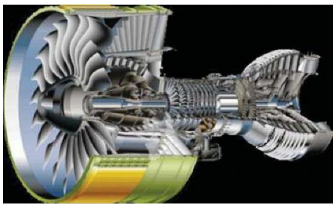 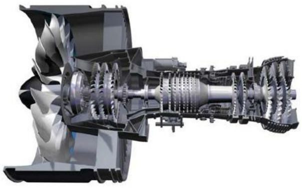  

UNIVERSITY OF NAPLES ***FEDERICO II*** *1224 A.D.*

Propulsione Aerospaziale

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The combustion process

Combustion is a controlled chemical reaction; it is not an ‘**explosion**’. The mixture induced into the cylinders consists of gasoline vapors (84.2% carbon and 15.8% hydrogen by weight) and air (78% nitrogen, 21% oxygen and 1% other inert gases).

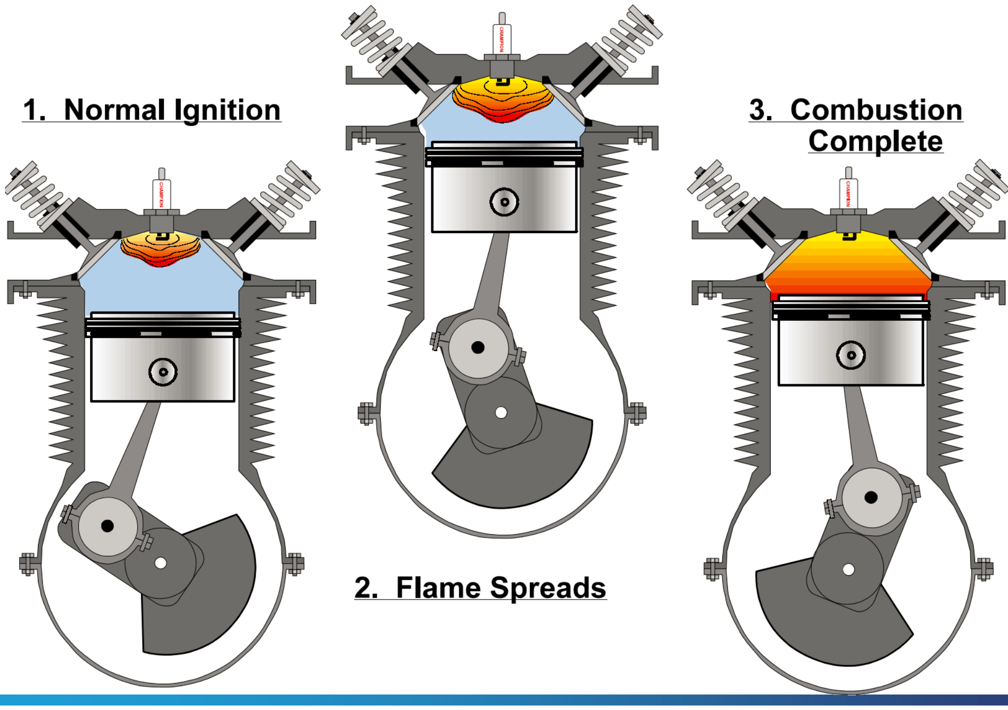
When combustion has been completed, the **hydrogen** in the fuel will have combined with the **oxygen** in the air to form H_20 which is **water** vapor, and the **carbon** in the fuel will combine with the oxygen in the air to form CO_2 - **carbon dioxide**.

The **nitrogen** and other gases **play no active part** in the combustion process, but they do form the bulk of the gas that is heated and expanded to create pressure energy.

The **nitrogen** also **slows down** the **rate of combustion**, without nitrogen, combustion would be an explosion with far too rapid a temperature and pressure rise to be harnessed to do useful work.

Flame rate

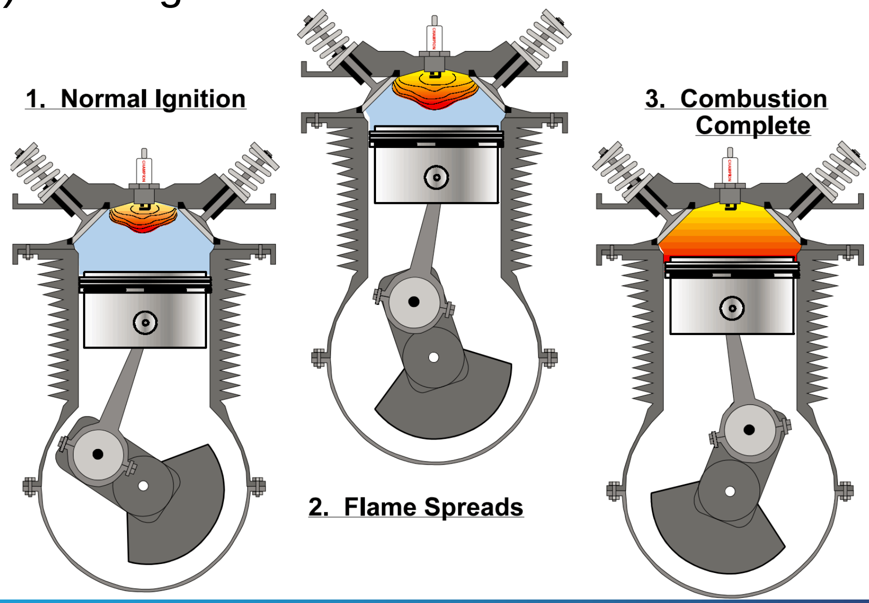
When normal combustion takes place, the compressed charge is ignited by the spark and burns rapidly and steadily with a **flame speed** of 20-25m/s (60-80 ft/s), giving a steady and **smooth temperature** and **pressure rise** in the combustion chamber.



Flame rate

Maximum pressure will be generated when combustion has been completed, and ideally this should occur when the crank is **at 8°-10° after TDC** where, because of the ineffective crank angle, the volume of the combustion chamber is still at a minimum.

Should maximum pressure conditions obtain in advance of this (i.e. at, or before TDC) the engine would tend to **run backwards**.



Variable ignition timing

As combustion takes a **relatively short** period of time, in order for combustion to be completed when the piston is at 8° - 10° after TDC, the spark must occur before the piston reaches TDC.

The flame rate remains reasonably constant, but the engine **speed varies** considerably:

- at **low** engine **speeds** it is necessary for the ignition to be **retarded** to prevent the maximum pressure building up before the piston reaches TDC.
- at **high** engine **speeds**, both the flame rate and the time required for complete combustion remain constant, but because of the increased piston speed, it is necessary to **advance** the ignition so that the maximum pressure still occurs at the right time.

Variations in flame rate

The **flame rate** does vary slightly, for instance the mixture will **burn faster** if it is made **richer** or the **pressure** in the cylinders **increase**. It is necessary to increase the mixture strength of all aircraft engines when they engine are producing high power to ensure stable combustion.

Therefore, the increased flame rate which results from the action of selecting a rich mixture **shortens** the time required for combustion so that, to obtain full power, it is necessary **to retard the ignition slightly**, or alternatively not to make any further advance of the ignition.

Detonation

The **higher** that the **pressure** of the fuel/air mixture can be raised before combustion, the higher will be the pressure of the burning gases. Consequently, the greater will be the **power output** and **thermal efficiency** of the engine. The **compression pressure** is governed by the compression ratio of the engine and **is limited by** the tendency of the **fuel to detonate**, or **knock**.

Detonation occurs after ignition and is **unstable combustion**. During normal combustion, the **flame travels smoothly** and steadily through the mixture as the advancing flame front heats the gases immediately ahead of it, so that they in turn burn.

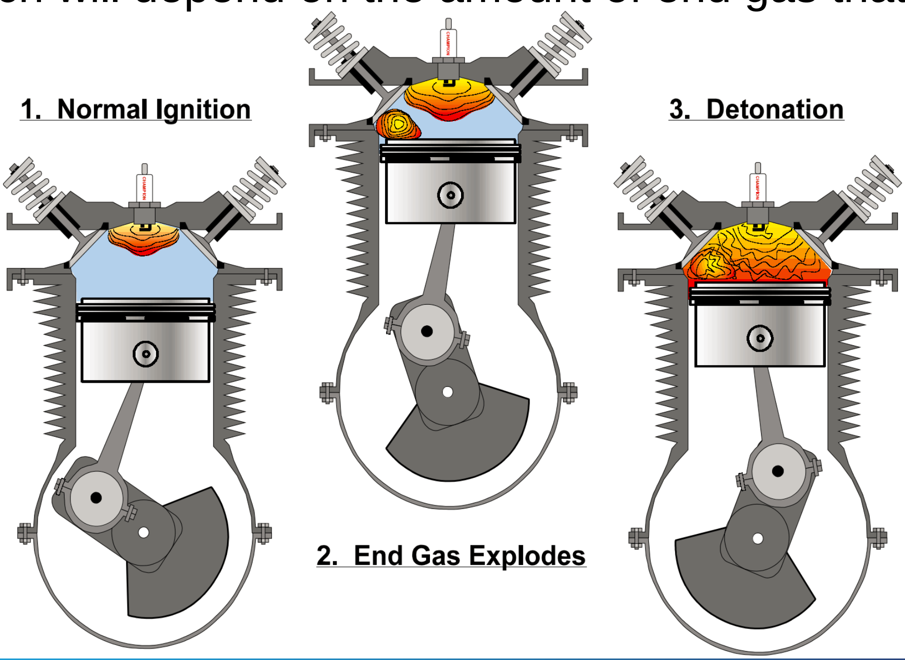
Progressively there is more and more **heat** concentrated in the **flame** front, which is brought to bear on the remaining unburnt portion of the mixture, termed ‘end gas’, and its temperature is raised.

In addition, the **burnt gases** have **expanded**, so that, the end gas is subjected to an increasing pressure.

Detonation

Ultimately there is **sufficient pressure** and **temperature** to bring all the end gas to the **point of combustion** at the **same instant** and it explodes.

The flame rate increases to 300 m/s (1,000 ft/s), with a **degree of violence** which will depend on the amount of end gas that remains.



Detonation

The effects of detonation are:

- The explosion of the end gas can cause the piston **crown** to **burn**, and eventually to collapse; **over-heating** of the **combustion chamber** can also occur. This may cause the **valves** to split and **distort** and possibly **burn** the **sparking plug** electrodes.
- There is also a sudden rise in pressure as detonation occurs, which applies a **shock loading** to the engine component parts, which may cause **mechanical damage**.
- The maximum pressure is generated **before** the piston is in the correct position to utilize it, the piston must overcome a high back pressure and **power is lost**.

Detonation

Any condition that **heats** the charge **before combustion** will aggravate matters in the end gas, pre-heating the air before it enters the engine (the use of 'hot-air' to overcome carburetor icing) or **over compression** in the supercharger may well give rise to excessive temperatures. Therefore, detonation may be caused by one or a combination of the following:

- **Incorrect mixture strength** - The greater the amount of fuel for a given amount of air, the greater the power obtainable **without detonation**. If the power output is high, then the mixture must be rich.
- **High charge temperature** - Anything that **raises** the **temperature** or the pressure of the charge unduly before burning, e.g. carburetor heating (at high power), overheated cylinders, high boost with very low RPM.
- **Incorrect ignition timing** - If the **spark** is too far **advanced** the charge ignites too early, giving higher temperatures.
- **Cooling** - If the combustion chamber surfaces are coated with carbon, or coke as it is commonly called, **heat** from the flame will **not dissipate** rapidly, resulting in high cylinder head temperatures.

Detonation

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- **Cylinder head design** - The **greater** the **time** taken for the flame front to travel through the combustion chamber, and the higher the **charge** temperature, the greater the **risk of detonation**. Design features which would directly affect these would be for example: the size of combustion chambers, the positions of the spark plugs and the valves, the compression ratio and effective cooling.
- **Use of incorrect fuel**.

Detonation

Detonation is a spontaneous combustion and can be **recognized** by its **metallic knocking sound** or pinking which is caused by the violent vibrating pressure waves striking the walls of the combustion chamber. Much damage may be done under high power circumstances, particularly in an aircraft, where because of the noise created by the propeller, the detonation may go unnoticed until it is too late.

Detonation may be **controlled** by:

- A **compact combustion chamber** helps in this respect by reducing the distance that the flame front has to travel, also the time taken to burn the charge can be reduced by initiating flame fronts from two sparking plugs.
- The flame should be started from the **vicinity** of some **hot spot** such as the exhaust valve, so that the end gas is pushed away from the hotter parts of the combustion chamber and compressed into a cooler part.

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Detonation may be **controlled** by:

- Running conditions can also assist in delaying the onset of detonation, for example, the **same power** may be obtained at a **higher engine speed** by using a **finer propeller pitch**. This enables a **smaller throttle opening** to be used, which helps in two ways, the smaller throttle opening **reduces** the **cylinder pressure** and the higher **running speed** cuts down the **time** available.

In short, anything which can **reduce temperature, pressure or time** will be instrumental in reducing, or at the very best preventing its creation.

Detonation

One of the easiest way of **controlling** detonation is by improving the **quality of the fuel**. There are two chemically pure fuels, **Iso-Octane** and **Normal Heptane**, which are employed as ‘reference fuels’ when determining the anti-detonation qualities of a fuel under laboratory conditions.

