Supercharged Miata

Determining the Effects of a Supercharger on a Spark Ignition Engine.

By Carter Breckenridge and Niall Lynch

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Determining the effects of a supercharger on a spark ignition engine.

A Major Qualifying Project

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1.0 Abstract

The goal of this project was to test and analyze exactly how much power would be gained supercharging the fairly small and low-powered engine in a 1990 Mazda Miata, and how supercharging would affect exactly how the car's engine operates. To prepare the car for testing and then supercharging, the car had multiple supporting modifications and upgrades done to it. The car was then tuned and tested by a professional tuner on a dynamometer, so that we could see exactly how much horsepower and torque the engine was producing. A supercharger was then fitted to the engine, using parts of a kit purchased online. This supercharger installed required the design and fabrication of a bypass valve system, a mounting bracket, a full engine intake tract, a relocated throttle body setup, and a belt tensioner. Once the supercharger was properly hooked up and running, the car was again tuned and tested on a dynamometer, and a comparison was made between the naturally aspirated engine and the supercharged engine using data taken from the dynamometer and the car's ECU. This data included power, torque, boost, spark advance, and volumetric efficiency. The data showed a large increase in power and torque made by the engine and demonstrated how effective a supercharger can be in increasing an engine's performance.

2.0 Background

2.1 History of the Internal combustion engine

The idea of the internal combustion engine dates back to 1680, when a physicist named Christiaan Huygens designed the first internal combustion engine, designed to run on gunpowder. Although it was never built, this was the first time the idea of using an explosion of fuel to push a piston within a cylinder was considered. It was not until the 1800s that any internal combustion engines (hereafter referred to as IC engines) were ever built. A few different inventors and engineers tried to create an IC engine during the early and mid 1800s, but it was not until 1858 that the first successful IC engine was created and used. This was done by Jean Joseph Etienne Lenoir, who created an electric spark ignition IC engine that was powered by coal gas. Lenoir mounted this engine to a three wheeled wagon and was able to complete a fifty mile road trip. New designs and developments of IC engines followed quickly after. In 1864 Siegfried Marcus built an IC engine with the first carburetor, and later created what was considered the forerunner of the gasoline powered automobile. In 1876, Nikolaus Otto invented a four stroke engine with a cycle known as the Otto cycle, the thermodynamic cycle still used in modern day four stroke gasoline engines. From here, IC engines continuously improved and became cheaper, more reliable, and more efficient. In 1892, a different type of engine was created by Rudolph Diesel that modified the otto cycle to be more efficient.

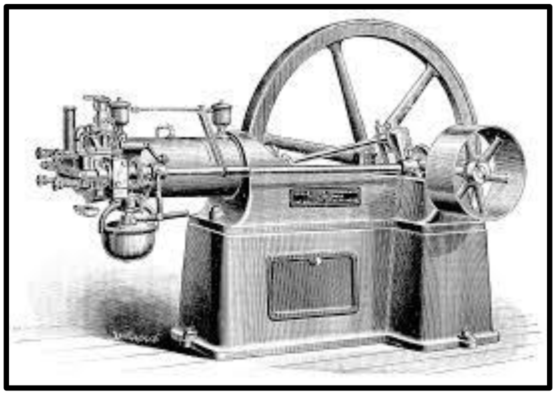


Figure 1: Old Version of a 4 stroke engine

2.2 Four Stroke Engine

The four strokes of the Otto cycle are intake, compression, ignition, and exhaust. First, gasoline or another fuel are either mixed together and then injected into the cylinder, with the expanding cylinder drawing the mixture into itself, or the fuel is injected separately but mixed with air in the cylinder. Next, this air/fuel mixture is compressed by the piston. This mixture is then ignited with an electrical spark from a spark plug, causing the mixture to explode, pushing the piston back down and expanding the cylinder. Lastly, the piston goes back into the cylinder and pushes out the waste gasses from the cylinder. The diesel cycle, on the other hand, uses a different method of combustion. The diesel engine followed the same 4 strokes as the Otto cycle: intake, compression, ignition, and exhaust, but with a few key differences. In the Otto cycle, fuel is injected before compression, and the ignition is created by a spark. In the diesel cycle, fuel is not injected until the compression stroke is complete. In a diesel, the compression stroke heats the air enough that when fuel is injected at the end of the compression stroke, it immediately ignites and creates the ignition stroke.

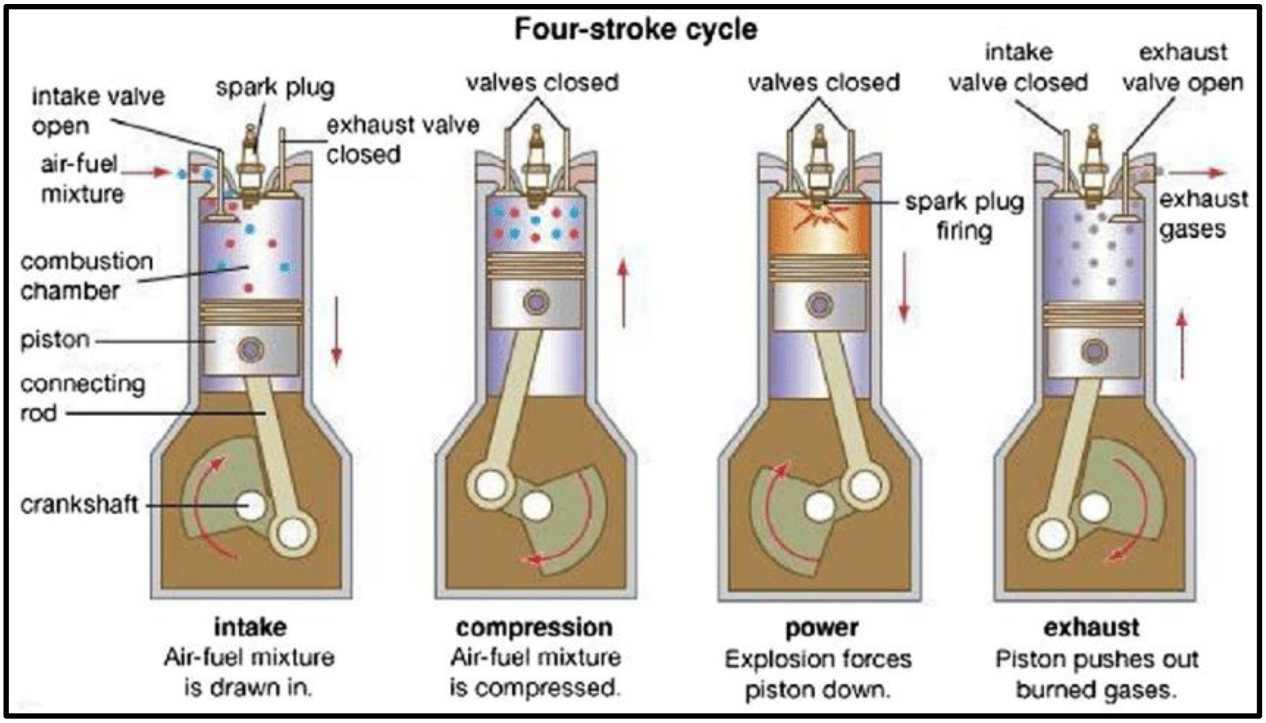


Figure 2: Four stroke cycle diagram (7)

2.2.1 Diesel Engine and Spark ignited engines

There are numerous advantages to a diesel engine. First, it can run at a wide range of air fuel ratios. Gasoline engines are limited by the fact they need a relatively stable air fuel (AF) ratio to operate properly without engine knock or engine overheating. This is due to the fact that a gasoline engine has its fuel injected prior to the compression stroke, and if the fuel has the wrong flash point due to an incorrect AF ratio, the air and fuel can ignite prematurely from the heat during the compression stroke, rather than from the spark plug, causing what is called engine knock. Diesels, on the other hand, can operate at a much wider range of AF ratios due to the fact diesels are compression ignition, rather than a spark plug, the heat from the air compression ignites the fuel, ignition is controlled by the timing of when the fuel is injected, rather than when the spark plug fires.The mixture is always lean there being an excess of air in the mixture. Diesels also must have higher compression ratios than spark ignition engines. This means that for a given engine of the same size, cylinder count, etc, a diesel engine will produce more torque and have better fuel economy. The downside to a diesel is that they are heavy, slow to rev up, and feel less smooth to operate compared to a gasoline engine. (8)

