SECTION BP05 – Fuel System

CONTENTS

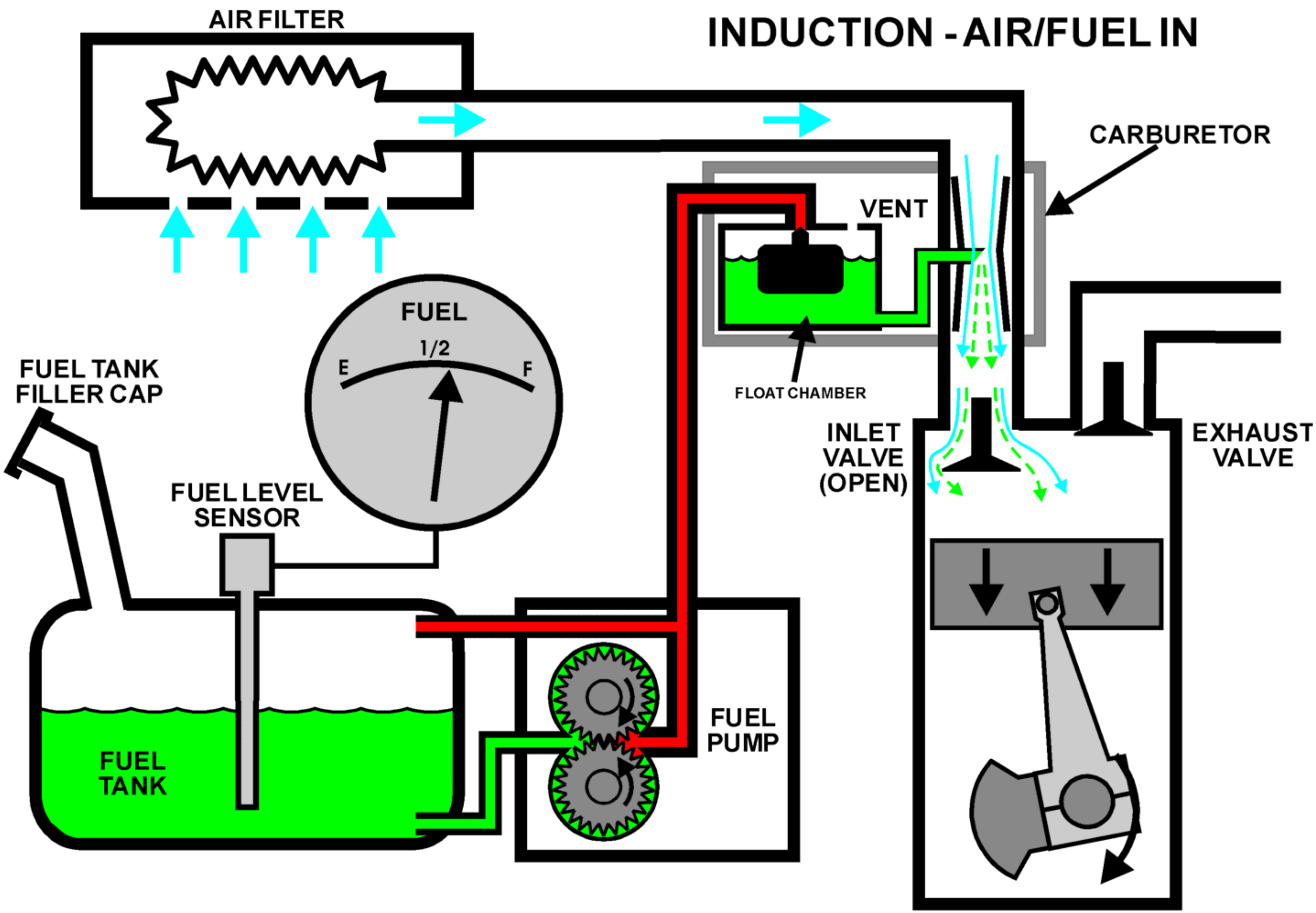
FUEL SYSTEM – Carburettor System

Introduction

Fuel is contained within the aircraft tanks (description on page 4 and 5) and is supplied to the carburettor by a pump (descriptions from page 6 to 11).

The carburettor controls the mixing of air and atomized fuel, and the flow of the mixture to the engine, therefore control of the fuel flow via the carburettor is control of the engine.

In this section we will cover the various parts of the system, the operation and features of the carburettor, including enhancements which improve the efficiency of the carburettor operation.



SIMPLIFIED PISTON ENGINE FUEL SYSTEM

FUEL SYSTEM – Fuel Tanks

Description

Fuel is stored in the aircraft wing tanks in most aircraft. These tanks are not usually a separate container built into the wing as would be found in a vehicle. Aircraft fuel tanks are actually formed by the structure of the wing, i.e. the upper and lower skins, the main spar and a rear spar. There are usually more than one tank in each wing i.e. the tank cavity is separated into sealed sections. This is to prevent total loss of fuel in the event of a tank rupture.

Fuel is usually pumped from the wing tanks into a central feeder tank, then distributed to the engines. Fuel can also be transferred from tank to tank to help balance the aircraft in flight. This allows trimming the aircraft efficiently without using aerodynamic forces which cause drag.

The tank is filled by simple external pump and supply from a main tank, either vehicle born bowser or underground storage tanks, as with vehicle filling stations.

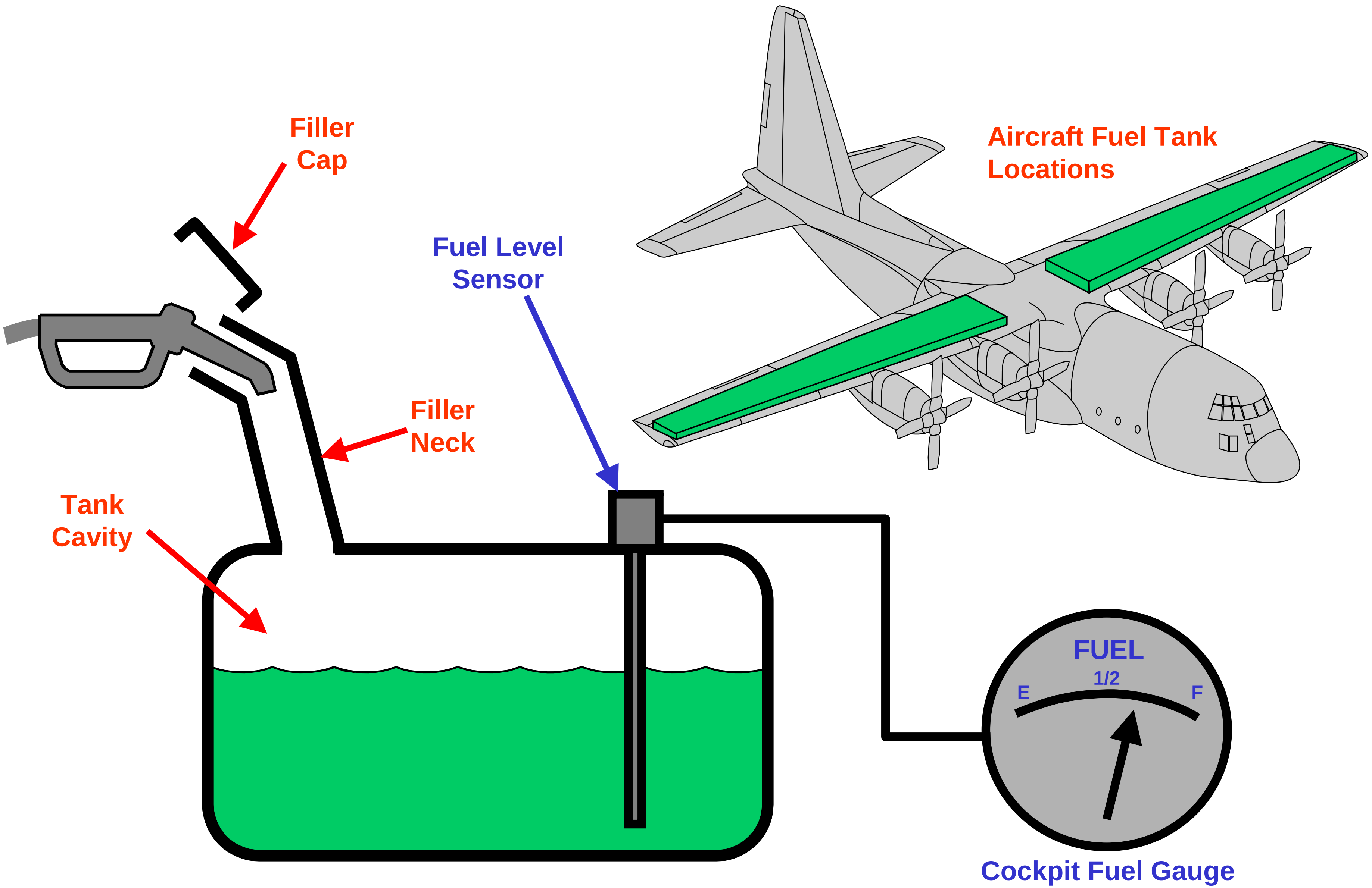
Extra fuel tanks can be added to military aircraft to increase range, and they can also take fuel onboard whilst in flight from flying tanker aircraft.