Iso-Octane has very good combustion characteristics and shows **little tendency to detonate** when mixed with air and ignited at high temperatures and is given a **rating** of **100**.

Normal **Heptane** detonates very readily and has a **rating of 0**.

The combustion characteristics of any **blend** of fuel can be **compared** with those of the two reference fuels by using each in turn under standardized conditions in a special single-cylinder engine.

The engine is run using the fuel under test and then **compared** to a **blend** of the two reference fuels to produce the **same** degree of detonation in the engine.

Detonation

If the blend of the reference fuels is **95% iso-octane** and **5% normal heptane**, then the fuel under test would be given an octane **rating of 95**.

The octane rating is, therefore, a measure of the fuel's Anti-Knock value.

The **original** tests were based on an air/fuel ratio which **gave maximum** detonation, but this condition is not **truly** representative of the working range of the engine.

Maximum detonation occurs with economical mixtures used for cruising but, for take-off and climbing, rich mixtures are used. It is important to know how the **fuel** will behave under these **varying mixture** strengths, and so **aviation** fuel has **two ratings**. This is sometimes referred to as the performance number or performance index.

Detonation

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As an example, Avgas 100LL is a 100 octane fuel with a perf number of 100/130, the **lower** figure is the **weak mixture** detonation point and the **higher** figure the **rich mixture detonation point**.

A rating above 100, e.g. 100/130 grade gasoline is a performance number, although in practice the fuel would still be referred to as a 100 octane fuel.

It follows that if an engine is designed to use a certain grade of fuel, then **a lower grade should never be used**, as this would cause detonation.

If at any time the correct octane rating is not available, then a **higher octane** rating **must be used**.

Detonation

Detonation can be avoided by putting small quantities of additives into the fuel, the principal one used being **Tetra Ethyl-lead** (TEL *Piombo tetraetile*). The action of TEL. is to reduce the formation of peroxides which act as fulminates to explode the end gas, but it has to be used with care as, during combustion, **Lead Oxide** is formed which is not volatile at that temperature, and has a **corrosive** effect on the exhaust **valve**, its **seat**, and the **sparking plug electrodes**.

It is necessary to add to the fuel Ethylene Di-bromide which changes the reaction during combustion to form Lead Bromide which is volatile and is ejected with the exhaust gases.

In the course of time, fuels with **better combustion characteristics** than Iso-octane were produced and, to rate these, comparisons are made with Iso-octane doped with TEL.

Detonation

Better quality fuel permits:

- **Increased compression ratios** with an increase in **thermal efficiency**, better fuel consumption, and an increase in engine power.
- **Increased induction pressure** and greatly **increased power** from a given engine by the use of a supercharger.

The power output of an engine is directly proportional to the weight of mixture burned in unit time increased induction pressure will increase this weight. (Although basically the quantity or 'weight of charge ' induced will still depend upon the position of the throttle butterfly).

The chemically correct ratio

Although air and fuel vapor will **burn** when mixed in **proportions** ranging between 8:1 (rich) and 20:1 (weak), **complete combustion** only occurs with an air/fuel ratio of 15:1 by weight.

This is the **chemically correct** ratio, at this ratio all the oxygen in the air combines with all the hydrogen and carbon in the fuel. The chemically correct mixture does **not** give the best results, because the temperature of combustion is so high that power can be lost through detonation.

The practical mixture ratio

Although the chemically correct mixture strength would theoretically produce the highest temperature and therefore power, in practice **mixing** and **distribution** are **less than perfect** and this results in some regions being **richer** and others being **weaker** than the optimum strength.

This **variation** may exist **between** one **cylinder** and another.

- A slightly **rich mixture** does **not** have much **effect** on **power** since all the oxygen is still consumed and **the excess** of **fuel** simply serves to **slightly reduce** the effective **volumetric efficiency**, in fact its cooling effect can be to some extent beneficial.
- **Weak mixtures**, however, rapidly **reduce power** since some of the inspired oxygen is not being utilized, and this power reduction is much greater than that resulting from slight richness. It is, therefore, quite common to **run engines** (when **maximum power** rather than best fuel economy is the objective) at somewhat **richer** than chemically-correct mixtures (e.g. about 12.5:1) to ensure that **no cylinder** is left running at severely reduced power from being unduly weak.

The practical mixture ratio

A mixture which is **weaker** than the chemically correct ratio, besides burning at **lower temperatures**, also burns at a **slower rate** (because of the greater proportion of nitrogen in the cylinder). **Power** output thus **decreases** but because of the **increase** in **efficiency** resulting from cooler burning, the fall in power is proportionally less than the decrease in fuel consumption. Thus, the **Specific Fuel Consumption** (SFC), **decreases** as the mixture strength is weakened below 15:1.

Problems caused by weak mixtures

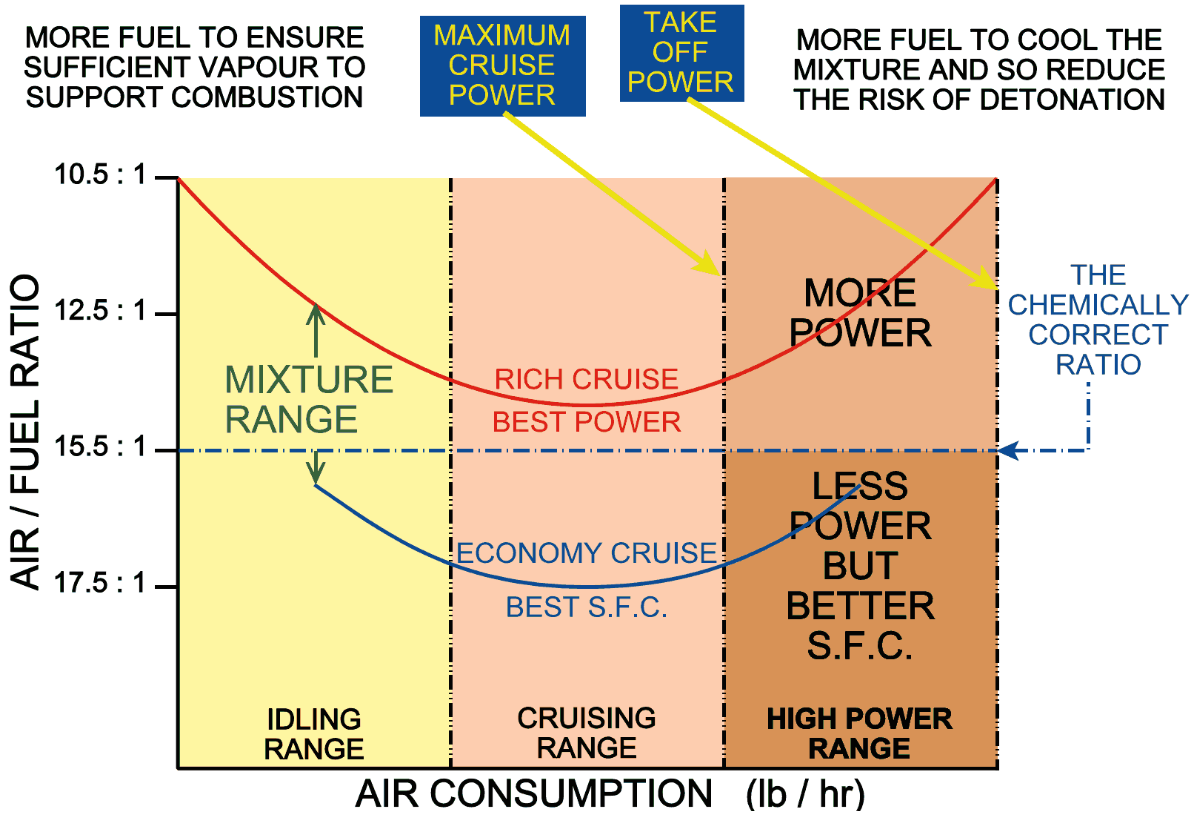
For **economical cruising** at moderate power, air/fuel ratios of 18:1 may be used, an **advance** in the ignition **timing** is necessary to allow for the slower rate of combustion.

With **extremely weak** mixtures, the gases may still be burning when the **exhaust valve opens**, exposing the valve to high temperatures which may cause the **valve** to **crack** or **distort**. As the **inlet valve opens**, the heat of the exhaust gases is still so high that it **may ignite** the **mixture in the induction system**, and ‘popping back’ occurs through the induction manifold.

This **slow burning** also causes **overheating**, as a certain amount of the **heat** is **not converted** into work by expansion and has to be dissipated by the cooling system.

Problems caused by weak mixtures

The mixture requirement is, therefore, dependent upon engine speed and power output.



Slow running and starting

A **rich mixture** is required for starting and slow running because:

- Fuel will only burn when it has vaporized and is mixed with air. When starting, the engine is **cold** and there is **little heat** to assist the **vaporizing** process, therefore only the lightest fractions of the fuel will vaporize. To make sure that there is **sufficient fuel vapor** in the cylinders to support combustion a rich mixture is required.
- The **exhaust valve** is given a certain amount of lag so that full advantage can be taken of the considerable inertia of the gases at normal engine speeds, to obtain efficient scavenging of the burnt gases, and to give impetus to the incoming charge. As engine speed reduces, the gas velocity falls and more of the **burnt gases remain** in the **cylinder**, whilst at still lower speeds there is the tendency for exhaust gases to be **sucked back** into the cylinder by the descending piston before the exhaust valve closes. The consequent dilution of the induction gases is such that, to maintain smooth running, a rich mixture is required.

Take off power

When **full power** is selected for **take-off**, the mixture must be further enriched to about 10:1. Apart from the cooling effect, the **excess fuel** is **wasted**, for there is insufficient oxygen available for it to burn completely. The **higher power** results from a greater weight of charge induced in a given time, and not because of mixture enrichment.

In practice, excess **fuel vapor** is not scavenged as vapor, the oxygen is shared out to some extent, so that **carbon-monoxide** (CO) is produced during combustion as well as carbon-dioxide (CO_2). With very rich mixtures some of the carbon **fails to combine** with oxygen at all and is exhausted as **black smoke**.

Climbing and cruise power

Climbing power:

- The engine power output is a product of **engine speed** and the mean effective **pressure** in the cylinders during the working cycle, **higher power outputs** involve **increases** in both of these factors. As the speed and the pressure increase, there is also an increase in the **temperature** of the gases and, therefore, their tendency to **detonate**. When higher power is required for climbing, the mixture is **enriched** to about 11:1. The extra fuel, in vaporizing, cools the mixture and reduces the **tendency to detonate**.

Cruise power:

- During cruising conditions only **moderate power** is required from the engine, and this should be produced with the **minimum expenditure** of **fuel** to achieve economy.

The exhaust gas temperature gauge

As the **mixture control** is moved from **fully rich** to a **weaker setting**, the air fuel ratio approaches the chemically correct value of approximately 15:1. At this ratio all the air and fuel are consumed and the **heat released** by combustion **is** at its **maximum**. More heat means more power. **RPM will rise** (fixed pitch propeller) **airspeed** will **increase** as more power is produced.

Both these **indications** can be used to **adjust mixture**, but a more **accurate** method is to indicate the change in **exhaust gas temperature** (EGT) as the mixture is varied.

The EGT consists of a **Thermocouple** fitted into the **exhaust pipe** of the hottest cylinder. A thermocouple produces a voltage directly proportional to its temperature. The voltage is indicated by a gauge calibrated to **show temperature**.

The exhaust gas temperature gauge

The mixture control should always be moved slowly. If moved toward lean the temperature will peak at the ratio of **15:1**. It should be remembered that this ratio **IS NOT USED** as **detonation** can occur. On reaching the peak EGT the mixture control would then be moved towards rich and the temperature would drop. A temperature drop would be specified in the aircrafts flight manual which would give the rich cruise setting.

Weakening the **mixture** beyond the chemically correct value will **lower EGT** and **raise** Cylinder Head Temperature (**CHT**) and **excessive weakening** will **lower both**.

Again the flight manual will specify the temperature drop required to set the economy cruise ratio's. **Mixture** is normally **only adjusted at cruise** power settings.

It should be returned to Fully Rich whenever the power is changed.