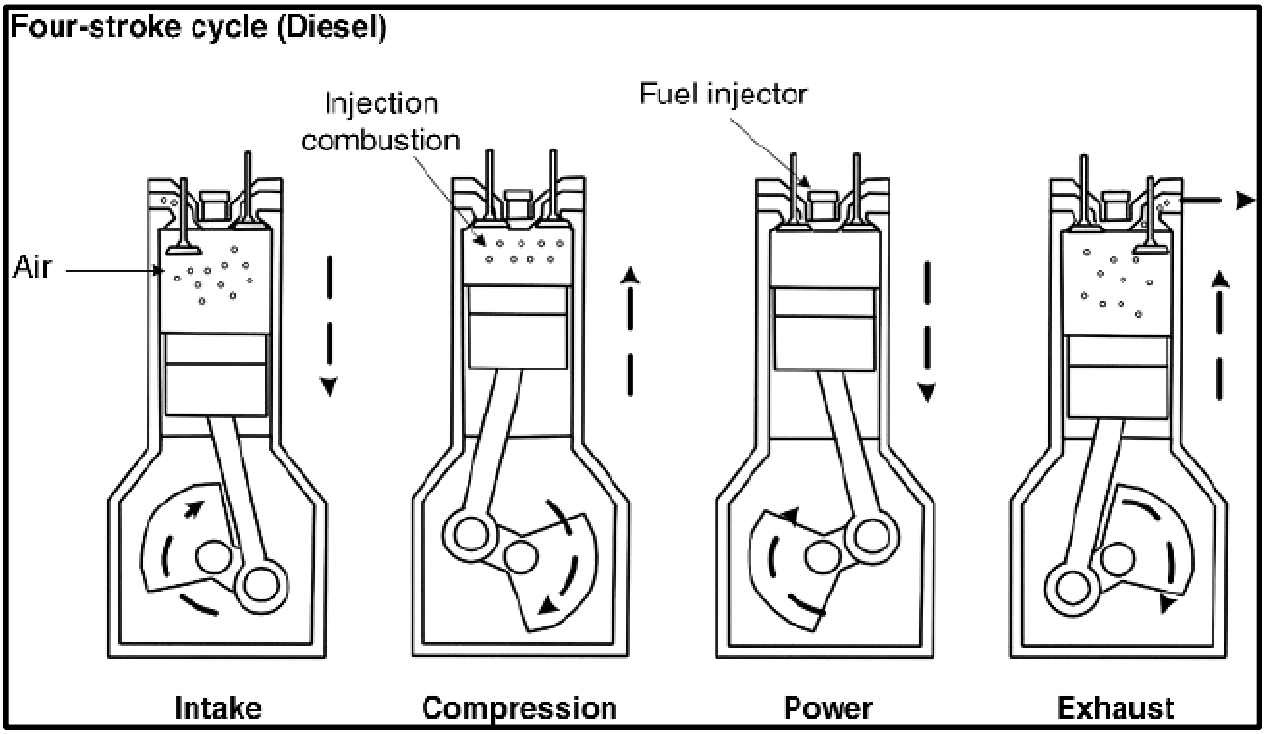


Figure 3: Four stroke Diesel cycle (5)

2.2.2 Engine power and Fuel efficiency

The power produced by Fuel Efficiency is defined as the capacity of an engine to obtain energy from fuel. Essentially it is how much power an engine can utilize from x amount of fuel. This correlates to how many miles a car can travel on a specific amount of fuel or how much weight a vehicle can move. The more efficient the vehicle the more miles it is able to travel on a lower amount of fuel.

2.3 Turbo Charger

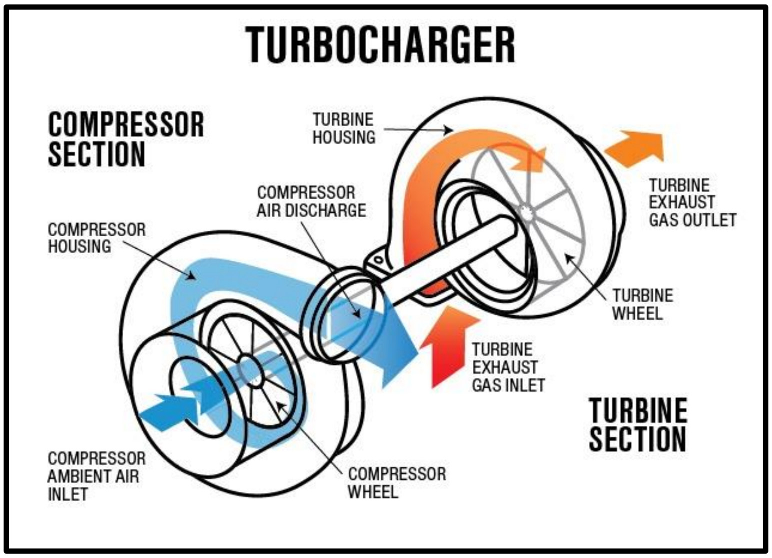


Figure 4: Turbo Diagram (13)

2.3.1 Turbo Function

A Turbocharger is a device used to force induction in order to increase an engine's efficiency and power output. Set up as two separate scrolls with turbines in the middle of each scroll, connected by a shaft :supplying oil and coolant for the bearings that support the shaft: the system forces extra compressed air into the combustion chamber.

2.3.2 Turbo setup

One scroll is hooked up to the engine exhaust: this is called the hot side. The hot exhaust gas coming from the engine spins the turbine, which is connected to the other turbine on the other side of the turbo, called the cold side. The cold side turbine, which is being driven by the other turbine and hot exhaust gas spins and acts as a compressor. This compressor sucks air in from the atmosphere, compresses it, and pushes it into the cylinder. The compressed air goes into the cylinder, and because it is more oxygen dense than regular air,allows for more fuel to be injected, and more power to be made from each cycle.

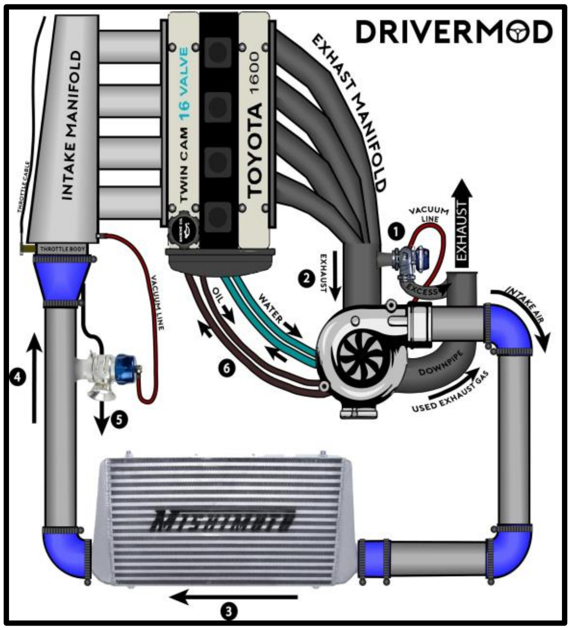


Figure 5: Turbo Setup Diagram (11)

As stated before a turbocharger further increases the amount of power that can be obtained from an engine, and improves the engines overall efficiency.(6)

2.3.3 Effects of a turbocharger on an Engine

Turbochargers are widely known as components of powerful, fast, sporty cars, but in recent years the automotive industry has begun using them for another reason: fuel economy. Turbochargers, when attached to an engine (as previously discussed), increase total power output by forcing more air into the cylinder and therefore allowing more fuel to burn per stroke, raising the power output. Figure 6 is a chart of two identical engines, one with a turbocharger, and one without. The engine with a turbocharger produced a much higher total horsepower than the engine without a turbocharger.

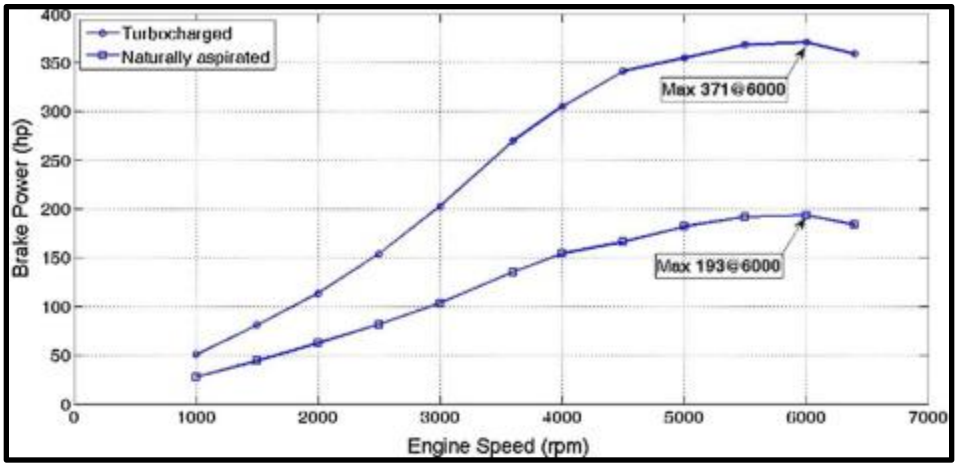


Figure 6: Brake Power vs Engine Speed Graph with and without turbocharging (6)

This means that an engine can be made more powerful by adding a turbocharger.

Turbos also have another benefit: higher fuel economy. Simply adding a turbocharger to an engine will not increase fuel economy, but because a turbocharger increases total power, it allows a smaller displacement turbocharged engine to take the place of a larger displacement naturally aspirated engine. This means that both engines can put out the same total amount of power, but the turbocharged engine will be lighter more efficient in a vehicle. This can be seen in figure 6. Figure 7 is a direct comparison of the fuel consumption of a naturally aspirated engine vs a turbocharged engine. It can be seen that the turbocharged engine used less fuel to produce the same amount of power as the naturally aspirated engine, making it more efficient. This means that turbochargers are a great option when trying to design a more fuel efficient engine.

