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AIRCRAFT GENERAL KNOWLEDGE 1

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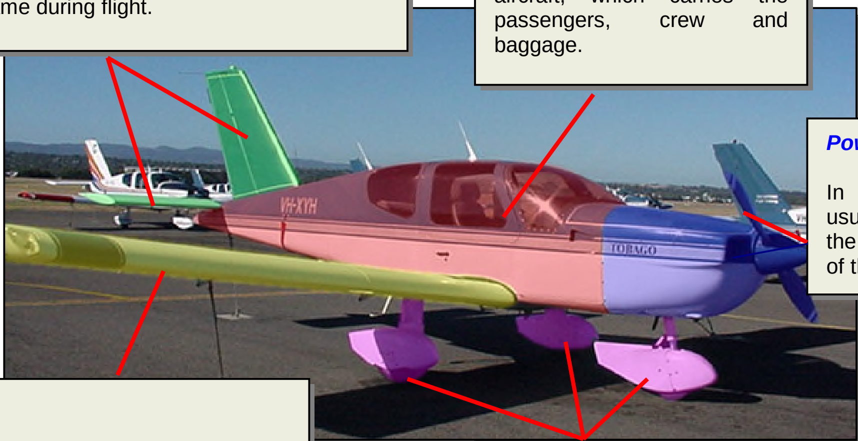
CONTENTS ....PAGE

The Structure of a Light Aircraft

Overview

The major components of the airframe of an aeroplane are:

- the fuselage;
- the wings;
- the tail section (empennage);
- the flight controls;
- the landing gear (or undercarriage);
- the engine and propeller.



Empennage

The empennage is that part of the aircraft which provides stability to the airframe during flight.

Fuselage

The fuselage is the body of the aircraft, and is that part of the aircraft, which carries the passengers, crew and baggage.

Powerplant/Propeller

In a small aircraft, the powerplant usually consisting of the engine and the propeller is mounted at the front of the fuselage.

Wing

It is the wing of the aircraft providing lift, which allows it to fly. It can be situated either on top of the fuselage ***(high wing)***, in the middle of the fuselage ***(Mid wing)***, or at the bottom of the fuselage ***(Low wing)***.

Landing Gear

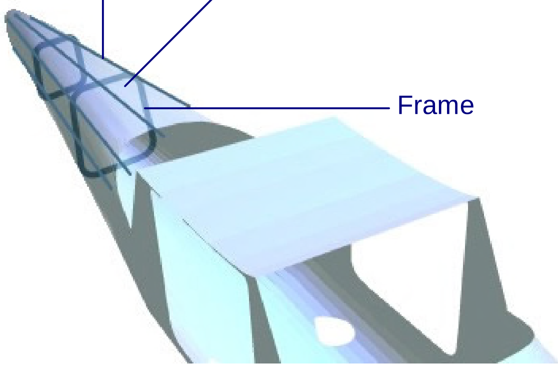
The landing gear provides the aircraft with support and gives it the ability to move around on the ground. The landing gear in smaller aircraft usually consists of three wheels, two below the wings, and one either below the powerplant, or below the tail.

The Fuselage

The fuselage forms the body of the aeroplane to which the wings, tail section, engine and landing gear are attached. It contains a cabin with seats for the pilot and passengers and the flight controls and instruments, and may also contain baggage compartments.

The fuselage must be able to absorb forces generated by the wings and undercarriage in flight and on landing, it must also absorb the bending and twisting moments of the engine and empennage and carry these loads with a minimum weight penalty.

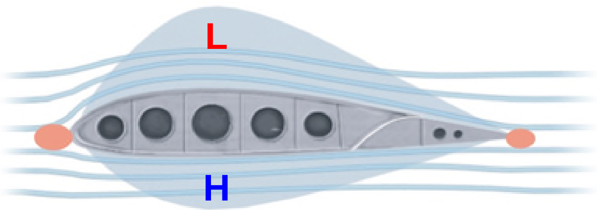
Light aircraft fuselage construction may be of fabric covered steel tube framework, wooden framework and skin, aluminium alloy framework and skin, or composite materials such as glass fibre. The fuselage of many modern training aeroplanes is of semi-monocoque construction, a light framework covered by a skin (usually aluminium) that carries much of the stress. It is a combination of the best features of a strut-type structure, in which the internal framework carries almost all of the stress, and a monocoque structure which, like an eggshell, has no internal structure, the stress being carried by the skin.



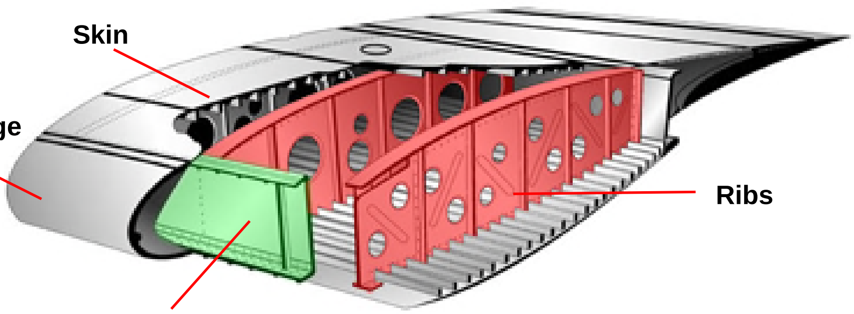
Example of a Monocoque Construction

The Wings

The wings are designed so that the airflow over the upper surfaces is accelerated, reducing the static pressure above the wing and causing lift. In level flight, the lift will equal the weight and counteract it. In manoeuvres such as steep turns or pulling out of a dive, the wings must produce lift well in excess of the weight, so they have to be very strong.



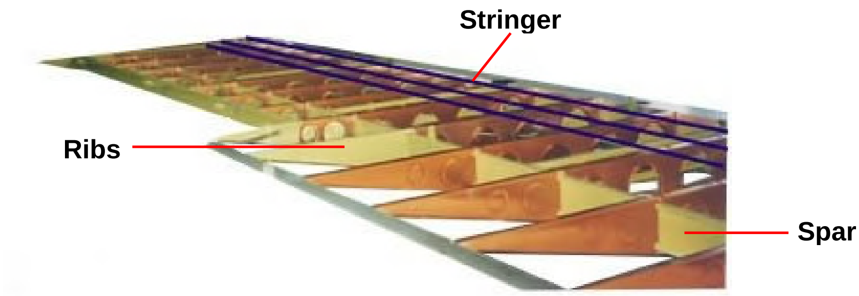
Wings generally have one or more internal spars attached to the fuselage and extending to the wingtips. The spars carry the major loads, which are upward bending where the lift is generated and downward bending where the wings support the fuselage and the wing fuel tanks. Twisting, and some of the bending loads are absorbed by the "D" nose section of the wing formed by the semi-monocoque construction of the skin, the ribs and the spar.



The condition of the wing's leading edge during daily inspection is particularly important. Dents or damage to this section may seriously affect wing strength. Also any roughness from dirt, insects, ice or frost on the leading edge will affect the wing's aerodynamic efficiency.

Some wing spars also have external struts connecting them to the fuselage to provide extra strength by transmitting some of the wing loads to the fuselage.

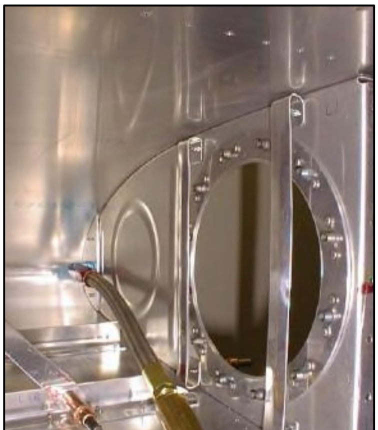
Ribs, perpendicular to the wing spars, assisted by stringers running parallel to the spars, provide the aerofoil shape and stiffen the skin, which is attached to them. The ribs transmit loads between the skin and the spars.



The ailerons are control surfaces which are installed at the outer trailing edge of each wing, and move simultaneously in opposite directions; eg. left aileron up - right aileron down, to allow the pilot to control roll.

Wing flaps are installed on the inner trailing edges and are lowered symmetrically to increase the lifting ability of the wing.

The wings of many aeroplanes also contain fuel tanks installed between the curved upper and lower surfaces. This is an efficient use of the space available, and the weight of the fuel in the tanks also provides a downward force on the wing structure that reduces the upward bending effect of the lift forces.


Inside a fuel tank

Monoplanes are designed with a single set of wings placed so that the aeroplane is known as a high-wing, low-wing, or mid-wing monoplane.

Biplanes, such as the Pitts Special, are designed with a double set of wings. The Cessna 172 is a high-wing monoplane; the Aerospacial Tobago is a low-wing monoplane.

The Landing Gear

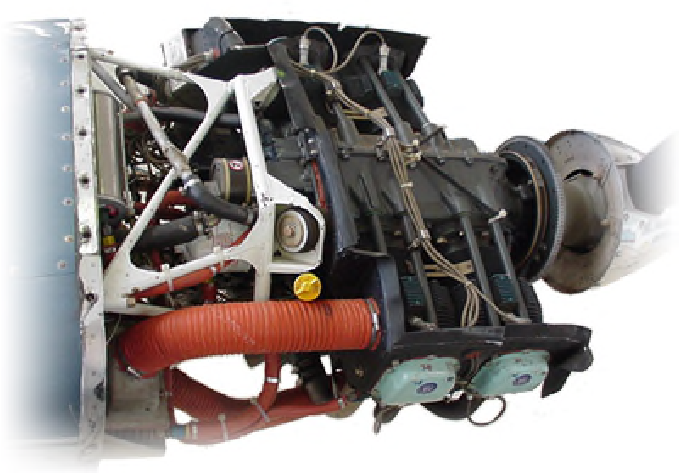
The landing gear or undercarriage, supports the weight of the aeroplane when it is on the ground, and may be either the tricycle type with nosewheel TB10, or the tailwheel type Citabria.

Most tricycle landing gear aeroplanes are equipped with nosewheel or tailwheel steering through the rudder pedals, and almost all aircraft have independent main wheel brakes.

Advanced aeroplanes have retractable landing gear to improve in flight performance by reducing drag, giving better climb capability, higher cruise speeds, improved fuel efficiency, and more range when compared to aircraft with non retractable gear. Most training aeroplanes have fixed landing gear that cannot be retracted.

The Engine and Propeller

In a single engine aircraft the engine is usually located at the front of the fuselage. The engine is mounted in a support frame fixed to a firewall, which isolates the cockpit from the engine. On simple training aircraft the engine drives a fixed pitch propeller; more advanced aircraft will have a constant speed variable blade angle propeller.



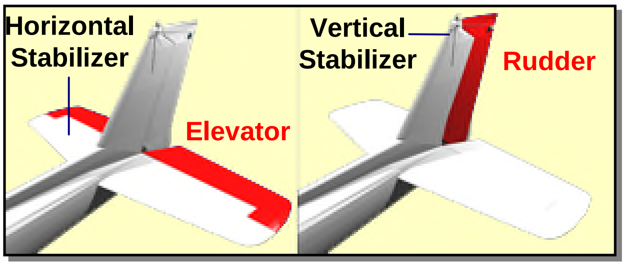
Lycoming 4 cylinder 160 HP

Stabilising Surfaces

Introduction

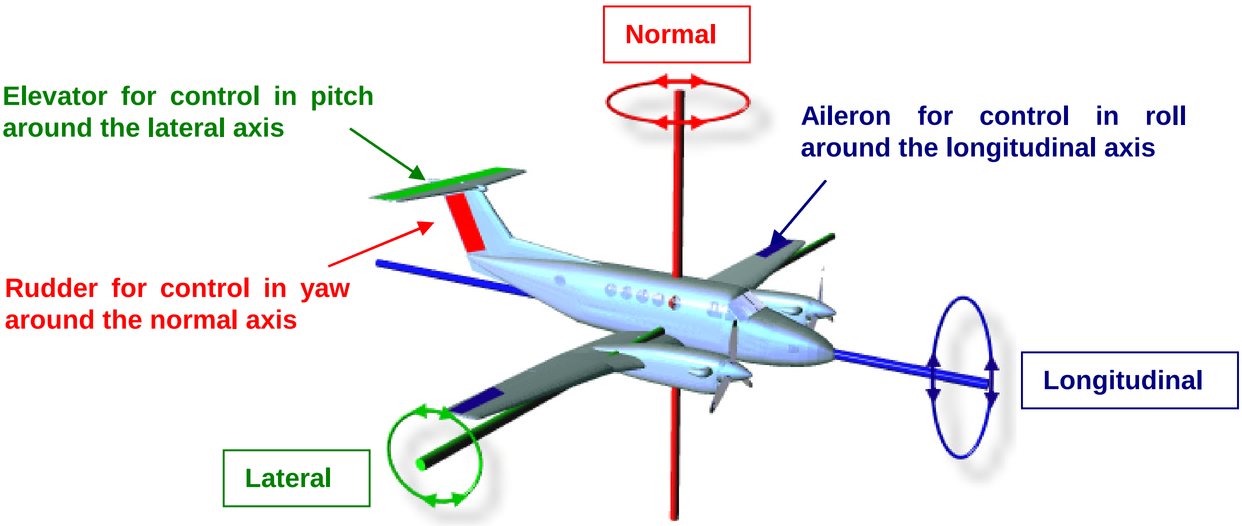
The vertical and horizontal stabilising surfaces of an aircraft ensure that the aircraft remains on its intended path without being affected by any disturbance, such as a gust of wind. They provide longitudinal as well as directional stability.

The tail section (or empennage as it is also known) of the aircraft are airfoil shapes, usually of similar construction to the wings. They consist of a fixed vertical stabilizer or fin to which is attached a movable rudder; and a fixed horizontal stabilizer, with a movable elevator hinged to its trailing edge either side of the vertical stabilizer.



The Aircraft Axes

In normal aircraft design, there are three separate control systems for manoeuvring the aircraft around its three axes.



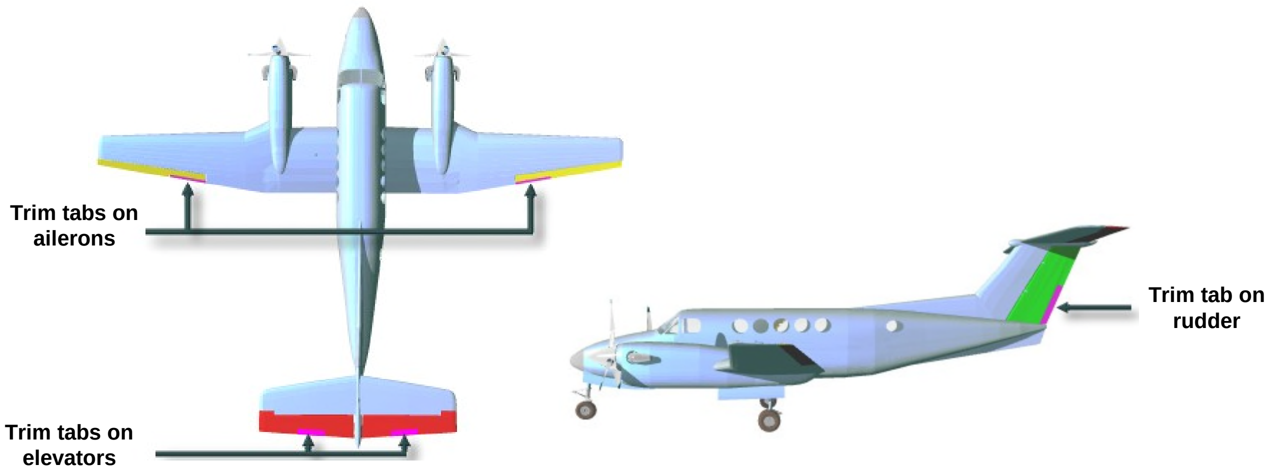
The Vertical Stabilizer provides the aircraft with directional stability about the vertical axis, while the horizontal stabilizer provides longitudinal stability about the lateral axis.

There are variations in design, some aeroplanes having a stabilator all-moving tailplane, others having a ruddervator combined rudder and elevator in the form of a butterfly tail, and yet others having a high T-tail, with the horizontal stabilizer mounted on top of the vertical stabilizer.

Trim Tabs

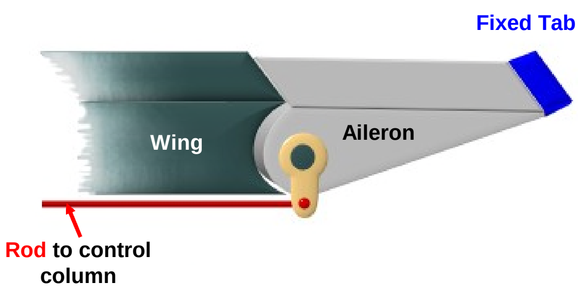
To maintain a certain attitude in flight, the pilot needs to exert a force on the control column to keep the aircraft pointing in the desired direction, whether it be a climb, descent or straight and level flight. On long flights, this can quickly tire the pilot. Trim tabs are therefore used to zero this force on the control column by means of a rotating wheel or switch in the cockpit to enable the pilot to fly the aircraft "hands-off".

Trim tabs are small-hinged surfaces and are normally situated at the trailing edges of the primary control surfaces.



Trim tabs can be fixed or adjustable in flight. The cross section and characteristics of a trim tab are similar to that of a wing, but trim tabs are physically much smaller.

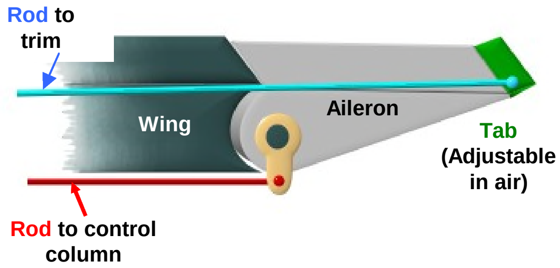
Fixed Trim Tabs



A fixed trim tab can only be adjusted on the ground and the correct position can be determined by executing one or two test flights.

When there is no control column force, the trailing edge of the particular flight control surface will be established by the tab.

Adjustable Trim Tabs



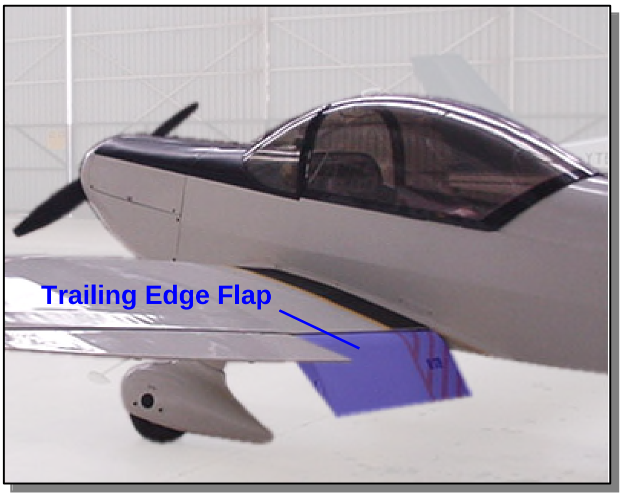
Adjustable trim tabs are used to get rid of unwanted forces on the controls, such as those occurring with a power change or a change in the CG position.

The pilot can adjust these trim tabs electrically or by means of a trim wheel from the cockpit. A **rod** or a system of cables and pulleys control the actual movement of the trim tabs.

The elevator trim tab is usually a small movable aerodynamic surface that forms part of the trailing edge of the elevator. It is controlled from the cockpit using the pitch trim wheel or trim handle to remove prolonged steady control pressures, so that the aeroplane can almost fly itself hands-off, if trimmed correctly, making the pilot's task a little easier.

Trailing Edge Flaps

Flaps are used to increase the camber of the overall wing, therefore increasing its lift.



This can have the effect of reducing landing speeds and allowing steeper approaches which affords better visibility. Landing distances are significantly reduced.

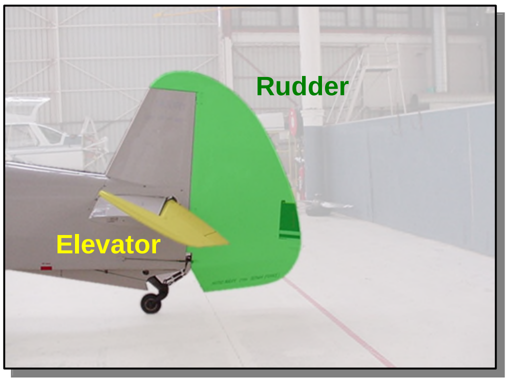
The most common type of flap fitted to most light aircraft is the trailing edge flap.

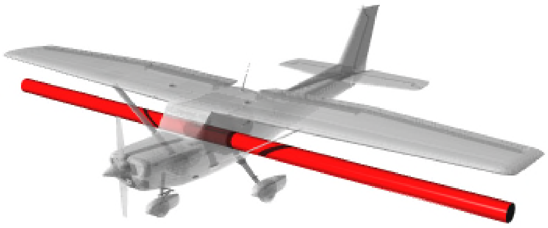
Lowering flap will cause both an increase in lift and drag; but overall a significant lift increase is applied. Applied in stages, the first stage of flaps will only cause a slight drag penalty, but as flap settings are increased the drag becomes significant. Sufficient power must be applied to overcome this increase in drag.

Depending on the aircraft design, lowering/raising flap will cause a nose up or nose down pitching moment. The proficient pilot will compensate by applying either forward or rearward control stick pressure as flaps are lowered.

The Flight Controls

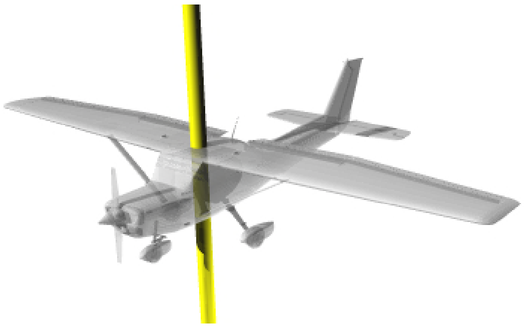
The primary flight control surfaces are the elevator, ailerons and rudder; they control the aircraft in pitch, roll and yaw.

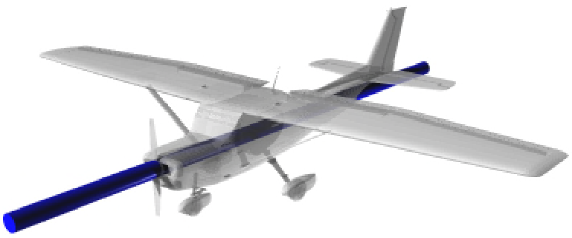




The aircraft pitches around the lateral Axis. The pitch is manipulated by the elevator control.

The aircraft yaws about the normal Axis. The yaw is manipulated by the rudder control.



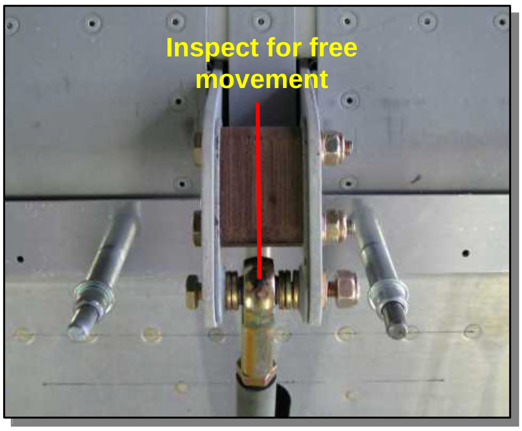


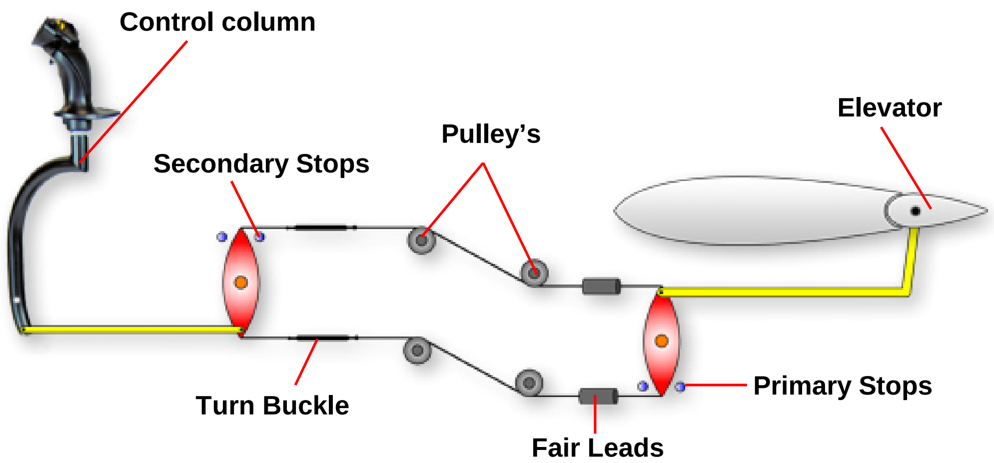
The aircraft rolls about the longitudinal Axis. The roll is manipulated by the ailerons.

The controls are operated from the cockpit by moving the control column or rudder pedals. In a typical aircraft, movement of the control column or rudder pedals operates an internal system of cables and pulleys that then moves the relevant control surface.

Turnbuckles may be inserted in the cables to allow adjustment of their tension, this is only done by qualified personnel. Some aircraft use tubular push-pull rods alone, or together with cables to transfer control inputs to the control surfaces.

These use bronze bush or ball bearing connectors, which when exposed to the elements may occasionally become stiff, affecting control input loads. Daily inspections and preflight checks should check most of these control links.





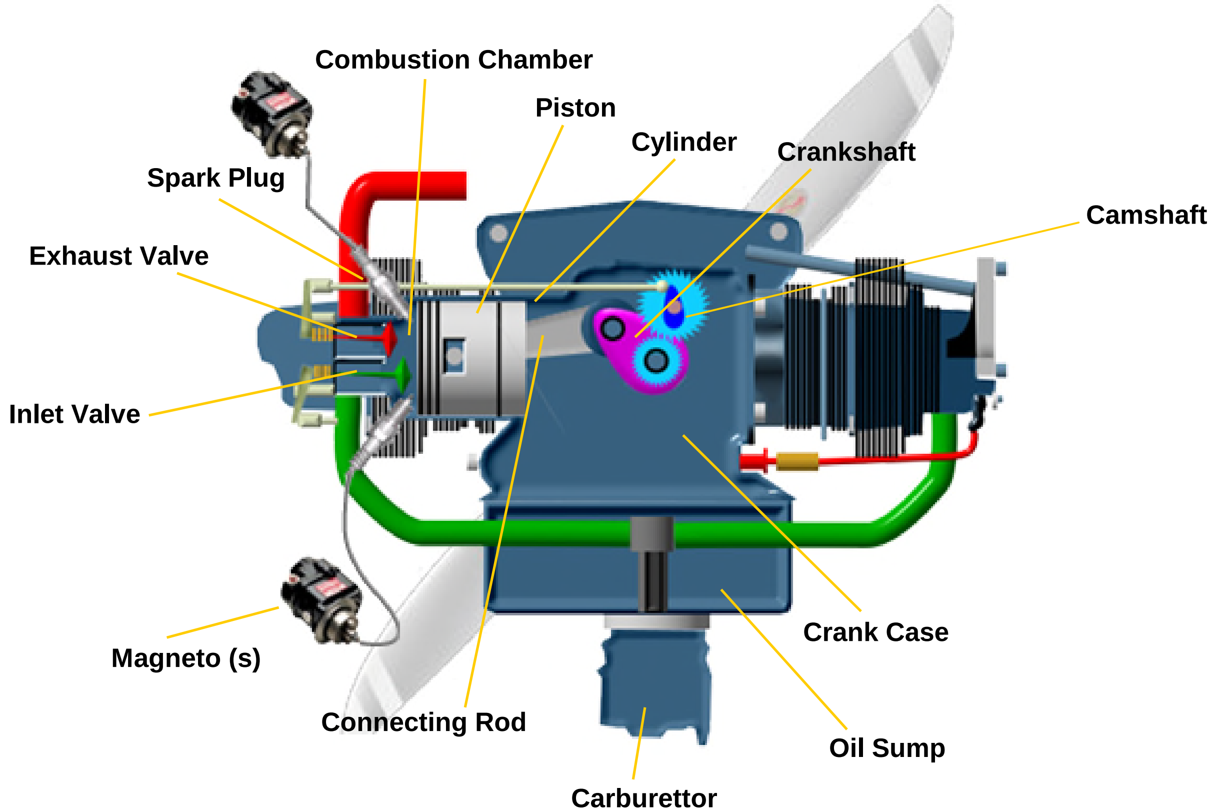
To limit the control surfaces from excessive movement in flight and on the ground, there are stops fitted to the airframe and the control surfaces. Primary stops are fitted to flight controls, Secondary stops are usually on the control column.

The Internal Combustion Engine

Introduction

The common piston engine is made up of many different components, mainly metals, which have been cast or forged then machined and assembled together.

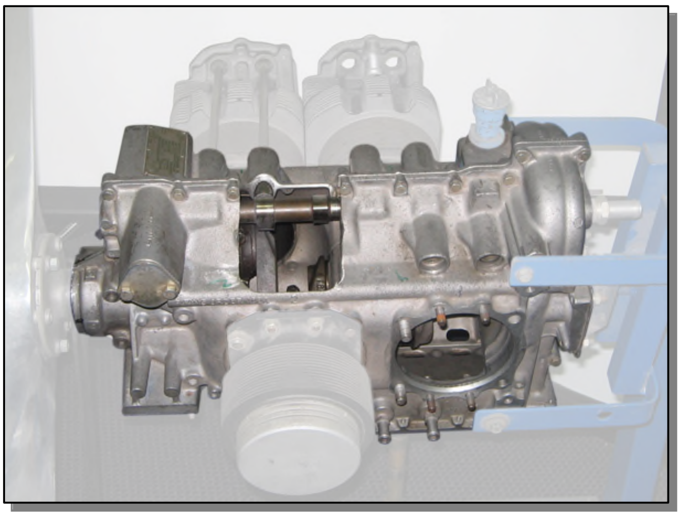
The engine is an energy conversion device operating on a four stroke cycle; it is supplied with aviation gasoline (AVGAS) which is converted into mechanical energy. This mechanical energy is then applied to turn a crankshaft, and in the case of an aircraft, applied to a propeller which produces thrust.



Components

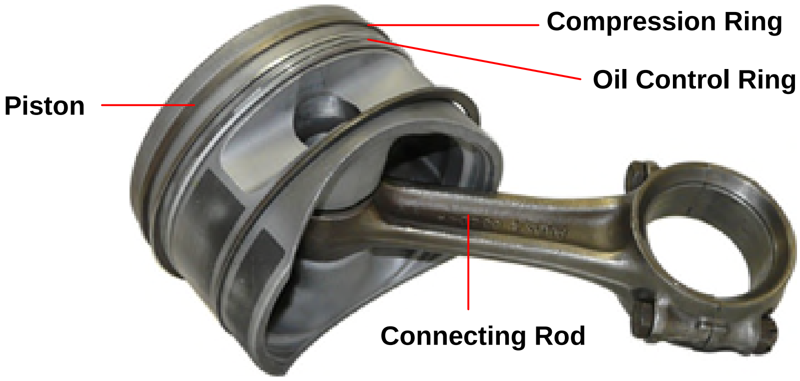
Crankcase

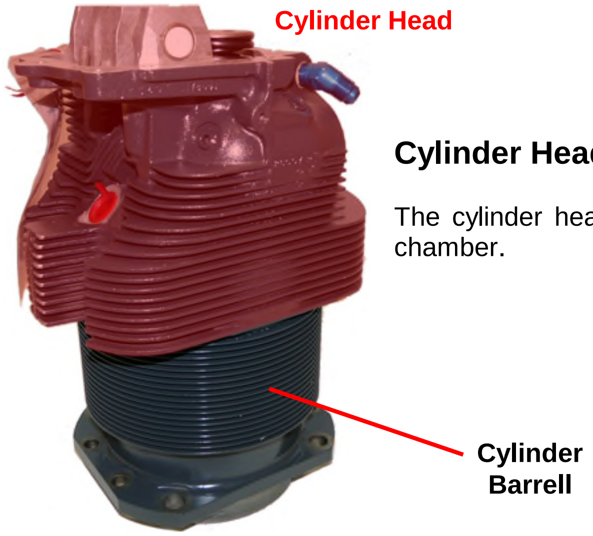
The crankcase is the main body of the engine. It is usually made of aluminium alloy and may be forged or cast. It has internal oil passages and is machined to house the crank and cam shafts. It usually carries the engine mounts for fitment to the airframe.



Pistons

The piston converts the combustion energy to mechanical energy to drive the crankshaft.





Cylinder Head

The cylinder head seals the top of the cylinder to form the combustion chamber.

Cylinders

The cylinders act as the compression and expansion chambers and provide the bore in which the pistons move.

Piston Rings

The piston (compression) rings provide a gas tight seal between the piston and cylinder.

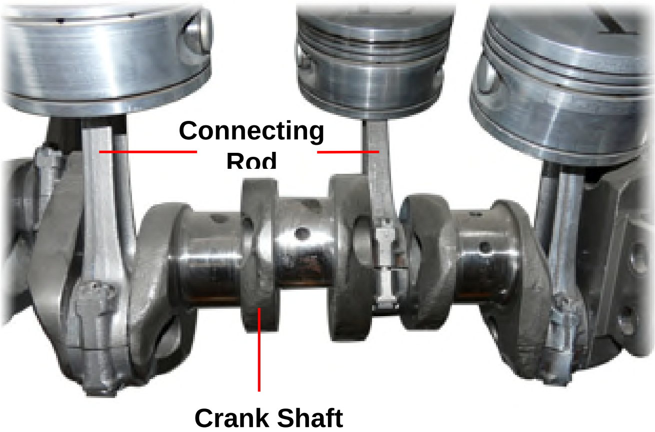
Oil control rings, usually fitted below the compression rings, scrape the lubricating oil from the cylinder walls to prevent it from entering the combustion chamber.

Crank Shaft

A crankshaft converts the reciprocating motion of the pistons to rotary motion to drive the propeller.

Connecting Rod

The connecting rod connects the pistons to the crankshaft



Inlet Valve

Exhaust Valve

Inlet Valve

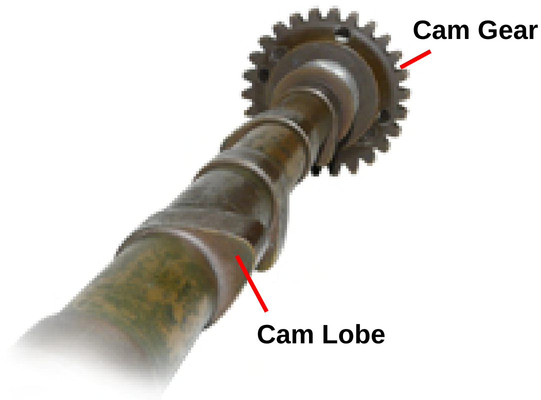
Inlet or intake valves control the air/fuel mixture entering the cylinder. The inlet valves are usually larger than the exhaust valve to improve the gas volume inflow to the cylinders.

Exhaust Valve

Exhaust valves control the flow of burned gases from the cylinder. Because hot gases are present on both sides of the exhaust valves they get very hot. Smaller than inlet valves, exhaust valves are sometimes Sodium filled to help dissipate heat.

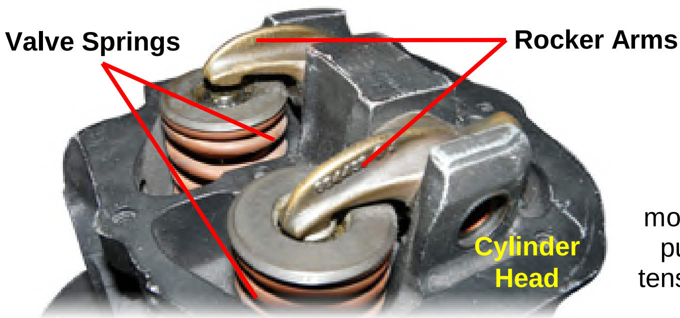
Cam Shaft

The camshaft is driven by the crankshaft at half crankshaft speed and controls the opening and closing of the inlet and exhaust valves (valve timing).



Push Rod

A push rod is a hollow metal tube (for light weight and rocker lubrication supply), which is pushed by a cam follower and in turn pushes on the rocker arm.



Rocker Arm

The rocker arm is a pivot device mounted on the cylinder head which when pushed causes a valve to open against spring tension.

Valve Spring

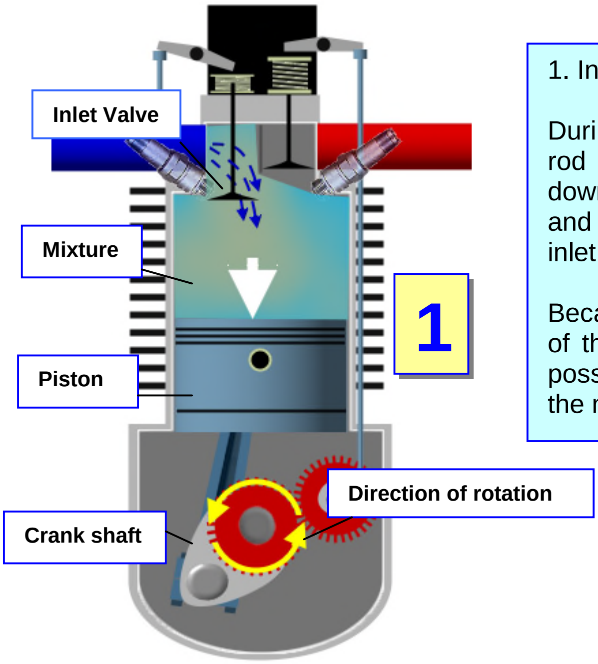
The push rod and rocker assembly open each valve. The valves are closed by strong valve springs when the cam rotates off its lobe. Often double valve springs are used to provide more rapid and positive valve closing as well as eliminating valve bounce.

Spark Plugs

Spark plugs are used to ignite the air/fuel mixture in the combustion chamber. In aircraft engines there are always two spark plugs per cylinder to promote complete combustion and provide a safety factor should a plug fail.

Four Stroke Cycle (Otto Cycle)

Induction



1. Induction

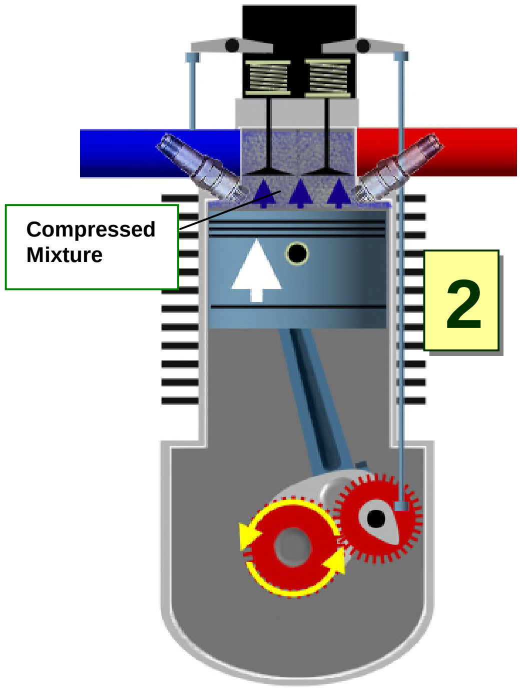
During this stroke, the inlet valve is opened by the cam, push rod and rocker arm mechanism and the piston is moving downward. This movement reduces the pressure in the cylinder, and the fuel mixture flows (or sucks) into the cylinder via the inlet valve.

Because the power output of an engine depends on the weight of the mixture induced into the cylinders, as much mixture as possible must be allowed to flow in a very short time. The flow of the mixture is controlled using a throttle.

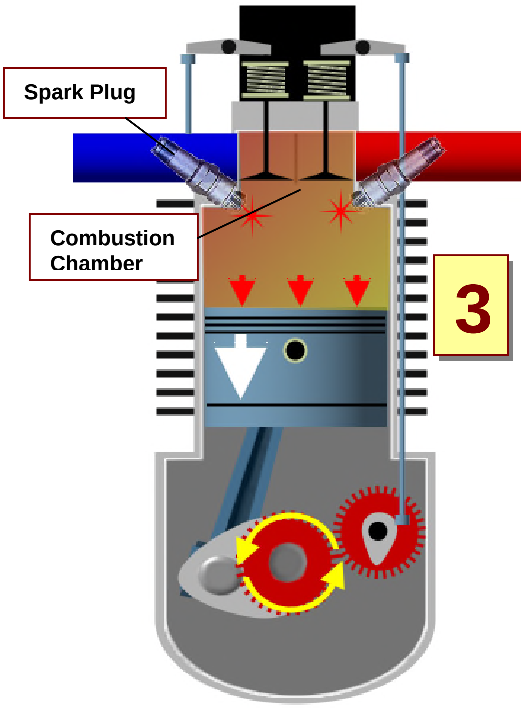
Compression

2. Compression

Once the induction cycle is completed the inlet valve closes, the piston starts to move upward and the mixture in the cylinder is compressed, due to the compression the mixture temperature also rises. Increasing the pressure of the mixture raises its ability to produce power when ignited.



Power

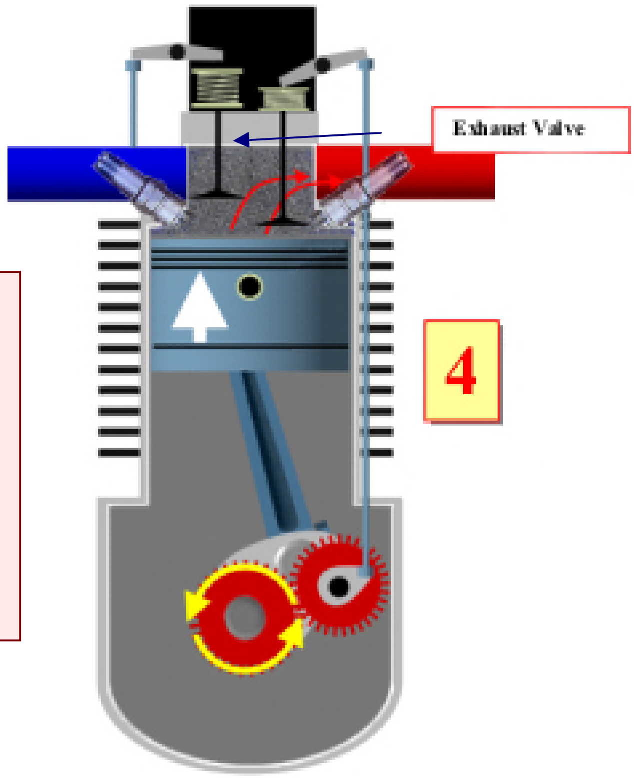


3. Power

As the piston reaches the top of the compression stroke, a spark (from the spark plug) ignites the compressed mixture. The mixture then ignites and the intense heat raises the pressure rapidly to a peak value which forces the piston down. As both valves remain closed, the expanding gases continue to move the piston down the cylinder.

As the piston is forced down, the crankshaft rotates under the influence of the connecting rod and the pressure drops until the piston reaches the end of the power stroke. Combustion is complete and the pressure on the piston is comparatively low.

Exhaust



4. Exhaust

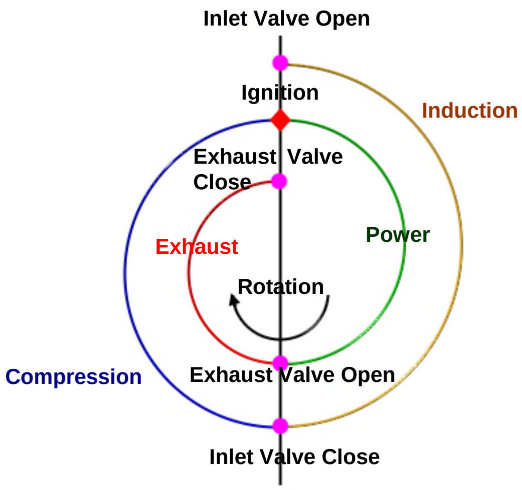
With the piston now at the bottom of the power stroke, the exhaust valve is opened by the cam pushrod and rocker mechanism. As the piston returns towards the top of the cylinder the gases, (at a much lower pressure), escape past the open exhaust valve into the exhaust manifold and then into the atmosphere.

At the end of the exhaust stroke, the exhaust valve closes, the inlet valve opens and cycle begins again.

Associated Principles to the Four Stroke Cycle (Otto Cycle)

Timing

Theoretical Timing Cycle



In theory, the opening and the closing of the valves, as well as the supply of the spark should be timed to take place at either Top Dead Centre (TDC) or Bottom Dead Centre (BDC) of each stroke.

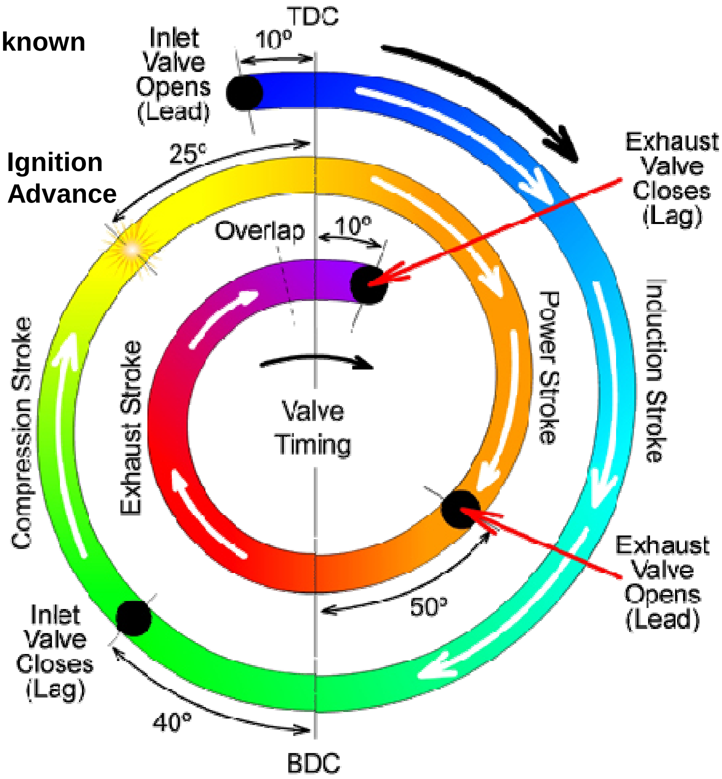
In practice however, a number of factors have to be taken into account including:

- The period of time the valves are opened and closed.
- As a valve is opened there is a period of inertia before the gases begin to flow.
- There is a time lag between the ignition of the compressed mixture, and the build up to maximum combustion pressure.
- Both the intake and exhaust manifolds impose restrictions on the flow of gases to and from the cylinders

Also consideration can be given to the fact, that during one revolution of the crankshaft, there are two periods when the travel of the piston is minimal; these occur as the piston approaches the top and bottom of each stroke. During these periods the piston travel is limited and an opportunity exists for the valves to open either earlier or later, depending on the stroke, thus improving engine efficiency.

Advantage can also be made of reduced piston travel as it approaches the top of the compression stroke. By igniting the mixture before reaching TDC on the compression stroke, the peak gas pressure can be applied to the piston as it begins its downward movement of the power stroke, approximately 30 degrees ATDC. This ensures that the pressure of the expanding gases on the piston apply maximum force to the connecting rod at the most **effective crank angle**.

