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AIRCRAFT GENERAL KNOWLEDGE

CHAPTER 5 – FUEL AND METERING SYSTEMS

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FUEL AND METERING SYSTEMS

5.1 Aviation Fuel

5.1.1 Types

In aviation, aviators will come into contact with two categories of fuel, those used for piston driven aircraft, and those used for jet and turbine driven aircraft.

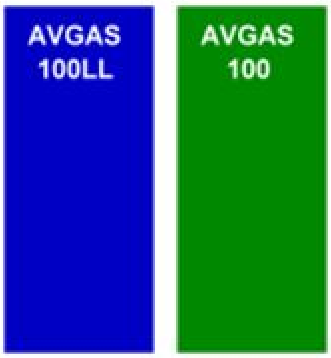
5.1.1.1 <u>Aviation Gasoline (AVGAS)</u>

AVGAS is gasoline fuel for reciprocating piston-engined aircraft. As with all gasolines, **AVGAS** is very volatile and is extremely flammable at normal operating temperatures. Procedures and equipment for safe handling of this product must therefore be of the highest order

AVGAS grades are defined primarily by their octane rating. Two ratings are applied to aviation gasolines, the lean mixture rating and the rich mixture rating, which results in a multiple numbering system, e.g. **AVGAS 100/130.** In this case the lean mixture performance rating is 100 and the rich mixture rating is 130. To avoid confusion and to minimise errors in handling aviation gasoline, it is common practice to designate the grade by just the lean mixture performance, i.e. **AVGAS 100/130** becomes **AVGAS 100**.

In the past, there were many different grades of aviation gasoline in general use, e.g. 80/87, 91/96, 100/130, 108/135 and 115/145. However, with decreasing demand these have been rationalised down to one principle grade, Avgas 100/130. More recently an additional grade was introduced to allow one fuel to be used in engines originally designed for grades with lower lead contents. This grade is called AVGAS 100LL, the LL standing for 'low lead'. Currently the two major grades in use internationally are AVGAS 100LL and AVGAS 100.

In specifying requirements for aircraft piston-engine fuel the principle objective is to ensure that the fuel has satisfactory combustion qualities. The most important property is the anti-knock (detonation) rating, but others such as the distillation range and volatility are also important because of their influence on mixture distribution and cold starting. Other specification items are included to ensure that the fuel has a good storage life, will not corrode engine or fuel system components and can be satisfactorily supplied to the engine under all operating conditions.



All equipment and facilities handling **AVGAS** are colour coded **RED** and display prominently the markings denoting the actual grade carried. To ease identification the fuels are dyed, i.e. **AVGAS 100LL** is coloured **BLUE**, while **AVGAS 100** is coloured **GREEN**.

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Certain engines require certain fuel—make sure that the correct grade is used. Make sure that the fuel already in the tanks is the same as the fuel being loaded. If you use fuel of a lower grade than specified detonation is more likely to occur, especially at high power settings, with a consequent loss of power and possible engine damage. If you use fuel of a higher grade than specified, the spark plugs could be fouled by lead. However, it is acceptable to use a higher octane ratio fuel for a short flight. Never use a lower octane fuel

Detonation: Normal burn rate is 60 – 80 ft/sec detonation burn rate can be up to 1000ft/sec

AVGAS fuelling nozzles for over-wing dispensing are painted **RED** to help prevent the possibility of jet fuel being supplied to a piston engined aircraft. Nozzles for jet fuel (painted **BLACK**) are normally a different shape and of a larger diameter than the aperture on most aircraft **AVGAS** tanks.

5.1.1.2 MOGAS (Motor Gasoline)

MOGAS is not octane rated the same way **AVGAS** is rated, so it is difficult to compare the ratings exactly. Super **MOGAS** is coloured red and is usually about 92 octane. In an aircraft engine, motor fuel would cause a lower output and an increased possibility of detonation. Motor fuel is also more volatile than **AVGAS** (it vaporises more readily), thus motor fuel can cause vapour locks in the fuel system of an aircraft engine and possibly starve it of fuel. Use of MOGAS is permitted in some aircraft if they have been properly modified and specifically approved by the aviation authority.

5.1.2 Aviation Turbine Fuel (AVTUR)

In specifying requirements for jet fuels the main objective is to ensure that fuel systems will function satisfactorily over a wide range of temperatures and pressures.

These environmental factors can be very severe owing to the conditions under which modern jet aircraft operate. In addition to these requirements engine developments and the continual effort to lengthen the period between engine overhauls has led to the introduction of a number of new sophisticated specification requirements, far removed from those for aviation gasoline. Among these are the need for high thermal stability, low luminosity and compatibility with certain fuel system materials.

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Aviation turbine fuels are used for powering jet and turbo-prop engined aircraft. There are currently two main grades of turbine fuel in use in civil commercial aviation:

5.1.2.1 Jet A-1

Jet A-1 is a kerosene grade of fuel suitable for most turbine-engined and Diesel engined aircraft. It is produced to a stringent internationally agreed standard, has a flash point above 38ºC (100ºF) and a freeze point maximum of **-47ºC**. Jet A1 is the most common Jet fuel available internationally.

5.1.2.2 Jet A

Jet A is a similar kerosene type of fuel. It has the same flash point as Jet A-1 but a higher freeze point maximum (**-40ºC**).This is the most widely available jet fuel in the USA.

5.1.2.3 Jet B

There is another grade of jet fuel, Jet B, which is a wide cut kerosene (a blend of gasoline and kerosene) but it is rarely used except in cold climates. It can be used as an alternative to Jet A-1, but because it is more difficult to handle (higher flammability) there is only significant demand in very cold climates where its better cold weather performance is important. Jet B has a freezing point of **-60°C**

Jet fuel will detonate in a piston engine; therefore it is unsuitable for spark ignition piston engines. Diesel piston engines may use **AVTUR**.

Jet fuel is not manufactured like **AVGAS** and is therefore not octane rated. When compared with **AVGAS** it would have a very low octane and usually no tolerance to detonation.

CAUTION: A fuel of lower octane than the engine rated fuel must never be used. Fuel of a higher octane rating will function satisfactorily with small risk of plug fouling. High octane fuel costs more; there is no power gain so it is not cost effective to use fuel of higher octane rating.

5.1.3 Aviation Fuel Additives

Aviation fuel additives are compounds added to the fuel in very small quantities, usually measurable only in parts per million, to provide special or improved qualities. The quantity to be added and approval for its use in various grades of fuel is strictly controlled by the appropriate specifications. A few additives in common use:

- Anti-knock additives reduce the tendency of gasoline to detonate. Tetra-ethyl lead (TEL) is the only approved anti-knock additive for aviation use and has been used in motor and aviation gasolines since the early 1930s. The higher the rating or grade the greater the compression that the fuel/air mixture can take without detonating.

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- Anti-oxidants prevent the formation of gum deposits on fuel system components caused by oxidation of the fuel in storage and also inhibit the formation of peroxide compounds in certain jet fuels. Only certain anti-oxidants are allowed in aviation fuels.
- Static dissipater additives reduce the hazardous effects of static electricity generated by movement of fuel through modern high flow-rate fuel transfer systems. Static dissipater additives do not reduce the need for 'bonding' to ensure electrical continuity between metal components (e.g. aircraft and fuelling equipment) nor do they influence hazards from lightning strikes.
- Corrosion inhibitors protect ferrous metals in fuel handling systems, such as pipelines and fuel storage tanks, from corrosion. Some corrosion inhibitors also improve the lubricating properties of certain jet fuels.
- Fuel System Icing Inhibitors (anti-icing additives) reduce the freezing point of water precipitated from jet fuels due to cooling at high altitudes and prevent the formation of ice crystals which restrict the flow of fuel to the engine. This type of additive does not affect the freezing point of the fuel itself. Anti-icing additives can also provide some protection against microbiological growth in jet fuel.
- Metal de-activators suppress the catalytic effect, which some metals, particularly copper, have on fuel oxidation. Only specific metal de-activators are allowed in aviation fuels.
- Biocide additives are sometimes used to combat microbiological growths in jet fuel, often by direct addition to aircraft tanks.

5.1.4 Fuel Checks

Fuel which is about to be loaded should be checked first for contamination. The most common contaminant is water. It can leak into ground fuel storage tanks and from there be loaded into the fuel truck and into the tanks of an aircraft. Fuel naturally contains a small amount of water and this too can contaminate the fuel system.

It is necessary to remove any water which if introduced into an engine would cause rough running, loss of power or interrupt the combustion process, completely causing the engine to stop. Water can also block the fuel passages within the carburettor through the formation of water globules.

There are fuel-testing pastes and papers available that react when water is

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present. The fuelling agent will use these on regular basis to guarantee the purity of the fuel in the storage tanks.

In Australia checks must be carried out **before the first flight of the day and after each refueling.**

The approved methods of testing fuel include the use of fuel paste or test kit. Otherwise, having a small quantity of fuel already in your container as you do the fuel drain provides proof that you have not just taken a 100% sample of water from the tank.

5.1.5 Condensation

There is usually a drop in atmospheric temperature overnight and if the airspace above the fuel in the aircrafts fuel tanks is large (i.e. the tanks are close to empty), the fuel tank walls will become cold and there will be condensation from the air above the fuel. If the tanks are kept full when the aircraft is not being used for some days, or overnight if low temperatures are expected, condensation will be minimised. Also, the seal on the filler caps deteriorate and may allow water ingestion.

However, refuelling to full tanks without knowing the next flight fuel requirements can cause difficulties, including:

- If the aircraft has a take-off weight restriction the following day, it will have to be partially defuelled to reduce the weight or adjust the balance.
- If the tanks are full and the temperature rises, the fuel will expand and possibly overflow the tank a little, which could be a fire hazard.

There can be other impurities besides water. Rust, sand, dust and micro-organisms can cause similar problems. Filtering of straining the fuel should indicate the presence of these and hopefully remove them prior to refuelling.

Be especially careful when refuelling from drums that may have been standing for some time. Always check drum fuel with water-detections paste, for date of expiry and for correct grade of fuel. Filter the fuel through a Chamois Leather Filter prior to loading.

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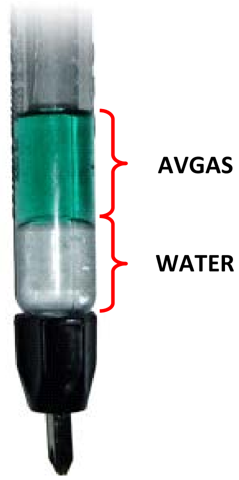
Water is denser than fuel and will gravitate towards the low points in the fuel system. A small quantity of fuel should be drained from each tank and from the fuel strainer drain valve to check for impurities, especially water.



If water is found in the tanks, your actions should include the following:

- Drain the lines until all the water has been removed
- Positively rock the wings to allow any other water to gravitate to the water trap
- Drain off more fuel and check for water at all drain points
- Inform the ground engineer.