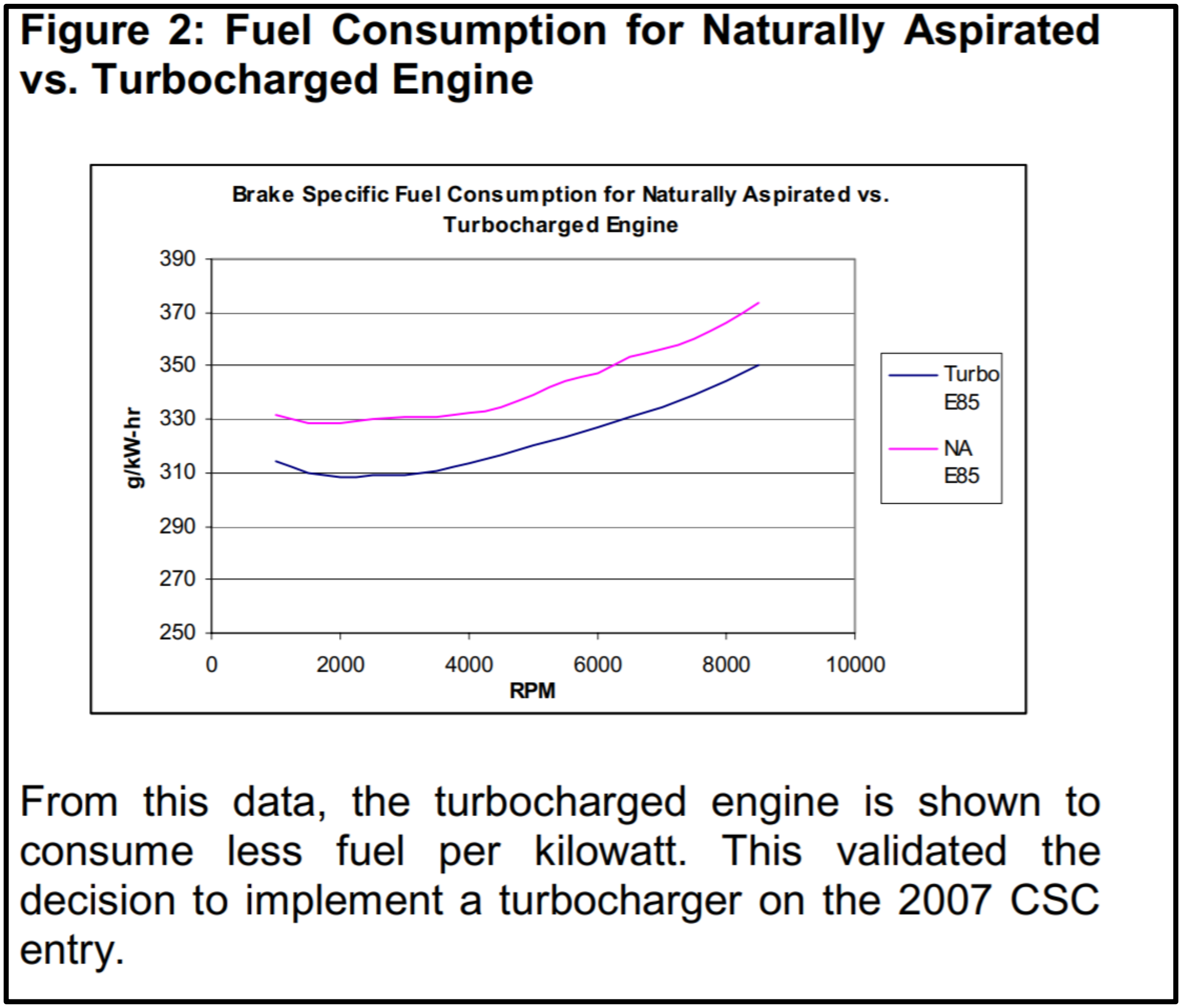


Figure 2: Fuel Consumption for Naturally Aspirated vs. Turbocharged Engine

From this data, the turbocharged engine is shown to consume less fuel per kilowatt. This validated the decision to implement a turbocharger on the 2007 CSC entry.

Figure 7: Fuel Consumption Comparison with and without turbocharger (1)

2.3.4 Choosing a Turbocharger

The biggest thing to consider when selecting a turbocharger is the size of the engine and the turbo itself. Selecting the correct turbo for the selected sized engine is detrimental for it to function properly. If the turbo is too small then while the turbine will have a high rotational speed it will be restricted at the top end of the cycle. If the Turbo is too large then it causes not enough power to go into the compressor at the low end. (3)

2.4 Supercharger

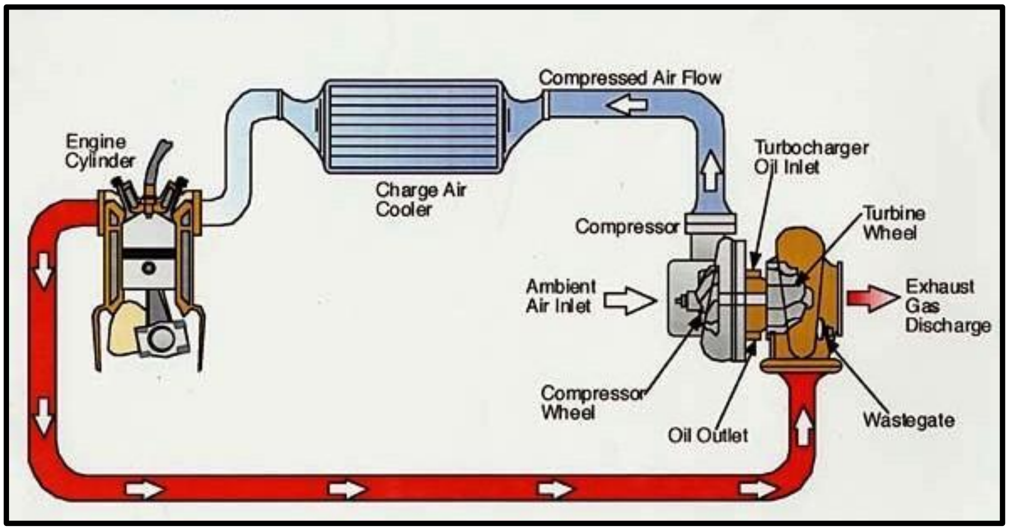


Figure 8: Supercharger Setup Diagram

The difference between a supercharger and a turbocharger lies in the method of powering the compressor. Like a turbo, a supercharger's primary function is to force air into the combustion chamber resulting in more fuel into the engine causing it to generate greater horsepower. Superchargers are externally powered rather than by recovering exhaust energy Superchargers are essentially an engine driven air compressor. As they are directly powered by the engine, superchargers respond more quickly to changes in engine operation. Turbochargers will be unaware of such changes until they affect the exhaust condition, resulting in a momentary delay in engine response, termed "turbo lag." (10)

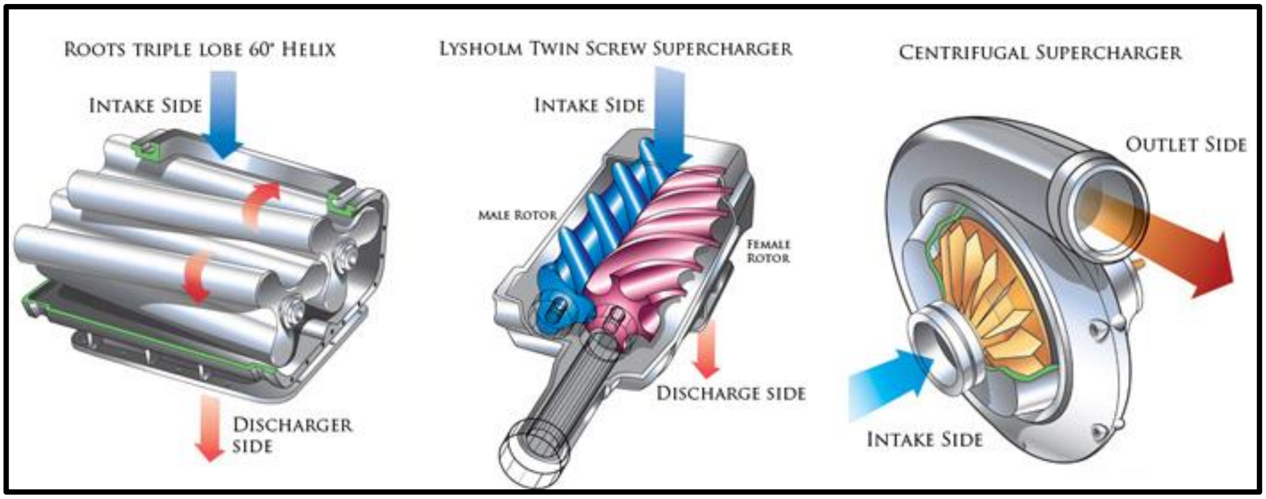


Figure 9: The Three types of Superchargers

2.4.1 Roots Supercharger

The Roots Supercharger works by having two rotors rotate in opposing directions to rap air in between the gaps. This pushes the air against the compressor housing during rotation towards the discharge port. The advantages of a roots supercharger is that it has the ability to produce large amounts of air at lower speeds, making it ideal for 4-6 cylinder engines that generally struggle in lower RPM range. Another key advantage is its simple design, it has such few moving parts when you combine that with its air compression at low RPM it becomes a reliable and durable design. (14)

2.4.2 Twin Screw Supercharger

Although initially similar to the Roots type in appearance, the main difference for a twin screw supercharger is that the air is compressed directly in the supercharger as the clearance between the screws tightens as the air moves towards the outlet. In the roots type the compression occurs at the outlet as a fixed volume of air into the intake with each lobe. The two rotators rotate drawing in and squeezing the air before being sent to the engine. The twin screw can require less power to drive allowing more power to go to the engine to transmit to the wheels, acceleration, etc The air may also discharge into the engine at a cooler temperature, allowing for even more power. (10)

2.4.3 Centrifugal Supercharger

A centrifugal supercharger works by having the built in propeller spin at a high speed in order to draw in the air into a small compressor housing similar to a turbo’s. As the air leaves the impeller it does so at a high speed but at a low pressure. This air goes through the diffuser converting the air into a high pressure low speed air flow. Afterwards the air is then fed into the engine in which the airflow allows the engine to burn more fuel and have a higher level of combustion. This in turn creates a faster, more responsive engine. (2)

2.4.4 Effects of a Supercharger on an Engine

The primary purpose of any supercharger is to simply supply more air into the engine to generate more power. This is done through the methods the various superchargers utilize as explained in earlier sections. The effect of a supercharger can be quite profound on an engine, if the supercharger can add just an extra 6-7PSI the power output can be increased by thirty to forty percent. This increase can result in an engine with roughly 300 to 400 HP gaining an additional 120 to 160 HP. One of the downsides to using a supercharger is that in order to add more air into the engine, the supercharger requires more fuel thus reducing a cars overall fuel economy. (12) Another downside is that higher octane fuel must be run, which is more expensive than normal octane. When more boost is shoved into a cylinder, temperatures and pressures increase, and engine “knock” is more likely. Engine knock happens when fuel in a spark ignition engine ignites from high temperatures and pressures before the spark plug fires. This can cause the engine to make a “knocking” sound and is very bad for an engine. To account for the higher temperatures and pressures, higher octane fuel has a higher ignition point so that it will not self-ignite under these conditions. The downside to higher octane fuel is that it is more expensive, generally 20% more expensive or so.