The practical timing arrangement (also known as the modified Otto Cycle) is as follows:



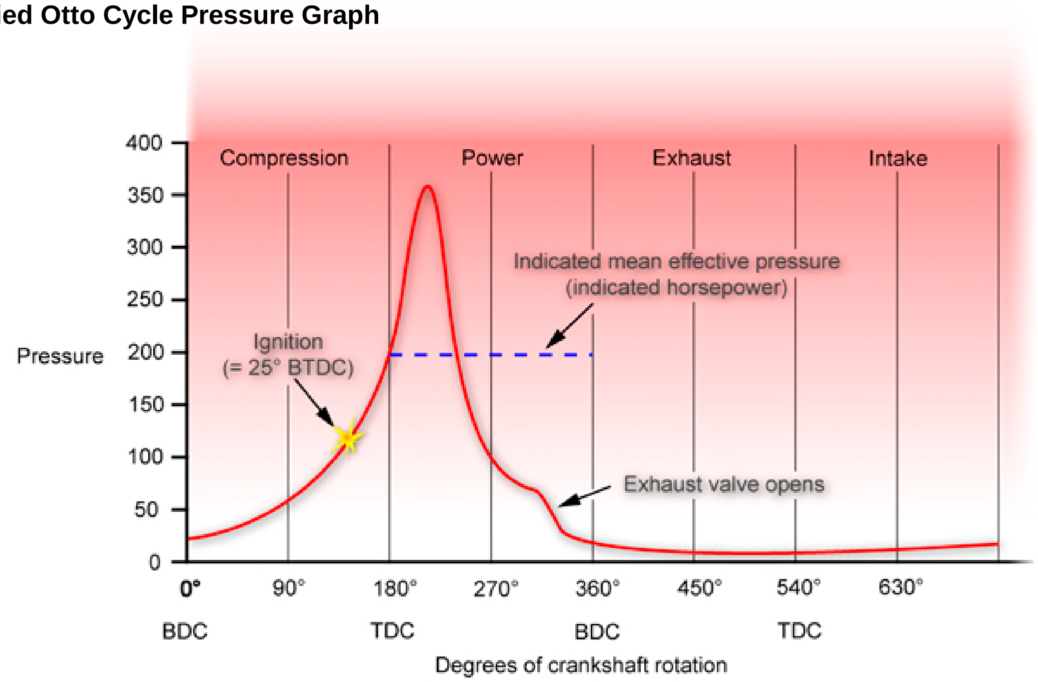
Induction – The inlet valve is opened before TDC at the commencement of the induction stroke *(valve lead)* and remains open past BDC *(valve lag).* These actions add to the weight of the charge by increasing the time period for the mixture moving into the cylinder, and thus increase the volumetric efficiency.

Compression – During the compression stroke, the spark takes place before TDC, *(Ignition advance – 25º)* this ensures that the maximum build up of combustion pressure is reached early in the power stroke (approximately 30° after TDC).

Power – The exhaust valve opens before the BDC on the power stroke *(valve lead).* This means that the exhaust gases begin to flow out of the cylinder before BDC thus ensuring that the cylinder is completely purged of waste gas .

Exhaust - The exhaust stroke continues past TDC *(valve lag),* overlapping with the induction stroke. Therefore at this point both valves are open *(valve overlap).* The partial vacuum left in the cylinder with the rapid exit of the exhaust gases induces the fresh charge to enter, and in fact increases the charge weight with an increase in volumetric efficiency.

Modified Otto Cycle Pressure Graph



Volumetric Efficiency (VE)

Volumetric efficiency is the ratio between the charge (air and fuel mixture) that actually enters the cylinder and the amount that could enter under ideal conditions (piston displacement).

An engine would have 100% volumetric efficiency if, at atmospheric pressure and normal temperature, a charge exactly equal to piston displacement could be drawn into the cylinder.

Normally aspirated (non-turbocharged) piston engines have a VE of approximately 70%-80%, while a turbocharged engine is able to achieve 100%+.

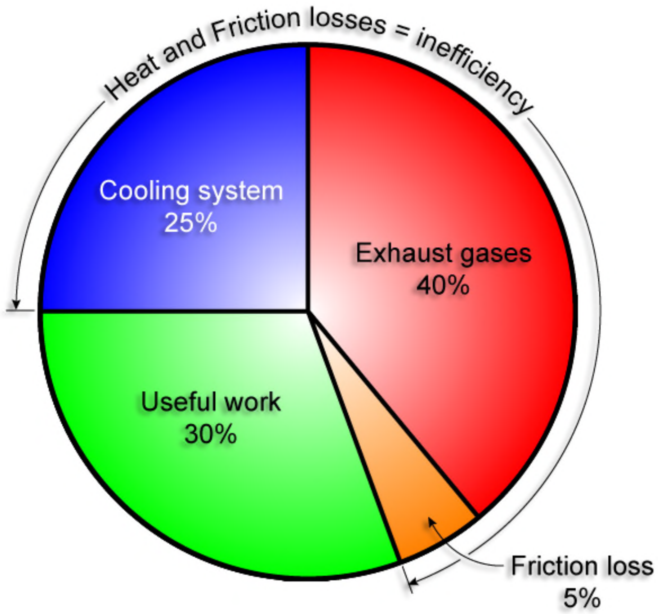
Therefore, volumetric efficiency is deter-mined by measuring (with an orifice or venturi type meter) the amount of air taken in by the engine, converting the amount to volume, and comparing this volume to the piston displacement.

$$\text{Volumetric Efficiency} = \frac{\text{Volume of charge admitted into the cylinder}}{\text{Piston displacement Volume}}$$

Thermal Efficiency

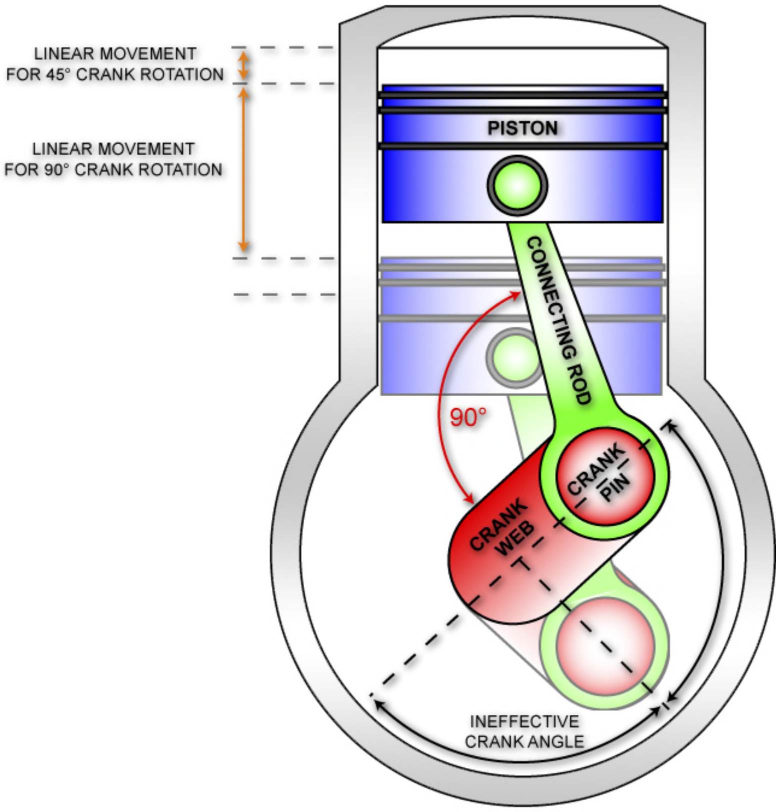
The piston engine is actually a very inefficient power plant, as only about 30% off the power available in the fuel is converted into useful work! During the combustion process, a lot of the heat produced, will be conducted and lost to the engine components and through the exhaust gasses expelled to the atmosphere.

Thermal efficiency (TE) is the ratio of the power actually produced by the engine to the power theoretically available in the fuel; most piston engines operate at approximately 30% thermal efficiency.



Effective Crank Angle

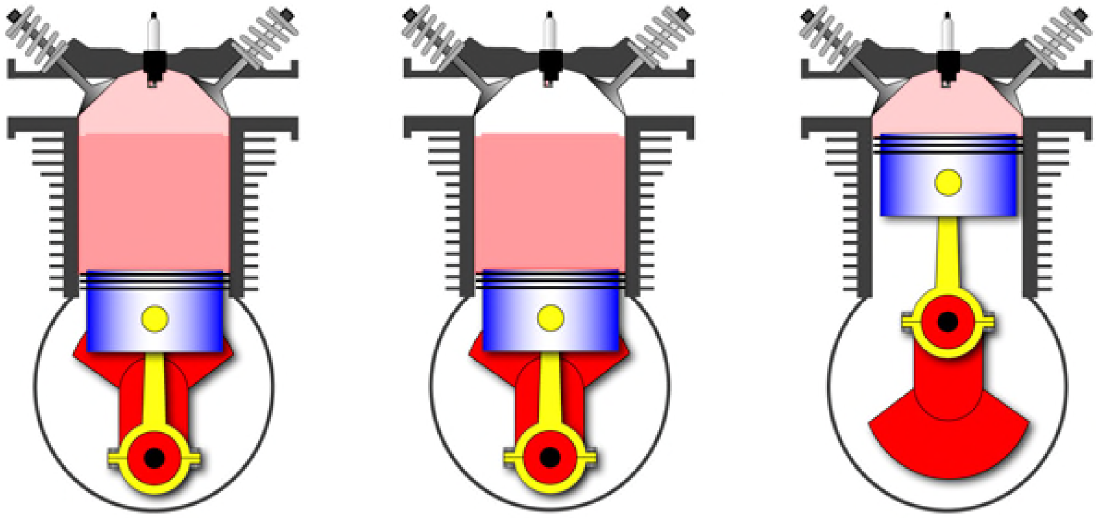
The most effective transmission of power occurs when the angle between the connecting rod and crankshaft is 90°, the thrust in the connecting rod has its greatest leverage at this point. The timing of the ignition spark (25° BTDC)) is set to ensure that the maximum combustion pressure released during the combustion process (30°ATDC) coincides with the piston/crank angle being at 90°. Once the crankshaft has turned approximately 120° ATDC, the effective angle has diminished to the point where leverage is lost and the exhaust valve begins to open.



Compression Ratio

The compression ratio of an engine is the ratio of the total cylinder volume compared to the clearance volume. The area swept by the piston in the course of a stroke is known as the swept volume and the unswept volume above the piston is known as the clearance volume. The clearance volume is where the combustion event takes place and is generally considered to be a constant volume area. Raising compression ratios add to engine power output.

Total Volume **Swept Volume** **Clearance Volume**



Engine Performance Terminology

These terms describe the results of the power produced by the engine.

Work

Work is the force multiplied by the distance expressed as foot pounds (ft/lbs) or Newton metre (N-m).

W = F x d

> Note: Work is the transfer of energy and energy units are called Joules. Thus, work can also be expressed as Joules.

Power

All engines produce some sort of power, thus power can be determined by measuring the amount of work expended in moving an object a certain distance over a period of time. The basic power formula is:

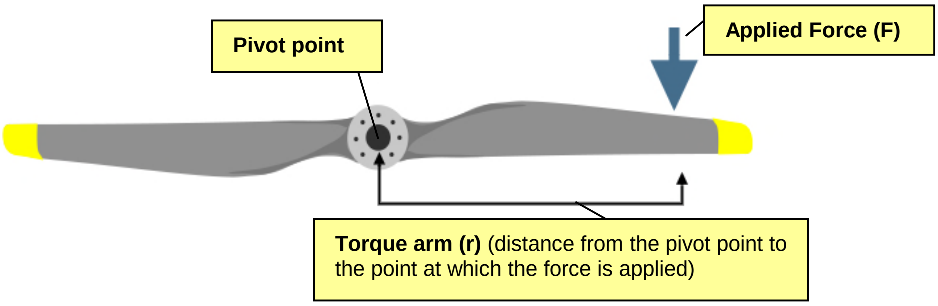
$$\text{Power} = \frac{\text{force x distance}}{\text{time}}$$

A Horsepower is a British unit for **Power,** defined as the force needed to move 550 pounds one foot in one second (550ft/lb per sec), or 33000 foot pounds per minute (33000 ft/lb per min)

(In the metric system the term for the unit of power is the Watt. One horsepower is equivalent to 760watts or 0.76kilowatts)

Torque

In a rotational system, there is a "twist", which is called **torque**. Torque is the tendency to produce change in rotational motion, it is equal to the **applied force (F) X the length of the torque arm (r)**. Torque is measured in foot-pounds (ft-lb) in the British System.



IHP - Indicated Horsepower

Indicated horsepower is the theoretical power developed in the combustion chamber of a frictionless engine.

FHP - Friction Horsepower

Friction horsepower (FHP) is a measure of all the losses which occur within the engine due to friction and auxiliary equipment such as the alternator, fuel and oil pump. The movement of the pistons up and down, as well as the rotation of the crank and camshafts, all create frictional losses.

BHP - Brake Horsepower

Brake horsepower is the actual power available at the crank shaft, or propeller shaft. It is less than the IHP and is a function of both RPM and torque.

IHP – FHP = BHP

SHP - Shaft Horsepower

Shaft horsepower is the power delivered to the propeller shaft of a turbo shaft engine.

THP – Thrust Horsepower

Thrust horsepower is produced when the propeller converts the engine power in to thrust horsepower. The thrust is a function of the blade pitch of the propeller relative to the velocity of the aircraft. Thrust horsepower is also the equivalent of the thrust produced by a jet engine.

Mechanical Efficiency

Mechanical efficiency is the ratio of the IHP to the actual BHP, generally considered to be about 70% in a piston engine, expressed by the formula:

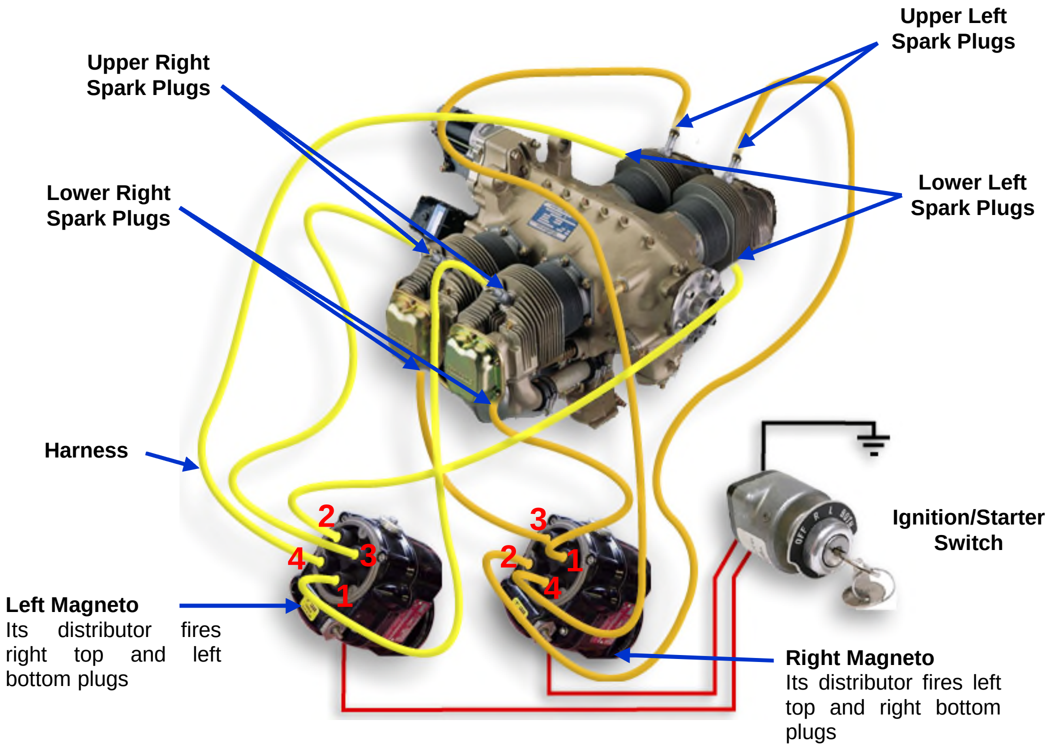
$$\textbf{Mechanical Efficiency} = \frac{\textbf{BHP}}{\textbf{IHP}}$$

The Ignition System

Overview

The ignition system provides a reliable, timed ignition, to the charge in the cylinder at the beginning of the power stroke. **N.B.** Ignition systems in most aircraft are entirely independent of the aircraft electrical system. The ignition system consists of the:

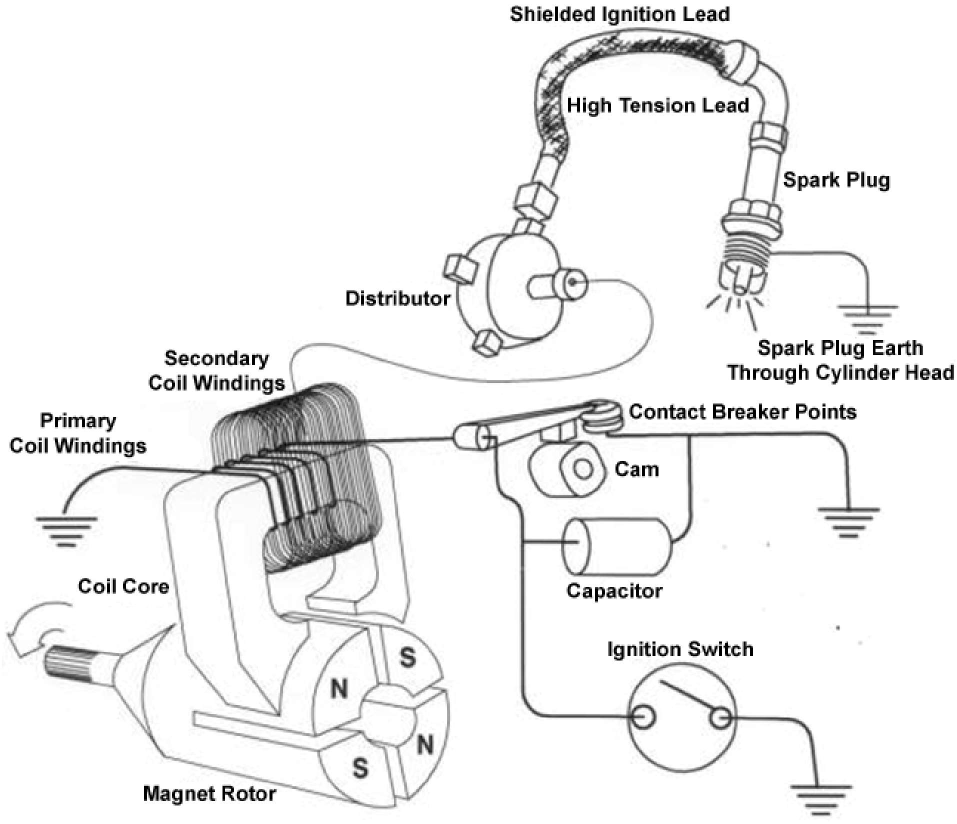
- Magneto
- ignition switch(s)
- spark plug leads (harness); and
- spark plugs



Aircraft engines are fitted with dual ignition systems to increase engine reliability and safety. As two sparks are produced in the combustion chamber this has a positive effect by increasing combustion efficiency (complete burning), which results in a useful power increase.

The Ignition Circuit

The magneto consists of a wire coil (primary coil) in which a flow of electricity is induced by a magnet rotated by the engine. This low voltage current (approximately 300 volts), experiences a series of interruptions, by the timed opening of contact points within the magneto at about 25°BTDC. As a result, a higher voltage is induced in another secondary coil. The high voltage (approximately 30,000 volts), is applied to spark plugs and a current is forced to flow across the air gap making the spark. The high tension leads from the magneto to the spark plugs are shielded, to minimize interference to avionics.



Ignition Switch

The magneto switch is a fail-safe system. To turn a magneto on, the ignition switch is opened which allows the primary circuit to operate. To turn a magneto off the switch is closed and the primary circuit is earthed. Should an earth wire break or the switch fail during flight, the magneto should continue to operate.

the

The ignition switch is designed to:

a) earth **L** magneto (when R is selected),
b) earth **R** magneto (when L is selected),
c) earth both Left and Right magneto when **OFF** is selected,
d) earth neither Left or Right when **ON** is selected.

Note: If the primary circuit or the switch fail, that magneto would be "**LIVE**". This allows the engine to continue to operate which is very useful during flight. However, a live magneto on the ground is a hazardous situation as any movement of the propeller may allow the magneto to spark causing the engine to "kick over". The propeller could contact any one near it.

Contact Breaker

The contact breaker, in the primary circuit of a magneto, interrupts the flow of current through the primary coil; there is a resultant collapse of magnetic field around this coil which induces a current flow in the surrounding secondary coil. The output of the secondary coil is directed to the spark plug.

The Capacitor

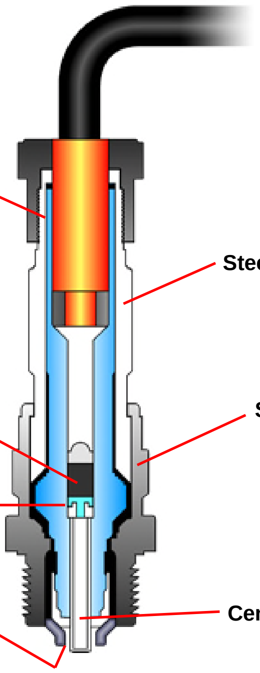
The capacitor in the primary circuit assists in a rapid collapse of the primary magnetic field as the contact breaker opens, it also helps prevent erosion and sparking at the contact breaker. The faster the primary magnetic field collapses the greater will be the output of the secondary coil. It also cuts down on radio interference.

The Distributor

The distributor directs the output from the secondary coil to the spark plugs in the correct sequence of cylinder firing order.

Spark Plugs

Aircraft spark plugs, screwed into the cylinder heads, have a centre electrode which carries the high tension current from the ignition harness; the harness leads are screwed to the spark plugs. this current jumps across an air gap to earth at the plug outer shell; in doing this a high tension spark ignites the fuel air mixture in the combustion chamber.



Plugs operate best at a specific heat temperature. When the engine is operated for long periods below optimum temperature, carbon or oil fouling may occur. When mixture is excessively rich, lead fouling may also occur.

Starting Devices

The magneto is timed to produce a spark at about 25° BTDC for normal running. For the spark to occur at 25° BTDC during engine start the combustion would be complete before TDC due to the low crankshaft speed.

At low RPM the peak pressure in the cylinder would occur well before TDC, thus causing a dramatic loss of power, starting problems and possibly kick back.

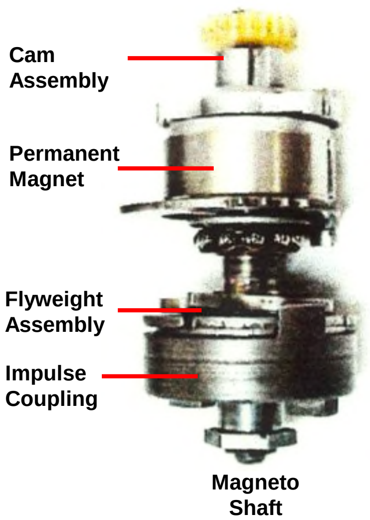
A **starting device** is fitted to :

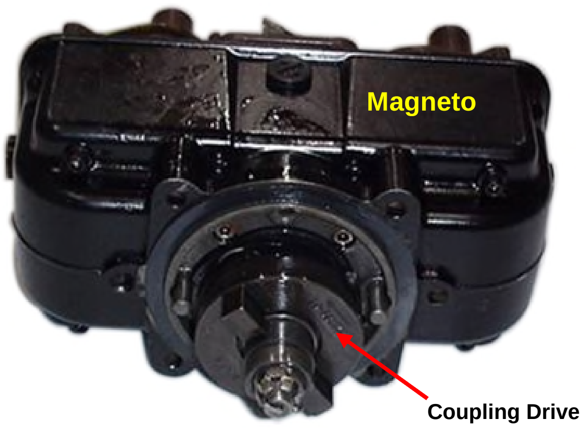
a) Retard the spark; and
b) Make a stronger spark (hotter).

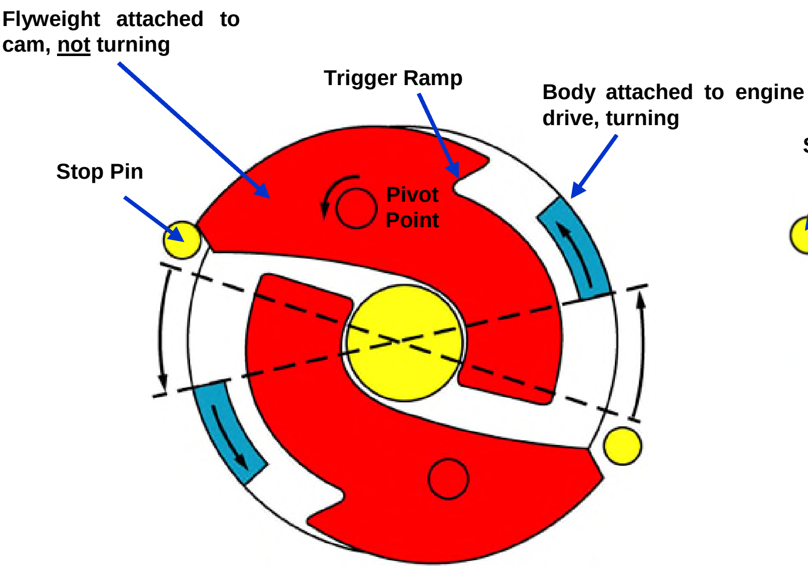
Impulse Coupling (Impulse starter) **:**

This device is mechanical and uses a spring and a centrifugal clutch. At low RPM the magneto rotor is held for about 60° of rotation, then released, rapidly rotating the magnet which produces an intense spark at TDC.

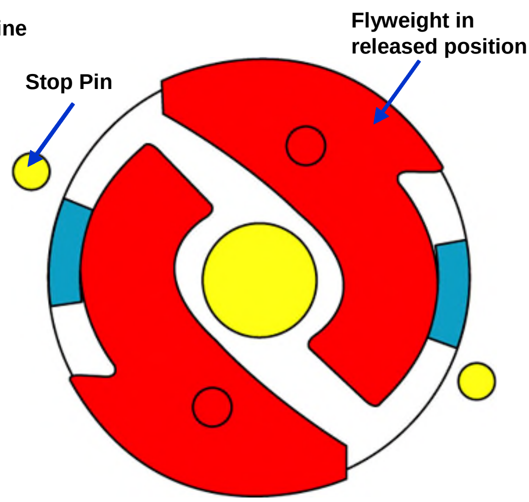
Once the engine has fired and the engine is running at idle speed, this mechanism is disengaged and the spark timing resumes its 25° BTDC setting.







Impulse Coupling - Start



Impulse Coupling - Run

Note: Impulse coupling does not require an external power source and is common on modern light aircraft. Other starting devices are:

- Booster Coil **(with trailing electrode) ; and**
- Induction Vibrator **(with retard breaker points)**

These devices require the aircraft battery for their operation.

Starting devices are normally only fitted to the left magneto (commonly referred to as the Master Magneto). Most modern aircraft are fitted with a rotary ignition switch to select magneto and start functions. The impulse coupling will decouple (centrifugal clutch) at about 500 RPM; the ignition spark will then occur at its normal position (≈25° BTDC).

Pre-Ignition

Pre-ignition is an engine problem not related to the electrical function, the sparking process. of the ignition system.

Should a spark plug overheat and glow white hot, an exhaust valve be damaged and partially melt or a carbon deposit in a cylinder retain a large amount of heat, the incoming charge may be ignited before the spark occurs.

Carbon Deposits

The charge will burn at its normal rate, but because the combustion has started early, it will produce its maximum pressure in the cylinder well before the optimum piston and crankshaft position.

Pre-ignition will result in rough running, loss of power and will cause the temperature to increase, which perhaps could lead to detonation.

Detonation

Detonation is a condition of uncontrolled burning which occurs inside a cylinder when the fuel-air mixture reaches its critical pressure and temperature. Under normal conditions, the fuel air mixture is compressed and ignited by two spark plugs, and as it burns, the flame fronts move across the fact of the piston from both sides. Ahead of the flame front, the mixture is heated and further compressed.

With normal combustion, the cylinder pressure rises smoothly until it peaks about 20 degrees after the piston passes over the top of its stroke (T.D.C.). This gives a smooth push to the piston, but if for any reason the fuel-air mixture reaches its critical pressure and temperature, it will explode rather than burn, and instead of pushing smoothly on the piston, the pressure inside the cylinder will rise almost instantaneously and apply a sharp blow to the piston.

The pressure shock waves caused by the explosion, travel at sonic speed and produce a ping, or knock. This is easily heard in automobile engines but, because of other noises, it is not generally heard in an aircraft engine. the rapid rise in pressure and temperature imposes extreme loads on such internal parts of an engine as the connecting rods, bearings, valves, piston heads and combustion chamber walls, and it often leads to complete destruction of the engine.

Detonation is always due to excessive cylinder temperatures. Because of adiabatic heating, an increase in pressure will always result in an increase in temperature. The density of the mixture will influence both pressure and temperature, and the ratio of fuel to air will also be an important factor. In practical terms therefore, detonation may be caused by any or all of the following;

a) too weak or lean a mixture
b) the ignition timing being too far advanced
c) engine torque loading, too high for rpm selected
d) a high charge temperature, due to inappropriate use of carburetor heat, or of alternate hot air in a fuel injected system, or of excessive supercharging
e) with a constant speed propeller, the selection of high power at low rpm
f) fuel octane rating too low

Piston Engines - Aviation Fuel

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.

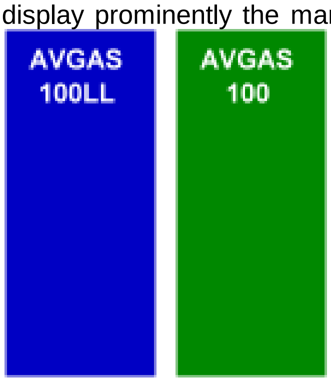
Aviation Gasoline (AVGAS)

Avgas is gasoline fuel for reciprocating piston-engined aircraft. As with all gasoline's, 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 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.

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

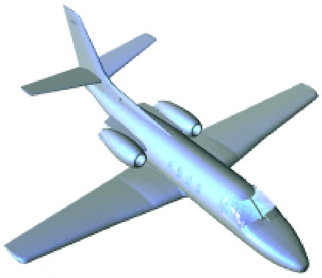
Avgas fuelling nozzles for over-wing dispensing are **painted red** to help prevent the possibility of jet fuel being supplied to a piston engined aircraft. Nozzles for jet fuel (painted black) are normally a different shape and of a larger diameter than the aperture on most aircraft Avgas tanks.

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.

Aviation Turbine Fuel (Jet Fuel)

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.

Civil Jet Fuels

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:

- **Jet A-1**

  Jet A-1 is a kerosene grade of fuel suitable for most turbine-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 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).

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 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.

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.

- **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.

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.

Fuel Tester

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 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 includes 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.

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 ; and
- 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.

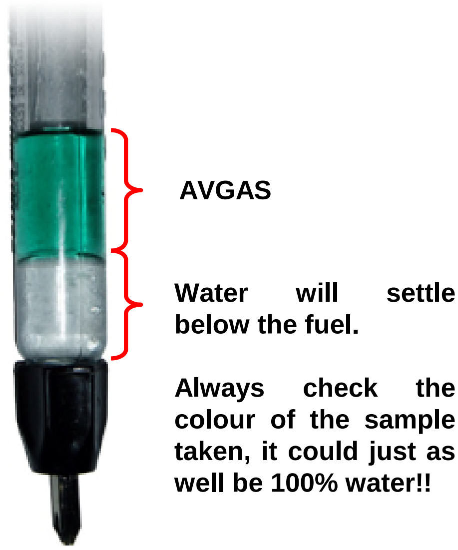
There can be other impurities besides water. Rust, sand, dust and micro-organisms can cause similar problems. Filtering of straining the fuel should indicate the presence of these and hopefully remove them prior to refuelling.

Be especially carefull 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 prior to loading.

Water is more dense 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 and
- inform the ground engineer.



Aircraft Fuel System

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.

Fuel Flow Systems

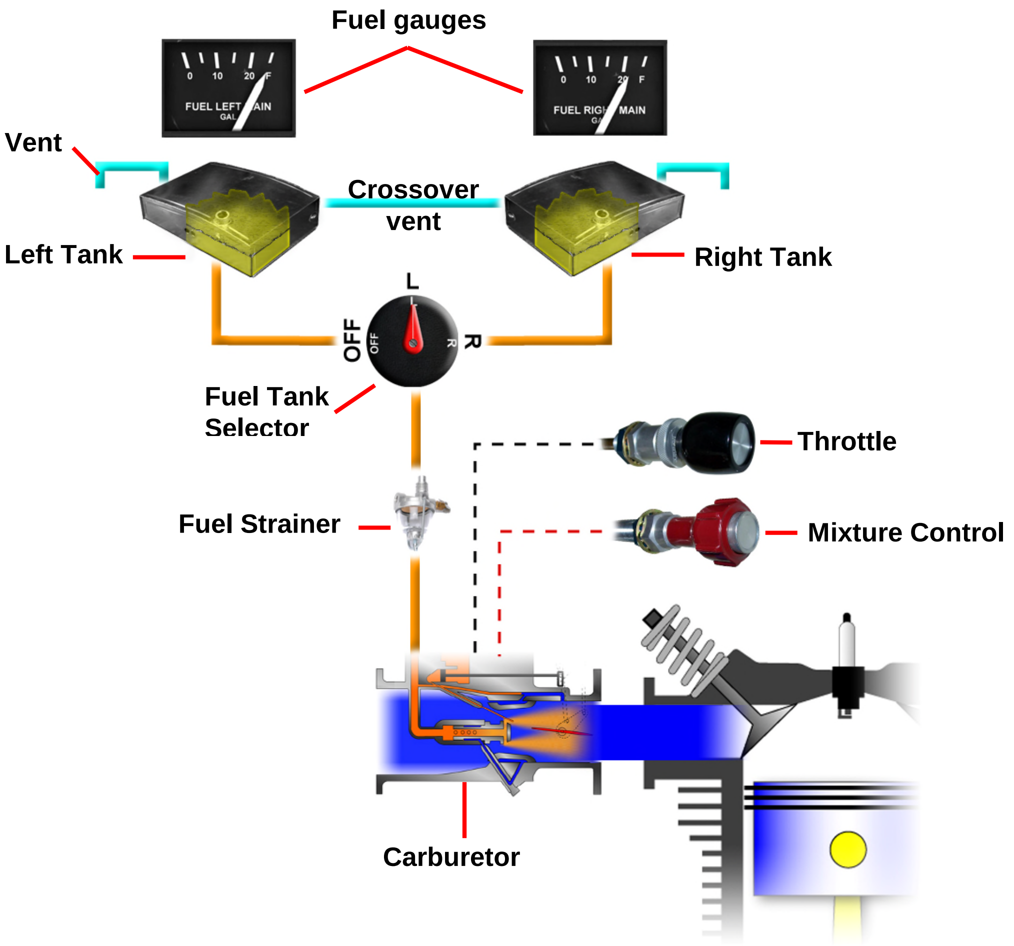
The fuel flow systems of the aircraft are required to move the fuel from the storage tanks to the point at which combustion occurs, and power is developed in the engine. There are basically two types of fuel flow systems:

- Gravitational systems, and
- Pressure pump systems

Gravitational System

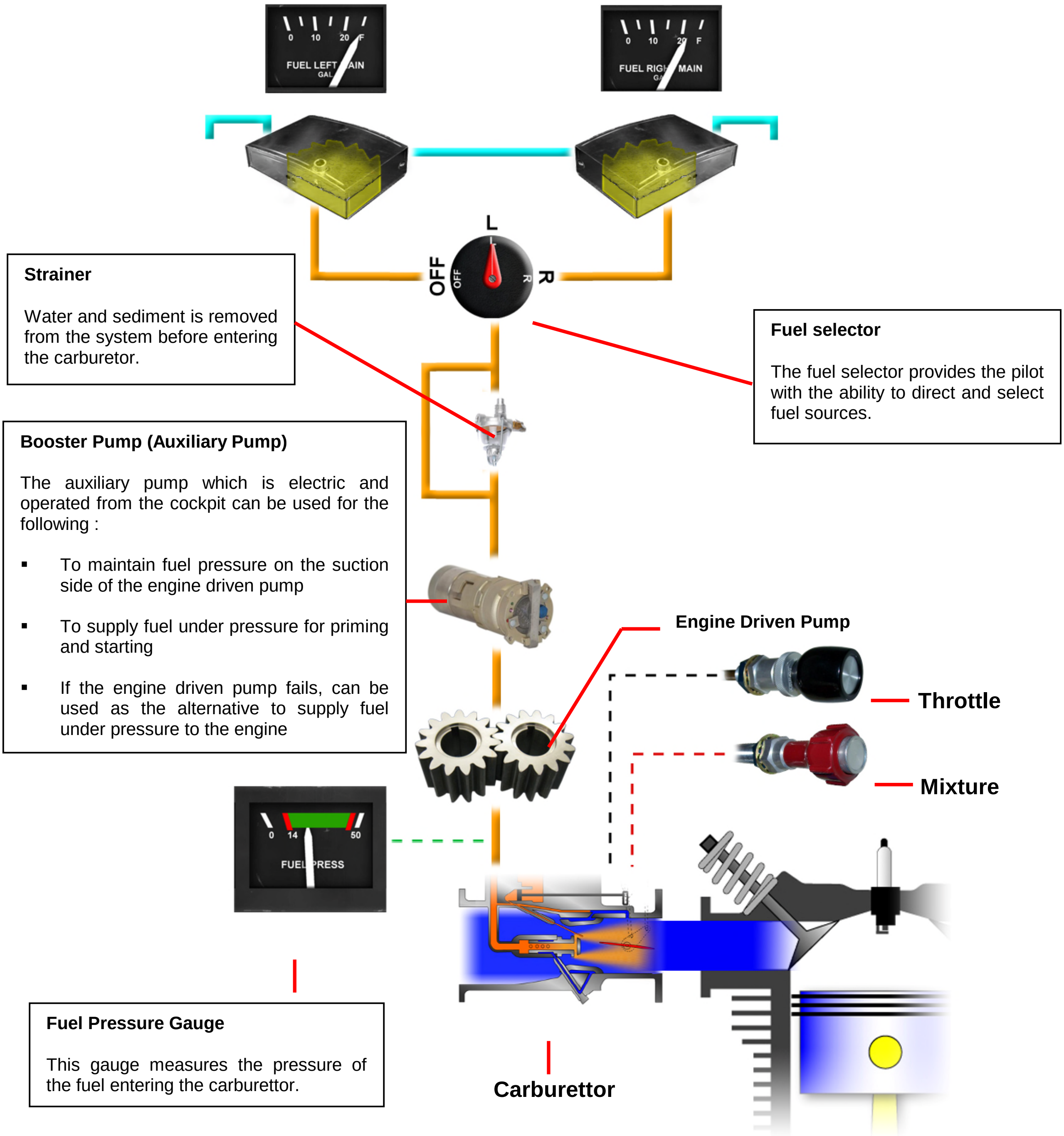
In the gravity fuel system, the fuel tanks are usually mounted in the wings of a high-wing aircraft, placing the fuel well above the carburettor. The height provides enough (gravity) pressure for the fuel to flow through the system.

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.



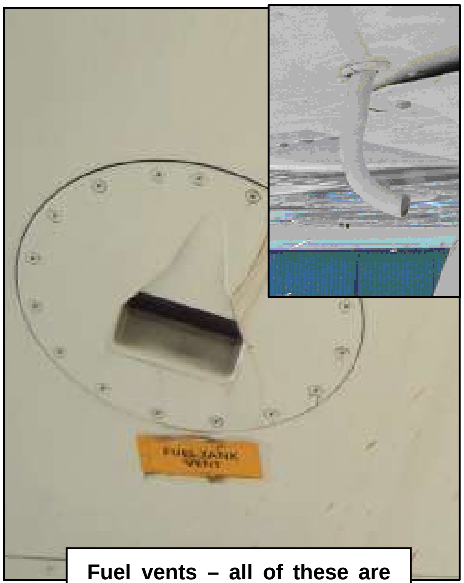
Pressure pump system

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 in case the engine fuel pump should fail.

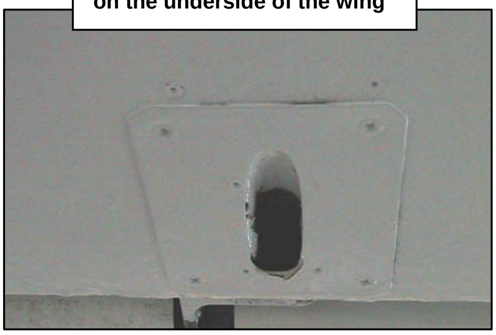


Fuel Tank Vents

Venting is required for the internal tank pressure to adjust to the changing outside pressure; these pressure variations can be the result of temperature, pressure or altitude changes.
Furthermore, as fuel is used during flight, the space that was occupied by the fuel should be replaced by air; to prevent the tanks from collapsing.



Fuel vents – all of these are on the underside of the wing



Venting is needed both for liquid and gas. The gas air mixture in a partially empty tank must be able to adjust to changes in the outside pressure, as the aircraft climbs and descends, to prevent excessive pressure on the wing skin. Care must be taken to ensure that these vents do not become blocked.

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

Fuel Metering Systems

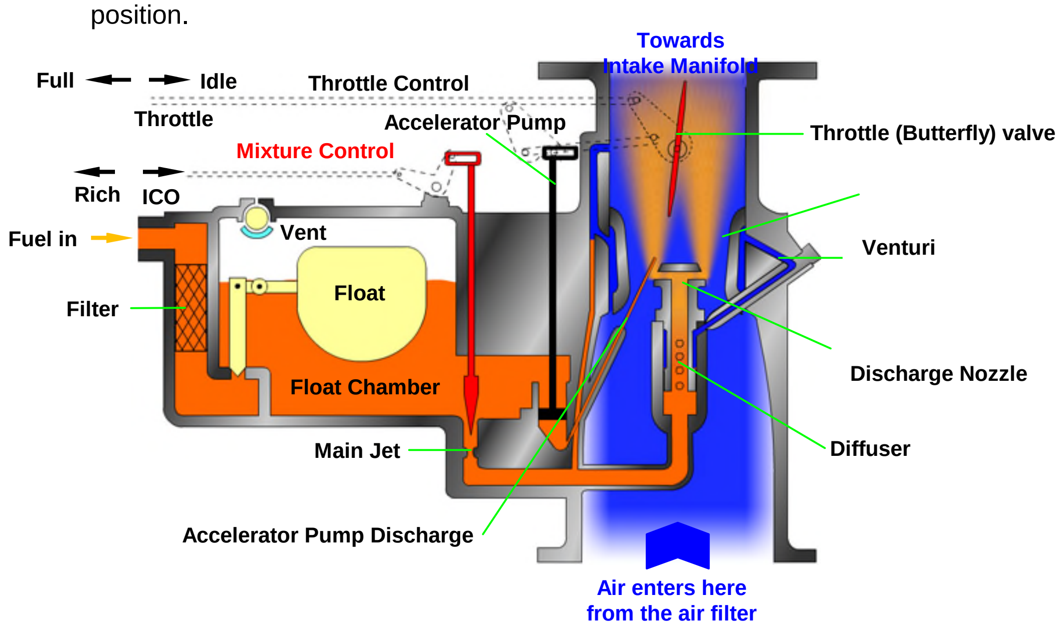
Introduction

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:

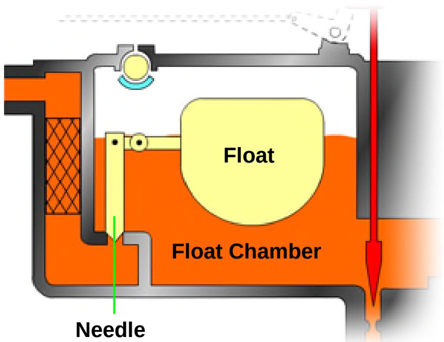
- The charge at the correct air fuel ratio
- Control of the amount of charge entering the cylinder using the throttle.
-
- Mixture leaning (mixture lever) and priming (usually with the throttle).
- A means of stopping engine by moving the mixture lever to the Idle Cut Off (ICO) position.



Outside air first passes through an airfilter, after which the air flows through the venturi located inside the carburettor. A low air pressure area is created within the venturi, which causes the fuel to flow from the float chamber, under atmospheric pressure, through a discharge nozzle located in the venturi. The fuel then flows into the airstream, where it is mixed with the air entering the intake manifold.This fuel/air mixture passes through the intake manifold and into the cylinders, where it is ignited.

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 into the carburetor bowl, thus regulating the fuel pump supply.

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 carburetor.



Manifold Pressure (MAP)

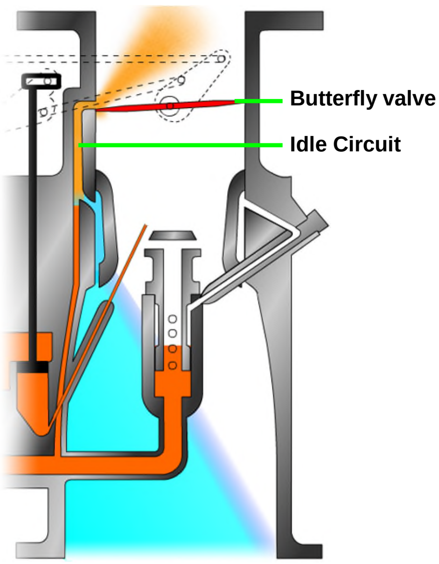
At sea level on a standard atmospheric day, the ambient air pressure is 29.92 inches of mercury; on many aircraft engines a guage is installed iin the inlet manifold to display manifold pressure.

On a standard day at sea level, with an engine running at idle the throttle is partially closed, this restricts the amount of air passing through the inlet manifold into the cylinders, and manifold pressure will typically be around 8-10 inches of mercury.

At sea level with a fully opened throttle, manifold pressure will rise to approximately 27 inches of mercury. Inlet air filters and manifold design restrict airflow so that it cannot reach the atatic pressure level of 29.95 inches of mercury.

It can be seen therefore, that engine power and manifold pressure are closely related to throttle movement.

Throttle Operation



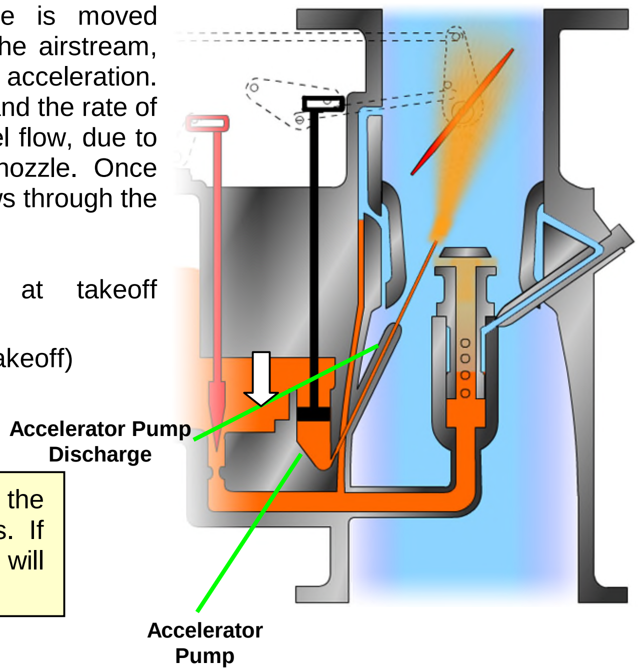
At idle, the throttle (butterfly) valve is almost closed and the venturi is unable to function. Only a small amount of air can enter the engine, and this is directed past an idle discharge port. A low pressure area beside this port causes a small but appropriate amount of fuel to be drawn into the manifold from the idle circuit.

This means the :

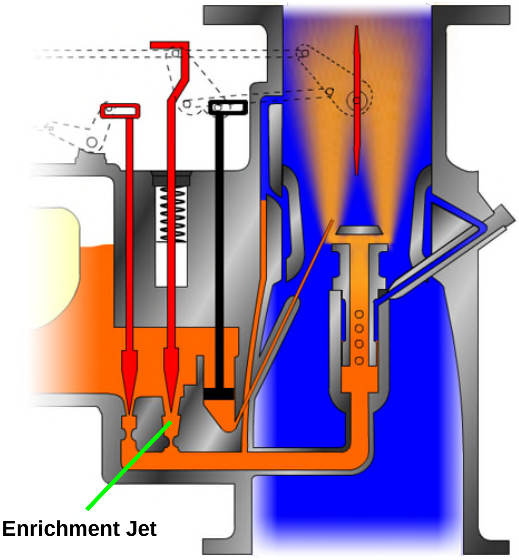
- Manifold air pressure is LOW (8-10 inches HG)
- Volumetric Efficiency is LOW (10-15%)
- ENGINE power is LOW

As the throttle is moved forward an accelerator pump delivers extra fuel to the airstream, this is necessary to avoid engine hesitation during acceleration. This may come about if the throttle is opened rapidly and the rate of increased airflow momentarily axceeds the rate of fuel flow, due to inertia of the fuel from the float bowl to the discharge nozzle. Once this condition stabilises, the increased air and fuel flows through the venturi will again be proportional

- Manifold air pressure increases (MAX at takeoff approximately 27 inches HG)
- Volumetric Efficiency increases (MAX. 70% at takeoff)
- ENGINE power increases.