The exhaust gas temperature gauge

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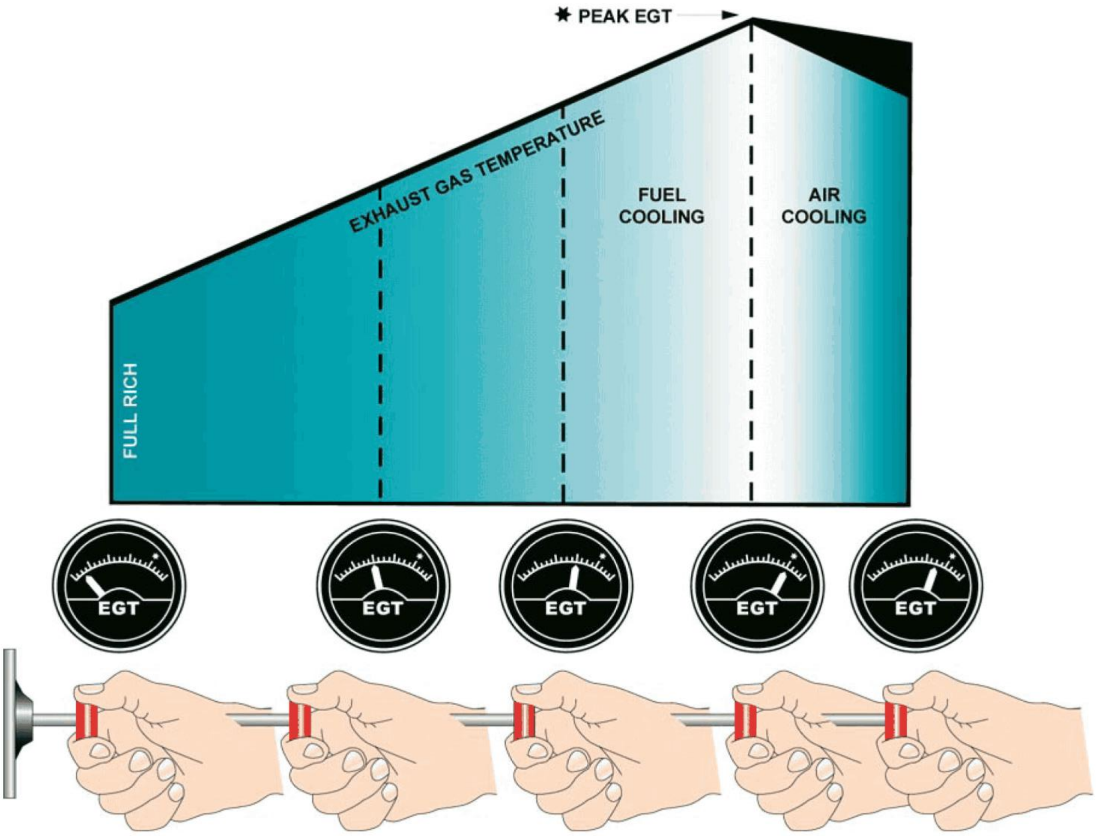


The basic requirements of a carburetor

The carburation system must:

- **Control the air/fuel ratio** in response to **throttle setting**, at all selected power outputs from slow-running to full throttle, and during acceleration and deceleration.
- It must function at all **altitudes** and temperatures in the operating range.
- It must provide for ease of **starting** and may incorporate a means of shutting off the fuel to stop the engine.

The **float-chamber** carburetor is the cheapest and simplest arrangement and is used on many light aircraft, however it is very prone to carburetor **icing**, and may be affected by flight maneuvers.

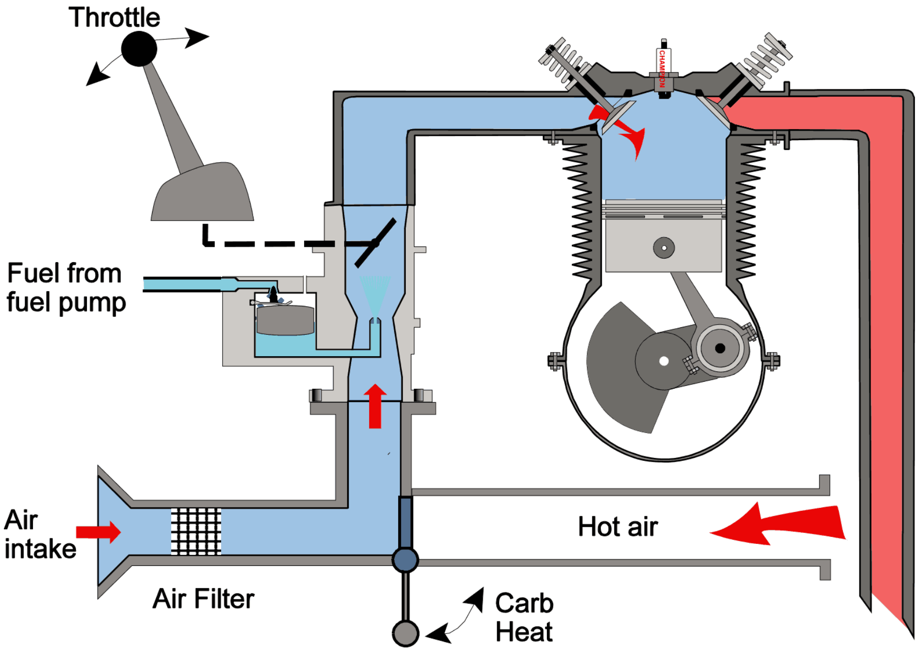
The **injection** carburetor is a more sophisticated device and meters fuel more precisely, thus providing a more accurate air/fuel ratio, it is also less affected by flight maneuvers, and is less prone to icing.

The **direct injection system** provides the best fuel distribution and is reputed to be the most economical, it is unaffected by flight maneuvers and is relatively free from icing.

The basic requirements of a carburetor

Any of these systems may be fitted with a **manual mixture** control, by means of which the most economical cruising mixture may be obtained. However, in order to assist the pilot in selecting the **best mixture**, some aircraft are fitted with fuel flowmeters/pressure gauges or exhaust gas temperature gauges.

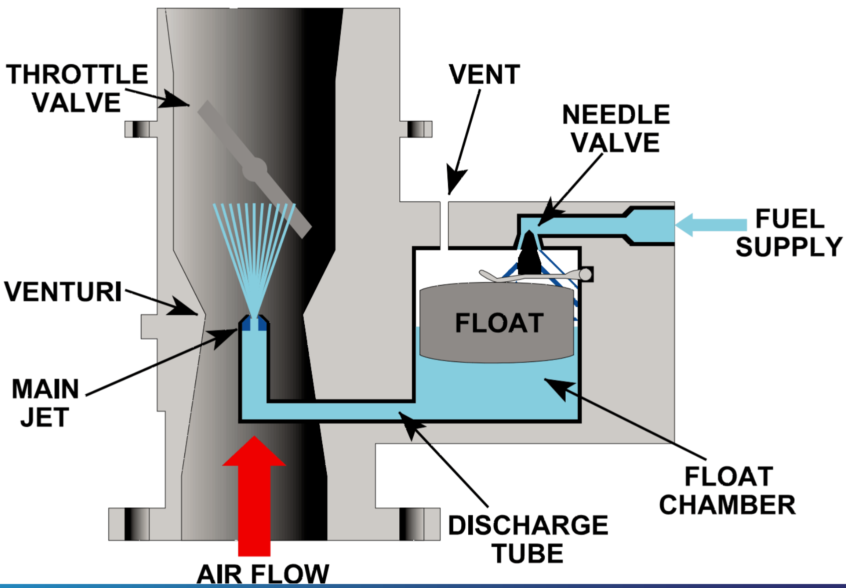
Diesel engines do not have **carburetors** but do have an inlet-system to allow air to be induced towards the cylinders incorporating an Air-filter. The air-supply is not ‘throttled’.



The simple float chamber carburetor

This carburetor employs **two basic principles**, those of the **‘U’ tube** and the **Venturi**.

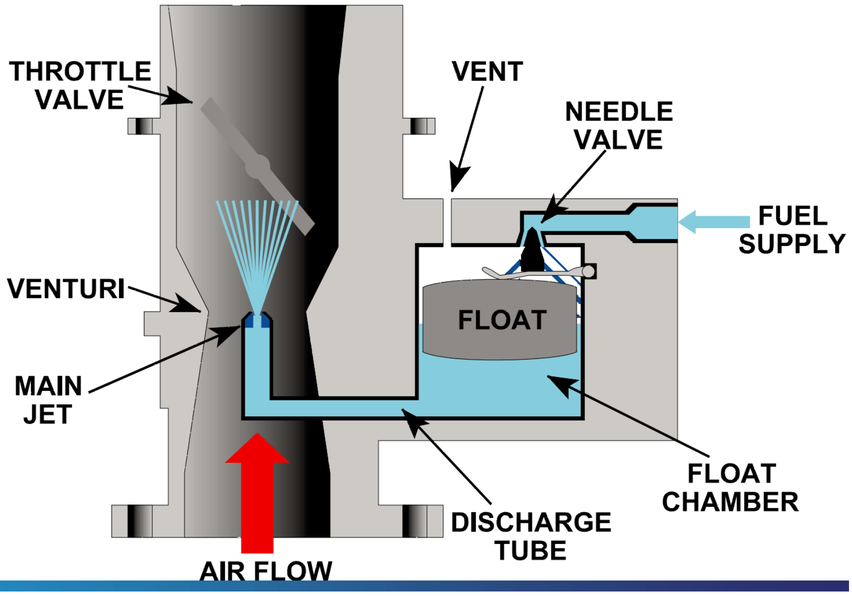
- The **'U' Tube Principle** - If a tube is bent into the shape of a ‘U’ and then filled with liquid, the **level** in either leg will be the **same**, provided that the **pressure** acting on the tube is the **same**. If the pressure **difference** is created across the ‘U’ tube it will cause the liquid to flow. In practice one leg of the ‘U’ tube is opened out to form a **small tank**, a constant level being maintained by **a float** and valve mechanism regulating the flow of fuel from a fuel pump (or pumps) deliver in a supply from the main aircraft tanks.



The simple float chamber carburetor

This carburetor employs **two basic principles**, those of the **‘U’ tube** and the **Venturi**.

- **The Venturi Principle** - Bernoulli’s Theorem states that the total energy per unit mass along any one streamline in a moving fluid is constant. The fluid pressure and temperature decrease for an increase of velocity and viceversa.
- As air passes through the **restriction** of the Venturi its velocity increases, causing a **drop** in **pressure** and **temperature**. The pressure drop at the throat of the Venturi is proportional to the mass air flow and is used to make fuel flow from the float chamber by placing one leg of the ‘U’ tube in the Venturi.

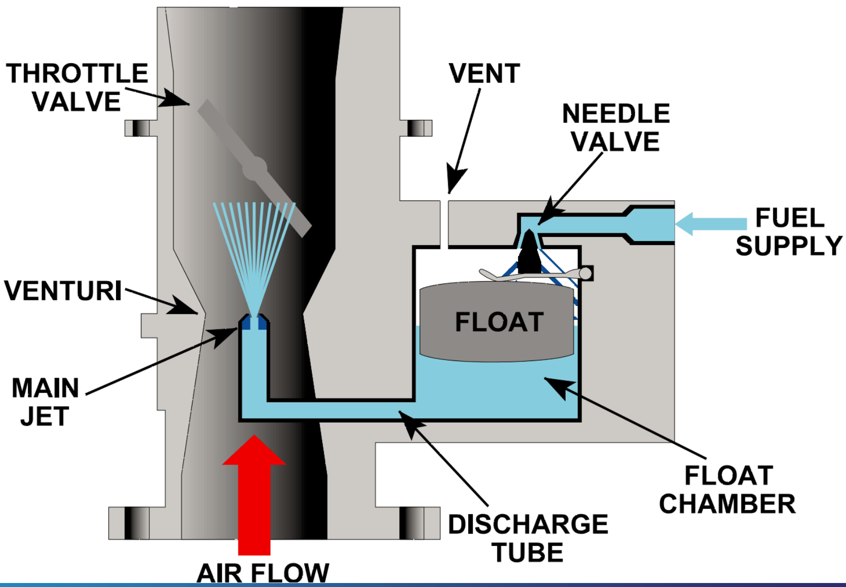


The simple float chamber carburetor

In a float-chamber carburetor, the **airflow** to the engine is **controlled** by a **throttle valve**, and fuel flow is controlled by metering jets.

Engine **suction** provides a flow of air from the air intake through a Venturi in the carburetor to the induction manifold. This air speeds up as it passes through the Venturi, and a drop in pressure occurs at this point. Within the **induction manifold** however, pressure rises as the throttle is opened.

Fuel is contained in a **float chamber**, which is supplied by gravity, or an electrical booster pump, or by an engine-driven fuel pump, and a **constant level** is maintained in the chamber by the float and needle-valve.



The simple float chamber carburetor

Where fuel **pumps** are used, a fuel **pressure gauge** is included in the system to provide an indication of pump operation. Air intake or atmospheric air pressure acts on the fuel in the float chamber, which is connected to a fuel discharge tube located in the throat of the Venturi.

The **difference in pressure** between the float chamber and the throat of the Venturi provides the force necessary to discharge fuel into the airstream.

As **airflow** through the Venturi **increases** so the pressure drop increases, and a higher-pressure differential acts on the **fuel** to **increase** its flow in proportion to the airflow.

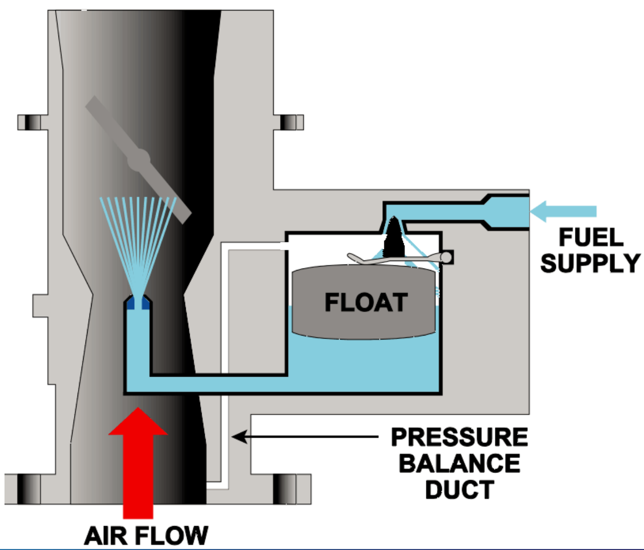
The **size** of the main jet in the discharge tube determines the quantity of fuel which is discharged at any particular pressure differential, and therefore **controls** the **mixture strength**.