5.1.6 Aircraft Fuel System

5.1.6.1 Introduction

The function of the fuel system is to store fuel, and deliver that fuel to the carburettor. Once this has been done, it is delivered to the combustion chamber and converted into mechanical power.

5.1.6.2 Fuel Flow Systems

The fuel flow systems of the aircraft are required to move the fuel from the storage tanks to the point at which combustion occurs, and power is developed in the engine. There are basically two types of fuel flow systems:

- Gravitational systems
- Pressure pump systems.

5.1.6.3 Gravitational System

In the gravity fuel system, the fuel tanks are usually mounted in the wings of a high-wing aircraft, placing the fuel well above the carburettor. The height provides enough (gravity) pressure for the fuel to flow through the system.

The fuel flows from the tanks, through the fuel selector (shut-off) valve and fuel strainer to the carburettor. The fuel gauges in the cockpit provide the pilot with information regarding the amount of fuel on board.

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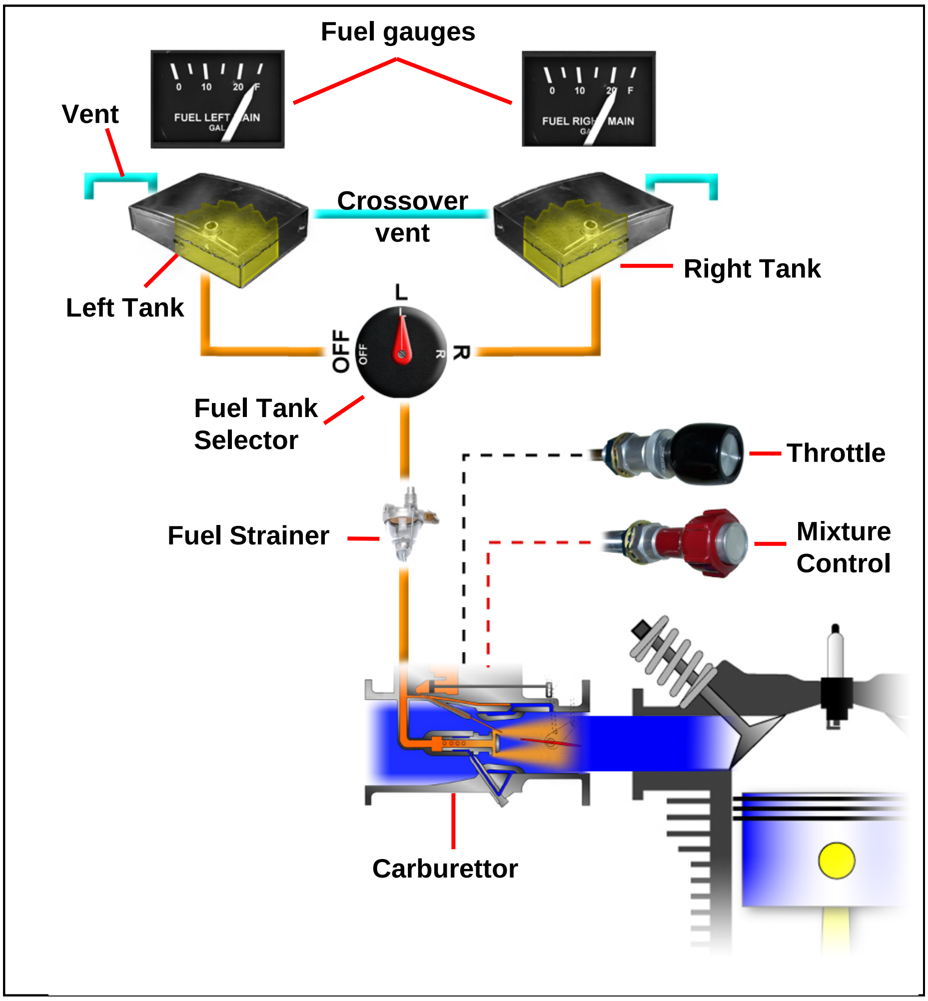
Fuel gauges
Vent
Crossover vent
Right Tank
Left Tank
L
OFF
R
Fuel Tank Selector
Throttle
Fuel Strainer
Mixture Control
Carburettor

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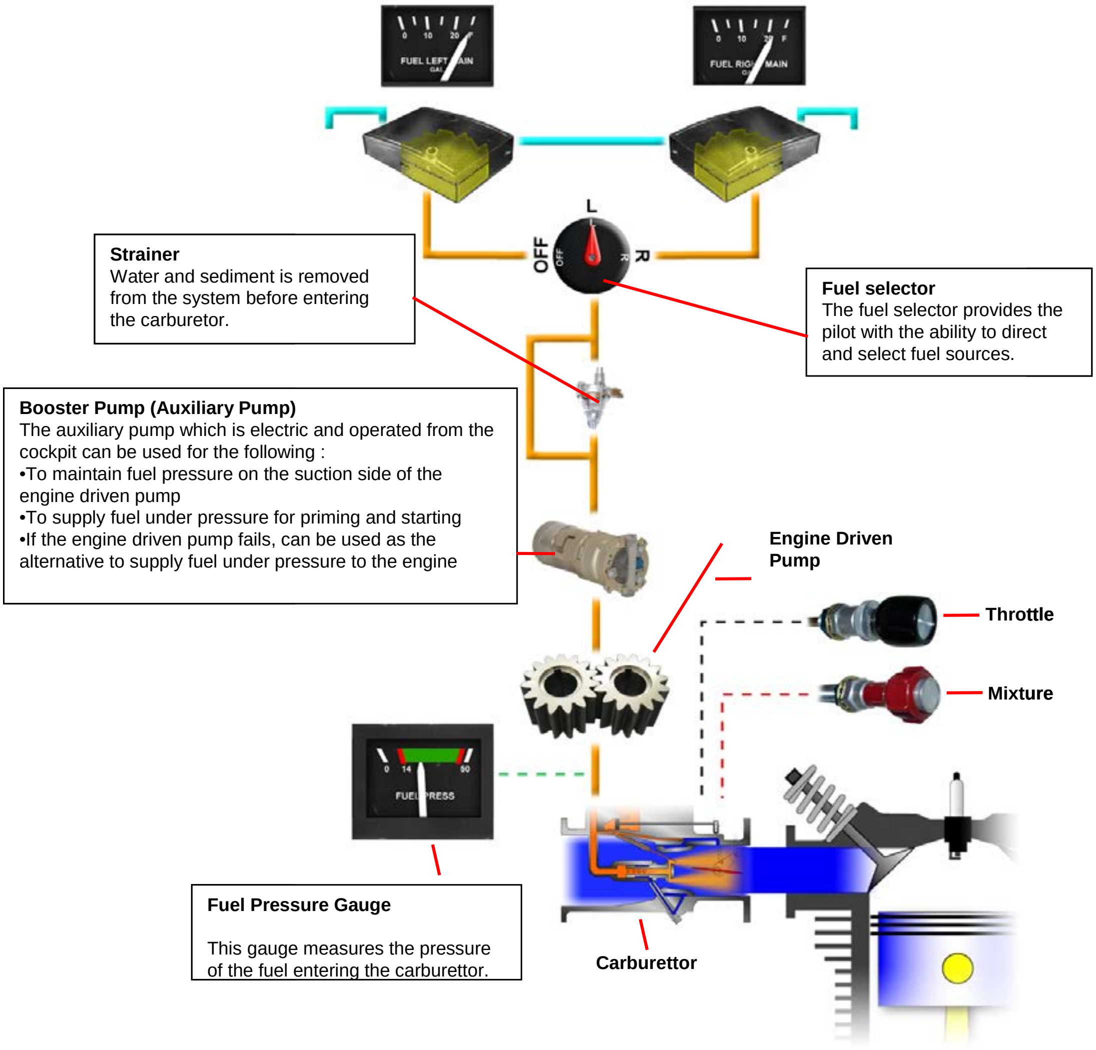
5.1.6.4 Pressure Pump System

In this type of fuel system, an engine-driven pump supplies the fuel pressure. Because the pressure in the system is derived from a pump, the pressure will remain constant throughout the flight. It also means that the fuel tanks can be positioned anywhere in the aircraft, which is beneficial to low wing aircraft. In order to ensure system integrity, systems using engine driven fuel pumps incorporate an auxiliary fuel pump (Boost Pump) in case the engine fuel pump should fail.



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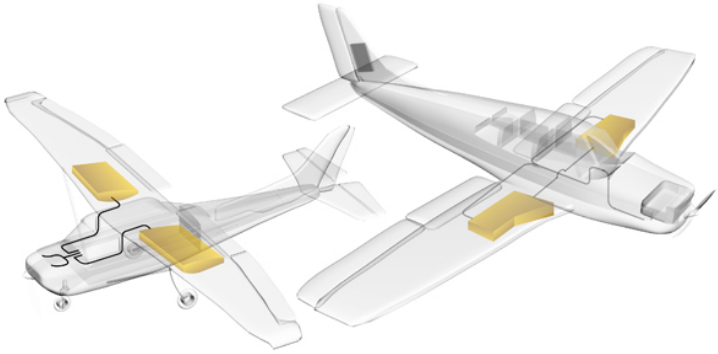
5.2 Fuel and Metering Systems

5.2.1 Introduction

The function of the fuel system is to store fuel, and then deliver that fuel to the engine under all conditions of flight. The pilot must have a positive means of knowing the quantity of fuel available and be able to select fuel from any of the available tanks.

The fuel system should incorporate the following functions:

- Storage of the fuel
- Fuel Feed
- Transfer of fuel
- Fuel Jettison
- Refuel and de-fuel
- Venting
- Gauging.



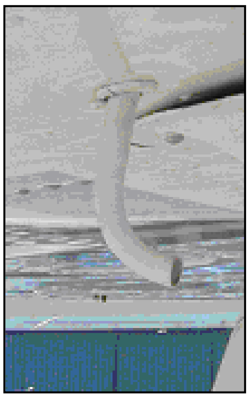
5.2.2 Fuel Storage Tanks

Storage of fuel in aircraft is generally accomplished by the use of tanks mounted within, or on, the aircraft frame. The positioning of these tanks will depend upon available space, structural consideration and positioning of the tanks, whilst maintaining the aircraft centre of gravity (C of G). Depending on the design of the aircraft, any one or a combination of the following storage methods will be found:

- Bladder Tanks (sometimes called bag tanks), which are flexible fuel cells made or rubber or nylon.
- Rigid Tanks are usually constructed from fibreglass, reinforced plastic or a light metal alloy. They can sometimes be used as external drop tanks.
- Integral Fuel Tanks are an integral part of the aircraft structure. These tanks are popular amongst aircraft manufacturers, because of the effective utilisation of space and the saving in weight.