Note: If the engine is fitted with a fixed pitch propeller, the RPM will increase as MAP (manifold pressure) increases. If a CSU variable pitch propeller is fitted, the RPM will increase until the CSU starts governing at its <u>SET</u> RPM.



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 :

e) extra fuel cooling due to evaporation.

f) reduced risk of detonation as more anti-detonation additives from the rich mixture reach the cylinders.

Full Throttle Height (FTH)

FTH occurs at the altitude where the throttle valve is fully open and any further climb results in a manifold pressure decrease. This means the maximum manifold pressure (max. power) is achieved for that engine RPM. For a normally aspirated engine, this 'height' is sea level. For a supercharged engine, the FTH could be as high as 15,000 to 20,000 ft.

Air and Fuel Mixture

Air Density

Both pressure and temperature influence air density. As altitude increases, there is less weight of air above causing a decrease in pressure. Density therefore decreases with altitude. Temperature also decreases as distance from the earth's surface increases.

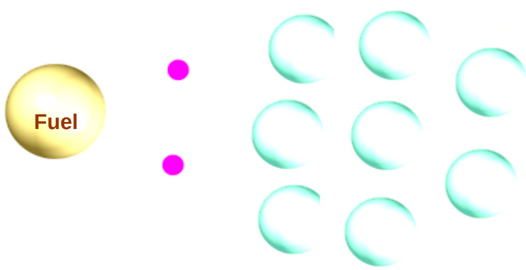
As the air density decreases, there is less oxygen to burn, and for the same amount of fuel the mixture will be richer.

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.

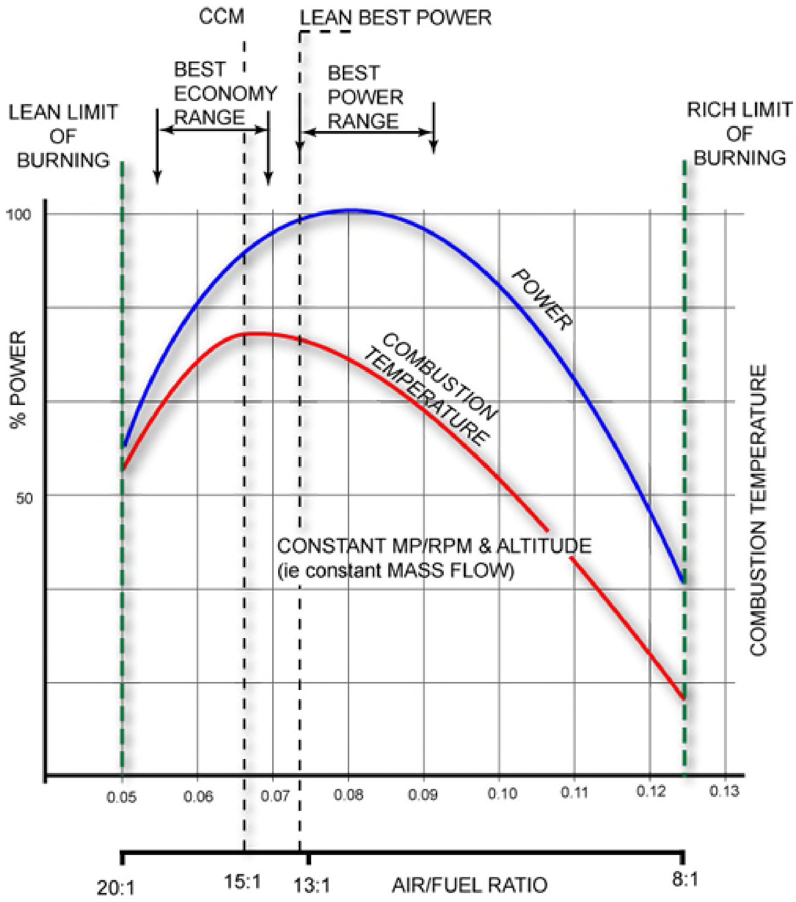
Combustion of the mixture will take place when the mixture of fuel to air is between 1 (fuel): 8 (air), and 1: 20 (limits of burn).

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.



Note: Lean mixtures burn hotter and rich mixtures burn cooler

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 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

Leaning an engine to the CCM produces the highest Cylinder Head temperature (CHT) and Exhaust Gas temperature (EGT). This is the 'best economy' range of the engine and is potentially dangerous because of the high temperature. Some roughness of the engine operation may be evident.

Enriching the mixture from the CCM reduces the operating temperature (fuel cooling) operation is smoother and power output is increased initially then starts to decrease if enriched further. The aim when leaning the mixture is to achieve the lean best power for that power setting and altitude. LEAN BEST POWER is the leanest selection in the best power range where the engine operation is smoothest.

Operating the engine at the CCM is impractical because:

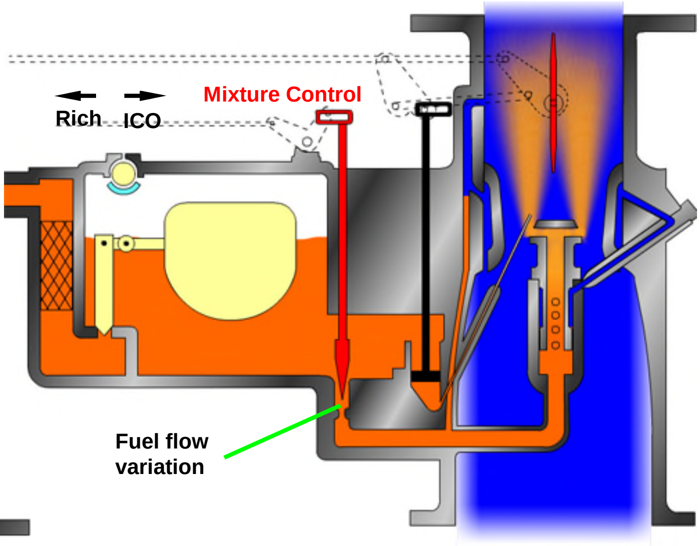
a) Temperature of combustion is at its maximum, and
b) Mixture distribution problems related to the inertia differences of the air and fuel molecules.

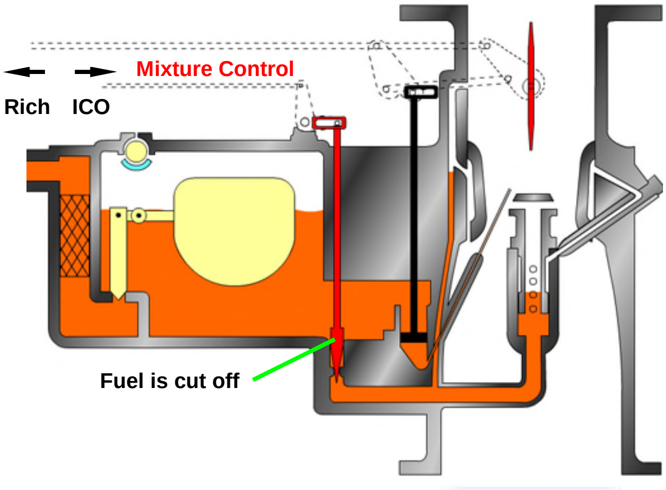
Due to different engine designs, some cylinders may get a weaker mixture. This causes uneven temperatures, which will decrease engine performance and power. A slightly richer mixture improves engine power by keeping the mass of the combustion gases closer to optimum.

Controlling the mixture

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

The mixture control can vary mixture strength between rich and lean, to suit atmospheric conditions and different power settings.





Idle cut-off (ICO)

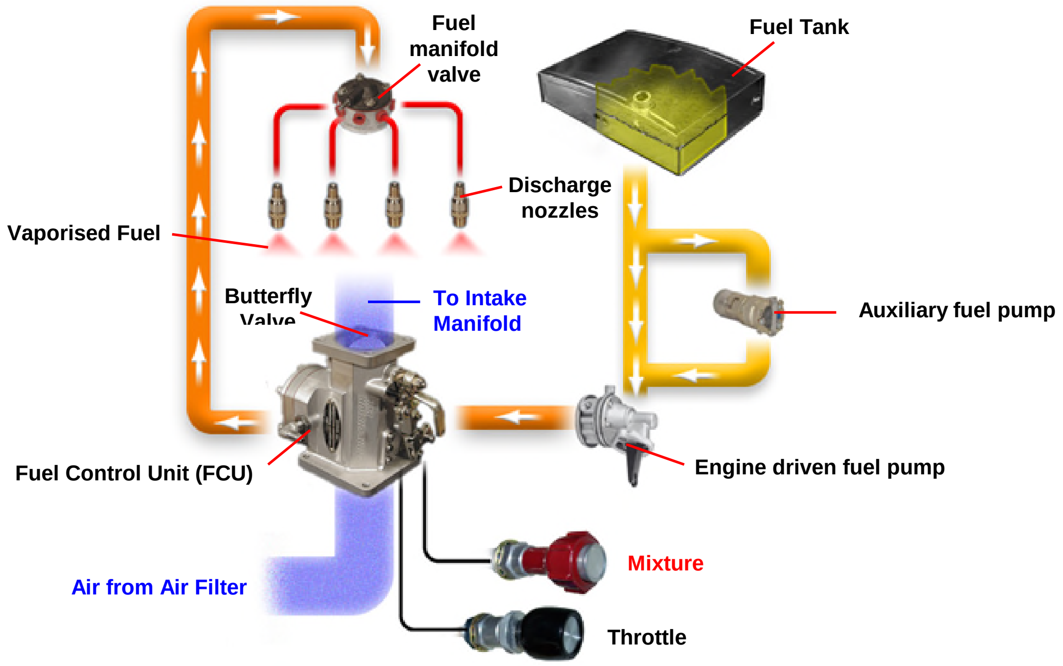
Selecting idle cut -off is the general method used for shutting down the engine. The mixture lever is taken to the position where the mixture needle allows no fuel to enter the venturi, and therefore starves the engine of fuel.

Fuel Injection

A fuel injection system provides the same general functions for an engine as the carburettor. It does this by using a more complex fuel control unit and pump. It measures the amount of air passing a throttle valve, and then delivers the exact amount of fuel into the air near the inlet valve port.

Compared to a carburettor where fuel is ingested by the venturi effect, a fuel injection system injects fuel either directly into the cylinders, or alternatively, inside the intake manifold (just before the intake valves) by an engine driven fuel pump.

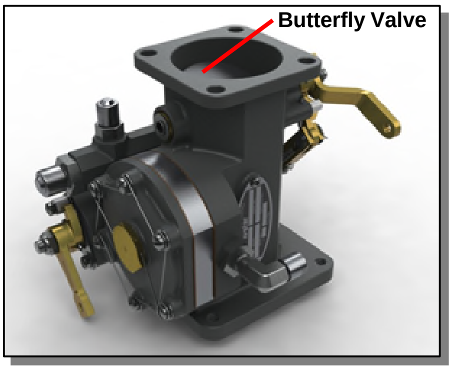
The fuel injected system is also supplied with an alternate air source, in case the primary air source becomes obstructed. The alternate air source is operated automatically and may have a manual back up system.



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.

Like the carburettor, the fuel control unit (FCU) is also equipped with a butterfly valve which is controlled by the pilot by means off the throttle lever. The butterfly valve controls the amount of air to the cylinders.



The fuel control unit, as the name suggests, measures the incoming air along with the mixture setting chosen by the pilot, and directs the pressurised fuel to the "Fuel Manifold Valve".

From the Fuel Manifold Valve, fuel is injected into each cylinder, or intake manifold, via the Fuel Discharge Nozzles.

Carburettor vs Fuel Injection

Advantages of Carburettor

- Reliable
- Simple construction

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

Disadvantage off 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.

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

Mixture during the various stages of flight

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.

Climb

MIXTURE FULL RICH to assist cooling and to maximise the availability of anti - detonation additives in the fuel.

Cruise

At a constant ALTITUDE and a constant power setting, lean the mixture to LEAN BEST POWER.

Descent

MIXTURE FULL RICH (procedure) to reduce the risk of engine damage should a rapid power increase be necessary.

Consequences of Incorrect Air/Fuel Ratio

Too lean

A mixture, which 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 white ash deposits in the exhaust pipes.

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.

Risk of Backfiring

A lean mixture burns quite slowly. An extreme case is 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.

Too rich

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

Risk of After firing

An excessively rich mixture can result in unburnt fuel being deposited in the exhaust system. As oxygen becomes available this mix 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.

Induction System Icing

Introduction

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.

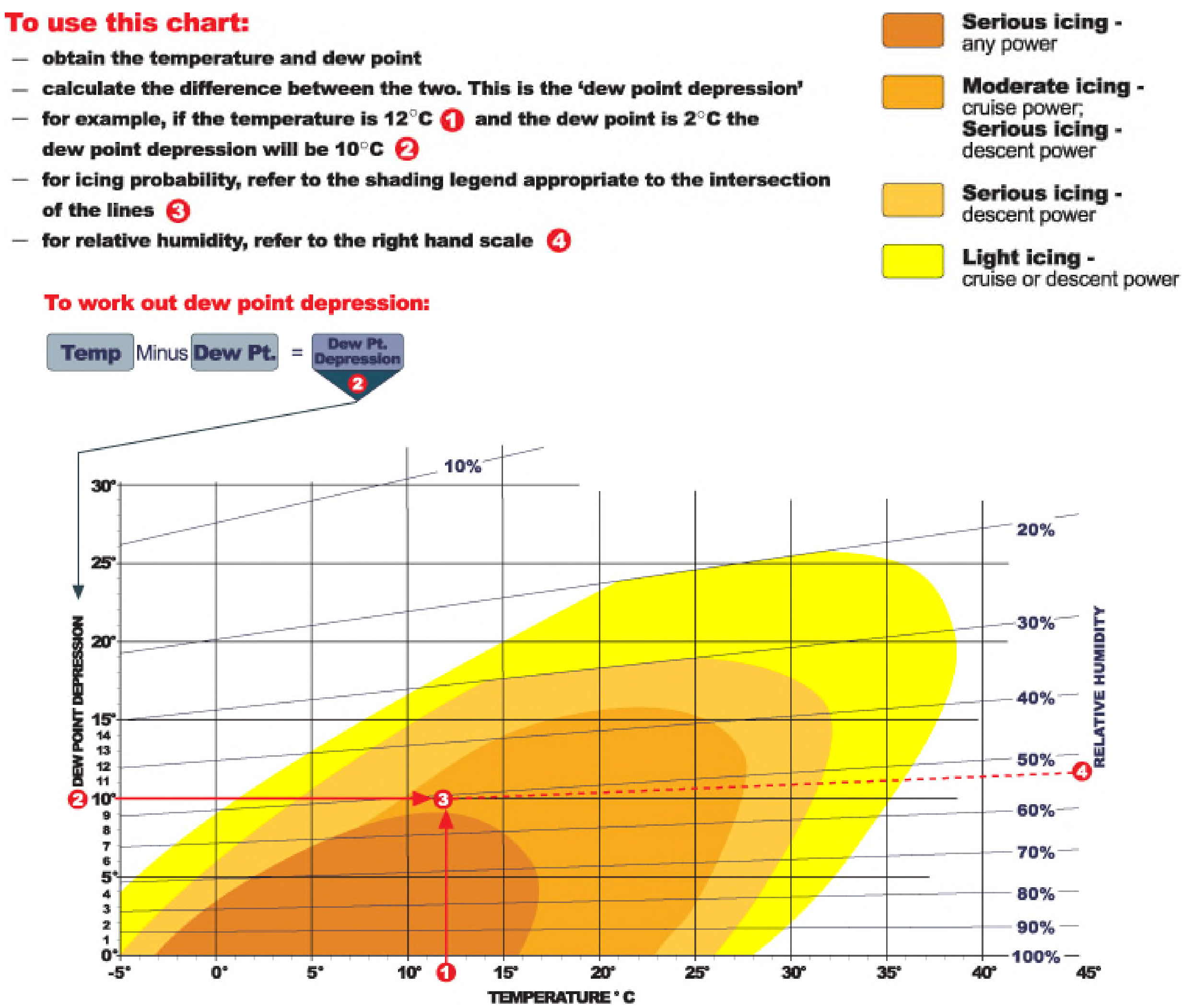
Induction icing is often the cause of engine failure which leads to forced landings. Close monitoring of engine instruments and quick corrective measures are the keys to coping with this threat.

For icing to occur two conditions must exist:

1. water must be present
2. localised air temperature must be below 0°

The chart below illustrates the risk of icing.

Carburettor Icing – Probability Chart



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 which can affect the carburettor, are known as:

- Impact Icing
- Fuel Ice, and
- Throttle ice

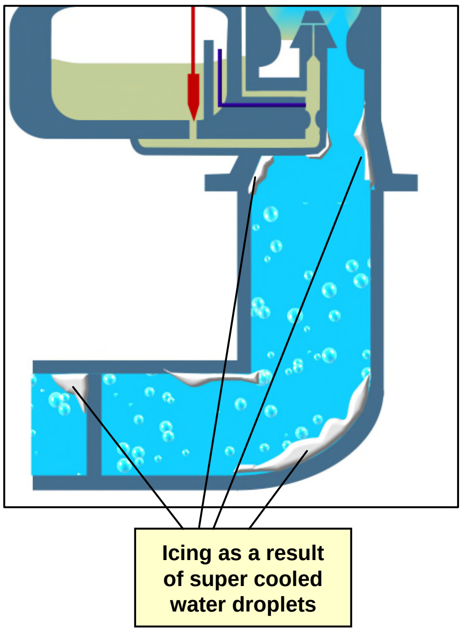
Impact Icing

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

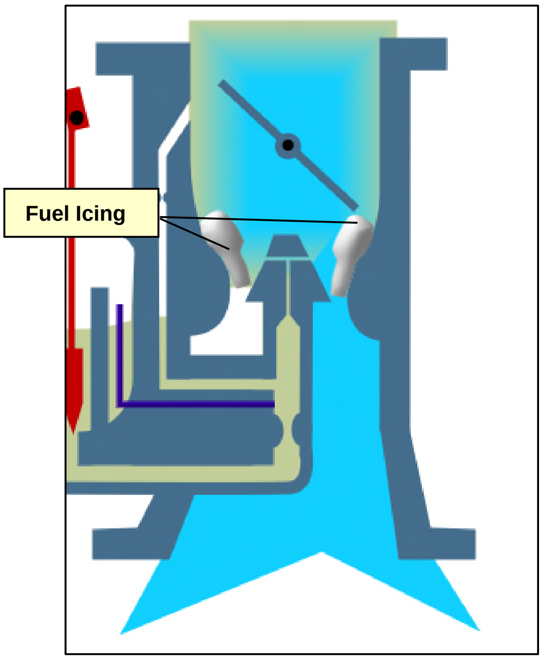
This type of icing will occur when super-cooled water droplets, in the intake air, form ice as they come into contact with the surface of the air inlet scoop or filter.

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 themselves 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.



Fuel Icing (Fuel Vaporisation Icing)



Carburettor ice also forms during the vaporization of the fuel, downstream of the jet 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.

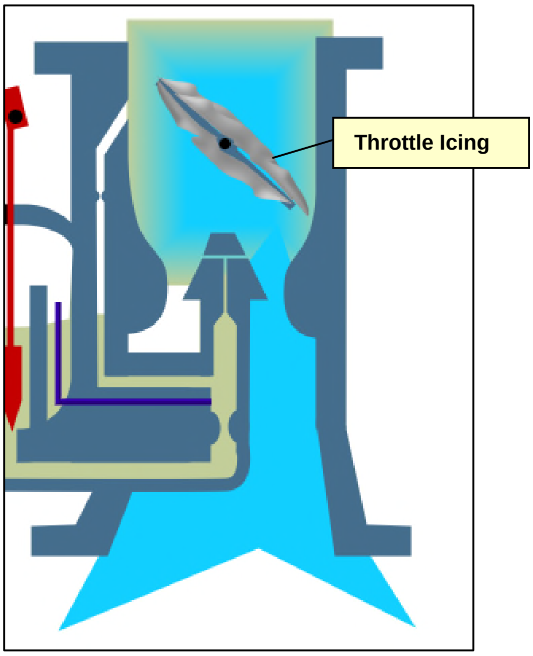
Fuel ice can even occur in temperatures of between 20º and 30ºC if the relative humidity is around 50% or more.

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

Throttle Icing

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

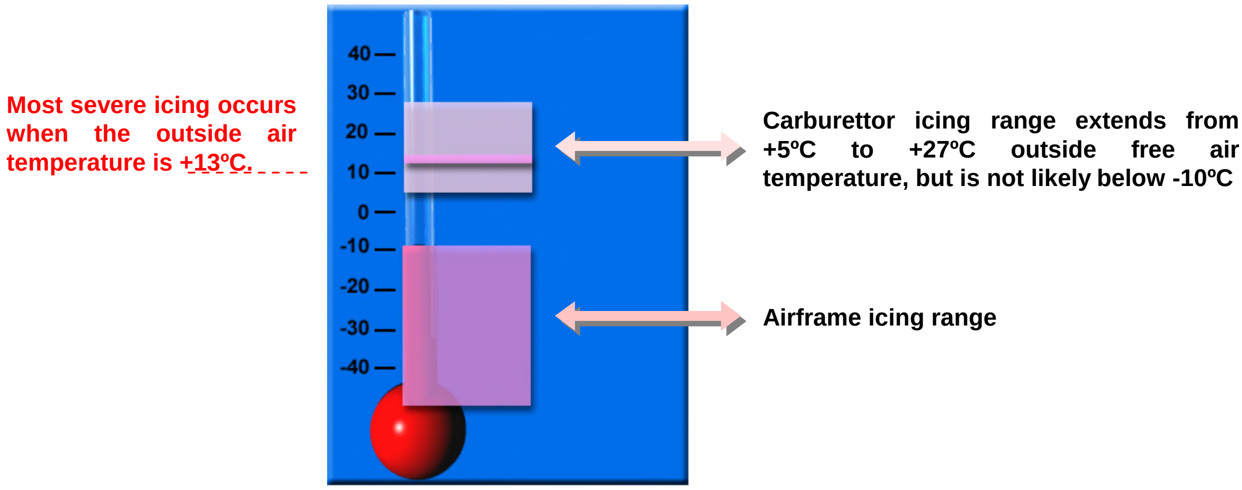
If sufficient moisture is present, icing can occur. Ice may form in the venturi, on or around the butterfly. *Visible moisture is not necessary for throttle icing*.



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.

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 humidity is high, icing can form easily.

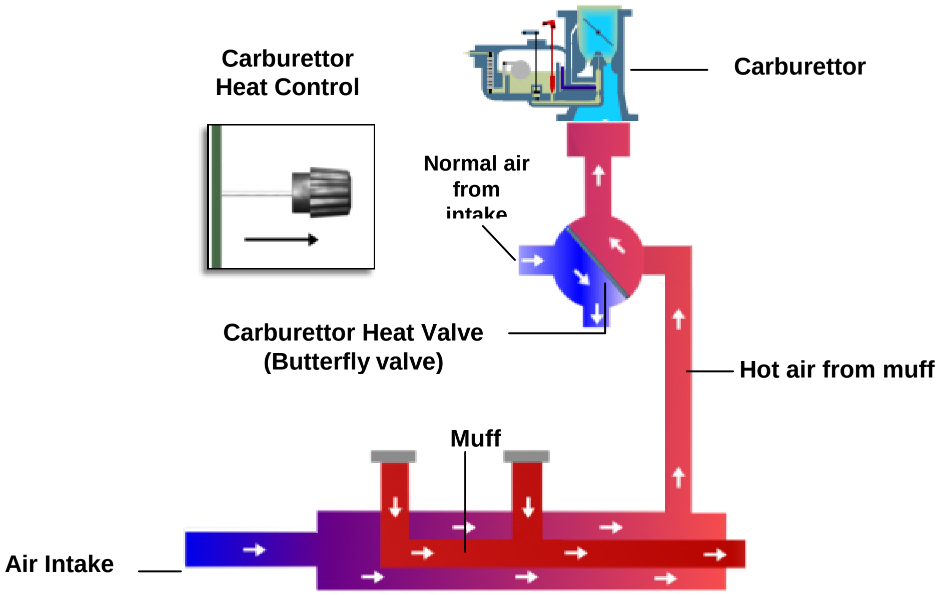


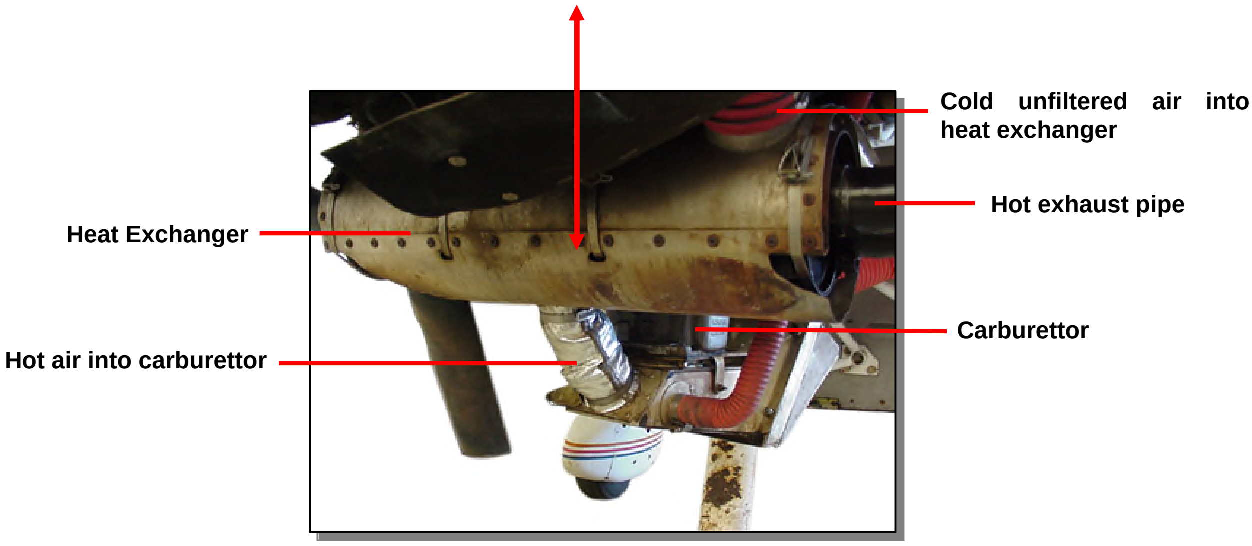
Typical symptoms of carburettor icing

- 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.

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.





The carburettor heat control is usually located near the throttle and should be applied <u>fully</u> 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.

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 fuel mixed with the airflow 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.

Precautions During Phases Of Flight

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 !

Taxying

If there is a risk of carburettor icing before take-off, carburettor heat should be applied; full on while taxying 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 sould be carried out on a hard surface.

Cruise

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 (MP), 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 MP, RPM or airspeed loss is noticed is simply to advance the throttle to correct the MP. If this cycle occurred two or three times, 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.

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.

Icing Suspected - Try Carburettor Heat

Carburettor Icing causes a decrease in MP, RPM and airspeed on an aircraft fitted with a fixed pitch propeller. An aircraft fitted with a CSU variable pitch propeller loses MP 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.

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 until the advanced stages of commercial flying and the aircraft must have a serviceable CAT gauge.

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.

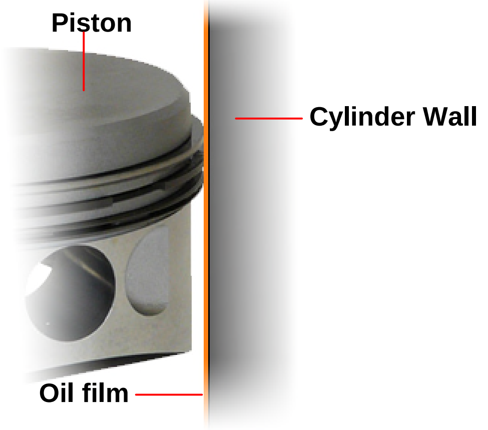
Lubrication and Cooling

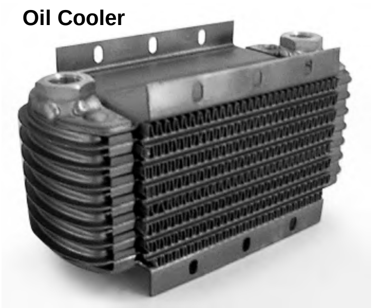
Function of Lubricating Oils

The engines oil system has two very important roles in the operation of the engine, namely lubrication of the moving parts, and aiding the cooling of the engine by reducing friction and therefore some of the heat from the cylinders.

Lubrication

A film of oil is provided between the moving parts of an engine. This oil wets the surfaces, fills in the slightly irregular metal surfaces and keeps those surfaces apart. The movement is now between layers of the oil, which slide over each other with very little friction.





Cooling

The oil is in contact with the moving parts of an aircraft engine, and it absorbs much of the heat from the combustion process. This heated oil then flows through the system into the oil cooler (heat exchanger), where the heat is given up to the outside air passing through the core of the cooler.

Cleaning

During normal engine operations metal particles, carbon and water can enter the oil. The ability of oil to hold these contaminates until they can be trapped in the filter helps keep the inside of the engine clean.

Protection

When metal is allowed to remain uncovered in the presence of moisture or some of the chemicals that contaminate the air, rust or other surface corrosion will form. This is especially true of metals surfaces such as cylinder walls or crankshaft, which have been hardened by the process of nitriding. A thin film of oil covering these surfaces will prevent the oxygen reacting with the metal and forming corrosion.

Sealing and cushioning

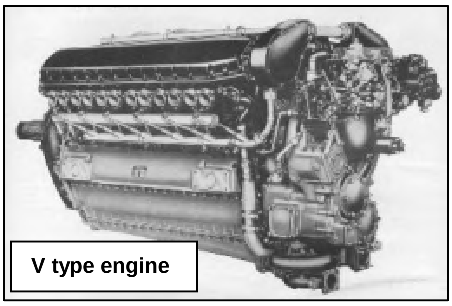
The viscous nature of oil, that is, its ability to wet the surface it contacts, makes oil a good sealing agent between the moving parts. The oil film on the cylinder walls and around the piston increases its ability to form a tight seal in the cylinder and the thin film of oil between the rocker arm and its bushing takes up much of the hammering shock from the valve action.

Lubrication System

A typical oil system includes the following components:

- sump or tank holding the unpressurised oil;
- oil pump circulating the oil

- pressure regulator controlling upper and lower limits of oil pressure
- filters removing foreign matter
- oil cooler shedding excess heat from the oil, and
- oil pressure and temperature gauges displaying system pressure and temperature.



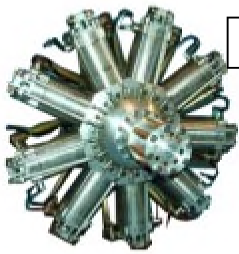
V type engine

There are two types of lubrication systems used in aircraft engines. Both systems concern themselves with the circulation of oil throughout the engine. The two systems are known as:

a. The wet sump system, holding the oil within the engine

b. The dry sump system, holding the oil external to the engine

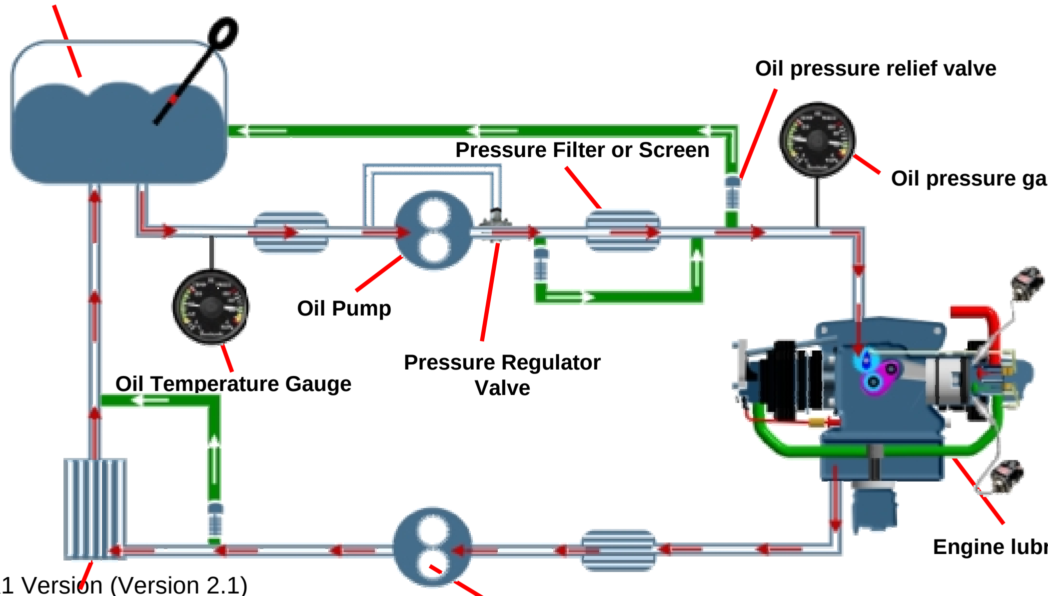
Horizontally opposed



Radial

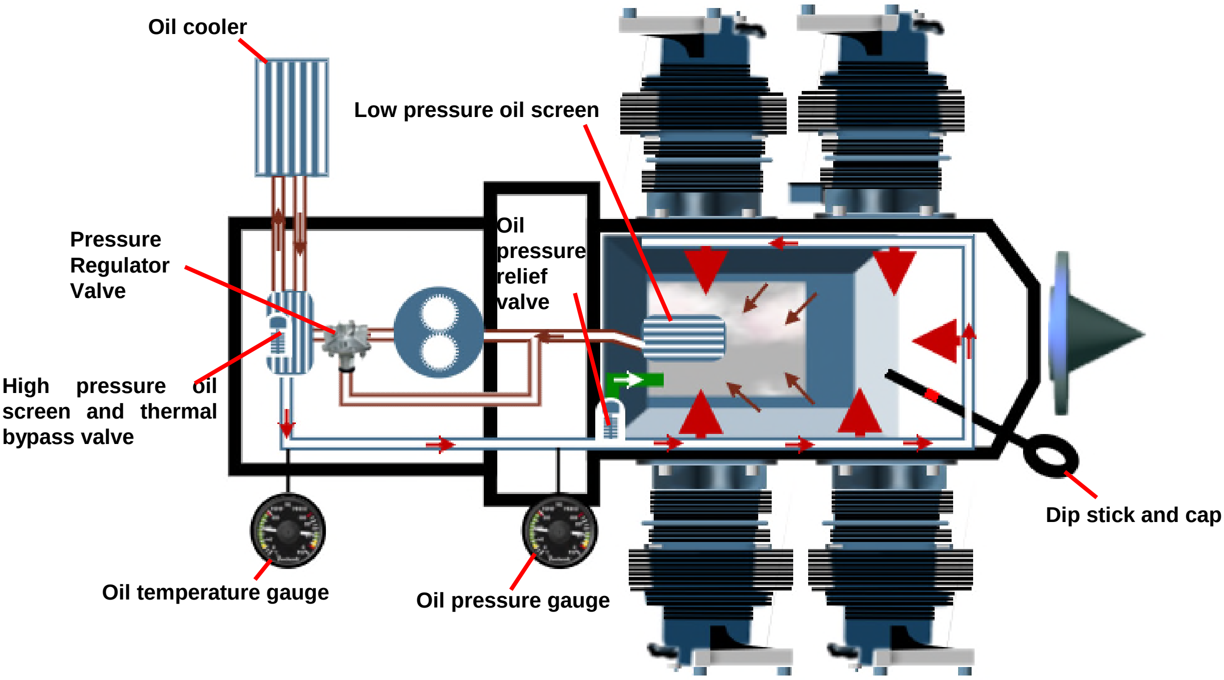
Dry sump lubrication system

In the dry sump lubrication system, oil is stored in a separate tank, circulated through the engine, and then returned to the oil storage tank via a scavenge pump. Generally the scavenge pump has a greater flow capacity than the pressure pump, to ensure that the external tank maintains sufficient supply for the pressure pump.



Wet sump lubrication system

In the wet sump system, oil is carried in the lower part of the crankcase called the sump (A). An engine driven pressure pump (B), draws oil from the sump, passes it through a pressure regulator valve, then a pressure filter or screen and bypass valve, (should the filter be blocked). Passing through an oil cooler, the oil continues past the oil pressure and temperature sensing ports before entering the internal lubrication galleries. Having lubricated the engine the oil returns to the sump.



Types of Aviation Oils

In aviation there are generally three types of engine oil used:

Straight Mineral Oil (Red Band)

Straight mineral oil has been used for many years as the chief lubricant for aircraft engines. It has one main limitation, that being its tendency to oxidise when it is exposed to elevated temperatures or when aerated.

Carbon deposits form in aircraft engines because of the normal combustion process and heat from the exhaust gases. This carbon and other metal particles provide the solids to form sludge, which can form in the oil at the relatively low temperatures of 150°F, or lower. The sludge forms in the sump from such combustion products as partly burned fuel, water vapour and lead compounds. These particles unite to form a loosely linked mass, and normally settle to the bottom. If disturbed, it can clog oil screens and filters starving the engine of oil; resulting in serious damage or engine failure.

Ashless Dispersant Oil

By far the most important oil is use today is Ashless Dispersant, or AD oil. It does not have the carbon-forming characteristics of straight mineral oil, nor does it form ash deposits or sludge as the straight mineral oil did. Lycoming, Continental, Pratt and Whitney, and Franklin approve AD oil for use in their engines, and is the only oil used by the military services for their piston engine aircraft.

Ashless-dispersant oil does not have any of the ash-forming additives, but uses additives of the dispersant type, which, instead of allowing the sludge-forming materials to join together, causes them to repel each other and stay in suspension until they can be picked up by the filters. It has been argued that these contaminants, held in suspension, will act as liquid hones and accelerate the wear of the engine parts, but this has proven untrue.

It is interesting to note that most engine manufacturers recommend that new engines be operated on straight mineral oil (Red Band) for the first fifty hours, or at least until oil consumption stabilizes, and then switch to AD oil. The reason for this, is that AD oil has so much better lubricating characteristics, that it will not allow enough wear to properly seat the piston rings with the cylinder walls.

Synthetic Oil

The higher operating temperatures of modern reciprocating engines, and the lower temperature environment in which turbine aircraft operate, have in the past few years caused synthetic oil to be produced which is proving superior to mineral oils for lubrication.

The wear characteristics of synthetic oil appear to be about the same as those of ashless dispersant oil and superior to straight mineral oil. Synthetic oil is not in common use in modern piston engines. It offers few advantages over AD oil and costs significantly more.

Compatibility of Oils

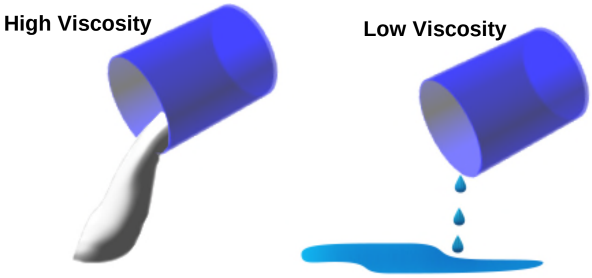
Contrary to popular opinion, oils within their basic categories are compatible. All straight mineral oils are compatible with each other, and it is extremely doubtful if mixing several brands of oil would compromise engine performance, wear or cleanliness.

All ashless dispersant mineral oils meeting aviation specifications are compatible with each other, and one brand may be added to an engine operating on another brand without compromising the overall cleanliness of the engine. Ashless dispersant oils are also compatible with straight mineral oil. The airlines proved this while converting to the ashless dispersant type. In the transition, straight mineral oil and ashless dispersant oil were mixed in various proportions, and it was found that there were no adverse side effects other than a reduction in the degree of the advantages offered by total AD oil.

At the present time, because of a lack of data, it is not advisable to add synthetic oil to engines operating on straight mineral oil or on ashless dispersant oil. Before changing from either of the mineral oils to synthetic, be sure to follow the detail the procedures for flushing and draining established by the synthetic oil manufacturer.

Viscosity

The viscosity, or fluid friction, of an engine oil is one of its more important ratings, The clearance between the moving parts determines the viscosity of the oil required to prevent this film breaking away and allowing the metal-to-metal contact that causes wear.



A rather elaborate laboratory instrument known as a Saybolt Universal Viscometer is used to measure the oil. The number of seconds required for 60 cubic centimetres of the oil to flow through an extremely accurately calibrated orifice, at a specified temperature, is known as the S.S.U. or Saybolt Second Universal viscosity.

The viscosity of any liquid is its resistance to flow. A fluid with a high viscosity will be thick and will not flow easily, and a fluid with a low viscosity will be thin and will flow easily.

Viscosity Index

This is the temperature range a fluid can be heated to before it will change its viscosity.

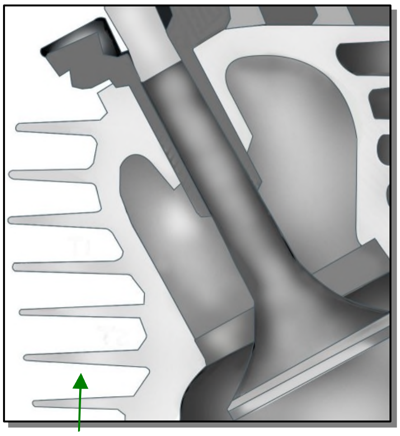
Burning Oil

An old engine, an engine not properly maintained or a damaged engine may burn some lubricating oil. Either the oil can find it's way into the combustion chamber or the combustion gases push passed the piston rings and burns the oil on the cylinder walls. Burning oil produces a rich blue smoke. This smoke is a good indication of a worn or damaged engine and if not corrected, will lead to poor performance or possible engine failure.

Air Cooling

Cylinder Cooling Fins

Most modern light aircraft engines are air cooled by exposing the cylinders and their cooling fins to the airflow. The fins increase the exposed surface area to allow for better cooling.



Cylinder Cooling Fins

Cooling Fins

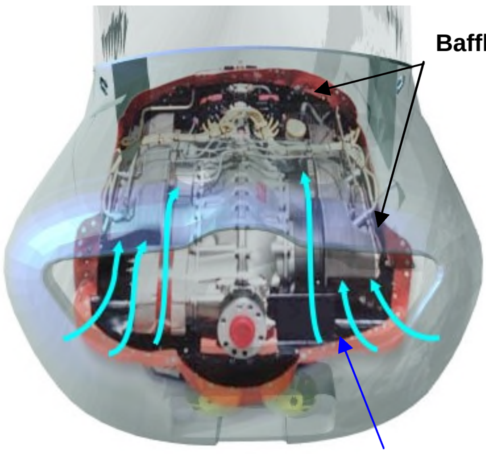
Cylinder heat is conducted through walls into the cylinder fins which increase the surface area and thus rate of heat dissipation by radiation to the atmosphere is increased. Broken fins induce local hot spots.

Cowlings, Baffles and Deflectors

As the airflow passes around a cylinder it may become turbulent and break away in such a manner that uneven cooling occurs, forming local, poorly cooled hot spots.

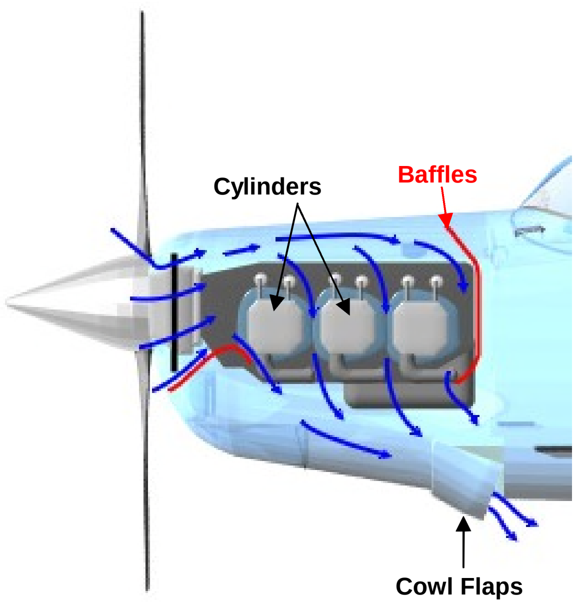
To avoid uneven cooling, cowling ducts at the front of the engine capture air from the high-pressure area behind the propeller and baffles distribute it as evenly and close as possible around and through the cylinder cooling fins. After cooling the engine, the air flows out

Baffles



Cowling Ducts

of cowl openings at the bottom rear of the engine compartment.



Cowl Flaps

Some aircraft have movable cooling cowl flaps that can be operated (electrically or manually) from the cockpit, giving the pilot more control over the cooling of the engine.

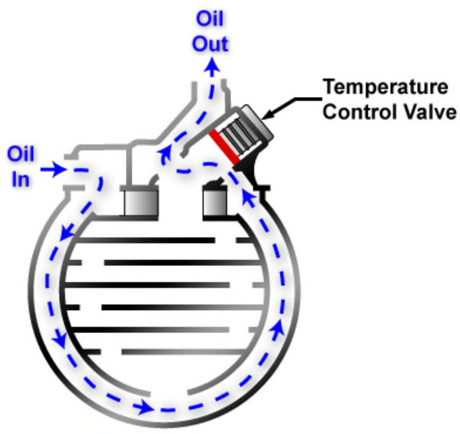
Open cowl flaps permit more air to escape from the engine compartment, causing an increased airflow over and around the engine. By closing the cowl flaps, the exit area is reduced, which effectively decreases the amount of air that can circulate over the cylinder fins. Thus, a constant temperature over the cylinders may be maintained across a wide range of engine operations.

Cowl flaps are normally open for take-off, partially open or closed during the climb and the cruise, and closed during a power-off descent. Cowl flaps should be open when taxiing, to help dissipate the engine heat.

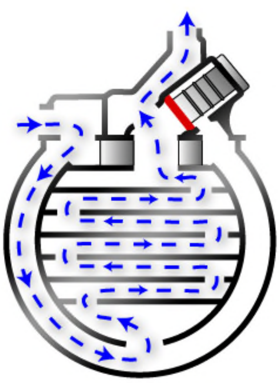
Oil Cooling

Oil is used as a cooling medium in the engine. As the oil reaches the oil cooler, it has a high temperature, and therefore the viscosity is low. In order to return the desired characteristics to the oil before recycling, it is cooled.

If the oil gets too hot then it will fail as a lubricant and, as a consequence, the engine will also fail. To prevent the oil temperature becoming too high, an oil cooler is introduced into the system. The oil cooler consists of a matrix block which forces the oil into a thin film as it passes through it. The cooler matrix is exposed to the flow of cold slipstream air which is directed through the cowlings.



When the oil is cold, it flows around the core of the cooler



When the oil is hot, the temperature control valve shuts off the passage in the shell of the cooler, and the oil must pass through the core, where it transfers its heat to the air passing through the cooler

Some engines have thermostat controls fitted to the oil cooler, these help maintain a more even oil temperature over a variety of engine power settings.

Oil System Common Faults

Pre-Start :

1. Oil leak from engine area.
   - Report to maintenance.
2. Oil level low.
   - Top-up
   - Use correct type of oil.

On Ground :

1. Oil pressure does not rise within 30 seconds of engine start or drops to zero at any time.
   - Immediate shutdown.
2. Oil temperature too cold for engine run-up.
   - Idle at 1500 RPM.
3. Oil temperature or pressure too high (above normal operating limits).
   - Reduce power and taxi back for maintenance.

