Automotive Engineering: Designing an Engine Fuel Map

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Abstract

Over the years, automobiles have become a form of expression for some and a livelihood for others, but for tuners, automobiles have evolved into a type of precision art. Tuners take it upon themselves to unlock the maximum potential in their vehicles. This has been done through many means, but we experimented with the most recent advancement in engine tuning technology, EFI (electronic fuel injection). For some vehicles, such as formula racing cars, peak engine performance is essential.

Tuning an engine involves measuring the fuel requirements at various engine speeds and loads. After discussing engine theory in depth, we performed a dynamometer test on a lawnmower engine at various loads and did the initial tuning of the formula car's engine. We graphed the torque and horsepower data obtained from the lawnmower experiment, concluding that at higher RPMs, the horsepower increases gradually while the torque drops off after 3000 RPM. We then used the TecGT unit in conjunction with the Win-TEC4 software to tune the racing car, mainly adjusting the engine's volumetric efficiency (VE) and spark advance tables. We present our results from the dynamometer test for the lawnmower engine along with our final VE table and graph for the formula car's engine. We conclude with a discussion of more advanced engine tuning techniques and a list of informative tips for the average tuner.

1. Introduction

The most important factor in a vehicle's performance is the engine. Each task requires different amounts of torque, fuel economy, and horsepower. Since these factors cannot be mutually optimized, engine tuning is a way to compromise and obtain the best possible performance for the application needed.

Electronic fuel injection (EFI) allows more precise and variable control over the fuel flow to an engine, as well as better fuel economy [9]. For these reasons, it has quickly become the preferred fuel delivery system for high performance vehicles. EFI allows tuners to regulate the amount of fuel mixing with the incoming air in order to maintain an optimum air-to-fuel ratio, ensuring maximum engine performance.

We learned a great deal about engine function and fuel injection, along with how each pertains to racing by getting hands on experience with the Win-TEC4 software and the TecGT unit that the Rutgers Formula SAE Team uses to tune their car, the chance to evaluate the preliminary performance of an engine using a dynamometer, and numerous lessons in engine theory. The goal of the project was to learn about engines and to tune a formula car engine for peak performance by designing a suitable fuel map.

2. Background Information

The tuning process and basic function of an automobile starts with the engine. The engine is the most dynamic part of an automobile. Consequently, there are many variables and systems that need to be monitored, adjusted, and integrated.

2.1 Engine Overview

The engine in a car is an internal combustion engine. Internal combustion engines are so named because the flame is contained inside of the cylinder as opposed to in an open area or heat source [8]. Internal combustion engines use the pressure of expanding gas to push a piston down and thus convert chemical energy to kinetic energy [6]. Two of the more popular types of internal combustion engines utilize two stroke cycles or four stroke cycles.

Two stroke engines add the fuel-air mixture into the cylinder, below the piston, while the piston is moving upward and compressing the previous mixture. As the combustion takes place, the piston moves downward and pushes the fuel mixture from below into the top portion of the cylinder. This compressed mixture forces the exhaust gas from the previous combustion out the cylinder [9]. This type of engine creates a large amount of power for its size, but causes a large amount of pollution, since not all of the exhaust gas leaves the cylinder before the next cycle. In addition, it is possible for some of the unburned mixture to exit along with the exhaust gases.

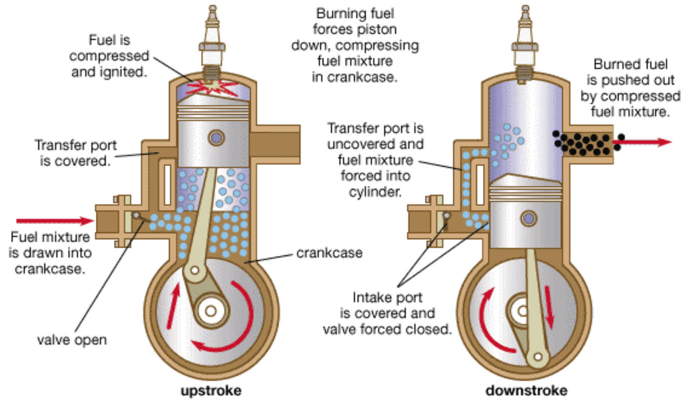

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Fig. 2.1.1 – 2-stroke diagram – intake and exhaust valves are open at the same time [10]

A four-stroke engine replaces the first stroke of a two-stroke engine with three separate ones: intake, compression, and exhaust. There is a combustion stroke in both types of engines, but in a four-stroke engine, each cycle consists of intake, compression, combustion, and exhaust strokes [9]. This is done in order to minimize emissions.

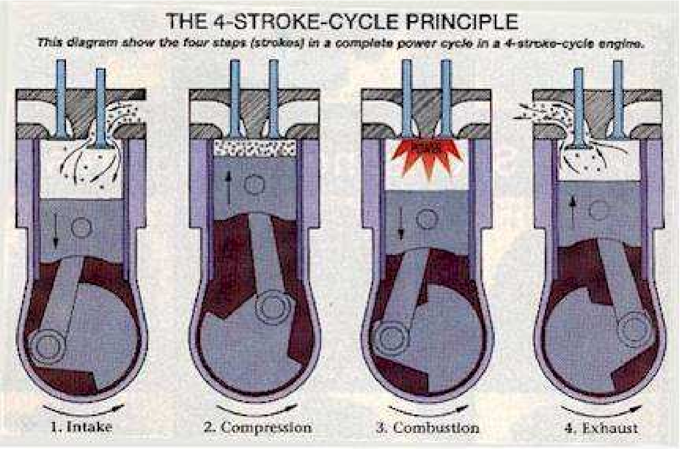


Fig. 2.1.2 – 4-stroke diagram – intake and exhaust occur at different times, power is produces once every two turns of the crankshaft. [4]

During the intake stroke, the intake valve opens and allows the fuel-air mixture to flow into the cylinder as the piston moves downward, creating negative pressure. The intake valve closes and the mixture is then compressed as the piston moves upward. Near the top of its motion, the piston has compressed the mixture significantly, resulting in an increase in pressure and temperature. At this point, a spark plug ignites the mixture. The burning of the fuel exerts pressure on the piston, which is now once again moving downward, putting torque on the crankshaft. After the combustion is complete, the exhaust valve opens and the exhaust gas is pushed out of the cylinder as the piston moves upward, starting the cycle again at the next downward stroke [6]. Although a four-stroke engine only makes power every 2 revolutions of the crankshaft, it results in a cleaner fuel-air mixture, since the incoming mixture does not mix with exhaust gases [9].

