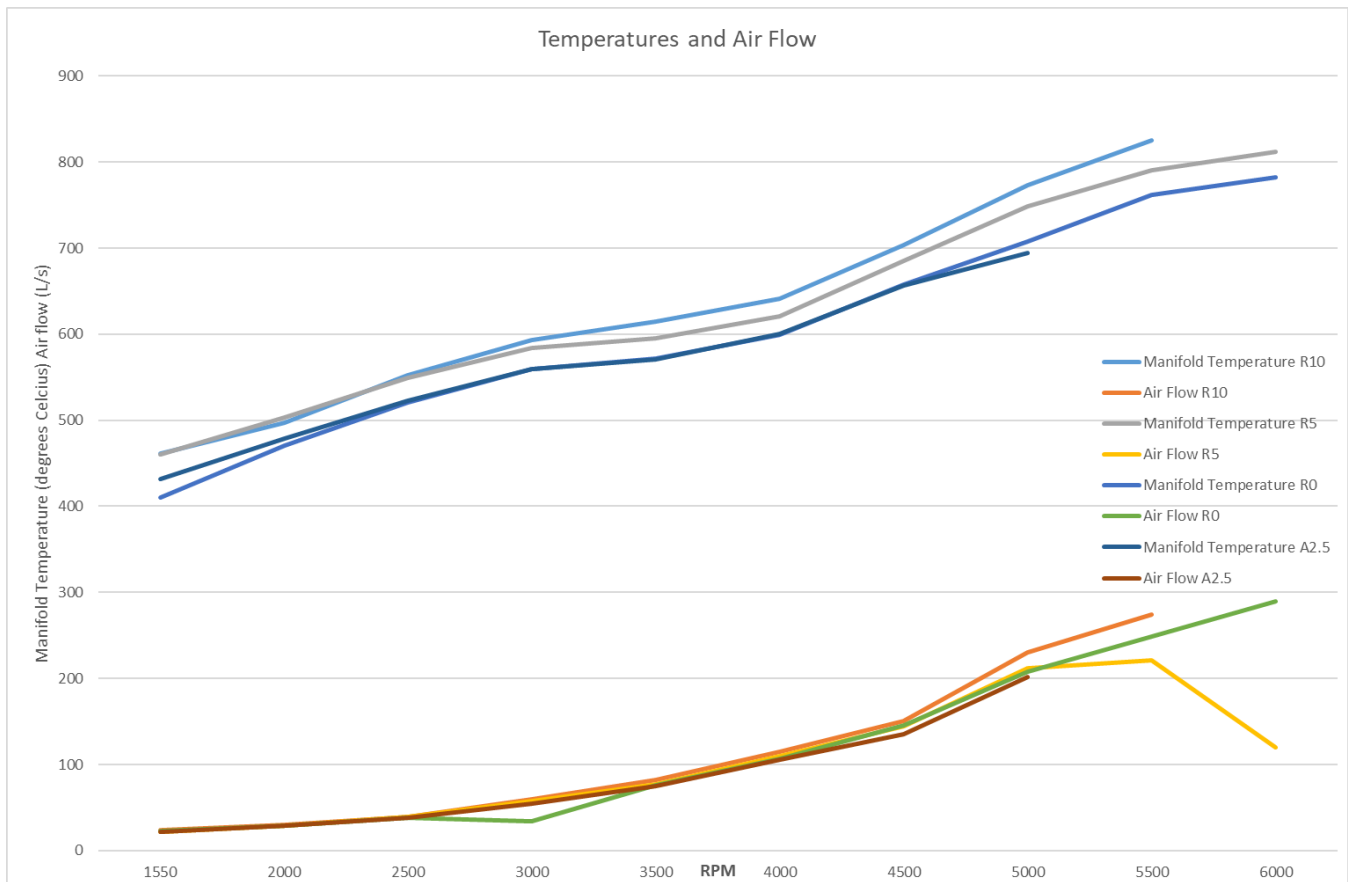
10.3.1 Results



Graph 19 - Difference in Power and Torque due to Timing

The graph shows the difference in power and torque when the timing has been changed. The labels are referring to the standard running map of the car, where R is retarded timing and A is advanced timing. The graphs show that there is more chance of getting higher torque and power figures when the timing has been advanced. Depending on what the car is going to be used for will determine the limit of the timing. It will also depend highly on what type of engine there is in the car, if the car is naturally aspirated then the engine isn't as knock limited, however there will be a limit as to where the increase in power ends due to negative work being done within the engine and the explosion opposing the piston too early. However with a boosted engine the engine is knock limited due to higher combustion pressures and temperatures, therefore it is not possible to get a boosted engine to the optimum timing point for power, therefore the amount of knock within the engine needs to be monitored. A knock sensor can be bolted to the side of an engine block, this will pick up frequencies within the engine and therefore need to be set up using a safe map where there is no knock occurring. With a properly calibrated knock sensor the engines limits can be found using the knock count built into the ECU functions. If the amount of knock increases rapidly then it is obvious that knock is occurring, and the timing has been

advanced too much. With the runs shown above, the advanced 2.5 run incurred knock and meant the run had to be ended short. However, as this engine is boosted the power and torque was still increasing, so there is still more power to be gained from timing, if the octane rating was improved it would mean the fuel burns slower causing a higher knock limit, it is also possible to cool the air going into the intake further meaning the inlet temperatures are lower and again furthering the knock limit, this can be achieved using a larger intercooler or a charge cooler. There is also the possibility of getting a larger radiator core to keep the engine cooler or getting a more efficient water pump as the standard water pump at high rpm causes airlocks within the system. With a lower engine



Graph 20 - Air flow and Temperature Changes due to Timing

temperature means a lower combustion temperature and therefore improving the knock limit. (RHDJapan, 2019)

	Air Flow (L.s)					
RPM	10 Degrees	7.5 Retard	5 Retard	2.5 Retard	0 Retard	2.5 Advance
2000	29.683583	29.435817	29.1608	14.96135	28.6606	28.65841667
2500	38.834417	42.941867	39.087517	38.275317	38.01778	38.5604
3000	59.991417	59.400083	57.107017	56.458083	33.6742	54.22056667
3500	82.59095	79.439867	77.1882	77.668683	76.00862	74.91175
4000	115.1471	110.61818	109.2955	108.08097	106.9937	105.7907667

Table 14 - Air flow Comparison to show less Boost

The graphs show that as the timing is advanced then the manifold temperature comes down. This is because the spark is fired at a late point which will cause some of the combustion to spill into the exhaust and therefore cause the temperatures to be higher. In this instance it isn't obvious what is happening in the combustion chamber when using the manifold temperature as the timing changes is what's going to be the biggest factor when it comes to temperature change. However, generally as the pressure in the cylinder increase as does the temperature in the cylinder and with an advanced ignition timing the pressure will increase and therefore cylinder temperatures will also increase hence the reason for knock. So in this instance although the manifold temperature decreases it doesn't mean the combustion temperature had decreased. Due to the temperature decreasing within the exhaust the boost pressure isn't as high as there isn't as much enthalpy available, therefore the turbo is doing more work when the temperature is higher due to the higher availability in energy. This is shown when looking in the mass airflow table. The general trend of the table that has been obtained using the vehicles mass air flow sensor is that as the timing is advanced then the amount of air per second is decreased. This means the turbo isn't working as hard and the boost pressure is going to be less. Although the Mass air flow sensor isn't very accurate past a certain RPM due to the volume of air being too large for it to read it is useful to use to get a generally idea of any trends that may occur. As the mass air flow meter isn't needed anymore with the standalone ECU it is no longer needed to be upgraded for the power due to the ECU's on-board manifold pressure sensor.