During Flight :

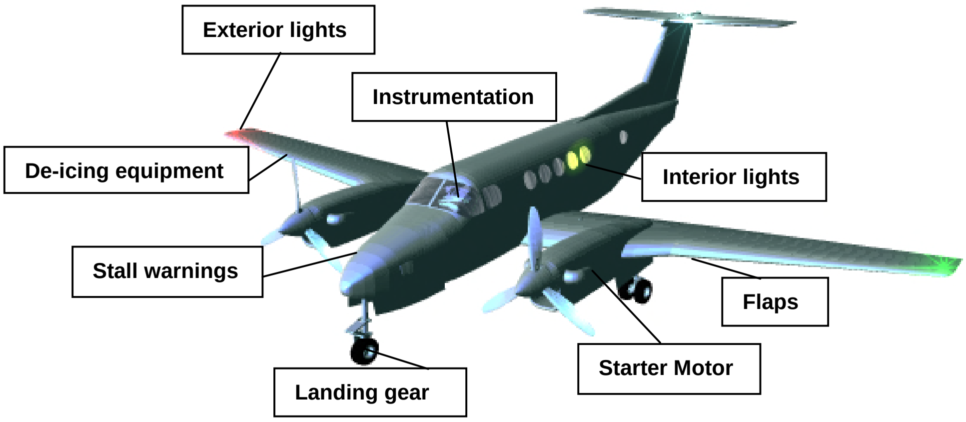
1. High oil temperature.
   - Reduce power.
   - Reduce rate of climb.
   - Mixture rich.
   - If temperature does not return to normal, return to airfield. Be aware of any suitable landing areas
2. High oil pressure.
   - Reduce power. If pressure remains high, return to airfield.
3. Low oil pressure
   - Reduce power to minimum to maintain level flight.
   - Turn towards nearest suitable airfield.
   - Be aware of any suitable landing area.
   - Consider position, terrain, radio for assistance, review mayday call. Be prepared for forced landing.
4. Fluctuating oil pressure.
   - Reduce power. Use procedure as for low oil pressure.

N.B. If a precautionary forced landing is decided, your judgement and use of available power must be good; a 'go-round' should not be considered an option.

The Electrical System

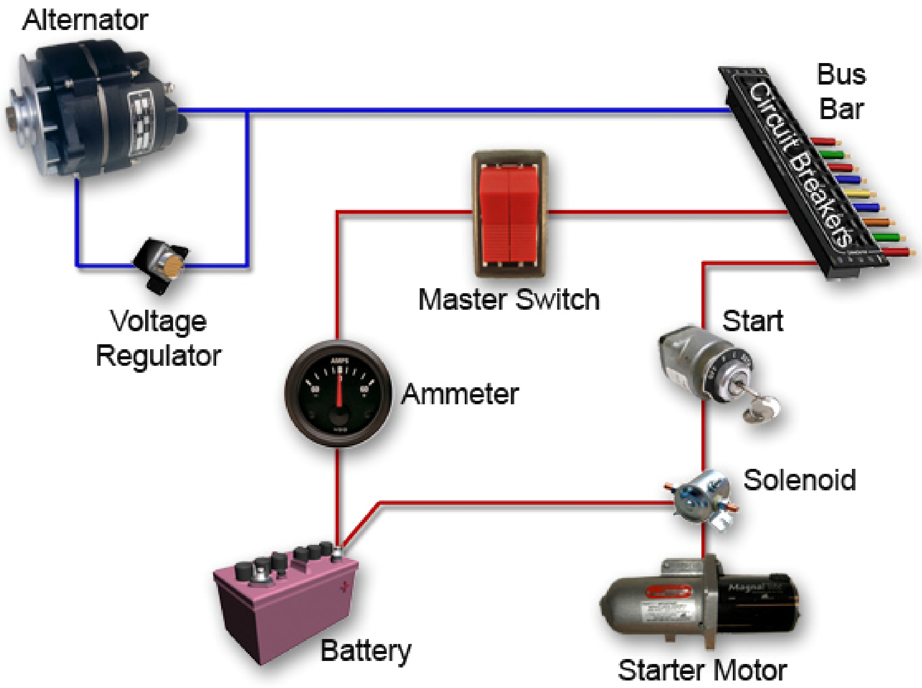
Introduction

The aircraft is required to have an electrical system to operate a vast array of equipment, this equipment includes but is not restricted to:



A general aircraft electrical system includes the following components:

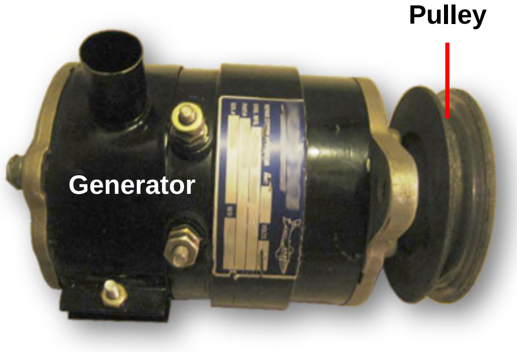
- Battery
- Alternator/Generator
- Voltage Regulator
- Bus Bar
- Ammeter
- Starter Motor
- Circuit Breakers
- Master switch



- Normally, aircraft power is from either an alternator or generator which are driven by the engine.
- The electrical power is either 28 or 14 volts DC and distributed to the various systems via a bus bar.
- Circuit breakers are provided to protect the electrical system in the event of a malfunction.
- The Pilot uses the ammeter to monitor the electrical system to see whether it is operating correctly or not.
- Before and during engine start, when the alternator/generator is not able to provide any current, the storage battery provides the necessary current. After engine start, the alternator/generator charges the battery.
- The ignition system is not part of the electrical system, as it is a self contained engine driven system.
- The aircraft's structure forms the earth return path for the electrical current.

Electrical System Components

The Generator



The purpose of the generator is to change mechanical energy into electrical energy which will supply power to operate all the electrical devices and keep the battery fully charged.

A generator produces **direct current (DC)**

Disadvantages of a Generator

- Heavy construction
- Insufficient electrical current at low engine rpm
- Less efficient

Generators are rarely used now in modern aircraft.

Alternator

An alternator can be considered as an AC generator. It produces **alternating current (AC)**. Most small aircraft require electricity as direct current, so the current must then be rectified to DC by the use of diodes.

Unlike the generator, the alternator uses an engine driven magnet that rotates between coils (stator) to produce an electrical current. Before start, the magnet rotor of the alternator <u>needs an exciter voltage from the battery</u> to produce the necessary magnetic field.

Advantages of an Alternator

- Produces consistent and sufficient power through the whole engine rpm range
- Simple and light construction
- Cheaper to maintain
- Less prone to overload when loads are heavy

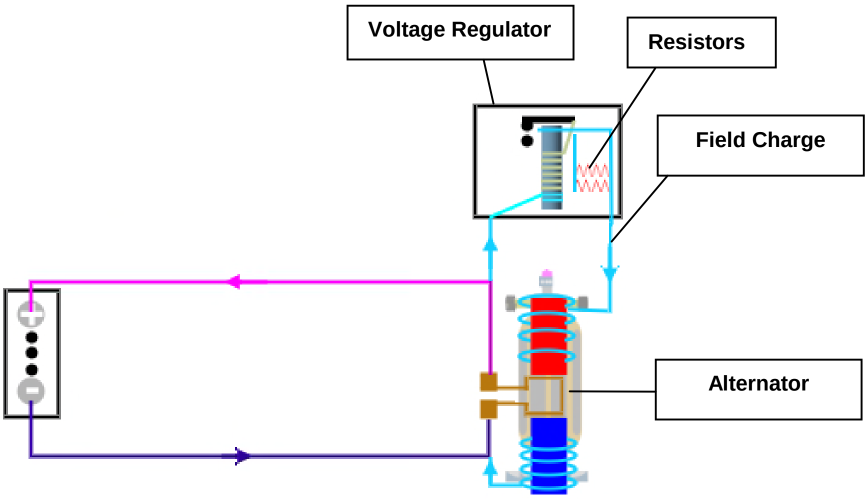
Disadvantages of an Alternator

- An Alternator needs an initial exciter voltage from the battery to produce a magnetic field, which in turn is needed to produce an electrical output.

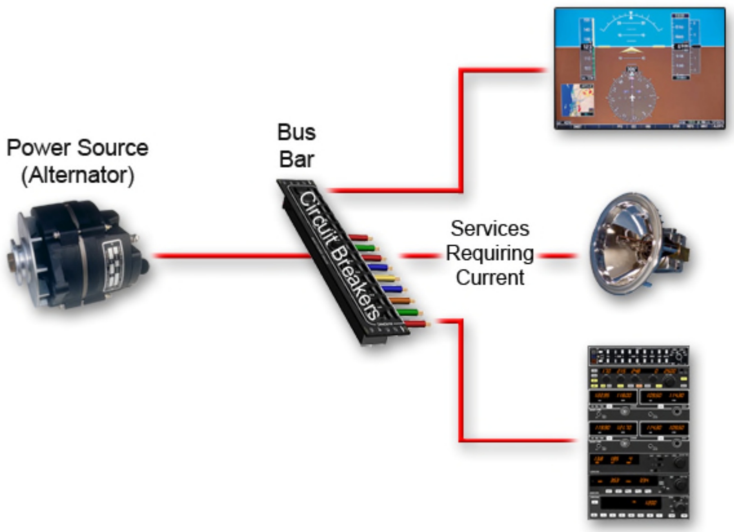
Voltage Regulator

A voltage regulator is simply a regulator within the electrical circuit which ensures that the alternator provides a constant supply to the battery and aircraft electrical demand throughout the engine rpm range. By providing a constant charge, the battery and other accessories are protected from damage.

The voltage regulator regulates this charge by controlling the amount of current in the field charge (the windings) of the alternator. If the current in the field charge is high, the alternator will produce more charge, while if it is low, the alternator will produce less charge. By controlling the amount of current in the field charge, the output of the alternator can be controlled.



Bus Bar



The power which has been generated, is passed on to the various electrical consuming items by means of **bus bars**. The bus bar is the means by which the power carried in a single wire can be sub-divided into many wires for distribution to the various circuits. The bus bar is the main component in the distribution system.

Bus bars are often classified in accordance to their importance, and a typical aircraft system could have the following bus bars:

- Vital services bus bar
- Essential services bus bar
- Main bus bar
- Synchronizing bus bar (AC only)

The Battery

During normal aircraft operation, electrical power is supplied by the alternator or generator.

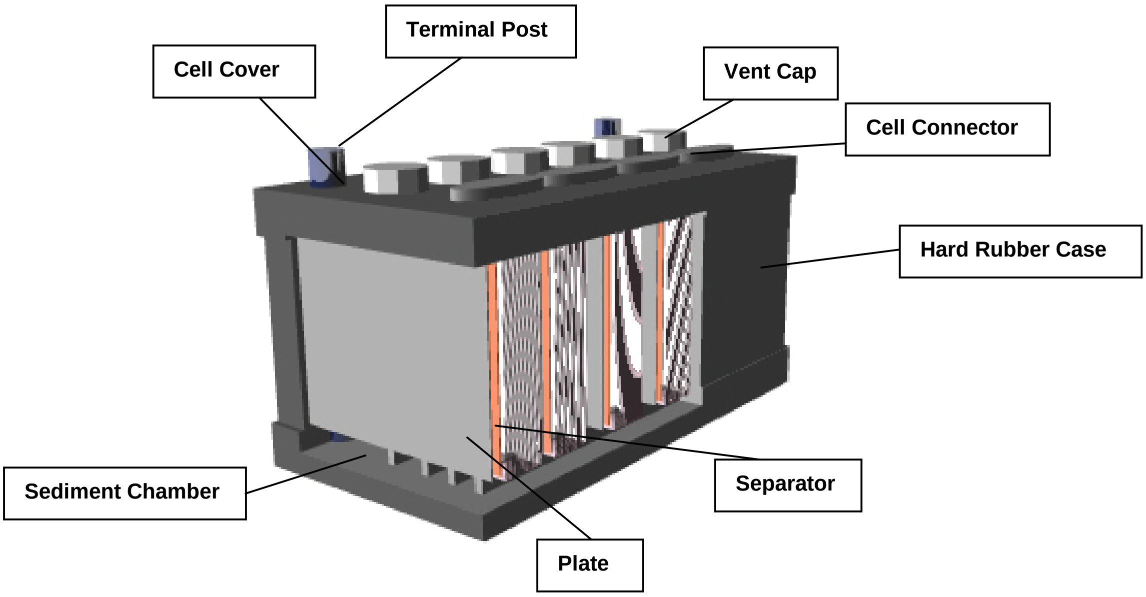
However, an aircraft battery will be required when power is needed to:

- start the engines or
- cope with the failure of the generating system, or
- energise alternator field windings

The most popular types in use are the **lead-acid** and the **nickel cadmium** batteries. The light aircraft electrical system normally uses a 12 volt and larger aircraft use 24 volt lead-acid batteries; more complex aircraft would use a nickel cadmium battery. These two types of batteries are very different and cannot be interchanged.

The battery is continually charged by the generator/alternator. The charging rate is controlled by a voltage regulator, which stabilises output from the generator/alternator. The generator/alternator voltage output is usually slightly higher than the battery voltage. For example, a 12v-battery system would be fed by a generator/alternator system of approximately 14v. This voltage difference keeps the battery charged.

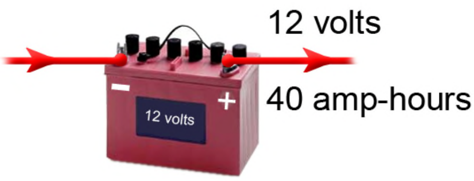
A lead-acid battery creates an electrical current (amps) by a chemical reaction between lead plates immersed in weak sulphuric acid that acts as an electrolyte. The battery is housed in its own case in order to prevent corrosion from any spillage of the acid.



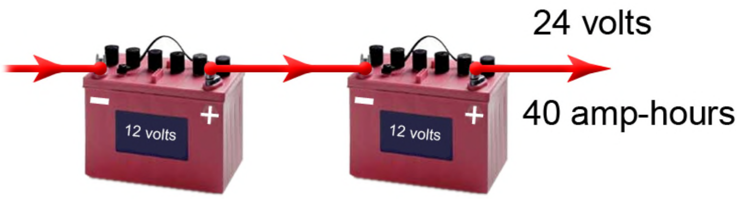
Batteries are rated in ampere-hours, which indicate the number of amps the battery can deliver over a period of hours.

- A 45 ampere-hour battery for example, can deliver 1 amp for 45 hours or
- 5 amps for 9 hours.

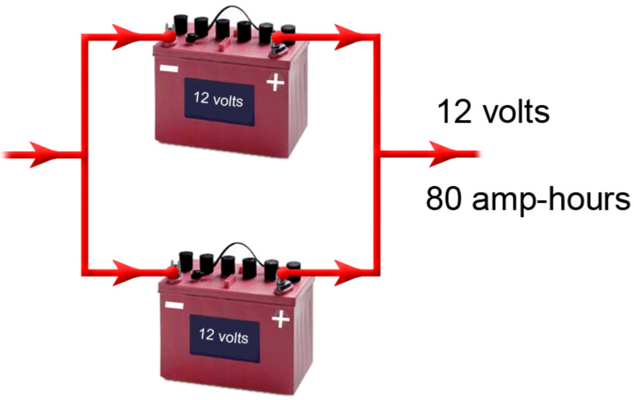
Batteries connected in series will increase the total voltage, while batteries connected in parallel, will increase the total ampere-hours.



Single Battery



Two batteries in series



Two batteries in parallel

Battery charge condition can be determined by a **hydrometer**. This measures the specific gravity (SG) of the electrolyte.

Specific gravity of a fluid is the ratio of the density of a fluid relative to that of water

Battery safety precautions:

Before engine start, ensure all ancillary equipment is switched off as the large voltage fluctuations during starter engagement, can damage sensitive electronic equipment. Ensure the battery is being charged before switching on all of the electrical equipment. The same applies when shutting down the engine, first switch off all electrical equipment.

Charging batteries emit a mixture of hydrogen and oxygen. They are highly inflammable and will explode if a flame is brought too close to them. Lighted matches and torches should be kept away from charging batteries.

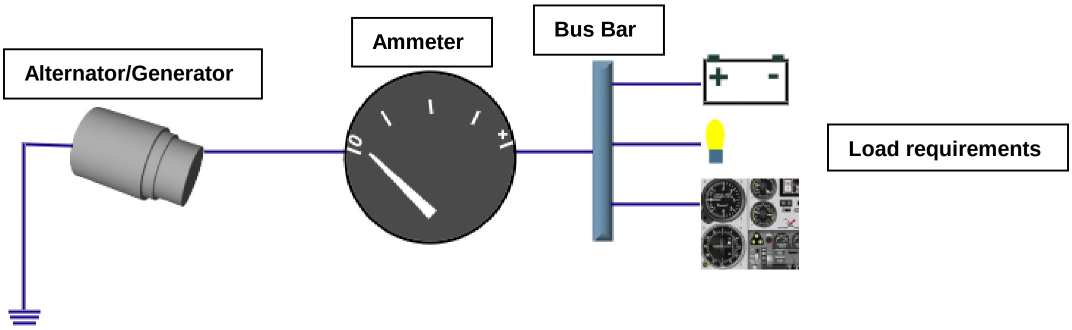
Ammeter

The ammeter is the instrument which measures current flow into or out of the battery. Some aircraft also employ a voltmeter to measure the electro motive force available to deliver the current. (1 volt is required to force 1 ampere of current to flow through a 1 ohm resistor).

There are two types of ammeter used to measure the current flow, they are the **Left-Zero** ammeter and the **Center-Zero** ammeter.

Left-Zero Ammeter

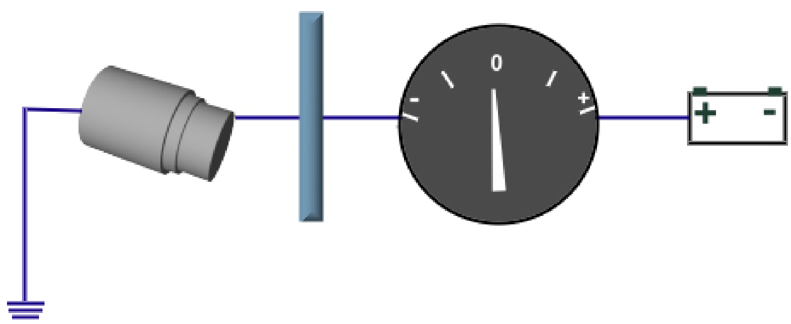
This ammeter measures only the output of the alternator or generator. It has a graduated scale starting at zero (on the left), with indications of increasing amperes toward the right. Because this ammeter shows alternator/generator output only, it can also be referred to as a load meter. It indicates what load is being required from the alternator/generator.



- If the battery switch is on, and the engine is not running the ammeter will show zero.
- If the engine is running and the alternator is off, the ammeter will show zero
- If the engine is running, and the alternator switch is on, then the ammeter will show the alternator output
- After starting, the battery will have depleted some of its charge, therefore the ammeter will initially show a relatively high charge rate
- Once the battery is charged, the ammeter should show just above zero if all other circuits are off, as these circuits are switched on the ammeter reading will increase

Center-Zero Ammeter

The center-zero ammeter measures the flow of current both into, and out of the battery. Current flowing into the battery is charge, and the needle will indicate right of centre (toward the +).Current flowing out of the battery is discharge, and the ammeter needle will indicate left of the centre 0, (toward the -). When there is no charge or discharge of the bettery, the needle will indicate 0 (centre).



- With the battery switch on, and the engine not running, the needle will indicate discharge (the battery is supplying power to any powered circuits).
- With the engine running and the alternator/generator providing adequate current, there will be a flow of charge to the battery (until it is fully charged), and the needle will indicate a charge, right of the centre.
- If the electrical circuits are absorbing more current than the alternator is capable of producing, the battery will provide current to asist with the demands, and the needle will indicate discharge (left of the centre point).

Voltmeter

Some aircraft also employ a voltmeter to measure the electro motive force available to deliver the current. (1 volt is required to force 1 ampere of current to flow through a 1 ohm resistor).

When the engine is not running, a voltmeter will indicate the voltage of the battery, i.e., a 12 volt battery will show 12 volt on the voltmeter.

The generator/alternator voltage output is usually slightly higher than the battery voltage. For example, a 12v-battery system would be fed by a generator/alternator system of approximately 13.8 - 14v. This voltage difference keeps the battery charged. This voltage will then be displayed by the voltmeter. For a 24V battery, 28V will usually be displayed on the voltmeter while the engine is running.

Master Switch

The master switch controls all the aircrafts electrical systems, except the ignition system ***(receives power from the engine driven magneto)***.

The master switch must be **ON**, for any electrical system to receive power, (If the aircraft has an electrical clock, it will draw a small of amount of power at all times).

The master switch must also be on, even if the engine is running for the battery to be charged. Once the engine has been shut down, the master switch must be switched off to prevent the battery from discharging via the services connected to it.

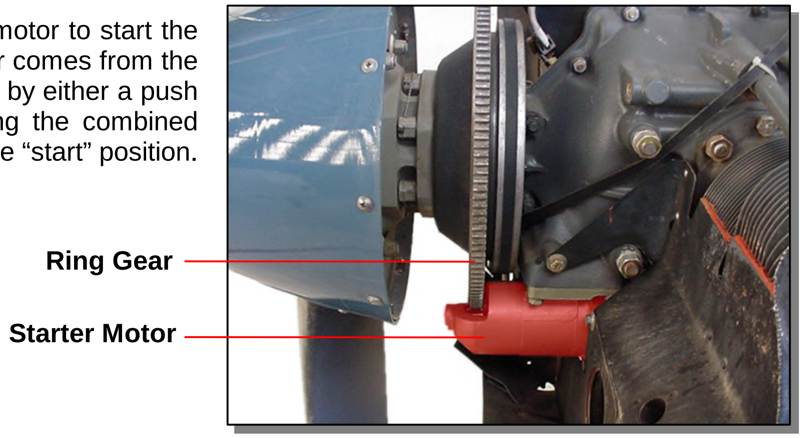
If the aircraft is fitted with an alternator, the master switch will consist of two "halves", :

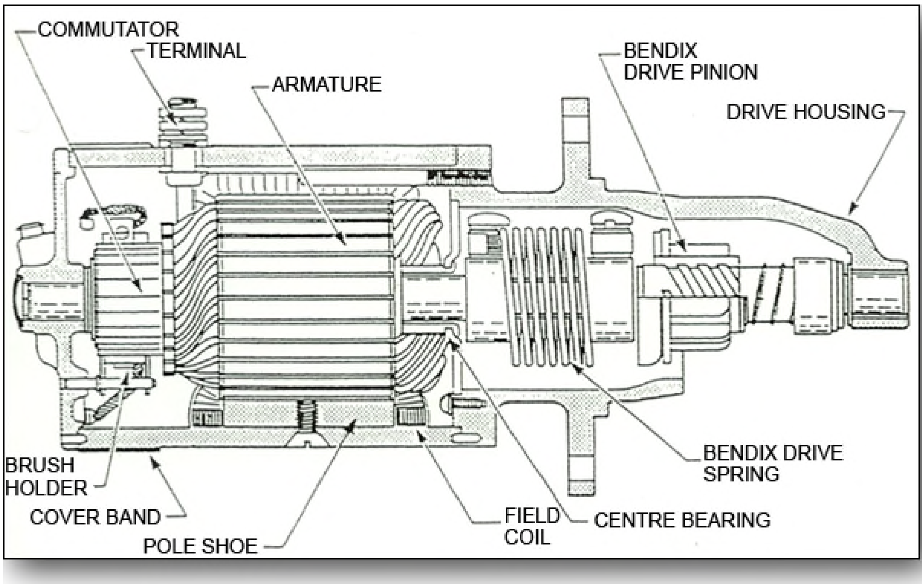
- One which connects the battery to the bus bar
- The other connects the alternator field to the bus bar, providing the alternator with battery power for the excitation of the field.

Both switches must be on for normal operation of the electrical circuit. Although the switches can be switched on separately, only the alternator switch can be switched off separately. If the battery switch is switched off, the alternator switch is automatically switched off as well.

Starter Motor

Modern aircraft uses a starter motor to start the engine. The starter motor power comes from the aircraft battery and is controlled by either a push button type switch or by turning the combined magneto/starter switch key to the “start” position.





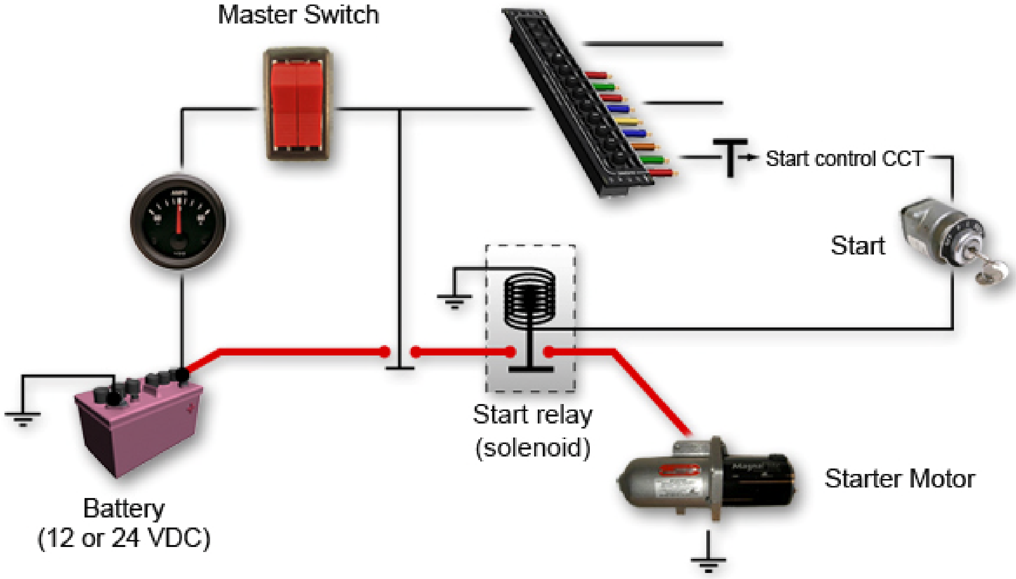
Schematic of the Starter Motor

Starting an engine causes high current to flow between the battery and starter motor, heavy duty wiring is therefore needed. For safety reasons, a solenoid relay is installed in the start circuit which is operated by the ignition switch, this avoids the use of heavy duty wiring through the cockpit.

Moving the ignition switch to “start”, causes a small current to energise the solenoid, creating an electromagnetic field which moves an iron core (heavy duty switch) , closing the heavy duty circuit.

The engine cannot be started unless the master switch is on. The high starting current is not seen on the ammeter because it takes a direct path through thick, low-resistance wires via the starter solenoid to the starter motor.

See diagram below:



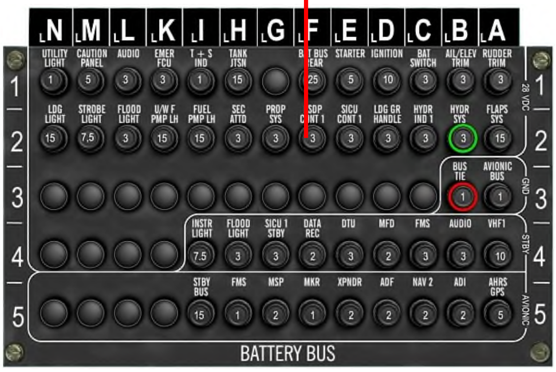
Fuses and circuit breakers

Fuses and circuit breakers are provided to protect electrical equipment from current overload, each will be marked to display the correct current rating.

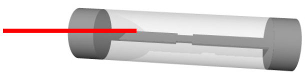
If there is current overload (or short circuit), a fuse wire will melt, or a circuit breaker will pop out, and break the circuit, preventing the flow of current. This action may prevent fires, and damage to expensive equipment.

If a circuit breaker "pops", and there is no obvious sign of distress (smell burning electrics, smoke etc.) it is normal practice to reset the circuit breaker. If it "pops" again however, an electrical malfunction should be assumed and the circuit breaker should not be reset.

Circuit breakers



Glass tubular fuse



When a blown fuse has been detected, it should be replaced with a fuse having the correct amperage. It is bad practice to replace a fuse of low amperage with one of greater amperage, (ie replace a 5 ampere fuse with a 15 ampere fuse), such action allows more current to flow through the circuit and reduces the protection function.

Fuses should not be replaced more than once, and spare fuses of the appropriate type and rating should be kept in the cockpit.

Overload switches

The overload switch is simply a "trip switch", which automatically switches off when an electrical overload is detected. The pilot resets the switch (to on), after a short waiting period (which allows the circuit to cool).

External Power

External power is often used whilst an aircraft is on the ground; it is usually applied for the following reasons:

- To conserve the aircraft battery
- Substitution for a flat battery
- Assistance in engine starting
- Aircraft maintenance and servicing

The external power source is often called a Ground Power Unit (GPU) and can be either mobile or fixed.

During external power operations, the aircraft battery is bypassed by means of a switch either inside the cockpit or externally at the external power receptacle. After start and external disconnection, the aircraft battery is introduced back into the electrical system.

Always consult the pilots operating handbook (POH) for the correct procedures in using external power.

Abnormal Electrical System Operation

Circuit Breaker pops out

- Wait about 90 seconds to cool off
- If no sign of fire or smoke, reset the circuit breaker
- Don't reset circuit breaker if it pops out for a second time

Ammeter indicates insufficient current from the alternator or alternator failure

- Switch off all non essential equipment
- Land as soon as possible

Note: If the alternator produces insufficient current, or no current at all, the battery is not being charged. The battery now supplies all of the required current to the various electrical equipment, until it runs flat.

Ammeter indicates excessive rate of charge

- Switch off the alternator as this could cause the battery to overheat and cause damage.
- Land as soon as possible

Note: Overcharging by the alternator is usually caused by a faulty voltage regulator. If fitted, an over-voltage sensor would automatically disconnect the alternator causing a red warning light to illuminate inside the cockpit.

Engine Instruments

Introduction

Engine instruments are a vital element in operating an aircraft engine in a controlled and safe manner. A pilot must have constant presentation of the engine condition in order to maintain aircraft performance parameters; in addition there is the necessity to operate the engine within the manufacturer's limits and tolerances.

Tachometer (RPM Indicator)

This instrument enables the pilot to select the required engine speed. On an engine fitted with a fixed pitch propeller this is the only power indicator available. An upper rpm limit is critical; to exceed this limit will harm the engine.

The Manifold Pressure Gauge

The manifold pressure gauge enables to the pilot to select and maintain the required manifold pressure in order to set the desired power output from the engine. It is a measure of the air pressure within the engine intake manifold and is influenced by throttle position and rpm settings. It is usually fitted to an aircraft that has a variable pitch propeller.

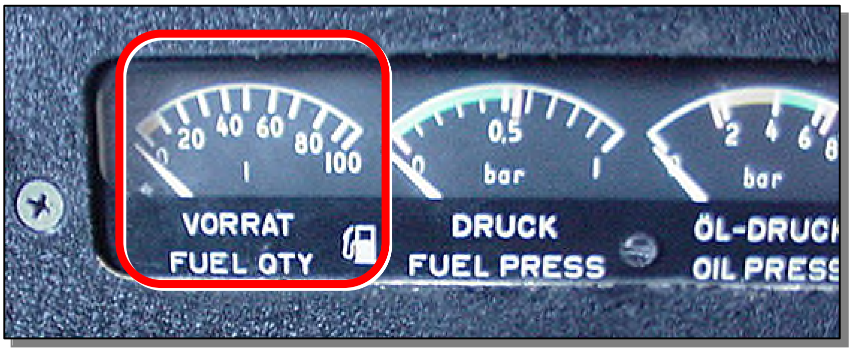
Fuel Pressure Gauge

The fuel pressure gauge has different purposes depending on the type of fuel system involved. These are:

- to indicate that the fuel pump (either engine or boost) is supplying fuel in sufficient quantity to the carburettor, or
- to indicate fuel pressure (fuel flow) at the discharge nozzles in a fuel injection system.

Fuel Quantity Gauge

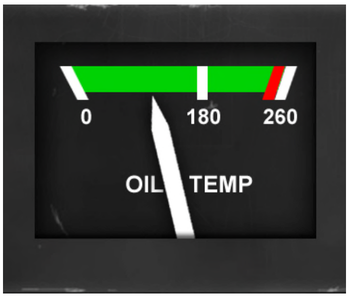
Provide the pilot with a continuous indication of the fuel tank quantities. Not considered to be entirely accurate at all times, a cross reference by visual checks is desirable before flight. Aircraft manoeuvring and attitude changes could create indicator errors.



Oil Pressure Gauge

An oil pressure gauge displays the regulated pressure output from the engine oil pump. Lack of indicated oil pressure is cause for concern; without lubrication an engine will soon fail. On initial engine start up, positive oil pressure must be displayed within 30 seconds, if not the engine must be shut down immediately. To enable proper lubrication of the engine, power settings are limited until a minimum oil temperature is reached; this ensures that the oil has reached an adequate viscosity level before high loads are placed on the engine.

Oil Temperature Gauge



For the oil to perform effective lubrication and cooling functions it needs to be within a prescribed temperature range, this gauge will indicate when those conditions exist. If the oil temperature is outside the prescribed limits proper lubrication will not be achieved.

Cylinder Head Temperature Gauge (CHT)

A CHT gauge indicates the temperature of the cylinder head; it is the best indicator of potential detonation occurrences. Operating on the thermocouple principle; a probe is embedded in the cylinder head fins and provides a constant reading of the engine operating temperature. While ever there is heat applied to the probe it will generate a current and thus it is not dependent on the aircraft electrical system.

Temperature changes within this mass of metal are not immediate and the gauge may lag in its indication.

Maximum and minimum temperatures are set for normal operations; to exceed these is likely to result in engine damage.

Exhaust Gas Temperature Gauge (EGT)

The EGT gauge operates with a probe, similar to the CHT, inserted in the exhaust pipe. It registers the temperature of the exhaust gases which are directly affected by the fuel air mixture ratio.

Carburettor Air Temp Gauge (CAT)

The carburettor air temperature gauge is useful in detecting potential engine icing conditions. Usually the face of the gauge is calibrated in degrees Celsius (ºC), with a yellow arc indicating the carburettor air temperatures at which icing may occur; this yellow arc ranges between   -15° C and + 5° C.

The temperature probe is usually located near the throttle valve as this is the area most prone to icing.

Flight Instruments

Flight instruments enable an airplane to be operated with maximum performance and enhanced safety, especially when flying long distances. Manufacturers provide the necessary instruments, but to use them effectively, pilots need to understand how they operate.

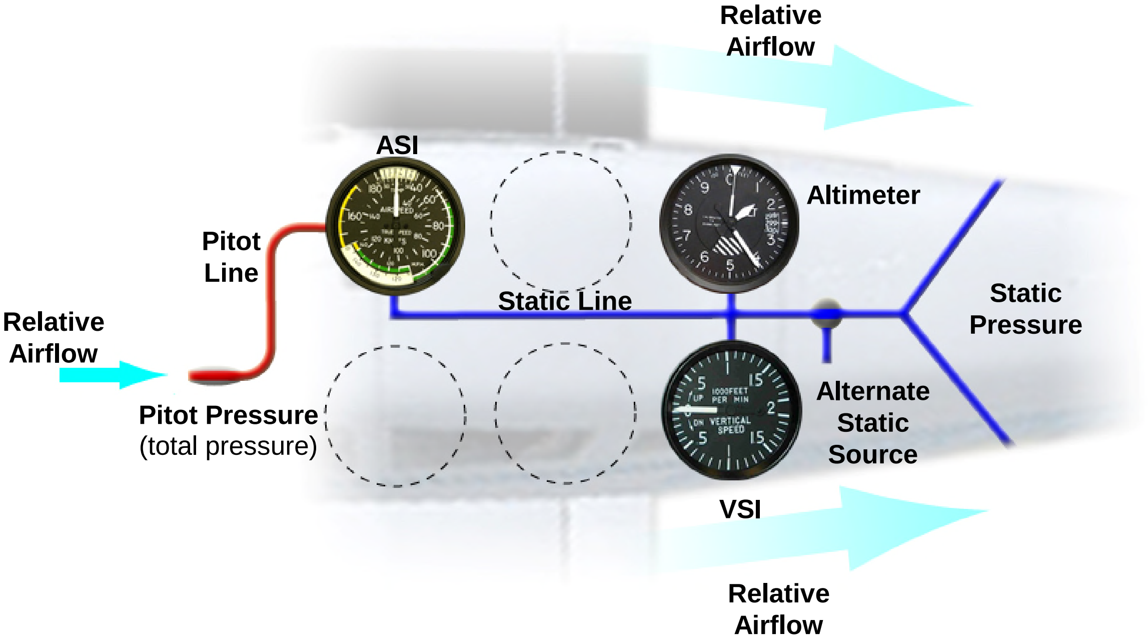
Pitot Static (Pressure) Instruments

The three pressure flight instruments that make use of the pitot and/or static pressures are:

The altimeter which is sensitive to static pressure for altitude indication

The airspeed indicator which determines the difference between total pressure (dynamic + static pressure) and static pressure to provide indicated air speed; and

The vertical speed indicator that relates the rate of change of static pressure to a rate of climb or descent.

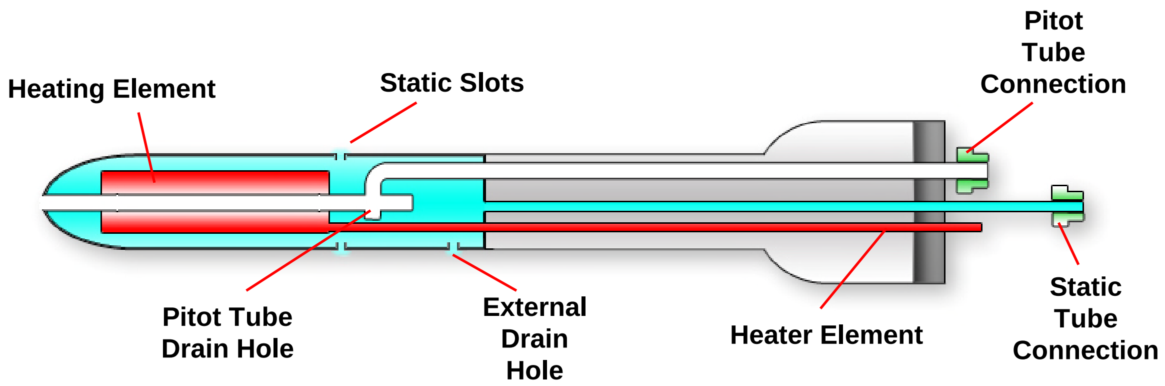


The pitot tube senses total pressure and the aeroplane's static vent provides the measurement of static pressure. There are two common arrangements of the pitot/static sensing systems:

- A combined pitot/static head, or
- A pitot tube usually on the wing and two static vents on opposite sides of the fuselage.

Most aeroplanes have two static vents, one on each side of the fuselage, so that the reading for static pressure, when evened out, is more accurate, especially if the aeroplane is slipping or skidding. This is known as a *balanced static system.*\

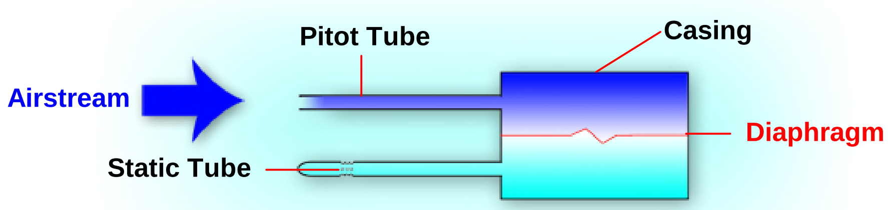
The Pitot/Static Probe



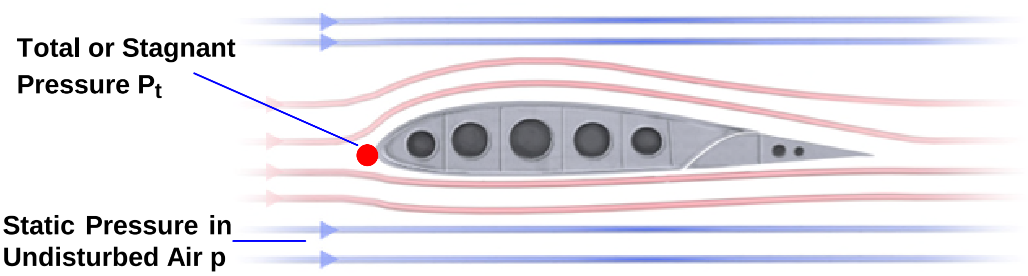
The basic Pitot-Static System probe is mounted at a position where it projects into the undisturbed airflow *(along the Longitudinal Axis of the aircraft)*, and can measure the required pressure accurately, without distortion of the pressure by airflow over the probe itself, or from disturbed airflow from the aircraft structure.

The probe measures total pressure, this is a combination of dynamic and static pressures. The value of dynamic pressure depends both on the speed of the aircraft through the air, and on the density of the air. The probe, therefore, encounters a total pressure consisting of static plus dynamic pressures. You can feel this type of "total pressure" for yourself if you hold your hand out of a moving car with the flat of your hand facing the direction of motion.

If the probe was to ice up during flight, airspeed indication would be lost; for this reason most probes are fitted with a heating element powered by the aircraft battery. A functional check of the heater is a normal pre flight requirement; power should be applied only briefly, on the ground, to avoid overheating the element.



Principle of Airspeed Indicator



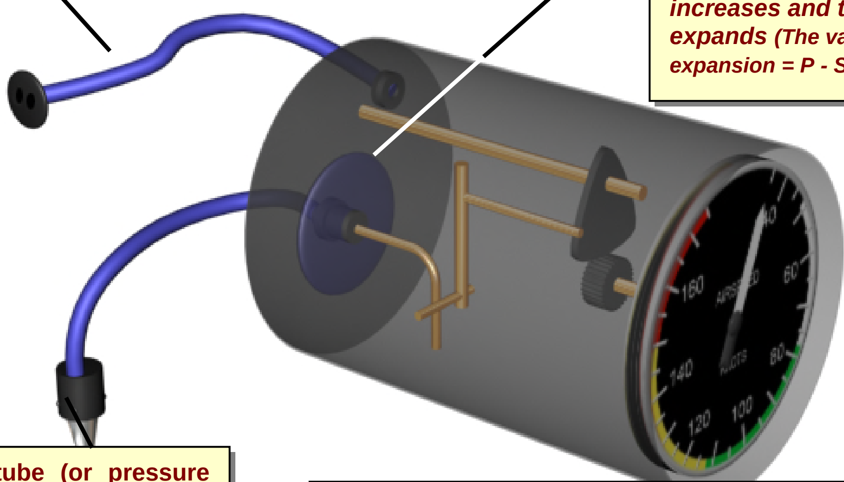
The Airspeed Indicator

Description and purpose

Pilots need to know the speed at which an aircraft passes through the air because not only is it essential to air navigation, but it is also vital to the safe handling of an aircraft.

The Airspeed Indicator (ASI) is basically a very sensitive pressure gauge that measures the atmospheric pressure around the aircraft, as well as the pressure due to the movement of the aircraft through the air.

Construction



The Airspeed Indicator continuously subtracts the static pressure from the pitot pressure and presents this information in terms of the aircraft's airspeed on a graduated scale in Knots in the cockpit.

ASI Colour Coding

Colour coding on the face of the ASI highlights important speed limits which can affect aerodynamic loading on an aircraft structure.

The white arc indicates the flap operating range, from stall speed at maximum all up weight in a landing configuration, to the maximum flap extension speed (Vfe).

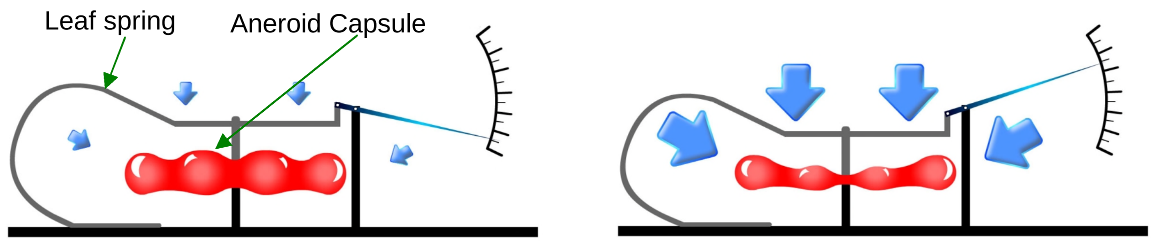
The green arc indicates the normal operating range of airspeeds from stall speed at maximum all up weight, landing gear up, flaps up and power off (Vsi) to maximum structural cruise speed (Vno).

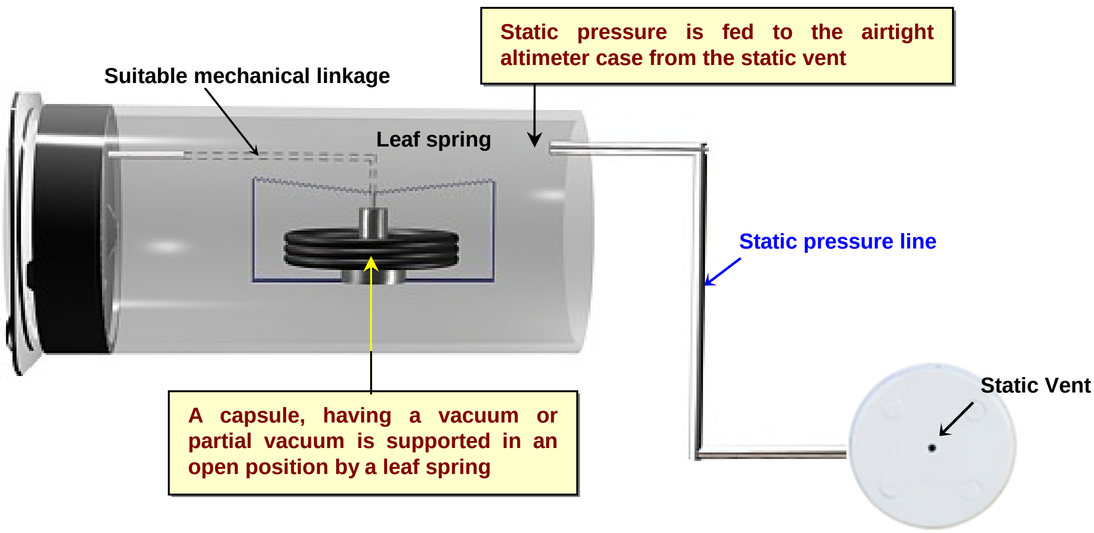
The yellow arc indicates a caution range of speed which should only be used in smooth air extending from Vno to Vne.

A red line marks the maximum structural speed limit and should never be exceeded, it is described as Vne.

The Altimeter

An altimeter is very similar to an aneroid barometer. The aneroid is a partially evacuated metal capsule placed in an instrument casing that is completely sealed and connected to the static system. As the aircraft climbs and descends, the static pressure acting on the capsule varies resulting in expansion and contraction of the capsule which, when relayed by the mechanism, causes a change in the indication of height.





The dial of a typical altimeter is graduated with numerals arranged clockwise from 0 to 9. Movement of the aneroid element is transmitted through gears to the three hands that indicate altitude. The shortest hand indicates altitude in tens of thousands of feet; the intermediate hand in thousands of feet; and the longest hand in hundreds of feet.

Because sea level and aerodrome pressures change with the weather, a mechanical device and subscale is fitted to the altimeter so that a starting point (zero reference) or datum can be set. The common datum used is mean sea level and this datum pressure is known as QNH. In most cases QNH is used so the altimeter will indicate altitude or vertical distance from mean sea level.