Engines can be found in a variety of configurations. Car manufacturers have experimented with inline, slant, flat, and “V” style engines. An inline engine has all of its cylinders in a line in the upright positions. They generally take up a larger among of vertical space, making them impractical to mount under the hood. A slant engine is an inline engine that is tilted to the side. This is done to save vertical space under the hood. A flat engine lies horizontally, but has two sets of cylinders that are 180 degrees apart. As the name implies, a “V” style engine looks a “V”, with two sets of cylinders that are both offset from the vertical axis by the same angle, usually 45 degrees. This style is wider than the rest, but solves the balance and vibration problem found in slant engines [4].

Besides being classified by configuration, engines are also described by their displacement. The displacement is the difference between the volume of air that can fit in a cylinder when the piston is all the way down and when it is at top dead center, multiplied by the number of cylinders in the engine [9]. Top dead center (TDC) is when a piston is at its highest point, which is also when compression is highest. The relationship between these two volumes is known as the compression ratio [6]. The air in an engine with a compression ratio of 10 to 1 has a volume that is ten times less than it had when the piston was at its lowest point. Each of these values is an important indicator as to how the engine will perform.

2.2 Engine Function

Any combustion process requires oxygen. For engines, that source of oxygen is the air surrounding it. The air delivery system begins at the air filter, which gets rid of most suspended particles that might harm the engine. It is important to design the air filter so as not to impede airflow. The air then moves to the throttle body. When a driver steps on the pedal, it opens a butterfly valve, which allows air to flow into the plenum. The plenum is simply a chamber that distributes the air to the runners. Runners are the tubes that carry the air from the plenum to the cylinders. In the meantime, fuel is carried from the tank through the fuel line by a fuel pump. The fuel is then combined with the air right before the intake valve. Injectors control the amount of fuel that is pumped into the runner and ultimately into the engine for the next combustion cycle. The intake valve opens, as the piston is moving downward, allowing the air-fuel mixture to be drawn into the cylinder. The piston is attached to an arm that spins the crankshaft as the piston moves up and down. After combustion, the exhaust valve opens and allows the burned mixture to exit the cylinder. The intake and exhaust valves are opened and closed by a camshaft. The camshaft is mounted above the cylinders and has lobes that push on the valves, opening them for a finite distance and time, which is directly related to the speed of the engine: the valves stay open for a shorter amount of time when the engine is spinning faster [4].

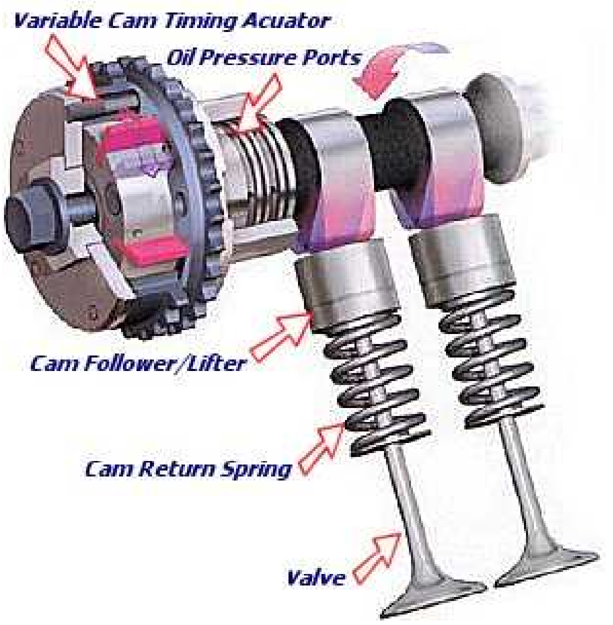


Fig. 2.2.1 – Camshaft – forces intake and exhaust valves down using egg-shaped lobes [11]

The air-fuel mixture that enters through the valves must contain the right proportion of fuel in order to produce optimal combustion. This is known as the air to fuel ratio, or AFR [9]. In an ideal situation, all of the fuel would react with all of the oxygen in the air, resulting in the complete consumption of both reactants. In such a situation, the perfect air to fuel ratio, also known as the stoichiometric ratio, would be 14.68 parts air to one part fuel. A lean mixture has too much air, and a rich mixture has too much fuel. A lean mixture results in a higher combustion temperature and the complete combustion of the fuel, which produces less torque but better fuel economy [8]. Rich mixtures result in an excess of fuel that can usually be detected in the exhaust. More fuel produces more torque, but too much fuel can drown the engine and cause it to stall because the piston will be unable to compress the liquid fuel. Liquid fuel will not burn and therefore must be mixed with the air and turned into a vapor by the time it is ignited. For this reason, when a cold engine is started, more fuel must be injected to ensure that enough of it vaporizes and is able to be ignited [9]. Lean mixtures in these situations are not able to provide the required torque to start the engine.