Civilian aircraft do not need extra tanks, these aircraft are design for a maximum range, and only go further than that range by refuelling on the ground.

The filler hose connection is usually underneath the aircraft wing and is actually a self sealing device to prevent spillage, and hidden away behind an access hatch to maintain aerodynamic smoothness.

Fuel level is measured via a level sensor and indicated on the flight deck. Modern systems can calculate possible range from the quantity on board and the usage at any given point.

Other indications can be flow rate, fuel used, fuel temperature.


Filler
Cap
Fuel Level
Sensor
Aircraft Fuel Tank
Locations
Filler
Neck
Tank
Cavity
FUEL
1/2
E
F
Cockpit Fuel Gauge

FUEL TANKS

FUEL SYSTEM – Mechanical Diaphragm Pump

Description

A Positive Displacement pump. This usually means when the pump is operating, flow will occur, and when the pump stops, flow is prevented. However, this kind of pump would allow flow when not operating, if there were some other pumping force available.

Flow is relative to pump oscillations/cam speed.

This pump consists of a flexible diaphragm or rubber membrane, which is moved up by spring force and down by an engine driven cam, and two one-way valves.

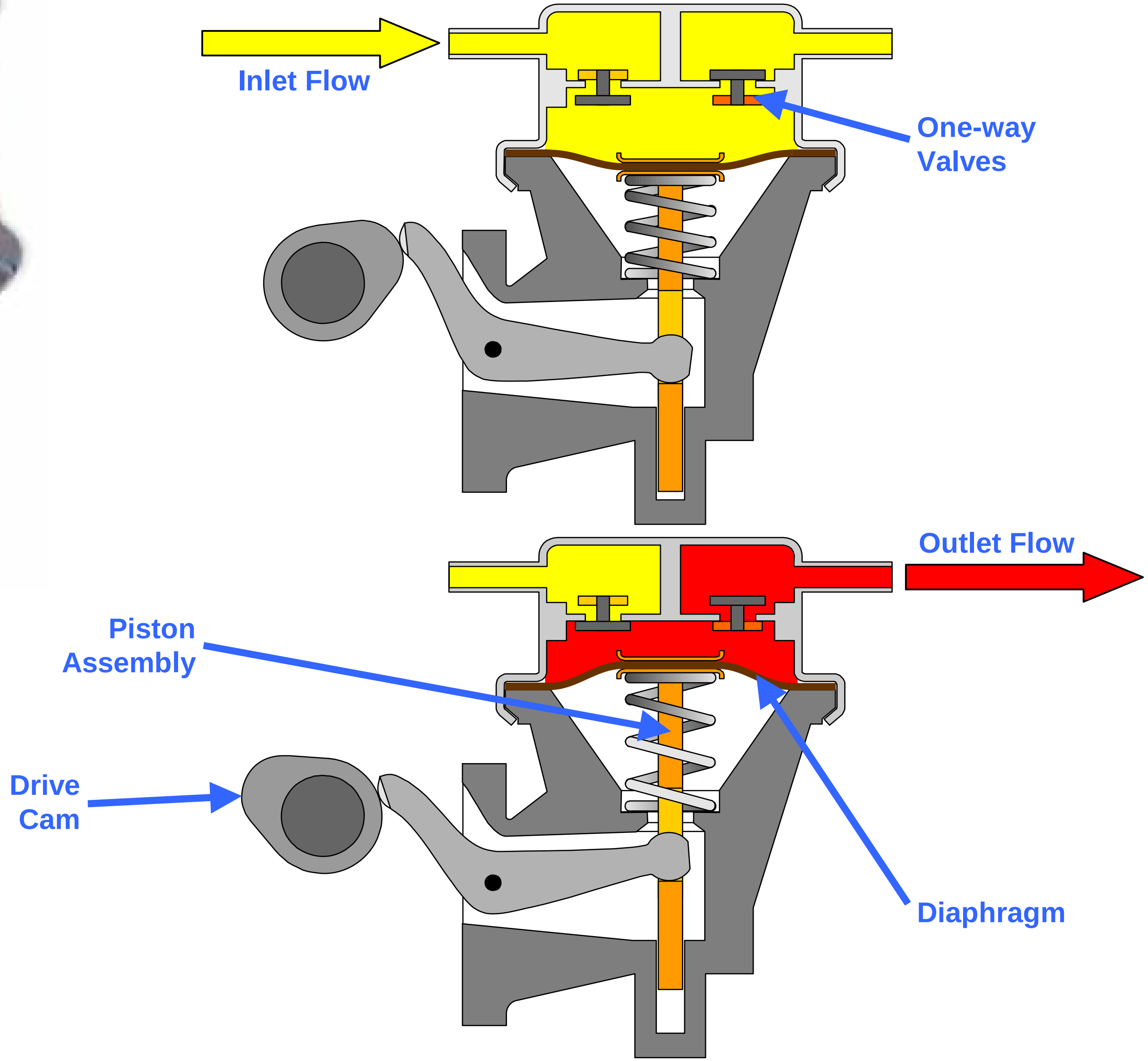
Operation

As the cam rotates it operates a rocker lever which drives the piston in the downward direction (in this case) and also compressing the spring.

The returning upward force is supplied by the compressed spring.

In the downward direction the chamber volume is increased which causes suction opening the one-way inlet valve (forcing the outlet valve to close) and pulling fluid into the chamber.

When the spring forces the piston and diaphragm upwards the chamber volume is reduced, the inlet valve is forced shut and the one-way outlet valve is forced open by the fluid passing through it.



FUEL PUMP – Mechanical Diaphragm Pump

FUEL SYSTEM – Solenoid Diaphragm Pump

Description

A Positive displacement pump.

Flow is relative to pump oscillations.

This pump consists of a flexible diaphragm or rubber membrane, which is moved up and down by an electro-magnetic force, and two one-way valves.

Operation

The solenoid diaphragm pump works in exactly the same manner as the mechanically driven pump described on the previous page, except for the motive force.

In this pump, the piston is moved up and down by magnetic field generated by the electrically powered coil underneath.

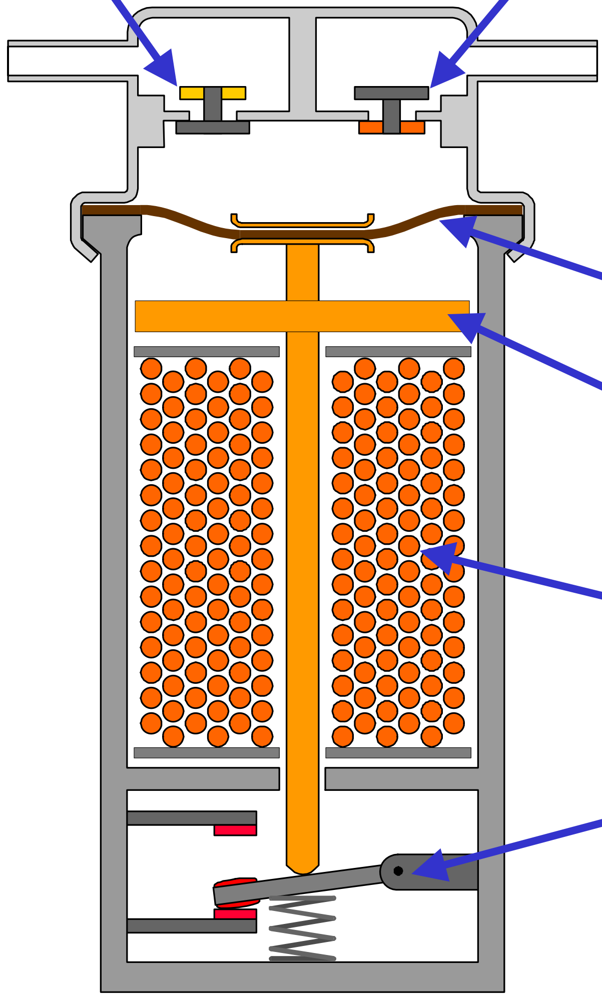
The movement of the piston and diaphragm also switches the coil operation, as follows: -

At the bottom of the downward stroke the coil is de-energized and immediately re-energized in the opposite direction. This switches off the ‘downward’ magnetic field and switches on the ‘upward’ magnetic field. At the top of the upward stroke the reverse happens.