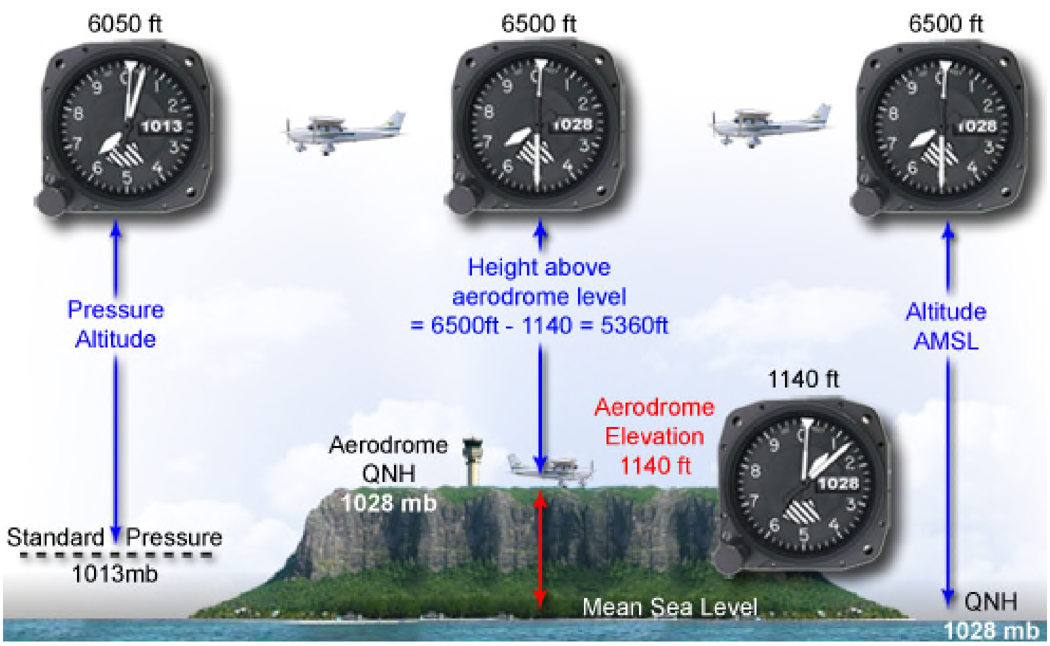
Setting the Subscale

The altimeter is calibrated according to ISA's sea level pressure of 1013.25 hPa.
ISA is however only the ideal. As sea level pressure changes however, a barometric error is evident. The error is corrected by the barometric setting control and the QNH (actual atmospheric pressure) is set.

The actual atmospheric pressure is obtained from Air Traffic Control and when set; the airfield's elevation will be displayed on the instrument. The altitude indication also serves as an instrument serviceability check.

Whenever the pressure changes, the indication is erroneous again.

When departing your airfield, you will need to set the forecast QNH or ATIS.



Up to about 5 000 ft, 1 hPa is approximately equal to 30 ft. If the QNH is set in error by 2 hPa, then the reading on the altimeter will be in error by approximately 60ft.

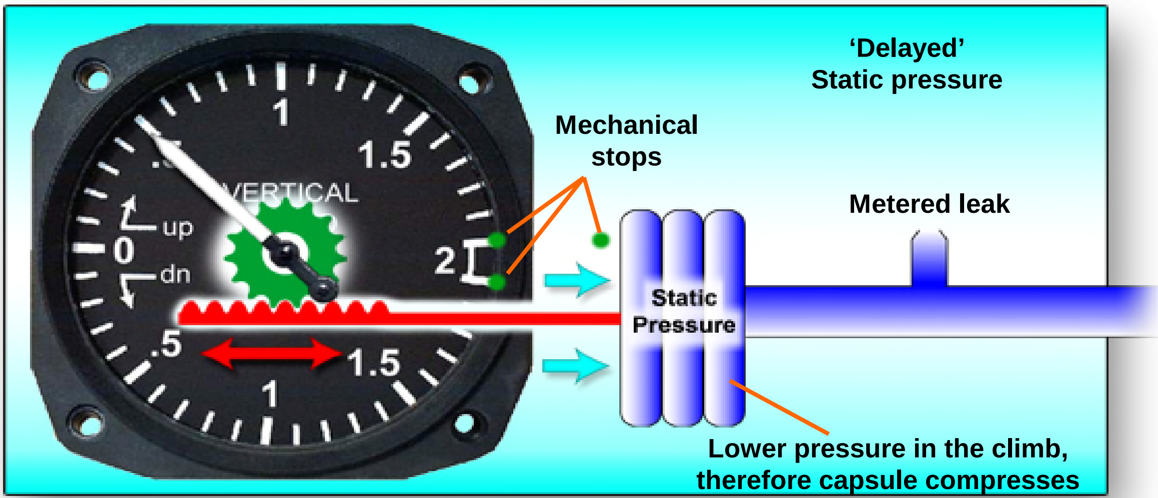
For example, if flying at 5 000 ft, and the subscale is set to 1026 hPa instead of the true value, 1028, then the altimeter will read (5000 – 60) =4950 ft. This is known as **barometric error**.

- If the subscale setting is too low, the altimeter will read low;
- If the subscale setting is too high, the altimeter will read high.

The Vertical Speed Indicator (VSI)

The purpose of the VSI is to indicate the aircraft's rate of climb or descent in feet per minute. The altimeter measures altitude from static pressure whereas the VSI measures rate of change of altitude from rate of change of static pressure.

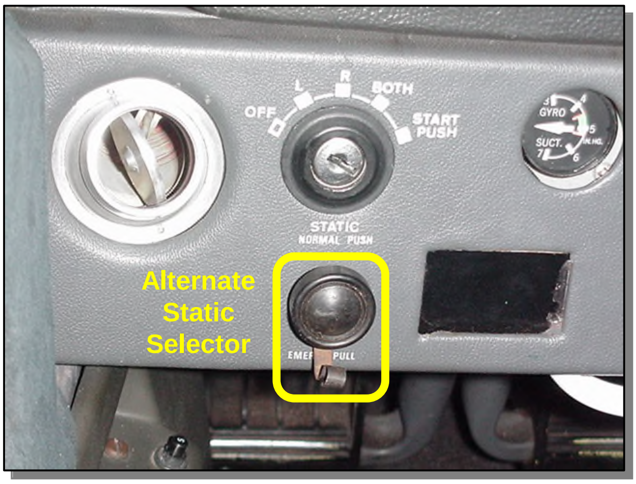
Static pressure is directed to the VSI where it is fed to the inside of a capsule and to a metering unit. The capsule will react when the pressure inside the capsule is different from the pressure outside the capsule.



The air flows through the metering unit, but the flow is restricted, causing a pressure difference between the inside and outside of the capsule. The amount of capsule expansion or contraction depends on the size of the pressure difference. If the pressure change is small
(slow climb/descent), the pressure difference will be small and so the indicated rate of climb or descent will be low. However, during a rapid climb or descent the pressure change is large, the metering unit restricts the air flow and a larger pressure difference is created, keeping the indicated rate high.

Alternate static

As a protection against blockages or icing, there is often an alternate static source that can sense ambient pressure inside the cabin or engine nacelle, control of alternate static is via a cockpit mounted selector. Due to the location of the source of alternate static pressure a correction table may need to be consulted for altimeter readings.



Blockages and Leaks

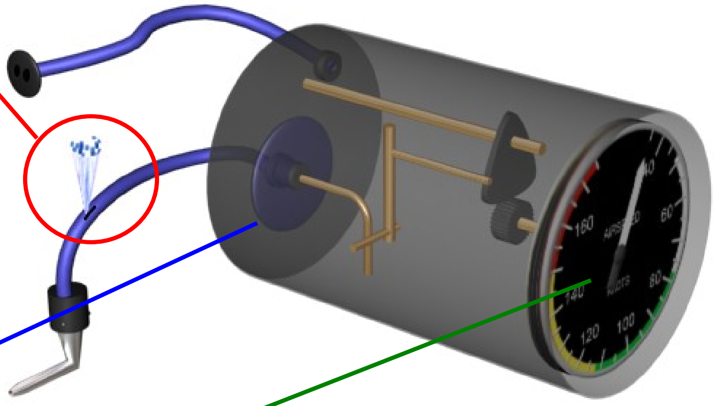
Leakage in the Pitot line

If there is a leak in the pitot line from the pitot tube to the ASI capsule,

the Dynamic pressure will decrease before it reaches the capsule in the instrument.

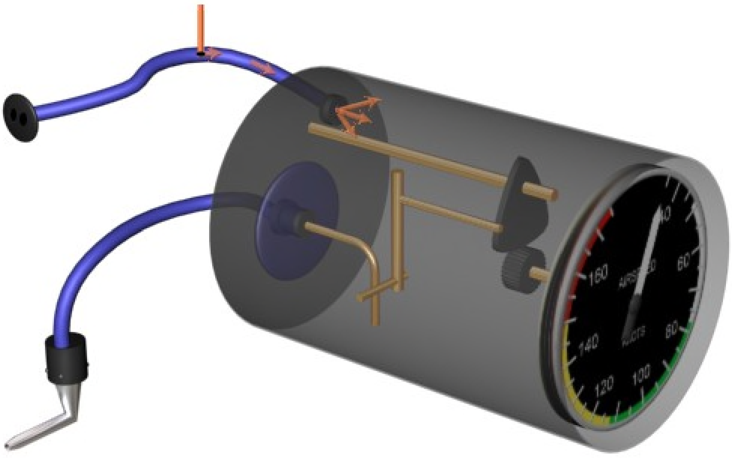
The capsule will expand less because of the reduced difference between the Dynamic - and the Static pressure,

causing the ASI to underread



Leakage in the static system

A leak in the static system would however not have a great influence in unpressurised aircraft where the outside air pressure (static pressure) = pressure inside the aircraft around the instrument case.



In pressurised aircraft, the situation differs in that the pressure inside the aircraft (that is higher than atmospheric or static pressure) enters the static system via the leak, causing the ASI to underread because of the decreased difference in the static and dynamic pressure.

Blockages

The effects that blocked Pitot- or Static lines will have on an aircraft during climbing and descending is as follows. *(NOTE : P = Pitot pressure and S = Static pressure)*

		
PITOT BLOCKED	P should decrease with altitude. P is too high - ASI **OVERREADS**. **Effect: Raise nose - Aircraft stalls.** 	P should increase descending. P is too low - ASI **UNDERREADS**. **Effect: Lower nose - Exceed Vne.** 
STATIC BLOCKED	S should decrease with altitude. S in instrument case too high. ASI **UNDERREADS**. **Effect: Lower nose - Exceed Vne.** 	S should increase descending. S in instrument case too low. ASI **OVERREADS**. **Effect: Raise nose - Aircraft stalls.** 

A good mnemonic to memorise, is PUDSUC:

P – Pitot Blocked
U – Under read
D – Descent
S – Static Blocked
U – Under read
C – Climb

Serviceability checks

The following checks are to be carried out on the ASI and pitot system before each flight:

- Ensure that the pitot cover and static vent pins (where applicable) are removed before flight.
- Check the pitot head for blockages, cracks or any other damage.
- Make sure the pitot head is not bent or misaligned with the airflow.
- As soon as possible after commencement of the take off run the airspeed indicator must be checked for a reading in order to ensure that the needle is not stuck on the dial.

The Gyroscope –

An Introduction

A Gyroscope can be defined as "any mass that spins on its axis". Tops, wheels and aircraft propellers are but a few examples of gyros.

Even the earth itself, spinning on its axis, is a gyro.

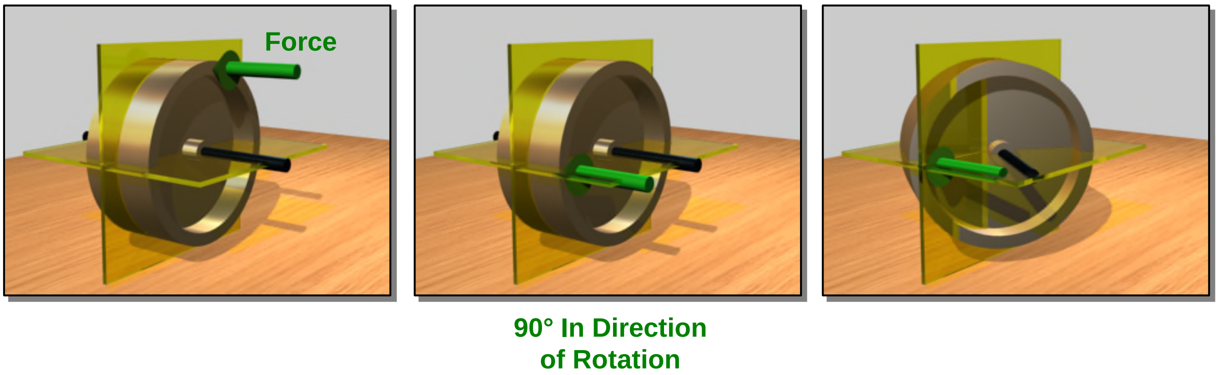
When a gyro spins on its axis, it acquires two properties, namely; precession and rigidity. These properties are the key components that make them useable for the aviation industry.

Rigidity

Rigidity is a measure of the gyros tendency to continue spinning in a set plane in space; this function will be dependent on the rotor mass, speed and radius.

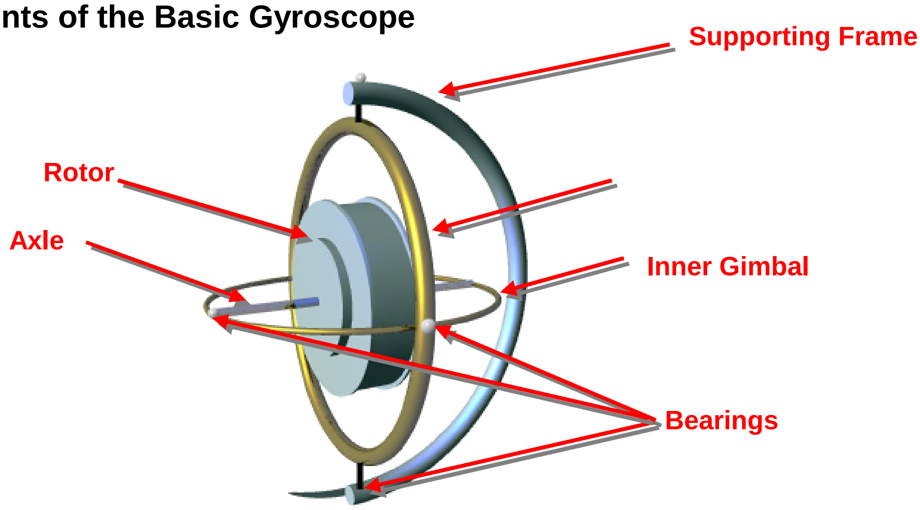
Precession

If a force is applied to change the direction of the gyro spin axis, the gyro will resist this force and will instead move its spin axis in a plane at 90° to the applied force.



Gyro Components and Types of Gyros

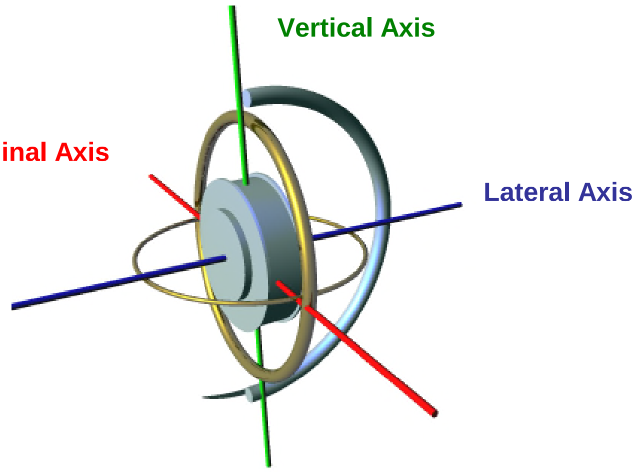
Components of the Basic Gyroscope



Types of Gyroscopes

Gyro's fall into various classes determined by the number of planes of freedom the gyro is allowed to rotate. Freedom of movement is achieved by mounting the gyro in frames or rings referred to as gimbals.

The gyroscope has three planes in which it can rotate:

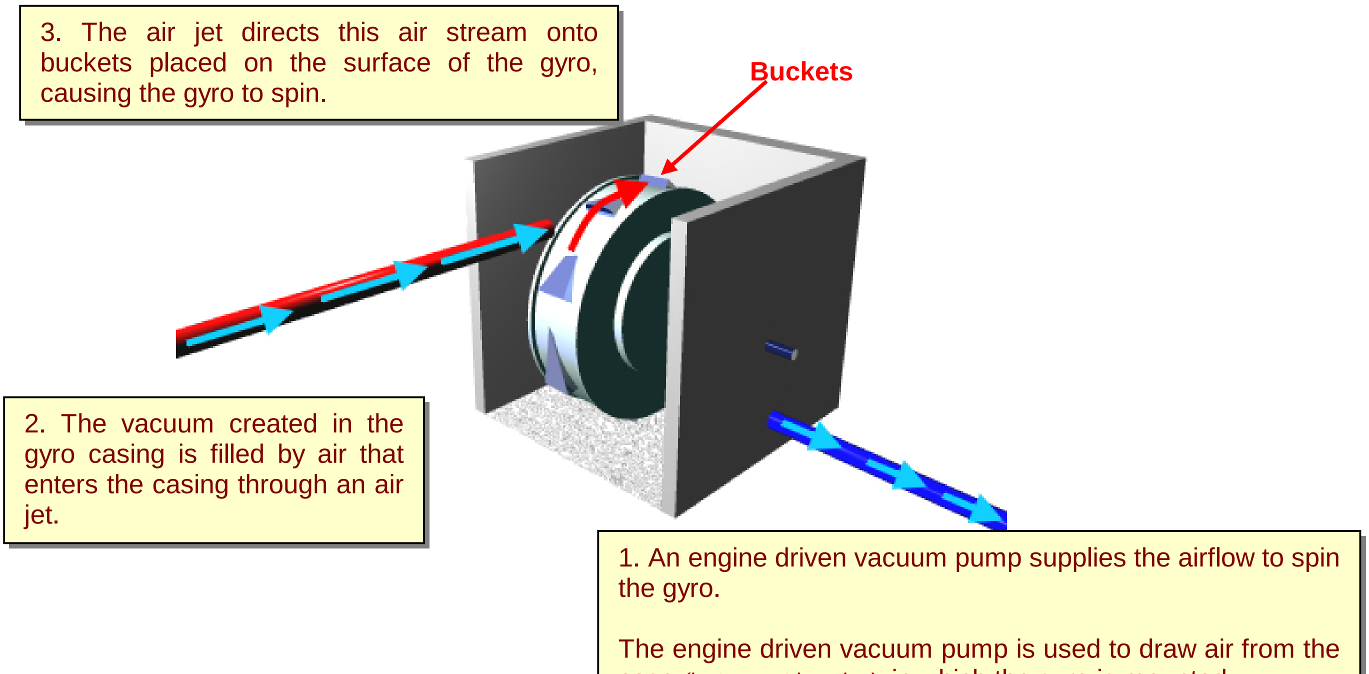


Gyro Driving Mechanisms

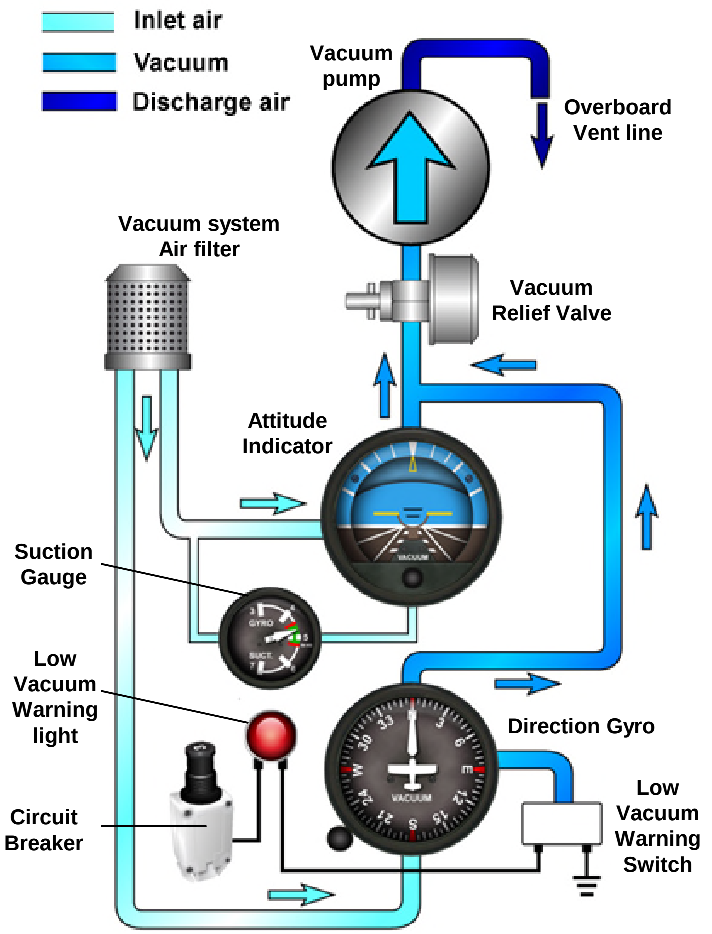
Air Driven Gyros

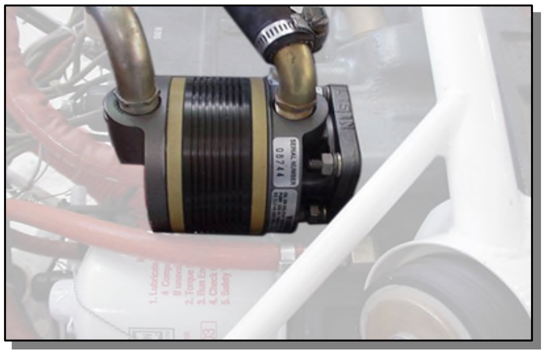
Although air driven gyros are the oldest and their rigidity decreases with increasing altitude, they are often still found in modern aircraft, especially in backup or duplicate instruments. The reason for this is twofold:

- Air driven gyros are relatively cheap to manufacture.
- Air driven gyros do not depend on an electrical supply of power and are thus not exposed to the hazards due to electrical problems such as those that can be encountered when flying in thunderstorms.



A schematic is shown of the Engine Driven Vacuum System with its various components:





Example of the engine driven vacuum pump

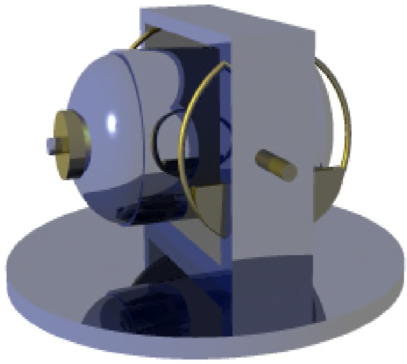
Example of the Suction Gauge Located in the cockpit.

Disadvantages of air driven gyros

- At high altitudes, the reduction in atmospheric pressure causes the amount of air that the vacuum pump displaces to decrease. This in turn causes less air to enter the gyro casing through the air jet which causes the gyro to rotate at a lower speed. The slower the speed of rotation - the less the rigidity of the gyro and the less accurate the indications given by the instrument using the gyro.
- The air driven gyro takes quite a long time to attain its operational rotor speed. This is quite important in situations where aircraft have to get airborne in a minimum amount of time, such as when interceptors are scrambled in operational circumstances.
- Because atmospheric air is used to rotate the gyro, moisture and dust in the atmosphere will in the long run accumulate in the instrument, impairing its efficiency and reliability.

Electrical Driven Gyros

Electrically driven gyros are nowadays the norm in the aviation world. The reasons for the industry preferring the electrically driven gyro to the air driven gyro are:



- Electrically driven gyros are more efficient than air driven gyros as higher rotor speeds are possible at all altitudes (with air driven gyros - high altitude - lower outside air pressure - thus less air supply to gyro suction pump). The electrically driven gyro has thus greater rigidity and more reliable indications at high altitudes.
- The electrically driven gyro attains its operational rotor speed much quicker than an air driven gyro.
- Operational life of the electrically driven gyro is longer than the life of the air driven gyro since the gyro's casing can be sealed - keeping out dust and moisture.

The Comparative Advantages of Suction and Electrical Gyros

Suction Gyros:

Suction (vacuum-driven) gyros are independent of the aircraft's electrical power supply, but otherwise suffer from a number of disadvantages when compared to electrically driven gyros.

As air must enter and leave the casing, a suction gyro cannot be contained within a sealed case. In spite of filters, dust and moisture will enter, affecting the balance off the gimbals and reducing bearing life.

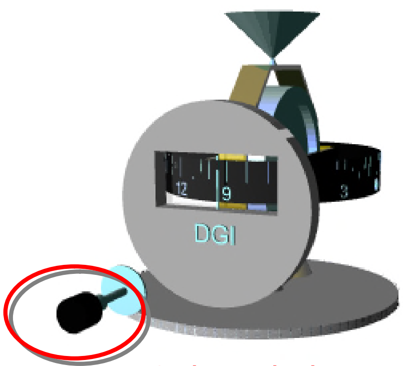
The suction pump is usually driven directly off the engine and so instruments cannot be run up until the engine is started. The electrical gyro will run up when the master switch is turned on. Additionally, at high altitude there is insufficient suction to maintain the correct rpm.

Electrical Gyros:

Electrically driven gyros can be constructed so that their rotors have a higher moment of inertia and spin speed. This is an advantage in instruments that rely on rigidity, HI and AI, to provide readings. Electrical gyros operate at constant speeds and this is an advantage when a predictable rate of precession is required.

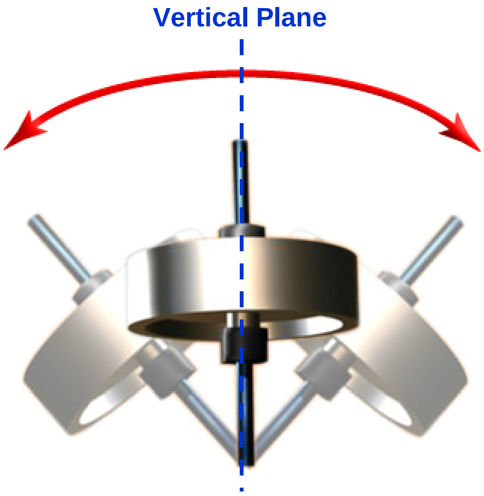
Caging

The term caging indicates the gyro gimbal are clamped so it can be re-erected or levelled. When uncaged, the gyro should be working again. The caging and realignment process can be mechanical or electromechanical but is rare in modern aircraft



Caging Mechanism on a Direction Indicator (DI)

Gyro Topple



Any movement of the gyro axis in the vertical plane is called topple (tilt). The effect of topple depends on the gyro axis alignment and can also relate to latitude and earth rotation. The types of gyroscopes used in aircraft make the effects off topple less obvious than drift.

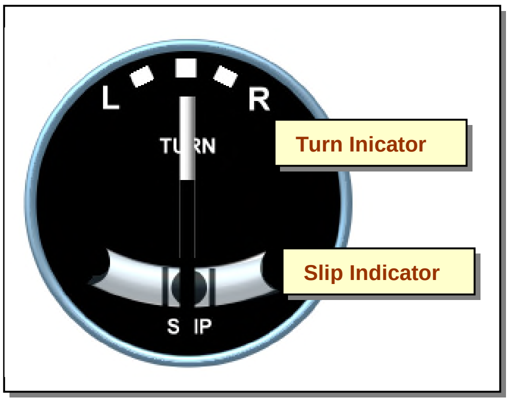
The term topple may also be used to describe the tumbling (severe and usually rapid misalignment) of a gyro that can occur when a gimbal limit stop is reached. The rotor is no longer isolated from the aircraft movement (instrument casing), and a rapid precession misaligns the axis.

Turn and Slip Indicator and Turn Coordinator

Turn and Slip Indicator

Description and Purpose

The Turn and Slip indicator was the first aircraft flight instrument to make use of a gyroscope. This instrument, combined with the Magnetic Compass, made a valuable contribution to the art of flying without external references.



Although in modern large aircraft the role of this instrument is of secondary importance, in smaller types of aircraft, the Turn and Slip indicator is second only to the artificial horizon in importance for instrument flying.

The turn and slip indicator contains two independent instruments namely a:

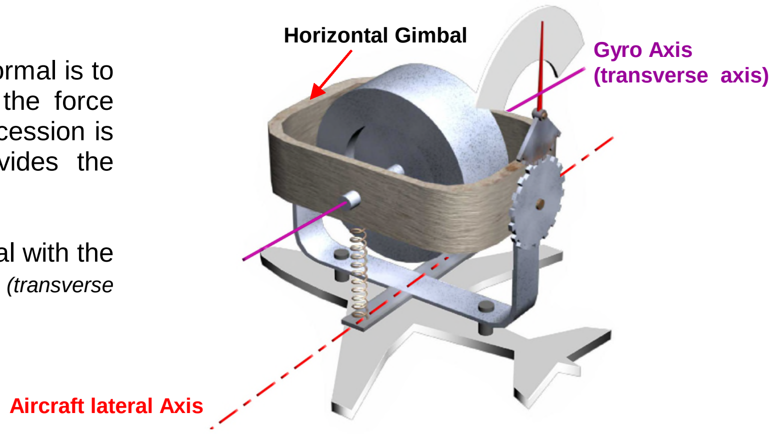
- Turn Indicator
- Slip Indicator

Construction - Turn Indicator

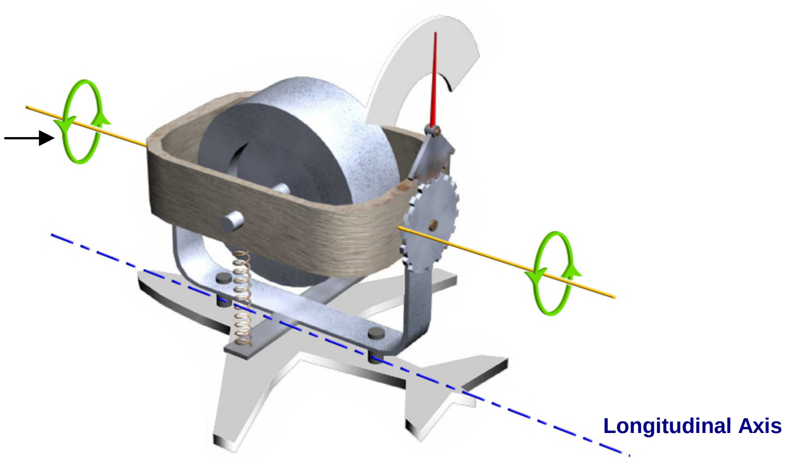
A turn indicator uses a rate gyro (horizontal axis gyro) that spins at a relatively slow speed - 9000 RPM.

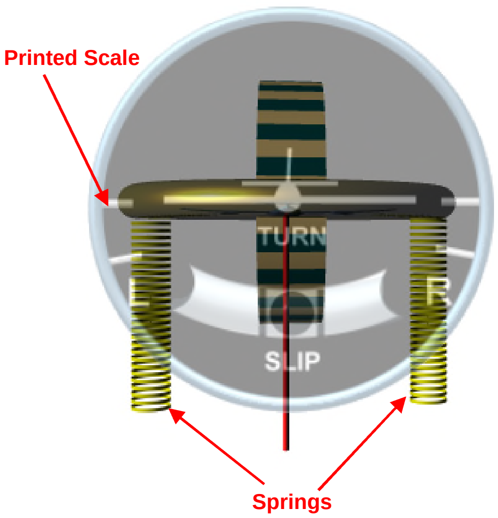
The reason the gyro spins slower than normal is to reduce the rigidity of the gyro so that the force required to precess the gyro is less. Precession is important in the instrument as it provides the measure of turn.

The gyro is mounted in a horizontal gimbal with the axis of the gyro parallel to the lateral axis *(transverse axis)*.



Because of the way the gyro is mounted in the horizontal ring in the instrument case, the gyro has freedom of movement in one plane only - that is about the fore - and - aft axis *(Aircraft's Longitudinal Axis).*

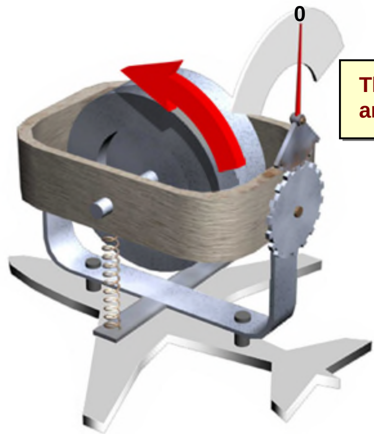




The rotor of the gyro can be driven either by air or electricity.

The instrument incorporates two springs, which hold the gyro axis horizontal when the aircraft is in level flight.

During normal straight and level flight, the two springs hold the gyro axis in the horizontal plane - thus preventing any unwanted precession - and the pointer attached to the vertical rotor indicates the central (or zero rate of turn) position on the printed scale.



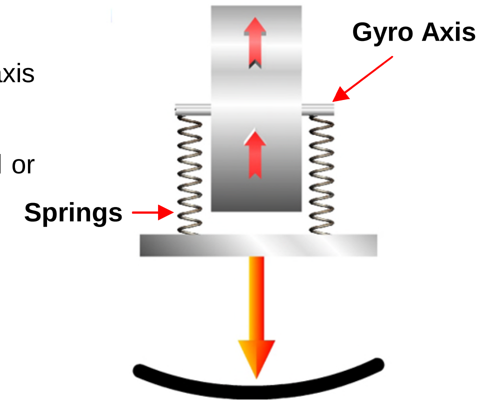
The gyro is installed so that it spins up and away from the pilot in the cockpit.

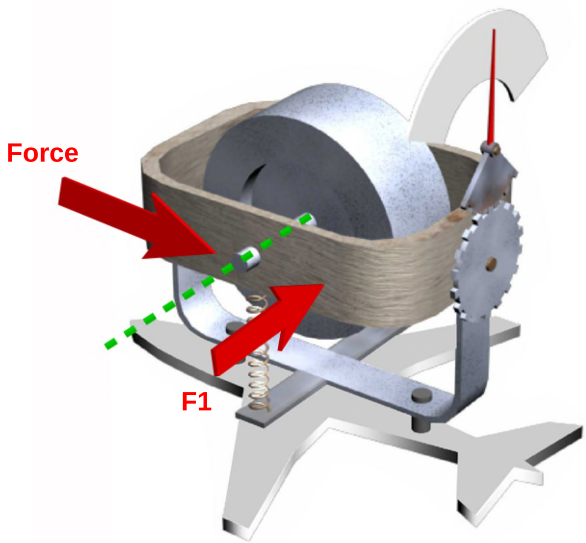
Principle of Operation

Turn Indicator

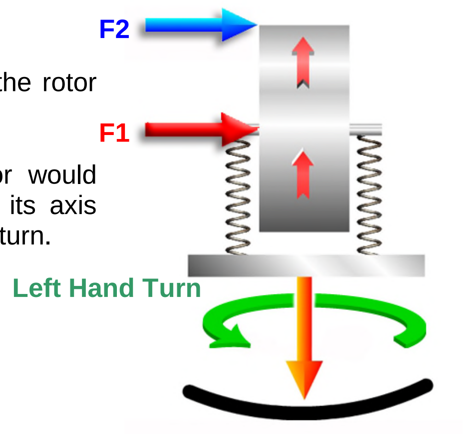
In straight and level flight the springs hold the gyro axis horizontal preventing unwanted precession.

The pointer attached to the vertical rotor indicates the central or zero position of the instrument against the printed scale.



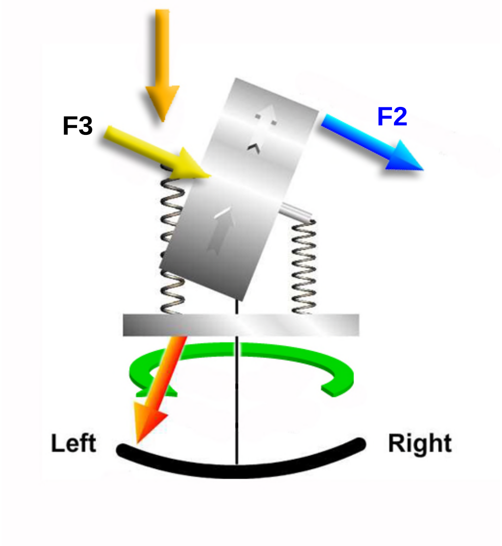


As the aircraft enters a turn - say a turn to the left - the gyro axis (being rigid) opposes the turn and a **force** is experienced on the axis. This force can also be represented by **F1**

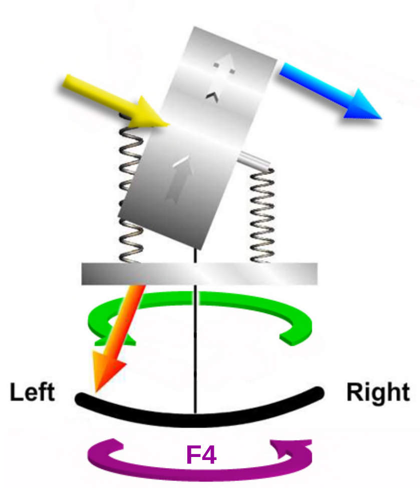


The force will precess through 90° and act at the top of the rotor **(F2)** tilting the rotor. This tilt is called primary precession.

If no springs were attached to the rotor axis, the rotor would continue to tilt until it spun in the horizontal plane, with its axis vertical. This attitude would give no indication of the rate of turn.



However, because springs are fitted, one spring stretches and the other contracts as the rotor starts to tilt. In a left hand turn the left hand spring is stretched. This produces a **force** pulling down on the left hand axis or a force pushing up on the right hand axis (F3).



This vertical force acting on the axis will precess the rotor in the horizontal plane in the direction shown - **F4**. This is called secondary precession. It will be seen that **F4** acts in the same direction as that of the turn.

As the gyro continues to tilt further, the spring tension vector and consequently the magnitude of the secondary precession - continue to grow. A stage will be reached where the rotor precessing under the initial force can no longer tilt any further against the spring tension. At this point, the magnitude of the secondary precession is the same as the rate of turn.

Secondary Precession = Rate of Turn

Now the gyro axis, which was initially reluctant to move with the aircraft because of its rigidity, is precessing with the aircraft at the rate of turn. Therefore there cannot be further tilting of the rotor.

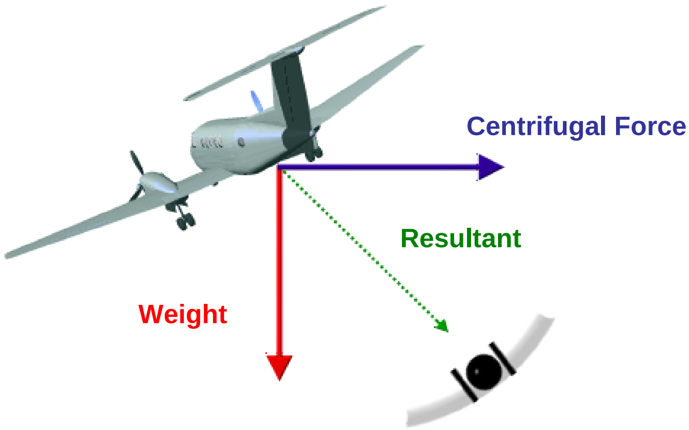
Whatever angle of inclination has been achieved during this sequence will be maintained as long as the aircraft continues turning at the same rate and no variations in the rotor speed (which affects its rigidity) occur.

Slip Indicator

The slip indicator is purely mechanical and depends on the forces acting on the steel ball *(gravity and centrifugal force),* which is in a tube filled with alcohol.

The slip indicator in a turn shows the *resultant between the gravitational force and the Centrifugal force* acting on the aircraft.

The indication on the slip indicator will be an indication of how balanced an aircraft is flying - during straight and level flight and manoeuvres such as turns.



NOTE:

a. **The steel ball rolls to the centre of the glass tube because it is the lowest part of the glass tube during level flight.**

b. **The function of the alcohol in the tube is only to create a certain amount of friction for the steel ball so that it will move slowly and not bounce from side to side when the aircraft is flying in turbulent conditions.**

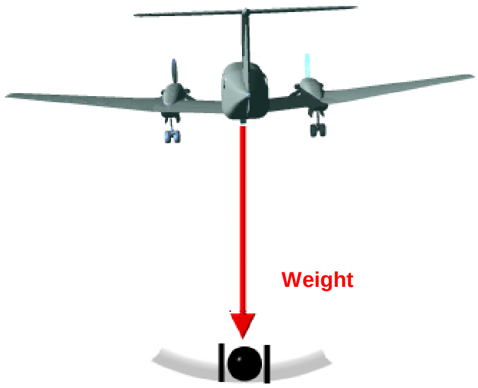
Indications

The following indications can be experienced during flight:

Straight and Level

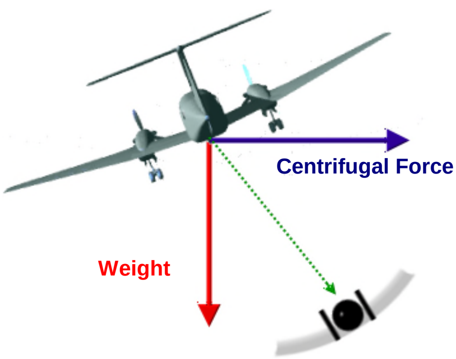
During straight and level flight, the four forces acting on an aircraft are in equilibrium.

In a case such as straight and level flight, the only force that will thus act on the weight of the steel ball (or the pendulous weight in the other type of indicator), will be gravity - acting in the true vertical.



Balanced Turn

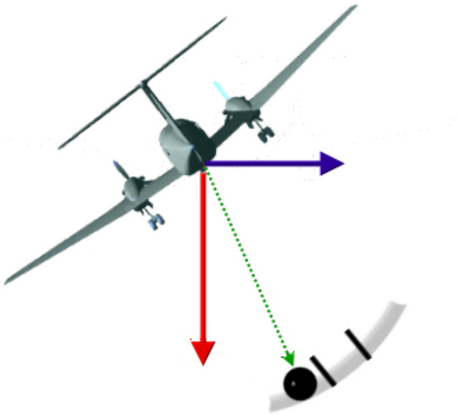
In a balanced turn the two forces, which act on the ball are gravity and centrifugal force. Gravity always vertical and CF always horizontally out of the turn. Being a balanced turn the resultant of the two forces will keep the ball in the neutral position.



Slip or Excessive Bank

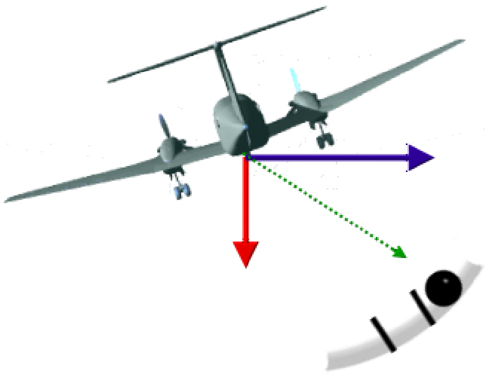
When a turn is overbanked the aircraft tends to slip into the turn. As it is slipping into the turn the horizontal CF force is reduced and the gravity force is greater.

The resultant vector of the two forces will favour the gravity vector and the ball will move in the direction of the larger force.



Skid or Insufficient Bank

When a turn is underbanked the aircraft tends to skid out of the turn. Now the CF is greater than the gravity and the ball will move in the direction of the greater force.



Serviceability Checks

While Stationary

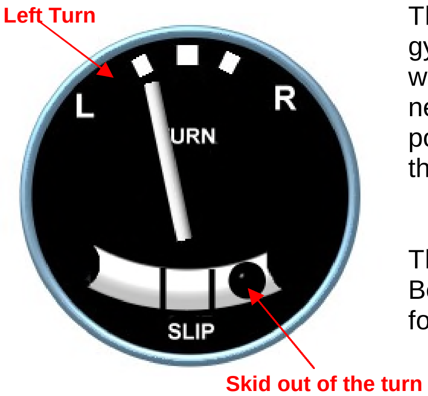
In the world of aviation, safety is always of paramount importance. Before commencing a flight, one will be expected to check and recheck most of the systems in the aircraft. Fortunately, the checks for the Turn and Slip indicator are straightforward and easy to perform.

When the aircraft is standing on level ground, both the Turn - and the Slip indicators should be in the central (zero) position.

It is important that the ground on which the aircraft is parked is level and that the aircraft's oleo legs are also equally compressed, so that the aircraft as a whole is level - thus the weight of the slip indicator can lie in the lowest part (the central position) of the glass tube and the springs on the axis of the gyro can keep the gyro axis in the true horizontal.

While Taxiing

The second check should be performed while taxiing the aircraft. While taxiing in a turn observe the turn and slip indicator individually:



The turn indicator senses a change in direction relative to the axis of the gyro and indicates correctly as it would while the aircraft is flying. Normally while taxiing, the rate of change in direction is fairly quick and the Turn needle then goes to the limit of its travel on the indicator. This does not pose a problem as we are only interested to see that it indicates a turn in the correct direction.

The slip indicator senses an increase in centrifugal force due to the turn. Because the aircraft doesn't bank while taxiing the value of centrifugal force will be high and the ball will skid out of the turn.

Calculating a Rate one Turn

Quite often during a flight, (especially during instrument flights), a Rate 1 turn is required (3º per second). The turn indicator, although designed to indicate a Rate 1 turn, can prove difficult in keeping the needle of the turn and slip indicator exactly on the correct mark. A rule of thumb that can be applied to determine an angle of bank required to maintain such a turn *(which can be monitored on the Artificial Horizon)* is as follows:

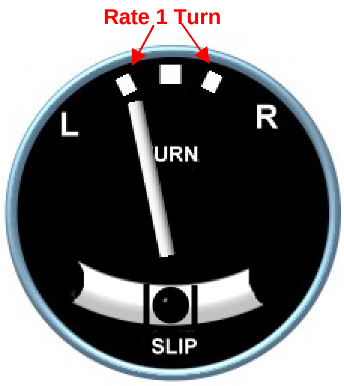
10 % of TAS + 7º = Angle Of Bank for rate one turn.

Example

If required to do a rate one turn in an instrument letdown at a TAS of 120 Knots, as a rule of thumb put on 19º of bank.

Errors

Turn Indicator



The tension of the spring is designed for a rate one turn and therefore at any other rate turns an error may be present.

The turn indicator is also calibrated for a specific rotor speed. If the rotor speed should change for any reason then an error can be expected.

ROTOR SPEED LOW - LESSER RATE OF TURN INDICATED
ROTOR SPEED HIGH - GREATER RATE OF TURN INDICATED

Note: the gyro of the turn indicator cannot topple as the springs hold it in the horizontal plane during level flight.

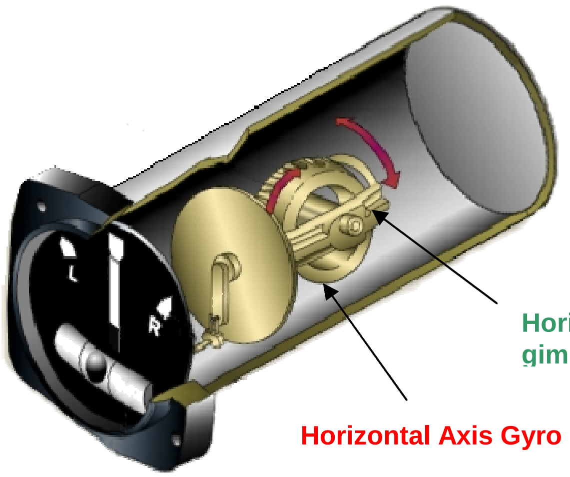
Slip Indicator

As this is an instrument that uses gravitational and centripetal forces there are no errors unless the tube in which the ball is suspended in, has no fluid in it.

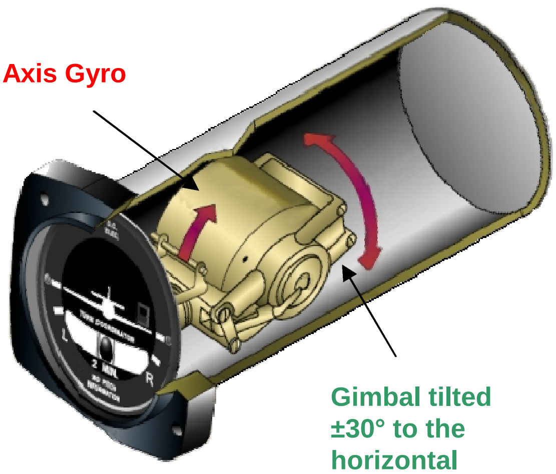
Turn Coordinator

The turn coordinator is a flight instrument which displays to a pilot information about the rate of yaw (turn), roll and coordination of the turn. The turn coordinator was developed to replace the older turn and bank indicator, which displayed rate of quality of turn but not rate of roll.