2.3 Carburetor vs. EFI

Until recently, carburetors controlled most engines. Carburetors are very effective and offer precision control over AFR but are complicated and difficult to

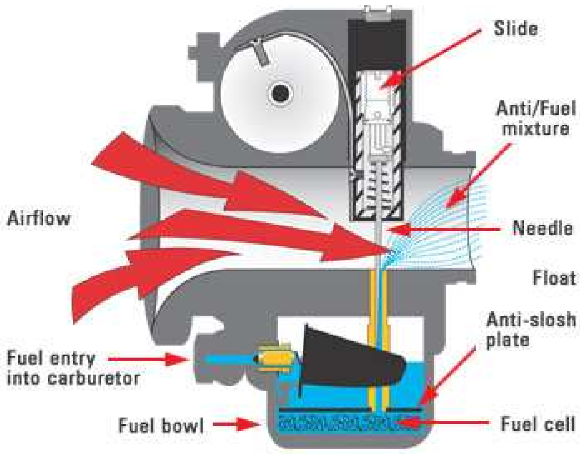


Fig. 2.3.1 – carburetor – needle regulates the amount of fuel that is exposed to the air stream [2]

adjust. In order to make any changes the entire carburetor must be removed and taken apart [5]. For example, in order to increase the amount of fuel that is injected, the fuel jets must be removed and replaced with larger ones. EFI systems, on the other hand, can provide various amounts of fuel without changing injector sizes, simply by changing a number on a computer [5].

Carburetors are purely mechanical devices that meter out fuel as dictated by various jets, slides, and floats. The floats and slides change position or orientation based on the status of the engine, allowing different amounts of fuel to be drawn into the air stream entering an engine [9]. Carburetors make use of the Bernoulli effect, which states that with an increase in air speed also comes a decrease in pressure. The difference in pressure is used to suck fuel into the air stream [5]. Carburetors often have numerous counterbalance devices that prevent extreme fluctuations in AFR due to large changes in throttle position. A carburetor uses jets to deliver the fuel into the air stream. Jets deliver fuel at a constant rate. If more or less fuel is needed than the jet can provide, the jets must be replaced or the carburetor must make use of multiple jets to meet the changing fuel requirements [9]. At idle and in low-throttle conditions, the pilot jet handles the fuel delivery for the system. In order to handle sudden acceleration, an accelerator pump is used to squirt more fuel into the air stream as the carburetor adjusts to the increase in load.

The main difference between carburetors and electronic fuel injection systems is the ease of correction of the AFR. One example of a situation where

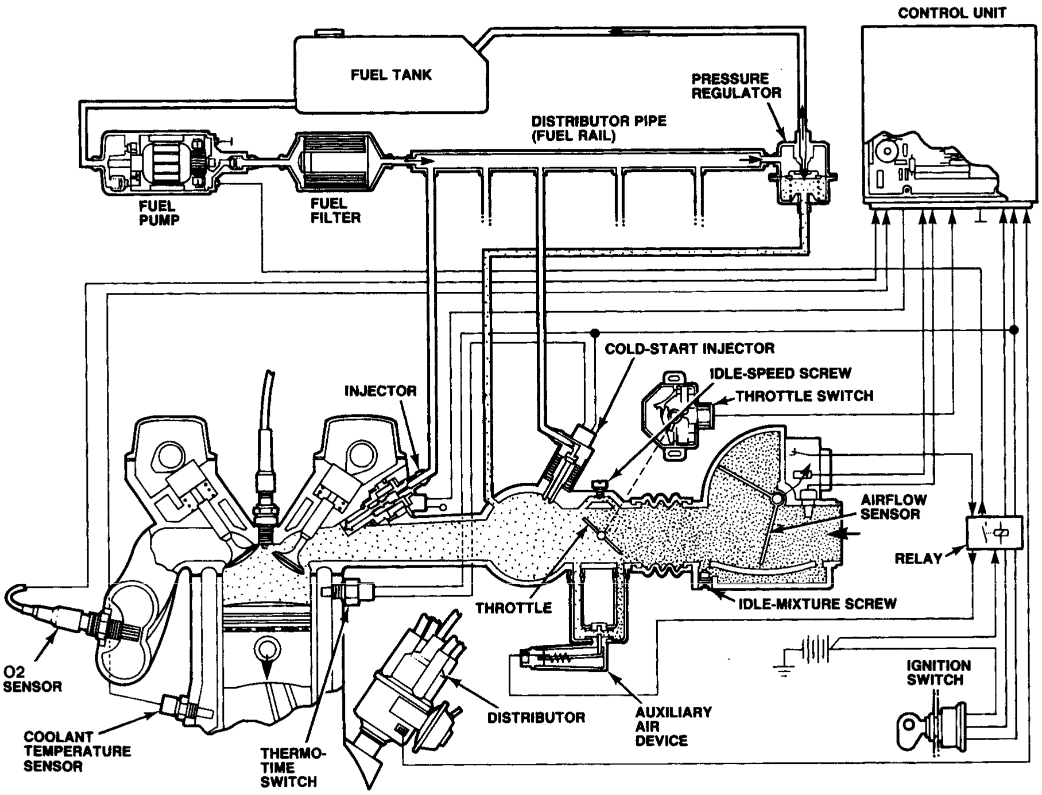


Fig. 2.3.2 – EFI system – Readouts from all of the sensors are fed into the ECU, which determines how long the injector must stay open [7]

the engine requires a different AFR is during cold starting, when an engine requires a richer AFR than normal. A carburetor uses a choke valve to allow the jets to feed more fuel into the cylinder before the air is added [9]. An EFI system does this in a much simpler and more consistent manner.

EFI systems control how long each injector is open for each cylinder based on a predetermined table of values [5]. This allows for concise and consistent fuel delivery and allows for easy tuning. The amount of time that the injector is open is called the “pulse width.” In a cold start situation the fuel injectors remain open for a longer length of time, usually displayed as a percentage of pulse width [4]. This added time is known as enrichment. The three types of enrichments are, starting, warm-up, and acceleration enrichments [8]. Starting enrichment provides constant enrichment for a set amount of time. The warm-up enrichment is an elongation of the pulse width, proportional to the coolant temperature, until the engine warms up. This compensates for the fact that not all of the fuel being injected will be burned. The acceleration enrichment compensates for the increased amount of air entering the engine as the throttle is opened. On the other hand, the deceleration fuel cut off is used to save fuel and improve emissions [4]. In order to create better torque during acceleration, the AFR must be richer than normal. During normal operation, the EFI system changes pulse width based on commands given by the Engine Control Unit (ECU) [5]. Each of these values is easy to manipulate in order to get the best performance out of the engine.

