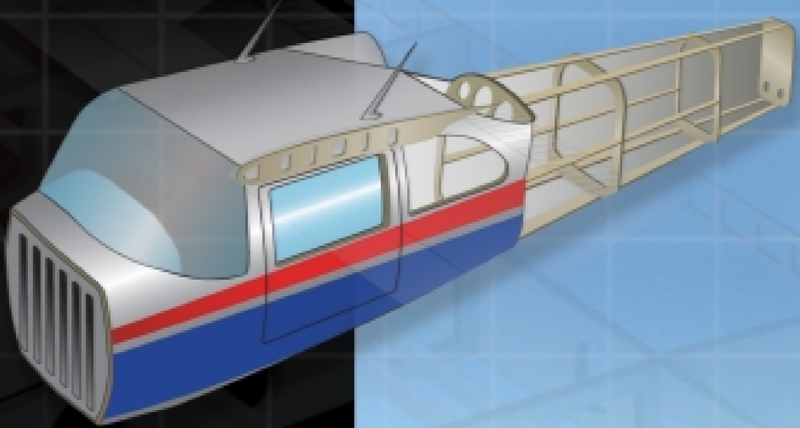
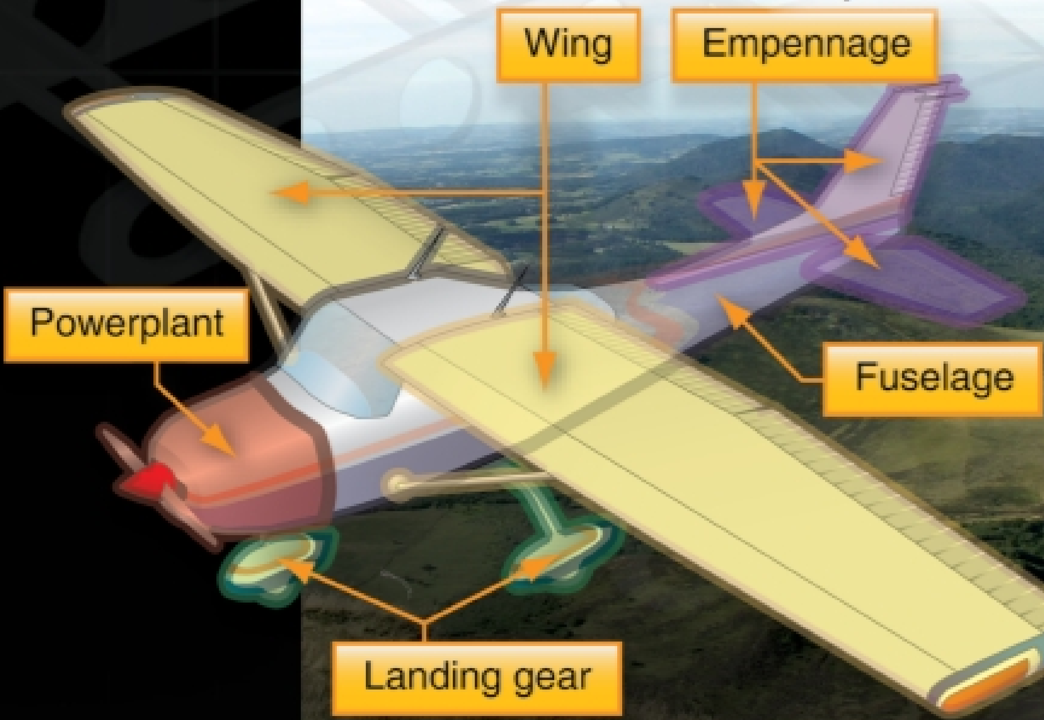
Aircraft Construction



Introduction

An aircraft is a device that is used, or intended to be used, for flight according to the current Title 14 of the Code of Federal Regulations (14 CFR) part 1, Definitions and Abbreviations. Categories of aircraft for certification of airmen include airplane, rotorcraft, glider, lighter-than-air, powered-lift, powered parachute, and weight-shift control aircraft. Title 14 CFR part 1 also defines airplane as an engine-driven, fixed-wing aircraft that is supported in flight by the dynamic reaction of air against its wings. Another term, not yet codified in 14 CFR part 1, is advanced avionics aircraft, which refers to an aircraft that contains a global positioning system (GPS) navigation system with a moving map display, in conjunction with another system, such as an autopilot. This chapter provides a brief introduction to the structure of aircraft and uses an airplane for most illustrations. Light Sport Aircraft (LSA), such as weight-shift control aircraft, balloon, glider, powered parachute, and gyroplane, have their own handbooks to include detailed information regarding aerodynamics and control.