2.4.5 Selecting which Supercharger to use

When selecting a supercharger there are various factors to consider: what you want, what can you fit, and how much you are willing to spend. The size of the supercharger is dependent on the size of the car engine, for one thing it needs to be able to fit inside the engine bay, for another only so much air can go into the engine meaning using one that is to small will have little to no effect and having one to large will only do so much for the engine. Furthermore the output of the supercharger must be matched with the pressure and flowrate required by the engine. The next major factor is obviously cost, the roots supercharger being the simplest will ultimately be the cheapest but it is also the least efficient compressor out of the lot.. Finally it all depends on the planned operation of the engine, if a simple increase in power is all that is needed than a roots will suffice, however if efficiency and fuel consumption are factors then the twin screw or centrifugal are better candidates. (2)(12)

3.0 Methodology

3.1 Why we chose to do what we did

The goal of this project was to take an existing engine and modify it to be more powerful by adding forced induction. Analysis of the difference in engine power, timing, boost, and intake and engine bay temperatures would then be carried out.

To accomplish this goal, we began by choosing a type of engine. The two most common types of commercially available automobile engines are diesel and gasoline. Both of these engine types can benefit from superchargers or turbochargers. We chose to use a gasoline engine, specifically that of a 1990 Mazda MX-5 Miata, due to its simplicity, abundance, low cost, ability to handle forced induction, and the fact one of the authors already had one on hand.

We then chose between the two most common methods of forced induction: superchargers and turbochargers. A supercharger was selected due to the fact this car is primarily used for autocross and track days, meaning instant low end acceleration is more beneficial than high end acceleration.

3.2 Modifications

The Mazda Miata engine produced 115 horsepower from the factory, is capable of handling about 250 horsepower on stock internals, allowing us to achieve much higher than stock horsepower without requiring a full engine rebuild with forged internals. The engine is non- variable valve timing, meaning the tuning will be simpler, and has a lot of parts available to support forced induction.

The car does not have OBD II due to its age, so to be able to properly tune and also collect all the necessary data for our tests, we installed a new ECU (electronic control unit). We selected a Megasquirt PNP Gen 2 due to its ease of tuning, ability to collect all the data we needed, its ability to plug straight into the stock wiring harness, and its compatibility with many aftermarket sensors. We also selected a wideband O2 sensor, intake air temperature sensor, boost sensor, variable throttle position sensor, and manifold air pressure (MAP) sensor.

All of these sensors will be necessary due to the fact that to achieve high horsepower from the car, the engine management must be converted from an air flow sensor based system to a speed density system. The stock air flow sensor system uses a metal flap attached to a sensor that opens up as the engine sucks in air, and the engine bases the amount of fuel injected on this data. The issue is that the stock air flow sensor is restrictive and inexact, meaning it is not suitable for a high performance forced induction system. Speed density, on the other hand, calculates the amount of air intake based on the speed at which the engine is turning, and the density of the air in the intake manifold, measured by the MAP sensor. This means the intake is essentially unrestricted as to how much air can move through it, and the supercharger will not be held back by a restrictive air flow sensor.

New injectors were also installed. The stock injectors were 230 cc/min (amount of fuel able to flow through per minute). We installed injectors from an RX-8, which are 420 cc/min. This meant the injectors had no trouble keeping up with the amount of fuel required to match the air coming in from the supercharger.

We also installed new headers. We selected MANZO headers for their low price, multiple bungs for different O2 sensors, and availability. These replaced one of the two catalytic converters from the engine and allowed it to have higher horsepower by being less restrictive.

To support these engine modifications, we had to modify the drivetrain also. We estimated the amount of horsepower made by examining other cars with similar setups, and determined that the possible horsepower we might achieve exceeded the parameters of the stock clutched and differential. As such, we replaced the stock clutch with a Flyin' Miata Level 1 clutch and lightweight flywheel designed for the latere NA8 miata, which would theoretically allow us to go up to 300 t-lbs of toque or so. We also replaced the stock NA6 open differential with a later NA8 Torsen type 1 limited-slip differential, allowing more horsepower and better track performance without failure of the component.

With all these modifications complete, we were able to tune the car and take baseline measurements.

Figure 10: Naturally aspirated engine bay

3.2.1 Tuning and baseline measurements

For all of the above modifications to work and to have their maximum benefit realized, the car had to be tuned. The tuning process was carried out by Turbo Mike Tuning. The tuning involved setting the car up for speed density based engine management, attaching the car to a dynamometer (also called a dyno), and then having the air fuel ratio tables and timing adjusted to reflect the modifications done. After this was done, the car performed a dyno run,in which the data listed below in the “Data” section was recorded.

3.2.2 Supercharging

The next step was to install a supercharger. The supercharger selected was an Eaton M45 supercharger. This is a roots type supercharger commonly found in Mini coopers and various models of Mercedes. It is cheap, relatively abundant, reliable, and simple to install. All of the previous modifications were done in support of the installation of this supercharger, allowing us to squeeze the maximum performance out of the supercharger. Installation involved attaching the supercharger to its mounting bracket, which turned out to be incorrectly sized. The bracket had to be cut, drilled and rewelded to properly fit the car. The tensioner included in the kit we purchased also did not fit, as it was intended for a car with power steering, which ours does not have. We were able to create a new tensioner using the existing air conditioner belt tensioner brackets. We welded a new piece of steel to the AC tensioner, and attached a wheel to that so that the supercharger belt could be routed around that.

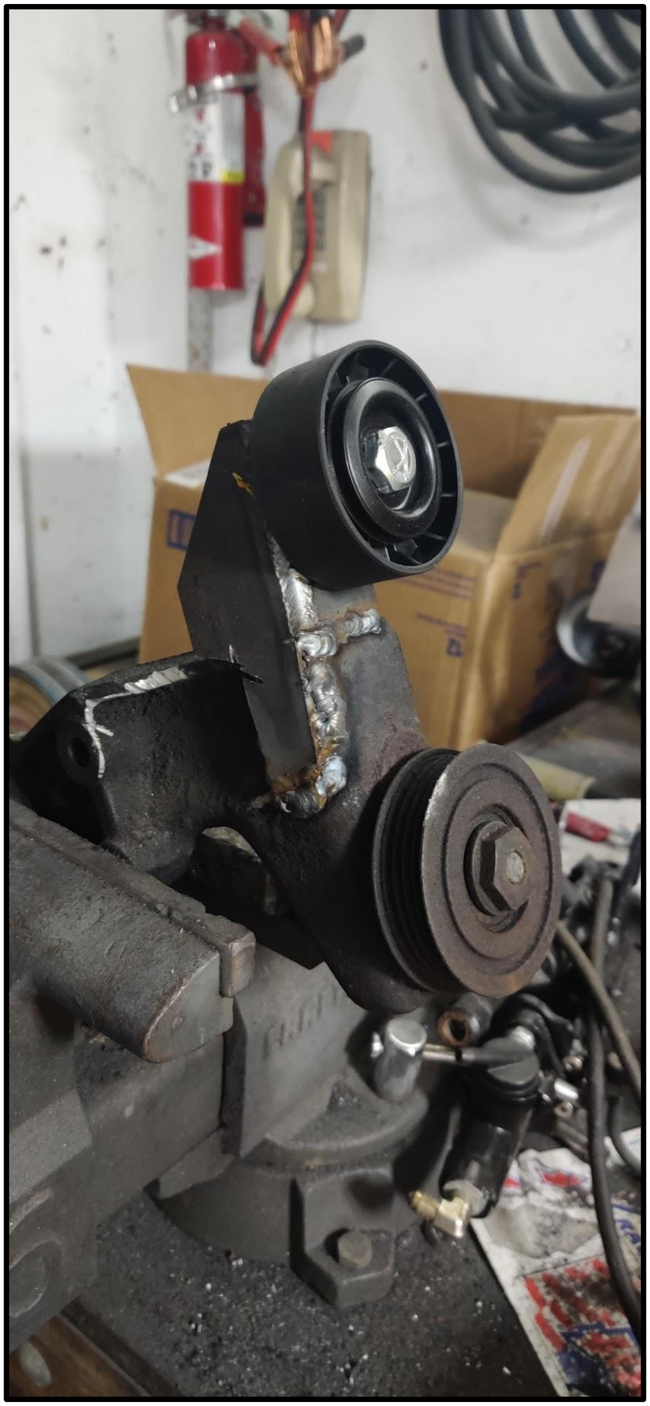


Figure 11: Belt tensioner assembly

The supercharger manifold, taken from an unknown model of Mercedes, also did not fit. We had to cut off a significant portion of it, and replace much of the intake manifold with silicone, aluminum, and steel piping. We also installed a bypass valve from a mini cooper to allow air to flow around the supercharger when the engine is under vacuum. We relocated the throttle body from the intake manifold to the intake of the supercharger so that we can control the amount of air getting to the supercharger.