10.4.0 PART LOADING

Part loading will impact the engine and dynamometer run in many different ways. Using a different load point will allow the engine to create different boost levels in different manners. It will also allow the engine to climb the rpm at different rates of speeds and therefore will affect the internal combustion temperatures due to the amount of time taken for the engine to complete the run. It will mainly effect the mixture of the engine as at lower throttle positions the air will become choked and will not flow as effectively, this means the air and fuel won't be as well mixed before entering the combustion cylinder.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	AFR	Boost Pressure	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1545	34.106	155.041	16.747	17.657	309.953	459.134	11.2	-5.7	4487.536	0.71076	1.51182	147.976	30.32611	20.024703	0.5177095	170.3196	40.85827	21.518067	0.27849584
2000	61.406	215.637	38.836	23.149	388.894	516.035	11.5	-5.7	4541.32	0.9075	1.3866	144.9175	31.33728	20.264703	0.3769827	303.0195			
2500	88.14	247.612	59.594	29.393	462.868	591.83	13.9	-1.7	4971.592	2.48142	0.38484	120.4495	41.27532	22.184703	0.3334808	397.3008			
3000	130.582	305.706	95.863	35.909	540.499	676.911	14	-1.3	4989.52	2.547	0.3431	119.43	41.77778	22.264703	0.274992	586.4978			
3500	171.088	343.313	130.097	42.61	594.818	718.14	14.2	-1.3	5025.376	2.67816	0.25962	117.391	42.80887	22.424703	0.2490531	762.9443			
4000	209.928	368.595	161.699	50.19	662.524	759.372	13.9	-2	4971.592	2.48142	0.38484	120.4495	41.27532	22.184703	0.239082	946.2736			
4500	248.541	387.905	192.982	57.695	687.165	773.929	14.7	-3.3	5115.016	3.00606	0.05092	112.2935	45.55042	22.824703	0.2321347	1088.912			
5000	260.677	366.161	196.889	65.843	740.583	824.2	15.8	-4.5	4746.2765	3.087719		0	106.077	44.7437	21.179279	0.2525846	1230.811		
5500	272.951	348.548	201.536	74.023	760.448	826.472	15.9	-5.1	4716.3259	3.087719		0	105.4073	44.74382	21.045631	0.2711952	1296.949		
5920	295.002	349.98	215.931	81.703	781.722	862.466	16.1	-5.5	4657.4347	3.087719		0	104.0906	44.74405	20.782841	0.2769574	1419.45		

Table 15 - 25% Load on the Engine

The above table shows the scenario when the car is under 25% load

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	AFR	Boost Pressure	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1535	30.182	138.094	13.117	17.296	247.828	438.828	13.7	-4.6	4684.744	1.43214	1.05268	136.7615	34.25484511	20.90470326	64.1%	558.0802	34.99533	21.040703	25.7%
2000	60.766	213.388	38.227	22.975	311.236	480.283	12.9	1	4899.88	2.2191	0.5518	124.5275	39.34777459	21.86470326	37.5%	920.7305			
2500	89.458	251.314	60.899	29.185	426.421	580.497	14.5	5.7	4774.384	1.76004	0.84398	131.664	36.26187872	21.30470326	31.7%	1132.116			
3000	130.868	306.373	96.184	35.595	505.052	662.496	14.2	10.3	4666.816	1.36656	1.09442	137.781	33.87125946	20.82470326	26.1%	1430.537			
3500	164.986	331.069	123.939	42.265	580.924	728.118	14.5	12.9	4541.32	0.9075	1.3866	144.9175	31.33727811	20.26470326	24.7%	1571.022			
4000	200.276	351.648	152.433	49.23	651.681	771.003	13.8	12.3	4666.816	1.36656	1.09442	137.781	33.87125946	20.82470326	22.7%	1684.062			
4500	246.43	384.61	191.707	56.543	681.4	781	13.4	12.5	4702.672	1.49772	1.01094	135.742	34.64419266	20.98470326	21.9%	1764.466			
5000	268.95	377.782	206.673	64.237	726.4	820.7	13.7	12.5	4756.456	1.69446	0.88572	132.6835	35.84813485	21.22470326	21.1%	1833.043			
5500	284.623	363.453	213.838	72.733	750.314	833.114	12.9	11.6	4774.384	1.76004	0.84398	131.664	36.26187872	21.30470326	22.2%	1763.122			
5910	302.366	359.324	224.617	79.781	775.565	863.965	13.9	11.3	4684.744	1.43214	1.05268	136.7615	34.25484511	20.90470326	23.5%	1731.084			

