WIKI

Powertrain Department

Contents

1. Introduction

1.1 What is Powertrain?

Powertrain deals with harnessing the maximum amount of power from the engine while working under the FSAE restrictions. The department is responsible for designing the intake, the exhaust, the cooling, and the lubrication systems.

1.2 FSAE rules & restrictions

All members of this department should familiarise themselves with the rulebook. There are several regulations applicable to Powertrain; The key ones are highlighted below:

I. All airflow to the engine(s) must pass through a single circular restrictor placed in the intake system.
   A. For gasoline fueled vehicles, the maximum diameter of said resistor is 20 mm.

II. The Exhaust Outlet(s) must be:
   A. No more than 45 cm behind the centerline of the rear axle
   B. No more than 60 cm above the ground.

III. The vehicle must remain below the permitted sound level at all times. (See the noise test and muffler section for details)

1.3 RICARDO

RICARDO Wave is one of the main tools we use in Powertrain. It allows us to replicate our engine and surrounding systems and run simulations. By using it, we have simulated the optimal length for exhaust headers, plenum airflow, and power vs torque plots.

You can find those examples in the archive section of Powertrain.

2. The Engine

2.1 The 4-stroke cycle

The four-stroke cycle refers to the operating cycle of combustion engines. It involves a 720° rotation of the crankshaft, i.e. two rotations, due to the four distinct positions occupied by the piston. The four strokes come in the following sequence:

I. Intake

The first stage of the cycle is when the air-fuel mixture enters the combustion chamber. The piston starts the Top Dead Centre (TDC) position and moves towards the Bottom Dead Centre (BDC) one. This movement causes the cylinder's pressure to drop. The inlet (intake) valve is open and allows the air-fuel mixture to enter the cylinder and fill the chamber. Once the piston reaches the BDC position, the intel valve closes.

II. Compression

When the intel valve closes, it seals the combustion chamber, enclosing the air-fuel mixture. The piston's movement causes the mixture to be compressed. As a result, the pressure in the cylinder rises and the air-fuel mixture is now ready for ignition (combustion). The spark, which starts the ignition, is responsible for the rapid increase in pressure.

III. Expansion (power)

The piston starts once again at TDC position and is pushed towards the BDC since the gases in the chamber have reached a very high temperature and pressure. The force applied on the piston by the gases causes the crankshaft to rotate. At the start of this process, both the inlet and outlet valves are closed. However, as the piston approaches the BDC position, the outlet valve opens slightly to prepare for the exhaust process.

IV. Exhaust

As the power stroke is completed, the combustion chamber fills with exhaust gases that need to be removed. For that to be achieved, the inlet valve must be half-closed and the exhaust valve must be half-open. From the previous stage, the piston is at the BDC position. As the exhaust valve opens, the inertia of moveable components in the cylinder causes the piston to move back to the TDC position. The piston's movement pushes the gases out of the exhaust valve. The pressure difference between the cylinder and the exhaust also contributes to this phenomenon. Once the piston returns to TDC, the exhaust valve closes and the cycle can start again.

Further resources:

Book:
https://drive.google.com/drive/u/1/folders/1vB5zOrkVv3POxbXYUpQARxw9c5EDt8IZ

How engines work - Good intro to engine terminology:
https://www.youtube.com/watch?v=zA_19bHxEYg

NASA animation of the 4 stroke cycle:
https://www.grc.nasa.gov/WWW/K-12/airplane/engopt.html

2.2 Engine Specs Explained

Our engine is from the Triumph Daytona 675 bike.

- Engine: Four-stroke, in-line-3-cylinder, DOHC, 4 valves per cylinder

Four-stroke: Each of the three cylinders has one piston with the four different operations that were outlined in the above article about the four-stroke cycle.

In-line-3-cylinder: The three cylinders are arranged in a straight line, side by side.

DOHC (Type of valvetrain): This stands for Double/ Dual Overhead Cam. 2 Camshafts are installed in the cylinder head. They operate 4 valves per cylinder. One camshaft controls the intake valves and the other controls the exhaust valves. DOHC allows better airflow and, therefore, more fuel efficiency and power.

4 valves per cylinder: Most modern cars now come with valves in each cylinder; 2 for intake and 2 for exhaust.

- Capacity: 675 cc

Capacity: This is also referred to as displacement. Engine displacement is the total available volume in the engines. It equals the summation of air volume in each combustion chamber. We measure it in cubic centimeters (1000cc = 1 litre). The bigger the displacement, the more fuel the engine burns. Thus, bigger displacement means more power. A smaller displacement means that the engine draws less fuel. While that means the car’s performance is lesser, the fuel efficiency is better.

- Bore x Stroke: 76 x 49.6 mm

Stroke ratio: An internal combustion engine is a type of a reciprocating piston engine. For such engines, the stroke ratio is defined by the bore/stroke ratio. Simply put, that is the ratio of the diameter of the cylinder bore to the length of the piston stroke. The stroke ratio is important for the efficiency of our engine. It affects friction and heat transfer.

- Compression Ratio: 13.1:1

Compression ratio: To create ignition in the car, the air-fuel mixture in the engine is compressed. The force of that compression depends on the compression ratio i.e. the volume of the cylinder when the piston is at the bottom of its stroke vs the when it is at the top of its stroke. Ignition occurs at the top stroke (see 4 stroke cycle article). A 13.1:1 ratio is considered to be on the higher end of the spectrum which gives us a higher combustion efficiency. While that offers us more power with less fuel and fewer exhaust gases, we have to be mindful of the friction and heat which can cause wear and tear on the internal components of the engine.

An interesting example to research if you're interested in this is Mazda's SKYACTIV tech. Their engineers specifically redesigned the internal components of the engine to withstand the increased friction and heat.

- Max Power: 95.4 kW/ 128 hp @ 12500 rpm

Max power: Power is directly related to torque (explained below).
$P = (T * rpm) /5252$. Power is synonymous with performance. The maximum power is taken to be the value reached at a specific rpm. It is measured in Break Horse Power (BHP). The higher the power, the higher the speed. In Powertrain, we often use the software RICARDO to examine the relationship between torque and max power at certain rpm. The graphs can be found on the Drive.

- Max Torque: 74 Nm/ 7.5 kgf-m / 55 ft.lbs @ 11900 rpm

Max Torque: Torque is the rotational force the engine exerts on the car's wheels. In powertrain, we are interested in the max amount of that force our engine can produce. This peak value can only be reached at a certain rpm; In this case, that is 11900 rpm. Torque is important because it defines the pulling capacity of the engine's powerband*. More torque allows the engine to operate at a lower RPM which allows the car to accelerate more comfortably. Fewer downshifts are required i.e. fewer gear changes.

*Powerband: The range of speeds at which the engine is operating most efficiently

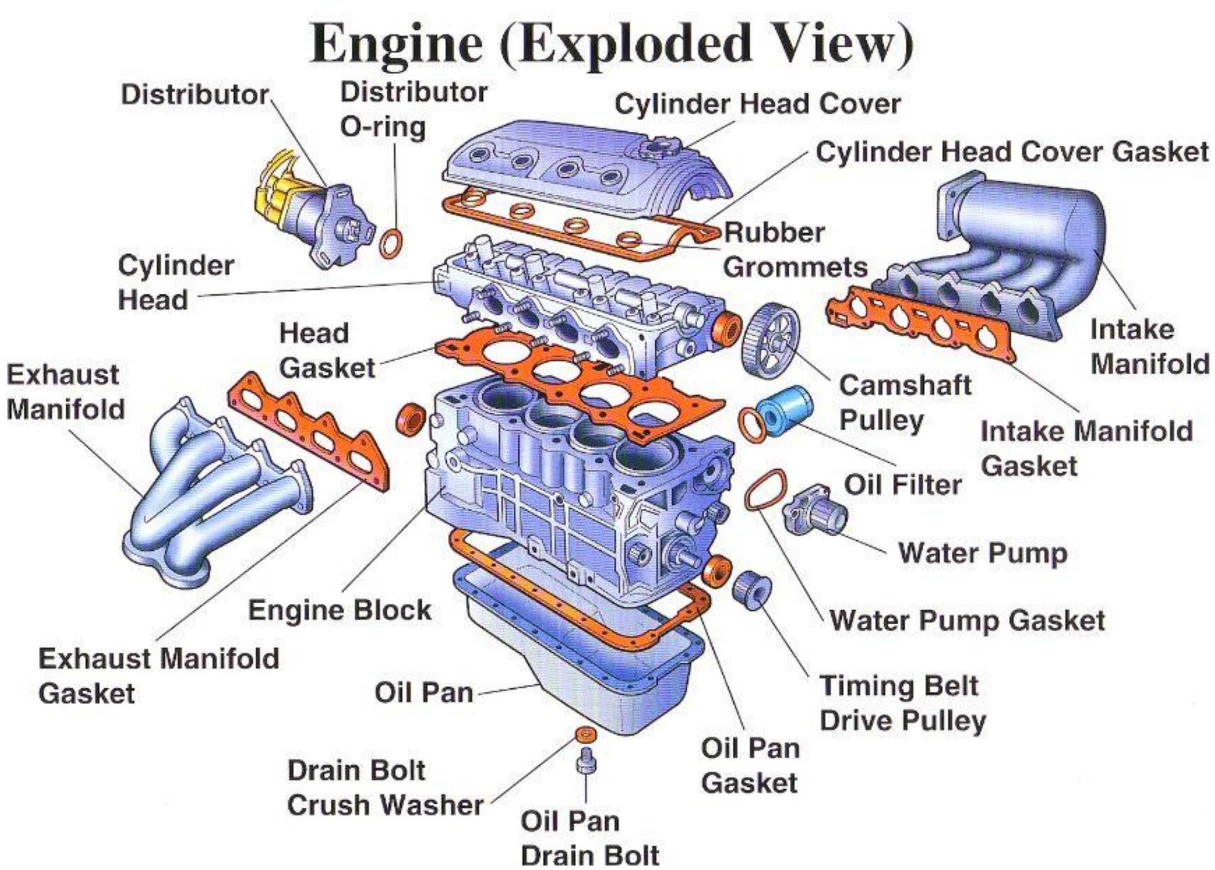
Resources:
Common engine specs explained:
https://www.cars24.com/blog/car-spec-sheet-terms-explained/