The continual up and down movement of the piston operates the diaphragm and valves as previously described.

This continues until the power to the coil is switched off.

The frequency of the oscillations in this pump is greater than the mechanically driven pump, therefore usually the solenoid pump chamber is a smaller capacity compared to the mechanically driven pump for a comparative flow rate.



FUEL PUMP – Solenoid Diaphragm Pump

FUEL SYSTEM – Gear Type Pump

Description

A Positive displacement pump, flow is relative to pump rpm and no flow is possible when the pump stops.

This pump consists of two intermeshing straight cut (in this example) spur gears rotating in a close fitting body.

Angled gears can reduce pressure pulsations which can occur with straight cut gears.

Gear type pumps are usually the choice of pump in modern electronic controlled systems, *and* because of the few, relatively easy and therefore cheaper to produce, moving parts.

In modern vehicle systems, the fuel pump is actually placed inside the tank as part of the pump and level sensor assembly.

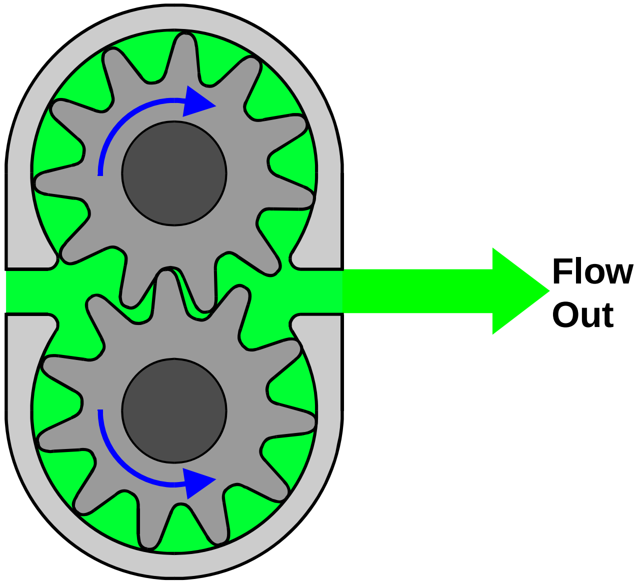
Operation

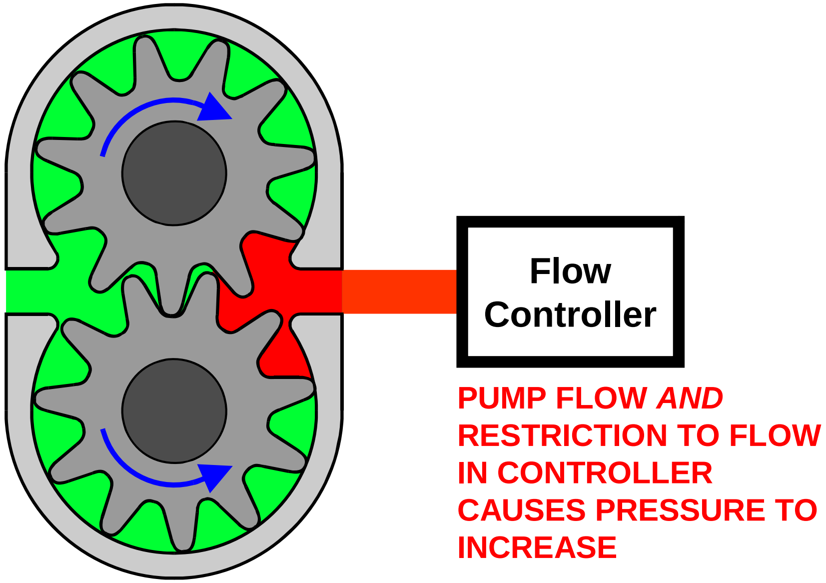
One of the gears is the ‘driver’ gear, engine or electrically driven, which in turn drives the ‘driven’ (idler) gear via the intermeshing gear teeth.

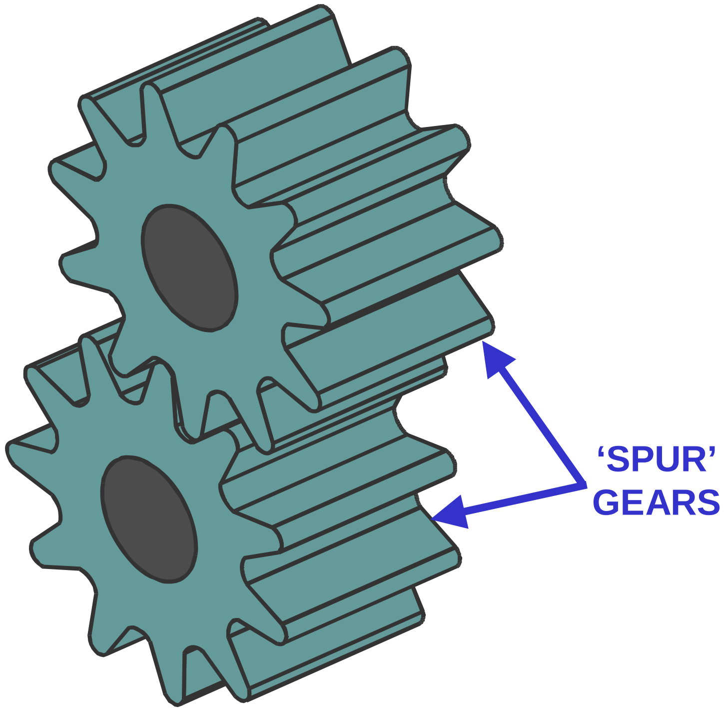
As the gear rotates, the fluid is carried around the outside of both of the gears between the gear teeth.

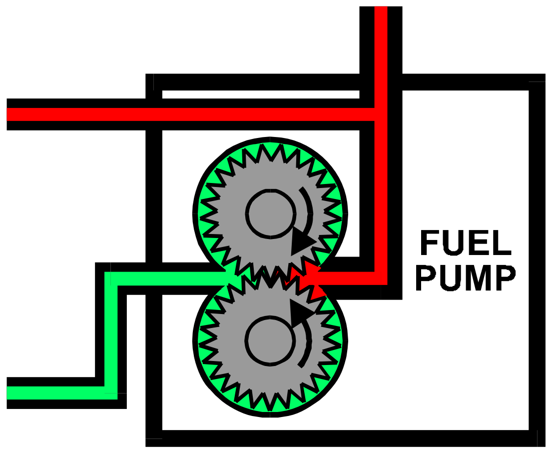
The pump provides the flow, but if there were no system to pump it through there would be no pressure. Pressure is only achieved because the flow control system works on flow restriction which causes the pressure to rise.

A pressure relief valve is usually included to limit absolute pressure in the system (not just the pump), to protect against physical damage. When the pressure relief valve opens, often the excess fluid is simply passed around to the inlet side (or LP – Low Pressure from the HP - High Pressure) side of the pump, or it can be returned to the tank.









FUEL PUMP – Gear Type Pump

FUEL SYSTEM – Air Filter

Description

Usually a paper based element bonded into a rubberized material which also serves as a seal.

Operation

The paper element is concertinaed into the rubber seal to get the greatest surface area in the smallest space possible.