The simple carburetor illustrated contains all the basic components necessary to provide a suitable air/fuel mixture over a limited operating range.

The pressure balance duct

To **maintain** the **correct** rate of discharge of fuel through the main jet, the pressure in the float chamber and the air intake must be equal. Admitting atmospheric pressure in the float chamber by means of a **drilling** in the float chamber cover plate is not a **satisfactory** method of ensuring equalized pressure because, due to maneuvers and the speed of the aircraft, the changes in pressure localized around the air intake would not be readily transmitted to the float chamber.

Equalized pressure **conditions** can only be obtained by **connecting** the float chamber **directly** to the **air intake** by a duct which is called the **pressure balance duct**. This duct also supplies air to the diffuser and is used in some carburetors to provide altitude mixture control.



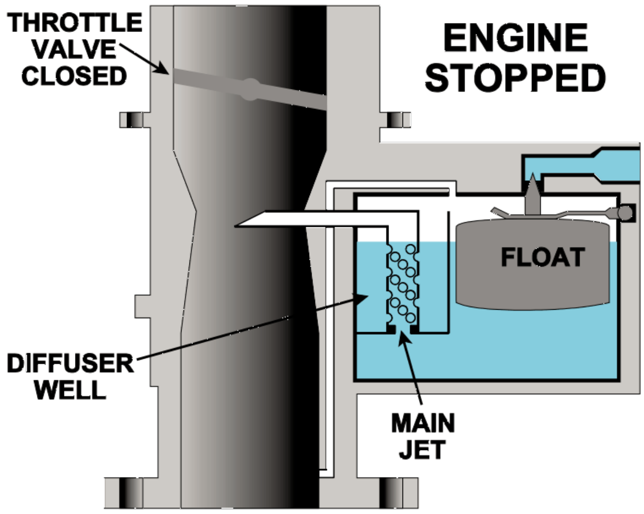
The diffuser

As engine speed and airflow through the Venturi **increase**, the proportion of fuel to air rises as a result of the different flow characteristics of the two fluids. This causes the **mixture** to become **richer**.

Therefore, some carburetors are fitted with a **diffuser**. As engine speed is progressively increased above idling, the **fuel level** in the diffuser **well** drops, and progressively **uncovers** more **air holes**.

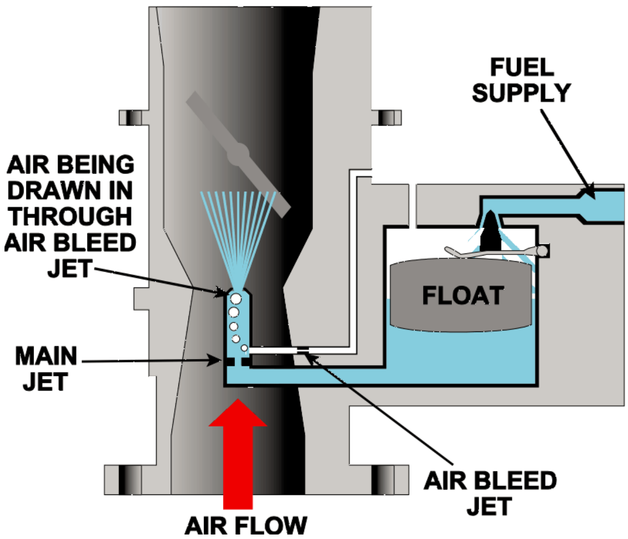
The **holes allow more air** into the discharge tube, and by reducing the pressure differential **prevent enrichment** of the air/fuel mixture.

The process of drawing both air and fuel through the discharge tube also has the effect of **vaporizing** the fuel **more readily**, particularly at low engine speeds.



The air bleed diffuser

A suction applied to a tube immersed in a liquid is sufficient to raise a column of liquid to a certain height up the tube. Should a **small hole** be made in the tube, under the same condition **bubbles of air** will enter the tube and the liquid will be drawn up the tube in smaller drops rather than a continuous stream. The liquid will be "diffused" or made to intermingle with the air. Air "bleeds" into the tube and **reduces** the forces acting on the fuel, **retarding the flow** of liquid through the tube.



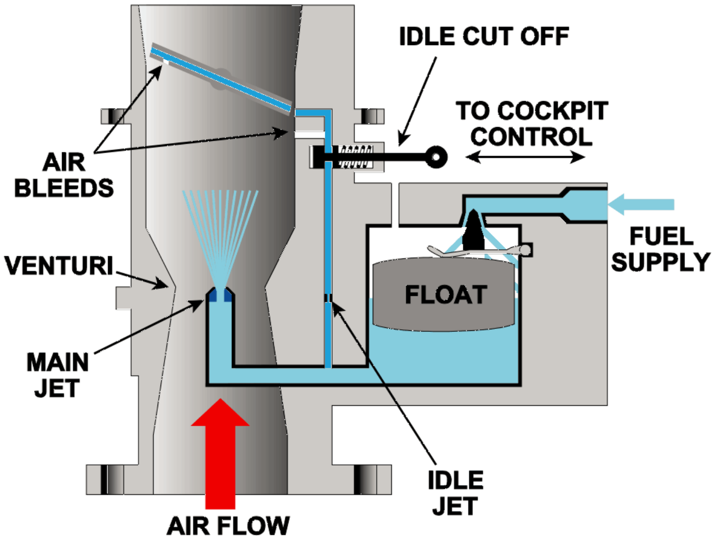
Slow running systems

At **low engine speeds**, the volume of air passing into the engine is so small that the **depression** in the choke tube is **insufficient** to draw fuel through the main jet.

Above the throttle valve exists a considerable **depression** and this is used to have a second source of fuel supply in slow-running conditions.

A **slow running fuel passage** with its own jet leads from the float chamber to an outlet at the lip of the throttle. The **strong depression** gives the needed pressure difference to create a fuel flow.

The size of the slow-running jet is such that it will provide the **rich mixture** required for slow-running conditions. An air bleed, opening into the choke tube below the throttle valve, assists atomization.

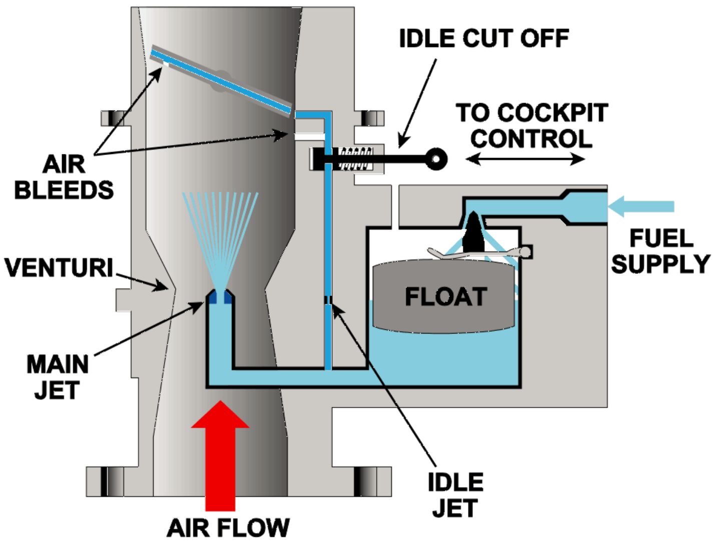


Slow running systems

The purpose of the transverse passage **drilled** through the **throttle** valve is to evenly distribute the mixture over the area of the induction manifold. A small hole is drilled into the transverse passage from the choke tube side, and acts as an **air bleed** to draw some of the fuel through the throttle valve to mix with the air passing to the engine.

As the **throttle** is **opened**, the depression at the lip of the throttle valve decreases and the depression in the choke tube increases to the point where the main jet starts to deliver fuel and the flow through the **slow running system slows down.**

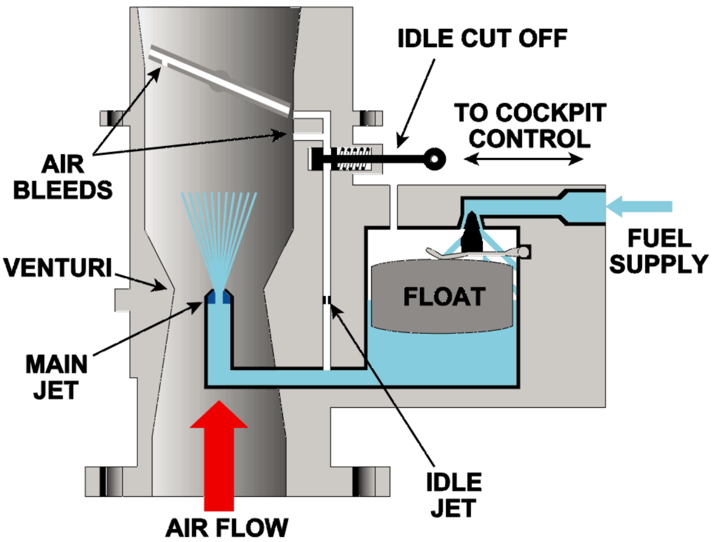
Carburetors must be carefully **tuned** in order to obtain a smooth progressive change over between the slow running and the main system to prevent '**flat spots**'.



Slow running systems

A **flat spot** is a period of poor response to throttle opening caused by a temporary **weak (lean) mixture**, it normally makes itself felt as a hesitation during engine acceleration.

A **cut-off valve** is usually incorporated in the slow-running passage and is used when stopping the engine. When the cut-off is operated the valve moves over to block the passage to the slow-running delivery, the mixture being delivered to the engine becomes progressively weaker until it will not support combustion and the **engine stops**.

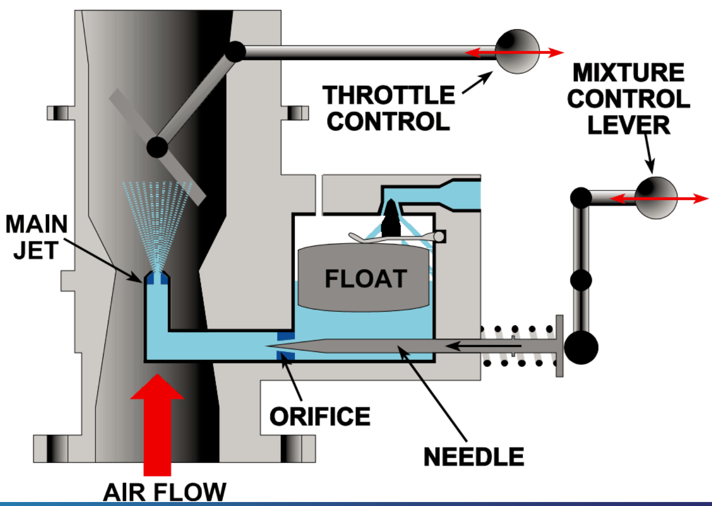


This prevents any possibility of the engine continuing to run erratically due to pre-ignition and also prevents **fuel condensing** in the cylinders which would tend to wash the oil from the cylinder walls, causing lack of lubrication when the engine is next started.

Mixture control - Needle type mixture control

As **altitude increases**, the **weight of air** drawn into the cylinder **decreases** because the air density decreases. For a given intake velocity, the pressure drop in the Venturi will decrease as ambient density decreases. However, the fuel flow due to the pressure drop will not decrease by the same amount and so **the mixture** will become **richer**. This progressive richness with increased altitude is unacceptable for economic operation.

A cockpit lever is connected to a needle valve in the float chamber. Movement of the cockpit lever **raises** or **lowers** the needle and **varies fuel flow** through an orifice.



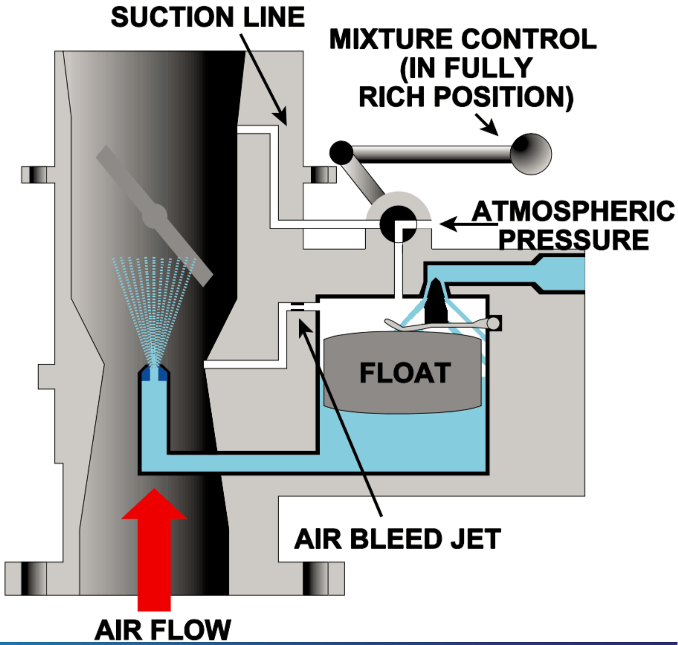
The position of the needle therefore **controls** the **mixture strength**, and in the fully-down position will block fuel flow jet, thus providing a means of **stopping** the engine.

Mixture control - Bleed Mixture Control

The air **Bleed Mixture Control** controls the pressure in the float chamber, thus **varying** the **pressure differential** acting on the fuel.