More information about the stroke ratio:
https://achatespower.com/stroke-to-bore/

More information about the compression ratio:
https://www.auto123.com/en/news/did-you-know-compression-ratio/49342/

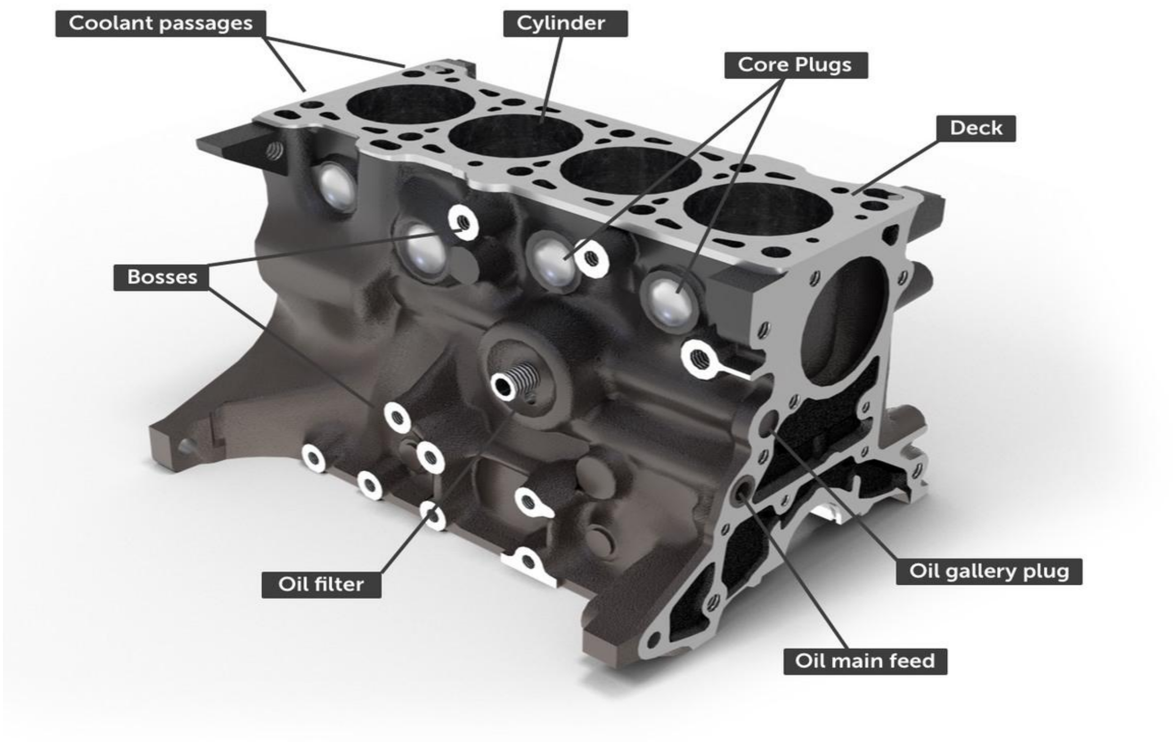
2.3 The basic parts of the engine

This section will be looking at a detailed analysis of the anatomy of an engine.



Source: anatomynote.com

I. Engine Block



Source: Car Parts Nigeria

The engine block is the biggest part of the engine. It is usually made from cast iron or cast aluminium, with cast aluminium being used more and more in modern vehicles. Aluminium alloys reduce the weight of the engine block significantly. Weight reduction directly correlates with a boost in performance and an increase in fuel economy

Functions:

1. Houses the cylinders
2. Contains pathways where the coolant and the oil can circulate
3. Contains the auxiliary components for the engine e.g. the starter motor, the alternator, the water pump etc.

A. Cylinders

The internal texture of cylinders is extremely important. Minimal friction is required as the pistons move up and down.There is a film of oil so as to prevent the piston rings from coming into contact with the cylinder wall.

- What is cylinder honing?

We need the walls of the cylinder to be smooth in order to minimise friction. But, if they are too smooth, then the oil will fall right off. Thus, we need a way to create very slight imperfections on the surface of the cylinder so that we can keep the pistons lubricated without increasing the frictional forces.

The process of honing creates a crosshatch (i.e. diamond) pattern through lines intersecting each other at about 60 degrees.

You can see that pattern pictured below:

Source: Dan's motorcycle repair course

- Why do we need to cool the cylinders?

If the cylinders overheat, 'knocking' can occur. Knocking refers to the premature ignition of the air-fuel mixture and it can cause extensive damage to the engine. Furthermore, heat causes the internal engine components to expand, thus making them more susceptible to wear and tear.

If for instance the cylinder gets too hot, the piston will overheat and expand as well. We want to avoid that metal-to-metal contact as much as possible. So, we circulate coolant through the cylinders from the bottom upwards and then back around the radiator.

B. Deck

The deck is the surface that meets the bottom of the cylinder head. In between the two is a gasket that acts as a seal. The deck must be completely flat in order to maintain a gas tight seal. The cylinder head is where the combustion takes place, so the resulting gas pressure is enormous.

C. Oil galleries

The oil pump pumps oil out of the sump and into a pipe and the into the feed pipe of the engine block. The oil then travels along the pipes and through the oil filter. Once it goes through the filter, it enters a drilled network of passageways that stem from the main gallery. Eventually, the oil comes out of a small hole on the deck that lubricates the camshaft and the valvetrain. It’s important to note there is an oil pressure switch there. It’s triggered by low oil pressure.

Oil also comes out of other galleries through jets to lubricate the inside of the cylinders. There is a constricted hole on the deck that acts as a pressure regulator and keeps the oil pressure in the block high. Once the oil has been supplied to the cylinder head, it goes back down through the return pipes into the sump and then makes its way around again.

Thus, most of the lubrication takes place on the underside of the engine block. For more details on this, read through the lubrication system section of this wiki.

D. Crankcase

At the bottom of the engine block, we can find the crankcase which houses the crankshaft.