Table 16 - 50% Load on the Engine

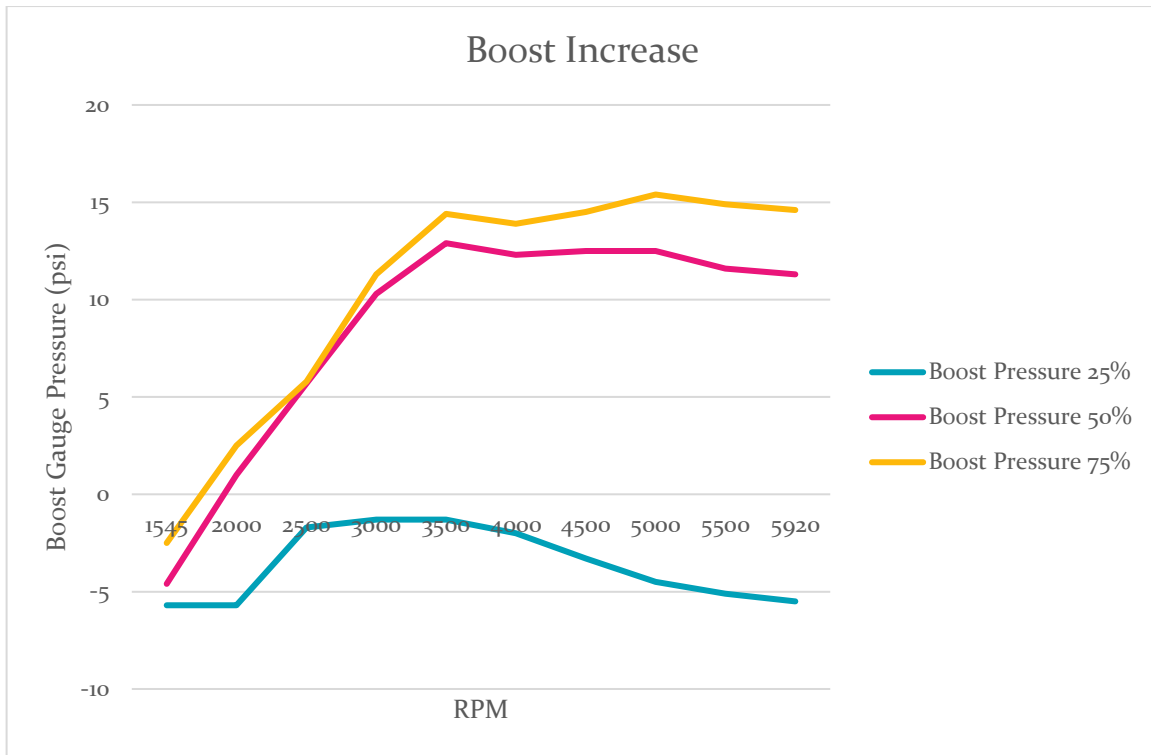
The above table shows how the engine is behaving when under 50% load.

n [rpm]	P-norm [BHP]	M-norm [Nm]	P-wheel [BHP]	P-drag [BHP]	Temp 1 [°C]	Temp 2 [°C]	AFR	Boost Pressure	Enthalpy (MJ/Kmol)	KG of CO ₂ /kg of fuel	KG of CO/kg of fuel	Mass of fuel	Energy Release/ Kg	Efficiency (%)	Drivetrain Efficiency	Fuel Power	Average Calorific Value (J/Kg)	Average Fuel Efficiency (%)	Average Drivetrain Efficiency
1550	28.688	129.99	11.875	16.88	264.3	448.5	12.7	-2.5	4756.456	1.69446	0.88572	132.6835	35.84813	21.22470326	58.8%	135.1633	41.23045	22.030524	26.8%
2000	60.629	212.905	38.721	22.053	334.317	494.05	13.3	2.5	4864.024	2.08794	0.63528	126.5665	38.43058	21.70470326	36.4%	279.3358			
2500	87.914	246.977	59.947	28.155	446	590.8	14.6	5.8	5097.088	2.94048	0.09266	113.313	44.98238	22.74470326	32.0%	386.5252			
3000	129.041	302.096	94.961	34.349	519.269	669.115	14.1	11.3	5007.448	2.61258	0.30136	118.4105	42.28888	22.34470326	26.6%	577.5015			
3500	158.896	318.849	118.515	40.733	587.561	738.656	15.5	14.4	4838.148	3.087719		0	108.1311	44.74337	21.58923695	25.6%	735.9964		
4000	202.457	355.479	155.425	47.497	645.124	762.898	14.8	13.9	5064.29728	3.087719		0	113.1872	44.74265	22.59838144	23.5%	895.8916		
4500	238.619	372.419	184.684	54.483	702.84	792.645	13.8	14.5	4953.664	2.41584	0.42658	121.469	40.7813	22.10470326	22.8%	1079.494			
5000	270.023	379.29	208.618	62.135	760.252	836.826	13.9	15.4	4971.592	2.48142	0.38484	120.4495	41.27532	22.18470326	23.0%	1217.158			
5500	281.835	359.892	212.216	70.171	791.139	854.607	13.3	14.9	4864.024	2.08794	0.63528	126.5665	38.43058	21.70470326	24.9%	1298.497			
5835	290.61	349.792	215.499	75.744	814.315	885.52	13.8	14.6	4953.664	2.41584	0.42658	121.469	40.7813	22.10470326	26.1%	1314.698			

Table 17 - 75% Load on the Engine

The final table is the engines performance under 75% load.

10.4.1 Results



Graph 21 - Boost Increase with Load

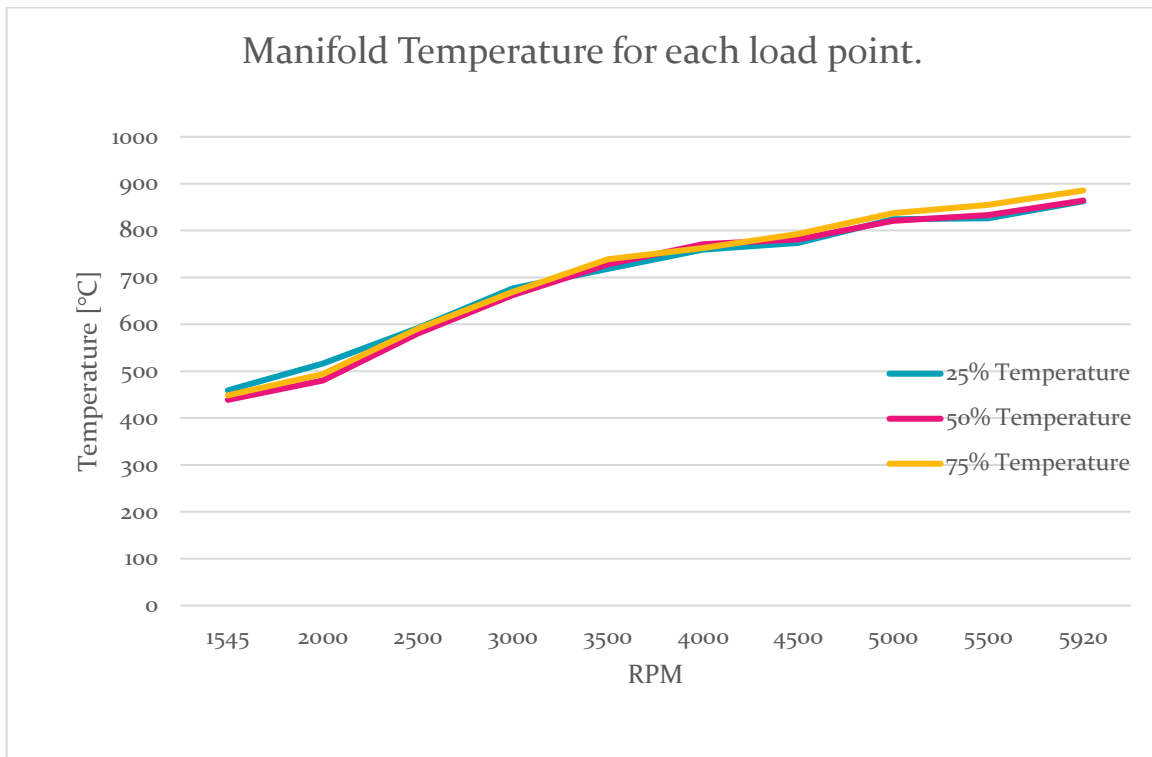
The graph above shows how the boost pressures are effected at different load points. When the throttle is at 25% the graph and data from the dyno run shows that the amount of air coming in was less than atmospheric pressure. This is similar to a naturally aspirated car and therefore means that the turbo is effectively adding no extra air to the inlet manifold. The 25% throttle position seemed to have the biggest effect during these runs as the throttle valve would be mainly closed allowing less air coming through. However with the differences between the throttle positions being at 50% and 75% there is less of a difference as the air isn't being as choked at both position and there is enough space for the air to go by the throttle. As shown by the graph with a throttle position of 75% the boost is able to increase at quicker rate of speed due to more pressure being built up in the cylinder and therefore more heat and enthalpy being made for the turbo to make use of. At 75% the boost pressure peaked at 15.4 psi and at 50% the peak pressure was 12.9 psi. The difference in peak pressures show that with a higher throttle position there are more available products being released through the exhaust and therefore more work