CHAPTER 2

AIRCRAFT GENERAL KNOWLEDGE

A great number of private pilots take great pleasure in being able to service their own aircraft, but it is not necessary to be a technical boffin. You will never be called upon to dismantle and reassemble a separately excited generator, or a slow running adjusting screw metered fuel chamber, unless you really, really want to!

What is handy, however, is to know as much as you can about the various systems and components of your aircraft. In this way you will be able to tell the technician who is qualified to work on your aircraft what is wrong, sending him in the right direction when he sets out to fix the problem. Your aircraft can be made serviceable a lot quicker if the guy knows where to start. Just saying that “the No 2 engine is missing”, could lead to the technician saying: “After a brief search, the No 2 engine was found on the left wing”.

An aeroplane, by its nature, must be an extremely efficient machine. In flight, its shape and contours must provide aerodynamic lift for overcoming gravity and for manoeuvring and control, and at the same time present a minimum area to keep the drag, or wind resistance, to a minimum. Inside the shape, space must be provided for housing all the necessary equipment, engines, and systems, as well as providing a safe and comfortable environment for the crew, passengers, and baggage or cargo. And the whole affair must be efficient, so it has to be as light as possible, but at the same time, strong enough to withstand all the loads imposed upon it, both in the air, and on the ground.

The main components of an aeroplane are the fuselage, the wings, the stabilizers (the horizontal and vertical tail sections), the controls and the landing gear or undercarriage. It does not matter what the aircraft is designed to do, all of these components must have high strength, low weight, safety, and have a shape that is aerodynamically efficient.

The Aeroplane

Figure 2.1. The Piper Cherokee

1. Before you take your first lesson in the air it will be necessary for the various vital parts of the aeroplane to be explained to you. You have arrived at the aerodrome, met your instructor, and are ready to start on your course of flying. The aeroplane in which you are going to be given your lessons is standing on the parking area in front of the hangar. It is a Piper Cherokee, a low-wing monoplane - that is, an aeroplane with a single wing on which rests the fuselage, so that the floor of the cockpit is roughly on a level with the top surface of the wing.

Flying Controls

2. When you approach the plane, you will see details which need explaining. Stretching from half-way along the rear edge - called the Trailing Edge - to the tips of each wing, is a flap which is hinged to the Rear Spar (inside the wing, so that you cannot see it) of the wing. These two flaps are Ailerons, and are vital

control surfaces. If you lift the right-wing aileron and look over the fuselage to the one on the other wing, you will see that the left-wing aileron goes down; and if you depress the right-wing aileron you will see that the left-wing aileron goes up. This is because they are interconnected at the Control Column in the cockpit. Now walk over to the cockpit and turn the control column (often called by pilots the Stick) to the left and right, and at the same time watch the ailerons. If the stick is turned to the left (anti-clockwise), you will see the left-hand aileron hinge upward and the right-hand aileron hinge downward. Turn the stick to the right (clockwise), and the reverse happens. The range of travel is 30° up and 15° down. This is known as Differential Ailerons.

Figure 2. 2. The Left-hand Aileron Fully Down

3. This aileron control is the means by which a pilot Banks his aeroplane from one side to the other, and it happens this way: Suppose he is flying along at 100 knots, and he wishes to lower his left wing; he moves his stick over to the left, and this hinges the left aileron upward. The rush of air over the left wing strikes this aileron, and naturally tries to blow it out of its way. What happens? The aileron is pushed downwards, but because the pilot is holding on to the stick and the aileron is attached to the wing, the wing-tip is pushed downwards. The same thing happens to the other wing in the reverse direction, because the right aileron is depressed and the rushing air pushes the right wing-tip up. The whole aeroplane therefore turns around its Longitudinal Axis (an imaginary line drawn through the Fuselage, or body, from nose to tail) until the pilot centralises the stick and the ailerons return to their original position flush with the wing. The movement of the plane around its longitudinal axis is helped by the ailerons in another way. Without going into aerodynamic details (we will be doing that in Chapter 1: Principles of Flight), the lift of a wing is increased a little by an aileron being depressed and decreased by an aileron being raised. Because of this fact, a wing which is dipped, due to the resistance of its raised aileron to the air-stream, is helped to dip further by the loss of lift to that wing. At the same time the gain in lift of the opposite wing helps the plane to rotate about its longitudinal axis.

4. The control surface which deals with YAW is the RUDDER. Take a good look at it. You will see that you can move it from side to side in the same way as you can move the ailerons. But instead of being hinged on a horizontal spar, it is hinged on the vertical Fin, which is fixed to the fuselage in the centre of the tailplane. You will see that the rudder has about a 30-degree movement, 27° to be exact, on either side of the centre line of the fuselage. Now go to the cockpit and climb into it. You will find two pedals on which to put your feet. They pivot about a centre point and as one moves forward, the other moves back. They are connected by cables to the rudder in such a way that when you push your left foot forward the rudder is deflected to the left. When in the air the air-stream striking this deflected rudder surface tries to push it out of its way, with the result that the tail of the aeroplane is pushed around and the nose of the plane yaws to the left. Put in its simplest terms, if you want the nose to turn to the left, you push your left foot forward, and to the right, your right foot forward.