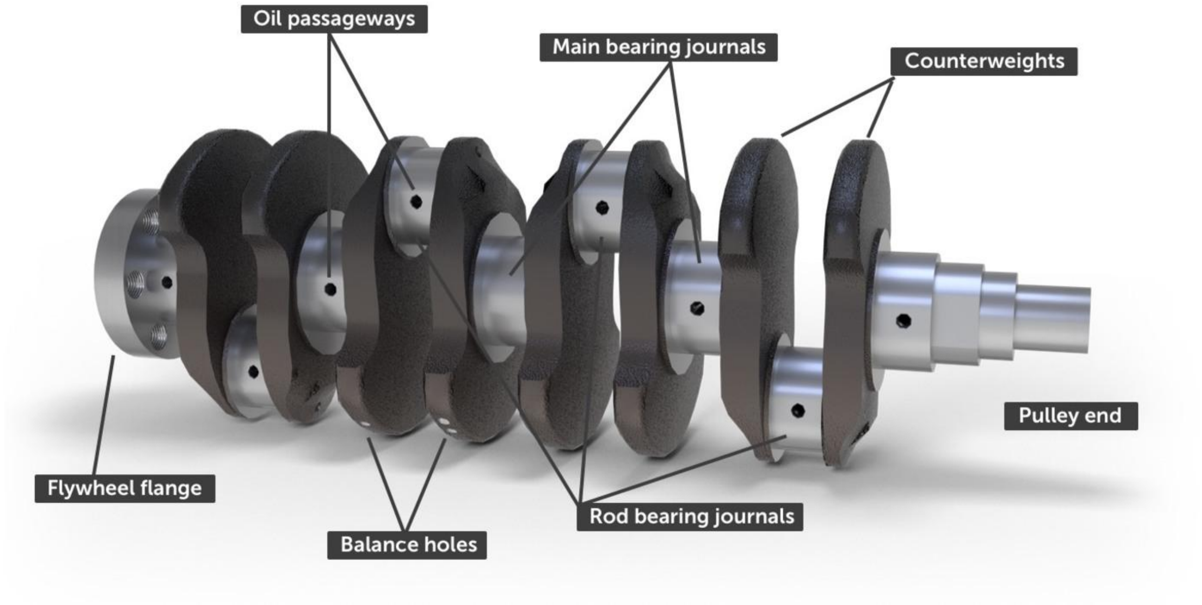
E. Core plugs/ Freeze plugs/ Expansion plugs

These are holes used to remove the sand from the engine after it’s cast. They are then plugged with thin metal core plugs. There is a theory that should the coolant freeze, these plugs come off to protect the engine block, hence their name.

It’s important to check these plugs for leaks as they are made from thin metal and can easily corrode.

Overall, the engine block has more bores called bosses which can be used to mount the engine to the chassis. Some bosses are tapped and can be used to connect the water pump, the alternator, the ac pump etc.

II. Crankshaft



Source: How a car works

A. Function

The combustion process causes the linear motion of pistons, as mentioned earlier. The crankshaft's job is to turn that linear motion into rotation. The rotation then passes on to the flywheel and it is ultimately delivered to the car's wheels.

B. Manufacturing

The crankshaft is usually made of cast iron or forged steel. To determine from which method our crankshaft is manufactured, we can examine the parting line on the counterweights.

Cast iron: There is a thin ridge where the two molds come together and are then released.

Forged steel: The ridge is a lot wider.

C. Components

2.5 Engine Testing

Engine testing allows us to inspect all Powertrain systems for safety purposes and examine their overall performance. We can collect valuable information on the effectiveness of our cooling and lubrication systems, the noise output, and potential tuning methods.

I. Cranking the engine

Cranking the engine is one of the first things we do after the initial inspection for any visible damage or leak. By cranking the engine, we are able to carry out a compression test in each cylinder and check the health of our engine.

This particular test is incredibly useful, because it allows us to test the engine before it's installed in the car and connected to the other systems. The following video shows what to expect:
https://www.youtube.com/watch?v=LjWVGdT-wGw

Required components:

1. A starter motor

Most engines need some help to start, because only one of the 4 strokes in the cycle produces power. That is the third stroke. Here is a video that explains the engineering behind a starter motor.
https://www.youtube.com/watch?v=VRe_hKxzKUg

2. Battery
3. Battery cables
4. A wire hooked on the positive terminal of the starter
5. Compression tester

It is important to space out the starter motor so that it is in line with the flywheel. It can be easily done using some sockets and spacings.

Method to crank the engine:

1. Hook up the negative terminal of the battery to the case of the starter motor. That's our ground.

2. Hook up the positive cable to the positive terminal on the starter
3. Use the wire to 'excite' the starter motor

Method to test the compression of each cylinder:

1. Take out the spark plug of the cylinder you want to test
2. Hook up the compression tester
3. Crank the engine
4. 4-6 cranks should be sufficient to get an accurate reading
5. Compare the psi measurement with the manufacturer's

II. Dynamometer

A dynamometer is one of the key instruments required for engine testing. It is designed to create a load to duplicate various speed (RPM) and torque (Nm or lb-ft) requirements. From this data, power (HP or kW) can be calculated. So, it allows us to test the output of the engine and, therefore, its performance. By varying the load and the resulting power output, we can compare the test results to the manufacturer's and see if our engine is producing the power it should.

Horsepower = Torque x RPM / 5,252

There are different types of dynamometers which you can explore here when you scroll down.

The purpose of the dyno test is to spot any red flags that could be hindering the engine's performance. For instance, we have to keep an eye out for inconsistencies in the throttle movements and the engine speed.

Resources:

Basic inspection & tests:
https://www.motor.com/magazine-summary/mastering-basics-comprehensive-engine-testing-november-2001/

Types of dynos and how they work:
https://powertestdyno.com/what-is-a-dyno/

3. Intake

3.1 How it works

The intake system takes atmospheric air, mixes it with fuel and delivers it to the engine cylinders during their intake strokes.

The intake system consists of

I. An air filter
II. A throttle
III. A restrictor
IV. A plenum
V. Three runners.

3.2 Throttle and restrictor

The throttle and restrictor control the amount of air that enters the engine.The throttle is simply a butterfly valve at the entrance of the intake system. When the throttle is open lots of air can flow into the engine and the engine will run at high RPMs. When the throttle is almost closed, the engine will run at a low RPM, as it is getting very little air.

The rules of formula student force every car to have a 20mm restrictor. This limits the amount of air that can enter the engine and thus limits the speed and power of the car.

Resources:

Optimisation of 20 mm restrictor:
https://www.researchgate.net/profile/Pranav_Shinde2/publication/279948000_Research_and_optimization_of_intake_restrictor_for_Formula_SAE_car_engine/links/559f376808ae03c44a5ce87b/Research-and-optimization-of-intake-restrictor-for-Formula-SAE-car-engine.pdf

3.3 Plenum

After the air passes through the throttle and restrictor, it enters the plenum. This is a box where the air is stored until it is sucked into the engine. The volume of the plenum can affect the power of the engine and the responsiveness of the throttle. Generally, a larger plenum will result in a higher average power, while a smaller plenum will have a quicker throttle response. RICARDO can be used to simulate plenums of different volumes and geometries to optimise it. Most formula student plenums have a volume between 1 and 3 litres.

3.4 Runners

The air enters the engine through the runners. Our engine has three runners as it is a three cylinder engine. The fuel injectors are connected to the runners where they meet the engine. This is where the fuel mixes with the air before combustion. When the runner length is optimised, a pressure wave is produced that can force more air into the engine.
The pressure/acoustic wave is caused by the rapid closing of the intake valves. This wave then refracts off the walls of the runner and bounces back when there is a sudden increase in diameter (i.e the entry into the plenum).

The length of the wave can be approximated with the following equation:

- **Target engine RPM / 60 seconds = engine RPS**
- **Engine RPS x 360 = crankshaft degrees per seconds**
- **No. of degrees intake valve is closed / crankshaft degrees per second = total time intake valve is closed at target engine RPM**
- **Length of pressure wave = total time intake valve closed x speed of sound**
- **No. of bounces = length of pressure wave / length of runner**

Notes:

It is ideal to have an even number of bounces, as we want the pressure wave to collapse at the intake valve so additional air can be rammed.

The more bounces the pressure wave endures, the weaker the pressure wave will be.

For triumph 675, to get 20 pulse bounces the length of the runner + intake valve should total to 263.5 mm for target RPM 5000.

3.5 Manufacturing

The material for the intake has to be fuel resistant. Nylon 6is a nylon based material that can be 3D printed and it is expected that the intake will be made from this. Treating has shown that test pieces of this material do not dissolve in petrol. Alternative materials could include aluminium or fibreglass however manufacturing would be more challenging and expensive with this.

4. Exhaust

4.1 How it works

The exhaust system has the following functions:

I. Removing the exhaust gases from the car
II. Noise reduction
III. Heat management

Exhaust parts:

I. Exhaust headers/ manifold
II. Catalytic converter
III. Muffler

Once the combustion process occurs in the engine. The byproducts are nitrogen, (mostly vapour) water, and carbon dioxide. The exhaust consists of a series of pipes that draw the gases away from the piston. This creates a stronger vacuum in the cylinder that increases the fuel/air mix that enters the piston in the first place. That allows us to get more power out of each combustion cycle. It is important to recognise that the exhaust plays a very important role in the car’s performance.