5.2.3 Venting

Fuel tanks are vented, the size of the vent being proportional to the size of the tank. Adequate ventilation will ensure the tank does not the collapse with ambient pressure changes, during climb and descent. Care must be taken to ensure that these vents do not become blocked.



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Fuel tanks are vented for the following reasons:

- To maintain atmospheric pressure within the tanks
- To prevent air locks
- To allow fuel overflow (due to expansion)
- To vent vapour that may have formed in the system.

5.2.4 Pressurising

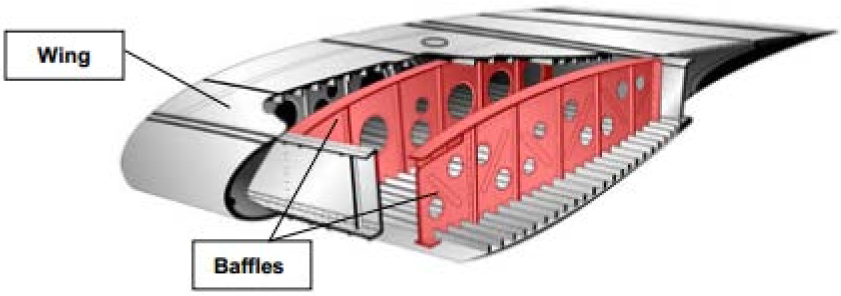
Pressurisation of fuel tanks is often accomplished by facing tank vents into the airflow. During flight, pressure within the tank is maintained at higher than ambient thus aiding positive fuel flow to the engine. *At high altitudes there is also a need to compensate for the lack of ambient pressure.*

5.2.5 Drain Plugs

Drains are positioned at the lowest point of the fuel tank, any water or sediment which has collected in the fuel tank can be drained from this point. Drainage of fuel from here is also used to inspect fuel during daily inspections.

5.2.6 Baffles

All fuel tanks are fitted with internal baffles, to prevent fuel from surging when rapid attitude changes are made. Baffles also prevent large shifts of fuel positions which could affect the Centre of Gravity of the aircraft. This is especially significant on larger aircraft.



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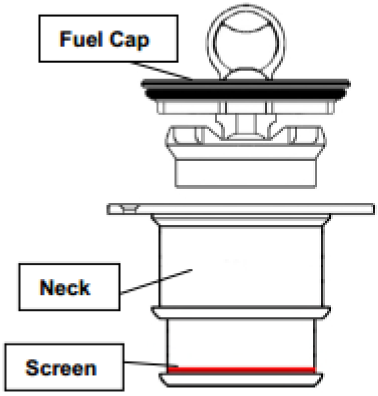
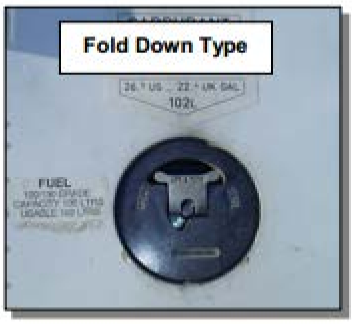
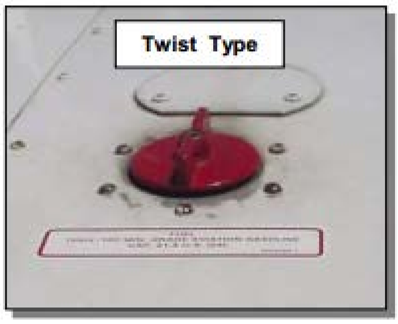
5.2.7 Filler Caps



The filler neck and cap are usually located in a recess in the wing or fuselage. A scrubber is positioned around the neck to prevent overflow fuel from entering the internal sections of the wing and fuselage. Most filler necks are fitted with a filtering screen which prevents foreign objects entering the tanks during refuelling operations.

Care should be taken when installing a fuel tank cap. Failure to properly secure a cap, can lead to fuel siphoning from the tank during flight due to localised low pressure areas on the airframe.

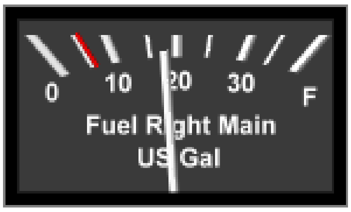




5.2.8 Indicating Fuel Quantity

Although there are a variety of methods for indicating fuel quantity in the fuel tanks, the most frequently used methods are electronic, or electrical.

5.2.8.1 <u>Electronic or Capacitor</u>



These types have no moving parts and have sensors immersed in fuel which measure the fuels density or mass rather than volume. Using this method, the indicators calibrate the amount of fuel being consumed, per unit of time, and electronically display the calculated remainder.

5.2.8.2 <u>Electrical</u>

Using this method, each tank is fitted with an electrical transmitter *(a variable resistor*), which is connected to a float by means of an arm. The float rides on the surface of the fuel, and as the fuel level rises and falls, the resistance in the circuit varies. This information is then displayed by the fuel gauges as *an approximate* fuel quantity.

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5.2.8.3 Precautions against water condensate in the tanks

Eliminating water from fuel is important to both piston and turbine aircraft. Water in the fuel can result in rough running engines, and too much water can cause an engine failure.

Water in the fuel freezes at high altitudes and blocks the fuel filters, restricting flow to the engine. This is usually overcome by making use of fuel heaters, which maintain fuel temperatures above freezing point. A second problem is the potential for a specific type of "corrosive bug" to form in the water in paraffin and turbine fuel; as the water is heavier than the fuel it sinks to the bottom of the tank and causes corrosion.

The following precautions should be taken with regards to refuelling:

- Fill the tanks immediately after a flight. After a flight the remaining fuel in the tanks is cold, while the air in the tank will be warmer. As the fuel cools the air, condensation will take place, the condensation then settles on the bottom of the tank.
- Sample fuel, before first of the day and after each refuel, (CAO 20·2) Perform adequate and proper draining at the quick release drains to verify water is not present.
- Filler caps. Ensure the seals on the filler cap are in good order.

Refuel well before the flight. If refuelling is required before a flight, ensure that as much time as possible exists between refuelling and the flight. This will provide adequate time for moisture and sediment to sink to the bottom of the tank from where it can be drained.

5.2.9 Fuel Instruments

5.2.9.1 Fuel Pressure Gauges

It is necessary to know that a pressure fed fuel system is delivering the proper amount of fuel to the engine. With carburettor engines a pressure sender unit is installed to the fuel inlet side of the carburettor. Pressure indication at this point, shows the output of the boost pump before the engine is started. When the engine is running and boost pump turned off, the gauge shows the pressure of the engine driven pump.

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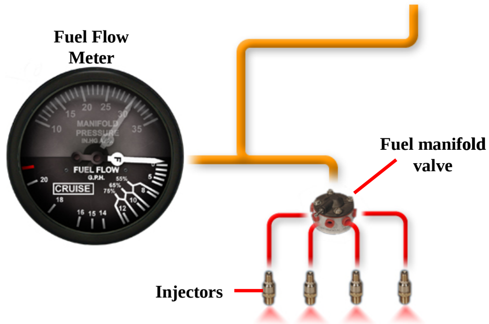
5.2.9.2 Fuel Flow Meters

A fuel injected engine will have a fuel flow gauge installed, to provide the pilot with an indication of the rate of fuel flowing into the injector nozzles.



The flow meter indicator is actually a pressure guage. The pressure reading taken from the fuel manifold valve and is measures the pressure drop across the injector nozzles. The greater the flow rate the greater the pressure drop will be*, this has the unfortunate result of showing a higher pressure when a nozzle is blocked rather than the other way round.*

5.2.10 Fuel Feed Systems

For light aircraft use, there are two common fuel feed systems; they are:

- Gravity feed
- Pressure feed.

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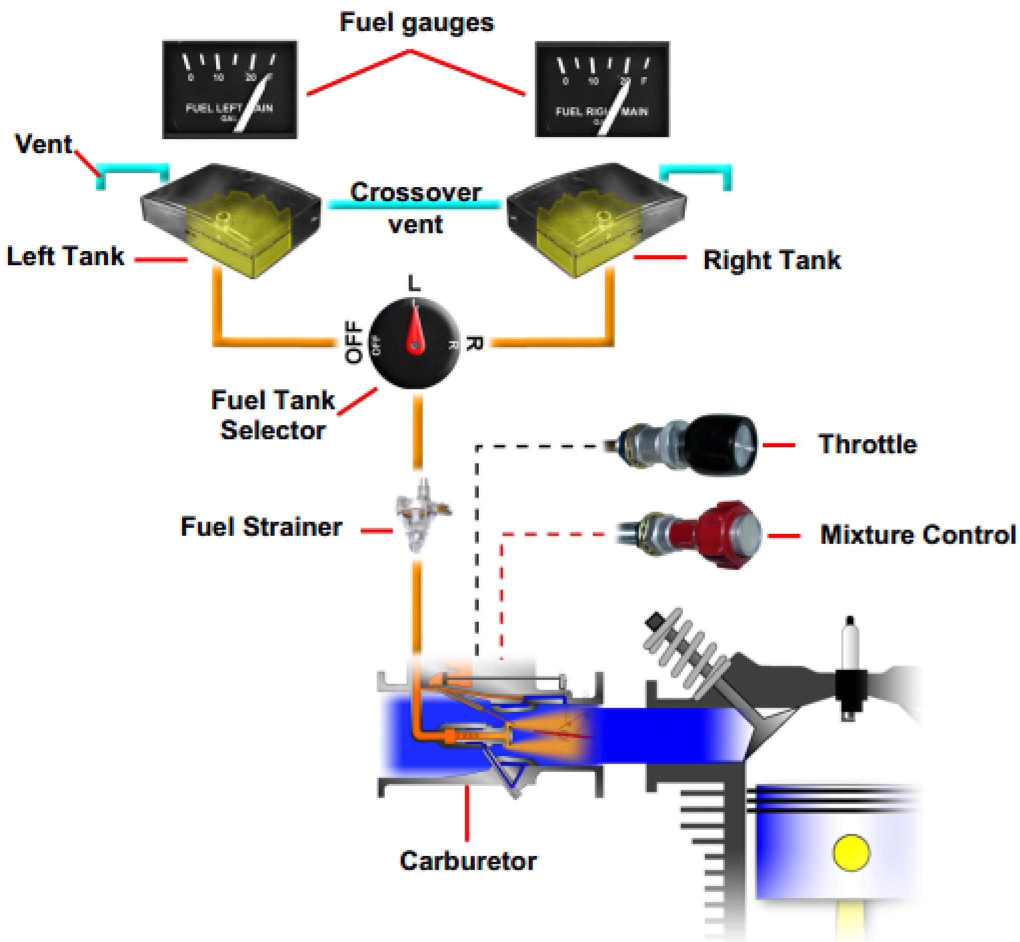
5.2.10.1 Gravity System

In the gravity fuel system, the fuel tanks are usually mounted in the wings of a high-wing aircraft, placing the fuel well above the carburettor. The height provides enough pressure (approximately 1.5 to 2 psi) for the fuel to flow through the system.