Figure 2. 3. The Tail Fin and Rudder

5. Before you leave the rudder for the time being, take a look at the fin. In some aircraft, at first sight this

appears to be in line with the centre line of the fuselage, and it serves the obvious function of helping to keep the machine straight. But if you look closely, you will see that it is just a few degrees out of the centre line. This is because the revolving propeller pushes the air back (it is the reaction to this which pulls the aeroplane forward) in a corkscrew shape, sweeping it back over the fuselage in a spiral. If the fin was built in line with the fuselage the air-stream would strike it at a slight angle all the time, with the result that, far from the fin helping the pilot to keep the machine straight, it would be tending to turn it. To counter this spiral effect, you will observe that the fin is therefore set at the slight angle to the centre line of the fuselage.

6. In the case of the Cherokee this is achieved by keeping the rudder aligned with the fore/aft axis of the aeroplane, but the engine is mounted in such a way that the propeller shaft (or thrust line) is offset a few degrees. A close look at the aeroplane from directly in front of the propeller will confirm this.

7. You have now been shown the rudder control, which controls yaw, and the aileron controls, which control the banking of the plane around the longitudinal axis. There is one more control to see, and that is the Elevator, which is hinged to the trailing edge of the tailplane on either side of the rudder. This control surface is hinged horizontally, and can therefore be moved up and down. Applying to it exactly the same principle as the action of the air-stream on rudder and ailerons, it is easy to understand that when the elevator is raised the tail of the aeroplane is pushed down by the air-stream, with the result that the aeroplane assumes an attitude in which the nose is higher than when in normal flight. The elevator is attached to the stick in such a manner that when the pilot wishes to climb he eases the stick back, and when he wants to dive he eases it forward.

8. In the case of the Cherokee, the whole tailplane moves, and is called a Stabilator (see Fig. 2.4). It is designed this way to correct the fact that the Thrust line is higher than the Drag line. In Chapter 1 you will see that the Drag line should always be above the Thrust line, and this arrangement allows for just that. The range of travel is 18° up and 2° down. On the trailing edge of the stabilator is the Stabilator Tab which assists in trimming the aeroplane. It has a travel of 3° up and 12° down.

9. There are several other arrangements between control surfaces on other aircraft. Take the V-tail Bonanza for example. Due to its design the rudders and the elevators are combined, and are called Ruddervators. On the Concorde the elevators and ailerons are combined and are called Elevons. The basic principle of operation remains the same.

10. In all these control movements it is very important to realise that they work only so long as the stick is out of its central position . As soon as the pilot has attained the attitude he desires, then he centralises his stick and the aeroplane will maintain that attitude. There are exceptions to this which will be explained later, but in principle, that is what happens.

Figure 2. 4. The Stabilator

11. While you are looking at the tail unit (Fig. 2.4), a refinement must be explained to you. It is easy to understand that under various conditions of load an aeroplane will be out of balance. In other words, it will not tend, without constant attention by the pilot, to fly level, as it should do. This may happen when a heavy pilot has been flying the aeroplane in perfect trim and the next man to take it up is light in weight. Under such conditions it is reasonable to understand that the aeroplane is out of trim for the lightweight pilot. The nose of the machine will either tend to drop or rise, according to the change of position of the centre of gravity of the machine occasioned by the different weight of the two pilots. Suppose the nose tended to drop - in other words, the machine was Nose Heavy (the opposite inclination is Tail Heavy) - the pilot would have to exert pressure on the stick in order to keep the elevators in the “up” position all the time he required to fly level. This is very undesirable. In your training

aircraft you will see a wheel which works the elevator trim, and, according to the position it is set, it increases or decreases the load on the stick. The pilot can therefore set it to the position that allows him to fly the aeroplane comfortably, irrespective of the disposition of the loading, providing, of course, that the limits for the type are not exceeded. The range of travel of the elevator trim tab in the Cherokee is 3° up and 12° down. It can therefore be seen that the purpose of the trim tabs are to alleviate control forces, some or all of the controls may be fitted with a pilot-adjustable trimmer. A trimmer usually takes the form of a small control surface. This small control surface produces an up- or a down-force of its own and applies this force to the flying control surface it is attached to. The most simple example of a trim tab is merely that of a bendable piece of metal fixed to the trailing edge of a flying control. For a control surface that needs regular in-flight trimming, the trim tab is controlled independently from the flying control surface by a trim wheel, as mentioned, in the cockpit.