While carburetors are less expensive than EFI, they contain many moving parts, are hard to tune, and are slower to respond to changes. EFI allows the tuner to make small changes without sacrificing precision or time. Although it is not necessary to change injector sizes during tuning, it is important to choose the proper injector size before tuning. It is recommended that the injector should not exceed 80% duty cycle at wide-open throttle [5]. One hundred percent duty cycle is when the injector is open all of the time and will not be able to deliver more fuel if it is needed unless the fuel pressure is increased.

2.4 Dynamometers

A dynamometer is a device that places a load or resistance on an engine by forcing the engine to turn against pressurized oil. The dynamometer, or “dyno”, measures oil pressure and engine speed. These can be used to calculate

2.5 ECU’s and Sensors

The ECU is an engine management system (EMS) that relies on a variety of sensors to feed it information in order to change engine parameters and injection pulse width. The ECU gets information from the following sensors:

Throttle position sensors (TPS) are mounted on the throttle body and detect the degree at which the throttle is offset from a starting axis. When the driver steps on the “gas” pedal, the ECU uses the new readings to determine the rate of change. They are used to activate transient fuel enrichment upon sudden throttle opening in order to prevent bog. The sensor is a potentiometer, offering variable resistance based on the throttle position. The ECU sends a 5-volt reference signal to the TPS. A wide-open throttle would provide a reading of +5 volts, while a near closed throttle reads at less than 1 volt. A TPS can also work in tandem with an engine speed sensor to estimate air volume entering the engine to calculate engine loading [5]. The ECU then uses this to determine engine fuel requirements.

Exhaust gas sensors, also known as oxygen sensors, are used to infer the AFR in the engine [9]. They do so by producing an electric voltage based on the difference between the exhaust gas oxygen content and that of the atmosphere. A relatively large amount of oxygen indicates a lean mixture, while too little oxygen indicates a rich mixture.

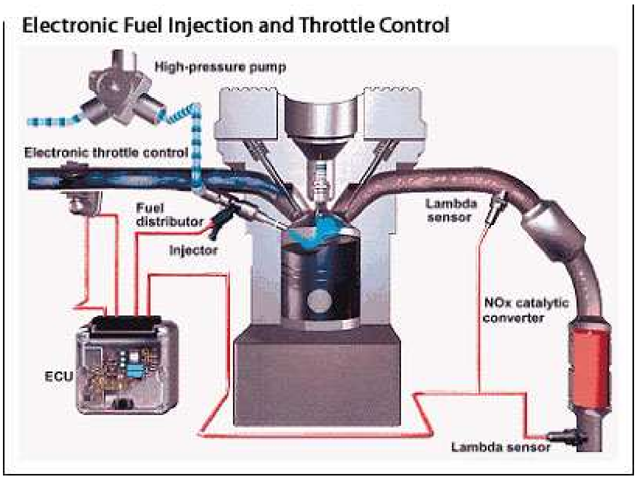


Fig. 2.5.1 – Closed-loop – oxygen sensor determines AFR and feeds information to ECU, which makes on-the-fly corrections to the mixture [3]

The sensor operates like a battery, where the exhaust gas is the medium through which current flows. The sensor can generate as much as .9 volts when the mixture is rich and as little as .1 volts when it is lean. A chemically balanced mixture generates around .45 volts [5]. This information can often be used in closed loop operation, where the EMS alters the air-fuel mixture in order to ensure maximum efficiency.

Standard oxygen sensors have a very narrow range, returning a volt signal between 0 and 1 volts. Wideband oxygen sensors can detect a wider range of AFR’s, returning a volt signal between 0 and 5 volt. These are more useful when operating in closed-loop mode, but are more difficult to install. Since most ECU’s deal with volt signals between 0 and 1 volts, addition wiring is needed to connect the wideband sensor and have it work [5].

The one drawback of oxygen sensors is that they take time in order to warm up and function. Therefore, they are not immediately available at startup. Most modern sensors contain heating elements, which speed up initial warm-up time and prevent cooling while idling. In addition, as the mixture moves further away from stoichiometric, changes in the exhaust gas content become very subtle, especially in the rich direction. Once a mixture is rich enough so that there is barely any oxygen in the exhaust gas, any added fuel is simply carried out with the exhaust [5].

Airflow is important to an engine since it provides the oxygen needed for combustion. One way to measure airflow is by using a manifold absolute pressure (MAP), which indicates the air pressure in the intake manifold. This lets the ECU know how much air is flowing into the engine. Pressure is low when the intake vacuum is high. This happens at idle, when the engine is drawing more air than is being let through the throttle body. Pressure is high when vacuum is low, usually when the throttle is wide open [5].

Mass airflow sensors (MAF) are located ahead of the throttle body and can measure the air that is flowing into the engine. There are two types of sensors: hot wire and hot film. Both types strive to keep the wire/film at a predetermined temperature. The sensors then measure the amount of energy required to counter the cooling effect of moving air. The MAF sensors send a signal back to the ECU, which uses it to infer air characteristics such as temperature, density, and humidity. One drawback of MAF sensors it that they must have clean aerodynamics since they usually obstruct airflow in order to measure airflow [5].

It is vital for the ECU to know the temperatures of coolant, oil, and exhaust gas. The ECU uses the coolant sensor to monitor engine temperature. This is especially important for startup and warm-up enrichments. The ECU also knows not to go into closed loop mode until the engine has reached normal operating temperature. If the coolant becomes too hot, the ECU will trigger the electric cooling fan if the coolant cannot cool the engine itself. Oil temperature is also important as it is used to prevent engine damage. At high temperatures, the oil will begin to burn and the engine will lose lubrication and heat dissipating abilities [9]. The exhaust gas sensor can often be used to determine if you are driving dangerously lean or rich. The exhaust gas temperature is highest when the engine is running with a stoichiometric AFR. It begins to drop off at AFR ratios above 15:1 [5].