The fuel flows under gravity from the tanks, through the fuel selector (shut-off) valve and fuel strainer to the carburettor. The fuel gauges in the cockpit provide the pilot with information regarding the amount of fuel on board.



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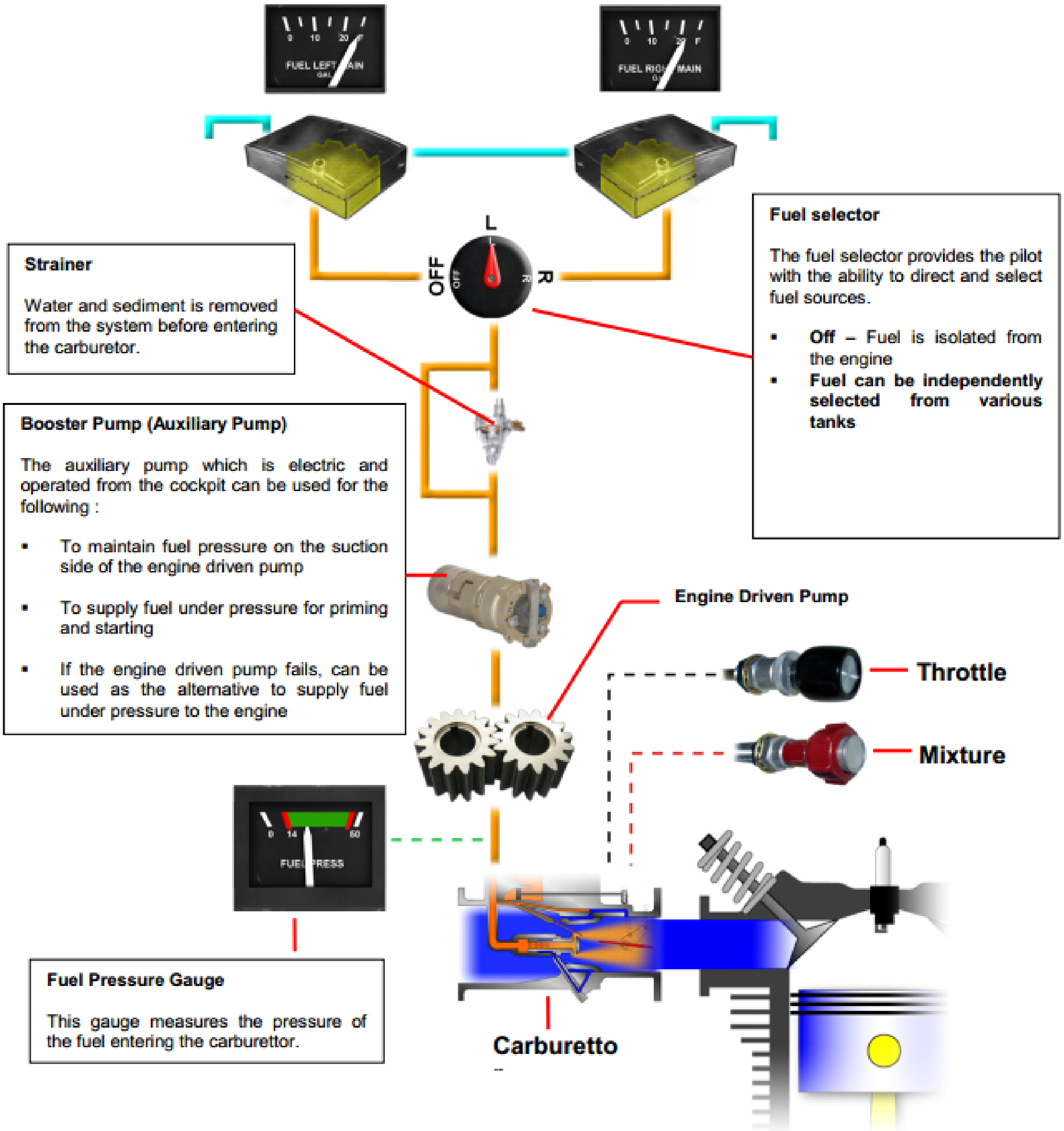
5.2.10.2 Pressure Feed

In this type of fuel system, an engine-driven pump supplies the fuel pressure. Because the pressure in the system is derived from a pump, it will remain constant throughout the flight. It also means that the fuel tanks can be positioned anywhere in the aircraft, which is beneficial to low wing aircraft. An electric auxiliary or boost pump is also installed, to supply pressure for engine starting, as a backup in the event of engine driven pump failure, and to assure positive fuel flow is maintained when switching from one tank to another. The fuel pressure produced by the electric pump should be noted before starting the engine.



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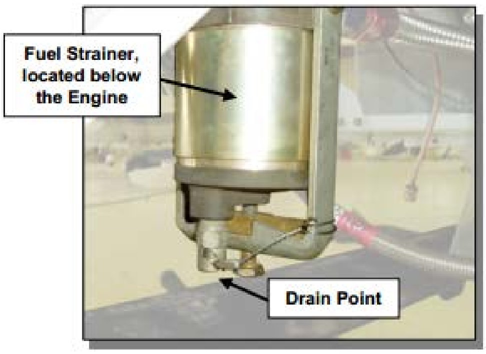
5.2.11 Check valves

Check valves are placed in the fuel flow lines to ensure flow in one direction only if different tanks or pumps are selected during flight.

5.2.12 Filters/Strainers

It is imperative that clean uncontaminated fuel is delivered to the fuel metering system. Filters or strainers are placed in fuel tank outlets as well as the inlet lines of carburettors, fuel injection control units and fuel discharge nozzles. These filters are removed, inspected and cleaned on a regular basis.



5.2.13 Engine Priming

Both gravity and pressure fed systems may incorporate a priming feature. The priming system can be used to draw fuel from the tanks and deliver it directly to the inlet manifold or cylinders, prior to engine starting. This is particularly helpful during cold weather when engines are hard to start due to poor vaporisation of the fuel.

Two separate methods may be used, they are:

- Hand or electric pump activated from the cockpit. Hand operated devices must be positively locked after use, as they are prone to vibrating open during flight resulting in excessively rich mixtures, or
- Carburettor accelerator pump, where the throttle lever is pumped a number of times to discharge fuel into the inlet manifold.

5.2.14 Vapour Locks

If fuel in the fuel lines changes to vapour, a partial or complete interruption of the fuel flow may result. The following conditions are conducive to vapour locks:

- The lowering of the fuel pressure. **(This causes the fuel to boil at altitude, and release air bubbles)**
- High fuel temperatures. **(Warm fuel on take-off, may boil at altitude)**
- Excessive fuel turbulence. **(Air is mixed in with the fuel, which may result in separation in the fuel lines, and the formation of air pockets)**

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5.2.14.1 Prevention of vapour locks

- Fuel lines should be kept away from sources of heat.
- Sharp bends in fuel lines should be avoided, and thereby reduce fuel turbulence.
- Volatility of the fuel should be controlled, and thereby reduce vaporisation.
- Use of booster pumps to maintain pressure in the fuel system.

5.2.15 Fuel Metering Systems

5.2.15.1 Introduction

Carburetion and fuel injection are processes by which air and fuel are mixed in suitable proportions (mixture) for ignition in an internal combustion engine. The carburettor has the added function of supplying and regulating the mixture to the cylinders in accordance with operational requirements. Both carburettors and fuel injection systems provide a feed of fuel and air to the engine, the difference is the method in which the mixture is supplied.

Simple Float Carburettor – Components and Operation

The carburettor provides:

- The charge at the correct air fuel ratio
- Control of the amount of charge entering the cylinder using the throttle.
- Mixture leaning (mixture lever) and priming (usually with the throttle).
- A means of stopping engine by moving the mixture lever to the Idle Cut Off (ICO) position.

Outside air first passes through an airfilter after which the air flows through the venturi located inside the carburettor, a low-pressure area is created, which induces fuel to flow through a discharge nozzle located at the carburettor throat. The fuel then flows into the airstream, where it mixes with the air entering the intake manifold.This fuel/air mixture passes through the intake manifold and into the cylinders for combustion.

The “float-type carburetor” acquires its name from a float, which rests on fuel within the float chamber. A needle attached to the float opens and closes an opening at the bottom of the carburetor bowl.

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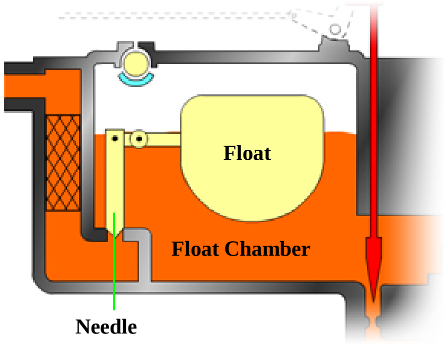
5.2.16 Float Chamber

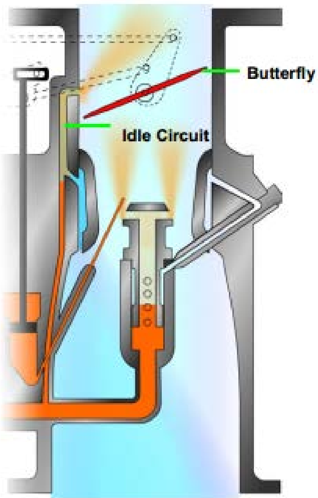
The "float-type carburettor" acquires its name from a float, which rests on fuel within the float chamber. A needle attached to the float opens and closes an opening at the bottom of the carburettor bowl.



A float mechanism meters the correct amount of fuel into the carburettor. As the fuel level in the float chamber drops, the needle valve opens, allowing fuel to enter the float chamber. When the level of the fuel forces the float to rise, the needle valve closes the fuel opening again and shuts off the fuel flow to the carburettor.

5.2.17 Throttle Operation

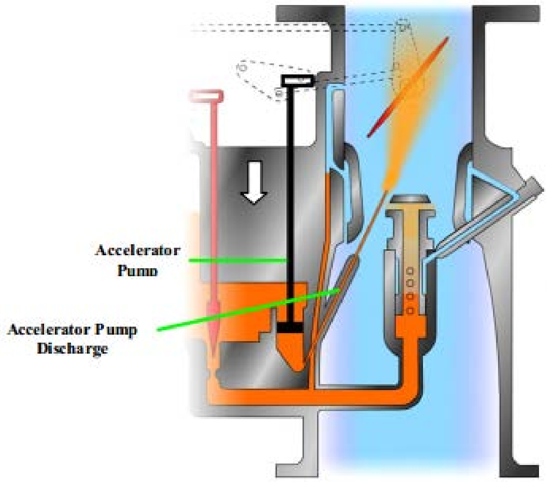
At idle, the throttle (butterfly) valve is almost closed. Only a small amount of air can enter the engine, and this is directed through the idle circuit taking a small but appropriate amount of fuel with it into the manifold.