The gases are collected by the exhaust headers from the cylinder head and fed into the catalytic converter to remove any harmful elements. Finally, they pass through the muffler where the noise is reduced and exit through the tailpipe, the visible part of the exhaust in most cars.

Resources:

How an exhaust system works:
https://www.youtube.com/watch?v=2m2b400Nd_4

4.2 Manufacturing

The exhaust headers are often made from cast iron. In general, stainless steel is the best option for exhaust manufacturing. The exhaust is often the most corroded and blackened part of the car due to the water vapour, carbon dioxide, and amount of heat passing through. Stainless steel has a high nickel and chromium concentration which offers strength and corrosion resistance. Different versions of stainless steel can be found in exhaust manufacturing, e.g. 304 or 409-L.

4.3 Noise test & Muffler

FSAE rules on noise testing state:

I. “The maximum sound level test speed for a given engine will be the engine speed that corresponds to an average piston speed of 15.25 m/s. The calculated speed will be rounded to the nearest 500 rpm. The maximum permitted sound level up to this calculated speed is 110 dB(C), fast weighting.

II. The idle test speed for a given engine will be up to the team and determined by their calibrated idle speed. If the idle speed varies then the vehicle will be tested across the range of idle speeds determined by the team. At idle the maximum permitted sound level is 103 dB(C), fast weighting.

The noise test is one of the things that catches out a lot of teams each year at scrutineering.

The muffler, also known as silencer, helps silence the noise produced by the engine. It consists of a series of chambers and tubes that reflect the sound waves produced by the engine, thus cancelling them out. Mufflers contain steel wool or other synthetic fibres to absorb sound. It is important to note that mufflers generally cancel out the high frequency waves, because they are the main cause of disruption.

Resources:

Mufflers and silencers:
https://www.youtube.com/watch?v=1KsZtyFhies

4.4 Tuning

Exhaust tuning is a fine art that when done right can optimise the engine's performance for a specific use case. For instance, Formula Student tracks are generally short, windy tracks with short straights and many corners. On tracks like these the engine tends to operate at the lower end of its RPM range. This means an exhaust system tuned towards lower RPM values would allow the car to perform better and achieve faster lap times.

The exhaust is tuned by changing the diameter and length of the primary or secondary pipes. This along with implementing various bends in the exhaust design can have a noticeable effect on the performance of the engine.

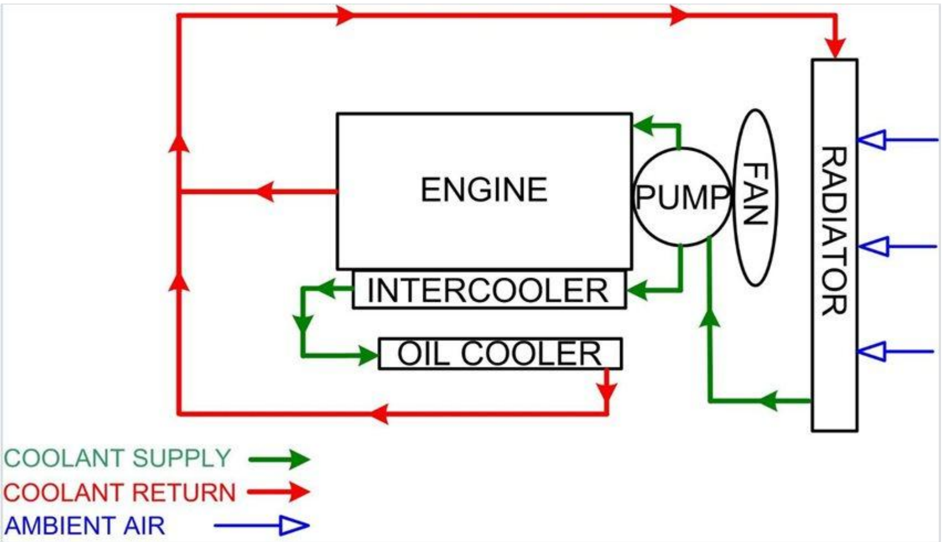
5. Cooling System

5.1 Why cooling is important

When the engine is running, it generates heat. Heat is generated from the combustion that powers the car in the combustion chamber and by friction made from the pistons rubbing against the engine block. The metal parts of the engine can be caused to expand by the heat generated. This can lead to lowered engine performance as the heat can cause fuel to ignite before it is supposed to in the combustion chamber, and most importantly lowered engine durability and reliability as the parts fit worse and get damaged due to friction and heat deformation.

5.2 How it works

The Second Law of Thermodynamics states that in a closed system, the transfer of heat moves from a hot object into a colder object. With this principle in mind, a pump in the car pumps cold liquid, in our case plain water, around the cylinder heads in the engine. The heat produced by the engine is passed into the liquid through the cylinder heads and walls, which is then brought to the radiator which passes the heat into the moving air. The liquid is then returned to the pump to be used again. The air however must be slowed down sufficiently in order to allow enough time for the heat to be transferred from the radiator to the atmosphere. Ducts pass the radiator and allows heat to be transferred from the radiator to the air in the ducts. The hot air is then dumped into the atmosphere through openings and vents on the body of the car. The fact that the cooling system is enclosed also increases the efficiency of the system. Due to the internal pressure in the cooling system, the boiling point for the coolant increases, and thus the system and engine has a higher tolerance for temperatures.



5.3 Radiator

The objective of the radiator is to diffuse heat from the hot liquid from the cooling system to the passing air, thus cooling the engine system. In order to do this the radiator must have a large surface area. This large surface area allows larger and easier heat transfer from the radiator to the air. Radiators receive airflow from the forward movement of the car, meaning radiators are usually mounted at the front. This allows air hitting the front of the car to contact the radiator and cause transferring of heat from the car to the air. Radiators are usually made of a pair of headers linked by layers of metal sheets, leaving narrow passageways for air to flow through. This construction gives large surface area relative to volume. The radiator may also have a fan attached to suck cool air through it.

A typical aluminium radiator

5.4 Coolant pump

Modern engines utilise centrifugal pumps to circulate coolant around the car. This pump is powered by a belt that is connected to the crankshaft. The water enters the pump through an inlet directly onto the rotating axis of the impeller. The spinning impeller then forces the water to the outside of the pump and out into the engine block.

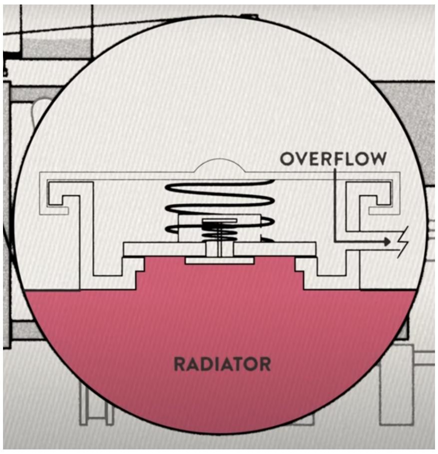
5.5 Thermostat

The thermostat controls coolant flow to the radiator from the engine block. If the coolant in the engine block is not hot enough, a valve controlled by the thermostat will remain closed and the coolant will return straight to the pump. If the coolant is hot enough, the thermostat will open the valve and that allows the coolant to flow to the radiator to be air cooled. This is necessary to improve cooling efficiency of the engine, and to regulate the amount of coolant going through the radiator. Nowadays the valves are controlled by an onboard computer, however they used to be mechanically controlled.

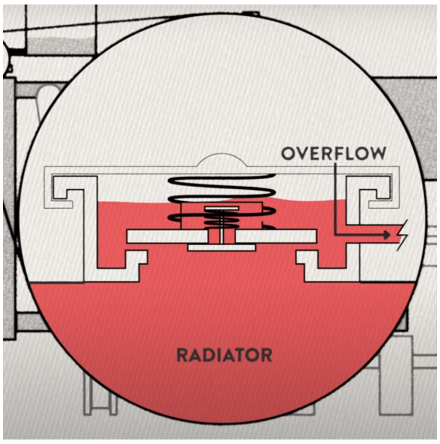
A typical coolant valve

5.6 Radiator Cap

In the case of the coolant and/or the radiator overheating, the radiator cap comes into action. When the coolant overheats, it expands just like any other liquid. This is very bad as the coolant system is an enclosed system, meaning pressure can build up and lead to damage and malfunctions. In order to counter this, a radiator cap is included on the radiator. This cap is basically a pressure sensitive valve. When pressure in the radiator exceeds a certain limit, usually 15 psi, the radiator cap opens and lets the excess coolant overflow into catch cans either side of the radiator through tubes. This releases the pressure in the radiator. Once the system is cooled sufficiently, the coolant in the catch cans gets sucked back up into the radiator and thus back into the cooling system. This arrangement also keeps air out of the system.