It is necessary to keep a constant fuel pressure to ensure consistent AFRs [9]. Higher fuel pressure allows for more fuel to be injected into the engine. However, it creates wear on the valves and springs. The fuel pressure sensor allows you to regulate and determine the tradeoff between air and fuel.

“Knock” is caused by the premature burning of fuel caused by ”hotspots” in the cylinder walls. The pressure and heat ignite the fuel before the sparkplug fires, creating two flame fronts whose combined speeds are greater than the speed of sound. The vibrations created by their collision resemble a pinging sound [9]. Knock sensors listen to the engine. When there is a loud supersonic sound, it warns the ECU. The ECU then retards the timing of the spark, which deprives the engine of power, but prevents detonation in the engine [5].

Crank position sensors simply tell the ECU how far from top dead center the crankshaft has rotated. The sensor is also used in determining spark advance and camshaft rotation. It can also be placed on the camshaft and perform the same function [5]. However, it is important to know that the camshaft rotates at half the speed of the crankshaft [9].

The ECU basically manipulates spark timing, injector pulse widths, and monitors the oxygen sensor in closed-loop mode to make changes to the AFR on the fly. The ECU draws information of a volumetric efficiency (VE) table, which establishes the AFR for designated RPM’s and loads that the engine may pass through. When the engine is operating at conditions that are not specified by VE table, the ECU takes an average of the surrounding values in order to produce a smooth change in injector pulse width. Spark advance is controlled by a separate table with a similar layout to that of the VE table and is used by the ECU in the same way [4].

3. Experimental Design

In order to understand how to optimize a car and basic engine performance, we performed two processes: the first a dynamometer test and second an ECU based test. These tests are used to simulate loading on an engine to evaluate performance and to observe the change engine function as a result of the changes made in the software.

3.1 The Dynamometer

By monitoring the RPM and fuel consumption of the engine, as well as oil pressure and flow rate of the dynamometer, we calculated torque, horsepower (HP), and brake specific fuel consumption (BSFC). The flow rate and oil pressure allowed us to determine the amount of load [8].

$$\boxed{Hp = P * n_b * R}$$

Equation 3.1.1 – Horsepower – P = pressure, R = oil flow and n = pump efficiency [NUMBER]

Using equation 3.1.1, we measured the torque of the engine, which is measured in foot-pounds.

$$\boxed{P[\mathrm{hp}] = \frac{(\mathrm{T}[\mathrm{ft} \cdot \mathrm{lbf}])(\omega[\mathrm{r/min}])}{5252}}$$

Equation 3.1.2 - This formula shows that torque equals horsepower at 5252 RPMs.

Torque is vital because it can be imagined as rotational force. When the wheels need to rotate, it is the torque that forces the wheels to turn, which in turn force the car forward [8]. The more torque an engine has the higher its acceleration will be. Horsepower is a measure of watts equal to 550 lbs per second [4]. It determines what the maximum speed will be because the power of wind resistance will oppose its motion. The more horsepower the more wind it can resist and higher speed it can maintain.

Finally, you can calculate the BSFC, which is a measure of fuel efficiency. It does not measure miles per gallon of gas; instead it creates a standard that can be applied to all engines. It measures how many pounds of fuel are required to create one horsepower, which measured in lbs/HP. The lower the BSFC, the higher the engine's efficiency. Because it is not a percentage value, it is not a true measure of efficiency [4]. However, since this measure can be found for all engines it is still a useful tool for comparison.

BFSC is calculated by measuring the weight of the fuel used and the amount of horsepower made over a certain stretch of time.

$$\boxed{BSFC = R_F / Hp}$$

Equation 3.1.3 – Formula for Brake Specific Fuel Consumption (BSFC)

3.2 Lawnmower "Dyno" Experiment

We used Rutgers' dynamometer to measure the torque and fuel consumption of an engine. The lab setup consists of a lawn mower engine attached to a dynamometer to mimic loading. A scale was set up near the dynamometer to monitor the amount of fuel consumed. We ran the engine at full throttle and set an oil pressure by altering the pump power. Then we recorded the amount of fuel in the tank, RPM of the engine, oil pressure of the dyno, and then started a timer. After 30 seconds passed, we recorded the amount of fuel left in the tank and repeated the test for different RPMs.

We took readings with the engine running between 1500 and 4000 RPM in intervals of 500 RPM. Then we calculated horsepower, torque, and BSFC.

3.3 Formula Car Tuning

The second part of the project took place at the Rutgers Formula SAE Racing Team's garage. We tuned the formula car's engine, using the Win-TEC4 software to manage the TEC-gt ECU. With the program, we were able to fine-tune various aspects of the engine, such as spark advance and volumetric efficiency. We were also able to set up starting enrichments, such as initial advance, fuel enrichments, and engine parameters.

Our main intention was to create an engine that ran well under many driving circumstances. However, due to the limitations of the formula car (i.e. missing/broken wheel and the lack of a dynamometer that fit the engine), we were unable to test the engine under a load. However, as stated before, we tested the lawn mower engine under load using the dyno and can apply the same procedure to the formula car.

4. Results

4.1 Engine Lab Results

Through the engine lab experiment, we observed that as the RPMs increased, so did fuel consumption. This is logical because if the crankshaft revolves more often, there are more combustion cycles per unit time, which require more fuel. However, at low RPMs we found that the fuel consumption was noticeably higher than at higher speeds. This is because the engine had too much load and the engine was using more fuel in order to keep it running. At a certain point, the load becomes too much, or too much fuel is added, thus flooding the engine and causing it to stall.