This means the:

- Manifold air pressure is LOW (8–10 inches/HG)
- Volumetric Efficiency is LOW (10–15%)
- ENGINE power is LOW.

As the throttle lever is moved forward, the accelerator pump discharges extra fuel into the carburettor throat. The throttle valve opens letting more air pass through the venture, which draws more fuel with it.



- Manifold air pressure increases (MAX at takeoff approximately 28 inches HG)
- Volumetric Efficiency increases (MAX. 70% at takeoff)
- ENGINE power increases.

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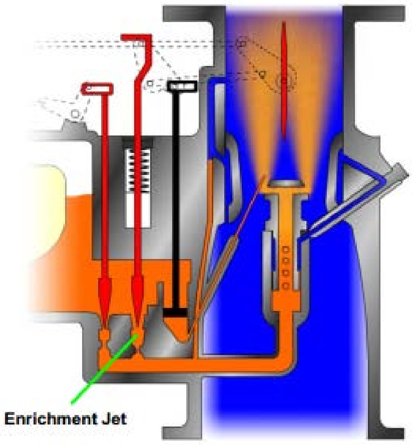
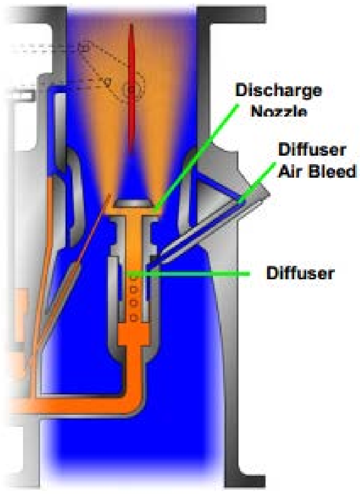


- A throttle selection above 75% engine power causes further fuel to flow into the engine from the power enrichment jet.
- The significant enriching of the engine at high power settings provides:
- Extra fuel cooling due to evaporation.
- Reduced risk of detonation as more anti detonation additives from the rich mixture reach the cylinders.

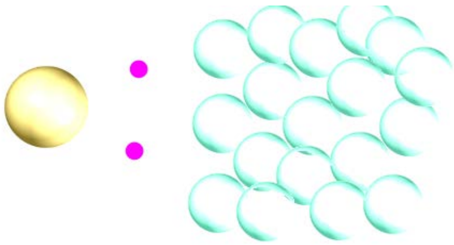
5.2.18 <u>Diffuser Air Bleed</u>



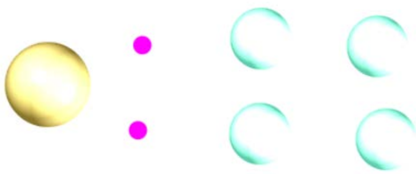
As fuel is drawn through the diffuser, the fuel level falls at the discharge nozzle due to the reduction in air pressure, as a result of increasing air velocity. In falling, it uncovers air bleed holes drilled in the diffuser, which permits air to enter, slightly breaking down the depression that exists above the nozzle. This has the effect of maintaining a constant fuel/air ratio throughout the whole range of throttle movement. This maintains a fairly accurate mixture over the RPM range.

5.2.19 Air and Fuel Mixture

The carburettor is designed to operate at ISA conditions (Mean sea level 1013.25mb, 15ºC), which means that the metering jet, which controls the fuel flow, is also designed for these conditions. In reality however the aircraft will generally operate in conditions which differ greatly from ISA conditions, and the fuel flow has to be altered to suit these non-ISA conditions, this is achieved using the mixture control.



Too much air (by weight) in relation to the same fuel = lean mixture



Too little air (by weight) in relation to the same fuel = rich mixture

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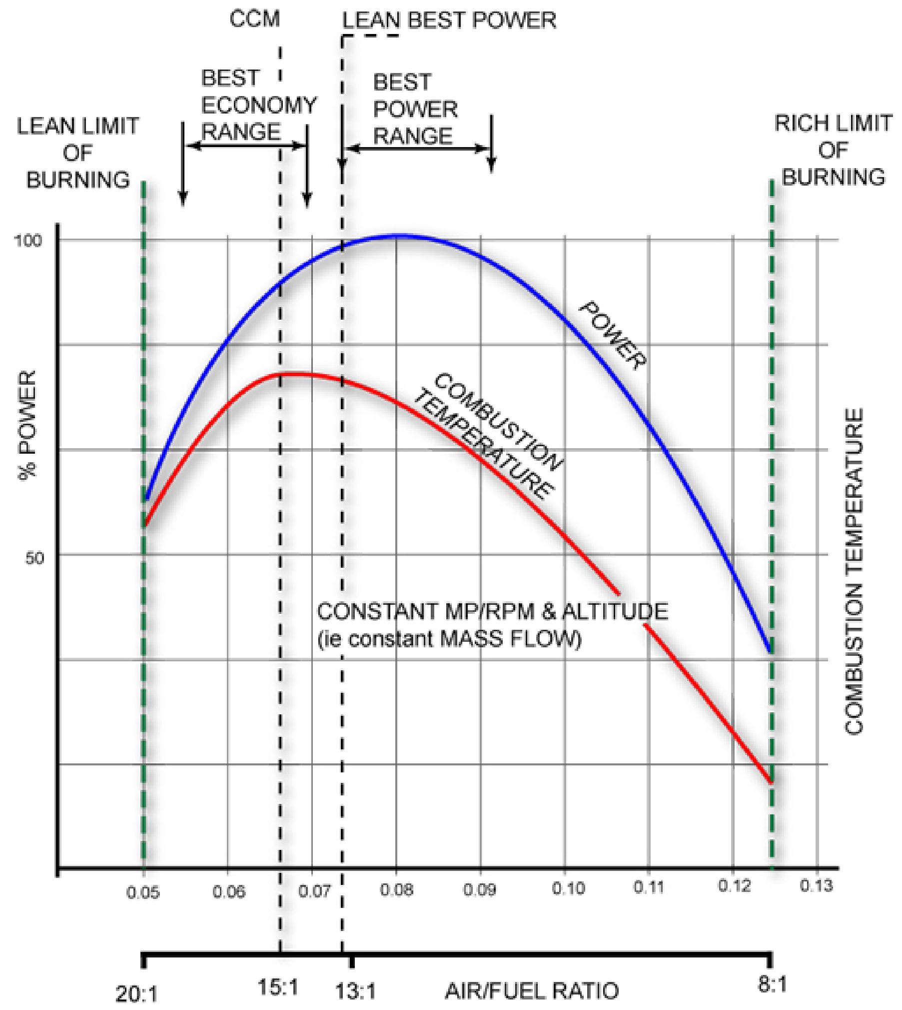
5.2.20 Requirements

Liquid fuels will not burn unless mixed with air (oxygen). In order for the fuel/air mixture to burn effectively, the mixture ratio has to be kept within a certain range.

Combustion of the mixture will take place when the mixture of fuel to air is between 1 (fuel): 8 (air), and 1: 20 (limits of burn).

1: 8 is generally a rich mixture, and **1: 20** is a lean mixture. These amounts are expressed as **Weight** (pounds - lb), because the volume varies considerably with temperature and pressure.

The ideal or chemically correct mixture (referred to as **CCM** or stoichiometric) is one in which all the fuel and air in the mixture burns (around **1:15**). If the mixture is too rich there will be excess fuel, while if the mixture is too lean there is not enough fuel for the mixture to burn successfully; either of these conditions will cause inefficient engine operation.



POWER VS. AIR/FUEL RATIO

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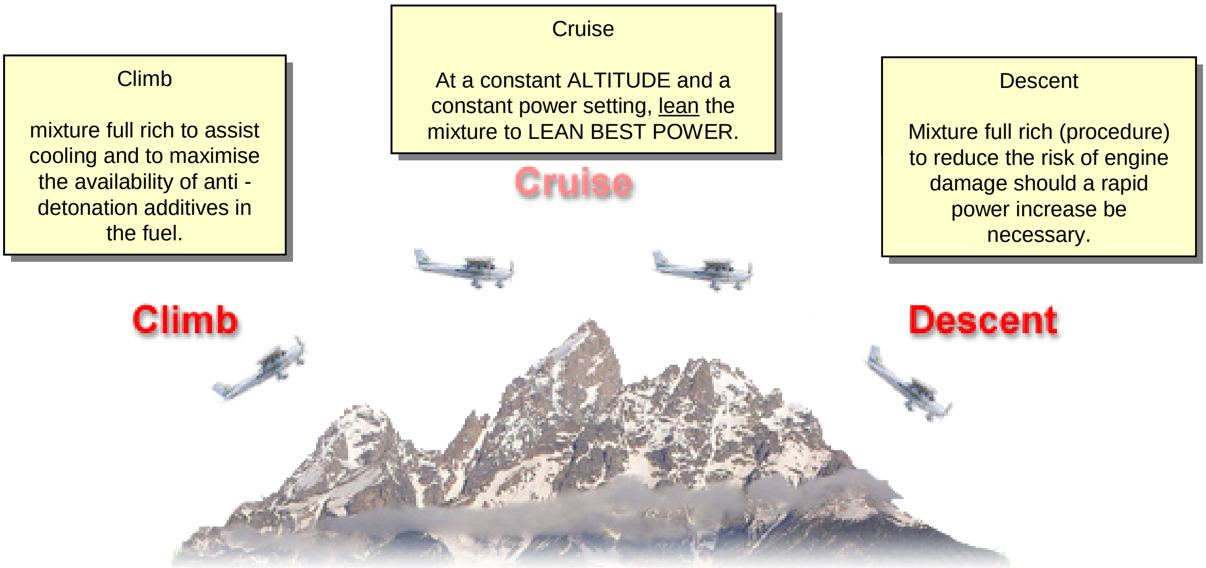
5.2.21 Mixture during the Various Stages of Flight

5.1.21.1 Initial Flight Training

During the early stages of flight training the mixture control is kept in the full rich position. This provides the engine with a 10:1 air/fuel mixture, which is suitable for circuit practice and training area operations. You will not become fully conversant with engine leaning until the navigation phase of your training.

There are some small penalties for operating full rich. One is the fuel consumption rate is increased and another is that during taxi or low power operations spark plug fouling can occur.



5.2.22 Consequences of Incorrect Air/Fuel Ratio

5.1.22.1 Too Lean

A mixture that is too lean results in loss of power, high temperatures and rough running. Pre-ignition is possible and, if power is increased, detonation would become likely. An engine running lean leaves pale ash deposits in the exhaust pipes.

a. **Detonation**

Detonation is described as the explosive combustion of the mixture in the combustion chamber at or after normal ignition. The explosion can occur as a result of incorrect fuel grades, excessively lean mixtures, lack of cylinder cooling and other conditions which cause excessive internal cylinder temperatures and pressures. In extreme cases the outcome of these conditions can cause severe mechanical damage to pistons and cylinders.