being created for the turbo to make use of. Hence a higher turbine speed sucking more air into the inlet manifold.

25% calorific value	50% calorific value	75% calorific value
40.86	35.00	41.23

Table 18 - Calorific Value Change due to Loading

Although there is no coloration between these result it does show that the calorific value of the fuel can be increased with a fuel and air mixture that is closer to stoichiometric. As both the 25% and 75% throttle position had an RPM point where the fuel and air mix was closer to stoichiometric and even leaned out ever so slightly, this proves the previous statement about how the fuel is mixed and how it can have an effect on the energy that is released per each mixture. As the fuel map wasn't setup correctly for each load point it meant that the lambdas didn't stay consistent and therefore caused no obvious trend, however if the fuel map was set up correctly then the 25% calorific value will be higher than the calorific value of the 75% this is due to having a map that gets richer as it goes through the throttle position. This would be in place, firstly to try and obtain some fuel economy when cruising down the motorway with little throttle input, while also considering engine and combustion temperature when the car is subjected to high loads.



Graph 22 - Change in manifold Temperatures due to Load

This graph shows the temperatures that are released from the exhaust manifold when subjected to each load point. As shown at higher RPM the temperature is higher with a higher load point, this will be due to the engine having a better mixed air and fuel through the manifold as well as more reactants going into the combustion chamber, this therefore will cause the flame to burn at a higher temperature. However due to the amount of time it takes for the vehicle to complete a run at lower load points it means they tend to gain temperature at each RPM. As the engine is subjected to load for a longer period of time it means the engine is going to get heated and retain some of the heat. It will also mean the engines cooling aid is going to increase in temperature and have a lesser effect on the engine cooling.

11.0 Further Results

Some further results that were calculated using the runs. They will remain roughly the same throughout each run and will be a characteristic of the vehicle. These will show some of the characteristics of the car and show where improvements can be made within the driveline to make use of more of the fuel power. Taken an average of each run, the results shown will be the calorific value of the fuel with the setup being used. The drivetrain efficiency, the amount of power that is lost through the transmission and finally a fuel efficiency to calculate how much of the fuel energy is actually used to make power.

Fuel Calorific Value	Fuel Efficiency	Transmission Efficiency
34.73336355	21.0%	25.4%

Table 19 - Vehicle Efficiency

11.1 CALORIFIC VALUE

As shown above the fuel calorific value is shown for a gasoline with mainly an octane rating of 99. As the fuel is just normal gasoline the normal calorific value should be around 44 MJ/kg. As shown when in use the calorific value is reduced by around 10 MJ/kg, this is due to the way the fuel is being mixed with air, the 44 MJ/kg is calculated when the fuel is being burnt at stoichiometric, while the figure that has been obtained above is when the engine is running rich. The engine is generally run rich to slow down combustion and therefore make the combustion temperature lower. The calorific value is an amount of heat that is given off by a certain mass of fuel at a complete combustion. (Warter, 2011) Therefore taken this definition, the calorific value will decrease with a rich combustion due to the mixture burning slower and therefore not creating as much heat, this is due to the heat having more time to escape into the cylinder walls. This would mean there is less heat being given out per kg of fuel causing the calorific value to decrease.

11.2 FUEL EFFICIENCY

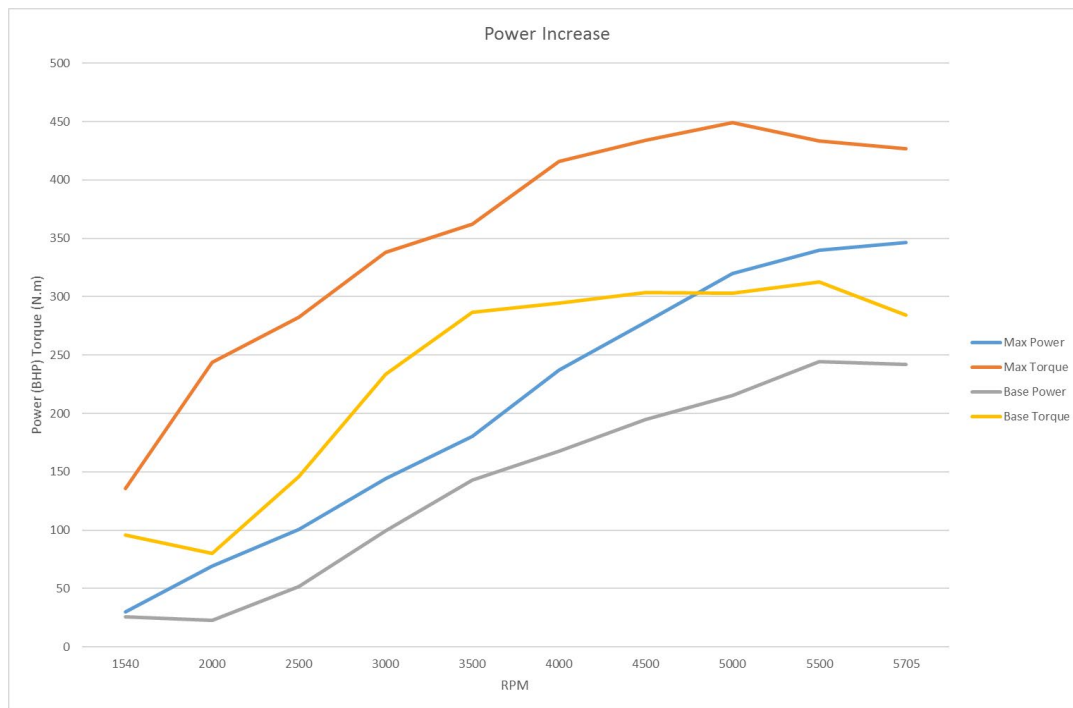
The fuel efficiency is the amount of fuel that is being used to make the enthalpy that is released from the engine. As shown on this vehicle the fuel efficiency is a low percentage therefore making the engine very inefficient. This is also known as the thermal efficiency