12. A moment's thought, and you will see that the three controls that I have just explained allow a pilot complete freedom of movement in the air. Various combinations of all three enable him to put his machine in whatever attitude he likes.

13. In order for an aeroplane to take-off and land at a slower speed than would be necessary for the wing to produce the required lifting force and not to stall, it is necessary to employ lift augmentation devices which allows the wing to produce the required lifting force at a reduced speed. These lift augmentation devices are known as flaps and slats. The effect of flaps and slats varies considerably and may cause an increase in lift, an increase in drag and change the stalling angle. On light aircraft, the flaps are sections of the trailing edge of the wing that can be moved and deflected downwards, altering the camber of the wing and hence its lift and drag. The altered down-wash behind the wing caused by lowering the flaps, alters the airflow over the tailplane. This generates a pitching moment, the direction and magnitude which varies between aircraft types. For example, on the low-wing Piper Cherokee aircraft, lowering the flaps causes a nose-down pitching moment. A Slat is a section of the leading edge of the wing that moves in and out and in doing so, creates a slot between the wing and the slat allowing relatively high pressure air from underneath the wing to flow over the wing's upper surface, re-energising the airflow and delaying the stalling of the wing. The use of flaps and slats enable the aircraft to take-off and land at relatively low speeds at high angles of attack, thus shortening the take-off and landing distance.

The Airframe (Aeroplane)

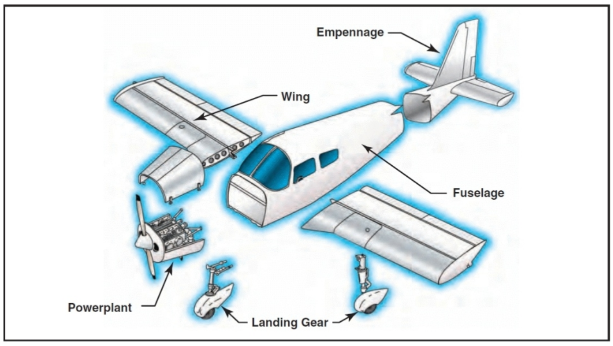


Figure 2.5. The Main Structural Components of the Cherokee

14. Let us take a look at the basic airframe components. The airframe basically consists of the fuselage which carries the crew, cargo and passengers; the wings which provide the lift; and the tail section, sometimes referred to as the empennage, which provides stabilisation during flight. All aeroplanes have this basic arrangement, with a few changes here and there, and to give you an idea, Fig. 2.6 shows the basic components in a large modern passenger jet.

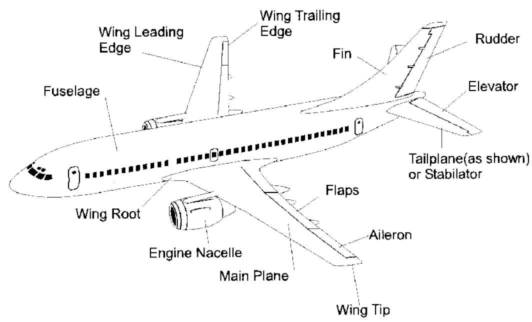


Figure 2. 6 Major Airframe Components

15. The fuselage, in light recreational aircraft, is where just about everything is kept. It houses the crew, passengers, freight, instruments, and most other things essential to the flight. It also provides structural strength by virtue of its design. In most modern light aircraft, the fuselage is a combination of Monocoque and Truss design features. It is called a Semi - monocoque design.

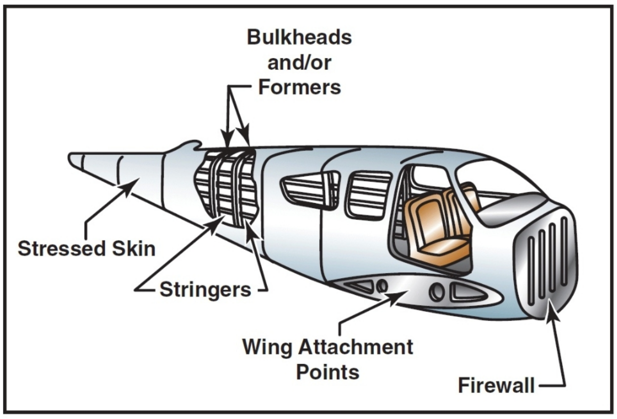


Figure 2.7. Basic Fuselage Construction

16. A monocoque design makes use of stringers, formers, and bulkheads which give a shape to the fuselage, and at the same time gives it strength (see Fig. 2.7). A stressed skin is used, which also adds to the strength of the structure. The truss design involves steel or lighter aluminium tubing called longerons which form the trusses used in the construction. Whatever design is used, the materials must be able to withstand all sorts of forces which are applied during flight and ground handling, such as tension, compression, torsion, shear, and bending, which is a combination of tension, compression, and possible shear. The difference between these forces are shown below.