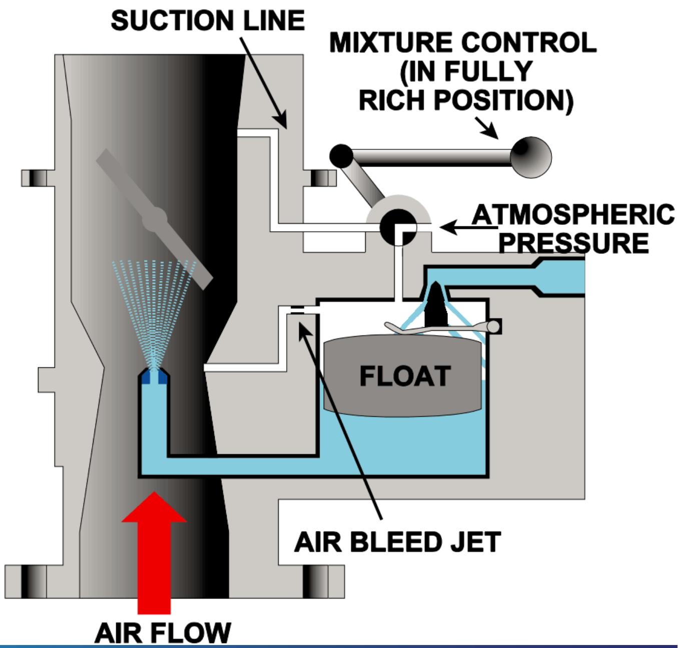
A small **air bleed** between the float-chamber and the Venturi tends to reduce air pressure in the float-chamber and a **valve** connected to a cockpit lever **controls** the **flow** of air into the float chamber.

When the valve is **fully open** the air pressure is **greatest**, and the mixture is **fully rich**, as the valve is closed the air pressure decreases, thus reducing the flow of fuel and **weakening** the **mixture**.



Mixture control - Bleed Mixture Control

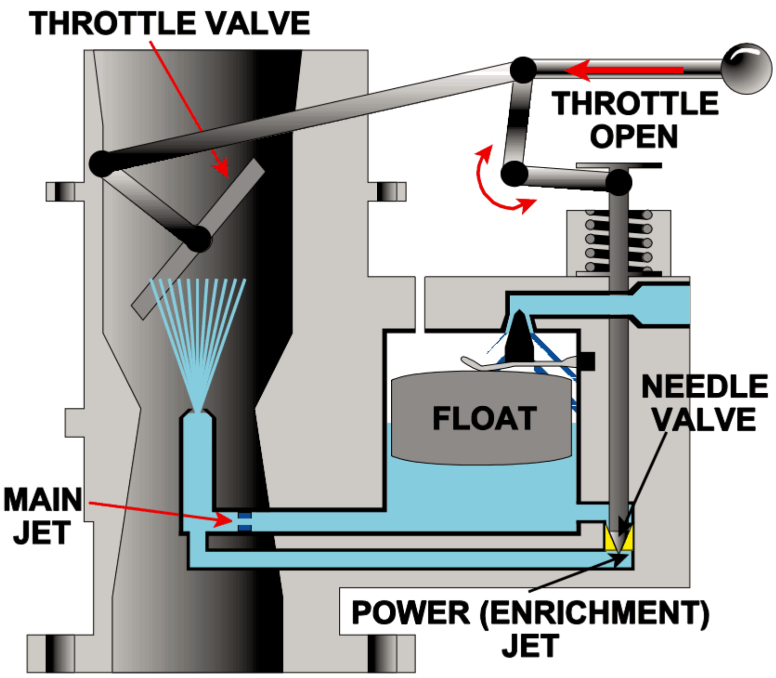
In the carburetor illustrated the valve also includes a **pipe connection** to the engine side of the **throttle valve**, when this pipe is connected to the float-chamber by moving the cockpit control to the 'idle cut-off' position, float-chamber air **pressure** is **reduced** and fuel ceases to flow, thus **stopping** the engine.



Mixture control - Power Enrichment

At **power** settings **above** the **cruising range**, a **richer mixture** is required to prevent detonation. This rich mixture may be provided by an **additional fuel** supply, or by setting the carburetor to provide a rich mixture for high power and then bleeding off float-chamber pressure to reduce fuel flow for cruising.

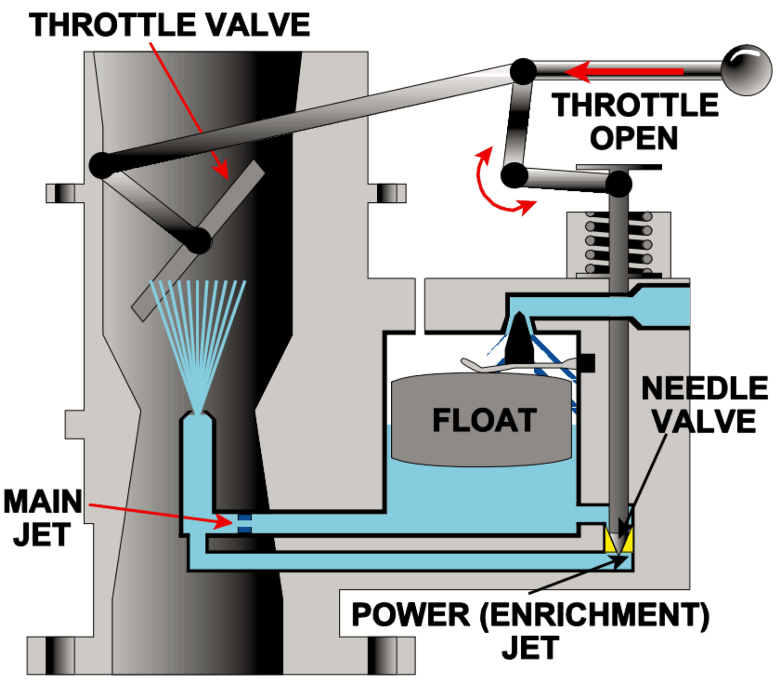
An additional needle valve, which may be known as a **power jet**, **enrichment jet**, or **economizer**.



Mixture control - Power Enrichment

The needle valve, which is connected to the throttle control, is **fully closed** at all **throttle settings below** that required to give **maximum** cruising power at sea-level, but as the throttle is opened above this setting the needle valve **opens progressively** until, at full throttle, it is fully open.

On some engines the power jet is operated independently of the throttle, by means of a **sealed bellows** which is actuated by manifold **pressure**. In this way high-power enrichment is related to engine power rather than to throttle position.

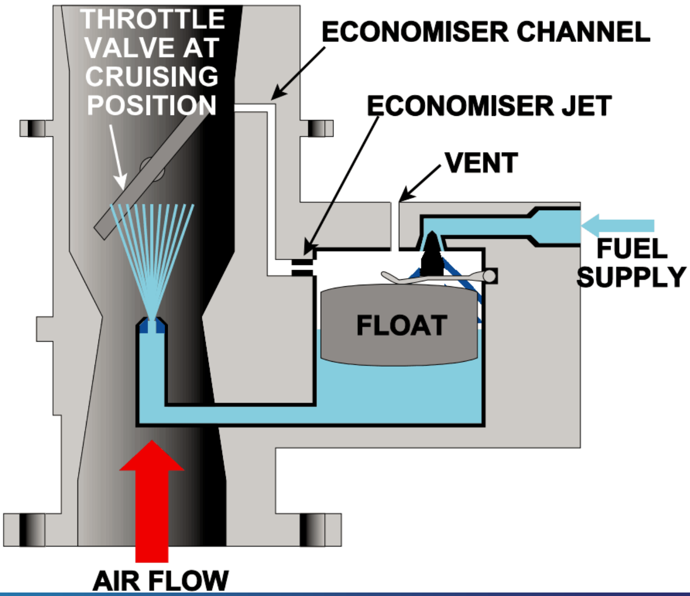


Mixture control – Air operated economizer

An air-operated economizer (known as a back-suction economizer) is illustrated in the Figure. When the throttle valve is at a high-power setting, the pressure of air flowing past the valve is only **slightly below atmospheric** pressure and will have little effect on air pressure in the float chamber, thus a **rich mixture** will be provided.

As the **throttle** is **closed** to the cruising position, air flowing past the throttle valve creates a **suction**, which is applied to the float-chamber through the economizer channel and air jet.

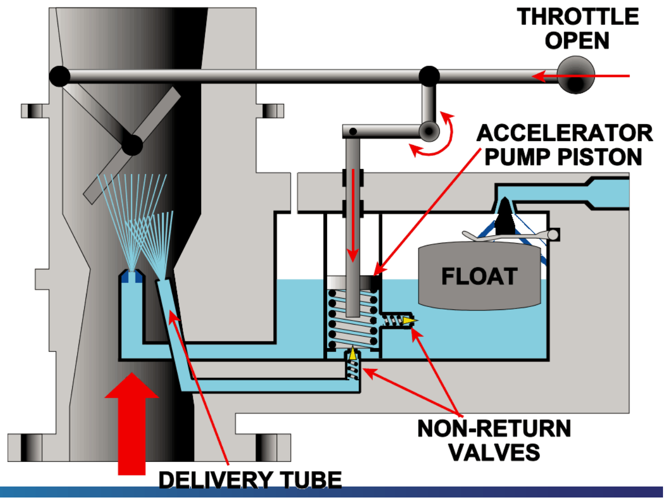
The **reduced** float-chamber **pressure** reduces fuel flow through the main jet to provide the **economical** mixture required for cruising.



The accelerator pump

If the **throttle valve** is opened **quickly**, **airflow** responds almost **immediately** and a larger volume of air flows through the carburetor. The **fuel** metering system however, responds **less quickly** to the changing conditions, and a temporary weakening of the mixture will occur, known as a flat spot (or at worst causing a 'weak cut') before fuel flow again matches airflow. This condition is overcome by fitting an **accelerator pump** which is linked directly to the throttle, and forces fuel into the Venturi whenever the throttle is opened.

In some pumps a controlled bleed past the pump piston allows the throttle to be opened slowly without passing fuel to the engine, in other pumps an additional delayed-action plunger is incorporated to supply an additional quantity of fuel to the engine for a few seconds after throttle movement has ceased.

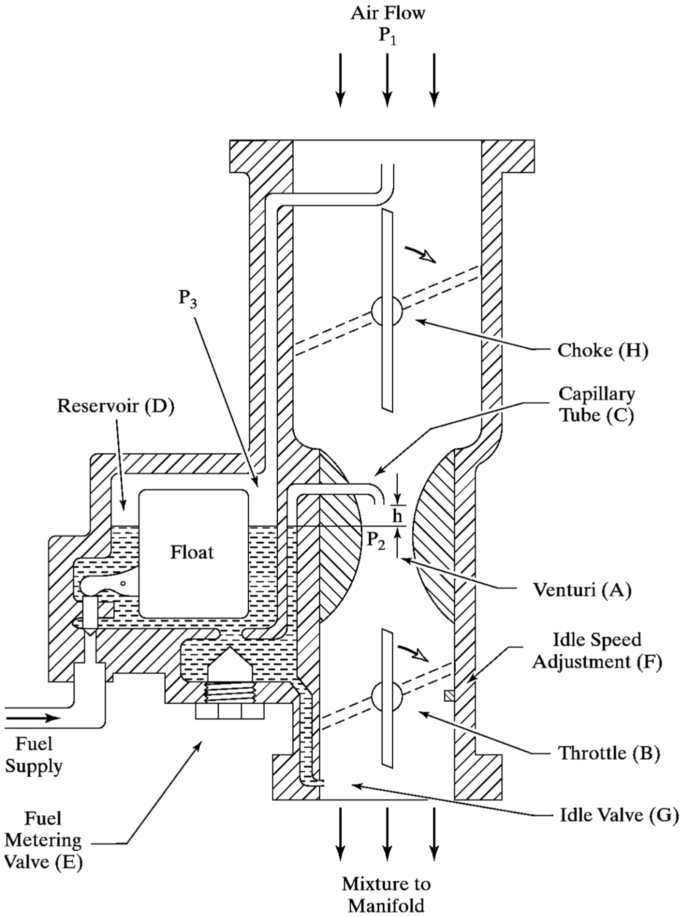


Starting system

As shown in the figure (**rotated of 180°**) another butterfly valve called the **choke** (H) is positioned upstream of the venturi throat. This is needed to **start cold engines**.

It is not really the air-fuel ratio that is important for considering combustion, but the **air-vapor ratio**; only fuel that is **vaporized** reacts in a **combustion** process.

When an engine is cold (as in an automobile sitting overnight in northern Minnesota in January), a very **small** percent of fuel will **vaporize**.