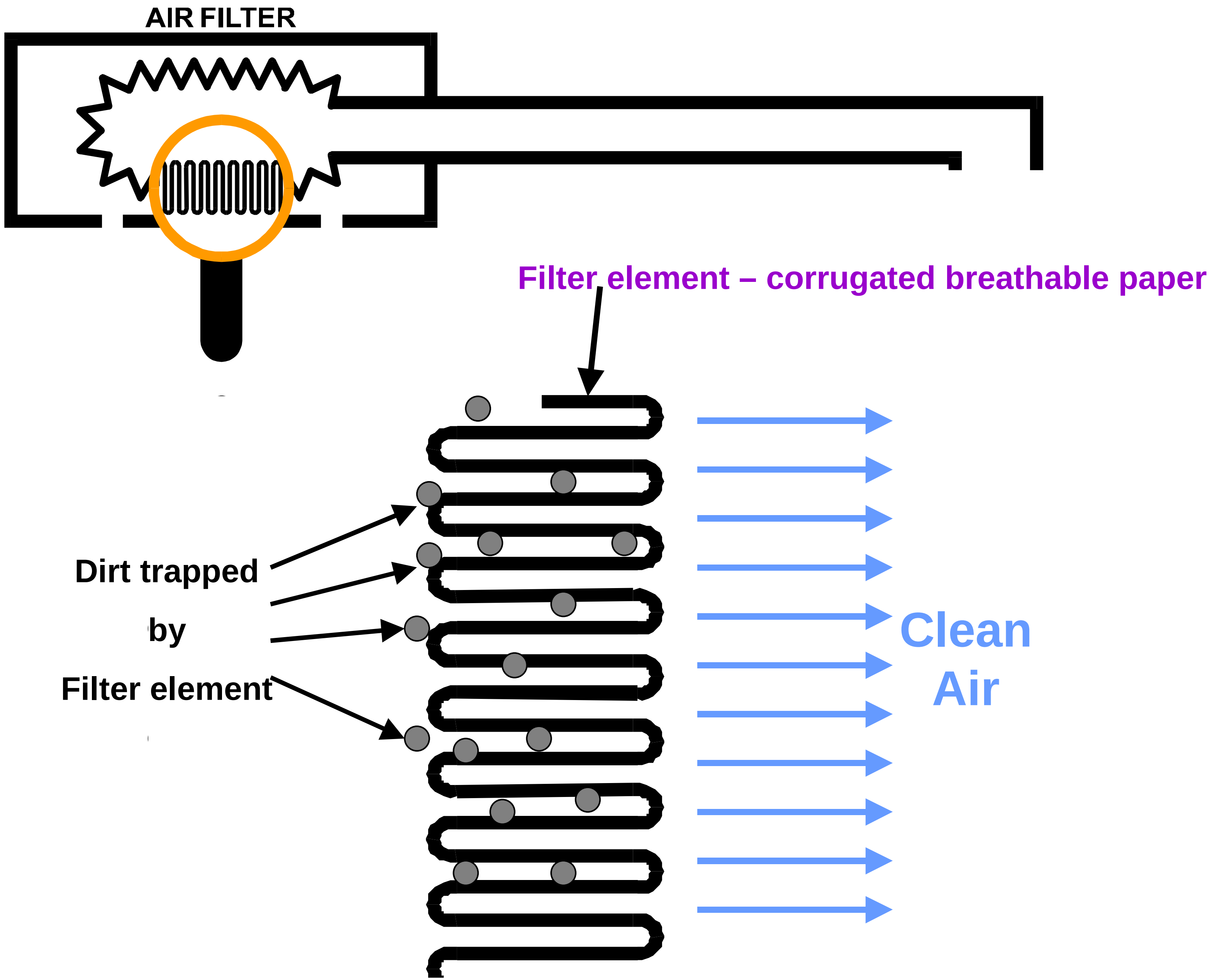
Air with contaminants passes through the filter, which catches the contaminants and leaves the air cleaner.

The filtration rate is determined in Microns (1 micron = 0.000,001 metre). So a filtration rate level of 30 microns would stop particles of 30 microns and bigger, but allow smaller particles to pass through. These smaller particles would not cause any damage or blockage in the fuel system or engine.

Fuel Filter

Some systems incorporate a fuel filter in the supply line to the carburettor.

The operation of a fuel filter is exactly the same principal as described above, except fuel with contaminants passes into a paper element, leaving the contaminants trapped upstream of the filter paper, and clean fuel passing to the fuel system.



Basic Air Filter Operation

FUEL SYSTEM – Carburettor Air and Fuel Mixing

Description

The carburettor is mainly a fuel reservoir and an air delivery tube

Fuel is supplied through a number of ‘jets’ (fuel delivery orifices) but mostly through the main jet. The main jet level is the same as the level in the float chamber (reservoir).

There are other features, which can make even the simplest carburettor seem very complicated, some of which will be covered in the following pages.

Basic Operation

Air is drawn through the carburettor everytime a piston is on the induction (suction) stroke. The air is accelerated through a ‘Venturi’ (a convergent and divergent duct).

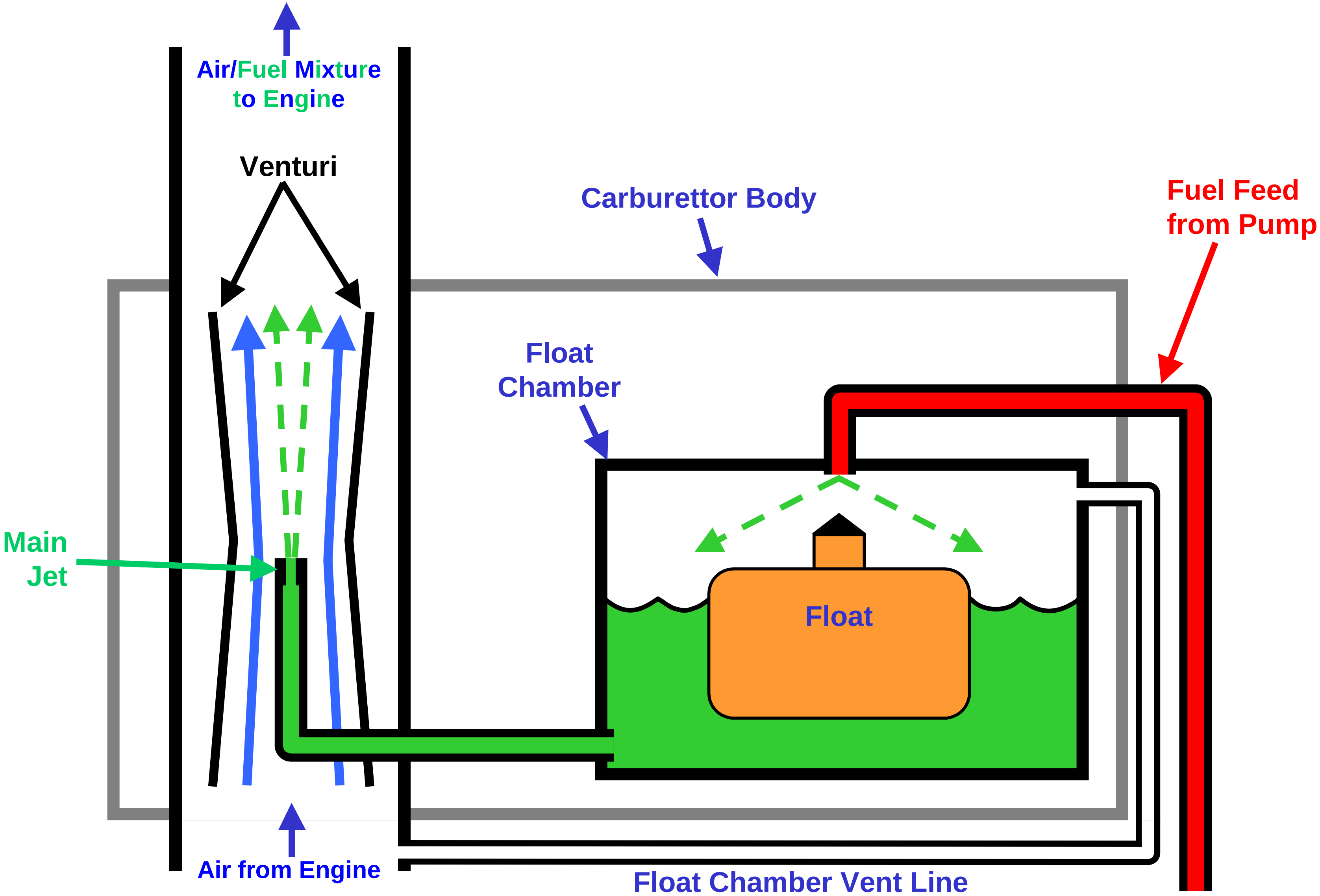
When air is accelerated the pressure is reduced, and the reduction in pressure pulls fuel out of the float chamber through the main jet.