Fuel Consumption for 30 Seconds

RPM	**Initial Fuel (g)**	**Final Fuel (g)**	**Fuel Used (g)**
1,500	2,130	2,119	12
2,000	2,104	2,098	5.7
2,500	2,091	2,084	7
3,000	2,074	2,065	8.6
3,500	2055	2,045	10.2
4,000	2035	2,025	10.2

Fig. 4.1.1 – Fuel consumption- more fuel used at high and low RPMs.

We used the fuel consumption along with the HP to calculate BSFC and therefore, indirectly determined engine efficiency. The BSFC showed that at certain RPMs more horsepower is created per unit of fuel.

Brake Specific Fuel Consumption

RPM	BSFC
1500	1.38
2000	.405
2500	.413
3000	.404
3500	.482
4000	.422

Fig. 4.1.2 – BSFC- efficiency band from 2000-3000 RPMs

Lower values are better for this chart because it means that less fuel is required per HP. This engine ran most efficiently between 2000 and 3000 RPM. The lawnmower engine was designed to operate mainly in this range. However, engines such as those used in cars rely on transmissions to alter the gear ratio between the engine and the wheels in order to keep the engine running in its most efficient RPM range.

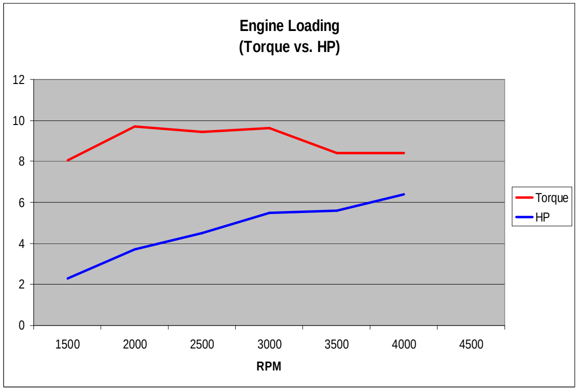


Fig. 4.1.3 – Engine Loading- At higher RPMs HP increases and Torque plateaus

Another way to evaluate an engine is to measure its torque and horsepower output. On most torque-horsepower graphs, the horsepower starts off low, but steadily increases, crossing the torque curve, which is usually relatively flat, with a slight drop-off as the engine reaches high RPM’s.

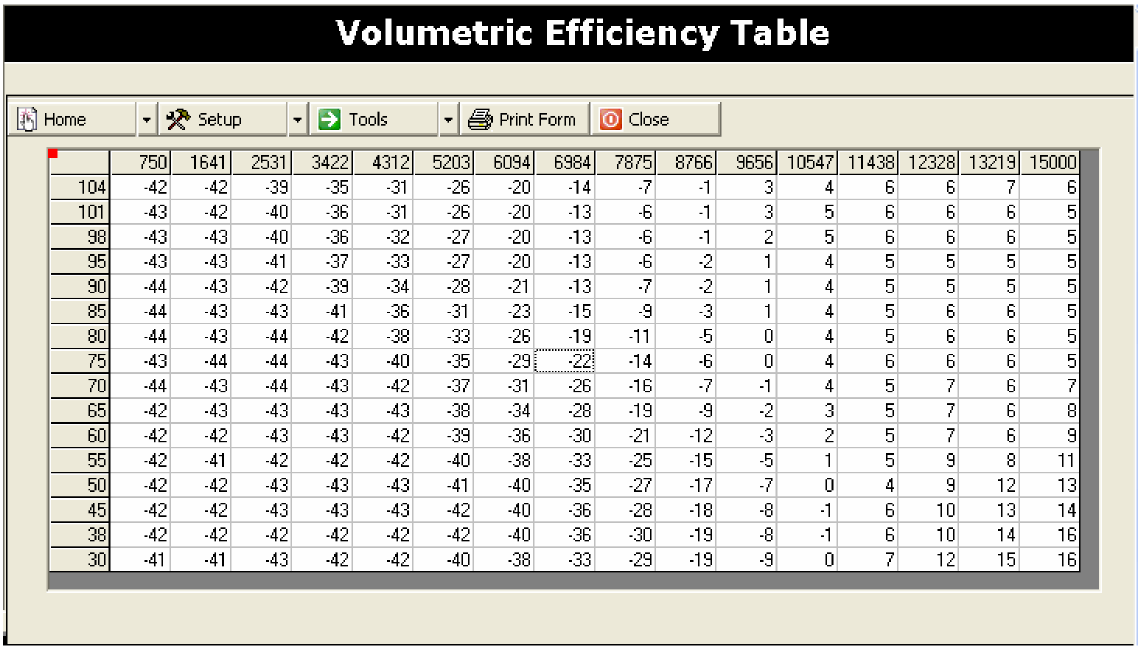
This shows that there is a trade off between torque and HP: the higher HP rose, the more the torque lowered. The trade off is high HP at 4000 RPM, peak torque at 3000 RPM and peak economy at 3000 RPM.

4.2 Formula Results

After a week of fine-tuning, backfiring, and throttle melting, we successfully tuned the engine to run smoothly. Specifically, we noticed that even small changes have a large effect on engine performance.

While working on spark advance, we discovered that too early of a spark causes the gasoline vapors to burn prematurely, resulting in backfiring, when the pressure from combustion pushes against a piston’s direction of motion. If the spark is too late, the gasoline will not be completely burned by the time the piston begins expelling the exhaust gas [9].