The turn coordinator differs from the older turn and bank indicator in that the turn coordinator has the gyro outer gimbal mounted at a 30° tilt and the turn and bank indicator has the gyro gimbal mounted horizontally. This allows the turn coordinator to respond to roll as well as turn. The TC indicator represents a sum of the roll rate and the yaw rate so it responds more quickly at the beginning and end of a turn than a turn and bank indicator. Pilots who are unfamiliar with this principle sometimes have difficulty using the turn coordinator properly, as they may see a roll indication and interpret it as a rate of turn.



Turn and Slip Indicator



Turn Coordinator

Indications

Coordinated turn

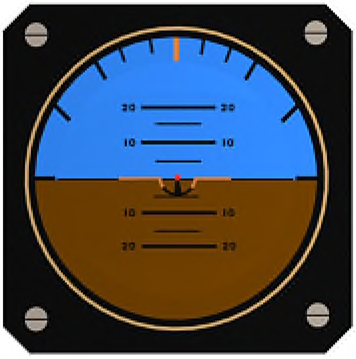
Slip

Skid

Unlike an attitude indicator, the turn coordinator indicates only yaw rate and roll. The attitude indicator indicates pitch and roll. To avoid possible confusion, some turn coordinators are marked "No pitch information" on the face.

The Artificial Horizon (AH) - An Introduction

Description and Purpose



When flying in limited visibility with no reference to the outside horizon, maintaining a straight and level attitude became increasingly difficult.

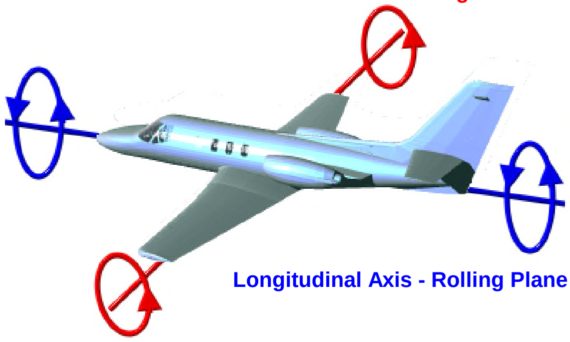
It was necessary to design an instrument that would indicate to the pilot their attitude with regards to the outside horizon. This instrument is known as an artificial horizon.

Principle of Operation

The Artificial Horizon provides a gyro-stabilised indication of the aircraft's ***attitude***. The gyro is therefore placed in the horizontal ***(spin axis vertical)*** and has freedom in all three planes, spinning at about 15 000 rpm in the air driven models and about 20 000 to 23 000 rpm in the electrical types.

As the aircraft changes its attitude, the **'*Earth gyro*'** that is the basis of the AH retains its rigidity relative to the Earth's vertical. What this means is that the aircraft moves around the gyro of the AH. This gyro has a **vertical spin axis**, which is maintained vertical to the earth's surface. The Artificial Horizon indicates the aircraft's attitude in:

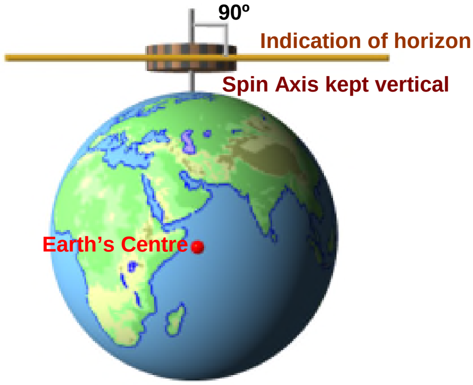
- **Pitching Plane**: Indication is given of the aircraft's nose attitude relative to the horizon.
- **Rolling Plane**: Indication is given of the aircraft's banking angle relative to the horizon.

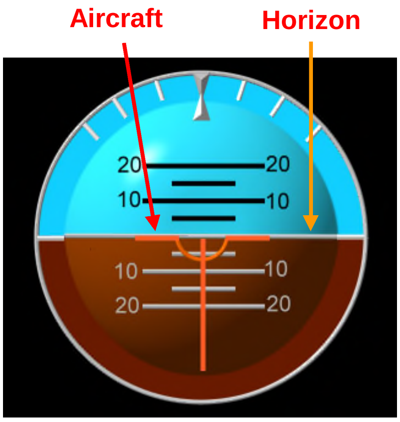


The spin axis is kept vertical with reference to the centre of the earth so that, a bar across and at 90º to the spin axis, indicates the horizon.

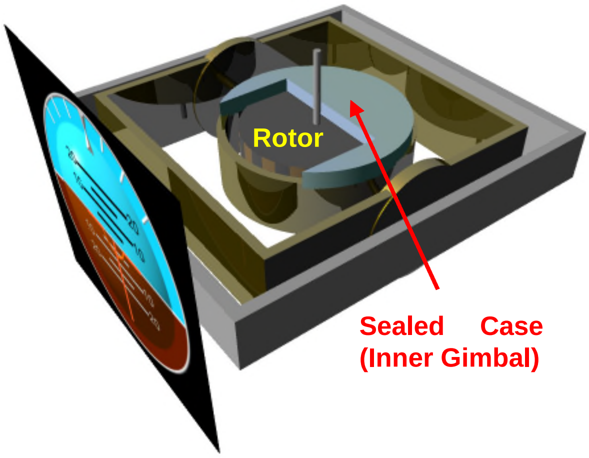
In flight an aircraft rolls and pitches about the gyro's axes, which remains rigid.

If the bar representing the horizon where replaced with a picture of the horizon ***(attached to the gyro),*** around which the aircraft moves, then the attitude of the aircraft with relation to the real horizon would be symbolised by the artificial horizon.





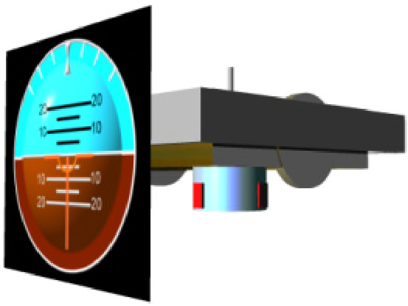
The aircraft attitude is symbolised by a small symbolic aircraft attached to the instrument dial.



Construction

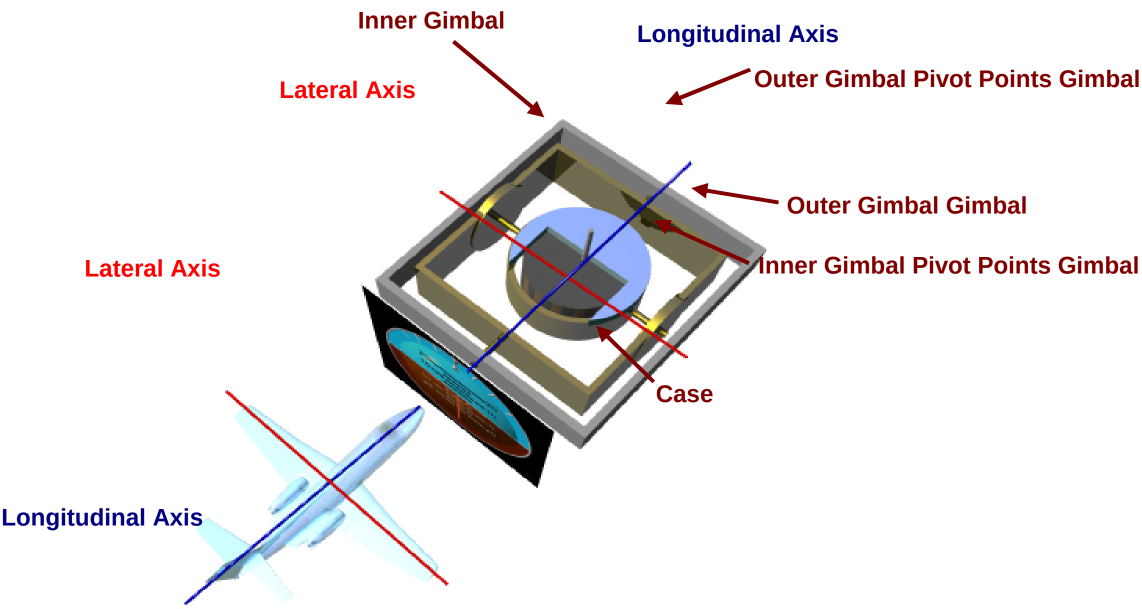
The rotor of the gyro is encased in a sealed case which acts as inner gimbal

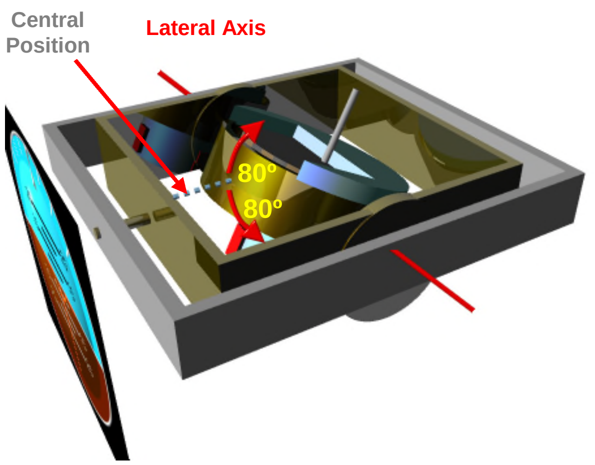
Air is let in to the case under pressure, the pressure is either created by a pressure pump or by creating suction inside the case. ***(The suction required is 4 - 5 inches of mercury).***



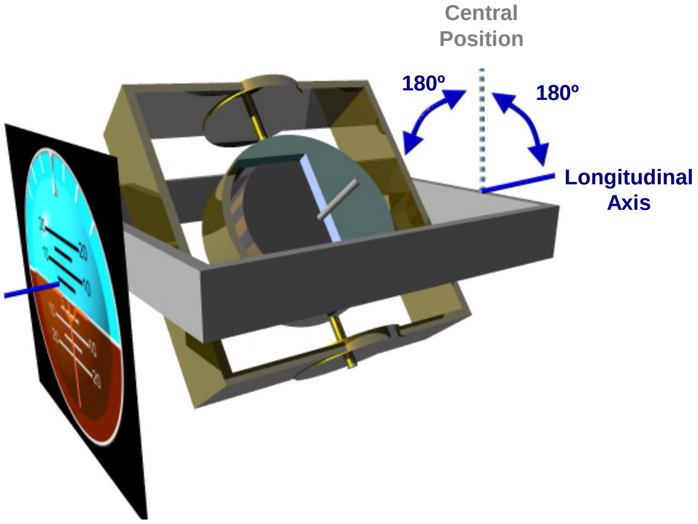
The rotor spins under pressure at the rate of approximately 15 000 rpm. Having spun the rotor, the air escapes from the case through four exhaust ports in a pendulous unit mounted at the base of the gyro.

The inner gimbal is mounted in the outer gimbal with its axis lateral. The outer gimbal is mounted in the case with pivot points in the longitudinal axis of the aircraft.

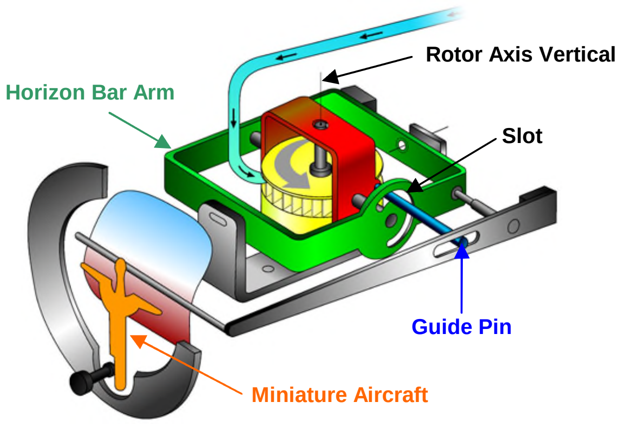




The inner gimbal having its movement about the lateral axis, controls the indications in the pitch attitude. It has freedom of movement of about 80º either side of the central position depending on the model and type.



The outer gimbal controls the indications in the rolling plane - bank (Longitudinal Axis) and has 180º freedom from the central position on either side.



Any movement relative to the inner gimbal is transmitted to the horizon bar arm through a guide pin on the inner gimbal.

During level flight the aircraft's vertical axis is parallel to the rotor axis and the guide pin is in the centre of the slot.

The horizon bar is in the centre and its extension across the face of the dial is in the centre of the miniature aircraft.

Instrument Indications

The instrument provides the pilot with visual indication of the aircraft's attitude in relation to the earth's actual horizon. These attitudes can be categorized as follows:

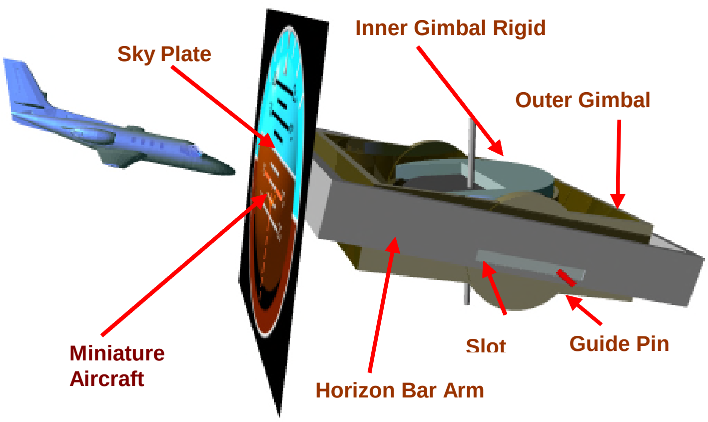
- Pitching
- Banking

Pitching

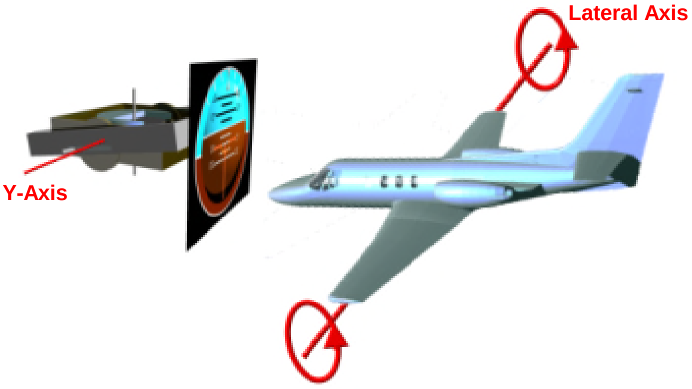
When the aircraft climbs or descends the inner gimbal (rotor case) remains rigid whereas the outer gimbal and the instrument case move with the aircraft.

Due to the movement relative to the inner gimbal the guide pin gets displaced in the slot taking the horizon bar arm with it.

Thus an indication of climb or descent results.



In this example the aircrafts nose is 10º below the horizon, as the miniature aircraft is below the horizon bar ***(in the brown portion of the skyplate).***



As the aircraft pitches about its lateral axis, it will pitch parallel to the Y-axis of the gyro rotor.

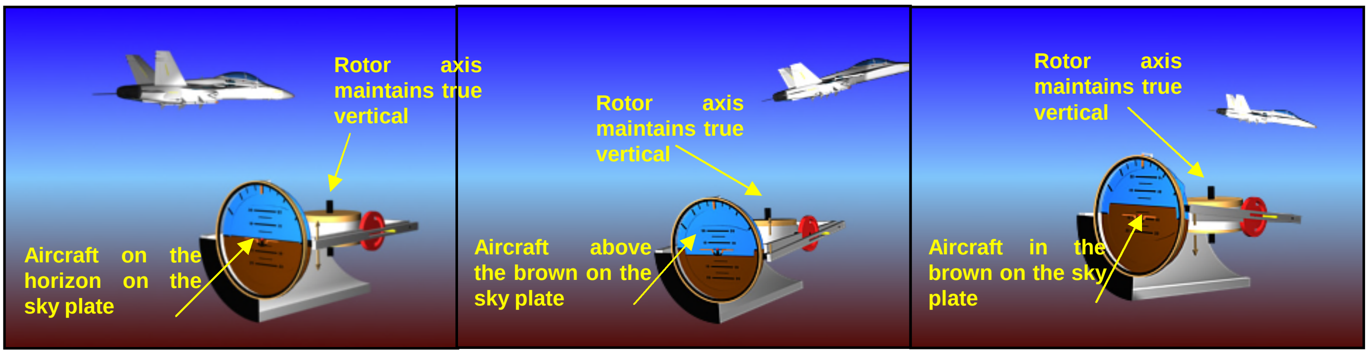
During pitching the only movement is around the Y axis of the gyro rotor.

As the aircraft pitches up and down parallel and along the Y axis of the rotor, the rotor remains in the true vertical and the outer gimbal moves up and down giving an indication of the aircraft's attitude above or below the horizon.

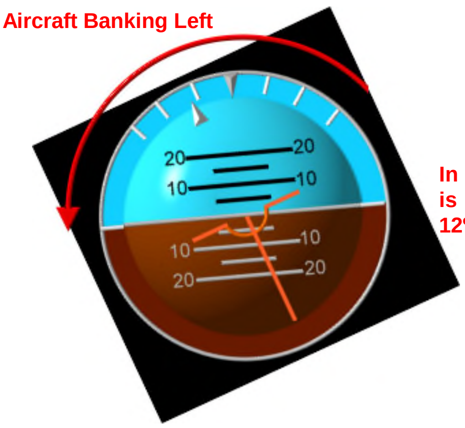
Note: The aircraft's movement around the axes represents the relative movement around the gyro rotor.

Pilot Indication

Indications of the pitching attitude are presented by the relative position of two elements:
One symbolizing the aircraft itself, and the other in the form of a bar (sky plate) stabilized by the gyro and symbolizing the natural horizon.



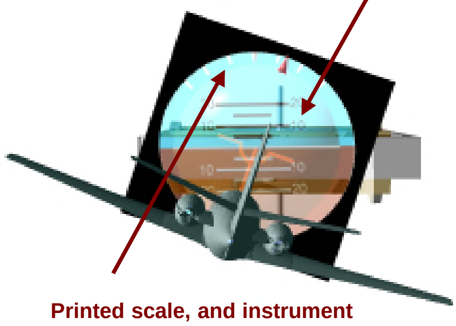
Banking

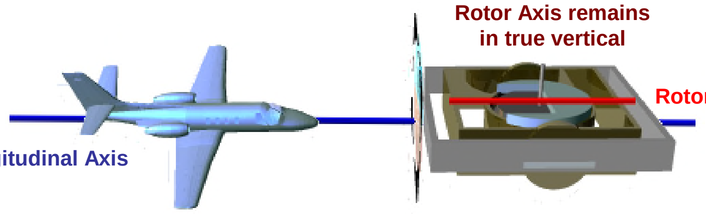


In this example the aircraft is banking approximately 12º to the left.

The bank indication is given by an index on the sky plate which is directly connected to the outer gimbal. The index reads against a scale linked to the instrument case.

When the aircraft banks, the rotor, inner gimbal and outer gimbal remain rigid in the level position and the instrument case together with the printed scale moves with the aircraft.





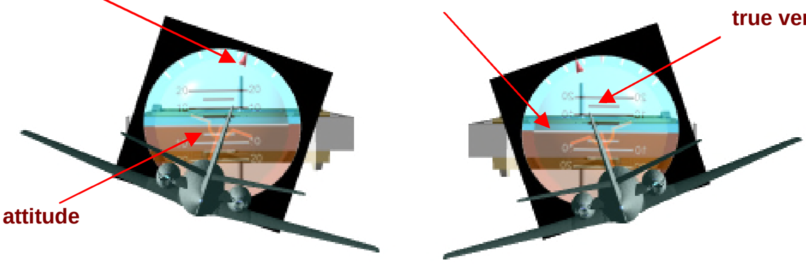
As the aircraft rolls about its longitudinal axis, it will roll parallel to the Z axis of the gyro rotor. During a level roll the only movement is along the Z axis of the gyro rotor.

As the aircraft rolls to the right or to the left parallel and along the Z axis of the rotor which remains in the true vertical, the instrument case *(mounted to the aircraft*) will move around the gyro giving an indication of the roll/bank.

> ***Note: The aircraft's movement around the axes represents the relative movement around the gyro rotor.***

Pilot Indication

Indications of the banking attitude (rolling) are presented by the relative position of two elements: One Symbolizing the aircraft itself, and the other in the form of a bar *(sky plate)* stabilized by the gyro and symbolizing the natural horizon.



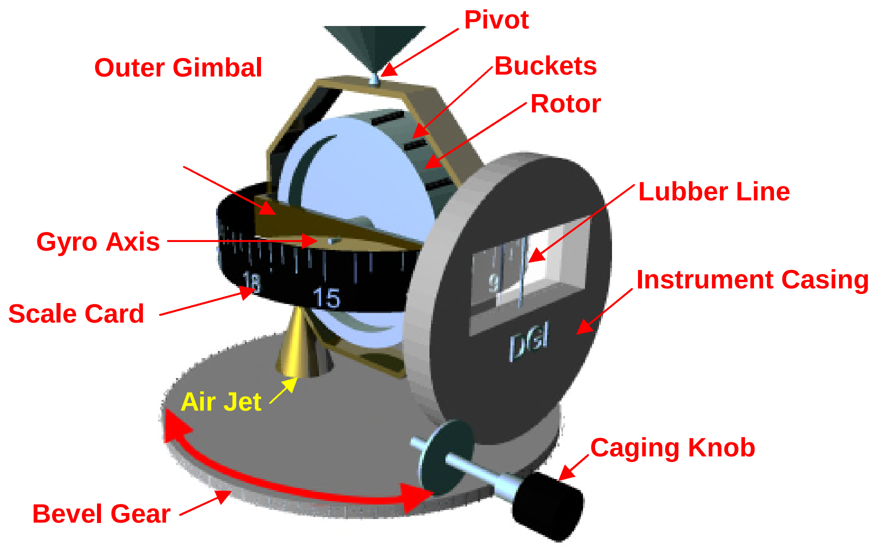
The Directional Gyro Indicator (DGI) – Technical

Introduction

The Directional Gyro (DGI) Indicator makes use of a horizontally aligned gyroscope. This gyroscope is connected via gimbals to the compass card (vertical or horizontal instrument). For the purposes of this discussion the horizontal compass card will be used to describe the workings of the DGI.

Vertical Compass Card

Components

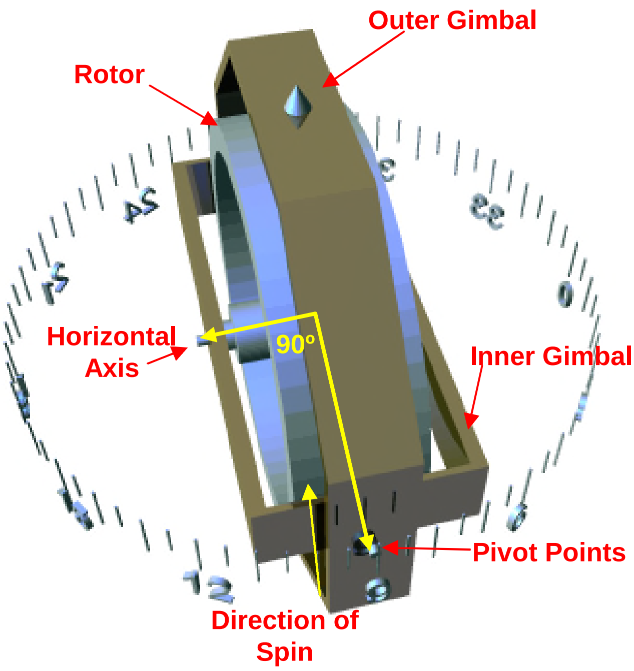


Construction

The DGI rotor is mounted in two rings, called the inner gimbal and the outer gimbal. Each gimbal has movement that is independant of the other gimbal.

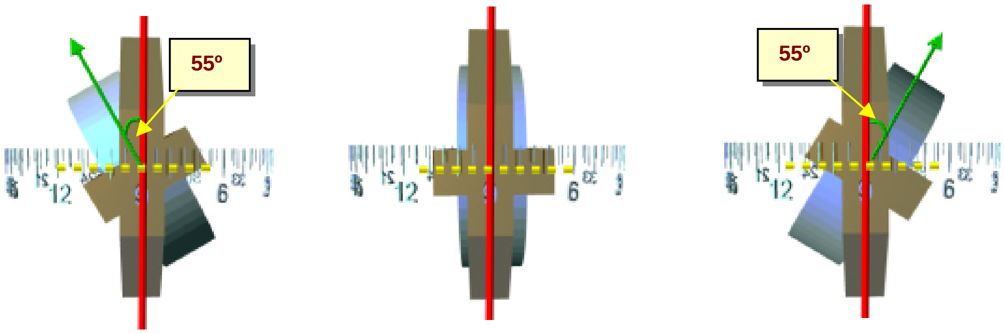
The inner gimbal lies in the horizontal plane and the rotor that it holds ***(a horizontal axis gyro)***, spins in the vertical plane.

The inner gimbal is mounted in the outer gimbal on two pivot points which are 90º removed from the rotor axis.



Inner Gimbal

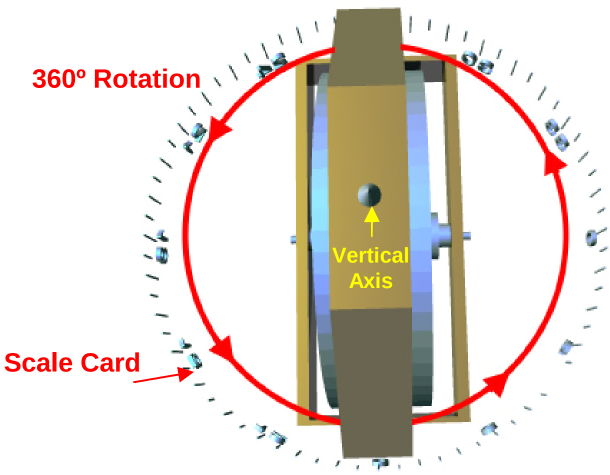
The movement of the inner gimbal on its pivot points about the horizontal axis is restricted to 110º, that is 55º either side of the rotors vertical plane.



This limits the aircraft's manoeuvres in pitch and roll and if these limits are exceeded, the inner gimbal will come in contact with a mechanical stop and the gyro will precess or topple.

This restriction on the old type of DGI's is necessary in order to prevent the inner gimbal from coming in contact with the outer gimbal and damaging the instrument.

Outer Gimbal

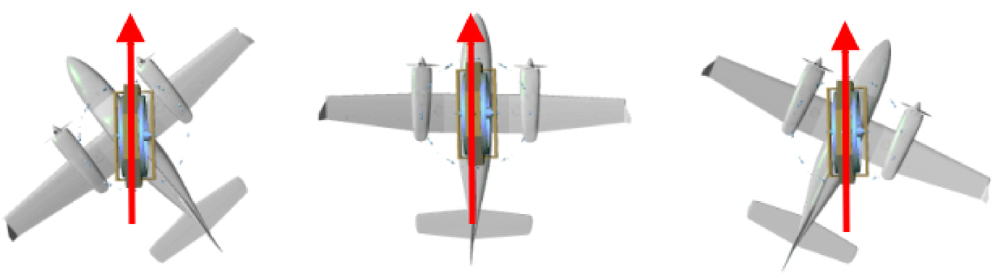


The outer gimbal ***(in which the inner gimbal lies)***, should allow movement of the rotor in the horizontal plane.

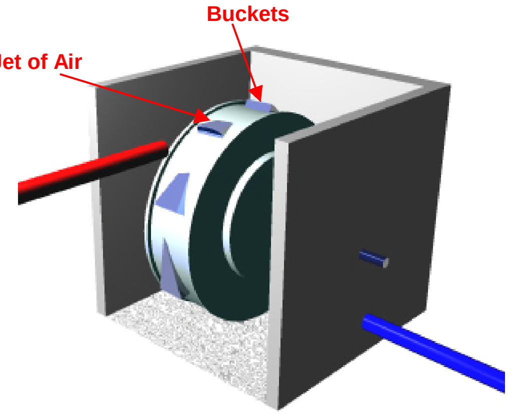
The outer gimbal is mounted in the case of the instrument and pivots around a vertical axis, in a horizontal plane.

The outer gimbal has freedom in the horizontal plane of 360º and it also carries the scale card from which headings are read in the cockpit.

The case of the instrument is fixed to the instrument panel of the aircraft and during turns, the aircraft and the gyro case turn around the whole gyro assembly ***(the assembly maintaining a fixed direction relative to a fixed point in space)***.



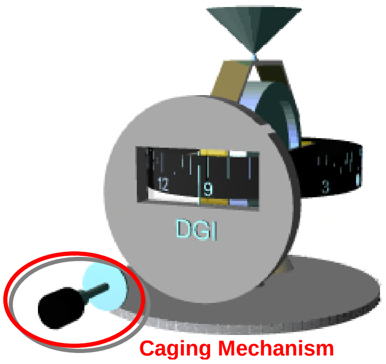
Gyro Driver



The rotor is driven by a jet of air from a nozzle. The jet of air is the result of a vacuum being created in the case.

The jet of air impinges on small buckets carved out of the rim and spins the rotor at about 10 000 to 12 000 rpm.

Pilot Control

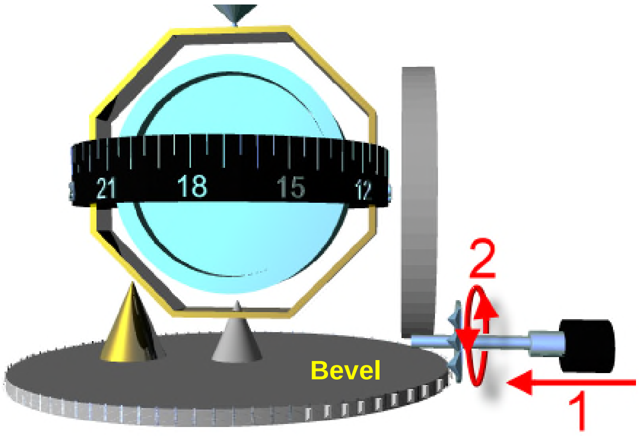


The mechanism that the pilot uses to realign or control the DGI is known as the "caging mechanism".

The initial setting of the heading as well as subsequent resetting during the flight are carried out by means of the gyro caging control.

The caging mechanism is operated by means of a knob on the face of the instrument.

In order to set the required heading on the DGI, the caging knob is depressed and turned until the heading appears in the window.



1. When the caging knob is depressed, a gear on the shaft attached to the knob engages a bevel gear that is part of the outer gimbal.

2. When the caging knob is turned , it turns the bevel gear on the outer gimbal. The cylindrical scale is also attached to the outer gimbal and thus the heading display in the cockpit is also adjusted.

If we change the direction in which the gyro axis is pointing with the caging mechanism, we are actually applying a force to the gyro.

In order to prevent damage to the instrument when adjusting the heading or when executing manoeuvres that are likely to exceed the limits of the instrument, the caging knob also operates the caging mechanism that locks the inner gimbal ***(thereby preventing any movement of the gyro in the vertical plane)*.**

Serviceability Checks:

Ensure the following:

- ✓ the glass is clean;
- ✓ the manual alignment functions; and
- ✓ it turns in the correct direction (during taxi) and without delay.

Errors and Adjustments

Because the gyro is a mechanical device it is subject to errors known as drift or topple, these errors are brought about by rotor bearing friction, unbalanced gimbals, excessive manoeuvres or even turbulence. If the gyro wanders in the horizontal plane it is known as drift, in the vertical plane this is be known as topple, and in severe cases, topple may cause the compass card to spin and oscillate on its axis; in these instances the instrument becomes useless and must be realigned with the magnetic compass.

As described above the DG needs a reference point when set for a directional heading, this is accomplished by aligning the compass card with the magnetic compass prior to takeoff.

For reasons just discussed, during the course of a flight the DG will drift or wander and will need to be reset on a regular basis as the flight progresses; common practice is to realign with the magnetic compass every 15 – 20 minutes, whilst flying wings level (unaccelerated flight) for about 30 seconds.

Hydraulic Systems and Fluids

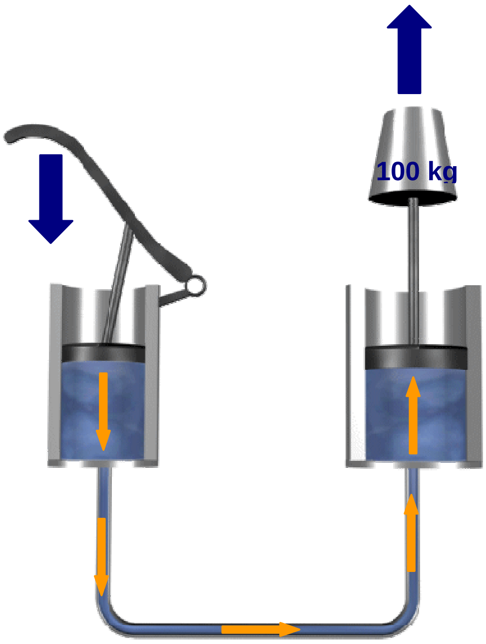
Hydraulic Systems

A hydraulic system affords a convenient way of transmitting power for the operation of devices such as retractable undercarriages, flaps and wheel brakes. These are devices that require considerable power for short periods at infrequent intervals. Hydraulics are also used in powered control systems for example to move flight control surfaces.

Flaps and undercarriage of this B747 is operated by means of hydraulic power.

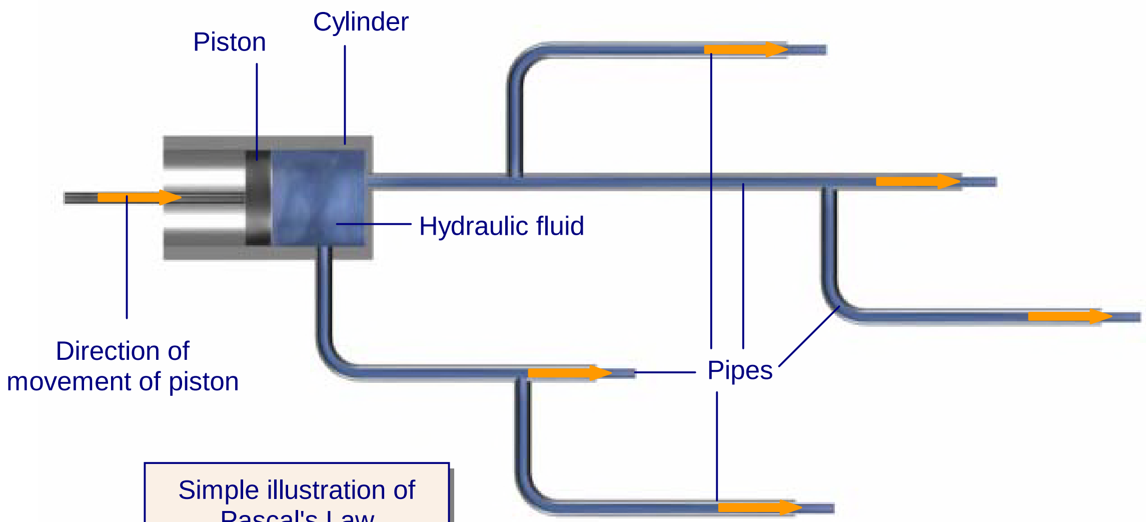
Description

Hydraulic systems are used primarily to transmit and distribute forces. Liquids are able to do this because they are incompressible.



Simple illustration of the principle of hydraulic power

Pascal's Law states, "Pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other part." Thus, if a number of passages exist in a system, pressure can be distributed through all of them by means of the liquid.



Simple illustration of Pascal's Law

In hydraulic systems, power is transmitted as **fluid pressure** to a mechanism, which converts this power into **mechanical work**.

Mechanical Work

In this context, actions like a cycling undercarriage or the movement of control surfaces, flaps, etc.

Fluid Pressure

Because the hydraulic fluid is not compressible, the force exerted on it is "carried over" to the areas that are in contact with the hydraulic fluid. This "force" or pressure in the fluid is known as fluid pressure.

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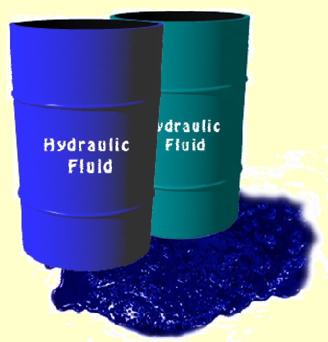
Hydraulic Fluid

Over the years, considerable effort has gone into the development and improvement of hydraulic fluids. As the material used in aircraft construction changed, so did the composition of hydraulic fluids.

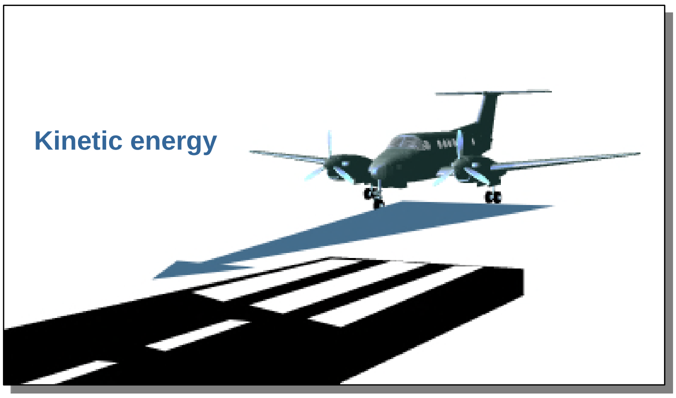
There are **three main types** of hydraulic fluid (i.e. each type uses a different base):

Vegetable based hydraulic fluids	**Mineral based hydraulic fluids**	**Synthetic hydraulic fluids**
		
▪ These hydraulic fluids are composed essentially of castor oil and alcohol.	▪ These fluids are processed from petroleum.	▪ Synthetic hydraulic fluids are normally phosphate ester (synthetic) based.
▪ It is dyed **blue** for identification purposes.	▪ It is dyed **red** for identification purposes.	▪ It is dyed **purple** for identification purposes.
▪ Vegetable based hydraulic fluid is flammable.	▪ This type of fluid is also flammable.	▪ It is fire resistant.

Note: Brake fluid of differing type must not be mixed. Hydraulic component materials, such as seals, may be damaged if they come into contact with incorrect fluids.

Braking Systems

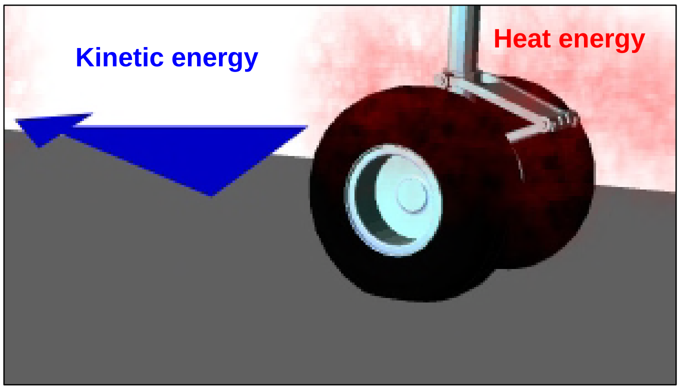
The relatively high weights and speeds at which many aircraft touch down for landing places a severe load on the wheel brakes which have to convert the aircraft's motion, (kinetic) energy, into heat and then dissipate the heat.



Brakes are also used to perform the following:

- Slowing the aircraft down during the landing roll.
- Stopping the aircraft.
- Steering.
- Holding the aircraft against power.

In general all braking systems work on the principle of rubbing two surfaces together, resulting in the conversion of kinetic energy into heat energy.

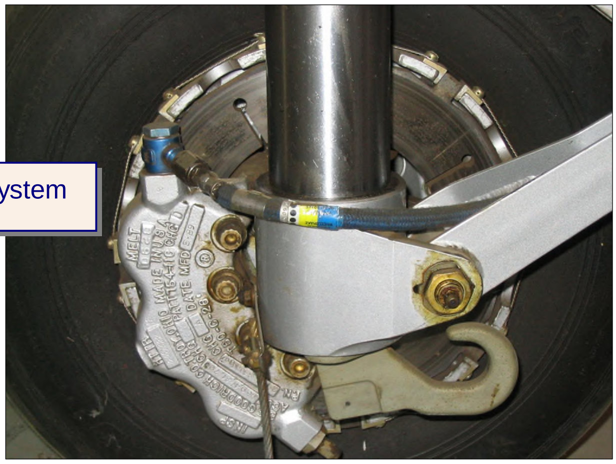


A typical light aircraft braking system would include the following components:

- Fluid Reservoir.
- Master cylinder.
- Slave cylinder.
- Brake disc assembly.
- Brake linings.
- Actuator (caliper) unit.

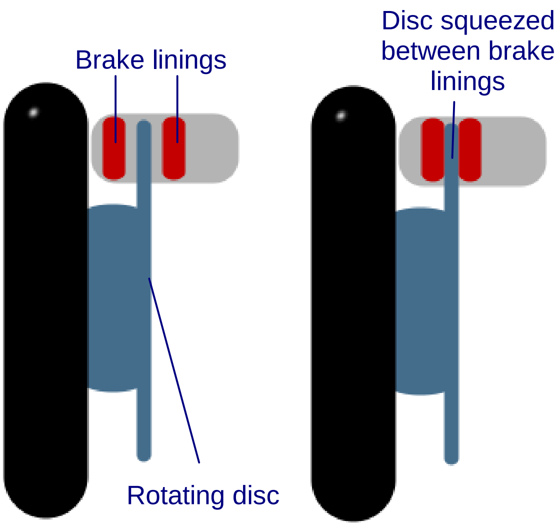
The most common braking system in use is a hydraulically actuated disc system.

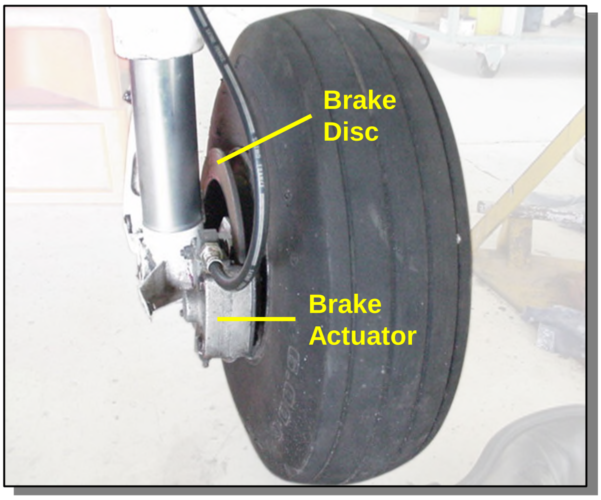
Disc Braking System

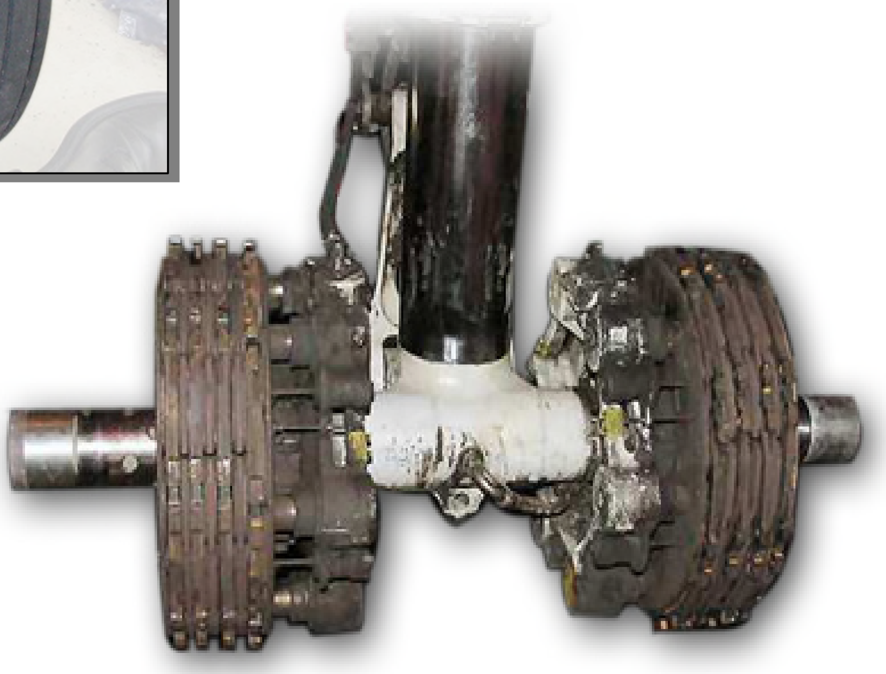


Disc Brakes

This type of braking system makes use of a rotating disc attached to the hub of the wheel. This disc rotates within a stationary assembly containing the brake linings, positioned on either side of the disc. As the brakes are applied, hydraulic pressure forces the linings onto the disc and the braking action is accomplished.



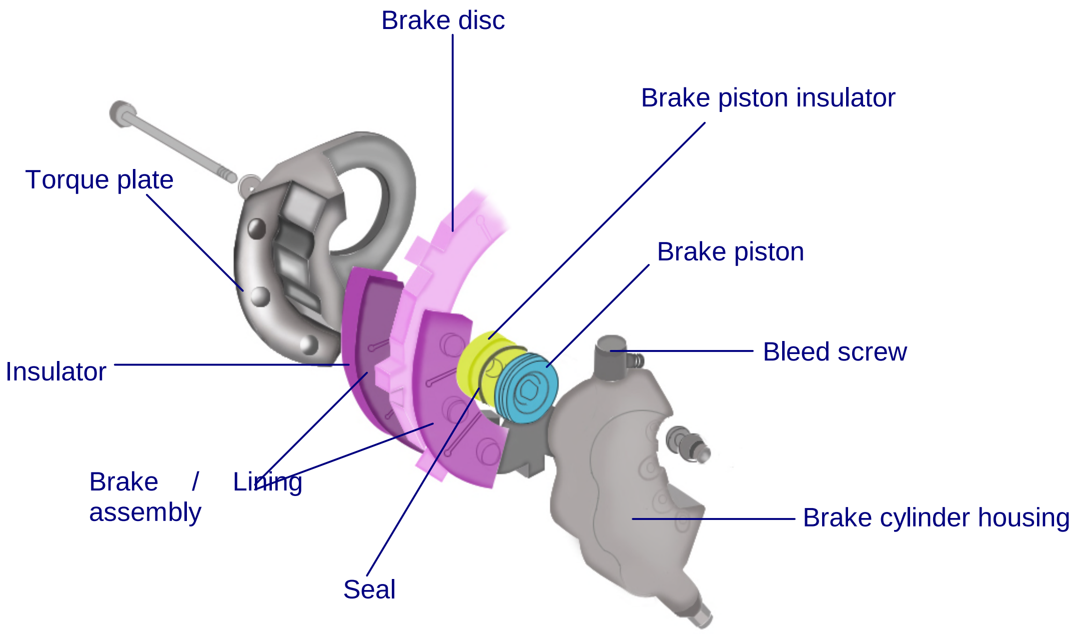




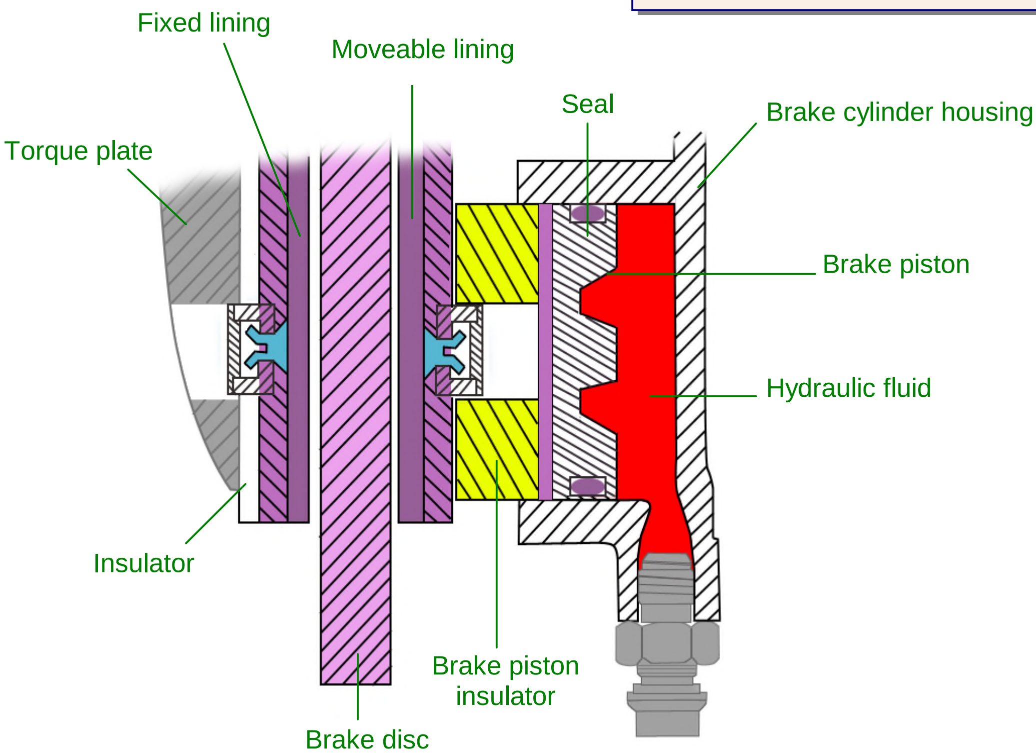
Larger aircraft will be fitted with multi disc brake units as illustrated above

Typical Disc Brake Assembly

When the brakes are applied, hydraulic fluid pushes a movable lining connected to a piston onto the brake disk, which in turn moves onto the stationary lining.