When fuel is taken from the float chamber, air enters the chamber via a vent, and the float drops opening a needle valve, allowing the fuel to be replaced by the fuel pump. As fuel enters the float chamber, air is forced out of the vent and the float rises, closing the needle valve again.

When the needle valve is closed the fuel delivered by the pump is returned to the tank or circulates in the pump as previously described.

The float chamber is vented to the inlet side of the carburettor.

This is to prevent the possibility of the main jet flow being to great due to a lower pressure in the carburettor air tube compared to atmospheric pressure, i.e. erroneously increasing the suction flow through the main jet.



SIMPLIFIED PISTON ENGINE FUEL SYSTEM

FUEL SYSTEM – Throttle Valve

Description

The throttle valve consists of a plate mounted in a central spindle an actuated via a linkage by the pilot (or driver) operating the throttle lever (or foot pedal respectively).

The plate shape is designed to closely fit the air down tube in the carburettor; the example shown below is round, but they can be any shape to suit the design of the carburettor.

Operation – fully open

In the fully open position, maximum airflow and fuel flow enters the engine (via the suction of the induction stroke), allowing the engine to run at maximum power and rpm.

The fully open position can be set by an adjustable screwed stop on the carburettor body.

Operation – fully ‘closed’ position

In this position, sufficient air, and fuel, is delivered to the engine to allow the engine to run at idle or ‘tick-over’. The latter term comes from the noise older engines used to make, i.e. the tapping of the valve mechanism at low rpm.

This position also usually has an adjustable stop on the carburettor body. Adjusting this stop will change the idle speed.

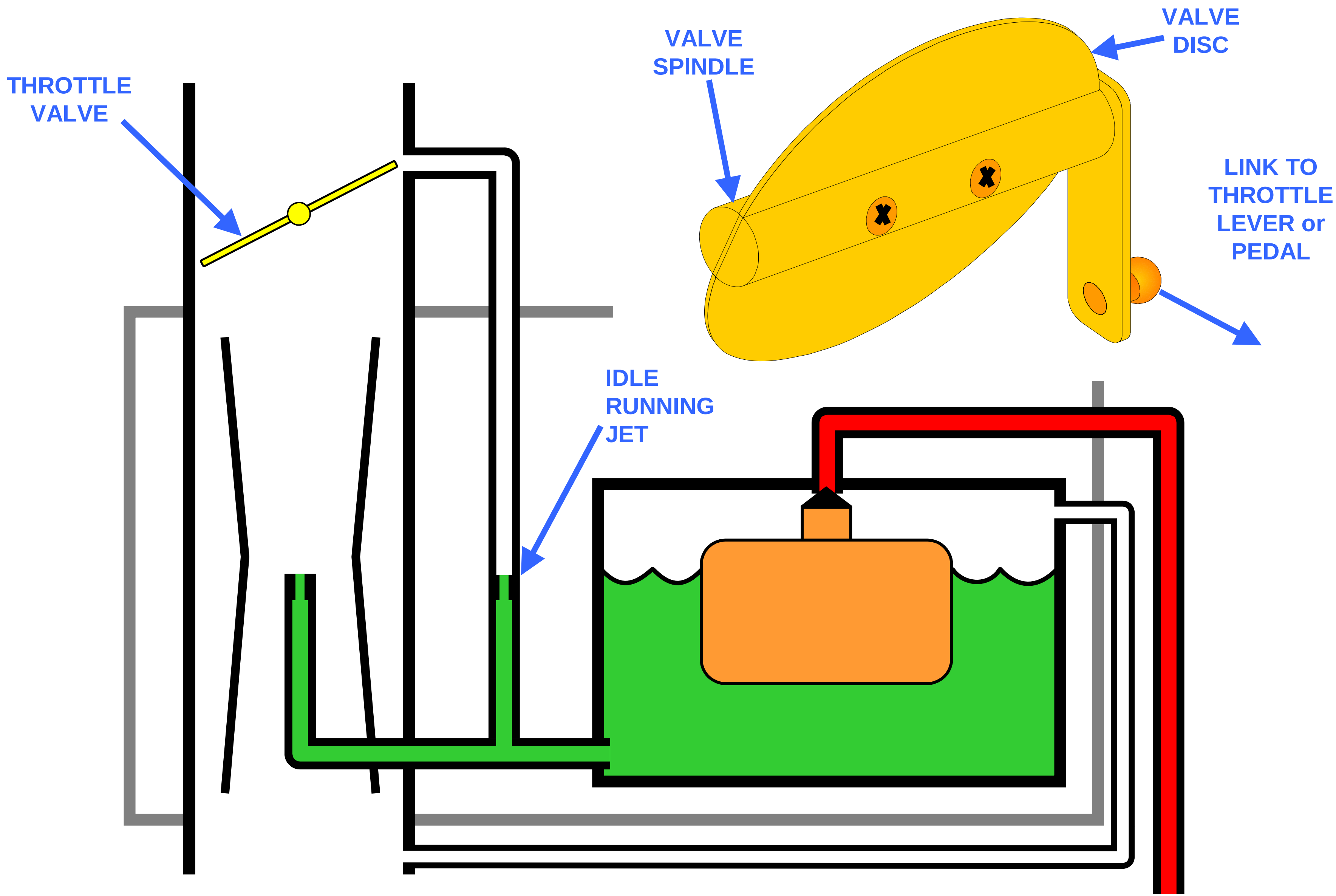
Fuel mixture can also be adjusted at idle to ensure the engine runs at the correct mixture, around 15 parts of air to 1 part of fuel by weight not volume, this is called the ‘chemically correct ratio’.

Operation - Idle Running Jet

When the throttle is at the idle position, the venturi is less effective because the idle airflow quantity is too low to cause a drop in pressure sufficient to provide the fuel flow to keep the engine running at idle, so the engine will ‘stall’, i.e. stop running.

However the airflow around the edge of the throttle valve plate does speed up sufficiently to cause a drop in pressure (venturi effect) which will supply sufficient fuel for the idle condition, preventing the engine from cutting out.

When the engine is accelerated away from idle the venturi effect around the throttle plate soon disappears and the main venturi comes into operation. At this point the fuel flow through the idle jet ceases and the main jet now controls the fuel flow.



SIMPLIFIED PISTON ENGINE FUEL SYSTEM

FUEL SYSTEM – Air/fuel mixing

Purpose

Efficient air/fuel mixing is essential for efficient combustion. The fuel needs to be ‘atomized’ i.e. broken down into the smallest particles possible.

The reason for this is fuel in liquid form doesn’t burn, it is the vapour from the fuel which burns. Fuel naturally vaporizes in normal atmospheres, but this becomes extremely rapid when heated. When fuel vapours are ignited, the resulting heat rapidly boils the liquid fuel (fuel has a low boiling point – as low as 37°C depending on additives etc) turning it to vapour which also burns; this happens so fast it produces an explosive force.