The engine ran at peak efficiency



	750	1641	2531	3422	4312	5203	6094	6984	7875	8766	9656	10547	11438	12328	13219	15000
104	-42	-42	-39	-35	-31	-26	-20	-14	-7	-1	3	4	6	6	7	6
101	-43	-42	-40	-36	-31	-26	-20	-13	-6	-1	3	5	6	6	6	5
98	-43	-43	-40	-36	-32	-27	-20	-13	-6	-1	2	5	6	6	6	5
95	-43	-43	-41	-37	-33	-27	-20	-13	-6	-2	1	4	5	5	5	5
90	-44	-43	-42	-39	-34	-28	-21	-13	-7	-2	1	4	5	5	5	5
85	-44	-43	-43	-41	-36	-31	-23	-15	-9	-3	1	4	5	6	6	5
80	-44	-43	-44	-42	-38	-33	-26	-19	-11	-5	0	4	5	6	6	5
75	-43	-44	-44	-43	-40	-35	-29	-22	-14	-6	0	4	6	6	6	5
70	-44	-43	-44	-43	-42	-37	-31	-26	-16	-7	-1	4	5	7	6	7
65	-42	-43	-43	-43	-43	-38	-34	-28	-19	-9	-2	3	5	7	6	8
60	-42	-42	-43	-43	-42	-39	-36	-30	-21	-12	-3	2	5	7	6	9
55	-42	-41	-42	-42	-42	-40	-38	-33	-25	-15	-5	1	5	9	8	11
50	-42	-42	-43	-43	-43	-41	-40	-35	-27	-17	-7	0	4	9	12	13
45	-42	-42	-43	-43	-43	-42	-40	-36	-28	-18	-8	-1	6	10	13	14
38	-42	-42	-42	-42	-42	-42	-40	-36	-30	-19	-8	-1	6	10	14	16
30	-41	-41	-43	-42	-42	-40	-38	-33	-29	-19	-9	0	7	12	15	16

Fig. 4.1.1 – VE table- higher RPMs require higher VE in order to create a leaner mixture and create more power. At low RPMs less VE makes the engine more responsive.

at a value around -40 (which indicates that the injectors deliver 40% less fuel than what the table originally created by the software provided for) at 3500 RPM, where the engine maintained a stoichiometric AFR.

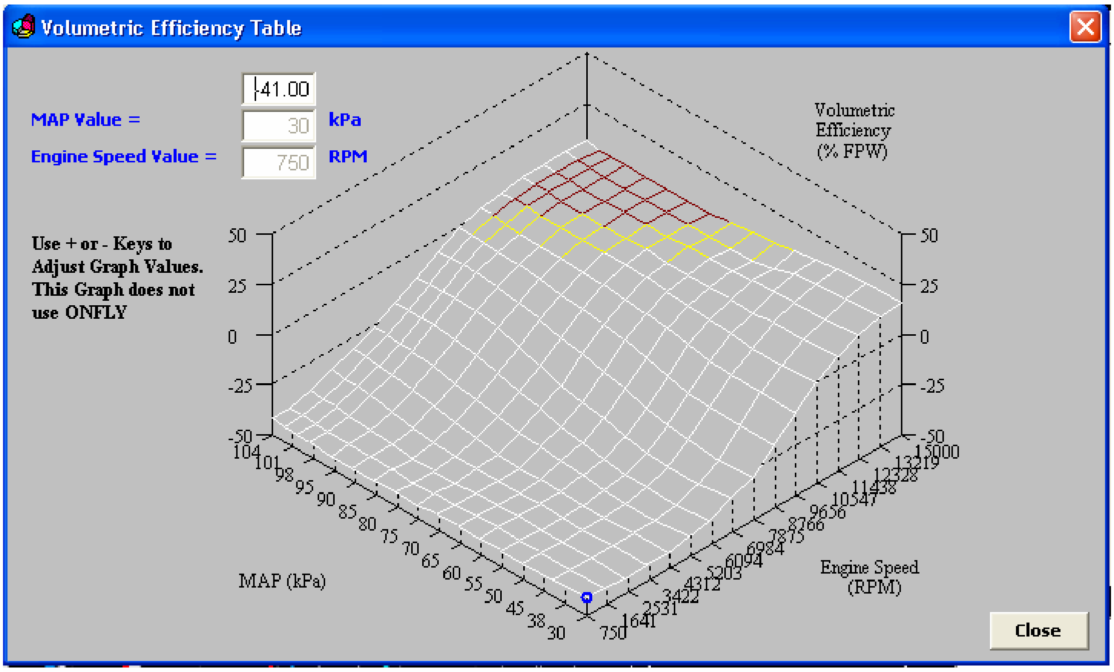
5. Analysis

As a result of the test we performed on the lawnmower and formula engines, we concluded that each engine system is highly interdependent. A small adjustment to one system would require changing nearly every other variable. The volumetric efficiency correlates to the air system by regulating the air-fuel ratio to prevent stalling, drowning, or other types of damage to the engine. The spark advance is crucial to the entire engine because of the precise timing needed to ignite the fuel; bad timing can lead to terrible consequences.

BSFC basically measures how efficient the engine is at producing horsepower with less fuel. At low RPMs, a car is basically a gas-guzzler, burning more than 3 times as much fuel than if it were driving at 4000 RPMs. It also led to the conclusion that 3500 RPM is the ideal speed for this particular engine, resulting in peak horsepower and torque. This ideal engine speed varies from engine to engine. The point of a dyno test is to find at which point the engine runs at its most powerful and/or most efficient.

The formula car tuning involved using software to track engine performance rather than a dynamometer.

We were able to observe how Volumetric Efficiency (VE) tables work. The VE controls the amount of air and fuel that enters the engine. The number correlates to the ratio of fuel to air.



-41.00

MAP Value = 30 kPa

Engine Speed Value = 750 RPM

Use + or - Keys to Adjust Graph Values. This Graph does not use ONFLY

Fig. 5.1 – VE graph- smooth graph allows for a smooth acceleration and stable engine idle.

Higher numbers add fuel to the mixture, while lower numbers take fuel away [4]. The VE is important because it allows for subtle changes to be made to the engine's performance.

The graph should make smooth transitions. We learned that if it did not, the engine would rev up and down, and then never stabilize. With this also comes the risk of stalling. As more load is applied to the engine, more fuel is required in order to make efficient use of incoming air [4].