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b. **Risk of Backfiring**

A lean mixture burns quite slowly. In extreme cases it is possible that combustion can continue through the power and exhaust strokes and ignite the incoming charge in the inlet manifold as the intake valve opens. The resultant flash back consumes the charge and can cause severe rough running as the inflow of the charge is disrupted. This causes a loss of engine power and there is some risk of fire and manifold damage as the gas flow in the manifold and through the carburettor is temporarily reversed.

5.1.22.2 Too Rich

A mixture that is too rich results in high fuel consumption, black smoke, spark plug fouling and rough running

a. **Risk Of After Firing**

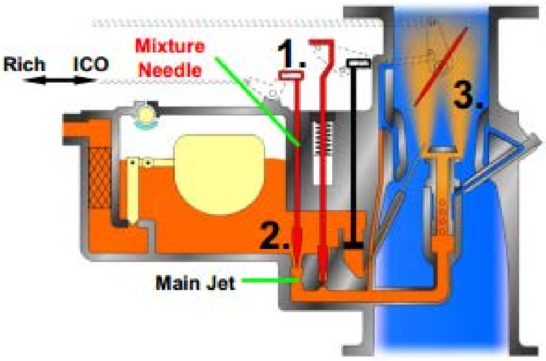
An excessively rich mixture can result in unburnt fuel being deposited in the exhaust system. As oxygen becomes available this mixture could reignite, causing a loud bang or series of bangs. There is little risk of engine damage with after-firing, but fuel is wasted and the engine is operating below its optimum power. The exhaust muffler can be damaged by after firing.

5.2.23 Controlling the mixture

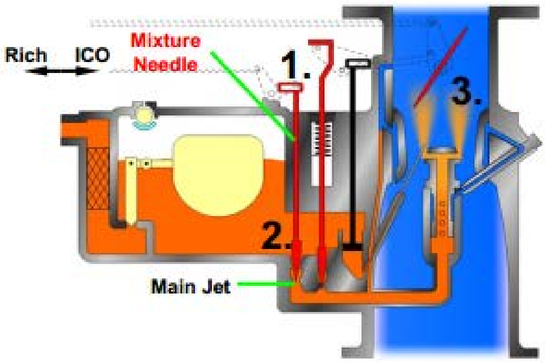
The mixture control lever is used to control the fuel flow to the venturi.

When the lever is pulled, linkages are activated which force the needle down, and restrict fuel flow - the result is a **leaner mixture**.

When the lever is pushed, linkages are activated which force the needle up, and increase fuel flow - the result is a richer mixture.



1. Mixture lever pushed
2. Mixture needle moves up
3. Fuel flow increased – richer mixture



1. Mixture lever pulled
2. Mixture needle moves down
3. Fuel flow restricted – leaner mixture

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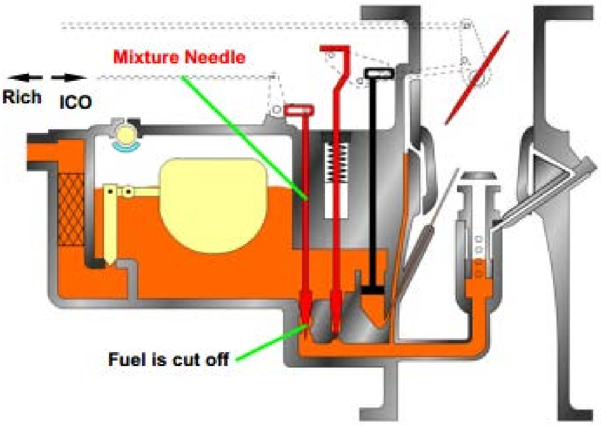
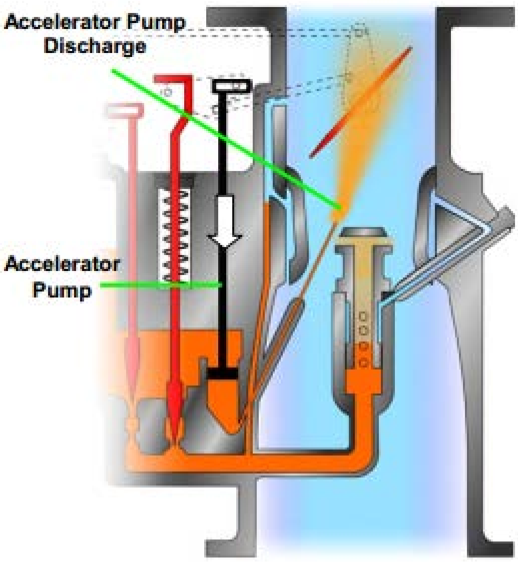
5.2.24 Idle cut-off (ICO)



The idle cut -off is the general method used for shutting down the engine. The mixture lever is positioned to move the mixture needle to cut fuel to enter the venturi, and therefore starves the engine of fuel.

5.2.25 The Accelerator Pump



Rapid opening of the throttle increases the flow of air significantly. A lag in corresponding fuel flow could lead to temporary leaning of the mixture.

To prevent this happening, the carburettor is equipped with an accelerator pump. The accelerator pump is simply a small plunger within the float chamber that is connected to the throttle linkage. As the throttle is opened the plunger is depressed, and extra fuel is sent to the accelerator pump discharge nozzle. The accelerator pump is used on some aircraft to prime the engine before starting. Depending on whether the engine is hot or cold the throttle is moved through the full range of movement a number of times, thus pumping fuel into the inlet manifold area.

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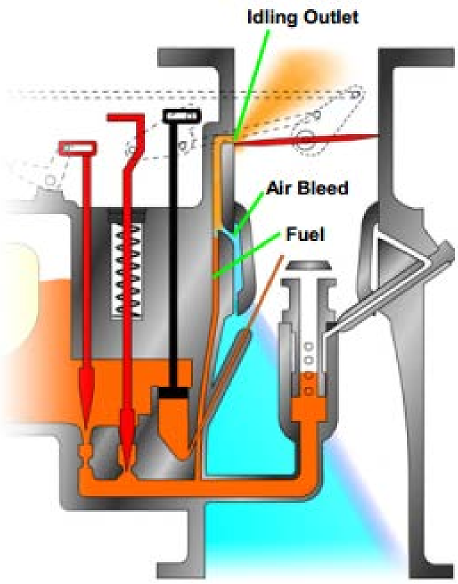
5.2.26 The Idling System

When the engine is idling *(low engine speed),* the butterfly valve is almost totally closed. The amount of air therefore passing through the venturi is not enough to draw in any fuel. In order to compensate for this, the carburettor makes use of a by pass system, with an outlet just above the butterfly, where there is is still considerable suction. This supply of fuel is solely for use in slow running engine situations. A small air bleed opening into the venturi, assists with the atomisation of the mixture. The size of the fuel flow inlet, and the air released into the venturi, provides a mixture rich enough to keep the engine running.



Due to reduced airflow over the engine at idle, a richer than normal mixture is scheduled by the carburettor to assist with cylinder cooling. Prolonged idling should be avoided where possible as these enriched mixtures could lead to plug fouling.

5.2.27 Induction System Icing

Induction icing is extremely hazardous as it could lead to complete engine failure; it may form under conditions in which there is no visible airframe icing and ambient temperatures may be quite mild.

Induction icing is often the cause of engine failure which leads to forced landings. Close monitoring of engine instruments and quick corrective measures are the keys to coping with this threat.

For icing to occur two conditions must exist:

- Water must be present
- Localised air temperature must be below 0°.

The following chart illustrates the risk of icing.

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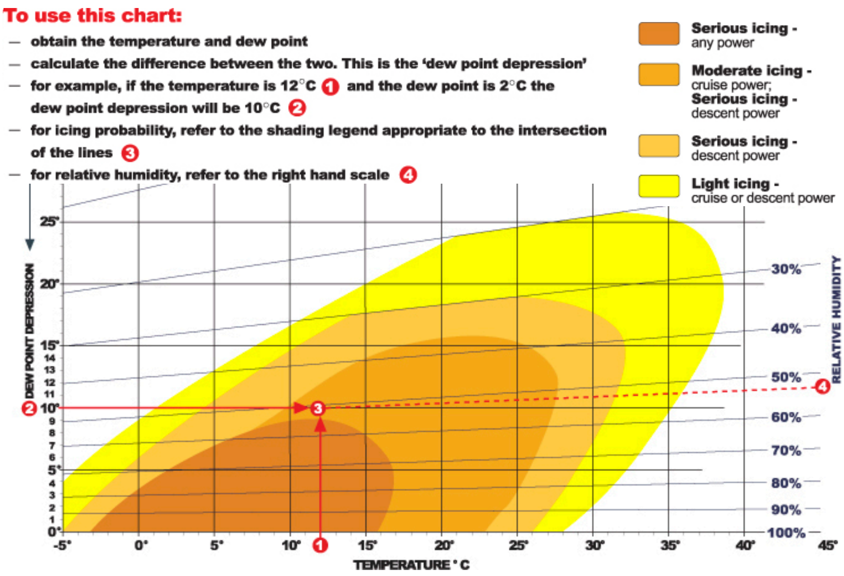


Carburettor Icing – Probability Chart

5.3 Carburettor Icing

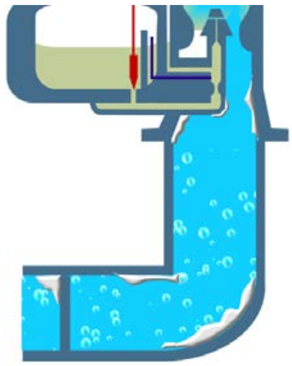
As air is accelerated through the carburettor its temperature can drop to below freezing point and if there is enough moisture in the air icing can occur. Icing seriously degrades the performance of the carburettor and in severe cases can even cause the engine to stop running. Types of icing that can affect the carburettor are known as:

- Impact Icing
- Fuel Ice
- Throttle ice.

5.3.1 Impact Icing

Impact icing can occur on both fuel injected and carburetted engines.

This type of icing will occur when super-cooled water droplets, in the intake air, form ice as they come into contact with the surface of the air inlet scoop or filter.



Icing as a result of

Impact icing occurs when the outside air temperature is near or below 0ºC, and the aircraft is operating in conditions with visible moisture (e.g. cloud, rain or mist) and the moisture droplets are at or below zero. It can also occur when the inlets and ducts are below zero (e.g. an aircraft descending from altitudes above the freezing level), and the moisture comes into contact with them.

Being external to the engine, impact ice cannot be removed by carburettor heat.