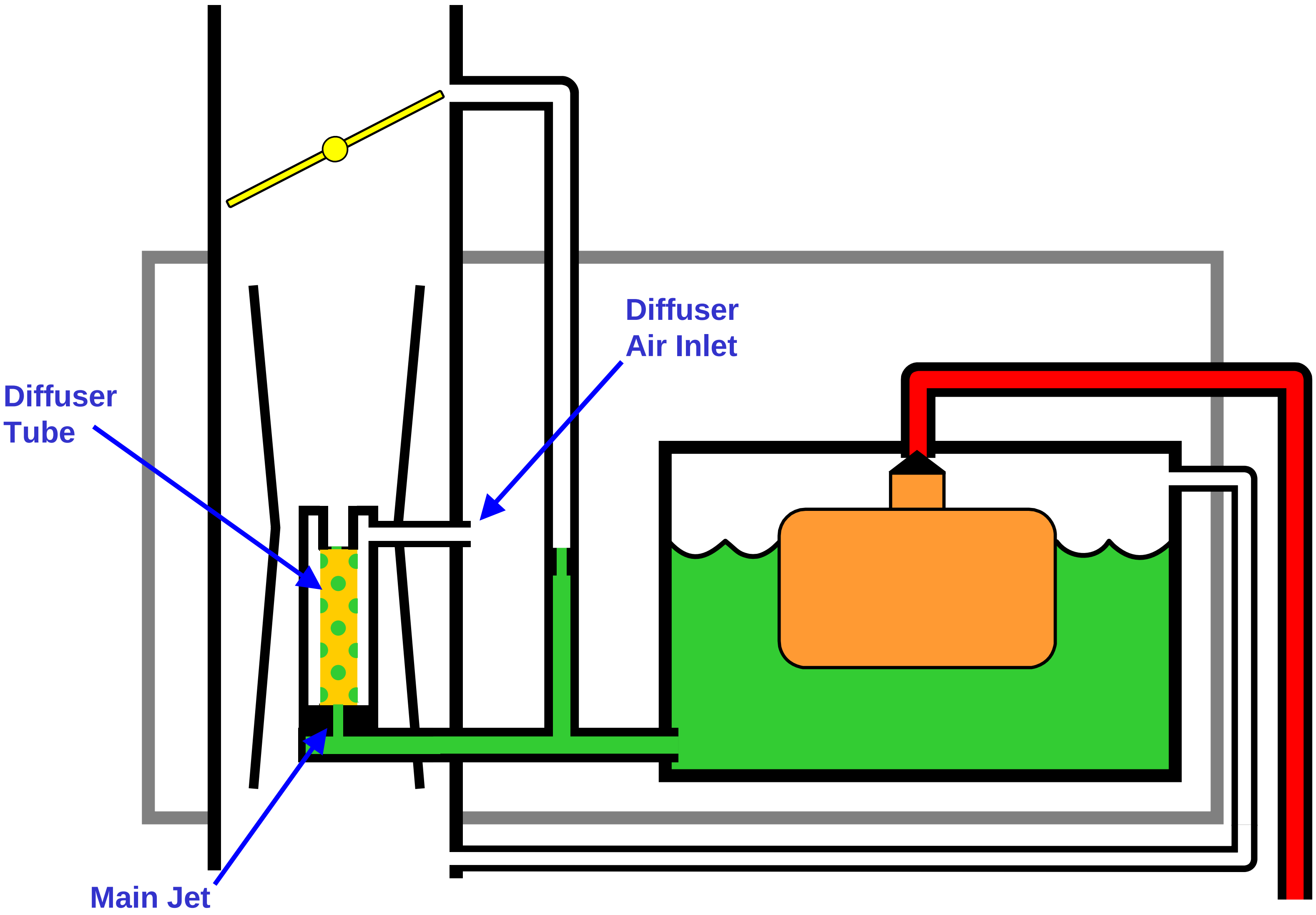
By atomizing the fuel, we are creating a greater surface area to give off vapours, therefore the smaller the atomization, the quicker it vaporizes and therefore the greater efficiency of combustion and the level of energy produced.

Vaporization of the fuel is achieved by the residual heat initially in the combustion chambers (cylinders), but then the intake manifold when the engine is up to normal operating temperature.

Description

Efficient mixing is achieved by including a diffuser tube. This is a tube fitted after the main jet and consists of a tube with holes (air inlet holes) drilled into it.

The top end of the tube is level with the fuel level in the float chamber.



SIMPLIFIED PISTON ENGINE FUEL SYSTEM

FUEL SYSTEM –Air/Fuel Diffuser

Operation

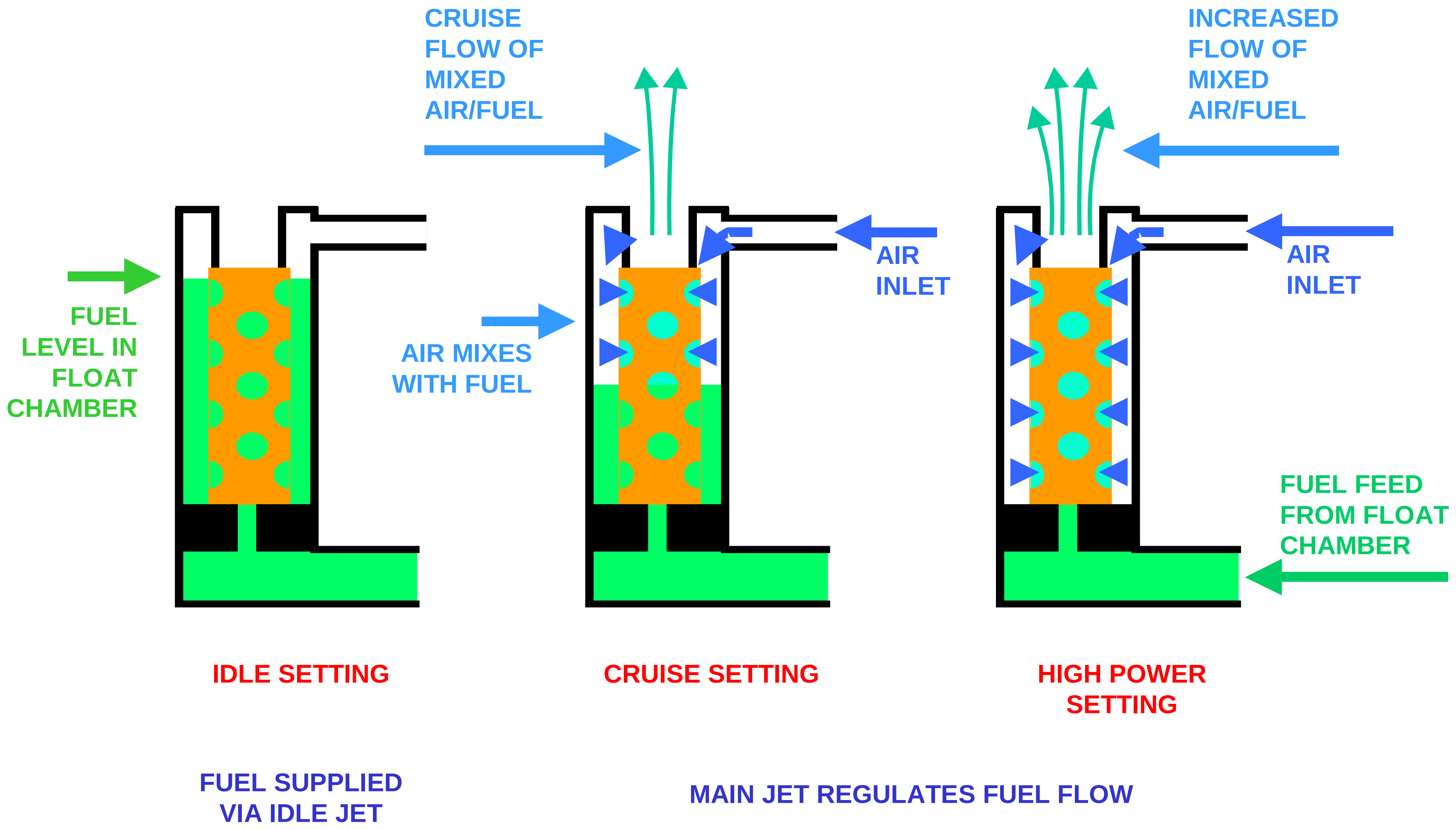
The illustration below shows the diffuser at three operating conditions: - Idle, Cruise and Maximum power.

At Idle – the diffuser is full of fuel but very little air is passing through it because the throttle valve is closed (idle position) and the idle jet is controlling the fuel flow to the engine.

At Cruise – The throttle valve is partially open providing sufficient power to run the engine at a cruise level i.e. straight and level flight at a constant air speed or vehicle road speed.

The venturi effect pulls fuel from the float chamber and pulls a small proportion of the main airflow into the diffuser from the inlet manifold. As the air passes through the diffuser air inlet holes it 'bubbles' through the fuel improving the atomization (when bubbles burst the produce a fine spray).

At Maximum Power – The throttle valve is fully open and maximum airflow is passing through the main venturi. A greater diffuser airflow is also being pulled through the diffuser tube air inlet holes, therefore the greater flow of fuel being mixed with a correspondingly greater flow of diffuser air.



SIMPLIFIED PISTON ENGINE FUEL SYSTEM

FUEL SYSTEM – Altitude Correction

Purpose

Air at higher altitudes is ‘thinner’ i.e. the molecules of air are further apart causing a lower pressure. The piston travels the same distance whatever the altitude it is working in, therefore at higher altitudes less air is taken into the engine during the induction stroke. Less airflow would mean a richer mixture, i.e. more fuel than air than the ideal 15:1 ratio.

This would not mean more power, but simply less efficient burning of fuel (less diffuser airflow, less efficient atomization etc).

Therefore some method of adjusting the fuel flow with airflow is required to maintain the idea 15:1 ratio. Since air pressure is easily mechanically sensed, the device used is an Aneroid Capsule.