Radiator cap at normal internal pressure



Radiator cap when pressure limit has been exceeded

5.7 Catch cans

The catch cans are required to “catch” the coolant if and when the coolant overflows from the radiator. The coolant enters the catch cans via an overflow tube that leads from the radiator cap when it is opened. This tube allows the coolant to be sucked back up into the radiator when the radiator cools down. There are several rules that are specified in relation to the catch cans. They must be able to hold a minimum volume of 10% of the liquid being contained or 900ml, whichever is greater. The catch can must also be permanently rated to hold liquid of 125°C. They must also be located rearward of the firewall below the driver’s shoulder level.

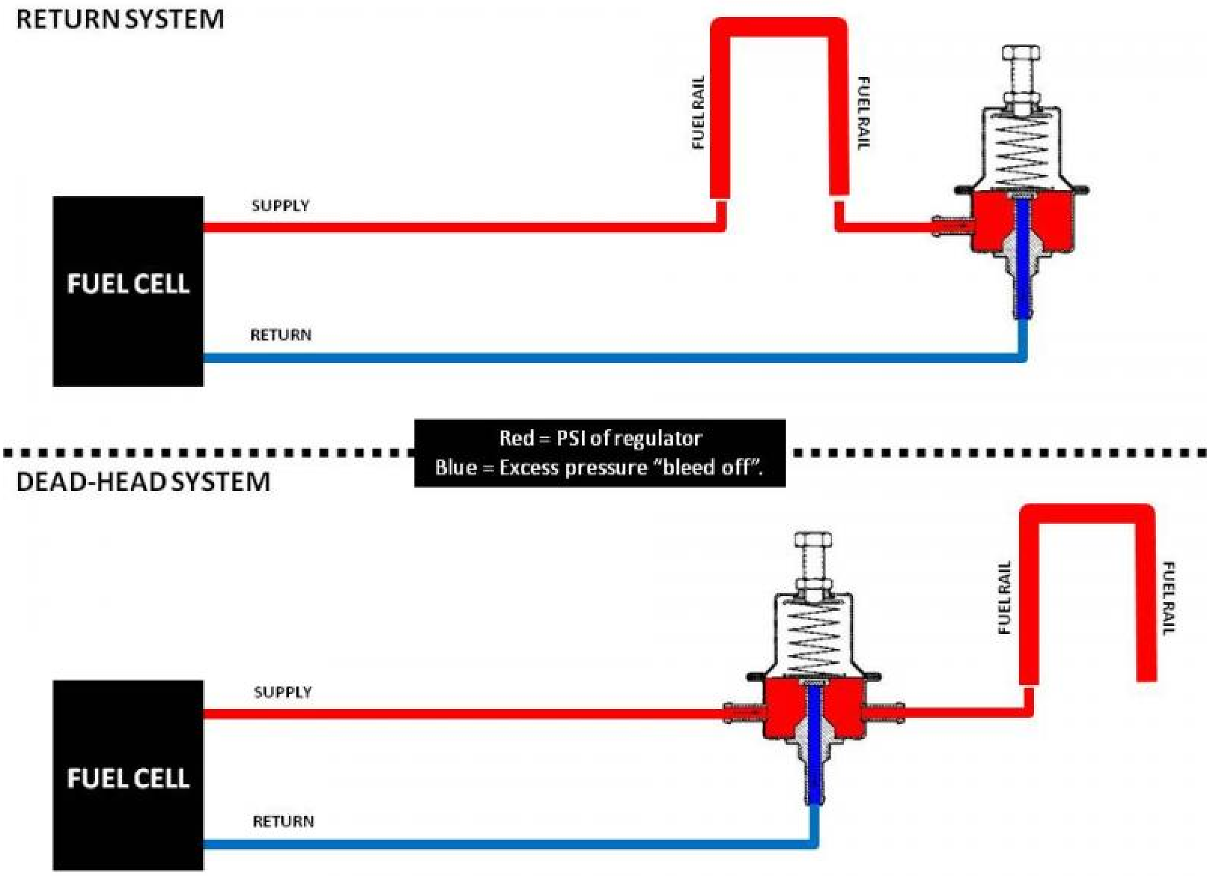
5.8 Hosing and Tubing

Hosing is required to transport the coolant around the engine, for example from the pump to thermostat and from the pump to the radiator. Hosing connects all the elements of the cooling system into one sealed system. The rule that applies to the catch cans also applies to the hosing in that it must be permanently rated to hold liquid that is at a temperature of 125°C. Most cooling systems have their hosing made of a rubber material, which should suffice our engine. Performance engines that are expected to run higher temperatures usually have their hosing made of aluminium or other high temperature rated metal.

7. Fuel

7.1 Return vs Returnless system

There are two types of fuel system; Returnless and return. Both systems supply fuel to the injectors with a constant fuel pressure. In a return system, a fuel pressure regulator (FPR) regulates the fuel pressure in the fuel rail and returns any unused fuel to the tank. This system requires little tuning as the fuel pump can be left constantly running at its max rate. A deadhead system is a type of return system where the FPR is placed before the fuel rail, this is the type of system that will be used on our car.



In a returnless system a fuel rail pressure sensor (FPRS) and a fuel pump driver module (FPDM) work together to supply fuel to the engine. Since excessive fuel cannot be returned to the tank the amount of fuel supplied to the engine has to be very close to what is needed. This system is more complicated and requires more tuning.

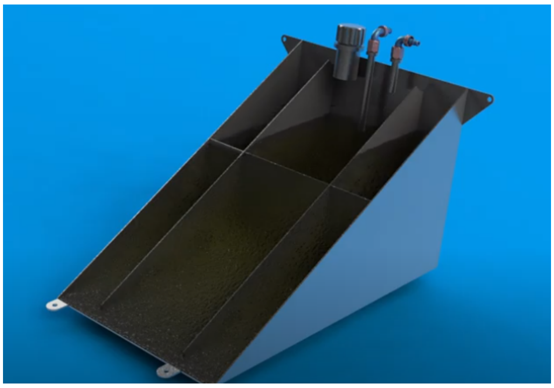
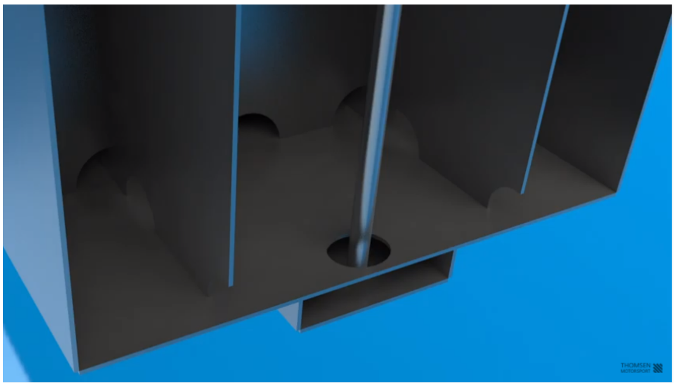
7.2 Fuel Tank

Every formula student car must have a fuel tank to store the fuel, petrol in our case. A typical fsae fuel tank has a volume of between 4 and 9 litres depending on the efficiency of the engine. According to the regulations, the tank can be made from any rigid material however they are normally made from aluminium or plastic. The fuel tank should be made in a way that prevents fuel from sloshing around too much as the car corners, this is normally done using fuel foam or baffles. Teams can manufacture their own fuel tank or they can buy a fuel tank from a go kart.

Nowadays people are more aware of harmful gases that can be emitted by automobiles. This is why gas tanks have a slightly more complicated design in order to prevent the leaking of harmful gases into the air. It also holds the fuel pump within its design.


When looking at the fuel tank it is essential to have a design that will aid the team into passing the endurance test. This test is deeply influenced by the design as it has to do with the fuel that is pumping into the car. When the tank begins to empty it becomes harder for the fuel to travel through. While the car is going on corners the fuel moves to the sides in a phenomenon called sloshing. This causes stresses on the walls of the tank thus causing fuel surges and unbalancing the car. To prevent this we can use baffles, which also provide internal bracing for the fuel tank. Baffles allow for the flow of fuel in the tank to be restricted.

One of the designs I saw was one where someone put the fuel tank behind and below the drivers back. The advantage of this was that the tanks are located right where the center of gravity is, which means that the balance won't shift as the car works through the fuel load. He has a triangular shaped fuel tank with three baffles which has three small holes on their base as shown in the picture below. He also had a small reservoir at the back which allows for fuel to flow into it and be picked up by the fuel pick up which has a small buffer which is extended to the reservoir through a small circular hole. By doing this he was able to prevent starving the engine when the tank is almost empty. This will be crucial in the endurance test.