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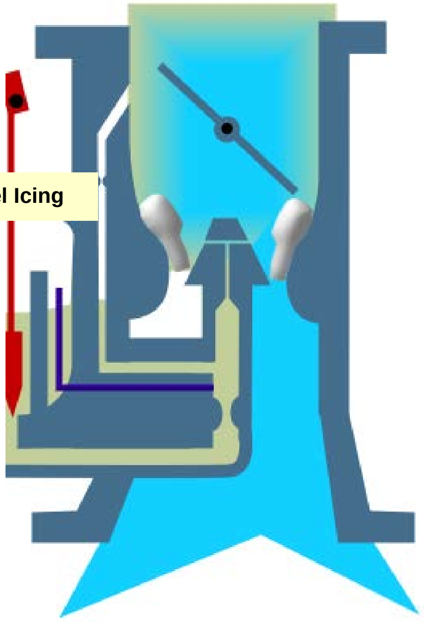
5.3.2 Fuel Icing (Fuel Vaporisation Icing)

Carburettor ice also forms during the vaporization of the fuel, downstream of the Discharge Nozzle where the fuel is introduced into the carburettor system, causing a substantial reduction of the temperature due to latent heat absorption of vaporisation.

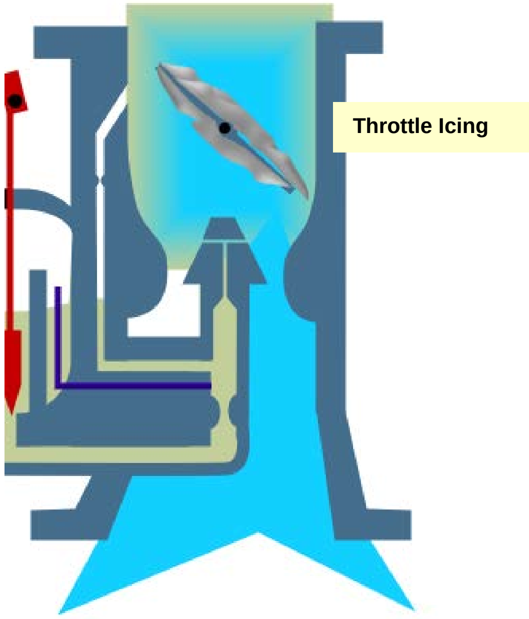


If the temperature of the fuel/air mixture drops between 0°C and -8°C, water will precipitate from the incoming air if it is moist and will freeze onto any surface it encounters, e.g. the inlet manifold walls and the throttle butterfly valve. This will seriously restrict the airflow, and the efficiency of the engine.

Fuel ice can even occur in temperatures of between 20º and 30ºC if the relative humidity is around 50% or more.

Fuel icing can also be referred to as refrigeration icing as this process is the same used in most refrigerators.

5.3.3 Throttle Icing



As the fuel/air mixture accelerates past the throttle butterfly valve, the pressure and with it the temperature decreases.

If sufficient moisture is present, icing can occur. Ice may form in the venturi, on or around the butterfly. Visible moisture is not necessary for throttle icing.

> The acceleration and resulting temperature drop is greatest at small throttle openings because the throttle butterfly restricts the airflow most at these power settings, creating a substantial pressure drop. This normally occur at low throttle settings, for instance on the descent, when reduced power is usually set.

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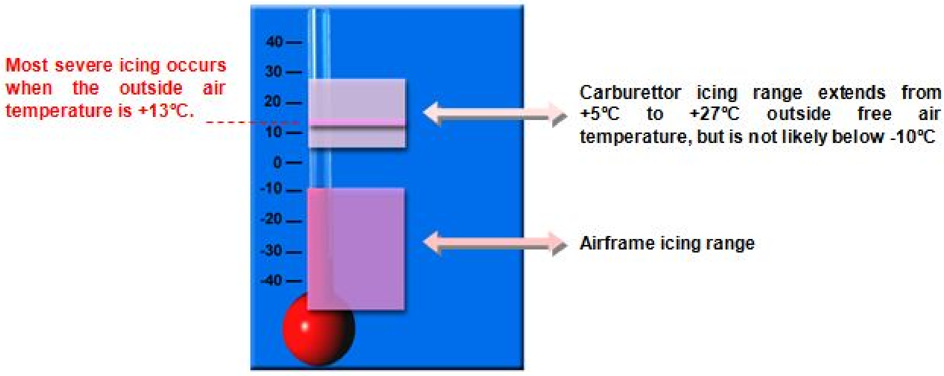
5.3.4 Formation of Carburettor Icing

Both fuel ice and throttle ice can occur when the outside air temperature (OAT) is high. It is expansion that causes the cooling to freezing point. If the Relative Humidity is high **(>50%),** icing can form easily.



5.3.5 Typical Symptoms of Carburettor Icing

- Power loss: Drop in RPM for a fixed-pitch propeller and a drop in manifold pressure for a constant-speed propeller, resulting in poorer performance, which will be indicated by a loss of airspeed or a poorer rate of climb.
- Rough running engine.

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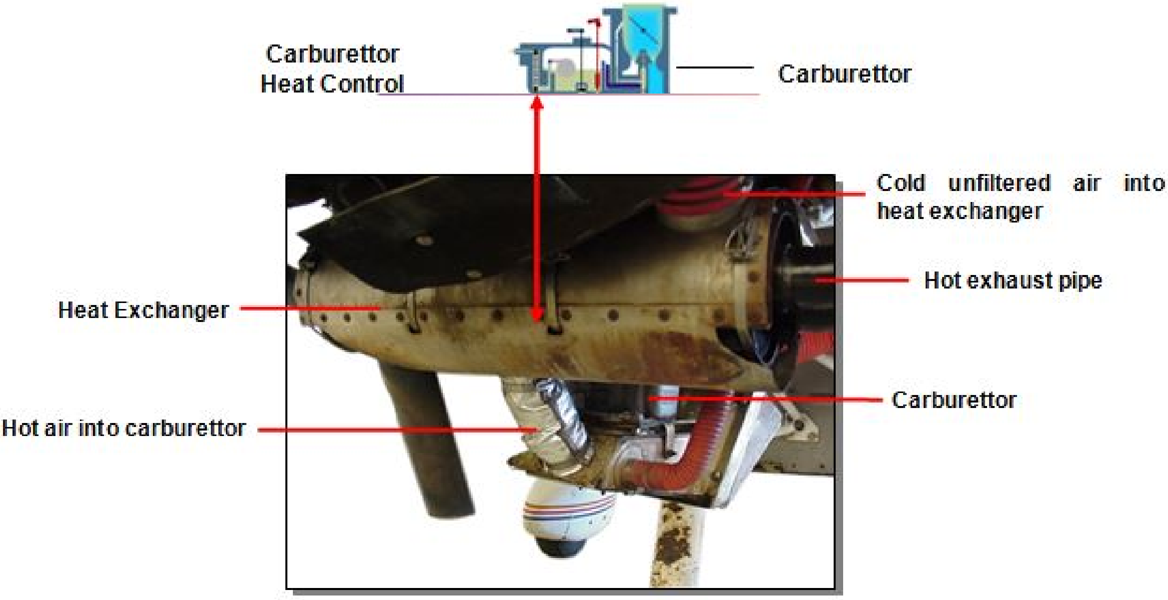
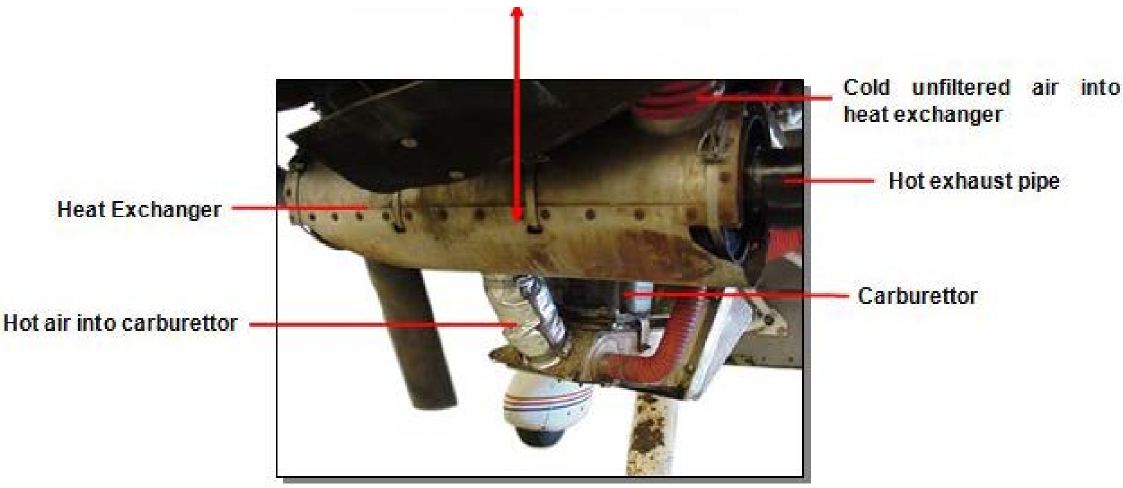
5.4 Carburettor Heat

Most modern light aircraft have a carburettor heat system to counteract icing. This usually involves passing unfiltered induction air past the hot engine exhaust manifold.





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The carburettor heat control is usually located near the throttle and should be applied fully when carburettor icing is suspected.

Partial use of carburettor heat is not normally recommended, as this may raise the temperature of the induction air into the temperature range that is most conducive to the formation of carburettor icing.

5.4.1 Alternate Air

An alternate air system, if fitted, allows the engine to draw unfiltered air from inside the engine cowl. This is common on fuel injected engines as they are not at risk of throttle ice due to the fact that there is no Venturi nor is the fuel mixed with the airflow when passing the throttle plate. If the air filter became blocked (dirt, ash, ice, etc.), selection of alternate air or carburettor heat will by-pass the air filter, providing a secondary source of air to the engine.

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5.5 Precautions during Phases of Flight

5.5.1 The Pre-Take-Off Checks are:

- Apply full carburettor heat and observe the RPM drop.
- Return the control to off and observe the RPM returning to its original value (indicating that no ice was present).
- If the RPM returns to a significantly higher figure, then ice was present and has been at least partially melted. Repeat the procedure until all ice is melted, taking care that no carburettor ice re-forms prior to take-off.

When heated the air density is less and so the initial effect of applying carburettor heat is a decrease in engine power (seen as a decrease in RPM for a fixed-pitch propeller), possibly by 10–20%. As the hot air passes through the carburettor venturi it will melt the ice. There may now be some rough running if there has been ice build-up and a lot of the melted ice turned to water is passed through the cylinders. Once ice has cleared the RPM will rise; however, it will not return to its original value until the heated air is turned off.

Don't forget, ice takes a while to melt !

5.5.2 Taxiing

If there is a risk of carburettor icing before take-off, carburettor heat should be applied full on while taxiing to de-ice or prevent the formation of ice. Carburettor heat is then turned off as full power is applied for take-off. Under full power the throttle valve is wide open and engine heat is very high; the risk of carburettor ice is greatly reduced.