Schematic diagram of a typical brake unit

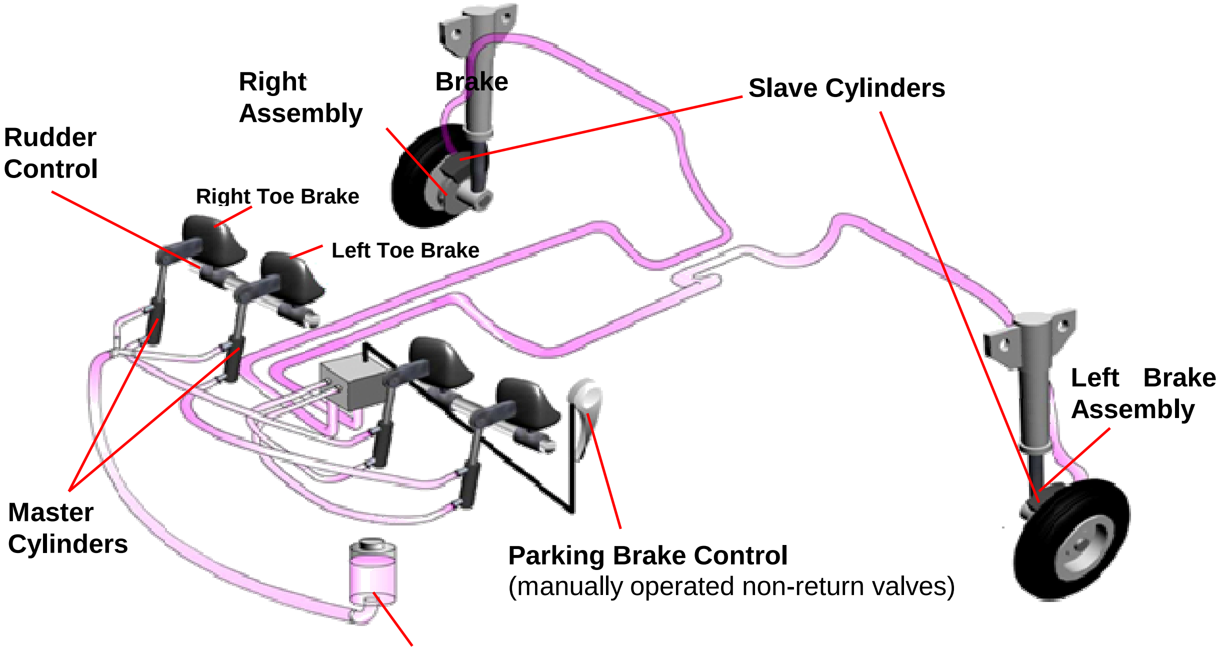


Light aircraft Brake System

The pressure on hydraulic fluid is raised in the master cylinders by the action of the pilot pushing the brake pedals. This pressure is then transmitted from the master cylinders to the piston in the slave cylinder of the brake actuator. The piston moves and applies pressure to the brake linings which clamp against the rotating brake disc.

Each brake system is independent of the other, differential braking is used to assist steering by applying pressure to the right or left brake pedal as required; the spring in the master cylinder returns the brake pedal to its original position

This hydraulic system should be completely free of air, however if some air did get into the system the brake pedals would feel very spongy (springy), and braking effectiveness would be reduced.



The parking brake is an integral part of the main brake system. To apply the parking brake, foot pressure must be applied to put the brakes ON. The parking brake control is then applied, locking in system pressure. Thus two actions are required to apply the parking brake: - foot pressure and parking brake ON. To release the parking brake only the control lever needs to be moved to OFF.

Parkbrake - ON

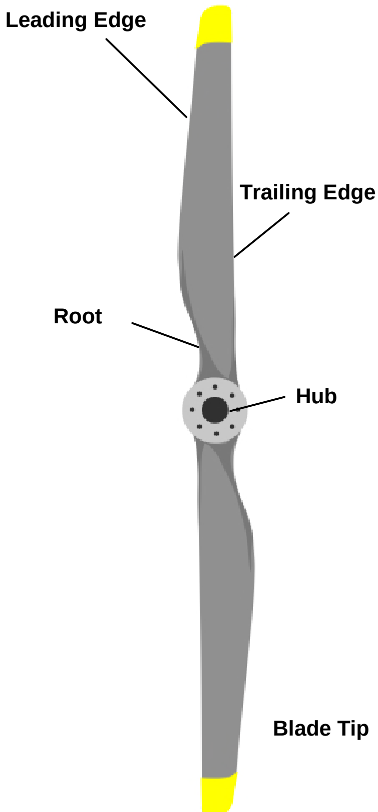
Parkbrake - OFF

Propellers

Familiarisation and Terminology

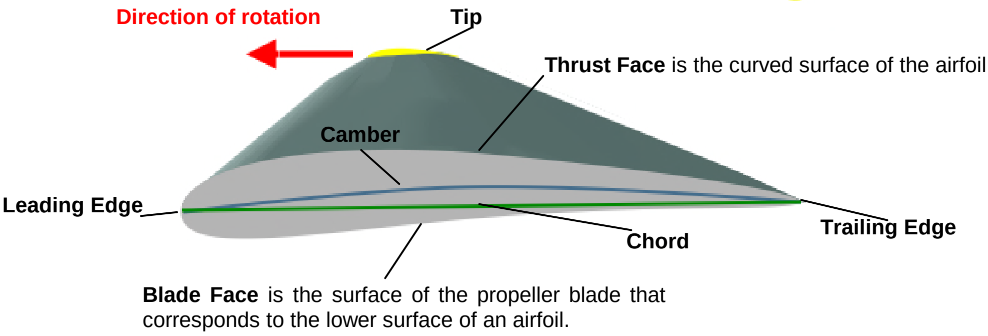
The propeller is designed to move the aircraft through the air. A propeller will consist of two or more blades, fixed to a hub, which serves to attach the blades to the engine crankshaft.

The blades are in the shape of an aerofoil much like the wing of an aircraft, and like the wing, the blades produce a force (Lift) when they rotate. This force (called thrust), provides the propulsive element to move the aircraft through the air. The majority of aircraft have propellers which pull them through the air (tractor propellers), while there are those which have propellers which push them through the air (pusher propellers). Either way, the basic designs of propellers are the same, and will have the following:



- **Leading Edge** - the cutting edge that slices into the air. As the leading edge cuts the air, it flows over the blade face and the cambered upper surface
- **Trailing edge –** rear blade surface
- **Root (Blade Shank)** - the section of the blade nearest the hub.
- **Blade Tip** - the outer end of the blade farthest from the hub.
- **Hub –** the mount point for the propeller at the crankshaft, an attachment point for moveable blades.

Propeller blade cross-section



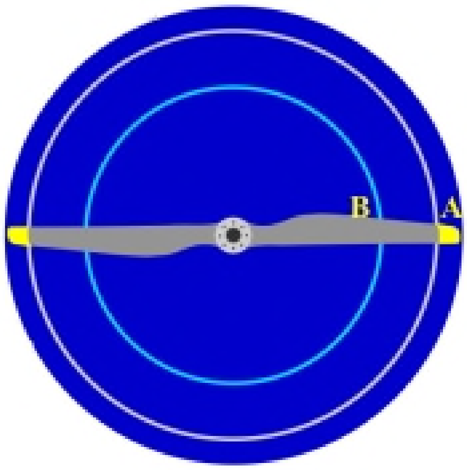
The Motion of the Propeller

Rotational Velocity

Because the propeller moves in a circular path, it is affected by the same laws of physics as any other object travelling in a circular path.

The circular path followed by the propeller is referred to as the **Plane of Rotation.**

A point on the propeller blade closer to the hub will move slower than a point at the outer edge. **A will have a greater rotational velocity than B.** This needs to be taken into account with blade size, particularly the length of the blade; if the tip speed approaches the speed of sound the propeller efficiency is drastically reduced.

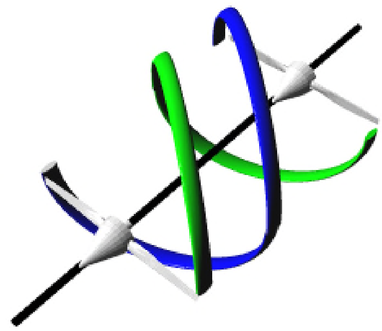


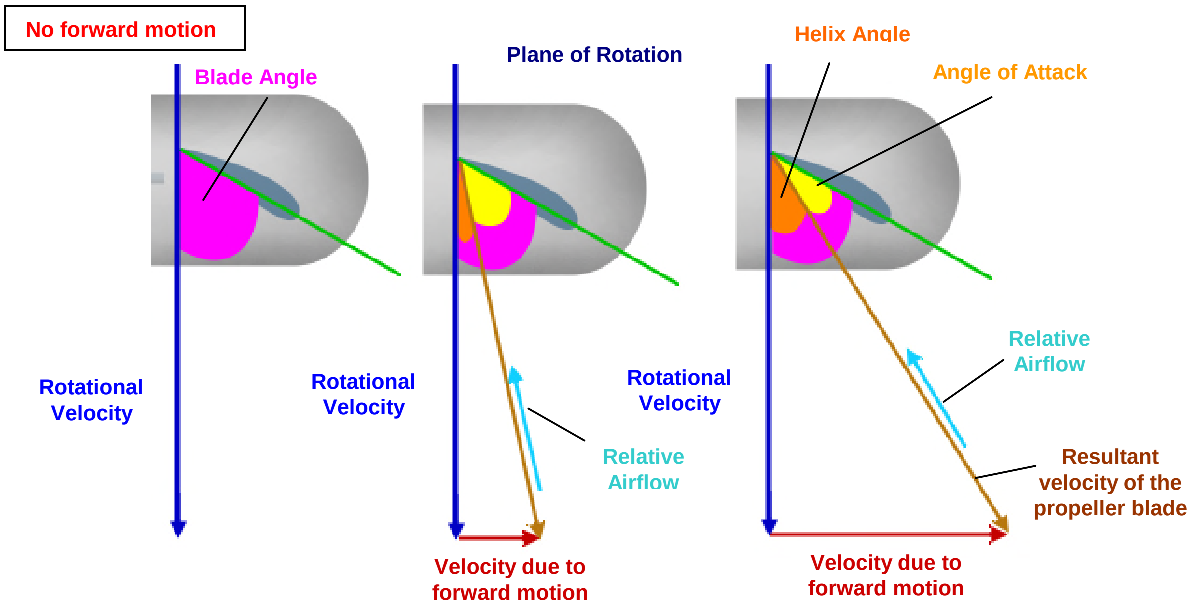
It is therefore apparent that at a constant RPM, the rotational velocity of a blade element will increase as the radius (r) increases towards the propeller tips.

Forward and Resultant Velocity

Apart from the movement around the plane of rotation, a propeller moves forward with the aircraft in the air, which when combined with the **rotational velocity** results in an overall **resultant velocity**.

This **rotational velocity**, combined with the **forward velocity**, means that each section of the blade follows a helical path (corkscrew) through the air.



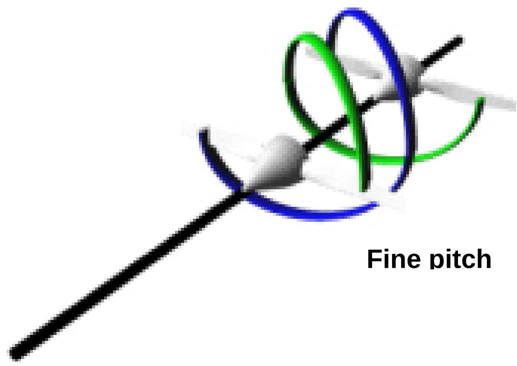


Helix Angle + Angle of Attack = Blade Angle

As the **resultant velocity** changes, the **relative airflow** (RAF) on the blade section also changes, and with it the angle of attack on the blade section. As with general aerodynamics, the angle of attack is that angle between the relative air flow, and the chord line of the aerofoil. In the diagram, the angle of attack is represented in yellow.

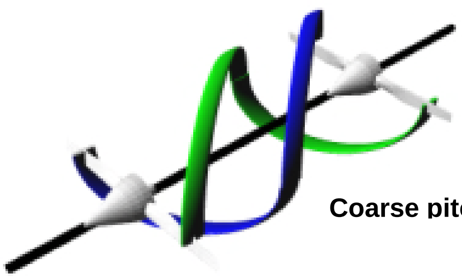
The orange angle indicated on the diagram, is termed the helix angle (or the pitch angle, or the angle of advance). Pitch can be described as the distance that a propeller will advance through the air for each rotation or the amount of "bite" that the blade has on the air.

- **A fine pitch propeller** has a low blade angle, it will move forward a small distance with each revolution and take a 'small' bite of the air. It requires relatively low power to rotate, allowing high propeller rpm, but achieves limited airspeed.

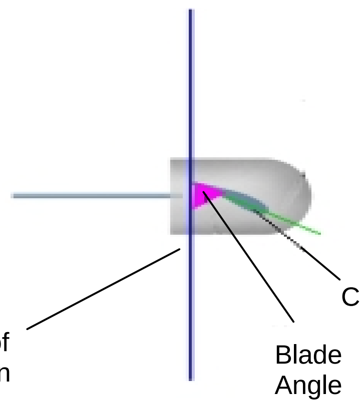


Fine pitch

- **A coarse pitch propeller** has a high blade angle and will advance a further distance through the air with each rotation; during each revolution it will take a large 'bite' of the air. It requires greater power to rotate, limiting the propeller rpm that can be developed, but achieving high airspeeds.



Coarse pitch

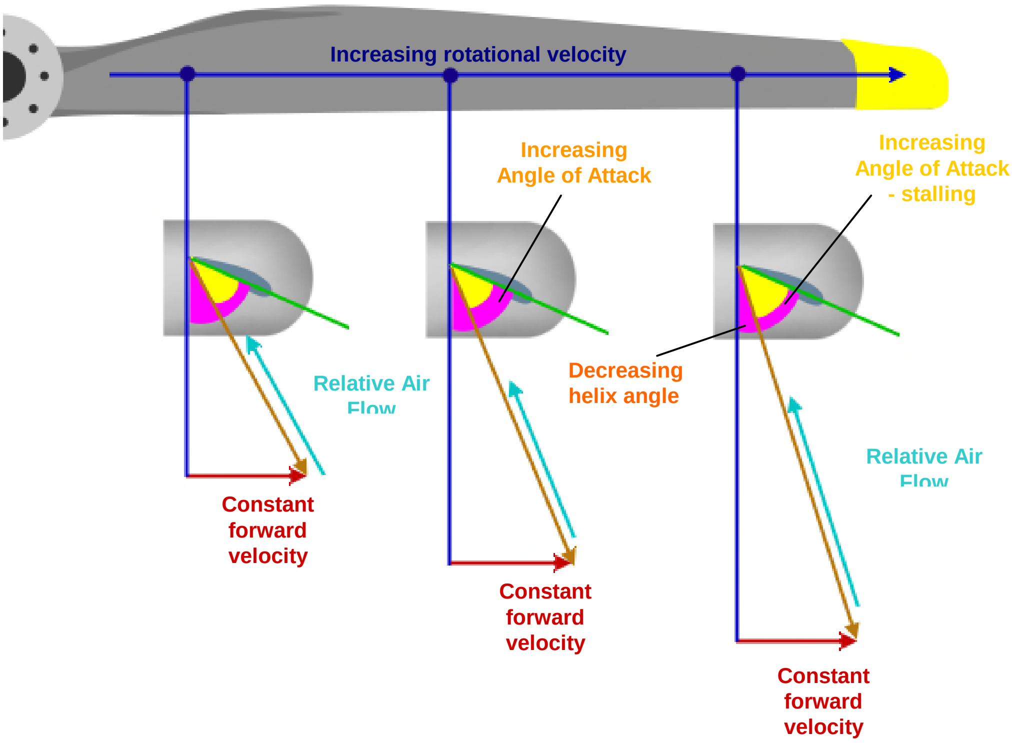


The Angle measured between the plane of rotation and the chord of the blade is known as the blade angle

Blade Twist

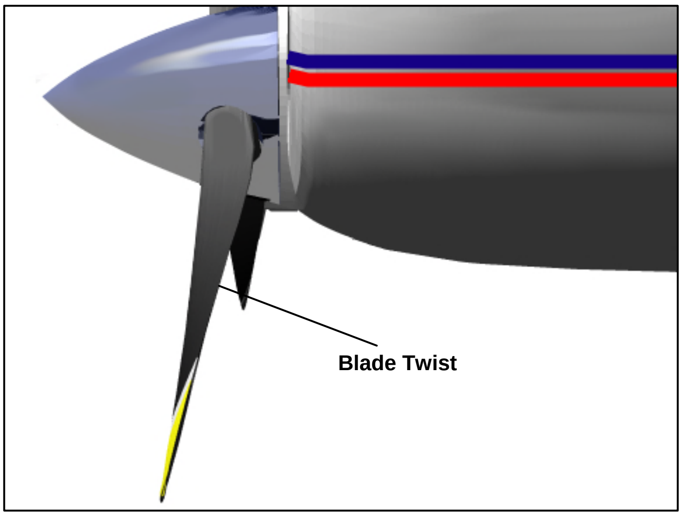
Let us assume that the blade angle of a propeller was the same for its entire length, and that the forward velocity of an aircraft was constant. The only variable therefore would be the rotational speed of various sections of the blade. From the diagram below, we can see that as the rotational velocity increases (towards the tip), the angle of attack increases, while the helix angle decreases. This means that the angle of attack along the entire length of the blade will be different at each point.

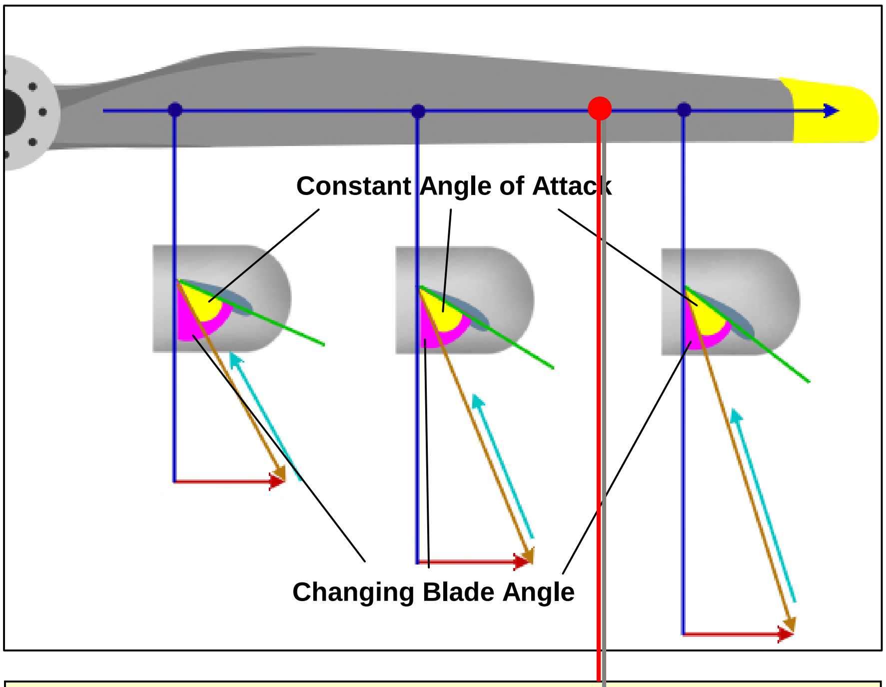
As with an aerofoil, a propeller blade has an angle of attack at which it is most efficient for a specific speed, or RPM and forward velocity. With a changing angle of attack the most efficient angle will only be present at one point on each blade; furthermore, the increasing angle of attack toward the tip can result in the blade stalling!



Designers of propeller blades therefore do not design a blade with a single blade angle but rather twist the blade to ensure a constant angle of attack, and therefore maximum efficiency. This is known as blade twist, and can clearly be seen in propeller blades.

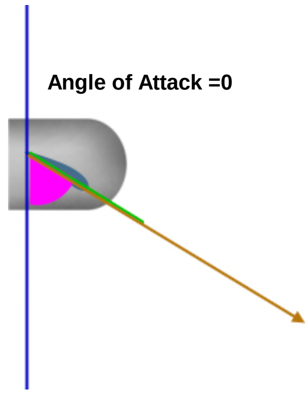
When looking at a blade from the tip toward the root, it is apparent that the angle of the blade changes along the length of the blade. This aids in maintaining the desired angle of attack and maximum efficiency for the blades and the propeller as a whole.



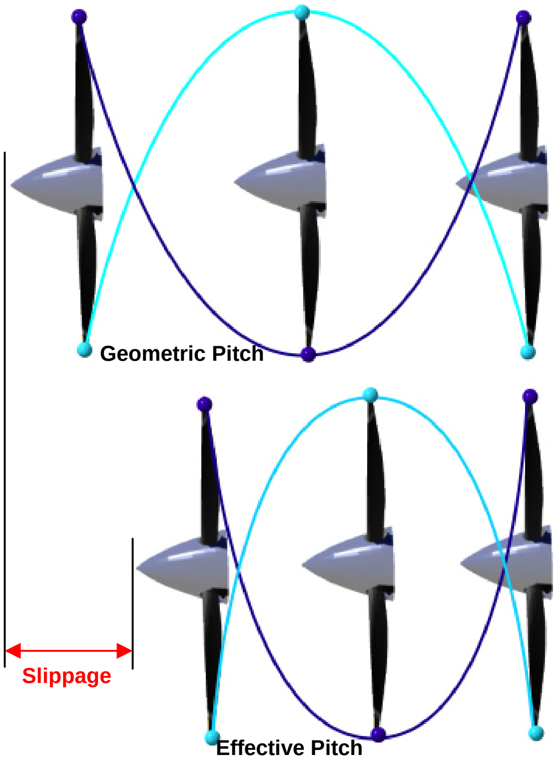


The twist of the blade is achieved by placing blade sections of different angles alongside each other. Because of the twist the blade angle will vary throughout the blade length so normally the standard blade angle is measured at the blade station 75% of the distance from the hub centre to the blade tip.

Propeller Pitch (Advance per revolution)



We have already said that pitch can be described as the distance that a propeller will advance through the air for each rotation. (or the amount of "bite" that the blade has on the air).



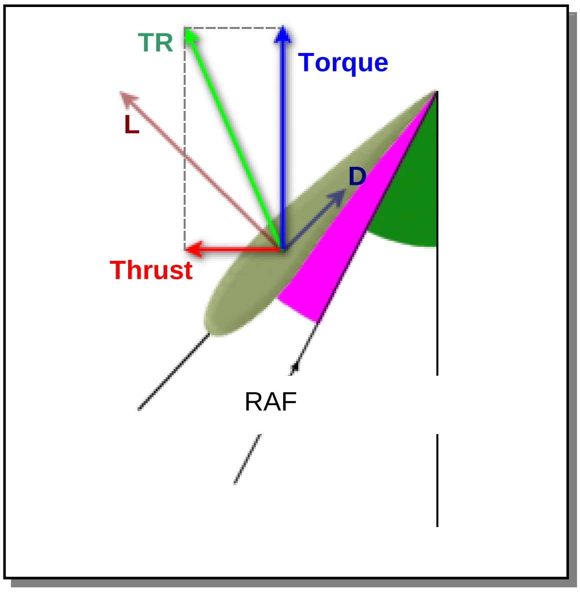
This forward distance for each propeller revolution can be calculated, and is termed the **Geometric Pitch** (*p*). The geometric pitch is calculated for a specific blade section moving along a line parallel to the chord (Angle of attack is 0º). Geometric pitch is thus not concerned with the thrust of the blade section, but is concerned only with the geometric dimensions.

Propellers are usually designed so that all blade stations have much the same geometric pitch.
While the **geometric pitch** is the theoretical distance the propeller would advance in one revolution, the **effective pitch** is the actual distance that the propeller advances in one revolution. Because of the fluidity of air, the geometric is never attained, and effective pitch is always less. The difference between geometric and effective pitch is termed **slippage**.

Forces on a Blade Element

Due to the positive angle (α) at which each blade element is set and the direction of the resultant relative air flow (RAF), the blade section produces **lift** and **drag** in the same way as an aerofoil. However, with a propeller, the forces parallel and perpendicular to the RAF are not the most important.

The forces of interest are those that act along the axis of rotation (**thrust**) and at right angles to the axis of rotation (**torque**).



The propeller torque force is the resistance to motion in the plane of rotation, and just as drag must be overcome to provide lift, so the propeller torque has to be overcome to provide thrust.

Twisting Moments

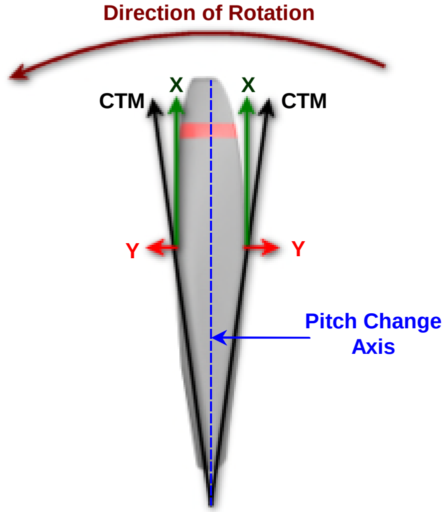
During flight considerable forces and stresses are placed on the engine, propeller and pitch changing mechanisms. The most important of these forces are:

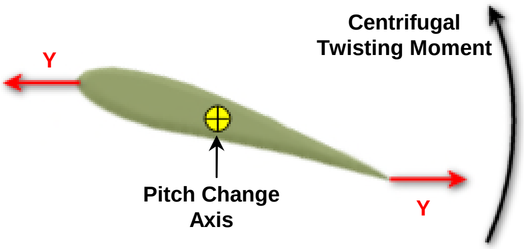
Centrifugal Twisting Moment

The centrifugal force (CTM) that acts on a blade can be divided into two components.

These are the **radial** (x) and **tangential** (**y**) components of the CTM.

The x-component produces a tensile stress at the blade root, while the y-component produces a torque moment about the pitch-change axis.



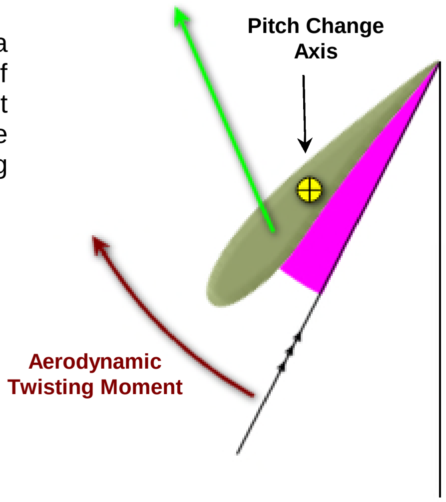


Torque produced by the CTM **y-component** causes a centrifugal twisting moment about the pitch-change axis that tends to <u>"fine", or decrease, the pitch.</u>

Thus, the effort required by the pitch-change mechanism is larger to increase the blade angle than it is to reduce the blade angle.

Aerodynamic Twisting Moment

Aerodynamic twisting moment (ATM) tries to twist a blade to a higher angle. This force is produced because the axis of rotation of the blade is at the midpoint of the chord line, whilst the centre of lift of the blade is forward of the axis. The force tries to increase the blade angle. Aerodynamic twisting moment is used in some designs to help feather the propeller.



This aerodynamic twisting moment will tend to increase the pitch angle of the blade and in so doing, partially offsets the centrifugal twisting moment.

Propeller Efficiency

The efficiency of a propeller is the ratio of useful work given out by the propeller, to the work put into it by the engine.

$$\text{Propeller Efficiency} = \frac{\text{Power Output}}{\text{Power Input}}$$

The **power output** extracted from the propeller is the product of thrust x TAS.

Power input to the propeller has to overcome the rotational drag of the propeller and is the product of propeller torque x rotational velocity ($2\pi N$).

Thus, propeller efficiency can be calculated from:

$$\text{Propeller Efficiency} = \frac{\text{Thrust x TAS}}{\text{Torque x } 2\pi N}$$

The power delivered by a propeller is measured in **thrust horsepower (thp)** while the power delivered by the engine is measured at the propeller shaft in **brake horsepower (bhp)**.

Therefore:

$$\text{Propeller Efficiency } (\eta) \quad \frac{\text{Thrust Horsepower}}{\text{Brake Horsepower}}$$

Variation of Propeller Efficiency with Speed

Fixed pitch propellers are not very efficient, as the angle of attack varies with changes in forward speed.

As forward speed increases, the angle of attack decreases and with it the amount of thrust produced. Thus, maximum efficiency on a fixed pitch propeller is achieved at only one speed for any given propeller RPM.

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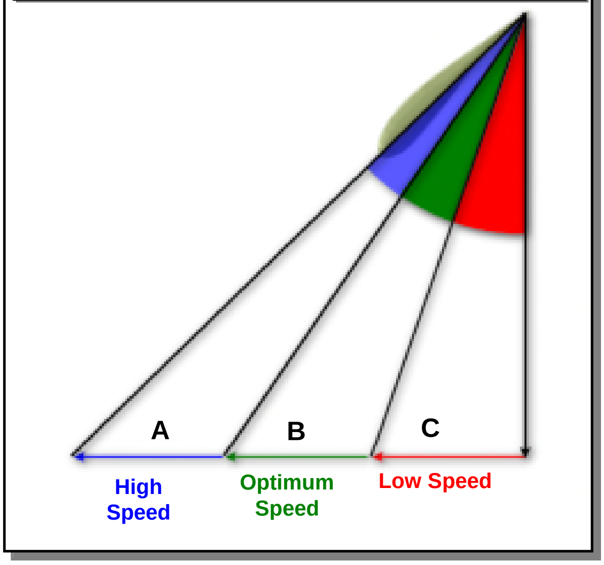
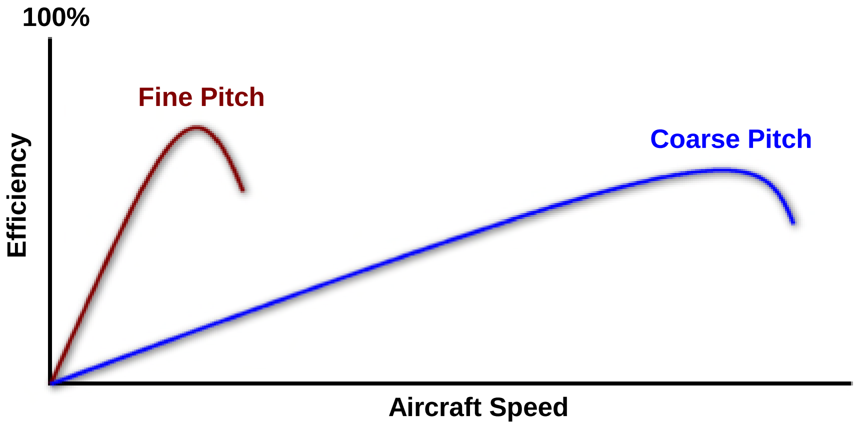
At some **high forward speed** (A) the angle of attack gets close to the zero lift incidence and thus thrust output is zero. Therefore propeller efficiency will also be zero.
The most efficient blade angle of attack and maximum propeller efficiency is found at one speed, known as the **optimum speed** (B).

As the **speed decreases** (C), the thrust will increase due to the increase in angle of attack. As long as the bladeis not stalled, thrust remains large, but efficiency is low due to the low forward speed.

The graphic shows a fixed pitch propeller at constant RPM, but at different forward speeds.



Types of Propellers



Because of the fact that aircraft do not operate at one speed, and rpm setting, the fixed pitch propeller is not efficient for most modern aircraft.

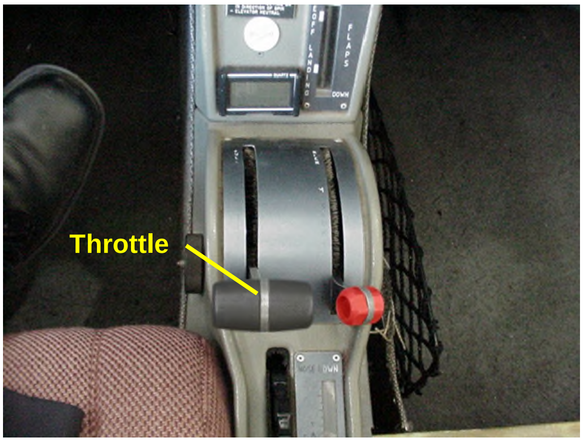
Fixed Pitch Propeller

With a fixed pitch propeller, the pitch of the propeller is fixed at the time of manufacture. Performance of the aircraft is pre-determined, and is limited within the constraints of the propeller and throttle setting. Often when fitting a fixed pitch propeller, a choice of either a climb or a cruise propeller can be made.

- The climb propeller is usually chosen when the aircraft normally operates from a restricted airfield or in high density altitude conditions. The climb propeller will produce maximum efficiency at full throttle around the best rate of climb airspeed and will perform fairly well at take-off, but during the initial take-off acceleration the climb propeller may restrict the engine rpm to less than 75% power.

- The cruise propeller will achieve maximum efficiency at 75% power at airspeeds around the design cruising speed but aircraft take-off and climb performance will not be the optimum. The cruise propeller usually has a little more pitch than the standard propeller fitted to the aircraft. A high speed propeller might be fitted when the aircraft is intended to be operating at, or above, rated power for short periods – in speed competition for example.

A climb propeller has a relatively fine pitch and a cruise propeller has a relatively coarse pitch, engine rpm can only be varied by use of the throttle.



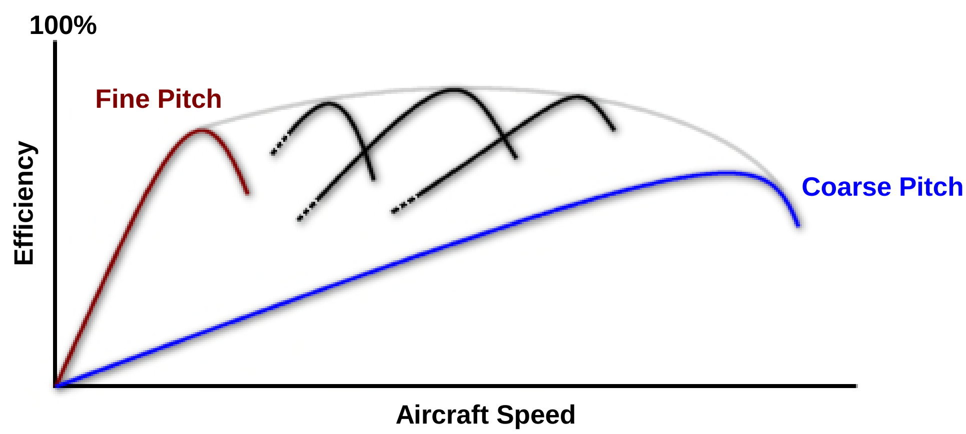
Variable Pitch Propeller

Due to the limitations of fixed pitch propellers a variable pitch propeller was developed; it can be controlled in flight to provide improved performance in each phase of flight. Typically one would take-off in a fine pitch allowing the engine to develop reasonable revolutions, before increasing the pitch as the aircraft accelerates to cruising speed.

As piston engine power settings are defined by RPM and MAP (manifold air pressure), the constant speed propeller allows the pitch and thus, the RPM, to be selected anywhere between the fine and coarse pitch stops within the propeller.

Once an RPM is selected, the engine speed is maintained by the pitch control unit or governor, despite any power or airspeed changes.

The main advantage of a fully variable pitch or constant speed propeller is the overall improvement in efficiency. As can be seen on the graph below, the efficiency of a constant speed propeller can be utilised across a wide range of aircraft speeds.



Constant Speed Propeller

With constant speed control, the pitch is automatically altered by a constant speed unit (CSU) or governor; this unit is engine driven and fitted to the accessory drive housing. After setting the desired engine/propeller speed with the propeller control, the governor acts to keep the propeller rpm at the same value.

If the governor detects the propeller speed increasing, it increases the pitch to restore the selected rpm. If the governor detects the propeller speed decreasing, it decreases the pitch to restore the rpm back within limits.

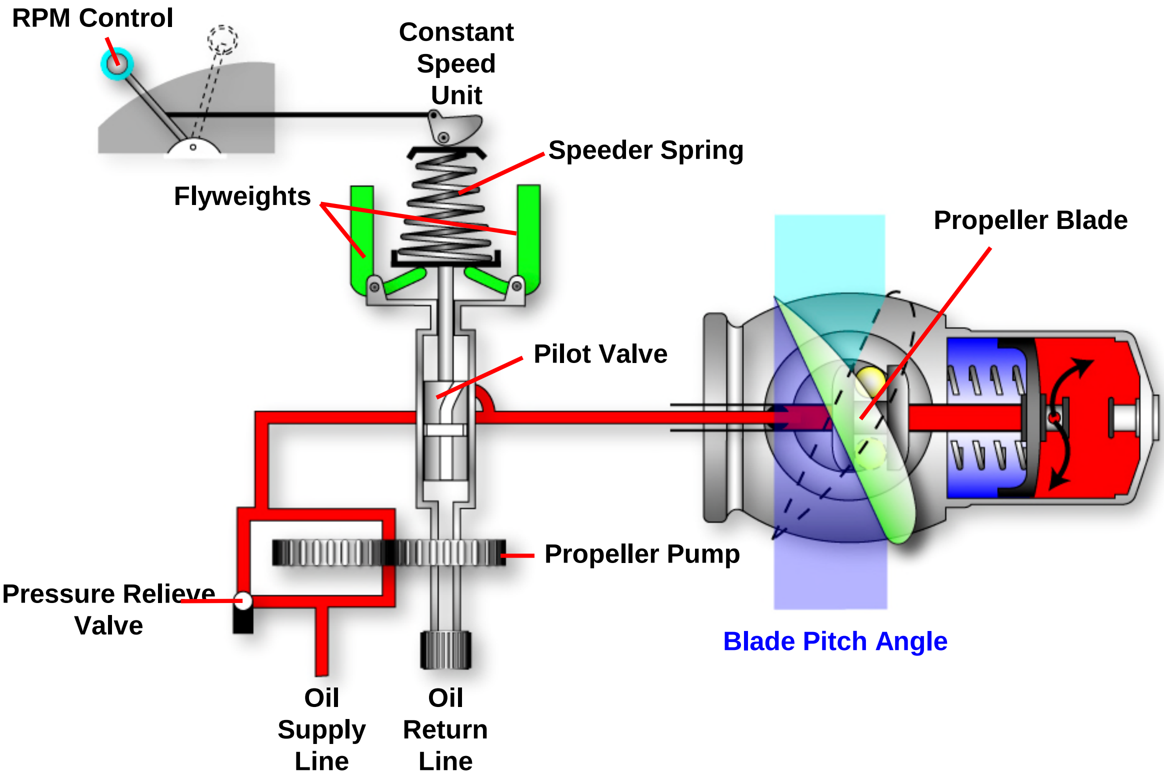
The Constant Speed Unit (CSU) or Governor

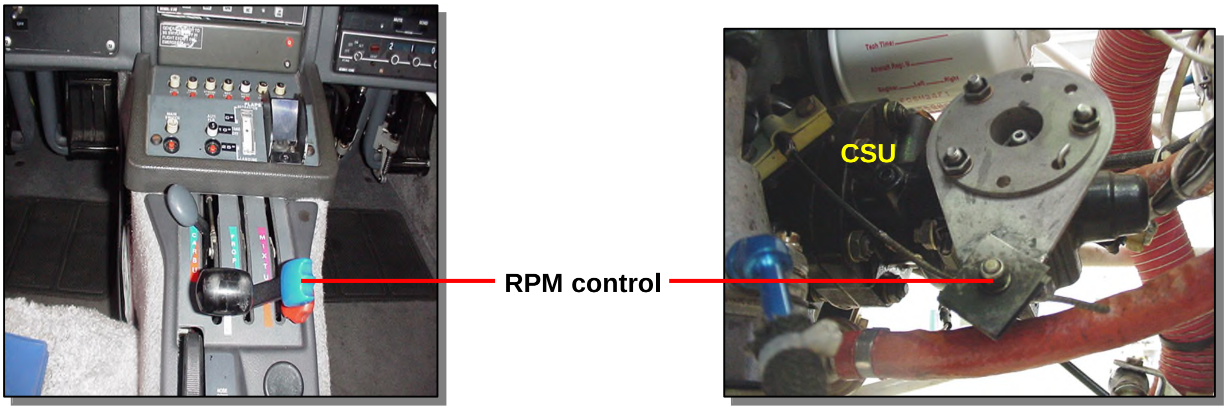
The Governor supplies and controls the flow of engine oil to and from the pitch control mechanism. It serves to maintain a selected propeller RPM setting by applying or removing the pressure within the control mechanism, and in so doing controls the pitch of the propeller.

The engine driven governor receives oil from the engine lubricating system and boosts its pressure to that required to operate the pitch-changing mechanism.

It consists essentially of:

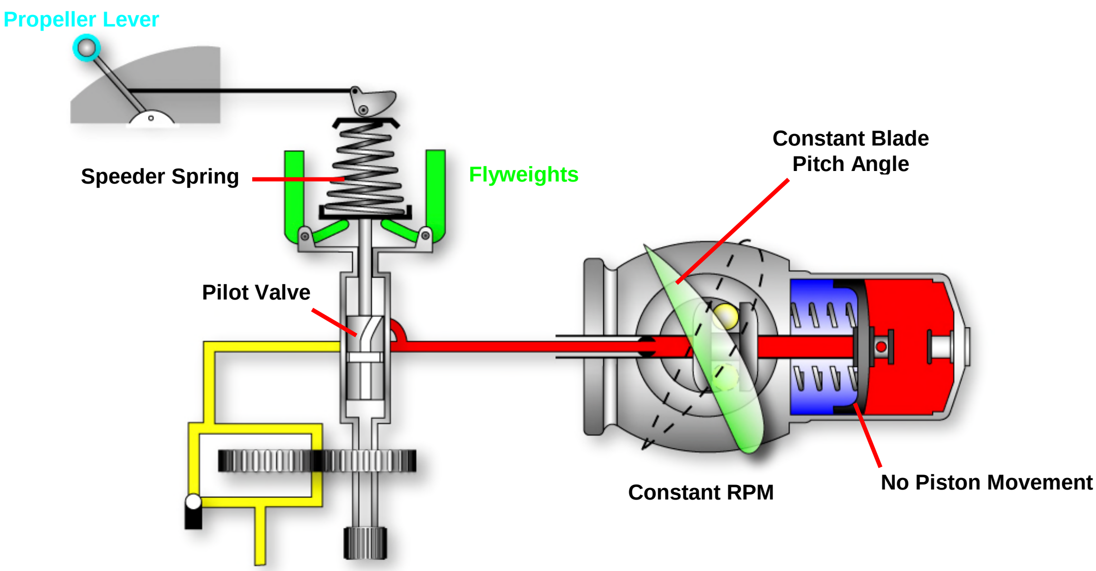
- A gear pump to increase the engine oil pressure to a higher value required for propeller pitch change operation.
- A pilot valve actuated by flyweights and opposed by a speeder spring, which controls the flow of oil through the governor
- The speeder spring provides a means by which the initial load on the pilot valve is applied; the tension can be varied from the cockpit using the rpm control lever.





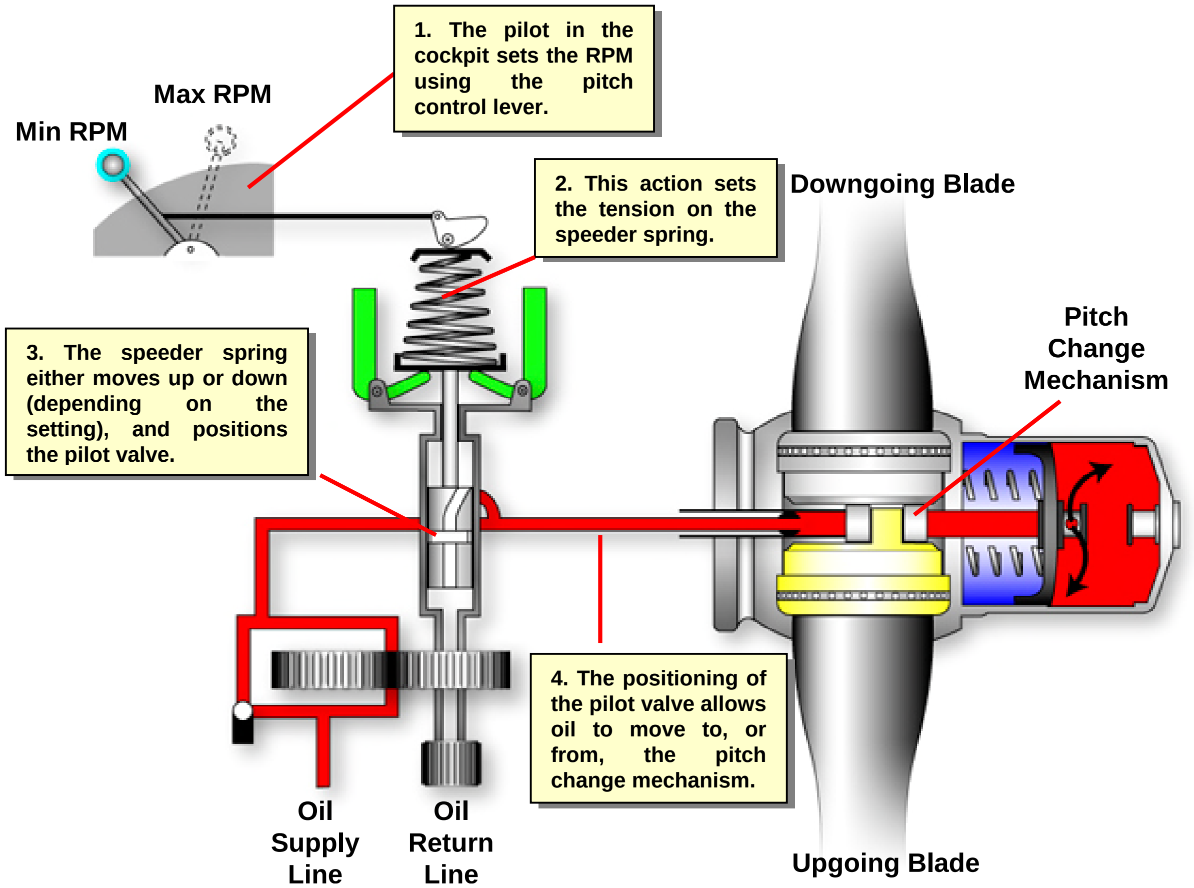
Maintaining the RPM

Movement of the propeller lever sets the speeder spring pressure. The flyweights position the pilot valve to direct oil to or from the propeller. This, in turn, positions the propeller blades at a pitch angle that absorbs the engine power at the RPM selected. When the moment of RPM balance occurs, the force of the flyweights equals the speeder spring load. This positions the pilot valve in the constant RPM position, with no oil flowing to or from the propeller. This balance represents the constant RPM.