of an engine. It is calculated taking the amount of work done by the engine and dividing it by the heat that is supplied. (Energy Education, 2018) With modern day engines tending to be around 30% efficient due to updated technology and Toyota reaching a maximum efficiency of 38% using gasoline. Therefore this car is starting to show its age, with this engine being designed and built in the 1990s, it means the efficiency is going to be a little lower due to less technology being used. Some reasons as to why the efficiency of this engine may be where it's at is due to the low compression of the engine, as the engine is turbocharged it means the compression needs to be lower. With higher compression ratios it is possible to use other technologies in the head to allow more air, making a higher thermal efficiency. (Ingram, 2014) It is also useful to remember that the car is running rich and will therefore not burn all of the fuel that enters the combustion chamber while also slowing combustion speeds, therefore causing a lower thermal efficiency.

11.3 TRANSMISSION EFFICIENCY

It is possible to use the data that is acquired during dyno runs to get an idea of how efficient the powertrain is and how much power is lost during the transition from engine to wheels. The data shows that a quarter of the power is lost through the transmission. With most rear wheeled drive cars achieving a drivetrain efficiency of around 20%, this lies roughly correct with the figures that have been achieved by the dynamometer. (A. Irimescu, 2011) There are many factors to the losses through the drivetrain, things such as gears having small amount of play, the drag that the oil will cause around gears and engine components, clutches and flywheels, drive shafts and prop shafts and differentials. Every component listed will have a weight that will require the engines power to get rotating or moving and therefore will be a factor of the powertrain loss. There are many ways that the drivetrain can be made more efficient. Easy things such as fitting light weight wheels, a lighter flywheel, and a high performance clutch can help to reduce any kind of slip. There is also the potential of upgrading the gearbox and differential to something more modern with tighter design to reduce the amount of play to a minimum. It therefore can be very beneficial in looking at the drivetrain and making improvements to get more of the engines power to the wheels rather than being wasted in spinning heavier components.

11.4 PERFORMANCE INCREASE



Graph 23 - Performance increase during Project

The project saw an increase of power from the start to end. With the base run making 250 BHP on the standard ECU with some light modifications, its shown that there is a drastic increase in both torque and power towards the end of the runs. There is still improvements to be made to the map to get a more even torque line which will in turn increase power and torque. During the project however there was increase of 100 horsepower and an even bigger increase of 140 Nm of torque, this shows that with some supporting mods and an increase of boost pressure the engine has a lot of potential to perform. Although cylinder pressure will have increased the power that has been made is safe and will not cause immediate damage to the engine but however will cause wear to happen a little sooner. The biggest changes were noted as the boost increased and with a more advanced timing, as these factors increased the cylinder pressure and therefore causes more heat to be turned into mechanical energy. A higher timing also allows more of the fuel to be used up as it gives more time for combustion to happen and for all the fuel to be burnt.

12.0 Improvements

Although a lot of data has been obtained during this project there is still plenty of things that could be improved upon and many more sensors that can be added into the engine to allow a better understanding of the engine and allow more calculations to be made. This was a first-time experiment and therefore a lot has been learnt along the way and therefore a better understanding of what could be improved during the experiment. It would be beneficial to have a bigger budget for the experiment as it was self-funded it, there was to limits as to how many sensors could be bought and used as the sensors are expensive.

12.1 THERMOCOUPLES AND PRESSURE SENSORS

Therefore with further funding it would be possible to get pressure sensors installed with the thermocouples to find out temperature and pressure, this will allow the work done by the turbo to be calculated using Bernoulli's equation and this will allow further work to be carried out as it will be possible to find the amount of work done with the wastegate in use and therefore look at the turbo efficiencies in real life with a wastegate in use. It is also possible to see the effects of the boost solenoid and how it can play an aid in the turbo efficiency. It would also be useful to have more thermocouples to use within the turbo casing, this way it is possible to know the temperature and pressure within the turbo housing and therefore get a more accurate efficiency reading. As the housing will be the air that is spinning the turbine blades and pushing the air through the inlet and into the engine. With the set up used it is not as accurate as it allows for heat loss after the sensor and therefore the incorrect temperatures are used when calculating efficiency. This means the turbo will likely be less efficient than the stated figures as the starting temperature is higher and there is also some of the heating escaping after the turbo before the next thermocouple.

12.2 LAMBDA IMPROVEMENTS

Another lambda sensor could used when completing the runs as the one that was used is place below the car with three joins within the exhaust before it and therefore will not read as accurately as there will be some gasses escaping through the joins. Although all of the exhaust gaskets were refreshed when the turbo was removed from the car to fit braided water lines, the exhaust is missing an exhaust flexi which means the exhaust isn't allowed

to flex and bend and therefore causes the exhaust to split from each other causing an incorrect reading at lower RPM where the flow speed isn't as high. When fitting an aftermarket exhaust to these cars they tend to sit low and become the lowest point of the car and therefore it is the first point of contact with the floor. This means the exhaust gets scraped often and eventually causes splits. As the lambda at idle was reading too high it was an indication of an exhaust leak and therefore meant the joins needed to be checked and tightened where applicable. Therefore, a suitable improvement for a more accurate lambda would be to have a flexi pipe fitted into the exhaust to allow more flex in the exhaust.

12.3 FUEL FLOW METERS

It would also be useful to have two fuel flow meters to place along the car, this will allow a more accurate representation of the amount of fuel that is being used by the vehicle. If there is an air fuel ratio and a mass air flow sensor attached to the engine then it is possible to get a reasonably accurate amount of fuel injected into the cylinder, it is also possible to use the fuel maps duty cycle to calculate the amount of fuel being used, however this is less accurate again as there will be no consideration for the injector opening and closing time therefore the actual amount will be more than the stated amount. However, with two fuel flow sensors it is possible to get a 100% accurate amount of fuel being used. One can be placed on the inlet to the fuel rail registering the amount of fuel going into the rail, while the second attached to the fuel return pipe to calculate the amount of fuel that is leaving the fuel rail. It is then possible to get the amount of fuel used in the rail by misusing the two numbers. However, these fuel flow sensors will need to have the ability to log to allow the amount of fuel to be plotted by RPM.