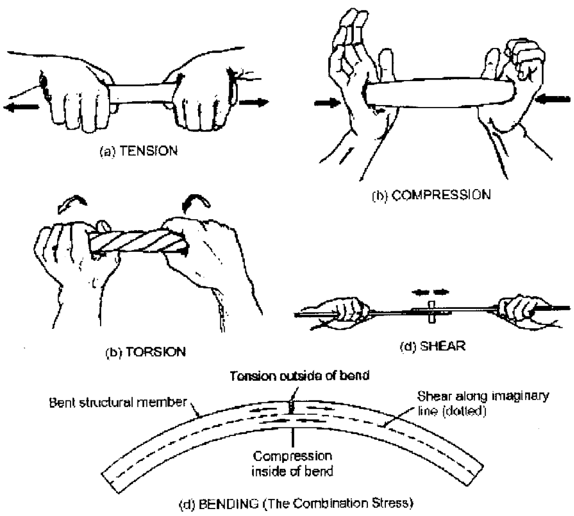


Figure 2.7a. Forces Applied during flight

17. In most cases the single engine aeroplane has it's engine attached to the front of the fuselage. Between the cockpit and the engine you will find the firewall which protects the occupants from any possible fire. For this reason it is made of a fire resistant material such as stainless steel.

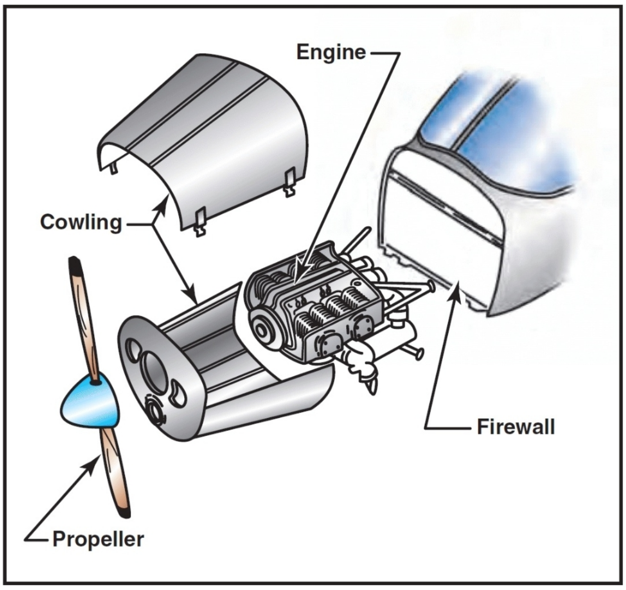


Figure 2.8. Engine Components

18. The wings are attached to each side of the fuselage, and may be high or, as in the case of the Cherokee, low. The Cherokee wing is unsupported by external bracing and this type of arrangement is known as a full cantilever wing. All the stress on the wings is carried by the wing spars, ribs and stringers that make up the wing itself (see Fig. 2.9). The skin of the wing, as in the case of the monocoque fuselage, also assists with the strengthening of the wing.

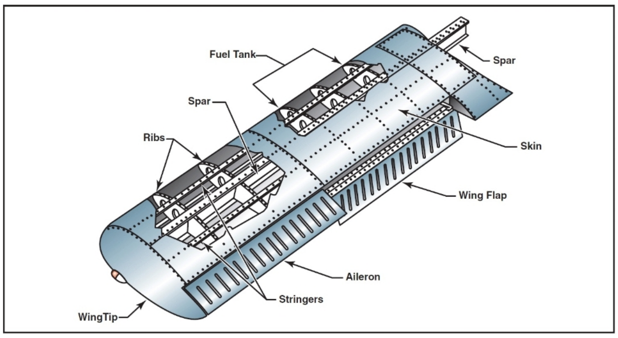


Figure 2.9 The Wing and its Components

19. If you consider the Cessna, you will note that it has external struts attached to the fuselage which help to brace and strengthen the wing. This is known as a semi-cantilever wing.

20. Most aeroplane wings contain fuel tanks which are either built in as part of the structure of the wing itself that take some of the load (hence the term "Wet

wings"), or are flexible tanks which are housed inside the wing. Retractable undercarriage may also be housed inside the wing structure.

21. The tail includes the horizontal and vertical stabilisers, as well as the elevators and rudders. As mentioned earlier, the tail structure may vary quite considerable between types.