Ignition advance is used to maximize the power output by guaranteeing that all of the fuel is combusted before the exhaust leaves the cylinder. This must change as the engine RPM increases because there is less time to burn the fuel so you have to start the combustion sooner. If the advance is too early, however, the combustion will be pushing against the piston before it reaches top dead center and backfire [9].

6. Related Work

Tuners and automotive companies around the world carry out tuning.

Automotive companies tune cars in a similar manner to what we experienced using the two engines. Depending on the type of car, auto manufacturers choose to focus on torque, power, or economy, but usually compromise in order to make the vehicle as versatile as possible.

Another aspect of tuning involves cylinder trims. Cylinder trims are individual adjustments of the pulse-width for each cylinder. Added fuel aids in cooling which compensates for the larger amount of heat retained in the middle cylinders since they are not exposed to the air to aid in cooling. It can also adjust fuel flow to each cylinder to guarantee maximum performance [4].

In order to further increase performance many car enthusiasts add superchargers or turbochargers. These compress the incoming air in order to increase VE. Since compressing air increases its temperature, most superchargers include intercoolers. These are normally air-to-air or air-to-water cooling systems. In both cases, the air moves around a series of pipes containing the coolant, which absorbs the heat [9]. This allows more air and fuel to be injected into the cylinder providing more power.

The engine's belt assembly drives superchargers, so, in essence, superchargers draw power from the engine in order to produce more power. To offset this drawback, the boost from superchargers is available instantly, without what is known as "turbo lag" [9].

Turbochargers are the same as superchargers in concept, but are instead run by exhaust gasses. The exhaust gasses must reach a certain temperature and pressure before they begin to effectively drive the compressor [9]. This is what causes turbo lag.

Turbochargers and superchargers allow an engine to operate at greater than 100% VE, since the air coming into it is at a greater pressure than atmospheric pressure. The increased amount of air allows more fuel to be added without altering the AFR. This greatly increases performance, but pressurizing the intake also has its dangers. Too much pressure could lead to detonation in the cylinder [9].

One way to counter knock, or detonation, is to use higher-octane fuel. Octane is the fuels resistance to combustion, which means that it will take higher pressure and temperature to ignite it. High performance engines generally use higher-octane fuel because they have high compression ratios, which would normally cause lower octane fuels to ignite prematurely and cause engine damage [4].

Some of the more complex tuning methods utilized by racers, automotive companies and professional tuners are harmonics and exhaust scavenging.

Harmonics happen when the tubes and plenum that transport the air expand and contract at the same frequency that the engine is running. As the intake valve is opening, the plenum and runners are contracting and forcing air into the cylinder. After it closes, the plenum expands and draws more air into it, increasing the pressure of the air inside. A similar sequence of events happens with the engine's exhaust system, improving the engine's VE in a certain RPM range [6].

Another way to improve an engine's performance is exhaust scavenging. The exhaust gas that is expelled from the cylinder travels along the exhaust pipes and creates an area of negative pressure behind it, which draws air out of the cylinder more quickly the next time the exhaust valve opens. This event also happens as the intake air enters the cylinder [6]. Designing the runners and exhaust pipes to specific lengths causes the air to pulse at the same rate as the engine.

Since both phenomena only apply to a certain RPM ranges, it is possible to optimize an engine's intake and exhaust system so that both effects occur within the vehicle's power band.

These techniques are very effective in increasing the power of an engine, but add an extra level of difficulty for amateurs. Engine tuning has been practiced and refined for many years and continues to evolve as new advances in technology augment our ability to push the limits of vehicle performance.

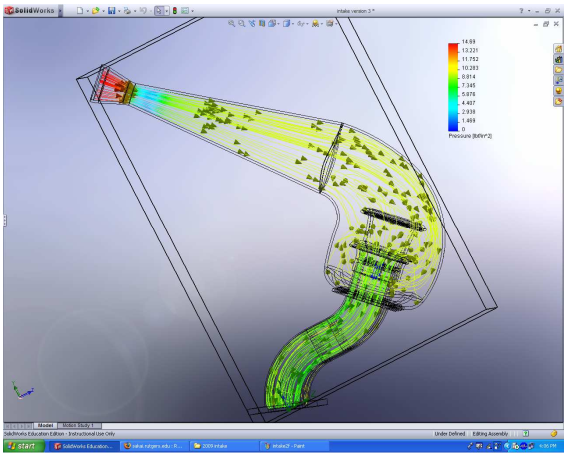


Fig. 6.1– Formula Car Plenum Design- Uses a venturi, Bernoulli's principle, and harmonics to optimize airflow.

7. Conclusion

Computer controlled engine management systems are the most recent advancement in precision engine tuning technology. They allow for real-time changes to be made, which permit faster and more exact tuning.

We found through the lawnmower dyno lab that each engine has a specific power band where it is most efficient. Engines running at RPMs higher or lower than the power band are less efficient. High loading caused the lawnmower engine to run at lower RPMs and consume much more fuel to provide the necessary torque.

Even with relatively little experience, it is possible to calculate an engine's torque, power, and BSFC with a dynamometer. We found that determining optimum efficiency was fairly simple after the data was collected.

In terms of performance, the most important rule to remember is that peak torque occurs at peak VE. Thus, optimizing the VE of an engine will allow it to perform at its best. Most naturally aspirated engines will not pass 100% VE, but advanced engine tuning techniques such as harmonics and exhaust scavenging can lead to quite high VE. Superchargers and turbochargers allow engines to operate at more 100% VE, since the air flowing into the cylinders is at greater than atmospheric pressure.

Through our formula engine tests we established that running an engine on the rich side of stoichiometric AFR and then proceeding to leaner mixtures is the safest method to tune. We also saw that small changes are necessary when altering the VE or ignition advance tables. This created a smoother and safer engine run.

We did however prove the concept that engines could be made more efficient and powerful via EMS tuning. It is important to remember, however, that there is always a trade-off between maximum power, torque, and economy.

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