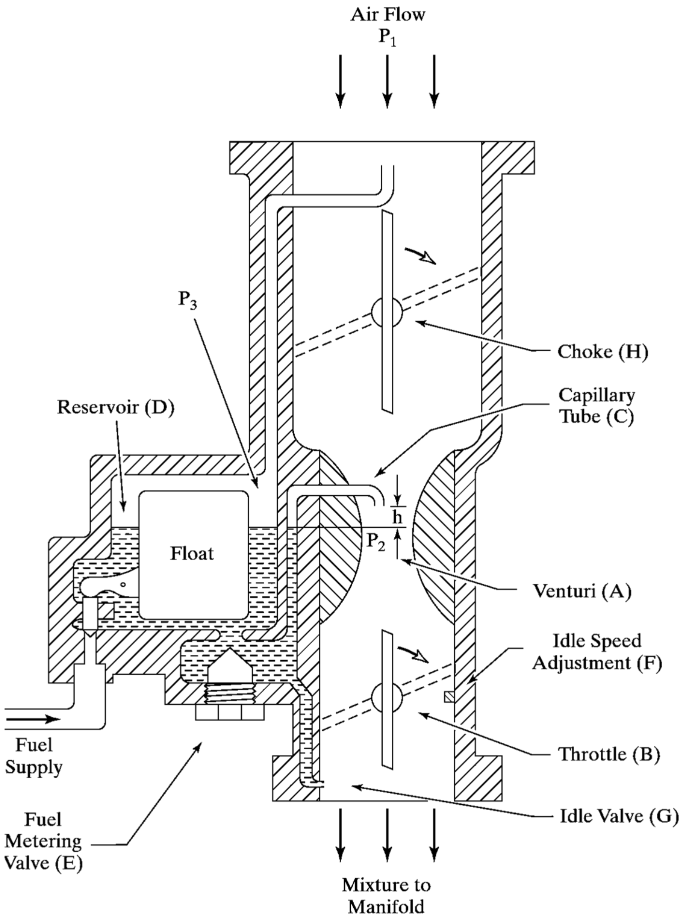


Starting system

The fuel is **cold** and much more **viscous**, creating a lower flow rate and **larger droplets** which vaporize more slowly.

Even in the compression stroke, which heats the air-fuel mixture, the **cold cylinder** walls **absorb heat** and reduce vaporization.

At **starting** conditions, the throttle is wide open, so no substantial pressure differential is established through the idle valve.

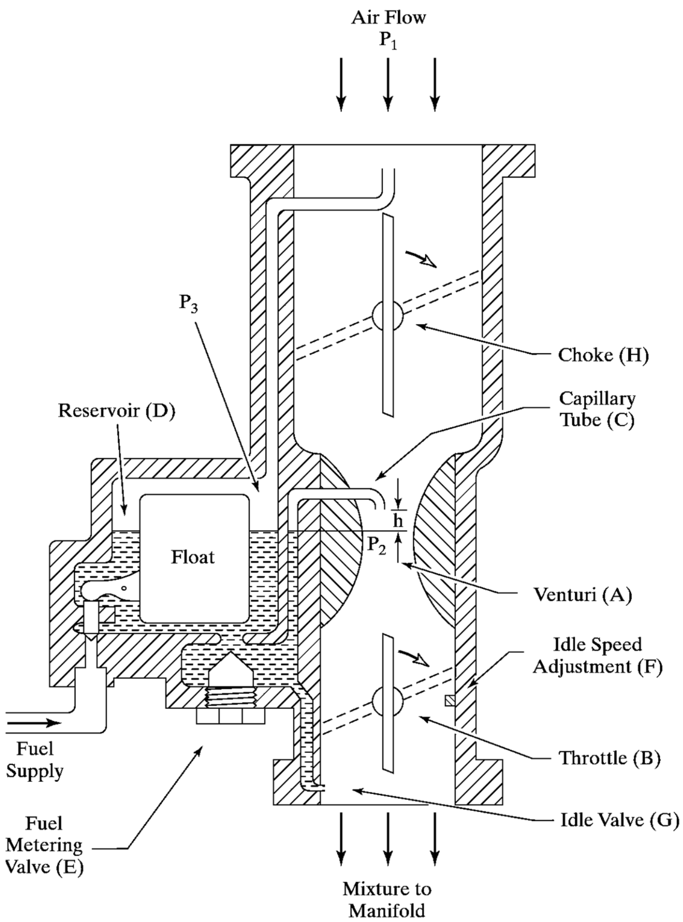


Starting system

All of this creates **very little fuel evaporation**, and if normal carburetor action were used, there would not be enough fuel vapor in the cylinder to create combustion and get the engine started.

When starting a **cold engine**, the first step is to **close** the **choke**. This restricts air flow and **creates** a **vacuum** in the entire intake system downstream of the choke, even at low air flow rates.

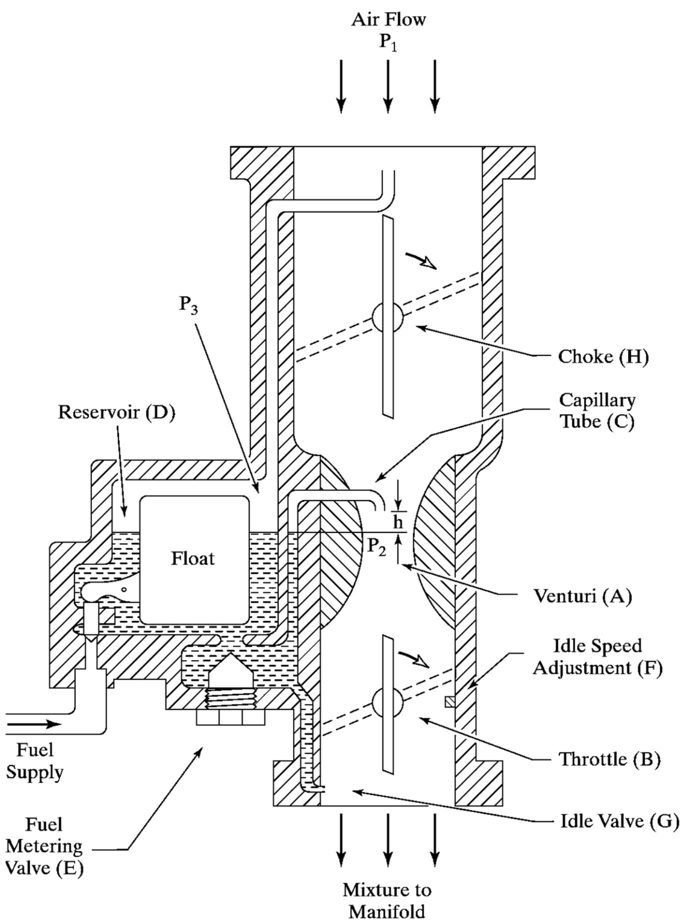
The large **pressure differential** across both the fuel capillary tube and the idle valve, cause a **large fuel flow** to mix with the low air flow.



Starting system

This gives a **very rich air-fuel mixture** entering the cylinders, up to for very cold starts. With only a small percent of fuel evaporating, a combustible air-vapor mixture is created, combustion occurs, and the **engine starts**.

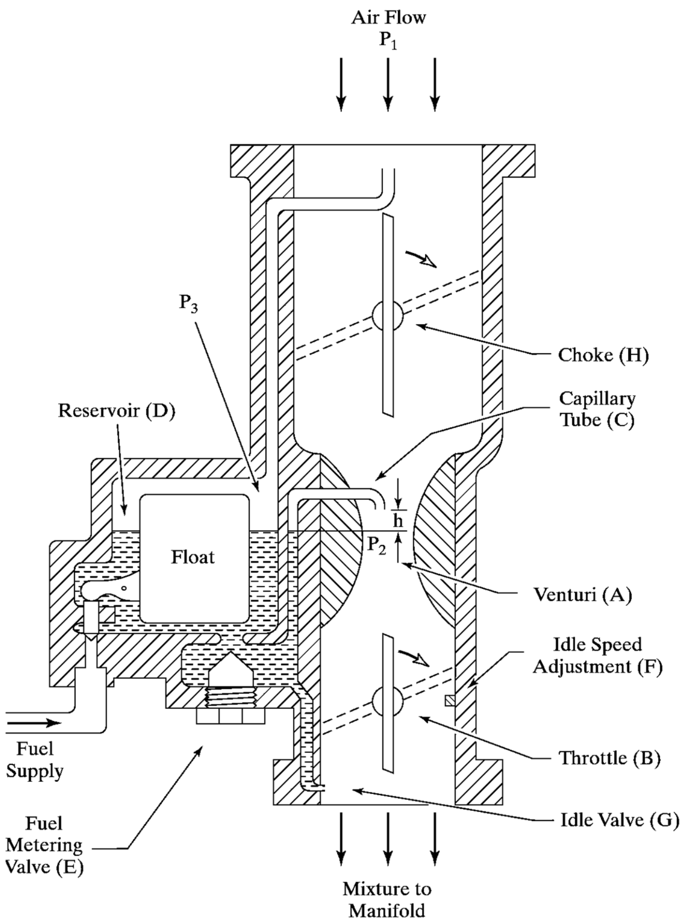
Only a few engine cycles are required before everything starts to **heat up** and more normal operation occurs. As the engine heats up, the **choke** is **opened** and has no effect on final steady-state operation.



Starting system

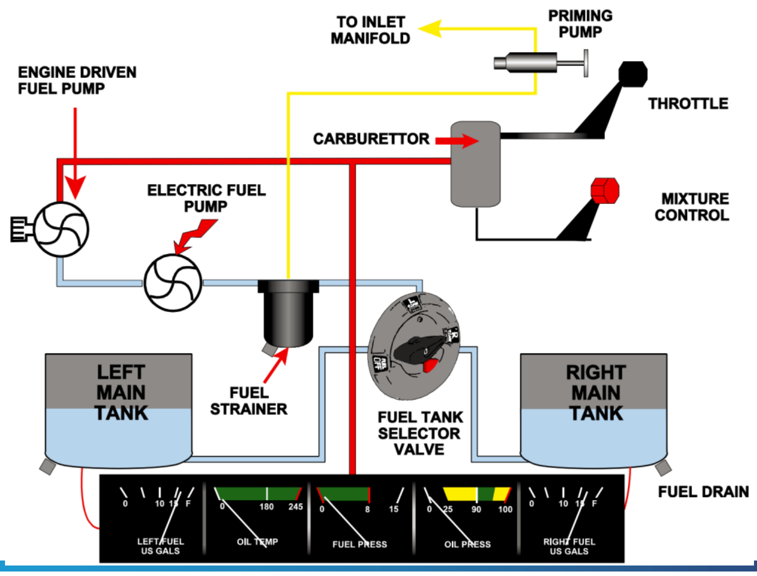
It does **not** require **frigid winter** temperatures to create the need for a choke for starting an engine. Anyone who has ever tried to start a chokeless lawn mower at 10°C will agree with this.

Present **carburetors** are equipped with automatic chokes.



Starting system - Priming

Normally a **priming pump** would supply fuel to the induction manifold, close to the inlet valve. In the absence of such a device, it is permissible on some aircraft to prime the engine by pumping the throttle (exercising the accelerator pump) several times. This practice must be discouraged in any other circumstance because it increases the chance of **carburetor fires**.

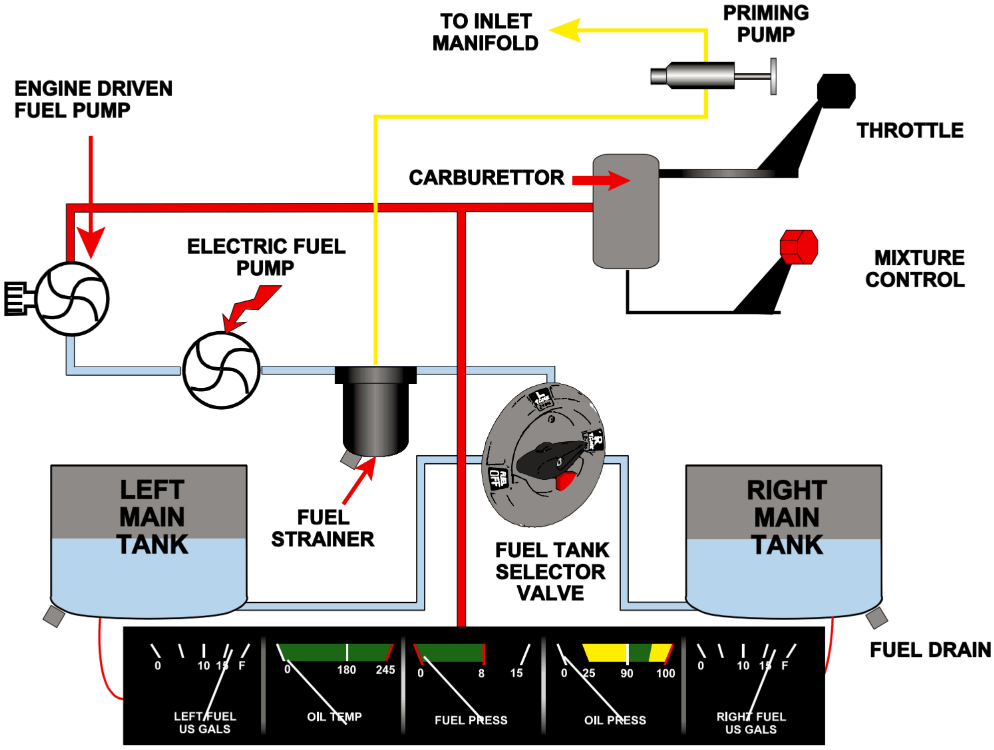


Starting system - Priming

The **fuel** is drawn from **the tanks** by a mechanical or electrical fuel pump through a tank selector and filter before being delivered to the carburetor.

Engine priming is achieved by use of a **priming pump** which takes fuel from the **filter** housing and delivers it to the inlet manifold.

The fuel system is monitored for contents and pressure and the fuel drains allow any water to be removed before flight.