7.2.1 Fuel Tank Manufacturing

If using aluminum there are several steps to consider before welding sheets together. First all surfaces need to be removed from oxide. Aluminum already comes with a thin oxide layer which melts at a far higher temperature than the base layer so if it is not removed then the weld won't be successful. This can easily be done by sanding the aluminium sheets and the surfaces can be cleaned with acetone. Once all elements are welded together it is important to do a simple leak test with an air compressor by applying a slight pressure. However, overpressurizing could cause some issues. Although the tank is able to withstand intense pressures it would not do well with internal pressures as the panels could bend easily. You can then rub some soapy water around the tank and then it is easier to locate minor leaks.

Another option to investigate is HDPE (High-Density Polyethylene) which is a special grade plastic. It is incredibly strong, durable and reliable. Some say that these tanks are a better choice as they are lighter, cleaner, will not oxidise, condensate less and can last as long as a steel tank would.

a. Advantages:
    i. 30% lighter than steel which in turn will improve fuel efficiency.
    ii. Heat from the environment transfers slower to the fuel in the tank because plastic is an insulating material.
    iii. Plastic tanks can be manufactured to be any shape and size required.
    iv. Plastic condensates less than steel which means that there will be less water in the fuel.
    v. Plastic does not corrode which will eliminate the factor of contaminating in future.
    vi. Plastic fuel tanks won't tend to have seams as they are made and moulded. Which means there is a lower chance of leakage.
    vii. Upon impact (if to occur) plastic tanks are a lot safer because instead of shattering into pieces it will bend out of its natural shape and they will not spark.
    viii. There is a limit on the size of how big plastic tanks can be. The maximum capacity is generally 6,500 liters which for a single car

Thermophysical properties of High Density Polyethylene (HDPE)[3]

Density	940 kg/m^3
Melting Point	130.8 °C.
Temperature of crystallization	111.9 °C.
Latent heat of fusion	178.6 kJ/kg.
Thermal conductivity	0.44 W/m.°C. at °C.
Specific Heat Capacity	1330 to 2400 J/kg-K
Specific heat (solid)	1.9 kJ/kg. °C.
Crystallinity	60%

Table 1 Physical and chemical properties of HDPE

Physical description	Properties or value
Melting point	110–140 °C
Specific gravity	0.9–1.0
Density	0.9–1.0 g/cm^3
Volatile matter (wt)	<0.1 %
Water absorption (wt)	<0.05 %
Melt flow index	6 g/10 min (2.16 kg at 190 °C)

Table 5 Mechanical properties of HDPE and HDPE composites at different CS contents

CS content (% by wt of HDPE)	Yield stress (MPa)	%Elongation at yield	Tensile strength (MPa)	%Elongation at break
0	19.56 ± 0.47	10.3 ± 0.47	15.66 ± 0.38	53.75 ± 2.56
2.5	20.90 ± 0.24	9.34 ± 0.68	16.76 ± 0.21	47.82 ± 8.47
5.0	20.93 ± 0.11	8.82 ± 0.71	17.36 ± 1.24	27.92 ± 10.15
7.5	20.72 ± 0.27	8.67 ± 0.52	17.25 ± 0.79	23.76 ± 12.95
10.0	21.07 ± 0.35	8.22 ± 0.48	17.57 ± 1.43	21.11 ± 7.01

7.3 Fuel pump

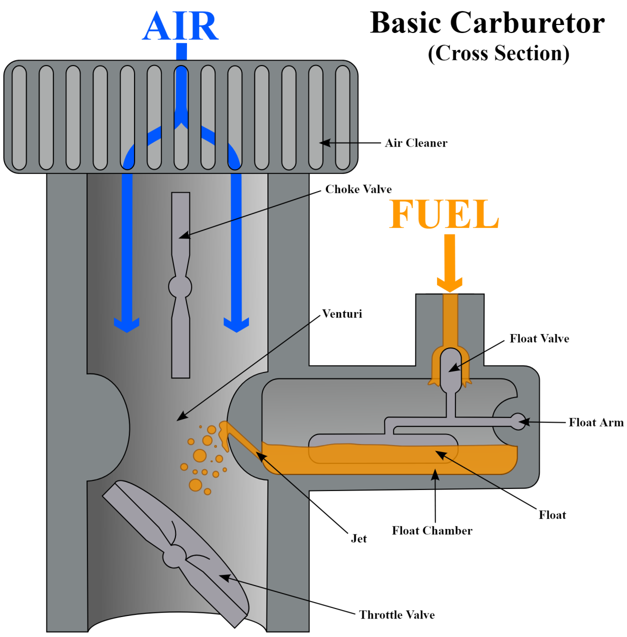
In a return fuel system, the fuel pump supplies a constant volume of fuel to the fuel rail and any excess is returned to the tank. Some fuel pumps are built into the fuel tank, however our one is located outside the tank.

The reason for why mechanical pumps can use deadhead systems is because the pressure of the fuel increases with the revolutions per minute (RPM), which on a car can be seen over a tachometer, (which essentially measures the speed at which the disk in the motor is rotating at). The design of mechanical pumps allows for only the amount of fuel needed by the carburetor to pass through the pressure side of the system.

- Tachometer

7.4 Carburetors

In the past cars would use a device called a carburetor to feed fuel and air into the combustion chamber of an engine. This worked due to a vacuum that was created by the engine in order to pull in air and fuel into the cylinders. As the throttle opens and closes it allows specific ratios of air to come into the engine. This vacuum was needed to keep the engine in a steady state and working. Apparently in modern day, carburetors are no longer used but instead have been replaced by computerized fuel injection systems which work in exactly the same way. Carburetors will typically cost between €170 and €260 and replacing it would incur an even greater cost to be more than double the original cost.



7.5 Fuel Injectors

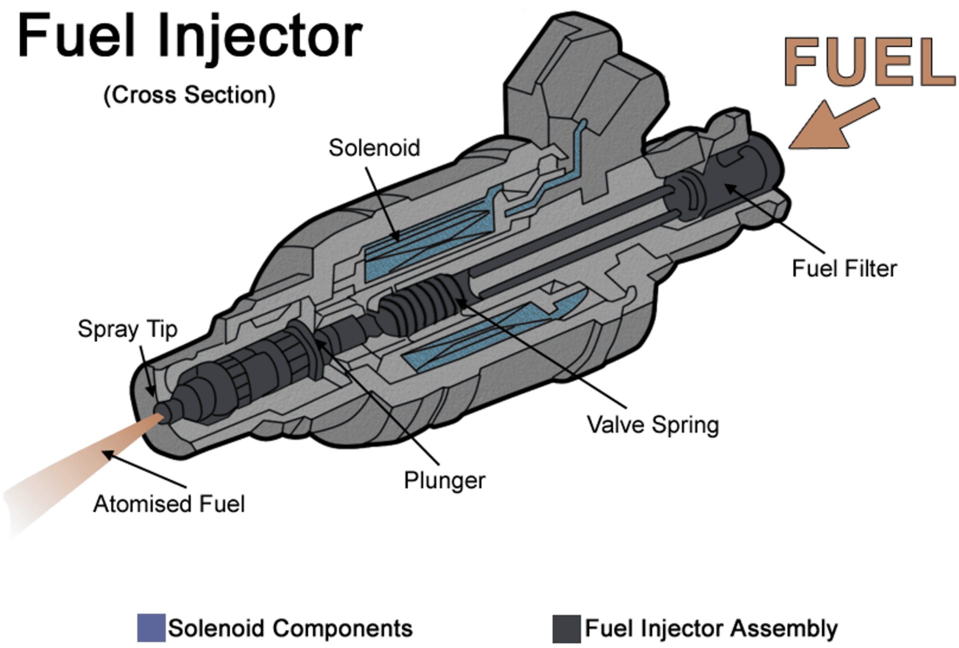
These are very simple devices that have practically replaced the carburetor. They are essentially small electric valves that open and close on command to allow the flow of fuel into the engine. These little valves, as it were, are operated by a computer instead of a carburetor which would mix the fuel and air together. Fuel injectors have had a positive effect ecologically and economically. Basically fuel is pumped through the injector and travels across it thus keeping it atomized. This will help when igniting the fuel with the spark plug (bottom picture). An average injector can cost between €670 to €1230 to replace and if you buy the parts alone for self assembly the cost drastically drops around €250.