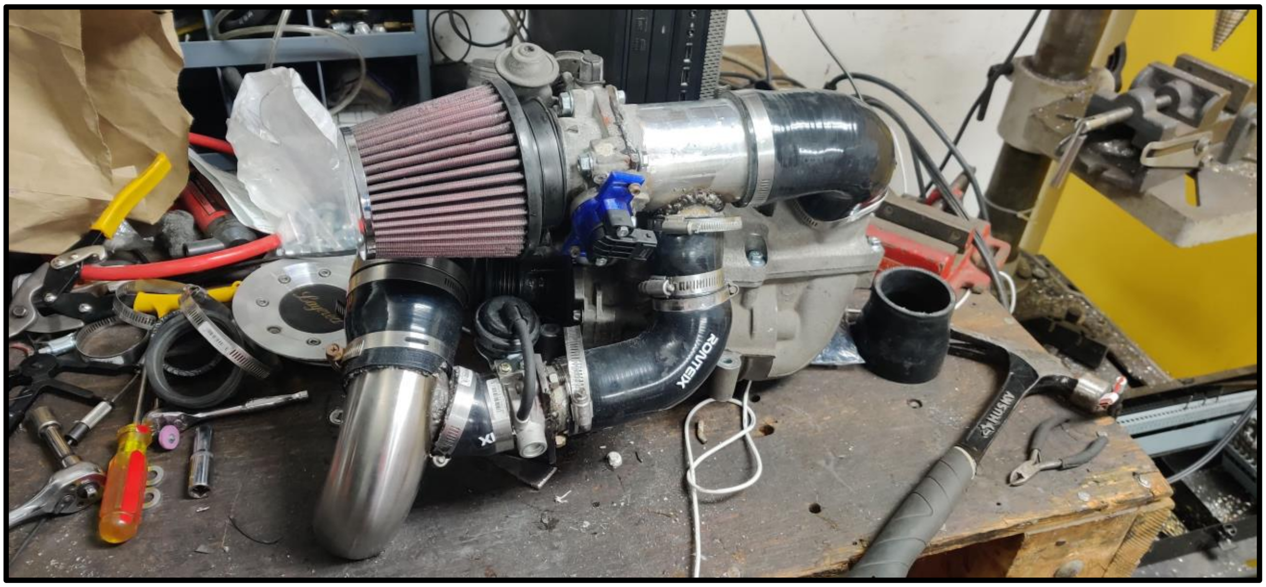


Figure 12: Supercharger and bypass valve assembly

3.2.3 Final tuning and measurements

Once again, the car was brought to Turbo Mike Tuning, where it was again attached to the dyno. Tuning was carried out in the same manner as before, until the maximum safe potential from the cars engine was realized. The same data as above was collected.

Figure 13: Car getting tuned

3.3 Comparison

We were then able to compare the data from before and after the supercharger installation. We analyzed the torque-rpm and horsepower-rpm curves for differences before and after, and able to compare if the differences matched up to our hypothesis on what would happen.

3.4 Data

3.4.1 Power

Power, measured in horsepower, is the measure of the amount of power produced by a car's engine. This is the number most often sighted by car manufactures when comparing performance of a car's engine. Advertised horsepower is generally measured at the engine's crank. All cars have a power and torque loss through the car's drivetrain, varying from 10-25% loss. This means that the power put down by the wheels, and therefore the power measured by a dyno, is 10-25% than the horsepower produced by the engine. As a rule of thumb, our model of car is often assumed to lose 15% of the horsepower from the crank to the wheels due to losses in the transmission, differential, driveshaft, etc. This means that to do an accurate comparison of our results, we will be multiplying our measured dyno numbers by 1.15 to account for losses. After browsing through forums and magazine articles of people who have the same supercharger on their Miatas, we estimate a 60-80% increase in power based on similar setups in other Miatas.

3.4.2 Torque

Similar to horsepower, we will be multiplying torque by 1.15 to account for drivetrain losses. We estimate a 60-80% increase in torque based on similar setups in other Miatas.

3.4.3 Boost

Boost, measured in PSI relative to atmospheric pressure, will show exactly what benefit the supercharger is producing. The boost chart will show what is responsible for the increase in horsepower and torque from the supercharger. As discussed in the background section, the air-fuel ratio must remain relatively constant to achieve peak power production. Fuel injectors are designed to have a higher capacity than an engine needs, so that there can be room for improvement. This means the limiting factor of how much power an engine can produce is not the amount of fuel, but the amount of air that can get into the cylinder. At wide-open throttle, a naturally aspirated car will never be able to produce boost, meaning the intake will always be under vacuum or at most equal to atmospheric pressure. This means that the air going into the cylinder had the same pressure as the air outside of the car, which is the maximum air pressure that can be introduced into the cylinder without forced induction. A supercharger is designed to compress the air going into the engine, allowing air at a higher pressure than the atmosphere to be injected into the engine, and since more air can go in, more fuel can also go in. We expect a boost of between 4 and 7 PSI based on the pressure produced by this supercharger in a mini cooper.

3.4.4 Manifold air temperature

MAT, or manifold air temperature, is the temperature of the air going into the engine. The ECU uses this number, combined with the manifold pressure (boost), the gas constant of the atmosphere, and the speed and displacement of the engine to calculate the exact amount of oxygen going into the cylinder, and uses this to calculate how much fuel to inject to keep an optimal air fuel ratio. As a fluid is compressed, it's temperature increases, and as such, we expected the MAT when supercharged to be higher than that when the car was naturally aspirated. This may be an incorrect expectation as intake itself will be relocated during the supercharger install, and therefore will not be intaking air at the same point in the engine bay, meaning the temperatures may be different simply based on intake location.

3.4.5 Volumetric Efficiency

VE (volumetric efficiency) is the actual amount of air flowing through an engine vs the theoretical maximum amount. In an absolutely ideal environment, with perfect uninterrupted flow, the maximum volumetric efficiency a naturally aspirated engine can produce is 100%. Of course in real life, there are numerous things preventing an engine from reaching 100% VE. These include having to suc

air through a filter, through a throttle body, through the intake manifold, and through the valve into the cylinder. One boosted, the car will most likely have a VE greater than 100% due to the fact compressed air is going into the cylinder, and this VE will depend on how much boost is produced by the supercharger.

3.4.6 Spark advance

To produce power most efficiently, the spark advance degree must be advanced as far as possible, but not so far as to produce “engine knock” which is when the air fuel mixture ignites before it is supposed to, causing a “knocking” sound that can lead to engine damage. When running at maximum power, the spark is introduced to the cylinder before the engine reaches its most compressive point, referred to as engine top-dead center (TDC). The spark is timed in degrees from top dead center, referring to how many degrees of crankshaft rotation ahead of TDC the spark is introduced. After forced induction is added to an engine, due to the fact that there is more air and fuel in the cylinder and this mixture is under higher pressure and therefore higher temperature, meaning the fuel is more likely to ignite itself, and therefore the engine is more likely to knock, which is undesirable. There are two main ways to reduce engine knock. One is to “retard” the engine timing by reducing the amount of degree in advance of TDC the spark is introduced, but this reduces the amount of power made by an engine. The other way is to run higher octane fuel. Higher octane fuel must reach a higher temperature to ignite, and therefore is less likely to cause knock under the high pressure produced in a forced induction engine. This reduces the need to retard the engine timing, and therefore allows the engine to produce more power. This is why many higher performance cars require higher octane, normally 91 or 93 “premium” gasoline, or the engine will knock. Our naturally aspirated dyno run and tune will be done with regular 87 octane pump gas, and our supercharged dyno run and tune will be done on 93 octane fuel. This premium fuel will reduce the need to retard the timing when supercharging the engine, but we still expect a slight timing retard to be necessary, probably 2 to 3 degrees or so.

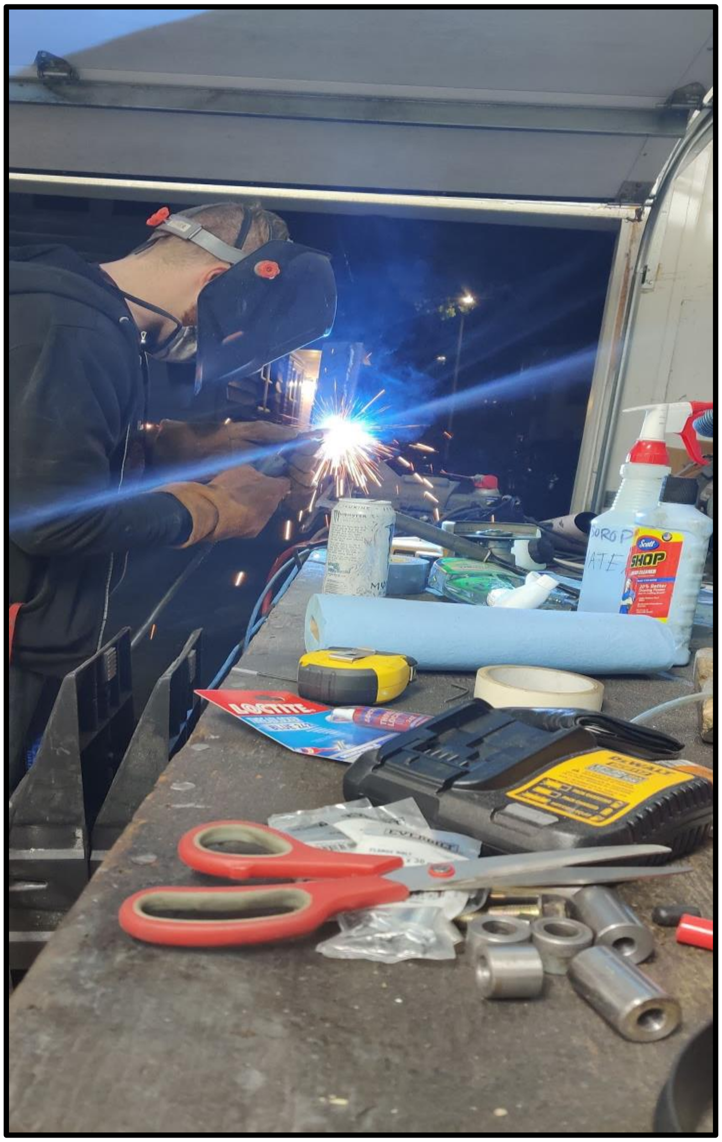


Figure 14: Welding supercharger intake

4.0 Results

After the first and second dynamometer tunes and runs were completed we were able to obtain all the information from the dyno and the car's ECU, and compare the naturally aspirated and supercharged results. Below are the graphs created from selected portions of the data obtained from both the dyno and the ECU. A complete and unabridged copy of the data can be found in the appendix.