Engine icing

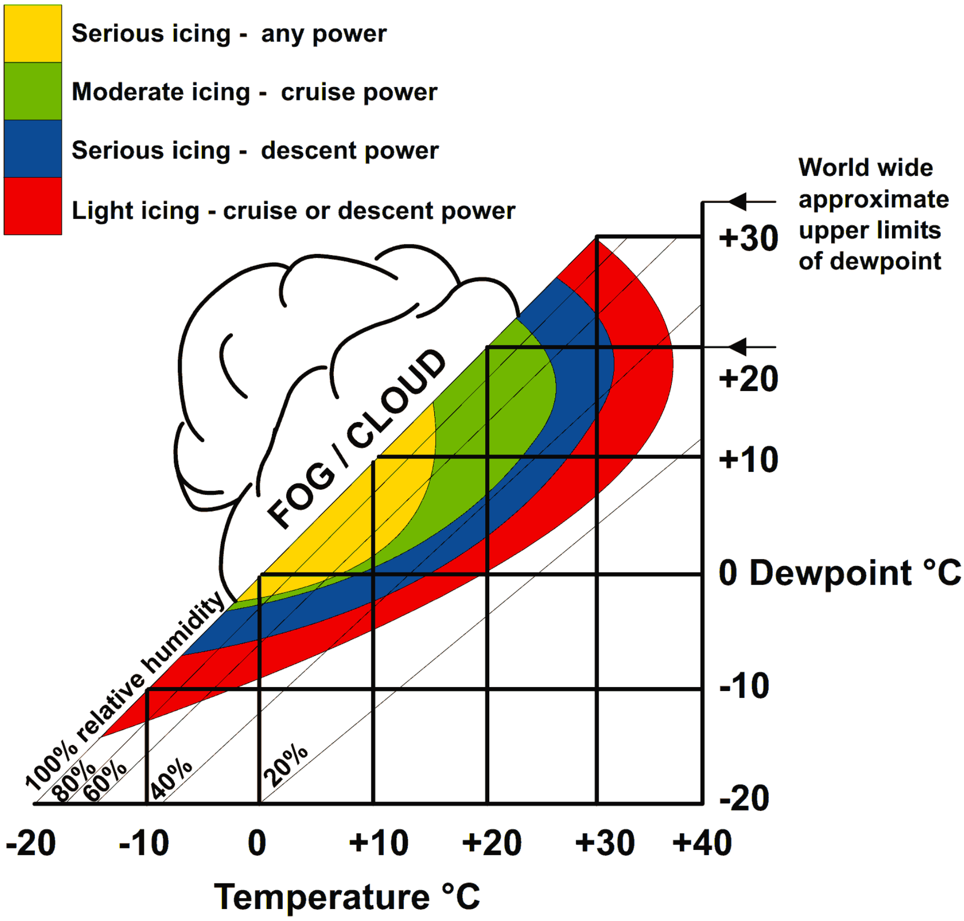
The **problems** of engine icing, particularly engines fitted with carburetors, have been known for some years, but **still accidents occur** in which induction system icing has been the cause, despite modern fuel metering devices.

Atmospheric conditions, particularly of high humidity (more than 50% Relative Humidity RH) and temperatures ranging from -7°C (20°F) to as high as +33°C (90°F), may cause icing in the induction system of all types of piston engine.

Engine icing

The figure shows the **range of temperatures** at which icing can affect the engine at different power settings.

The **dew point** (punto di rugiada) is the temperature to which **air** must **be cooled** to become **saturated** with water vapor. It is assumed that air pressure and water content is constant.

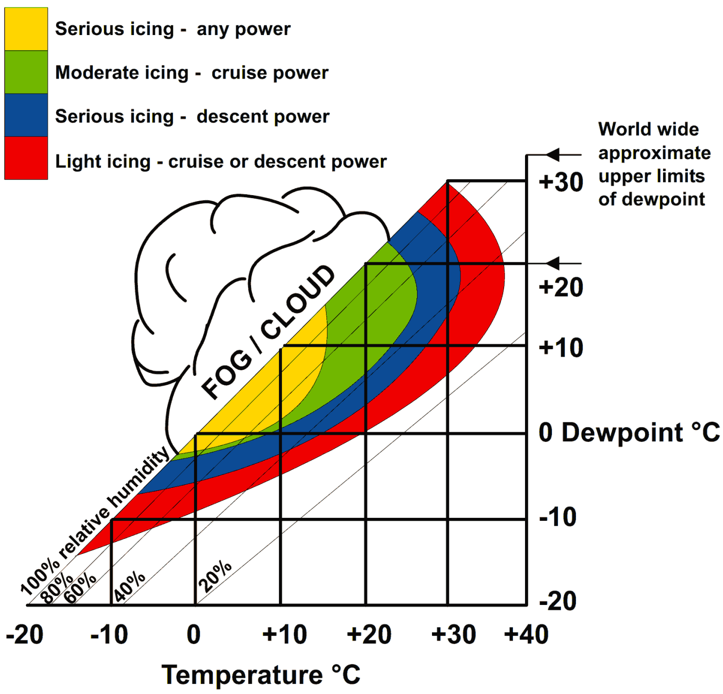


Engine icing

This temperature range and humidity occur throughout the year in Europe and **pilots** should be constantly aware of the possibilities of **icing** and take the **corrective action** necessary before such problems arise and the situation becomes irretrievable.

Once an **engine stops** due to induction icing it is most **unlikely** that it may be restarted in time to prevent an accident - therefore recognition and correction is vital.

All pilots operating piston engine should understand the problems associated with each particular type, but they also need to know how the engine reacts once heat is applied to prevent induction icing.



Engine icing

Basically, there are three forms of icing:

- **Impact ice** which forms on the **air filters** and bends in the induction system.
- **Refrigeration ice** (carburetor icing) which forms in float type carburetors as a result of the low temperatures caused by **fuel vaporization** and **low pressure** acting on moisture in the atmosphere.
- **Fuel icing** which is caused by moisture in the fuel coming out of suspension and **being frozen** by the **low temperatures** in the carburetor. This tends to stick to the inlet manifold around the corners and reduce air/fuel flow into the engine.

Carburetor icing

The **indications** of icing to the **pilot** of an aircraft fitted with a carburetor, if he has failed to anticipate the problem, would be a gradual **drop** in **RPM** which may be accompanied by engine **rough running** and **vibration**. In aircraft fitted with a **constant** speed **propeller** it would be indicated by a **drop in manifold pressure** or reduction of airspeed in level flight.

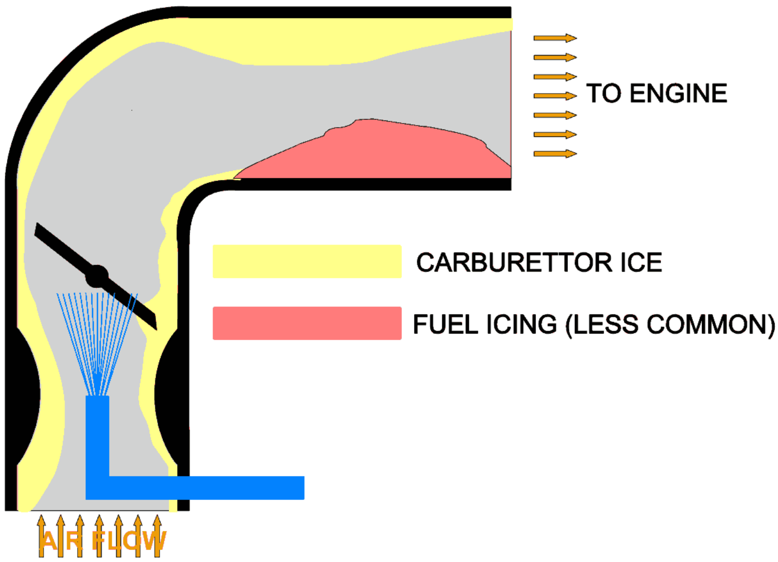
The problem is caused partly by the **rapid cooling** in the throat of the carburetor as heat is absorbed from the air during the **vaporization** of the fuel and by the **low-pressure** area in the **Venturi tube**.

Carburetor icing

The **temperature** in the induction system of the carburetor **drops** as much as **22°C** (70°F) below the temperature of the incoming air. If now the air contains a large amount of moisture this cooling process may be sufficient to cause **ice** to form in the area of the **throttle "butterfly"**.

Here it will **reduce** the area of the induction **intake** and may **prevent operation** of the **throttle** plate, resulting in the loss of power, and if not corrected the **ice** may **accumulate** sufficiently to **block** the **intake** completely and **stop** the **engine**.

At temperatures of **snow** (14°F) or below **moisture** in the air will be **already frozen** and will pass through the carburetor and so heat should not be used.



Action to be taken if engine icing is suspected

When **icing** is suspected, the **carburetor heat** control should be selected to **fully hot** and left in the hot position for a sufficient length of time to clear the ice. This could take up to **1 minute** or **longer** depending on the severity.

Partial heat should **not** be **used** unless the aircraft is equipped with a carburetor air temperature gauge. The **carburetor heat control** provides **heated air** from around the **exhaust** pipe into the induction system which will **melt** the ice and which then passes through the engine as water.

Engine **roughness** and further **power loss** may **occur** as the **water** passes into the **cylinders** and pilots should not be tempted to return the heat control to OFF (cold), thinking that the situation has become worse since applying heat.

Action to be taken if engine icing is suspected

Carburetor **icing** can occur during **taxying** at small throttle settings or when the engine is at **idle** RPM. In these circumstances ensure that **hot air** is used **before take off** to clear any ice but select cold air before opening the throttle to full power and check that the correct take off RPM/manifold pressure is obtained.

Under **no** circumstances should **carburettor heat** be used **during take off**.

Action to be taken if engine icing is suspected

Icing is also **more likely** during long periods of flight at **reduced power**, such as during a **glide descent** or **letdown** for approach and landing. Because the heat is derived from the engine, during long descents the engine temperatures will gradually cool, thus reducing the effectiveness of the hot air system.

Where **icing conditions** exist select **full hot air** before **reducing power** so that benefit is gained from the hot engine before the engine temperature starts to reduce.

To help maintain engine temperatures and provide a sufficient heat source to melt any ice, it is necessary to **increase power** periodically to a **cruising setting** at intervals of between 500 and 1,000 ft during the descent. Additionally, this action prevents lead fouling of the spark plugs.

Engine considerations

When using **carburetor heat** there are a number of factors which should be understood:

- The application of **hot air reduces** the **power** output by approximately **15%** and also creates a richer mixture which may cause **rough running**.
- **Heat** should **not** be applied at **power settings** greater **than 80% as** there is a danger of **detonation** and engine damage. Intake icing should not occur at power settings involving a wide throttle butterfly opening.
- The **continuous** use of carburetor heat should be avoided due to the change of mixture and increase of **engine temperatures**. Heat should be used only for a sufficient period of time to **restore engine power** to its original level. This will be noted by an increase of RPM or manifold pressure above the original setting when the control is returned to cold.
- Do **not** use carburetor **heat** once **clear** of **icing** conditions but check periodically that ice has not reformed.

Engine considerations

The fuel **injected engine** does **not** have the problems of **ice forming** at the Venturi, but **other parts** of the system may accumulate ice with a similar loss of power.

Fuel icing may gather at the **bends in the system**, **impact icing** may form at the impact **sensing tubes**, or on the **air filters**, particularly when flying in cloud at low temperatures. The alternate air system fitted to these engines should then be selected and the icing drill followed according to the aircraft check list.

Operational procedures - ground operation

The following points should be understood in the use of carburetor heat control:

- **Ground operation** - Use of the heat control on the ground should be kept to a **minimum** as the **air** is not **filtered** and may feed dust and dirt into the system causing additional wear on pistons and cylinders. A **function check** of the heater control should be made before take off. RPM should drop approximately 100 RPM when heat is applied and return to the selected setting when turned OFF (cold).
- **Take off** - If icing is evident on the ground before take off, use **heat** to **clear** the ice but return the control to **OFF** (cold) before applying **take off** power. Check that normal take off power is available.
- **Climb** - Do **not** use carburetor heat during the **climb** or at power settings above 80% (approximately 2500 RPM).

Operational procedures - Flight Operations

The following points should be understood in the use of carburetor heat control:

- Be aware of conditions likely to cause carburetor icing - **damp**, **cloudy**, **foggy** or **hazy** days, or when flying close to cloud or in rain or drizzle.
- Look out for an **unaccountable loss** of **RPM**/manifold **pressure**. Make frequent checks for icing by applying heat for a period of between 15 to 30 seconds, noting first the selected RPM then the drop of RPM as heat is applied.
- Listen to the **engine noise** and check the outside air temperature. Should **RPM increase** whilst **heat** is applied, or the **RPM** return to a **higher** figure than original when re-selected to cold, then **ice is present**. Continue to use heat while flight in icing conditions continues.

Operational procedures – Descent

The following points should be understood in the use of carburetor heat control:

- Apply carburetor **heat** during glide **descents** or long periods of flight at reduced power (below 1,800 RPM) remembering to warm/clear the engine for short periods every 500-1,000 ft.
- **Approach and landing** - The carburetor heat selector should remain at **cold** during approach and landing, **except** for a **glide approach**, but if **icing** conditions are **known** or suspected, full **heat** should be applied.
- However, the control must be returned to **cold** before applying **power** for a roller landing or carrying out an overshoot.
- **Caution** - During **Hot/Dry** weather application of hot air may cause a rich cut in the engine, therefore use the carburetor **heat** control sensibly, not just **as a matter of habit**. Think about what you are doing and check the prevailing conditions.