Two common fuel injectors are TBI and EFI injectors. In our race car we use an EFI injector. TBI injectors are an abbreviation for throttle body injectors which deliver fuel to a specific location within the intake chamber of the engine. EFI stands for electronic fuel injection. TBI and EFI are essentially the same as TBI injectors and are most definitely also an electronic fuel injection system. The difference comes down to placement and the sizing. These two injection systems can be tested quite easily.

Test for TBI Injectors:
To check the fuel spray on these injectors you can do so by simply removing the cover protecting the air cleaner and having someone start the engine. A spray will begin to come out and a healthy looking injector will have a partially atomized inverted V pattern. If the spray is coming in an irregular pattern then the injector requires cleaning. There may be other issues but this is the most common occurrence.

Test EFI Injectors: (This is the type we have)
EFI injectors unfortunately are a bit trickier as it is not as accessible to test. A lot of time there is very little room for accessing the injector where it is placed without having to remove the whole body. Even though we cannot inspect the injector on hand there are other tests that we can conduct. In order to conduct an easy test is by using a mechanics stethoscope to listen for the activity of the injector. First you need to start the engine and give it some time to run. Then hold on the brake and open the hood of the car from where you will insert the stethoscope and put the tip of it on the side of the injector. If you hear a clicking sound then it means the injector is running smoothly as this is the process where the injector is opening and closing where the solenoid is activating and deactivating the valve. If no clicking sound is produced then it is very likely you have a dead injector where either the solenoid has not been successful or the injector is not receiving signals from the computer.

-Mechanics Stethoscope (Average price = €30)



7.6 Fuel Filter

The quality of the fuel is essential to the performance and lifespan of an engine so therefore keeping the fuel clean is key. Fuel injectors have many openings or small crevices that can get clogged with impurities and particles. Filters are thin sheets usually made out of stainless steel or a paper element. A good idea is to get filters that have washable meshes so you can clean it every 3 months or so and avoid having to replace it. Although these are incredibly important they are not perfect and overtime impurities will begin to clog up the injectors. An additional cleaner that can be added is a STP injector cleaner or Techron fuel system cleaner which are sold in regular department stores and gas stations. These liquids are to be added into an empty tank before filling up the tank with fuel so that the system gets cleaned as you drive. It is recommended to do this every 3 months to keep the fuel injectors as clean and new to increase performance.

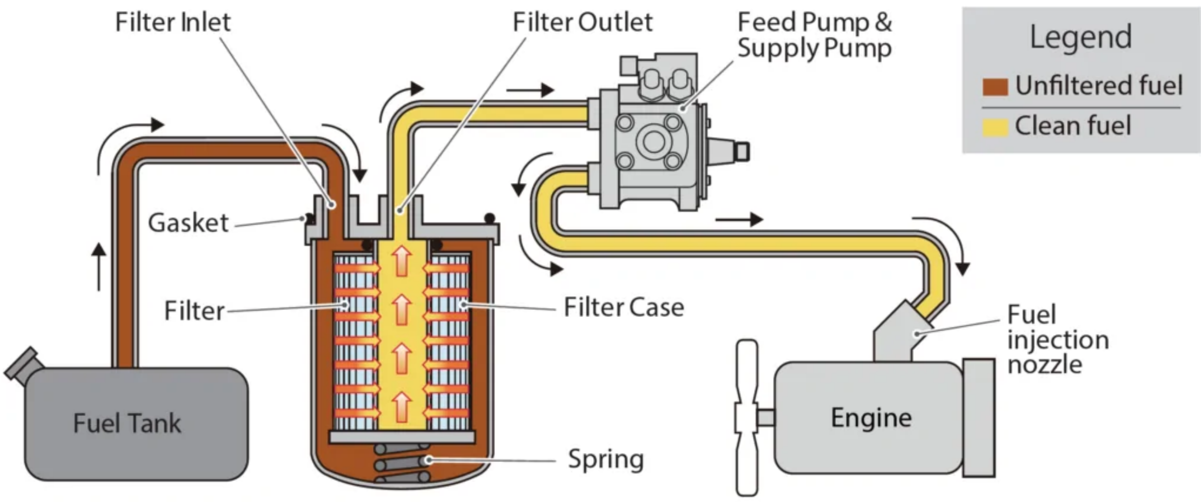


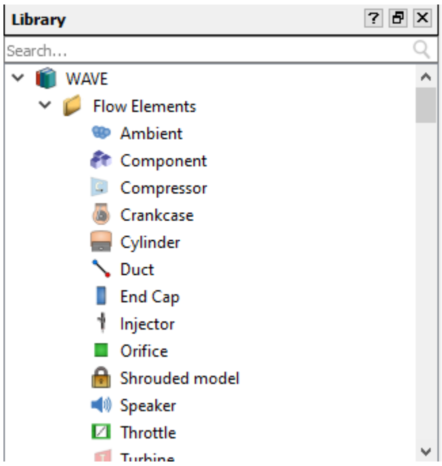
Fig. 1 Fuel Filtering

7.7 Sources for Section 7 (Fuel)

https://www.hotrod.com/articles/ccrp-0712-fuel-system/
https://www.youtube.com/watch?v=oIU-IGc3DL4
http://wiringnotes.rapfrance.fr/bmw-fuel-filter-diagram.html (Image fuel filter)
https://www.autoeducation.com/autoshop101/fuel.htm
https://axleaddict.com/auto-repair/How-to-Test-Fuel-Injectors-3-Simple-Methods
https://en.wikipedia.org/wiki/User:WikipedianProlific/Gallery (Image carburetor and fuel injector)
https://www.youtube.com/watch?v=2wq5K8LHNKU&t=195s
https://www.youtube.com/watch?v=00pwEs02W44

8. Ricardo (A How To):

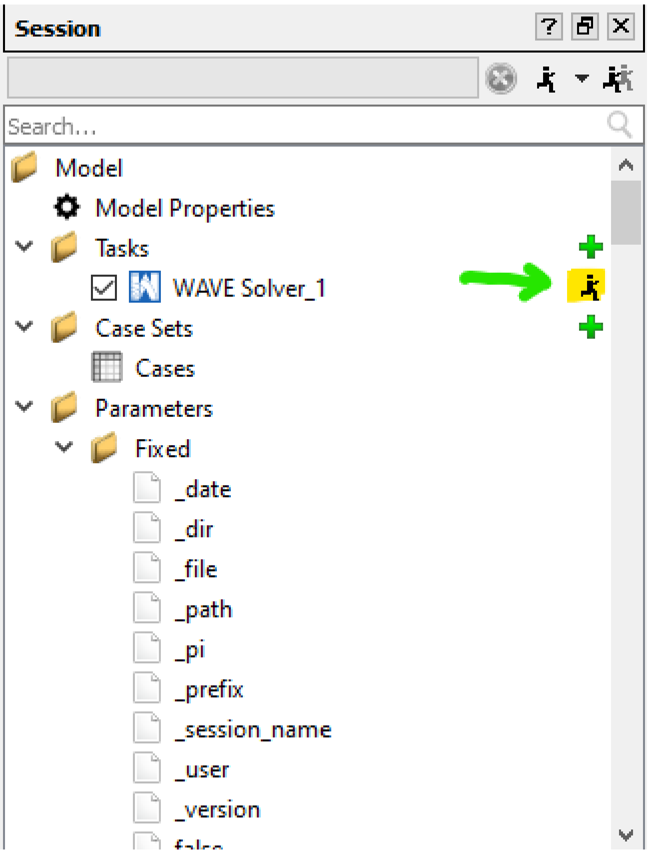
8.1: Wave Elements:



- Drag and drop wave elements onto main viewing window to begin
- Once elements are on the viewing window simply connect your model.
- To move around the viewing screen
    - Zoom in/out = scroll wheel
    - Move the model = press down on scroll wheel.