12.4 CYLINDER PRESSURE SENSOR

A cylinder pressure sensor would be a useful sensor to have if more time and money were acquired. This would be a complex process to fit the sensor in a practical manor where it will not interfere with the engine internals, read correctly and be a practical place to drill without causing the engine to lose compression. However with the cylinder pressure information a lot of calculations can be taken from it such as the amount of force the piston is being subjected and therefore it can be noted as to when the amount of pressure being

caused in the cylinder is unsafe for the engine internals, mainly the conrod and main bearings.

12.5 KNOCK SENSORS

Additional knock sensors could have been bought. They could be set up to read the amount of knock per cylinder and linked into the ECU. As this ECU will allow the user to setup each cylinder individually the knock sensors could be used to set up all of the cylinders and get the maximum amount of power from the engine. As the first cylinder will be cooler due to it being first contact with the coolant it means that this cylinder can be further advanced, while cylinder four burns the hottest due to getting the coolant last it means it is more likely to be subjected to knock and therefore will be retarded from cylinder one. Using this method will get every potential horsepower from the engine and will allow the engine to run reliably and safely.

12.6 CREATE AN EVEN LAMBDA MAP

Allowing a better understanding of the ECU and some of the features that are built into the dynamometer, some of the runs would have been benefitted with having a proper fuel map where target AFR's are met. The AFR could start to be close to stoichiometric and work its way richer as the RPM and load increases. This would allow a better understanding of how certain changes can affect the amount of fuel that is being burnt and the amount of fuel that is being wasted in the exhaust due to not having enough time to burn. As recently learnt the dyno has the capability of holding a desired RPM no matter the amount of load being applied and therefore means the fuel can be changed to get to the desired AFR for each RPM point and load point. This would improve the general running of the car and allow a smoother torque and power curve and therefore allow the peak torque and horsepower to be higher than previous maps.

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14.1.0 SPREADSHEET SET UP

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Carbon Dioxide			Water			Oxygen			Nitrogen			Carbon Monoxide		
2	Temperature	Enthalpy (MJ)		Temperature	Enthalpy (MJ)		Temperature	Enthalpy (MJ)		Temperature	Enthalpy (MJ)		Temperature	Enthalpy (MJ)	
3	0	-14.21		0	-9.5716		0	-9.4055		0	-8.8713		0	-9.0418	
4	1	-14.166694		1	-9.542193001		1	-9.375398		1	-8.842997		1	-9.012998	
5	2	-14.123376		2	-9.512772005		2	-9.345292002		2	-8.814688002		2	-8.984192002	
6	3	-14.08004601		3	-9.483337016		3	-9.315182005		3	-8.786373005		3	-8.955382005	
7	4	-14.03670403		4	-9.453888038		4	-9.285068013		4	-8.758051013		4	-8.926568013	
8	5	-13.99335006		5	-9.424425075		5	-9.254950025		5	-8.729725025		5	-8.897750025	
9	6	-13.9498411		6	-9.39494813		6	-9.224828043		6	-8.701392043		6	-8.868928043	
10	7	-13.90660617		7	-9.365457206		7	-9.194702069		7	-8.673053069		7	-8.840102069	
11	8	-13.86321626		8	-9.335952307		8	-9.164572102		8	-8.644708102		8	-8.811272102	
12	9	-13.81981436		9	-9.306433437		9	-9.134438146		9	-8.616357146		9	-8.782438146	
13	10	-13.7764005		10	-9.2769006		10	-9.1043002		10	-8.5880002		10	-8.7536002	
14	11	-13.73297467		11	-9.247353799		11	-9.074158266		11	-8.559637266		11	-8.724758266	
15	12	-13.68953686		12	-9.217793037		12	-9.044012346		12	-8.531268346		12	-8.695912346	
16	13	-13.6460871		13	-9.188218318		13	-9.013862439		13	-8.502893439		13	-8.667062439	
17	14	-13.60262537		14	-9.158629646		14	-8.983708549		14	-8.474512549		14	-8.638208549	
18	15	-13.55915169		15	-9.129027025		15	-8.953550675		15	-8.446125675		15	-8.609350675	
19	16	-13.51566605		16	-9.099410458		16	-8.923388819		16	-8.417732819		16	-8.580488819	
20	17	-13.47216846		17	-9.069779948		17	-8.893222983		17	-8.389333983		17	-8.551622983	
21	18	-13.42865892		18	-9.040135499		18	-8.863053166		18	-8.360929166		18	-8.522753166	
22	19	-13.38513743		19	-9.010477715		19	-8.832879372		19	-8.332518372		19	-8.493879372	
23	20	-13.341604		20	-8.9808048		20	-8.8027016		20	-8.3041016		20	-8.4650016	
24	21	-13.29805863		21	-8.951118557		21	-8.772519852		21	-8.275678852		21	-8.436119852	
25	22	-13.25450132		22	-8.921418389		22	-8.74233413		22	-8.24725013		22	-8.40723413	
26	23	-13.21093208		23	-8.8917043		23	-8.712144433		23	-8.218815433		23	-8.378344433	
27	24	-13.16735091		24	-8.861976294		24	-8.681950765		24	-8.190374765		24	-8.349450765	
28	25	-13.12375781		25	-8.832234375		25	-8.651753125		25	-8.161928125		25	-8.32053125	
29	26	-13.08015279		26	-8.802478546		26	-8.621551515		26	-8.133475515		26	-8.291651515	

Figure 10 - Enthalpy of Products

A table to show the amount of enthalpy that is released at each temperature of the combustion. (Mcdonald, 2019)