Description

The aneroid capsule is a sealed chamber made from concertinaed thin metal. The inside of the sealed container is a partial vacuum, the outside is sensing outside air pressure (termed atmospheric or referred to as ‘ambient’ pressure).

The partial vacuum tends to shorten the capsule length. If the capsule wasn’t sealed and sensed ambient pressure inside and out, its natural springiness would make it expand or increase length. Additionally, at higher altitude the lower pressures outside are not assisted by the trapped higher pressure inside.

One end of the capsule is fixed, the other end is allowed free linear movement. The free end has a tapered needle attached which is positioned inside the main jet.

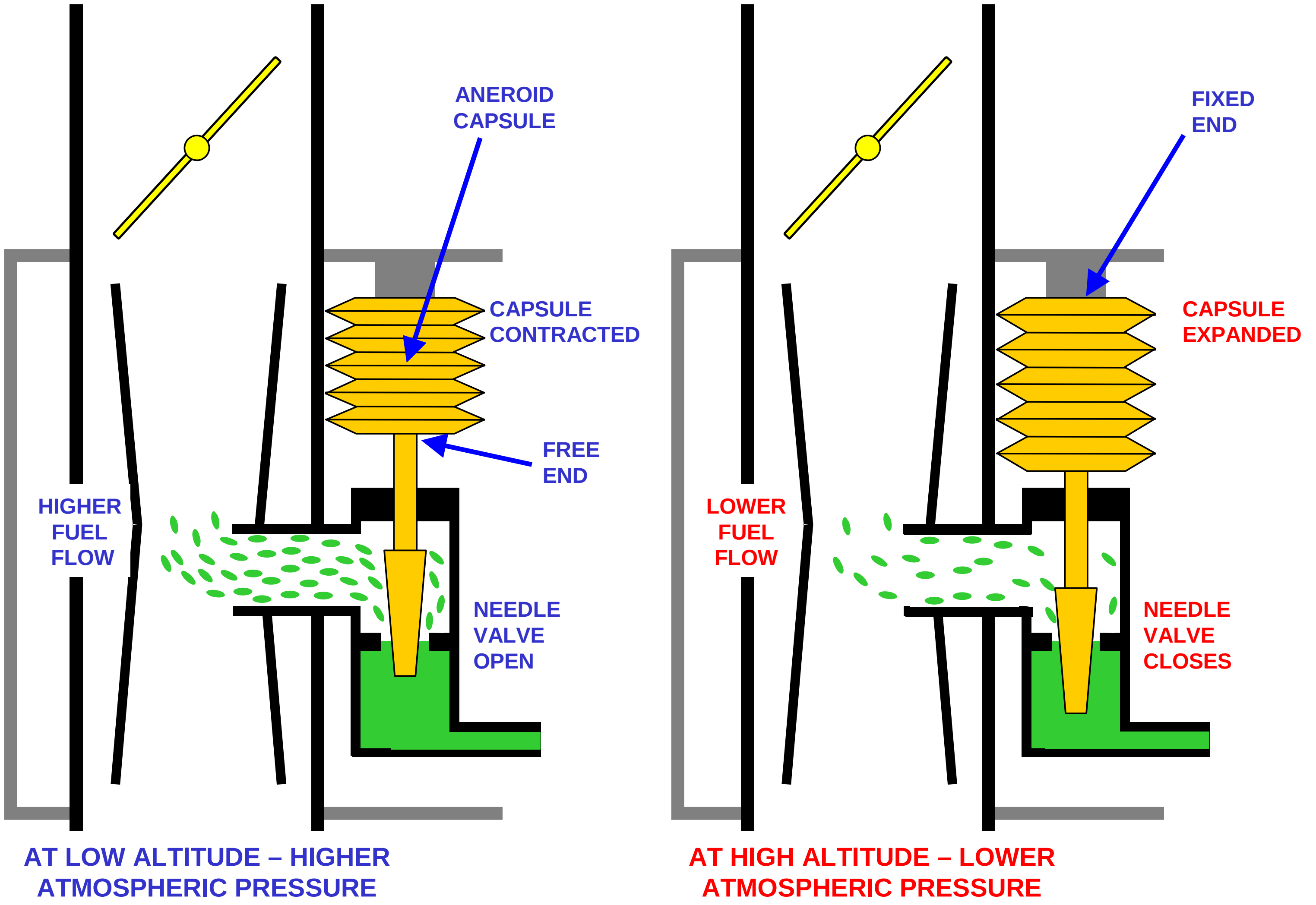
Operation

At lower altitudes (higher pressures) - the capsule is compressed by the outside air pressure. This allows the free end, and therefore the tapered needle to be pulled out of the main jet such that a smaller diameter of the needle is immersed in the main jet. The resulting annular orifice area of the main jet is sized to allow the correct quantity of fuel through for the weight of air passing into the engine.

At higher altitudes (lower pressures) – the capsule expands pushing the needle into the main jet. This positions a larger diameter of the taper needle in the jet which results in a smaller annular orifice area. Again, the resulting annular orifice area of the main jet is sized to allow the correct *lower* quantity of fuel through for the *lower* weight of air passing into the engine.

The result is the air/fuel ratio is therefore maintained at 15:1 at all atmospheric conditions.

Note: - Air pressures can vary at any altitude simply due to the state of the weather, i.e. at sea level (S.L.) the standard. on hot summer days the pressure can decrease, and increase on cold winter days. Whatever the reason for a pressure change, the aneroid capsule, being a pressure sensor, will adjust fuel flow accordingly.



SIMPLIFIED PISTON ENGINE FUEL SYSTEM

FUEL SYSTEM – Hydro-mechanical Fuel Injection System

Introduction

The injection system differs from the carburettor system primarily in the way the fuel is delivered.

In carburettors, the fuel is mixed with the air before it enters the cylinders. In injection systems, the fuel is injected directly into the air, either in the inlet manifold, or even directly into the cylinders.

Injection systems rely on squirting high pressure fuel through a small nozzle, or jet, to atomise the fuel; that is, to break it down to the smallest droplet possible.

Mixture Control

In the system shown below, the airflow to the engine is sensed by a 'Air Sensor Plate', the position of which regulates the fuel flow to the engine in the Mixture Control Unit/Fuel Distribution Valve.

In this system fuel is continuously injected into the inlet manifold just upstream of the inlet valve. The total flow injected is sufficient for when the inlet valve opens and the fuel/air mixture is drawn into the engine.

Other Features of the System

Primary Pressure Valve – Ensures maximum pressure is not exceeded, typically when at high rpm and the throttle is closed. The fuel flow to the engine is greatly reduced but still pumped by the pump. The excess is fed back to the fuel tank.