8.2: Running:

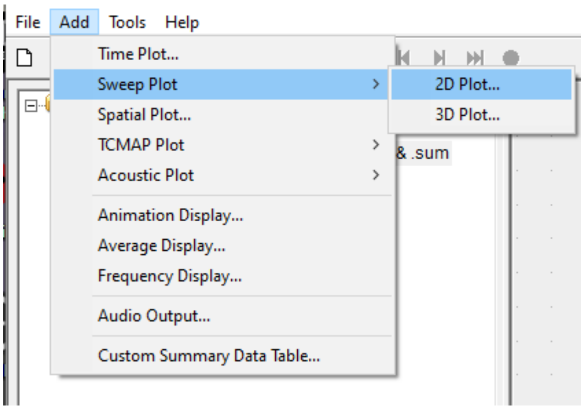
- First save by clicking  .
- Press the run button located in the *Session* window:



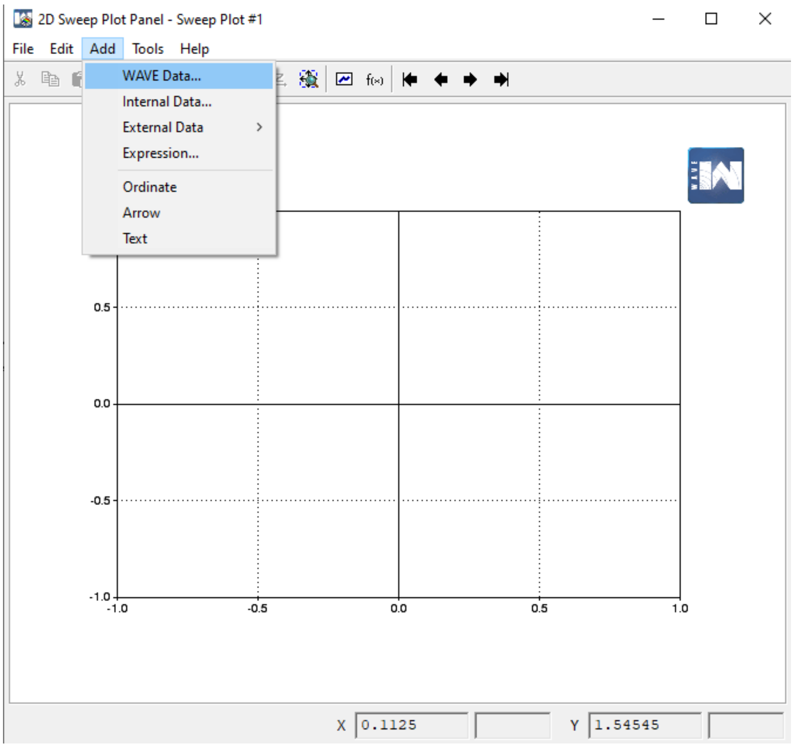
-
- Once the program has finished running you will see a “Done” message in the console. When this is the case you can begin extracting data.

8.4: Graphing:

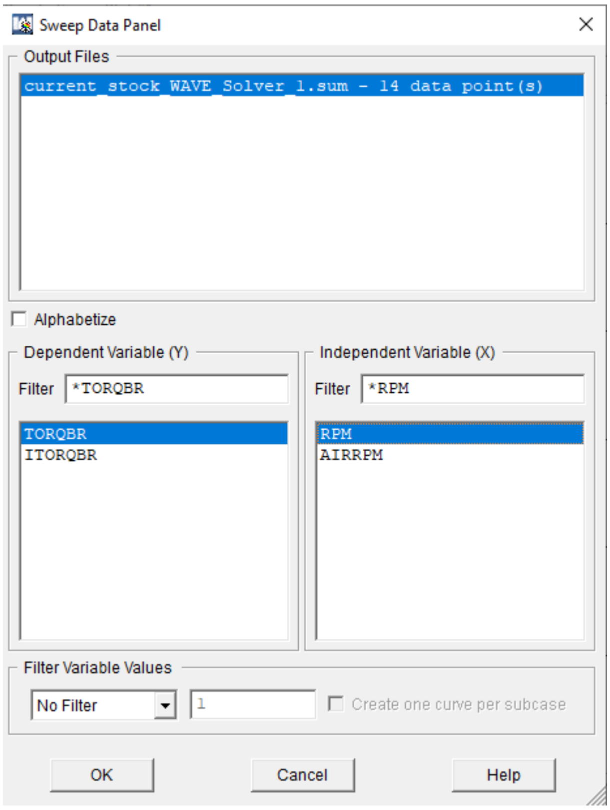
- Click on the WavePost icon located at the top of the screen .
- To create plots there are various options. The best is to:
    - Click “Add”, “Sweep Plot” and then “2D Plot”



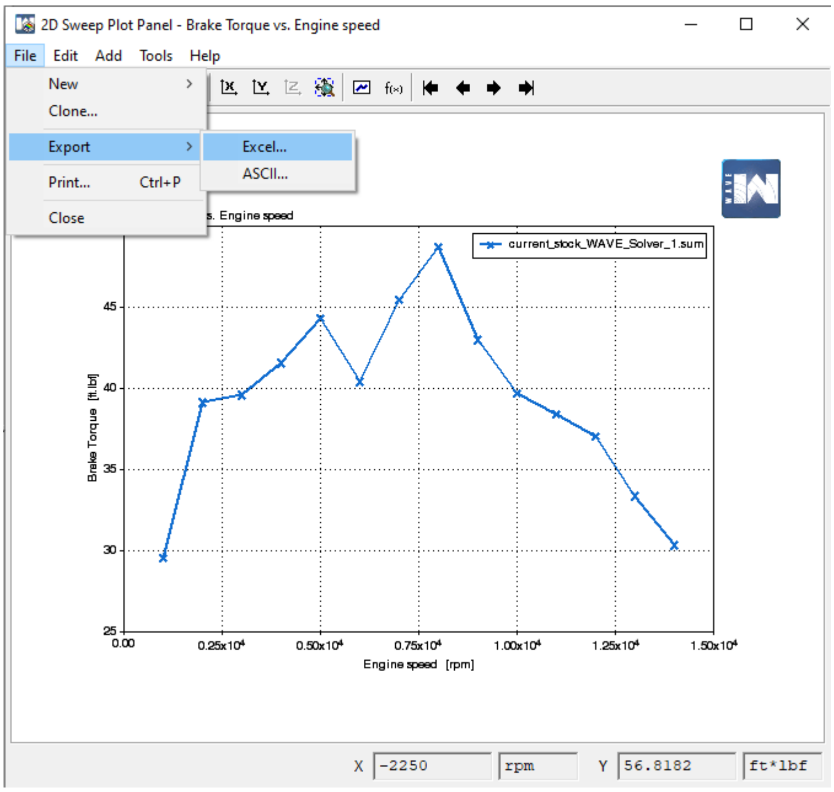
- This window will appear and you can press “Add” followed by “WAVE data”. This will allow you to create plots of many components across your model.



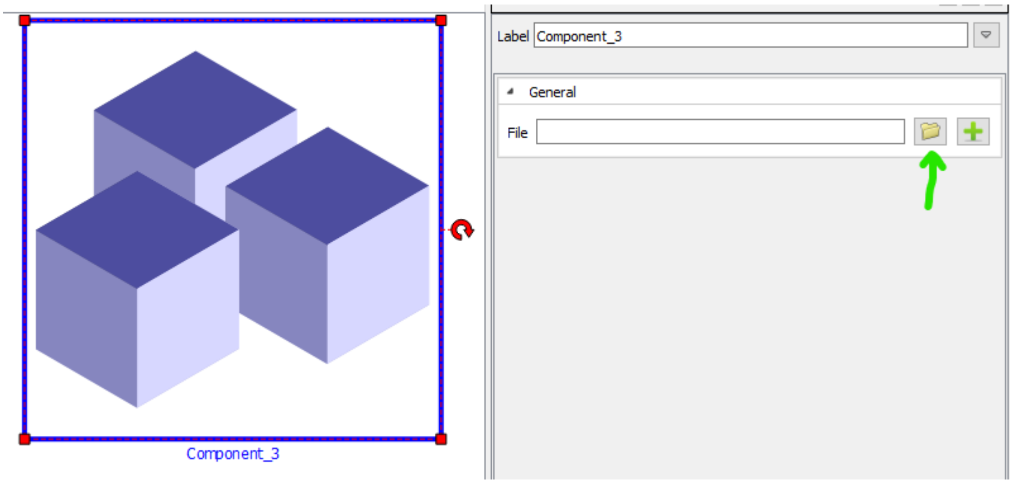
- To create a graph of Torque vs RPM look for the following on the search part:
- The process is the same to plot a graph of HorsePower (BHP) vs RPM.



- To export the graph to excel click file and export



8.4: External Components:

- You may wish to add either your own components or ones in the Ricardo library to do this drag and drop a “Component” element onto the screen and click on the folder icon:
- 

- If using files from the Ricardo library click through the following maze to find what is required:
    - Go into your “Program Files”
    - Ricardo
    - 2020.3
    - Products
    - WAVE
    - Examples
- If you are importing a design from Solidworks then click on the green plus sign.
- WaveBuild3D will start up as a separate program.
- Click on “File” and import your file. You will need to mark out the areas where the ducts will be connecting using the cutting tool (I cannot show this as I have lost my license...)