	Leaning off stochiometric	AFR	N1	N2	N3	N4	Net Enthalpy (MJ)	Mass of Fuel	Mass of CO ₂	CO ₂ / Kg of Octane							Fuel Ratio	Carbon	Hydrogen	Oxygen	Nitrogen
1	1	14.7	8	9	0	47	5100.1	114	352	3.087719							1	8	18	25	47
3	0.99	14.84848485	7.92	8.91	0.125	46.53	5049.099	112.86	348.48	3.087719							0.99	7.92	17.82	25	47
4	0.98	15	7.84	8.82	0.25	46.06	4998.098	111.72	344.96	3.087719							0.98	7.84	17.64	25	47
5	0.97	15.15463918	7.76	8.73	0.375	45.59	4947.097	110.58	341.44	3.087719							0.97	7.76	17.46	25	47
6	0.96	15.3125	7.68	8.64	0.5	45.12	4896.096	109.44	337.92	3.087719							0.96	7.68	17.28	25	47
7	0.95	15.47368421	7.6	8.55	0.625	44.65	4845.095	108.3	334.4	3.087719							0.95	7.6	17.1	25	47
8	0.94	15.63829787	7.52	8.46	0.75	44.18	4794.094	107.16	330.88	3.087719							0.94	7.52	16.92	25	47
9	0.93	15.80645161	7.44	8.37	0.875	43.71	4743.093	106.02	327.36	3.087719							0.93	7.44	16.74	25	47
10	0.92	15.97826087	7.36	8.28	1	43.24	4692.092	104.88	323.84	3.087719							0.92	7.36	16.56	25	47
11	0.91	16.15384615	7.28	8.19	1.125	42.77	4641.091	103.74	320.32	3.087719							0.91	7.28	16.38	25	47
12	0.9	16.33333333	7.2	8.1	1.25	42.3	4590.09	102.6	316.8	3.087719							0.9	7.2	16.2	25	47
13	0.89	16.51685393	7.12	8.01	1.375	41.83	4539.089	101.46	313.28	3.087719							0.89	7.12	16.02	25	47
14	0.88	16.70454545	7.04	7.92	1.5	41.36	4488.088	100.32	309.76	3.087719							0.88	7.04	15.84	25	47
15	0.87	16.89655172	6.96	7.83	1.625	40.89	4437.087	99.18	306.24	3.087719							0.87	6.96	15.66	25	47
16	0.86	17.09302326	6.88	7.74	1.75	40.42	4386.086	98.04	302.72	3.087719							0.86	6.88	15.48	25	47
17	0.85	17.29411765	6.8	7.65	1.875	39.95	4335.085	96.9	299.2	3.087719							0.85	6.8	15.3	25	47
18	0.84	17.5	6.72	7.56	2	39.48	4284.084	95.76	295.68	3.087719							0.84	6.72	15.12	25	47
19	0.83	17.71084337	6.64	7.47	2.125	39.01	4233.083	94.62	292.16	3.087719							0.83	6.64	14.94	25	47
20	0.82	17.92682927	6.56	7.38	2.25	38.54	4182.082	93.48	288.64	3.087719							0.82	6.56	14.76	25	47
21	0.81	18.14814815	6.48	7.29	2.375	38.07	4131.081	92.34	285.12	3.087719							0.81	6.48	14.58	25	47
22	0.8	18.375	6.4	7.2	2.5	37.6	4080.08	91.2	281.6	3.087719							0.8	6.4	14.4	25	47
23																					
24																					
25	Product	Molecular Weight																			
26	Carbon	12																			
27	Hydrogen	1																			
28	Oxygen	16																			
29																					
30																					

Figure 12 - Lean Fuel Ration Calculations

This table shows a lean mixture for the few tests that caused the car to run lean. This was taken from a previous assignment. (Hazlewood, 2019)

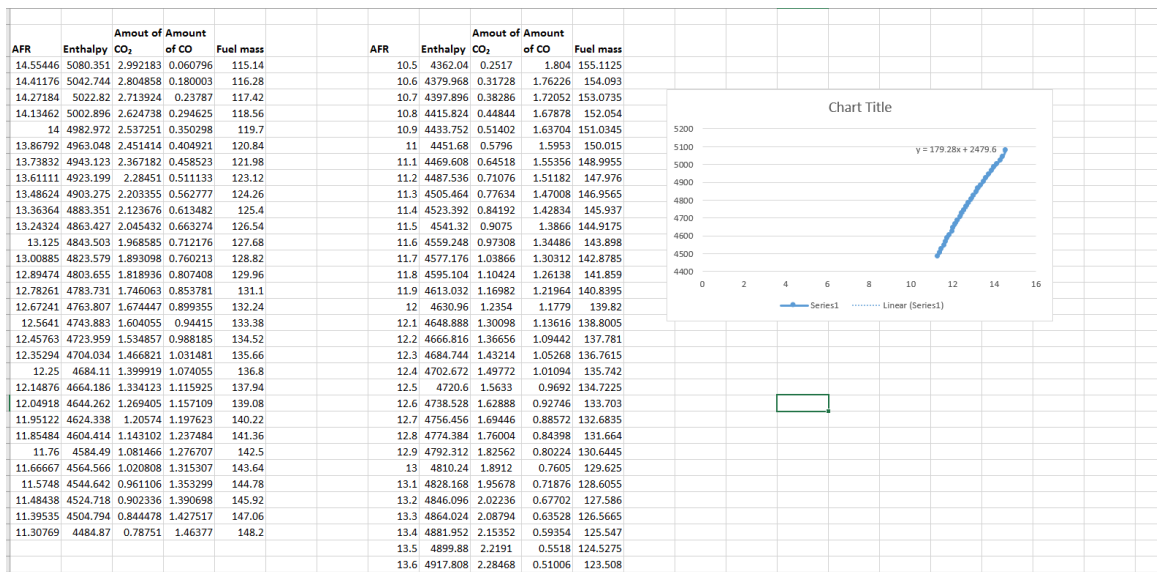


Figure 13 - AFR Enthalpies

The previous table is copied into a new sheet. On this new sheet a graph will be plotted using the AFR and information obtained. A trend line is then added to the graph with the equation being shown on the line. This equation can be used to calculate all the relevant and useful information and put it into terms of AFR rather than fuel ratio. As the runs use

the AFR returned from the lambda sensor. The same process needs to be completed for a lean mixture, making AFR the main product.

14.2.0 EQUATIONS

The equations shown have been used within tables to be able to create the graphs. They will allow a better understanding of how the engine works.

14.2.1 Chemical Equations

To start the spreadsheet needed all the information of product and reactants. This includes Enthalpies and masses. The amount of each product that is released is needed to calculate the amount of each product and get the amount of enthalpy released from the fuel. Therefore the molecular equation needs to be used, from here the amount of products can be calculated by breaking down each molecule, such as the amount of Carbon, Hydrogen, Oxygen and Nitrogen. The amounts are going to be varied for each fuel ratio therefore it is best to set up the spreadsheet to allow the number to be multiplied by the fuel ratio. This requires having a separate table with the amount of each reactant that is being inputted into the engine. As Carbon and Oxygen appear in multiple products another column is added which gives the number of oxygen minus the amount of Water released. With the amount of products produced being calculated it is possible to find the Enthalpy released from the fuel. This is calculated using the sum of each product multiplied by the enthalpy required to produce the product, the fuels enthalpy multiplied by the fuel ratio is then taken from the previous figure. To calculate the weight of a product in Kmols, it is the amount of product multiplied by its given molecular weight. This can then be calculated in terms of the weight of fuel to get the amount of product per Kmol of fuel. The mass of fuel can be calculated from the chemical equation of fuel multiplied by the weight of each reactant.