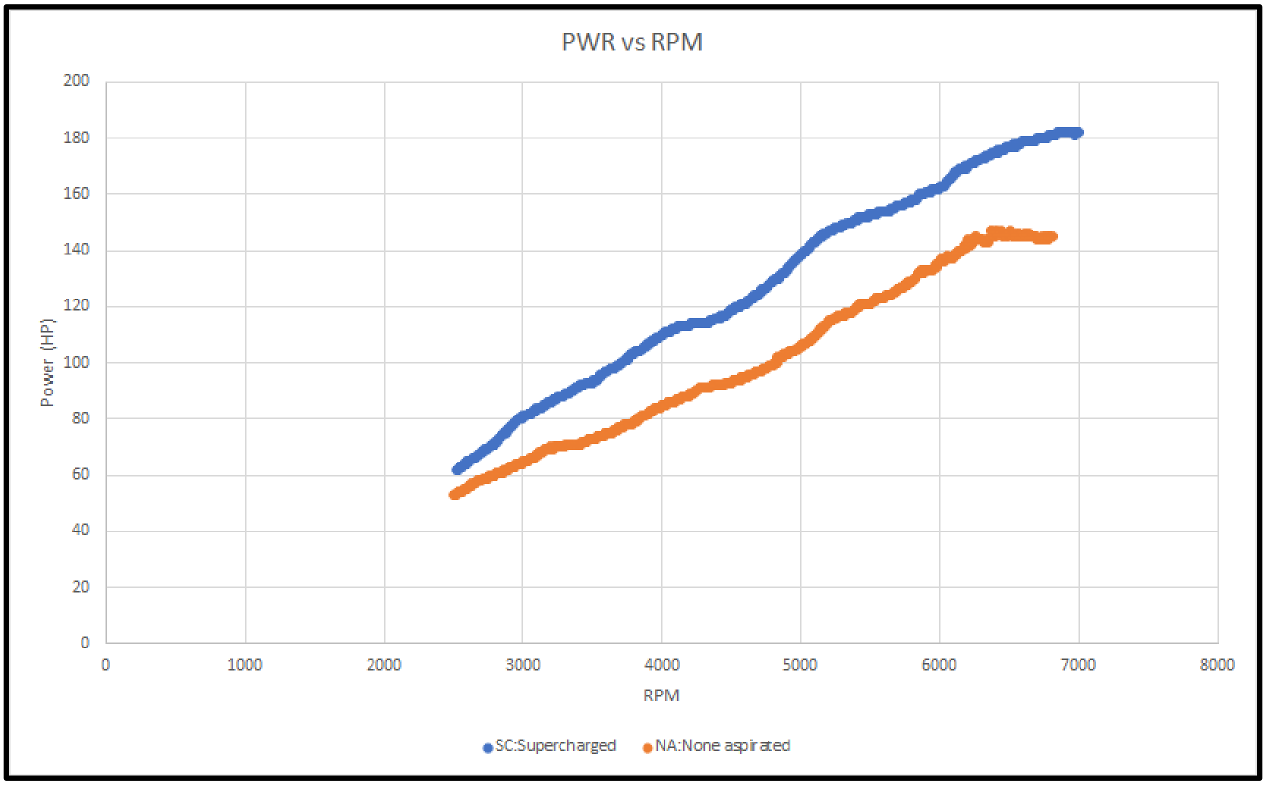


Figure 15: PWR VS RPM graph

The peak power at the wheels, taken from the dyno, was 145 horsepower for the naturally aspirated car, and 182 horsepower for the supercharged car. The car displayed relatively linear power bands, a very desirable characteristic, and one of the advantages of supercharging over turbocharger. These numbers demonstrate a roughly 25% increase in horsepower. We are assuming a 15% loss in drivetrain. This means that completely stock, the car was stated by the manufacturer to make 115 horsepower at the crank. After adding the ECU, headers, and intake, the car then made 166.75 horsepower at the crank (following the 15% loss estimate). After supercharging, the car made 209 horsepower at the crank. This means that with these modifications, the engine makes almost double the amount of horsepower it originally did, higher than what we originally estimated.

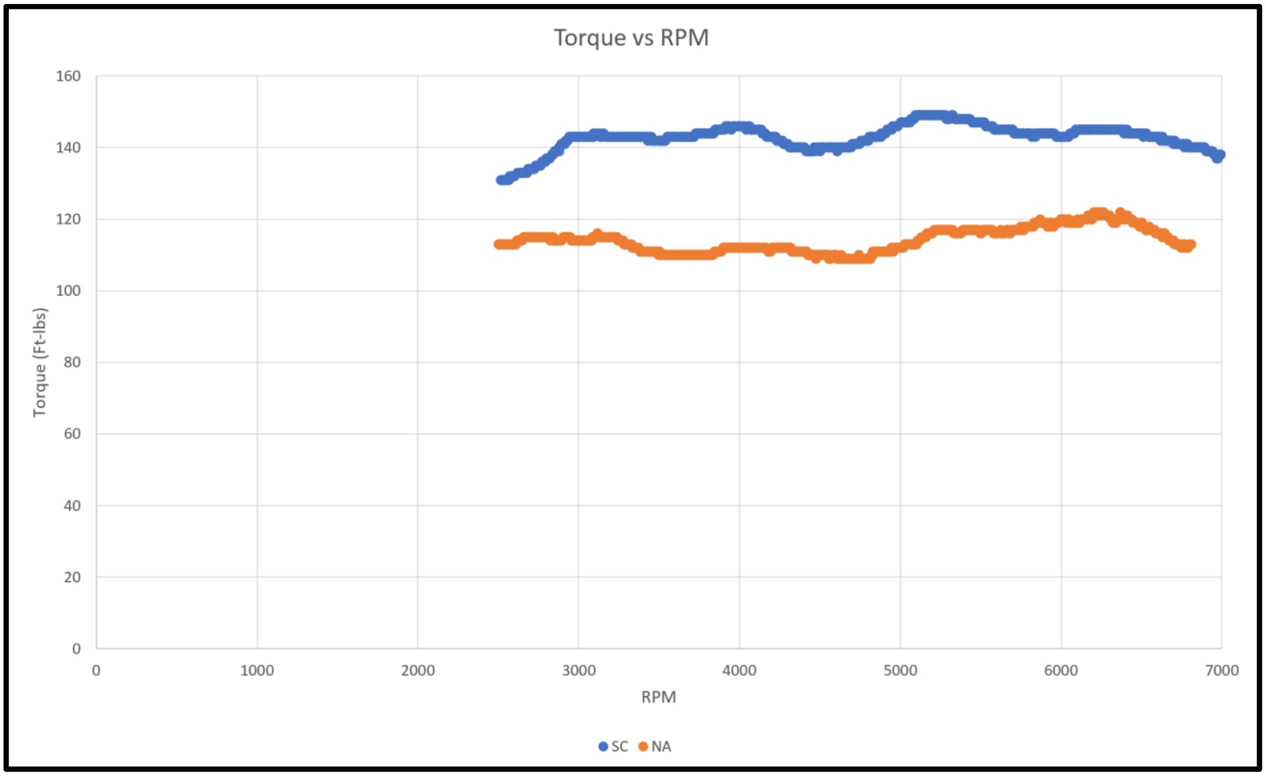


Figure 16: Torque vs RPM graph

The increase in torque was also significant. The peak naturally aspirated torque was 123 ft-lbs, and the peak supercharged torque was 149 ft-lbs. Drivetrain losses of torque are similar to that of horsepower, so once again we will assume 15% loss between the engine and wheels. The manufacturer specifications state the car made 100 ft-lbs of torque stock. After the initial modifications, but still naturally aspirated, the car is estimated to make around 142 ft-lbs at the crank. After supercharging, the car is estimated to make 171 ft-lbs. This is a substantial increase in torque, and within the range of what we estimated.