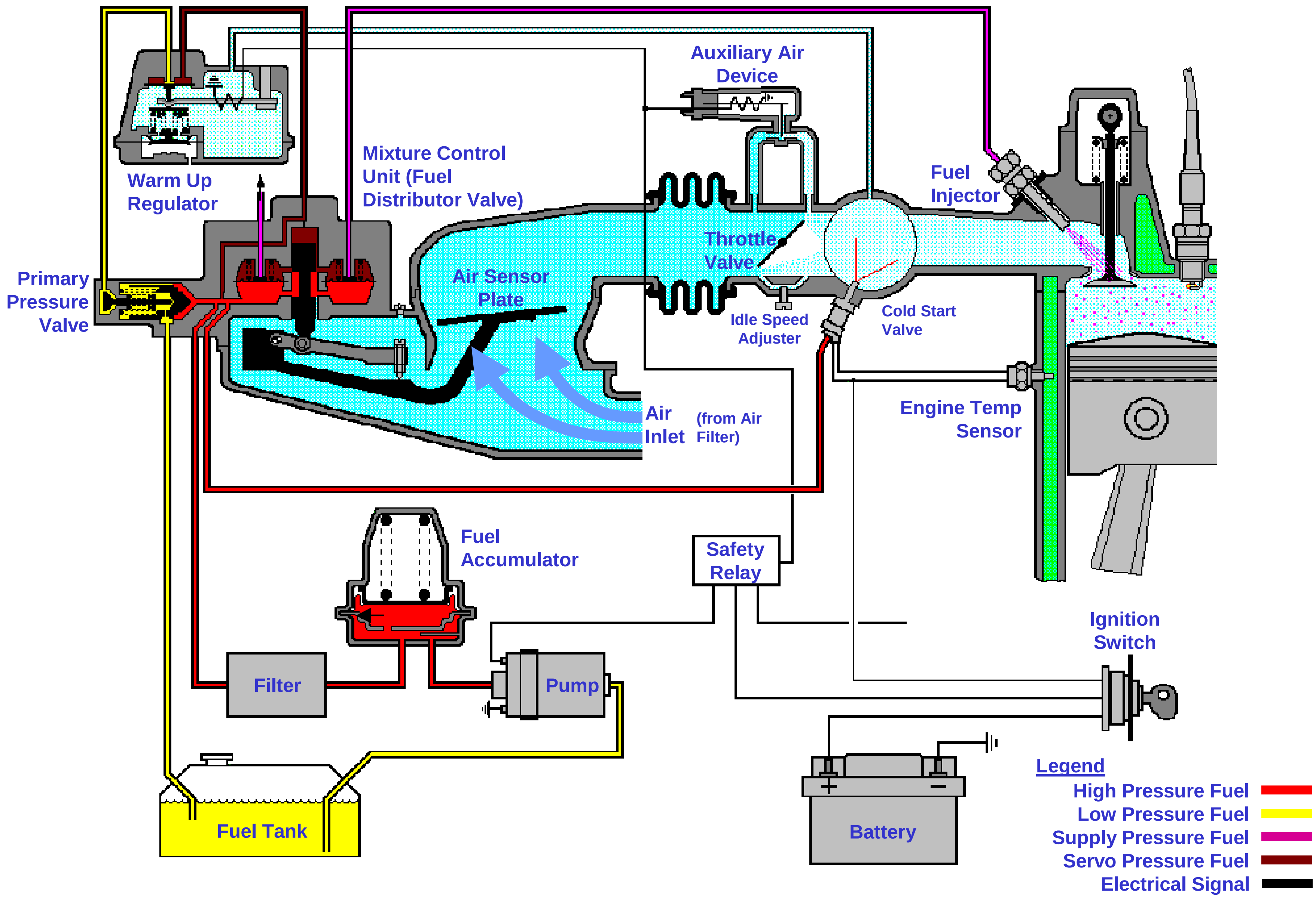
Idle Speed Adjuster – When the throttle valve is closed, air to the engine passes through this separate passage, the amount dictates idle speed. Turning the adjuster changes idle speed.

Cold Start Valve – Allows extra fuel into the inlet manifold enriching the mixture for cold starts. (equivalent to the carburettor choke). The CSV closes as soon as the coolant gets up to operating temperature.

Warm Up Regulator – Reduces the fuel flow weakening the mixture over time, at initially the mixture is enriched for starting

Auxiliary Air Device – Increase air flow weakening the mixture over time.

Note – the CSV, WUP and the AAD combined have a similar effect to the carburettor choke.



PISTON ENGINE – Hydro-Mechanical Fuel Injection System

FUEL SYSTEM – Electronic Fuel Injection System

System

Comparing the electronic system with the hydro-mechanical system, it can be seen that the electronic system is very much simpler, at least from the perspective of the number of manufactured parts, yet it has all the operating features of the latter system and more besides.

Common Rail System

All the injectors are fed from a common gallery (the common ‘Rail’) by the fuel pump. Pressure limiting is achieved by the Pressure Regulator.

Fuel flow then becomes a product of fuel pressure, injector jet size, and length of time the valve is open. If pressure is kept constant, and the injector jet is constant by virtue of the machined jet size, all that is required to control the fuel flow is the valve open duration.

Fuel to the engine is simply a matter of energising the injector solenoid to open the valve and squirt fuel into the inlet manifold or directly into the cylinders.

This latter operation is the overriding control aspect of the system. If more fuel is required the injectors are opened longer, less fuel means they are shut sooner. The difference in injector valve open times is minute, measured in milliseconds.

The Injector Control Unit

This unit controls the timing of the injector valve opening, in conjunction with the Engine Control Unit.

The diagram below shows numerous signals going to the ECU, but some of these signals could be fed into the ICU, depending on different manufacturers designs, and then cross fed via the electronic link as required.

System Functions: -

Cold Starting – Injectors opened for longer enrichening the mixture (choke effect).

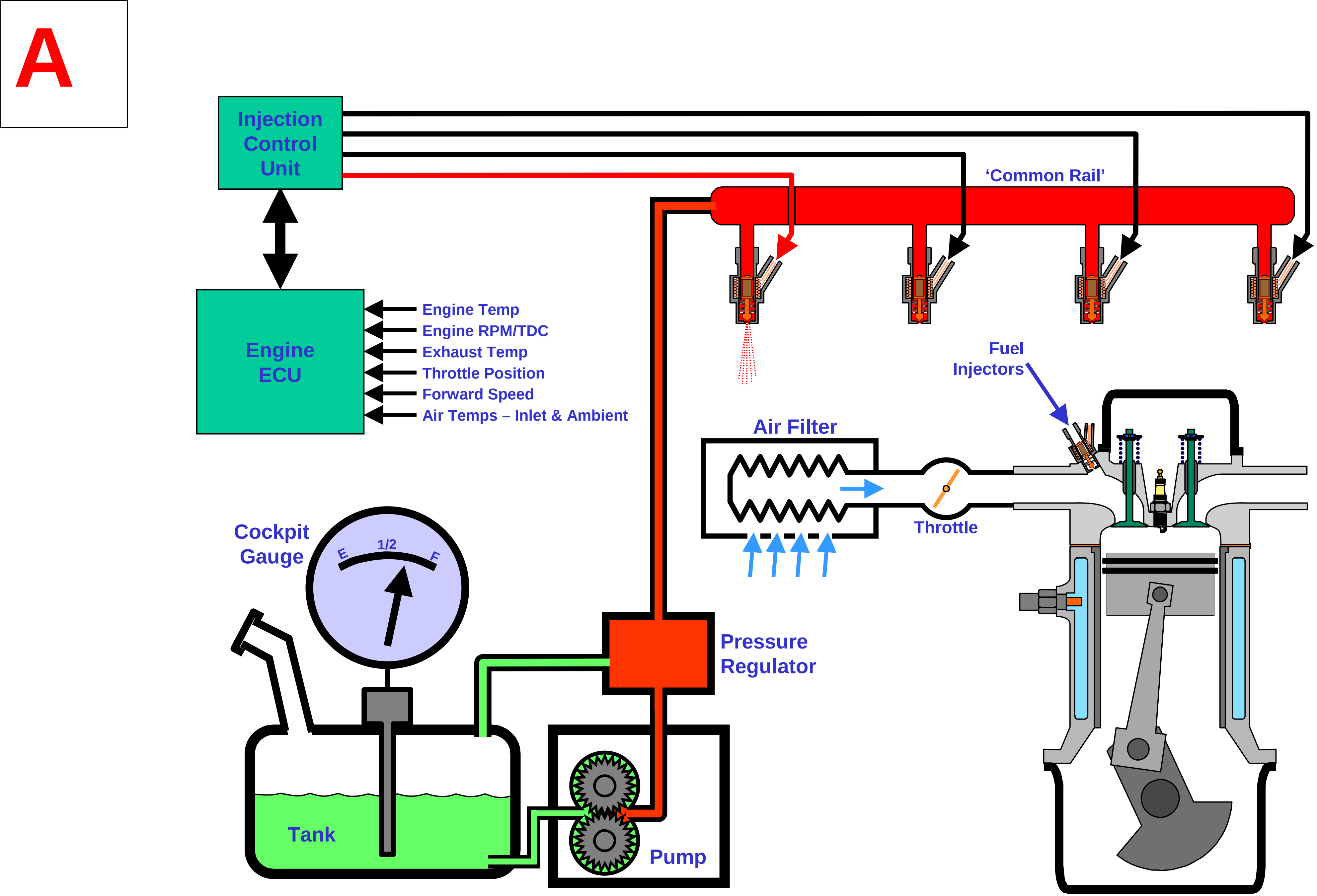
Engine Warm Up – Injectors open for progressively less time as the engine warms up.

Acceleration – Injectors open longer to deliver more fuel than is required for steady state (constant RPM) running.

Deceleration – Essentially the injectors open for shorter time to deliver less fuel. However, in road vehicles, on the overrun or coasting (that is decelerating the vehicle whilst in gear), the injectors can be controlled to constant closed. This saves fuel and lowers emissions and slows the vehicle by the engine saving wear and tear on the brakes.

Comment

It can be seen that electronic control systems can be cheaper to produce, and give greater flexibility, whilst achieving better fuel efficiency.



PISTON ENGINE – Electronic Fuel Injection System