Fuel injection

Indirect fuel **injection** is often employed on aircraft piston engines, but is of the **low-pressure**, **continuous-flow** type. In the low-pressure, continuous-flow method, fuel is sprayed continuously into the induction pipe as close to the inlet valve as possible.

The **advantages** claimed for the method are **low operating pressure**, good fuel distribution, **freedom** from **icing** problems and the ability to use a **pump** which does **not** have to be **timed** to the operating cycle.

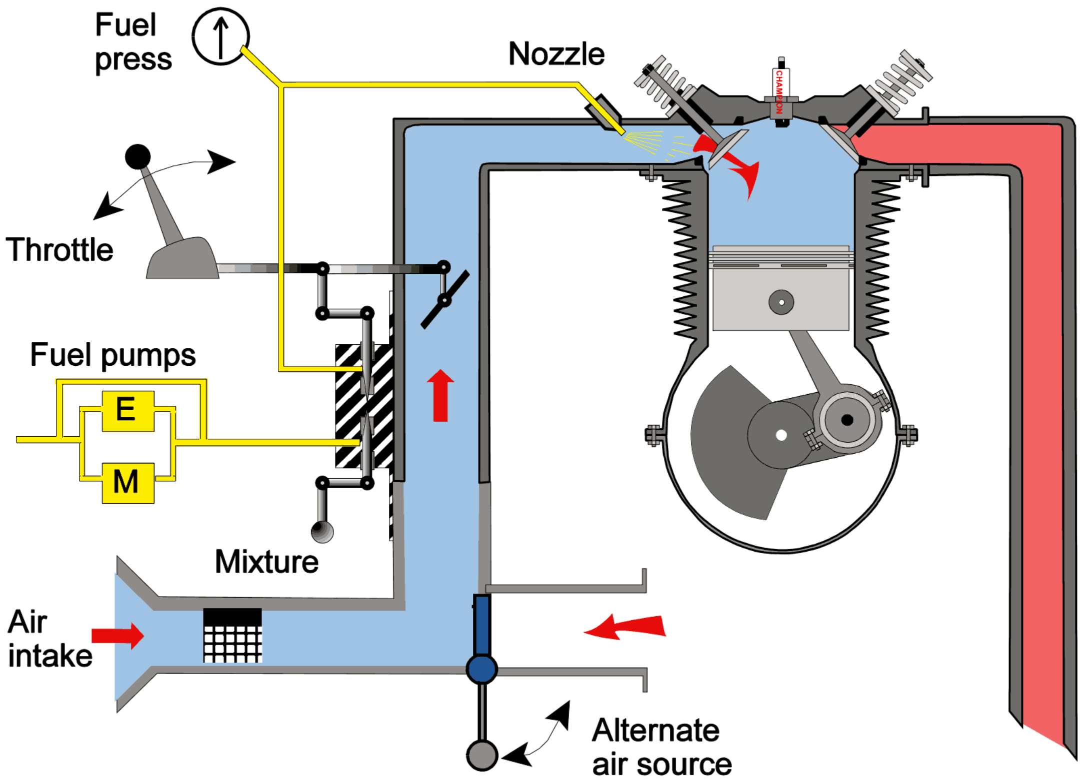
Some fuel injection systems operate on a **similar** principle to the **carburetor** but inject fuel under **pressure**, into the intake. In the indirect injection system, the air throttle metering valve varies the pressure of fuel according to engine speed.

Mixture strength is varied by a **manually** operated **mixture control** valve which adjusts the fuel pressure for altitude or operating conditions. Because of the method of operation of the injector, no special idling arrangements are required and a separate priming system for engine starting is unnecessary.

Fuel injection

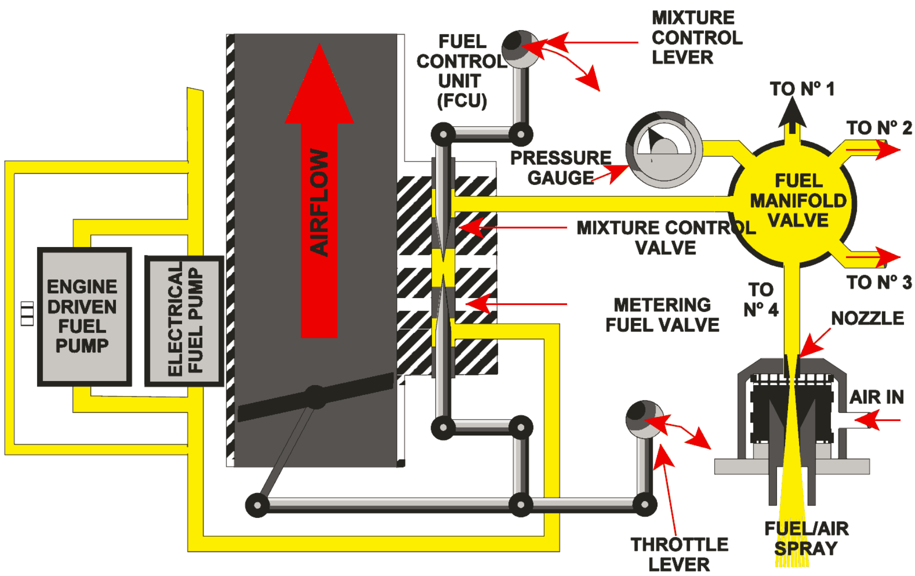
The main components in the system are a **fuel pump**, a **fuel/air control** unit, a **fuel** manifold (distribution) **valve**, and discharge nozzles for each cylinder.

In addition, a **normal throttle valve** controls **airflow** to the engine, and a fuel pressure gauge is fitted to enable **mixture adjustments** to be made.



Fuel injection – Fuel pumps

The **pump** supplies **more fuel** than is required by the engine, and a **recirculation path** is provided. **Two pumps** are provided, arranged in **parallel**, so that when the **mechanical pump** is not operating, fuel under positive pressure from the **electrical pump** can by-pass the mechanical pump, so allowing the electrical pump to be used for engine **priming** and **starting** and in an **emergency**.



Fuel injection – The fuel/air control unit

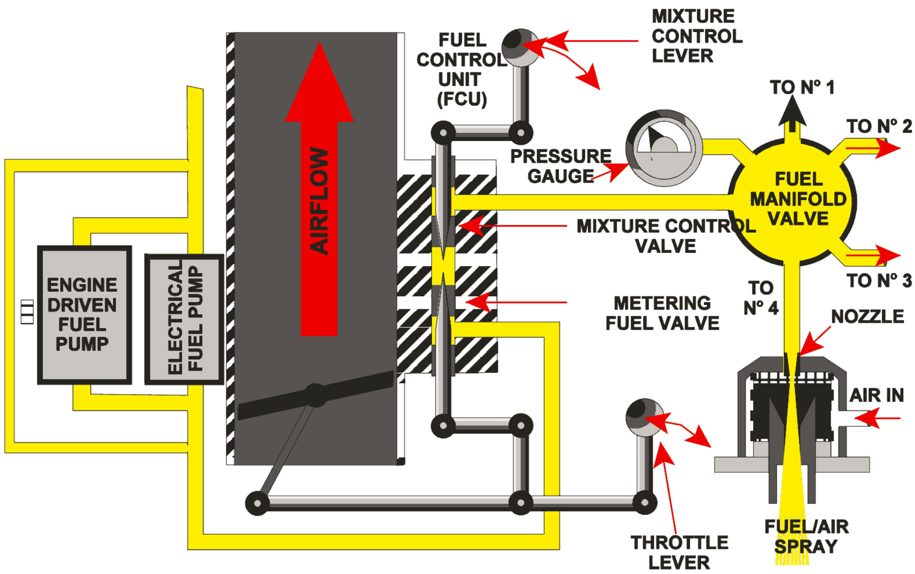
The fuel/air control unit is mounted on the intake manifold and contains:

- the **air throttle assembly** (**throttle valve**),
- the **throttle metering valve** (**metering fuel valve**)
- the **mixture control valve**.

The **air throttle assembly** contains the air throttle valve, which is connected to the pilot's throttle lever and **controls airflow** to the engine.

The **intake** manifold has **no Venturi** or other restrictions to airflow.

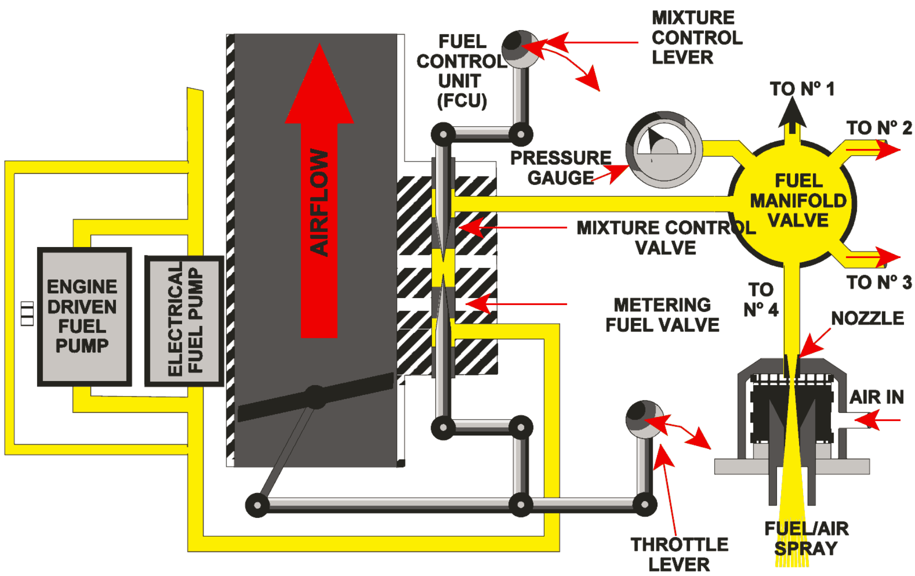
The **fuel control unit** is attached to the air throttle assembly, and controls fuel flow to the engine by means of **two valves**.



Fuel injection – The fuel/air control unit

The **fuel control unit** controls the flow to the engine with **two valves**:

- One valve, the **metering fuel valve**, is connected to the **air throttle** and controls **fuel flow** to the fuel manifold valve according to the **position** of the air **throttle**, thus fuel flow is proportioned to air flow and provides the correct air / fuel ratio.
- The second valve, the **mixture control valve**, is connected to the pilot's **mixture control lever**, and **bleeds** off fuel pressure applied to the metering valve. Thus, the air/fuel ratio can be varied from the basic setting of the metering valve, as required by operating conditions.



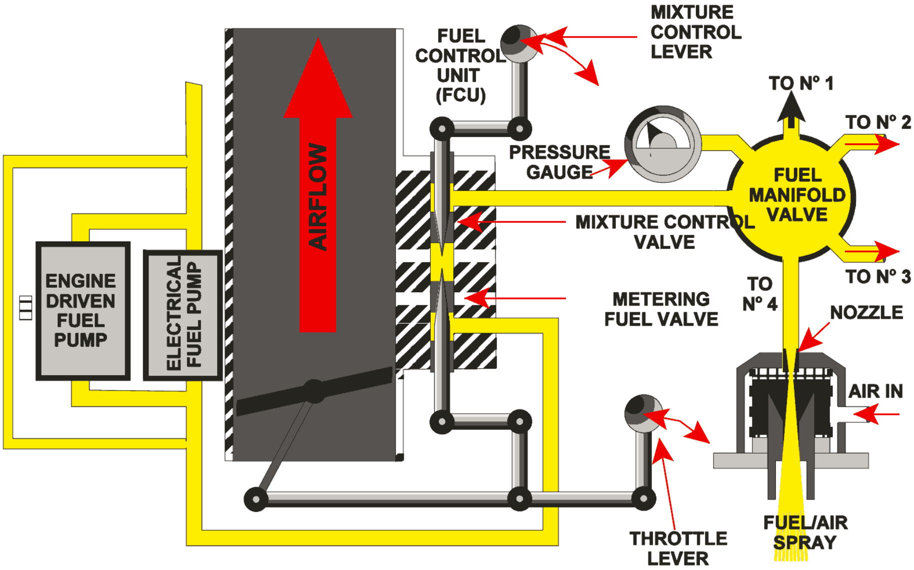
Fuel injection – The fuel/air control unit

A fuel **pressure gauge** in the system indicates metered fuel pressure, and, by suitable calibration, **enables** the **mixture** to be **adjusted** according to **altitude** and **power setting**.

The **fuel manifold valve** is located on the engine **crankcase** and is the central point for distributing metered fuel to the engine. When the engine is **stopped**, all the outlet **ports** are **closed**, and no fuel can flow to the engine.

As fuel **pressure builds up** (as a result of engine rotation or booster pump operation) **all the ports** to the discharge nozzles **open** simultaneously.

A ball valve ensures that the ports are fully open before fuel starts to flow.



Fuel injection – The fuel/air control unit

A **fuel discharge nozzle** is located in each cylinder head, with its outlet directed into the inlet port. Nozzles are calibrated in several ranges, and are fitted to individual engines as a set, each nozzle in a set having the same calibration.