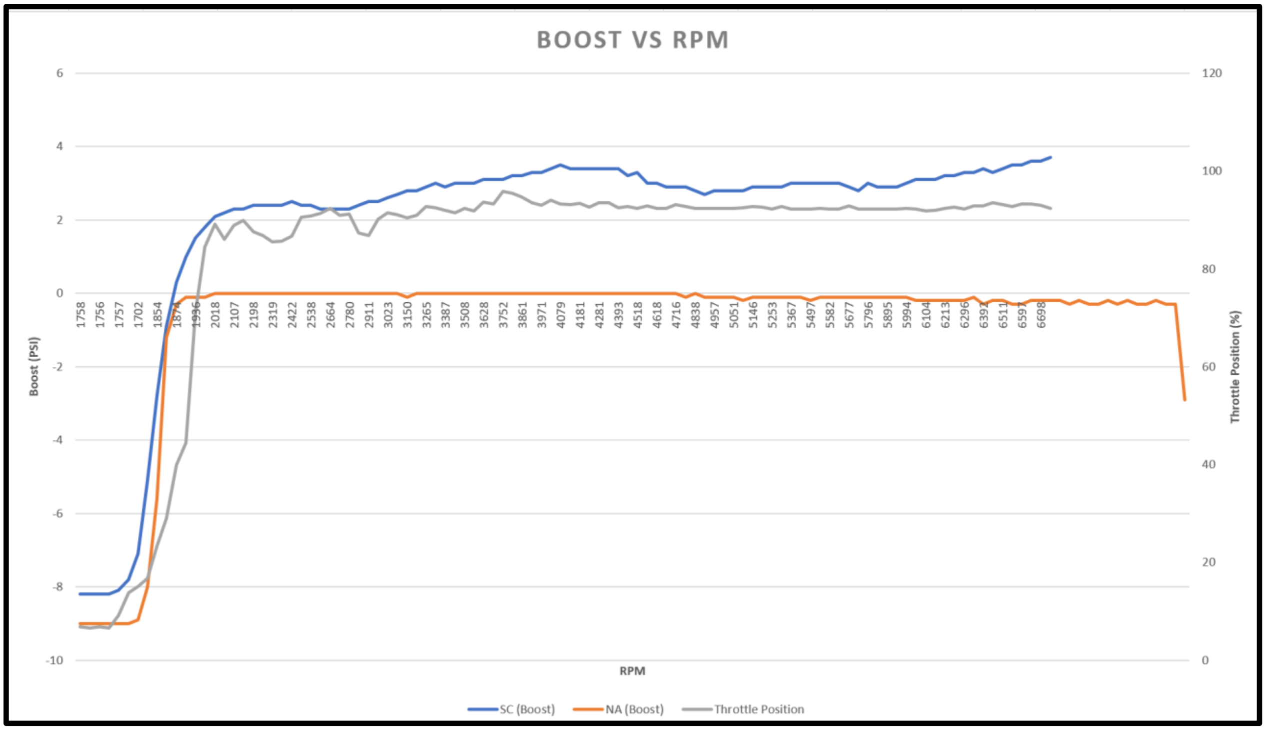


Figure 17: Boost vs RPM

As can be seen in the above chart, when the throttle is closed, the engine is under vacuum. When the naturally aspirated engine is at wide open throttle, the amount of pressure in the intake manifold is roughly the same as that of the atmosphere. This means that the air going into the cylinder had the same pressure as the air outside of the car, which is the maximum air pressure that can be introduced into the cylinder without forced induction. A supercharger is designed to compress the air going into the engine, allowing air at a higher pressure than the atmosphere to be injected into the engine, and since more air can go in, more fuel can also go in. The supercharger on the Miata produces 3.7 PSI of boost maximum, allowing for the performance gains outlined above, although not as high as we believed. We believe the reason for this is because the crank pulley on the miata is smaller than that off of mercedes the supercharger came off of.

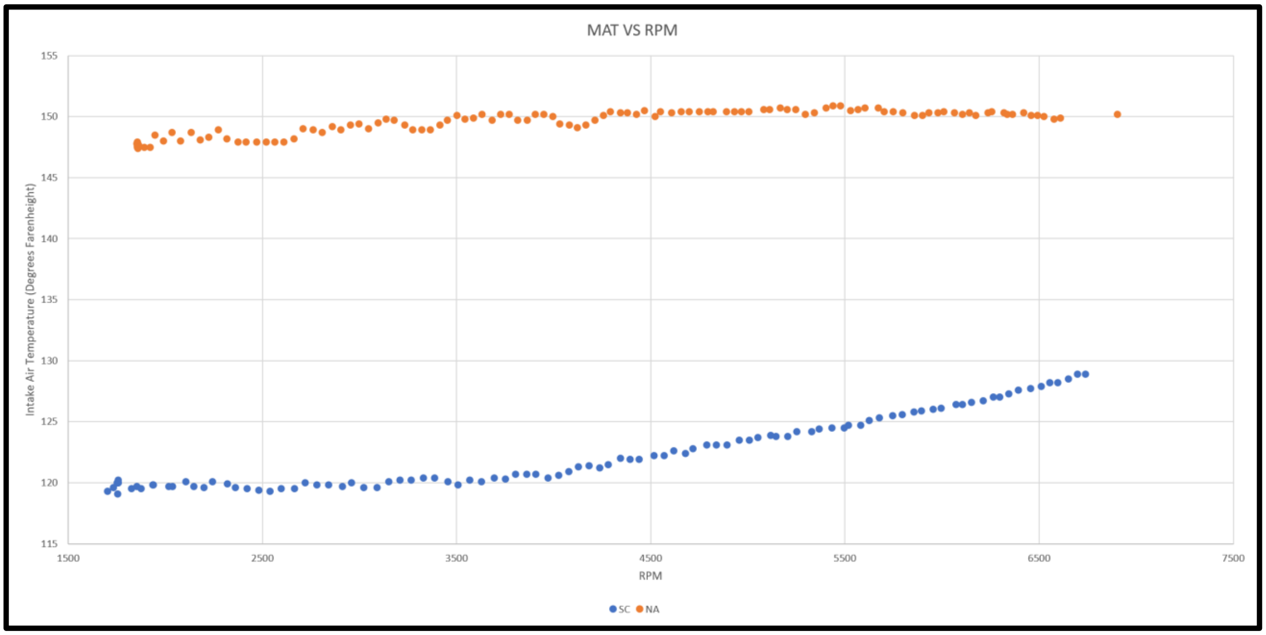


Figure 18 : MAT vs RPM graph

As a fluid is compressed, it’s temperature increases, and as such, we expected the MAT when supercharged to be higher than that when the car was naturally aspirated. As can be seen in the above chart, this was not the case. Although we do see an increase in temperature as engine RPM and therefore boost increased, overall the naturally aspirated air was hotter. The temperature of the air going into the engine when naturally aspirated was almost 30 degrees hotter than that when supercharged. Hotter air is undesirable due to the fact that the warmer the air, the less dense, and therefore less oxygen rich it is. The 150 degree air is about 5% less dense than the 120 degree air, meaning it has 5% less oxygen. We believe the reason for this is that when installing a supercharger, the air intake location was moved from directly behind the radiator and directly in front of the engine block when naturally aspirated to behind the headlight and away from the radiator or engine block when supercharged.

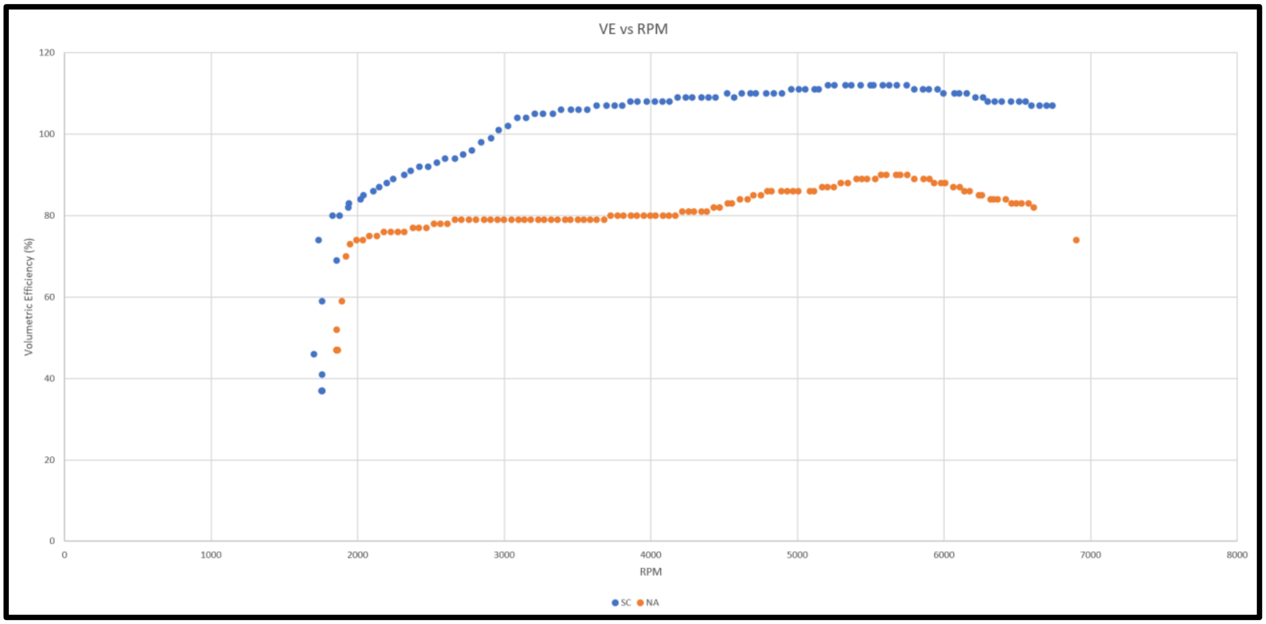


Figure 19: VE vs RPM Graph

VE (volumetric efficiency) is the actual amount of air flowing through an engine vs the theoretical maximum amount. There are numerous things preventing an engine from reaching 100% VE. These include having to such air through a filter, through a throttle body, through the intake manifold, and through the valve into the cylinder. This is why our engine showed a maximum of 90% volumetric efficiency when naturally aspirated. When supercharged, due to the fact that the supercharger shoves air into the engine at a higher pressure than the atmosphere, the VE goes above 100%. The supercharger showed a maximum of 112% volumetric efficiency, meaning the engine was using 112% of the maximum possible air at intake temperature and one atmosphere.