Landing Gear

22. The landing gear, or undercarriage, of an aeroplane includes the wheels, tyres and brakes as well as the main undercarriage leg components. The function of the landing gear is to absorb the shock of landing, and to allow the aeroplane to be manoeuvred on the ground. There are essentially two main landing gear arrangements: the tricycle and the tail dragger. The tricycle undercarriage has main wheels and a nose wheel (as in the case of the Cherokee, while the tail dragger has main wheels and a tail wheel. Most light aircraft have fixed undercarriage, but during flight the undercarriage is completely redundant, and the design is usually a critical compromise between optimizing performance on the ground and minimizing weight and drag penalties in the air. Many different types of shock-absorption systems have been used in undercarriages including springs, elastic bungees and rubber blocks. The two most common systems are spring leaf undercarriage legs and oleo undercarriage legs. Spring leaf undercarriages consist of a spring steel undercarriage legs bolted onto the fuselage with a wheel at the end. When a weight is placed on the structure, it bends and the undercarriage legs open. When the weight is removed, the undercarriage returns to its original shape. The simplicity of the structure makes it cost effective, light and easy to maintain. An oleo-type undercarriage incorporates a piston and cylinder assembly. In flight, with no weight on the oleo, the lower piston end, attached to the wheel, drops down to its full extent. The piston is hollow and filled with oil and the cylinder is also hollow and filled with air. Therefore the over- or under extension of the oleo is purely a function of air pressure. Between the two is a narrow opening allowing the oil to move in and out of the cylinder. On landing the aeroplane's weight pushes the piston into the cylinder, forcing the oil through the opening into the cylinder. As the piston and oil within it moves up into the cylinder, the air in the cylinder is compressed and this absorbs the landing and taxying loads. An oleo-type undercarriage is normally fitted with torque links or scissors joining the cylinder and the piston, preventing the piston from rotating in the cylinder and thus keeping the wheels aligned with the aircraft fore-aft axis. Also fitted to the undercarriage is a Shimmy Damper. This is a piston - like device that prevents high frequency vibrations of the nosewheel whilst taxying. This normally indicates the fact that the torque - links on the aircraft are worn.

23. Non retractable undercarriage is usually only found in light aircraft due to the weight of retraction systems. These systems can be mechanical, hydraulic, electrical or pneumatic, but the extra weight makes them impractical. To compound the problem of weight, there has to be a back up system, simply adding more weight, in the event of a primary retraction system failure.

24. The tricycle arrangement has several advantages over the tail dragger such as improved forward visibility and more accurate steering. During landing brakes can be applied quite harshly without the danger of the aeroplane tipping onto its nose, and the same is less likely when the aeroplane is parked in a strong tailwind. The centre of gravity (CG) of the nose wheeled aeroplane is forward of the main wheels and the aeroplane is not likely to go into a ground loop (a severe swerve) during ground operations at high speed (take-off and landing). The only advantage the tail dragger has is simplicity.

25. Steering. Whilst taxiing and during initial stages of take off and final stages of landing, airspeeds are too low for rudder control to be effective. A system of differential operation of the main wheel brakes, by using the brake pedals attached to the rudder bar, provides the steering in most aircraft at these lower speeds. When accurate ground manoeuvring is required in crowded aircraft dispersal areas, a system of positively steering the aircraft wheels is necessary. In light aircraft this steering is often provided through direct mechanical linkage of the rudder pedals to a steerable nose or tail wheel. A steerable nose wheel is automatically aligned centrally whenever aircraft weight is lifted off the wheels.

26. Wheels. Wheels must be light weight, be easy to replace, and must provide space for the brake unit and the dissipation of heat which is generated during braking. Aircraft wheels differ in many ways from those

fitted to road vehicles. For instance, aircraft wheels are made in 2 halves which unbolt to allow the fitment of tyres without stretching their beading over the wheel rims. Also the wheels house the wheel bearings, unlike motor vehicles in which a separate axle houses the bearings and the wheels bolt to this axle.

27. Tyres. Aircraft tyres must be able to withstand higher loads than road tyres, but they are not required to be capable of continuous running over great distances. However, the general structure of aircraft and road tyres is similar, and radial ply tubeless tyres are now used almost exclusively in both cases. Radial ply tubeless tyres offer higher strength, lower weight, cooler running and better overload capabilities than the earlier cross ply tyres fitted with inner tubes. Because the load bearing carcass and the tread are effectively two separate components of the tyre and the tread tends to wear out before the carcass, aircraft tyres are retreaded as a matter of course to extend their life. Most tyres used on fixed wing aircraft are retreaded several times before the carcass needs to be scrapped. Under the high impact loads experienced during landing, tyres tend to creep by small distances around the wheels. This presents no problem with tubeless tyres, but if tubed tyres creep, the valve stem of the inner tube which is firmly attached to the wheel is stretched and will eventually fracture. For this reason, white "creep" marks are painted on tubed tyres at fitment, so that the degree of creep can be monitored. Over-inflated tyres can cause excessive wear on the centre of the tyre and under-inflated tyres can cause damage to the sides of the tyres. Another problem is "flat spots" which can be created on all landings by the scouring effect of a non-rotating wheel having to accelerate to landing speed in a fraction of a second.