If there is no risk of carburettor icing, avoid using carburettor heat on the ground except during the vital pre-take-off check because the hot air taken from around the exhaust manifold is unfiltered. This will avoid introducing dust and grit into the carburettor and engine, with obvious benefits to both engine performance and wear. For this reason, the pre-take-off check of carburettor heat should be carried out on a hard surface.

5.5.2.1 <u>Cruise</u>

Ice can form during cruising flight and the effects initially are very subtle. As ice forms on the butterfly valve or in the throat of the carburettor the initial effect is a disruption to the airflow and a reduction in the size of the carburettor throat. This causes a small decrease in manifold pressure (MAP), the consequence of this is a small reduction in engine RPM (fixed pitch propeller) and a small loss of airspeed.

A common reaction when the MAP, RPM or airspeed loss is noticed is simply to advance the throttle to correct the MAP. If this cycle occurred two or three times,

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this is known as **Progressive Throttle Setting**, the ice would continue to build and may allow the throttle to reach its maximum stop. The build up of ice could be so significant that the amount of heat available through the carburettor heat system is insufficient to clear the ice and engine failure occurs. Now that the engine is no longer producing heat, there is less carburettor heat available and little chance of de-icing the engine for a restart airborne.

5.1.2.2 Carburettor Heat on Descent and Approach

On descent with low power and shortly before landing, particularly in conditions of high humidity, it is usual to apply full carburettor heat continuously to ensure that no carburettor icing forms or is present. Select hot before closing the throttle. The small throttle butterfly openings at low power increase the chance of carburettor ice formation. On final approach to land the carburettor heat control is normally returned to full cold, in case full power is needed for a go-around.

5.1.2.3 Icing Suspected - Try Carburettor Heat

Carburettor Icing causes a decrease in MAP, RPM and airspeed on an aircraft fitted with a fixed pitch propeller. An aircraft fitted with a CSU and variable pitch propeller loses MAP and airspeed, the CSU will keep a constant engine RPM.

Fixed Pitch Propeller

CSU Variable Pitch Propeller

Clearing ice from the carburettor will allow better running of the engine and the power to increase (and the RPM of a fixed-pitch propeller to rise) as the ice is cleared. A fixed-pitch propeller will show an initial drop in RPM (power) due to the lower density hot air which enriches the fuel/air mixture, followed quickly (normally) by an increase in RPM as the ice is cleared. Following this, carburettor heat may be removed and normal (cold) air used again.

If carburettor ice re-forms, this operation will have to be repeated. Under some conditions, continuous full carburettor heat may be required

CLIMB OR DESCEND TO REDUCE THE RISK OF FURTHER ICING.

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5.1.2.4 Carburettor Air Temperature (Cat) Gauge

Carburettor heat is normally operated as a de-icer. Ice forms, carburettor heat is applied FULL ON until the ice melts, then carburettor heat can be turned OFF. It is advisable to change altitude or keep the carburettor heat on until the atmospheric conditions change so the ice won't reform.

If your aircraft is fitted with a Carburettor Air Temperature (**CAT**) gauge, regulation of carburettor air temperature is possible by partial application of carburettor heat. The principle here is that ice will be prevented from forming this is an anti-icing process.

The use of partial carburettor heat is not permitted unless the aircraft is fitted with a serviceable CAT gauge and until the advanced stages of commercial flying.

5.1.2.5 Generic Material

The above information is generic in nature and the operation/application of engine ice control devices vary from one aircraft to another. Pilots should therefore follow specific instructions recommended in the Pilots Operating Handbook.

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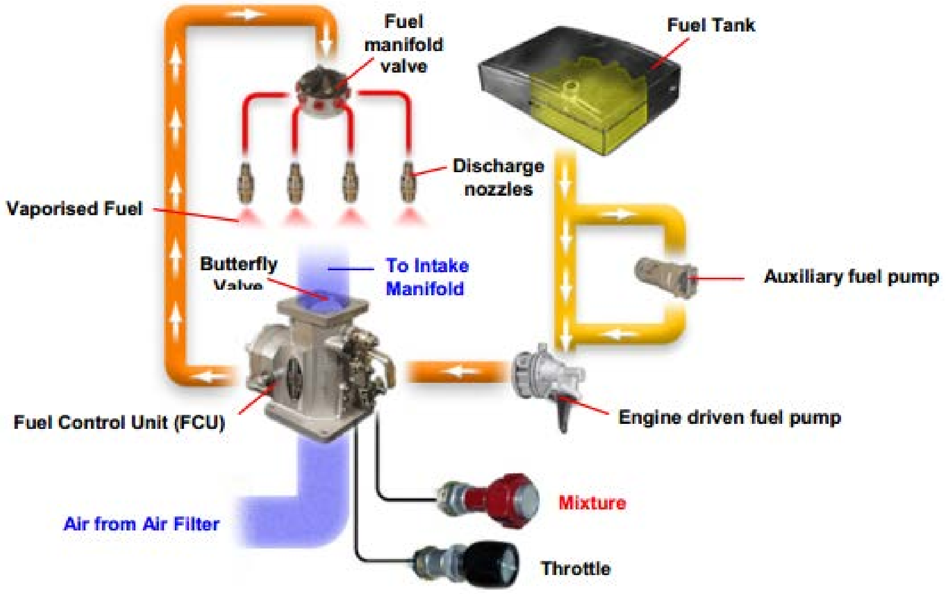
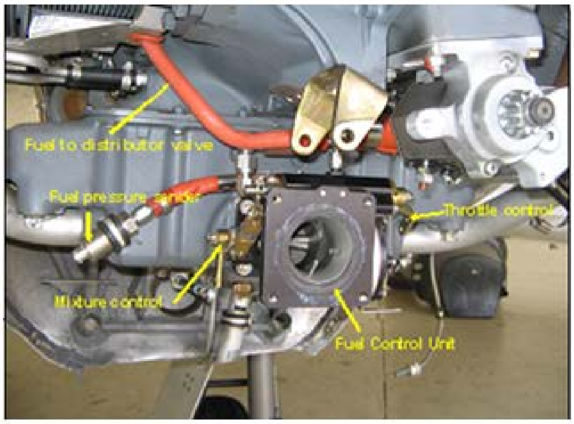
5.6 Fuel Injection Systems

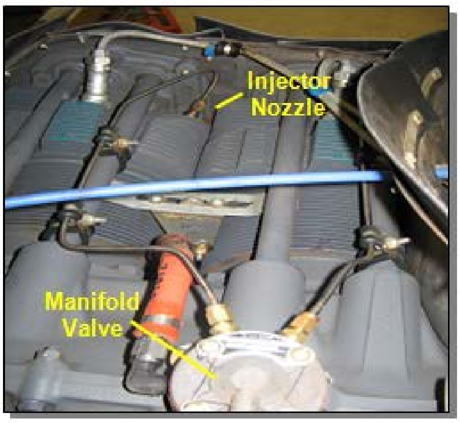
In a fuel injection system, the fuel is injected either directly into the cylinders, or just ahead of the intake valve. A fuel injection system is considered to be less susceptible to icing than the carburettor system. Impact icing on the air intake, however, is a possibility in either system.



The air intake for the fuel injection system is similar to that used in the carburettor system, with an alternate air source located within the engine cowling. This source is used if the external air source is obstructed. The alternate air source is usually operated automatically, with a backup manual system that can be used if the automatic feature malfunctions

A fuel injection system usually incorporates these basic components – engine driven fuel pump, fuel/air control unit, distributor / manifold valve, injector nozzles, electric auxiliary / boost pump and fuel flow / pressure indicators.





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The auxiliary fuel pump provides fuel under pressure to the fuel / air control unit for engine starting and / or emergency use. After starting, the engine driven fuel pump provides fuel under pressure from the fuel tank to the fuel / air control unit.

This control unit, which essentially replaces the carburettor, has connections to the throttle and mixture levers in the cockpit; it meters fuel based on the mixture control setting, and delivers it to the fuel manifold valve at a rate controlled by the throttle.

From the fuel manifold valve the fuel is directed to the individual injector nozzles, whilst the air is fed by the induction manifold to the cylinders. The injector nozzles, which are located in each cylinder head, inject fuel / air mixture directly into each cylinder intake port.

During engine start, the auxiliary fuel pump provides the necessary fuel pressure to the fuel control unit. The auxiliary fuel pump also serves as a back up in case the engine driven pump fails.

After engine start, the engine driven fuel pump takes over and the auxiliary pump is switched off. The auxiliary fuel pump is switched on again during the critical phases off flight, such as take off and landing. This serves as a backup if the engine driven pump should fail.

The system described is known as a continuous injection system; it will constantly deliver fuel to the injector nozzles, whilst ever the mixture control is open and one or both of the fuel pumps are operating. The timing of the inlet valves opening during the four stroke cycle has no influence on this system.

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5.7 Carburettor vs. Fuel Injection

5.7.1 Advantages of Carburettor

- Reliable
- Simple construction.

5.7.2 Advantages of Fuel Injection

- Correct mixtures are maintained at all times
- Evaporative icing is prevented (impact icing still a threat)
- Cold starting is made easier
- Backfiring is virtually impossible
- The Fuel Discharge Nozzles atomises the fuel to a greater degree as compared to a venturi carburettor
- Throttle response is more rapid and smoother.

5.7.3 Disadvantages of Carburettor

- Subject to carburettor ice and intake/impact ice
- Subject to fuel vaporization
- Affected by gravity/ inertia (non inverted ops)
- Fuel metering/atomization and distribution are less precise.

5.7.4 Disadvantages of Fuel Injection

- Starting an already hot engine may be difficult, due to vapour locking in the fuel lines. Electric Boost pumps that pressurise the fuel lines can alleviate this problem.
- The fine fuel lines to the injector nozzles are susceptible to any contamination in the fuel.
- Problems associated with restarting an engine that quits because of fuel starvation.
- Extra fuel management required as surplus fuel from pump is returned to only one tank in some aircraft.

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5.8 Engine start procedures

A different technique is used to start injected engines than that used with carburettors; the normal procedure is as follows:

- Open the throttle a small amount
- Turn the boost pump on
- Place the mixture control to full rich for a brief period (3 – 5 seconds), observe positive fuel flow on the fuel flow guage, indicating fuel is discharging from the injector nozzles
- Place the mixture control in idle cut off (any longer than this and the cylinders are likely to be flooded with fuel)
- Engage the starter motor and as the engine fires move the mixture control to full rich.

Starting a hot fuel injected engine may involve a different technique again, due to fuel vaporisation in the manifold valve and nozzle lines. Aircraft operating manuals will usually dictate this procedure.

Some of the advantages of fuel injected engines are:

- No risk of throttle ice
- More precise fuel flow
- Faster throttle response
- Precise mixture control
- Better fuel distribution
- Easier cold starts.

Disadvantages usually include:

- Hot starting difficulties
- Vapour locks during high power operations; particularly on the ground
- Difficulty in restarting a fuel starved engine
- A blocked injector nozzle may cause an erroneous high fuel flow indication.

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