RPM Control

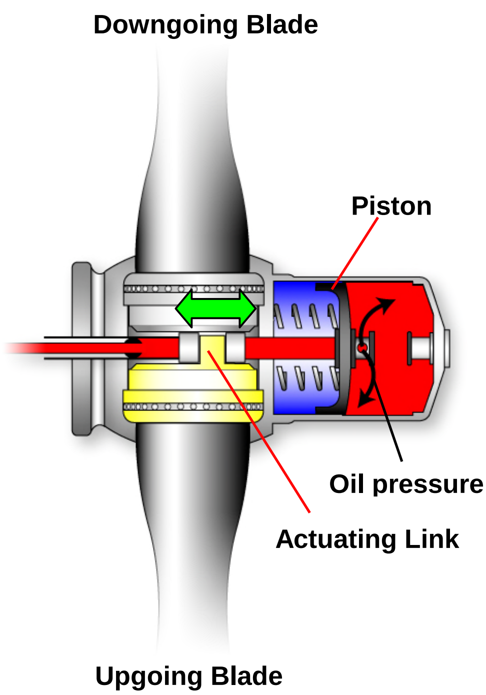
As the blade angle of a propeller is decreased, the torque required to turn the propeller is reduced and, for any given power setting, the RPM of the engine will tend to increase. Conversely, if the blade angle increases, the torque required increases and the engine and the propeller, will tend to slow down. By changing the blade angle, RPM will change.



The governor itself does not alter pitch; it merely controls the flow of oil to the mechanism that alters propeller pitch.

The system permits the pilot to select or set a desired RPM. When maximum power at low air speed is required for take-off, the pilot pushes the propeller lever full forward. With full throttle, this gives low pitch and maximum RPM, which whilst satisfactory for getting off the ground, is not desirable for cruising at high air speeds. For cruising, the pilot sets the manifold pressure with the throttle then adjusts back on the propeller control. This increases the pitch, and the engine speed settles to the desired RPM for cruise conditions. The RPM automatically stays set, until the propeller lever is moved again.

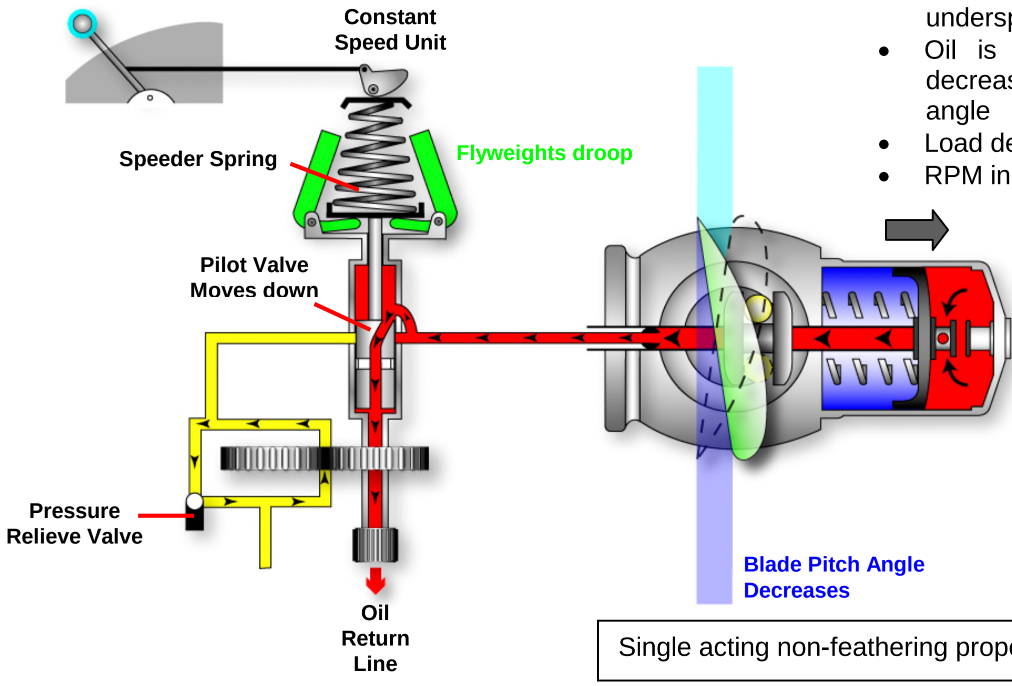
In the propeller hub, oil pressure acting on a piston produces a force that is opposed by the natural centrifugal twisting moment (CTM) of the blades. To increase the pitch or blade angle, we direct high pressure oil to the propeller. This moves the piston back. Motion of the piston is transmitted to the blades through the actuating links moving the blades toward high pitch.



When the opposing forces are equal, oil flow to the propeller stops, and the piston will stop. The piston will remain in this position, holding the pitch of the blades constant until the governor or CSU, directs oil flow to or from the propeller.

When a constant RPM is set, if the airplane begins to climb or engine power is reduced a temporary under speed results. Airspeed is reduced and, since the pitch of the propeller blades is too high, the engine starts to slow down. However, the instant this happens the flyweights will droop, causing the pilot valve to move down. Then oil flows from the propeller and CTM interacts, thus reducing the pitch of the blades. This automatically increases the speed of the engine to maintain the former RPM setting.

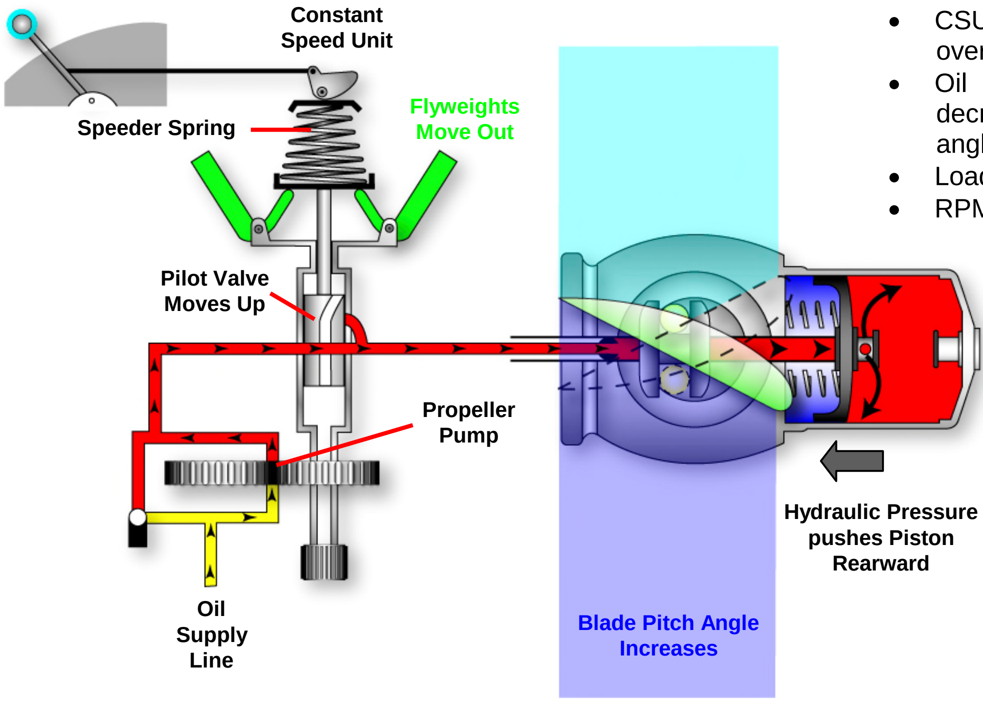
- CSU senses the underspeed
- Oil is directed to decrease blade angle
- Load decreases
- RPM increases



Single acting non-feathering propeller

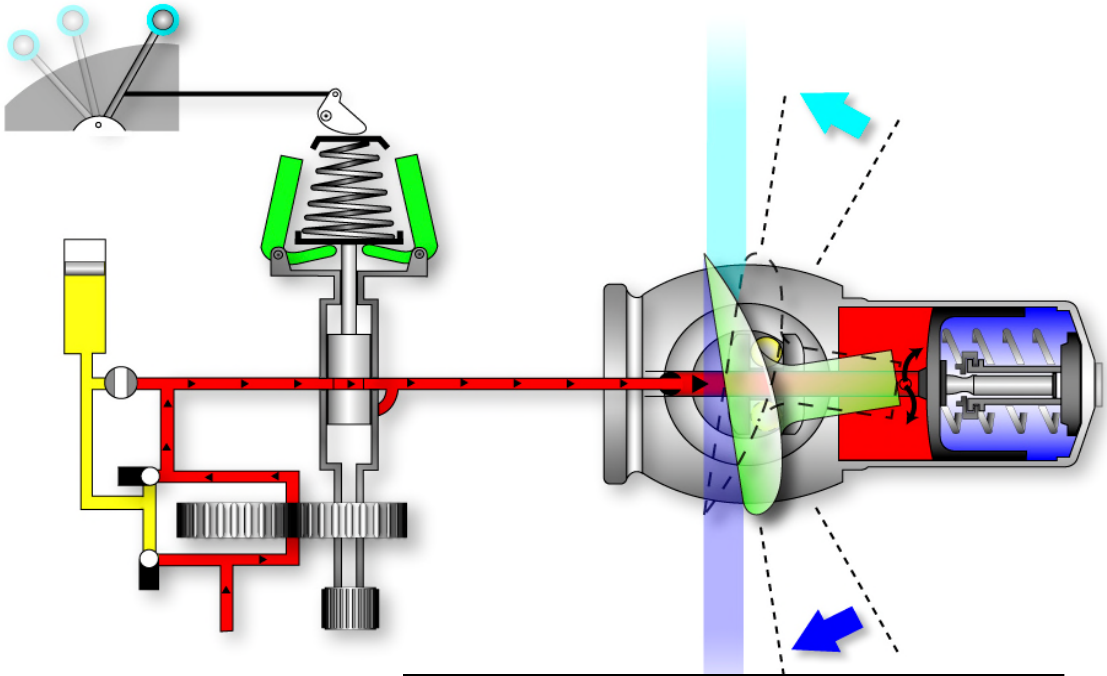
If the aircraft is put into a descent or engine power is increased, this causes a temporary over speed. The airspeed increases as the pitch of the propeller blades is too low to absorb engine power, and the engine RPM begins to increase. The instant this happens, the flyweights move out and raise the pilot valve which causes oil to flow to the propeller, increasing the pitch of the blades. Engine speed then slows down to maintain the original RPM setting.

- CSU senses the overspeed
- Oil is directed to decrease blade angle
- Load increases
- RPM decreases



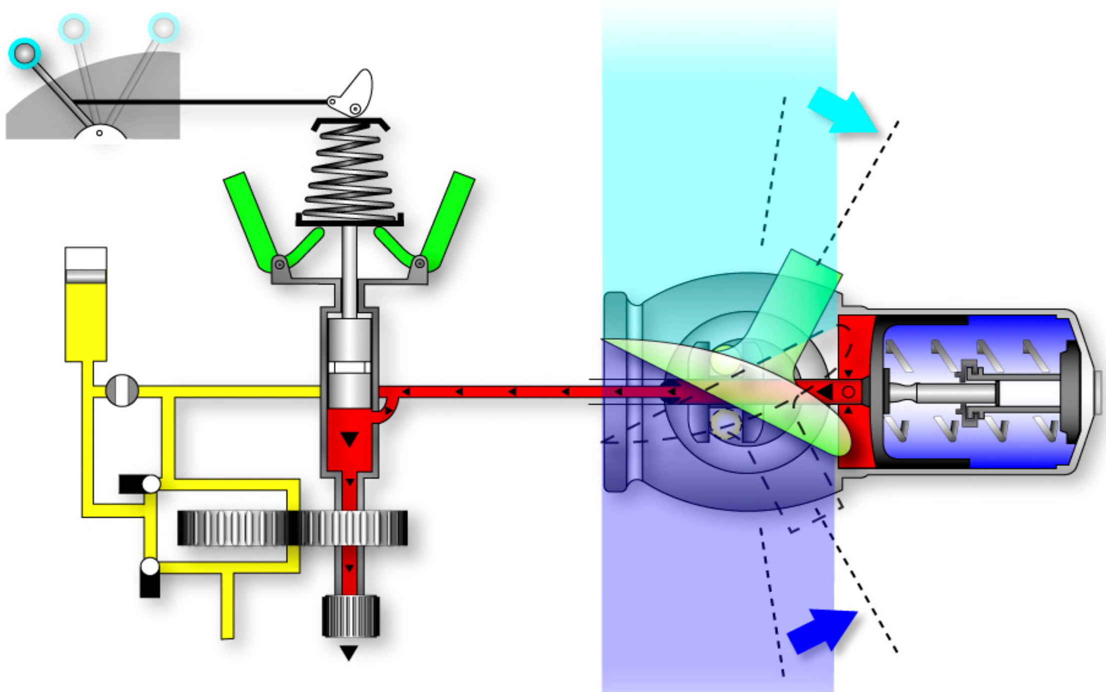
Single acting non-feathering propeller

We have so far only discussed propellers for Single Engine aircraft. Twin engine aircraft use Single Acting Counterweighted Feathering props.



Single acting counterweighted feathering propeller

These work the opposite way to Non Counterweight props in that oil pressure moves the prop to fine and ATM , CTM Oil ,Air and spring pressure move it to coarse.



Single acting counterweighted feathering propeller

They normally have pitch locks to prevent the prop going to coarse on shut down, This also means that the prop must be turning above a certain RPM (normally about 1200 RPM) to enable it to be feathered.

Pitch Stops

Mechanical stops are installed in the propeller to limit blade travel in both the high and low pitch directions. These stops are known as the fine and coarse pitch stops.

Whenever manifold pressure is decreasing, engine power will reduce and the blades will adopt a finer and finer blade angle until they reach the fine pitch stop. Any further reduction in MP will cause a drop in RPM, from this point the propeller behaves like a fixed pitch propeller.

During a fast cruise descent, if the throttle is not moved, the RPM will increase as propeller torque reduces, and the propeller moves progressively coarser. If it reaches the coarse pitch stop and this condition is maintained, the engine will over speed from the coarse pitch stop.

If RPM is higher or lower than the indicated power lever position, then the system is operating outside its normal operating range and cannot keep the RPM constant.

There are some further considerations when discussing fine and coarse pitch stops. When checking for a magneto drop the propeller is set to fine pitch and behaves as a fixed pitch propeller, this enables an rpm drop to be observed. If left in the governing range, the CSU would adjust blade angle and maintain constant rpm when a magneto was turned off.

On-speed, Under-speed and Over-speed

The terms on-speed, under-speed and over-speed with regard to the governor, mean the following:

- **On-Speed**: If the pilot has set a RPM which is to be maintained, and the RPM is in fact being maintained, the propeller RPM is said to be on-speed.

- **Over-Speed**: If the pilot has set an RPM which is not being maintained, and the propeller has a higher RPM, then the propeller is said to be over-speeding.

- **Under-Speed**: If the pilot has set an RPM which is not being maintained, and the propeller has a lower RPM, then the propeller is said to be under-speeding.

Power Output

A constant speed propeller allows the engine to develop maximum rated power and rpm during the ground roll and to develop full power throughout its normal rpm range.

With a constant speed propeller the pilot controls inlet manifold air pressure [**MAP**] with the throttle lever and the engine RPM with the RPM control lever.

The pilot has several combinations of RPM/MAP to achieve a particular power setting; Some typical examples would be the recommended combinations for 65% power at sea level:

- 2100 rpm + 26 inches Hg MAP
- 2200 + 25 inches
- 2300 + 24 inches
- 2400 + 23 inches.

The pilot can use low RPM and high MAP or high RPM and low MAP to achieve exactly the same power output. The low RPM/high MAP combination gives more efficient cylinder charging and better combustion with less friction.

Setting Power

To achieve smooth power transitions and avoid over stressing an engine, the following sequence for power changes with constant speed propellers is recommended:

- Power increase – ensure mixture is full rich, rpm lever to increase followed by throttle to increase
- Power decrease – throttle decrease, followed by rpm decrease

The saying – *revs up/throttle back* is a useful reminder of these actions.

The above procedures are designed to avoid excessive manifold pressure during power changes.

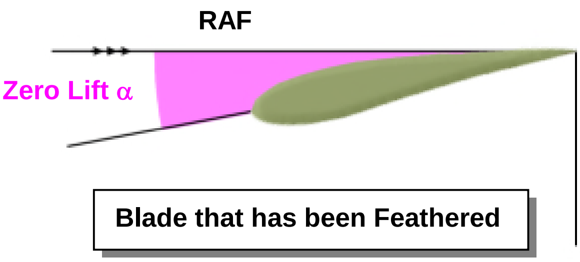
Propeller Inspection

A propeller pre flight inspection should pay close attention to the propeller blade surfaces. Because of the proximity to the ground, the blades are prone to impact damage from stones or debris on runway surfaces. Stress fractures in the blades can often originate from this sort of damage, and if left undetected, result in blade fatigue and ultimate failure. Given the normal stresses on a operational propeller, blade failure will be catastrophic.

Other Pitch Modes

Feather

A variable pitch propeller may have a **feathering** facility which turns the blades to the minimum drag position (i.e. the blades are more or less aligned fore and aft) and stops windmilling when the engine is stopped. **Such a feature is not usually fitted to a single engine** aeroplane.

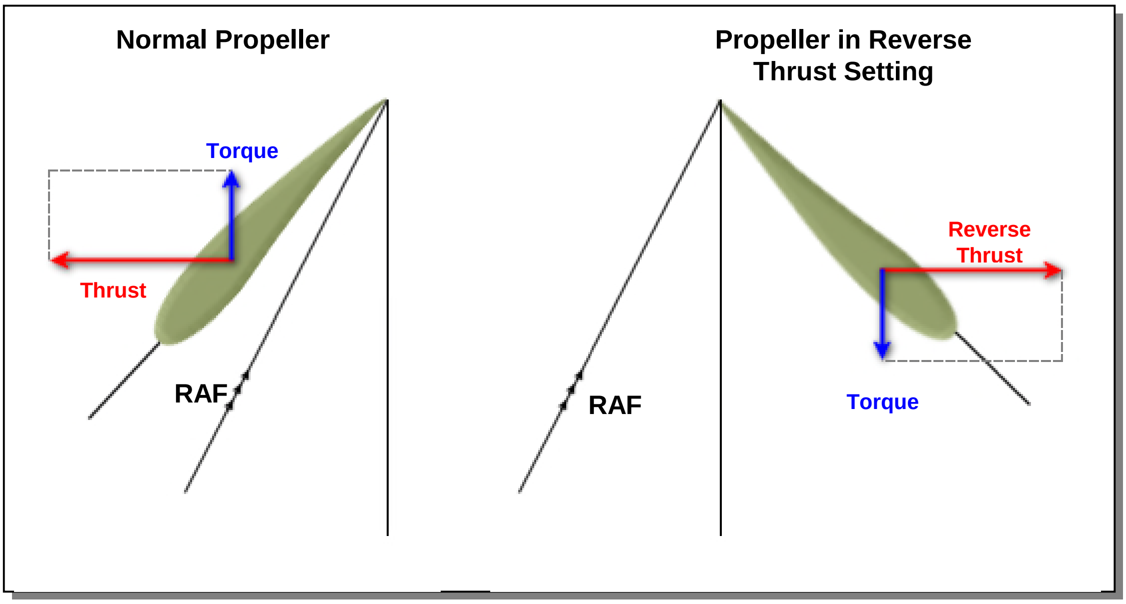


If a damaged engine continues to turn, it may seize, or even catch fire; for these reasons modern propellers have a feathering capability.

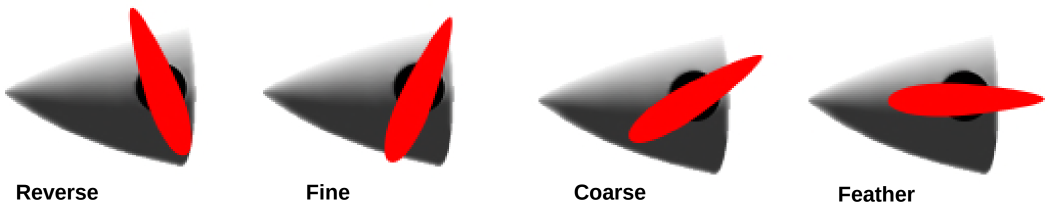
The blades are turned so that the collective effect of all the blade sections produces zero torque and therefore the propeller will stop turning. Drag is reduced to a minimum and further possible damage to the engine is prevented.

Reverse Thrust

Many aircraft are also equipped with propellers with a thrust reversing capability. Reverse thrust is used to shorten the after landing roll and so achieve better short field performance for transport aircraft operating into unprepared or semi-prepared airstrips.



Reverse thrust is obtained by moving the propeller blades past the fine pitch stop to a negative blade angle. The produces thrust in the opposite direction.



CSU failure

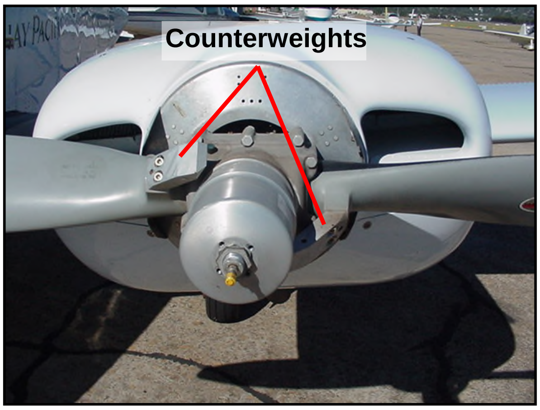
As a propeller system increases in complexity the possibilities for malfunction increase. A problem associated with constant speed propellers is governor failure or, loss of oil pressure during flight. Aided by CTM the propeller blades will default to a fine pitch setting; this greatly reduces the load on the power plant and the engine will ultimately over speed, particularly during descent. The rpm of an over speeding engine - sometimes referred to as a 'runaway prop' - will quickly exceed red-line RPM and, unless immediate corrective action is taken, the engine is likely to be severely damaged. In either event the following is a guide for actions that should be taken:

- Close the throttle
- Reduce the airspeed
- If unable to restore the propeller to constant speed conditions; attempt to feather it if possible.

If the problem is confined to the CSU and not engine oil pressure related it is quite likely, with careful attention being paid to throttle usage and airspeed, to maintain safe flight until a suitable landing point is found.

Counterweight Propellers

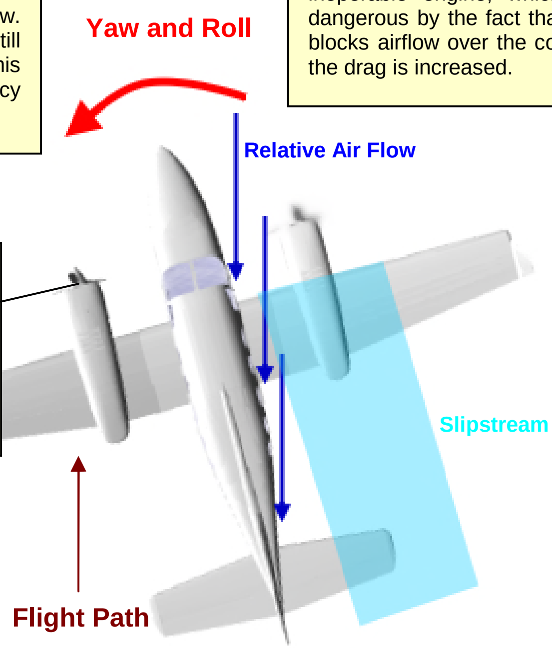
Twin engine aircraft commonly have their propellers designed to fail to the coarse pitch position. Counterweights are fitted to the root of each blade, during operation these weights act to increase blade angle; CSU oil pressure is therefore used to decrease blade angle against the counterweight force. Should there be an oil pressure loss, the action of the counterweights will move the blades to a higher angle, and this has the effect of reducing rpm and drag on the airframe.



In addition to the counterweights these propellers will usually have a feathering feature; the counterweights are designed to assist in moving the blades to feather, thus avoiding handling difficulties as illustrated below.

The asymmetric thrust from the operable engine causes a yawing tendency toward the inoperable engine, which is further made dangerous by the fact that the fuselage now blocks airflow over the control surfaces, and the drag is increased.

The induced airflow from the propeller slipstream on the failed engine is lost decreasing the total airflow. While on the side of the aircraft with the still operable engine thrust is still being produced. This difference in produced lift causes a rolling tendency toward the inoperable engine.

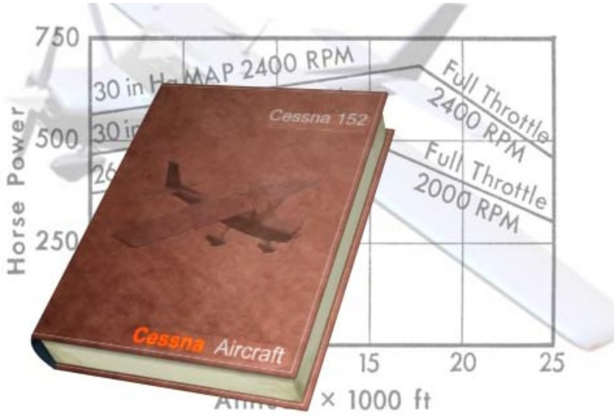


Drag is further increased by the windmilling propeller, which has the same effect as a solid disc of equal diameter. This creates a yawing tendency toward the inoperable engine, and it is for this reason that feathering the inoperable propeller as soon as possible is important, as this can be the greatest source of drag.

Engine Limitations and Handling

Introduction

The Aircrew Manual for each type of aircraft specifies certain engine limitations. These limitations are based on calculations and type tests on the bench. They may subsequently be modified in the light of service experience and operational requirements.



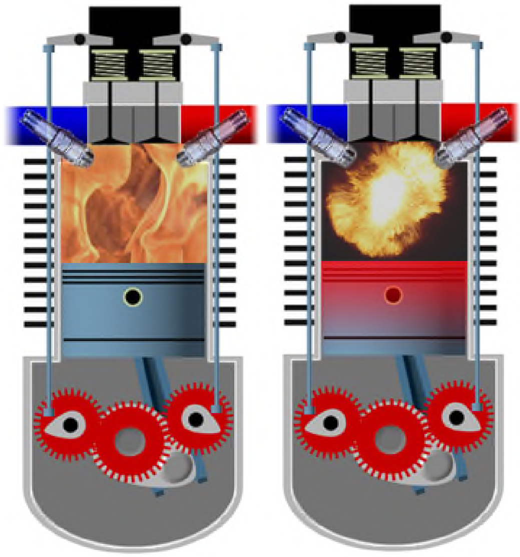
The limitations are designed to secure an adequate margin of safety against immediate breakdown and to give the engine a reasonable life. Proper handling throughout the life of an engine will improve reliability towards the end of the periods between overhauls and will also improve the chance of the engine standing up to operational overloads. With all engines, optimum reliability and long trouble-free life are assured by restricting the use of the higher powers as much as possible.

Detonation

Detonation has been described as the explosive combustion of the charge in the combustion chamber at or after normal ignition.

Detonation causes the peak (maximum) pressure to occur on top of the piston much too early to be used efficiently. This pressure can work against the momentum of the engine and will always result in a massive temperature increase. If not managed correctly this extremely high temperature (and pressure) will damage the engine and could cause engine failure.

The temperature rise in the cylinder on the compression stroke (before combustion), is due to the amount of compression occurring.



Normal Combustion **Detonation**

A low compression engine, Compression Ratio (CR) 6:1 causes only a modest temperature increase and can operate efficiently with a relatively low octane fuel the temperature remains just below the detonation threshold.

For an engine with a higher compression ratio, a higher octane fuel is required. A typical light aircraft engine with a CR of 8.5:1 requires AVGAS 100 (octane rating 100).

The Compression Ratio is fixed for that engine and cannot be altered without major engine modification.

Note:

i. *The CR determines how much power can be developed by the engine.*
ii. *The CR determines the type (octane rating) of the fuel required by the engine.*

If detonation occurs with the correct fuel the fault will always be related to excessive engine temperatures and will likely be related to a high power condition:

- Long slow climb at high power.
- Oil or air cooling systems restricted.
- Excessively lean mixture setting.
- Incorrect power setting high MP, Low RPM.
- High temperature of incoming charge.

Detonation will be likely to occur at low or moderate power settings should the wrong fuel (low octane) be used. A fuel of a lower octane rating than specified for that engine, will detonate at full power; an unrated fuel like AVTUR may detonate at start up or taxi!

Identifying Detonation

Detonation can often be observed when a car engine is accelerated in a high gear from low speed (High MP Low RPM); accompanied by a knocking or pinging noise in the engine. It is doubtful that this would be heard in an aircraft due to higher ambient noise levels; however symptoms may be associated with excessive CHT, EGT or oil temperatures.

Symptoms associated with detonation are:

- rough running
- loss of engine power
- rapidly rising engine temperatures.

Corrective Action

Cool the Engine.

Mixture Full Rich:
The extra fuel acts as a liquid coolant inside the combustion chamber. More anti-knock additives are present to reduce or stop detonation.

Reduce Power - make less heat:
Lower nose of aircraft - increase cooling airflow. The change in attitude allows better air circulation and increasing airspeed increases the cooling air flow.

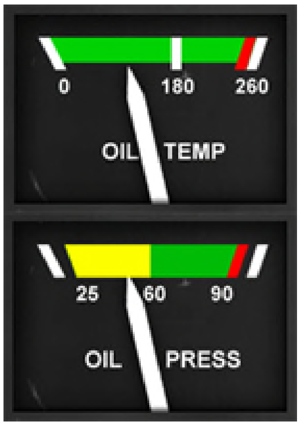
Limitations

The stresses and wear are increased at high rpm, owing to inertia loading, and at a high manifold air pressure owing to high gas pressures causing increased piston and bearing loads. Maximum rpm and manifold air pressure limitations are usually imposed which apply at the basic power conditions.

> **Note**:
>
> If the specified engine limitations are exceeded or extended beyond the time permitted a report must be made after landing.

High cylinder temperatures lead to a breakdown in cylinder wall lubrication, excessive gas temperatures and detonation at high manifold air pressures.

High oil temperatures cause failure of cylinder and bearing lubrication. Maximum cylinder and oil temperature limitations are also imposed for the main power conditions.



Shortage of oil, or a defect in the lubrication system, may result in inadequate lubrication and bearing failure. A minimum oil pressure limitation is therefore included. After start up, oil pressure must be observed within 30 seconds, if no pressure, the engine must be stopped.

The table below of engine limitations for an air-cooled engine is typical of those for a 4 cylinder light aircraft.

Power Rating	Time Limit	RPM	CHT °C	Fuel Pressure	Engine Oil	
					Pressure	Temperature
Take-off	Continuous	2700	260°C max	0.5-8psi	60-90psi	40-118°C
Cruise 75%	Continuous	2450	66-224°C	0.5-8psi	60-90psi	40-118°C
Cruise 65%	Continuous	2350	66-224°C	0.5-8psi	60-90psi	40-118°C

The specifications below show the principle limitations associated with each of the main power conditions.

Oil pressure:

a) 60 - 90 psi at 40-118°C for all operations.

b) Flight minimum 25 psi.

Oil temperature:

a) Minimum for take-off 40 °C.

Cylinder temperature:

a) Maximum operating temperature, 260°C

Considerations for Imposing Engine Limitations

Minimum oil and cylinder head temperatures

Minimum oil and cylinder head temperatures are specified to ensure the proper circulation of the oil and to prevent structural damage or failure due to rapid and uneven heating at high powers. Not exceeding 1500rpm before oil temperature reaches 40°C is a typical oil temperature limitation.

Maximum cylinder temperature: Take-off

A maximum cylinder head temperature for take-off is given for air-cooled engines to ensure that the high power used at take-off will not cause temperature to exceed the maximum permissible.

Low RPM and High MAP

A combination of high manifold pressure with low rpm can cause high bearing loads and lead to detonation. With high manifold pressure volumetric efficiency is increased, the weight of charge is increased, and high cylinder pressure result. These conditions, combined with lower than normal rpm can increase bearing loads beyond acceptable limits.

A good practical rule, when no minimum rpm figure is given, is to avoid the manifold air pressure number exceeding the rpm number ie. 26” MAP/2400 rpm

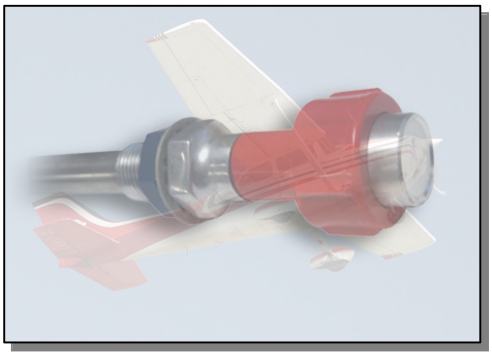
Lubrication System Faults

Serious damage may occur quickly through overheating or failure of the lubricating system and the limitations should be strictly observed. Frequent checks should be made of the oil temperature and pressure, and the cooling controls and/or power should be adjusted if necessary.

Make Frequents checks of the oil temperature and pressure and cooling controls

Mixture Control

Leaning Your Engine



As a general procedure you will not lean your engine for initial training area flights or circuit operations. Many power changes are required here and the overall risk to your engine is less if the mixture is kept full rich.

When you fly at a constant altitude and constant power setting correctly leaning your engine:

a) improves engine performance;
b) extends the engine life, and
c) saves fuel.

On cross country (navigation) flights, as you reach cruising altitude (Top of Climb) set cruise power then lean. Most flying training SOP's encourage leaning when cruising above 5000 feet for any period of more than ten minutes.

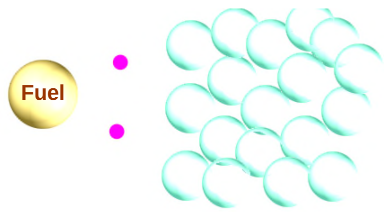
Leaning Without an EGT Gauge

- Pull mixture control rearwards until a little rough running occurs.
- Immediately move the lever forward until the engine is working smoothly then about one centimetre further forward, checking the CHT remains stable at the end of lever movement

Leaning With an EGT Gauge

- Pull mixture control rearwards until 'peak' EGT is found, then
- Push mixture forward until EGT falls, about 3 divisions (25°F each division) on the gauge (the aim is to SET 'LEAN BEST POWER'.)

Lean Mixture Problems



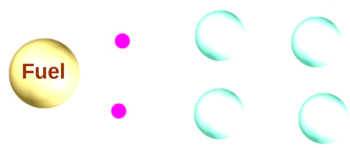
The mixture is usually only leaned for cruising flight, so that any mixture problems will usually relate to cruise and descent.

If the mixture was made excessively lean, rough running and loss of power would become evident. Engine temperature would rise and perhaps overheat, engine failure could occur from:

a) Ineffective lubrication and cooling; bearing or piston seizure, or
b) Possible detonation causing piston overheat and failure; (possible but not likely at CRUISE POWER settings.

If descent was made with the mixture left lean, the engine would become leaner (more air available, same amount of fuel). Overheating could occur and if power was increased, perhaps detonation. Another effect of a lean mixture is the burning rate is very slow. Some of the charge could still be burning as the intake valves open, igniting the charge in the manifold causing 'backfiring' (popping) rough running and loss of power.

Rich Mixture Problems



At full rich the mixture is about 10:1 at sea level. This provides good engine performance at high power settings when the engine is 'working' and the combustion temperatures are high; complete combustion occurs.

At low power settings, IDLE and TAXI power, the combustion temperatures are relatively low and complete combustion does not occur. The fuel additives (eg. lead) which reduce detonation at high power, are not consumed at low power settings and become deposited on the spark plugs. These deposits can interfere with the ignition process, reducing combustion efficiency, consequently the engine power is reduced. This is known as SPARK PLUG FOULING.

Running the engine to high power for about 30 seconds before takeoff should clear the plugs. A secondary problem during ground operations is engine overheating, as the cooling system is not designed for lengthy stationary periods. Pointing the aircraft into wind when ground running will reduce the overheating.

Engine Warming

Modern aircraft engines are very reliable and descents are usually made at power settings, which keep the engine gauges in the green (normal operating ranges).

Power off (idle) descents are common during practice forced landing drills; problems can occur during an idle descent. The most significant of these is carbon lead deposit build up on the spark plugs, because the engine is idling at rich mixture during descent. In an extreme case the engine could fail or falter when power is increased if corrective measures are not taken.

Plug fouling can be minimised during the descent if the engine is not left at idle for lengthy periods. A common procedure is to 'warm the engine' each 1000' on descent; the throttle is advanced to increase the engine speed to about 2300 RPM then reduced to idle. This is sufficient to heat the plugs to operating temperature and burn off any contamination. Note the primary reason for warming the engine on descent is to reduce spark plug fouling.

A secondary advantage of warming the engine during descent is heat being maintained in the exhaust system, should there be a need to apply carburetor heat. Carburettor heat is full on during forced landing practice to reduce the risk of icing.

Thermal Shock

Engine failure or damage (piston seizing, cylinder cracking) caused by very rapid engine cooling is known as thermal shock. The problem is generally confined to aircraft engines that are operated at the extremes of the temperature range, such as glider tugs. After climbing to 2000' or 3000' (high CHT) the glider is released and the aircraft is dived to land as soon as possible for the next launch. This very rapid descent at- idle power and high airspeed - can cause rapid uneven cooling and result in engine damage or failure.

Engine Exhaust Smoke – Colours

- White (too lean) - white deposits occur in exhaust system which are not easily seen.

- Black (too rich) - very black exhaust system deposits are easier to see than white smoke but difficult to distinguish from blue.
- Blue (oil burning). A very worn engine or broken piston rings, an impending disaster.

Operating Limitations

Engine Start

The first check after starting is 'oil pressure rising within 30 seconds'. Without oil pressure no oil circulation or lubrication will occur; the engine bearings and pistons would soon seize causing engine failure. If the oil pressure does not rise within 30 seconds, stop the engine immediately.

Starter Duty Cycle

Most engines have a limitation on how long the starter can remain energized; as well as a starter cool down period between start attempts, if the engine fails to start. Consult the aircraft operating instructions for this information.

Engine Run-up

Oil temperature must reach a minimum temperature before engine run-up to ensure uniform heating of oil and components and good lubrication so the engine will not be damaged.

Time limit on Maximum Power

Maximum Continuous Power

Is that power which can be used continuously without increasing the risk of engine damage or wear. Maximum Power (sometimes called Take-Off Power) is often limited to five minutes; if this limit is exceeded there is a likelihood of engine damage.

Maximum RPM

Each engine has a large number of moving parts, which have been proven to operate well at the maximum RPM. If this RPM is exceeded, push rod, crankshaft or valve and piston damage can occur. Exceeding maximum RPM is known as an 'ENGINE OVERSPEED' and must be reported to maintenance.

Ignition checks

Pre Take-Off: 'Magneto Check'

With 2000 RPM set the ignition switch is moved from BOTH to RIGHT.

Now only the right magneto is operating (left is OFF). Combustion efficiency is less, some power is lost and engine RPM decreases about 100 RPM.

When BOTH is re-selected both magnetos are again functional and the engine RPM recovers to 2000. When the ignition switch selector is moved from the BOTH to the LEFT position, the left magneto only is operating, and the RPM again, should decrease.

Points to Remember:

- For a magneto to function the ignition switch must open the primary circuit. To be OFF, the primary circuit must be closed (shorted to earth).
- If no RPM drop occurs when the RIGHT magneto is selected either the LEFT magneto is not working or the LEFT magneto has not been earthed.
- Selection of the LEFT magneto will then confirm this fault.
- If no RPM drop occurs when either the RIGHT or LEFT magneto is selected then the other is still working.

Airborne

The ignition switch should remain in the BOTH position during flight. To attempt a magneto check while airborne is more likely to exacerbate the problem rather than to solve it.

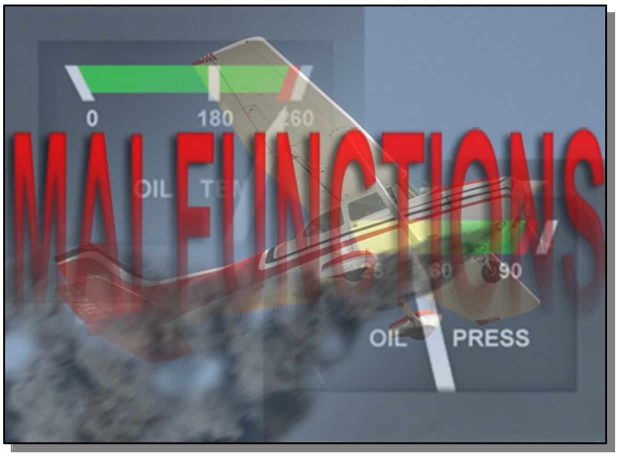
After Flight: 'Dead Cut Check'

Before shut down, at idle power setting, the magneto switch is placed momentarily to the OFF position and the engine without ignition will run down. Immediately place the ignition switch to BOTH and the engine will regain its RPM; this is called the 'dead cut' check by demonstrating both magneto primary circuits are shorted to earth. Failure of the engine to stop indicates a live magneto which should be immediately reported to maintenance; anyone moving a propeller under these circumstances is likely to sustain serious injury.

> ***Note:*** *Normal engine stopping procedures apply after the dead cut check, the mixture lever is pulled to ICO this cuts the fuel supply to the carburettor and ensures the available charge is consumed.*

MALFUNCTIONS

Introduction



In the previous chapter the normal operations of the aircraft was discussed. In this chapter we consider abnormal situations or malfunctions, their possible causes and rectifications of the problem.

It is here that the standardised safety checks and procedures performed by the pilot, and the redundancy of aircraft systems combine to assist the pilot in achieving a positive outcome, in the event of a malfunction.

Engine RPM

Indication	Cause	Rectification
a) Rough running	1. One magneto inoperative 2. Fuel system blockage 3. Vent system blockage. 4. Inoperative fuel pump. (Fuel pressure Low) 5. Blocked air filter. 6. Induction / Carburettor Ice	Check magneto on "BOTH" Boost pump ON Change tanks Boost pump ON, change tank Boost pump ON, change tank Use alternate air, carby heat Use carburettor heat
b) Excessive drop in RPM when L or R magneto is selected.	1. Magneto selected has failed 2. Spark plug fouling	Return switch to BOTH. Return for maintenance. Warm engine (inc power)
c) Engine stops when either L or R magneto is selected from BOTH position	Magneto selected is earthed (shorted) or inoperative.	Return switch to BOTH Return for maintanance.
d) No drop in RPM when either L or R is selected	1. Possible live magneto. 2. Possible switch or circuit failure	Return switch to BOTH Carry out "Dead Cut Check" Return to maintenance

e) No drop in RPM when magneto switch placed OFF (Dead Cut Check)	1. Live magneto. (switch or circuit failure)	Mixture lever to ICO Switches OFF. DO NOT TOUCH PROPELLER Inform maintanance
f) Fluctuating RPM	1. CSU failure 2. Propeller failure 3. Carburettor	Propeller pitch too fine. Return to airfield. Select full rich
g) Excessive CHT indication	1. Airflow restriction 2. Lean mixture	Reduce power, lower nose attitude, open cowl flaps, select full rich. Select full rich

Engine Oil Pressure

Indication	Cause	Rectification
a) Low pressure (normal oil temp)	1. Pump failure or worn pump. 2. Regulator failure (PRV)	Reduce power. Monitor for possible engine failure.
b) Low pressure (high oil temp)	3. Blocked oil cooler (oil circuit) 4. Blocked oil cooler (air circuit) 5. Low oil level.	Reduce power. Set rich mixture. Increase cooling. Monitor for possible engine failure. Land as soon as possible.
c) Fluctuating pressure.	1. Very low oil level. 2. Leak	Reduce power. Monitor failure. Land as soon as possible.
d) High pressure (normal temp)	3. Regulator failure (PRV)	Reduce power. Monitor.
e) High oil temperature	1. Oil cooler air flow restricted	Open cowl / cooler flap Reduce power, lower aircraft nose to improve airflow.
f) High pressure (low temp)	1. Oil cooler. 2. Thermostatic valve fail.	Reduce power. Monitor.

Electrical

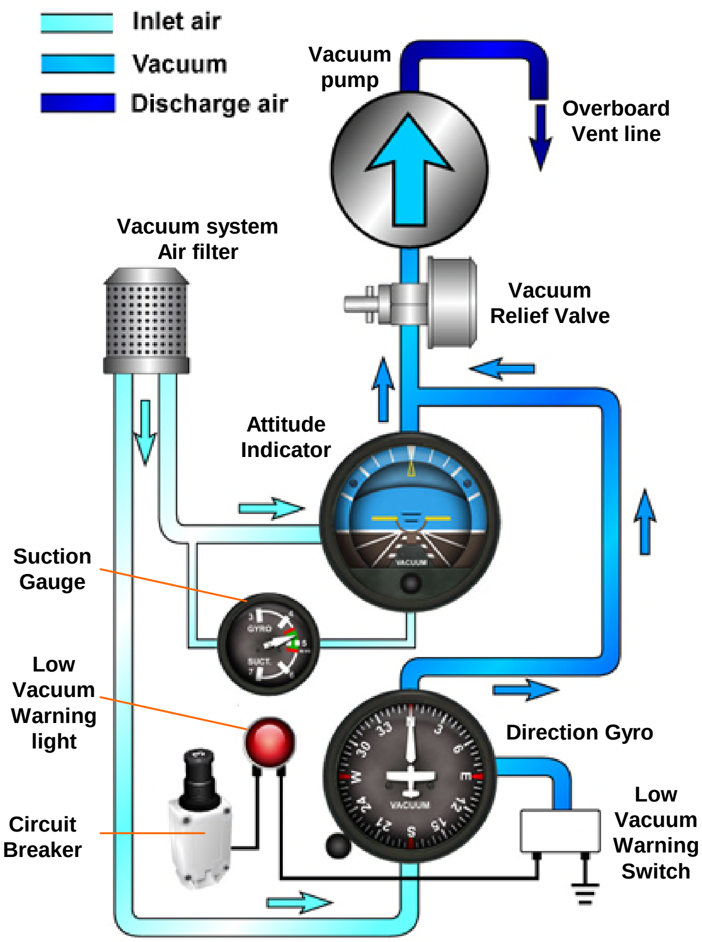
Indication	Cause	Rectification
a) Voltmeter - undervoltage	1. Alternator failure 2. Battery flat 3. Excessive load.	Check reset CB Reduce electrical load. Return
b) Voltmeter – overvoltage.	1. Voltage regulator failure.	Increase electrical load or Alternator OFF Reduce electrical load Land as soon as possible
c) Ammeter discharge	1. Alternator inoperative 2. Alternator output reduced	Check alternator field CB Switch alternator OFF Reduce electrical loads
d) Ammeter excessive charge (after 4-5 min)	1. Flat battery 2. Collapsed battery cell 3. Regulator failure	Switch alternator OFF Reduce electrical loads. If OCTA switch battery OFF (after nominating SARTIME)

Vacuum Pump Malfunctions

Suctions (vacuum-driven) gyros are independent of the aircraft's electrical power supply, but otherwise suffer from a number of disadvantages when compared to electrically driven gyros.

As air must enter and leave the casing, a suction gyro cannot be contained within a sealed case. In spite of filters, dust and moisture will enter affecting the balance of the gimbals and reducing bearing life. The suctions pump is usually driven directly off the engine and so instruments cannot be run up until the engine is started. The electrical gyro will run up when the master switch is turned on. Additionally, at high altitude there is insufficient suction to maintain the correct rpm.

Electrically driven gyros can be constructed so that their rotors have a higher moment of inertia and spin speed. This is an advantage in instruments that rely on rigidity, HI and AI, to provide readings. Electrical gyros operate at constant speeds and this is an advantage when a predictable rate of precession is required.



If the air filter blocks, or the vacuum system fails, a lower reading, i.e. below about 4.5 in. Hg, will be indicated on the suction gauge. The reduced airflow may allow the gyroscopes to run down gradually and the air-operated instruments will behave erratically, incorrectly, or sluggishly.

Failure of the vacuum pump will be indicated by a zero reading on the suction gauge. It may be that the gyroscopes have sufficient speed to allow the instruments to read correctly for a minute or two before the gyros run down following failure of the vacuum pump.