28. Brakes. Stopping an aircraft produces heat from kinetic energy, which is a function of the speed of the aircraft. Temperatures of up to 1400° Celsius are reached in high performance braking systems. To prevent damage to the tyres and undercarriage structure, the heat energy must be dissipated rapidly into the surrounding air. If this does not happen, as can be the case after an aborted take off and subsequent long taxi back to a dispersal, the tyres can overheat and burst, and brake fires are likely to occur. To prevent tyres bursting due to overheating, wheels are fitted with fusible plugs which melt at a preset temperature. This allows the tyre to deflate at a steady controlled rate.

Figure 2.10 Main Wheel Assembly (Piper Arrow)

29. Most light aircraft make use of single brake discs. They consist of the brake disc which is rotated with the wheel, and the brake housing, or calliper, which is attached to the main undercarriage leg. Each brake housing is connected to a master cylinder which is activated by brake pedals on the rudder bar in the cockpit. As the pilot depresses the brake pedals, hydraulic pressure builds up and is transmitted to the brake housing where a piston squeezes the brake disc between friction pads causing the wheel to slow down. On releasing the brake pedals, hydraulic pressure falls to zero, and a spring returns the piston to its original position, stopping the braking effect.

30. Remember that brakes are most effective when they are cold. As they heat up, braking efficiency will decrease. Also check for wear on the brake pads and the disc during the pre- and post flight inspection. As the disc and the pads wear down, the amount of heat energy that can be absorbed reduces, and the braking efficiency of the system reduces. Overheated brakes will squeal and make chattering noises.

31. Helicopters and other rotary wing aircraft vary widely in concept and configuration. We will relate primarily to the single rotor helicopter of the type that employs a compensating tail rotor. The same principles employed in the construction of fixed wing aircraft, are valid in the construction of helicopter fuselages.

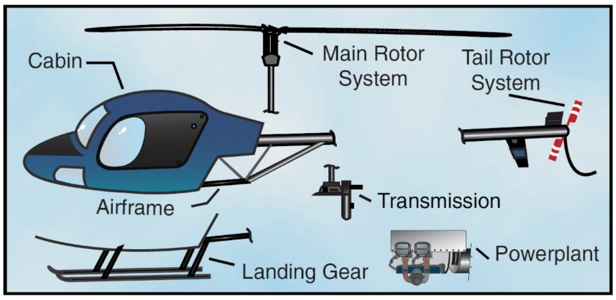


Figure 2.11 Helicopter Airframe

32. Rotors. The aerodynamics of the helicopter are based on the same laws that govern the flight of a fixed wing aircraft. Both rely on lift produced from air flowing around an aerofoil, but whereas the aeroplane must move bodily through the air, the helicopters "wings" move independently of the fuselage and produce lift with the aircraft remaining stationery. It can therefore be said that a helicopter has a rotating wing, called a rotor which are engine driven and provides both lift and horizontal thrust.

33. The design requirements and construction of rotors and rotor blades are complicated in that; the combined area of the blades is small compared to the wings of an aeroplane of similar weight, so a high Ç is needed. Blades must have a good lift to drag ratio to overcome power to weight ratio problems. Torsional stiffness is required so that pitching moment changes are minimised. A typical blade has an extruded alloy D spar leading edge with a fabricated trailing edge. It is symmetrical with a thickness ratio of about 1:7 and is rectangular in plan. Most modern blades are made of fibreglass reinforced plastic and stainless steel rather than aluminium. Trailing edge compartments are stiffened with light honeycomb-like materials. The use of carbon fibre increases the stiffness of the blades even more which helps to reduce vibration.

Figure 2.12. The Rotor Head.

Rotor Heads. The following rotor systems are commonly in use;

34. Fully Articulated Rotor. This system allows blades to flap, feather and lead-lag (drag). These movements are allowed through hinges or bearings. It is common for rotors with more than two blades to use the fully articulated system.

35. Semi-Rigid Rotor. This system allows blade freedom to flap and feather but not to lead-lag. This rotor utilises the "see-saw" principle where one blade flaps up while the other flaps down around a gimbal ring arrangement, also referred to as a teetering hinge. It is a common system used in two-bladed rotors.

36. Rigid Rotor. This system allows the blade freedom to feather only, it does not allow for freedom to flap or lead-lag (drag). Control loads in this type of rotor are very high and stability is difficult to achieve, it is usual to incorporate computer systems to facilitate ease of control and stability.