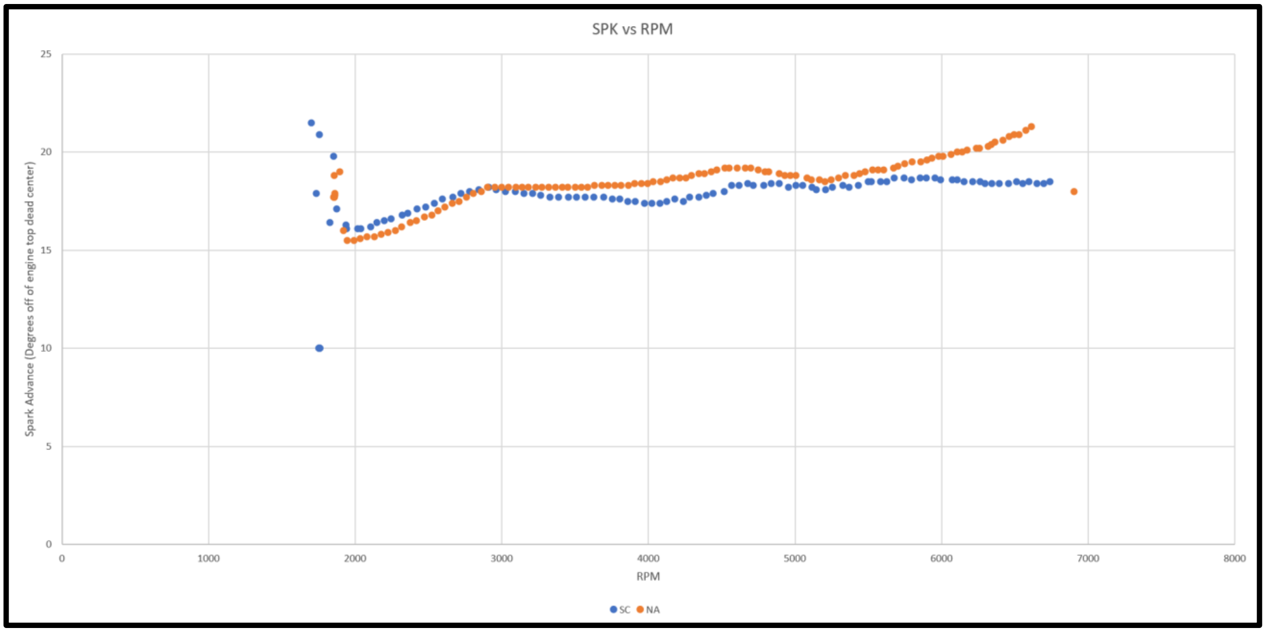
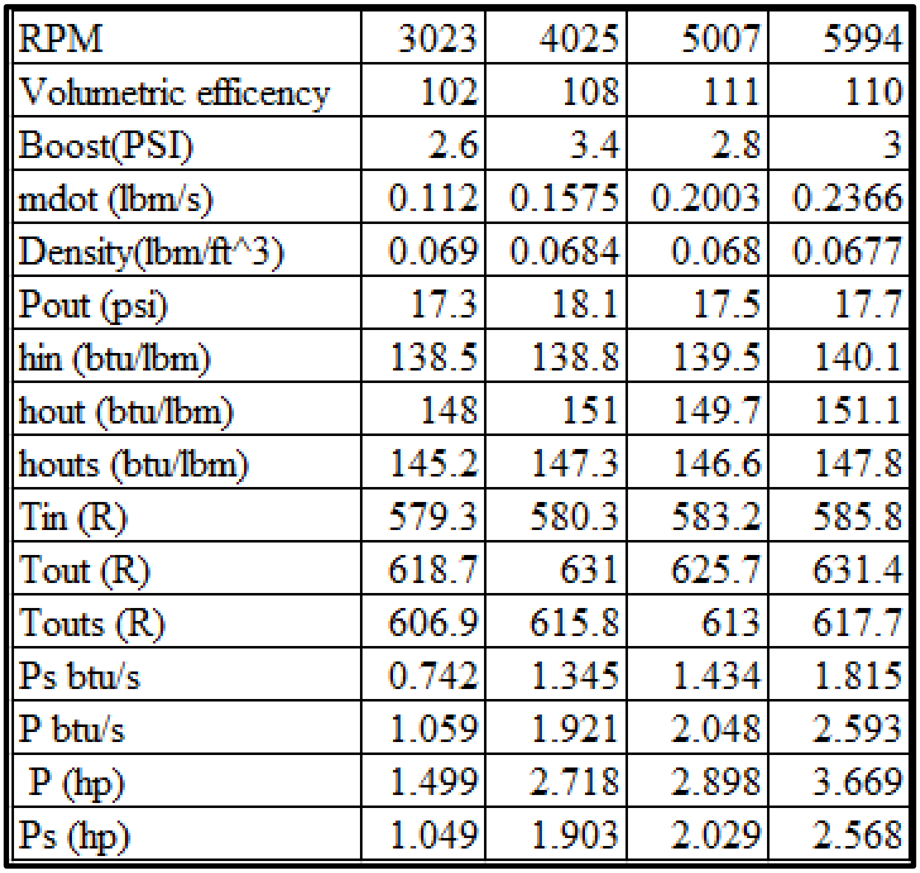


Figure 20: SPK vs RPM Graph

We estimated that the naturally aspirated spark would be advanced 2 to 3 degrees ahead of TDC. As can be seen, in the higher rpm the supercharged tune did in fact require a slight timing retard over that of the naturally aspirated tune, but for most of the rpm range they were within a degree or so. Only towards the higher rpm and higher boost did the timing need to be retarded almost 4 degrees behind the naturally aspirated tune.

4.1 Calculations



RPM	3023	4025	5007	5994
Volumetric efficency	102	108	111	110
Boost(PSI)	2.6	3.4	2.8	3
mdot (lbm/s)	0.112	0.1575	0.2003	0.2366
Density(lbm/ft^3)	0.069	0.0684	0.068	0.0677
Pout (psi)	17.3	18.1	17.5	17.7
hin (btu/lbm)	138.5	138.8	139.5	140.1
hout (btu/lbm)	148	151	149.7	151.1
houts (btu/lbm)	145.2	147.3	146.6	147.8
Tin (R)	579.3	580.3	583.2	585.8
Tout (R)	618.7	631	625.7	631.4
Touts (R)	606.9	615.8	613	617.7
Ps btu/s	0.742	1.345	1.434	1.815
P btu/s	1.059	1.921	2.048	2.593
P (hp)	1.499	2.718	2.898	3.669
Ps (hp)	1.049	1.903	2.029	2.568

Figure 21: Final calculations computed from EES using the methods shown in Appendix B

Using the thermodynamic equations for volumetric efficiency, compressor efficiency, and power, a theoretical number for both actual and isentropic power to run the Supercharger was found. The methods for solving these equations is shown in a sample problem in Appendix B, with the results shown in the figure above. Engineering equation software was used to obtain the enthalpy of the air at its various stages and to do the computations These numbers were calculated at various RPM ranges to get the best idea of the output. Looking at the data it can be seen that as the RPM increases the power required increases as well.

4.2 Other data

Taking data from what is colloquially known as a “butt dyno”, aka how fast the car feels to the driver, the car feels significantly quicker than it did before. It revs quicker, accelerates quicker, and feels faster overall. Fuel injector duty cycle was roughly 65% percent with the 230cc stock injectors when naturally aspirated, and around 70% duty cycle with the 420cc injectors when supercharged. This shows a significant increase in fuel consumption as more fuel is being injected in each cycle when supercharged.

5.0 Conclusion

As is proven by the above graphs, the supercharger makes a significant amount of extra power and torque over the naturally aspirated engine. The graphs of VE and boost demonstrate exactly how the supercharger improved the engine performance. The large horsepower gains greatly improve the acceleration of the car and will most likely greatly improve the track performance of the car. Superchargers are common on high performance cars, and the proven benefit of a supercharger in this project demonstrates the reason why. Superchargers and turbochargers allow a driver to squeeze more power out of a small displacement engine. For example, in the same year as our 1990 Mazda Miata, a 1990 Ford Mustang, with a 5.0 L engine produced 225 horsepower. Our 1.6 L engine originally produced 115 horsepower, but after the supercharger, it produced 209 horsepower. This means a supercharged 1.6 L engine can produce almost as much horsepower as a naturally aspirated 5.0 L engine. This demonstrates the benefit of a forced induction setup on a car, as a 5.0 L engine will inherently have lower fuel economy due to the fact that it has a higher displacement, whereas even with a supercharger, a smaller engine will get better fuel economy. This project has successfully demonstrated the performance benefits of a supercharger over a naturally aspirated engine.

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Appendix A: Raw Data

- NAlogs.xls
- sc-logs.xls
- WPI Miata SC(2020-09-29 18-45-43)

Appendix B: Calculations

This is an example calculation at 3000 RPM, 70 degrees Fahrenheit, with a 3 PSI boost

Volumetric efficiency to solve for mass flow rate:

$$\eta_V = \frac{m_a dot * n}{\rho_{ai} * V_d * N} \Rightarrow m_a dot = \frac{\eta_V * \rho_{ai} * V_d * N}{n}$$

$$= \frac{1 * 0.0749 lbm/ft\textasciicircum 3 * 0.6357 f\textasciicircum 3 \ * 50\ 1/s}{2}$$

$$= \quad 0.119083\ lbm/s$$

Isentropic compression:

$$\eta_{ctt} = \frac{h_{outS} - h_{in}}{h_{out} - h_{in}} \Rightarrow h_{out} = \frac{h_{outS} - h_{in}}{\eta_{cc}} + h_{in}$$

$$= \frac{(133.5 - 126.6)\frac{btu}{lbm}}{0.7} + 126.6 = 136.5\frac{btu}{lbm}$$

$$T_{outs} = T_{in}(\frac{P_{out}}{P_{in}})^{\frac{k-1}{k}} = 529.7R * (\frac{17.7psi}{14.7psi})^{\frac{1.4-1}{1}} = 570.5R$$

Power

$$Ps = mdot * (h_{outS} - h_{in}) = 0.12\ lbm/s * (133.5 - 126.6)\frac{btu}{lbm} = 0.8241\ btu/sec$$

$$= 1.166\ HP$$

$$P = mdot * (h_{out} - h_{in}) = 0.12\ lbm/s * (136.5 - 126.6)\frac{btu}{lbm} = 1.177\ btu/sec$$

$$= 1.666\ HP$$

Variables:

η_V: $Volumetric\ efficiency$ obtained from Supercharged data

$m_a dot$: $Mass\ flow\ rate$

n: $revolutions\ per\ cycle\ (2\ since\ \eta_V\ is\ generally\ defined\ for\ 4\ cycle\ engines\ only$

ρ_{ai}: $Density\ of\ air\ entering\ exhaust(air\ at\ atmospheric\ conditions)$

V_d: $Volume\ displaced\ by\ cylinder$

N: Speed of rotations

$\eta_{ctt} = Compressor\ efficiency$

Tin: Temperature going into the exhaust

Touts: Isentropic temperature coming out of the exhaust

Tout: Actual temperature coming out of the exhaust

hin: Enthalpy of the air at the intake

houts: Isentropic Enthalpy Air at the exhaust

hout: Actual Air enthalpy at the exhaust

P: Power required to run supercharger

Ps: Isentropic power required to run supercharger