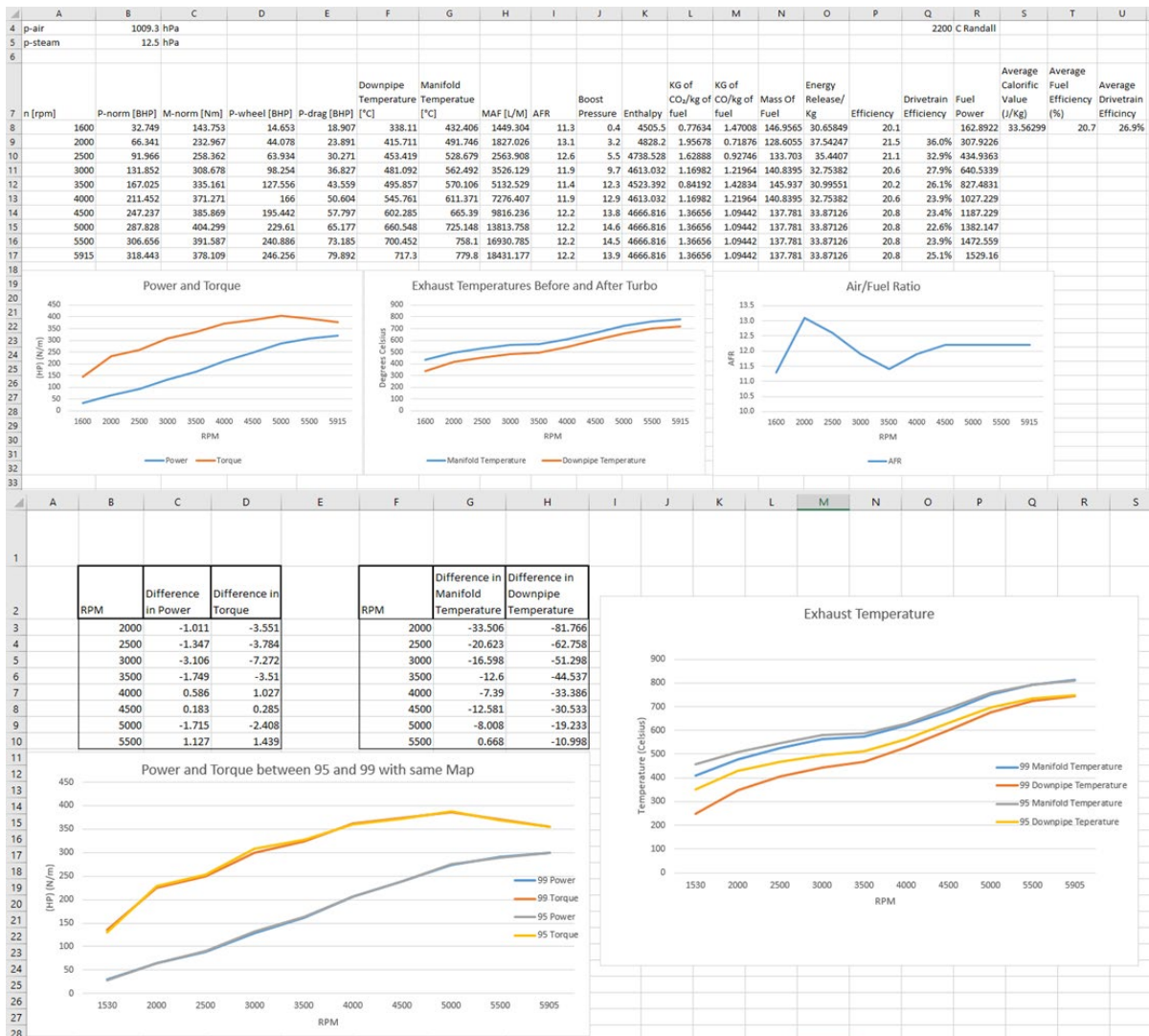


Figure 15 - Dynamometer Equations

14.2.3 Turbo Efficiency Calculations

With the information obtained from the previous slide, it is possible to get the manifold pressure, this is calculated using the boost pressure in BAR and adding it to the atmospheric pressure also in BAR. Again the calorific value is obtainable. The fuel mass per second can be worked out using the fuel power in watts divided by the fuel calorific value, this can then be used to find air mass per second, just multiply fuel mass and AFR. The molecular weight of the products released, this is the sum of each product multiplied by the molecular weight, all over the total amount of products released. The work into the

turbine is the difference in temperatures obtained from the thermocouples divided by molecular weight. Finally the turbo efficiency is the work done by the turbo divided by the total enthalpy released.

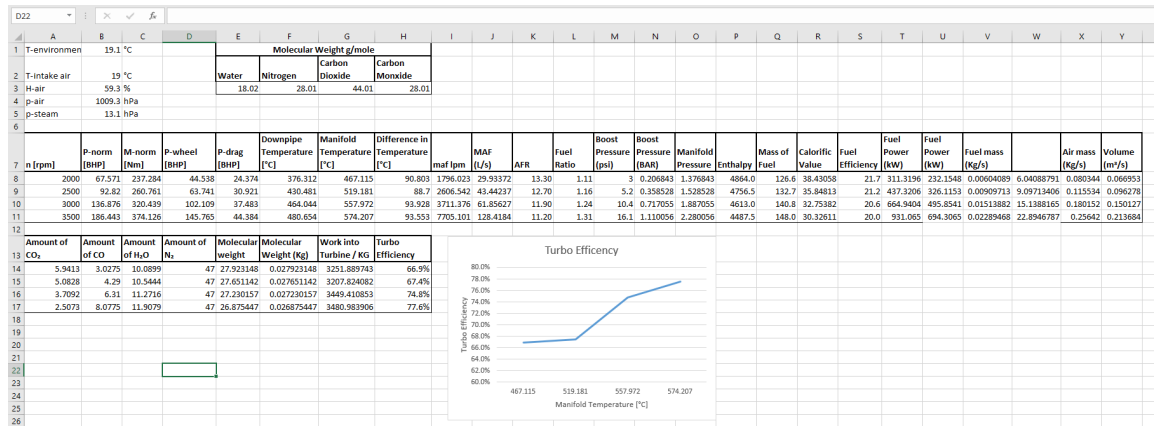


Figure 16 - Turbo Efficiencies

14.2.4 Vehicle Efficiency

The general efficiency of the vehicle can be calculated as they should stay very similar throughout the runs, the two main ones to calculate are thermal efficiency and drivetrain efficiency. This is simply done by using the Average equation in excel and selecting the average of each in every run.

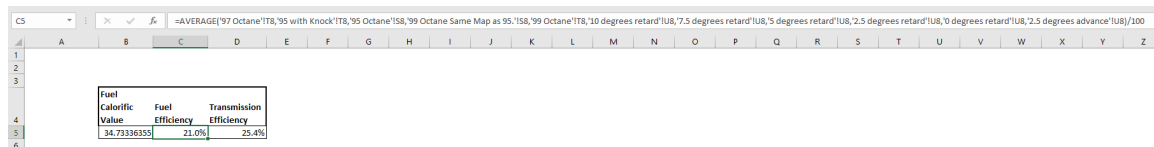


Figure 17 - Vehicle Efficiencies