Figure 2.13. The Rigid Rotor

37. Swashplate System. The swashplate arrangement consists of two circular or angular plates fitted horizontally one above the other and positioned on top or near the top of the mast. A ball bearing arrangement separates the two plates and allows

horizontal (circular) movement between them. The lower plate is fixed in terms of rotation, but has the ability to move up and down and or tilt in any given direction. It is referred to as the stationary or non-rotating plate. Pilot inputs alter the vertical position of the plate through the collective control and the tilt of the plate through cyclic control. Above the stationery plate is the rotating plate, which, as the name implies, has freedom to rotate. Since the rotating plate always follows the orientation of the stationary plate, any input to the stationary plate is transferred to the rotating plate above it. The rotating plate is connected to each individual blade via pitch links to either the leading or trailing edge of each blade. Thus the rotating plate can alter the blade angle of each blade.

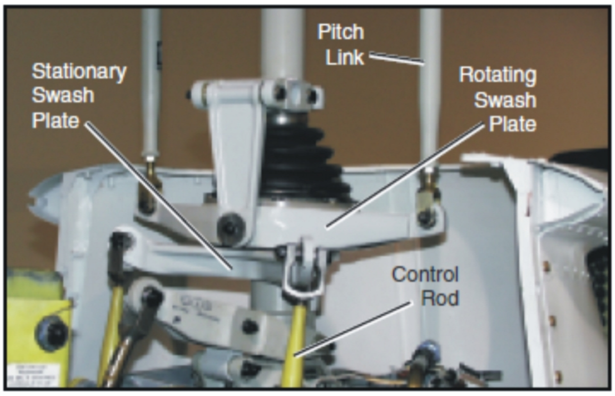


Figure 2.14. The Swashplate System

Anti-torque Rotor (Tail Rotor)

38. When in powered flight, the main rotor tries to remain stationary while the fuselage is subjected to a torque couple trying to rotate it in the opposite direction to that of the main rotor. The tendency to rotate (yaw), occurs when the rotor is driven from a central point (such as the mast) and the degree of yaw is determined by the amount of power used. Since the yaw is caused by a torque couple, it is logical that an opposing couple should be used to counteract it. This opposing moment is produced by the thrust of the anti-torque rotor (tail rotor) positioned at the tail. Thrust from the anti-torque rotor is produced on the same principle as thrust from the main rotor. Therefore the correct amount of tail rotor thrust will produce the required moment (anti-torque) to oppose the torque couple.

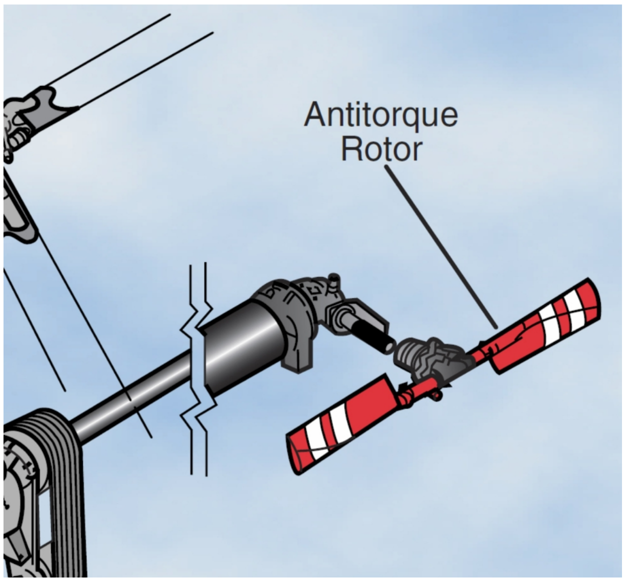


Figure 2.15. The Tail Rotor.

Helicopter Drive Systems

39. The transmission system transfers the work done by the engine to the main rotor and tail rotor. The transmission system include the main rotor gear box, drive shafts, freewheeling unit, rotor brake and the tail rotor gear box.

40. The main rotor gear box transfers engine power to the main rotor shaft and also provides reduction gearing between the engine and the main rotor. If the rotor rotated at engine rpm, tip speeds would be prohibitively faster than the speed of sound. In most cases, rotor rpm is about 1/7th of the engine rpm but it varies as turbines rotate much faster than piston engines and require greater reduction gearing. The main rotor gear box also include the drive mechanism for the tail rotor.

41. The tail rotor gear box contains gearing for the tail rotor rpm and tail rotor pitch control system.

42. The clutch allows the pilot to control the contact between the engine and the drive shaft. In most helicopters it takes the form of either a belt-driven or centrifugal arrangement. The belt-driven clutch is made up of a number of belts positioned between the engine drive shaft and the main rotor gear box. When disengaged, the belts are slack, but when engaged, the belts tighten so that engine power is delivered to the main rotor system. Most modern systems use an electric motor to move an adjustable pulley to tighten

or loosen the belts. On other helicopters the belt adjustments are managed manually with a pilot activated lever.

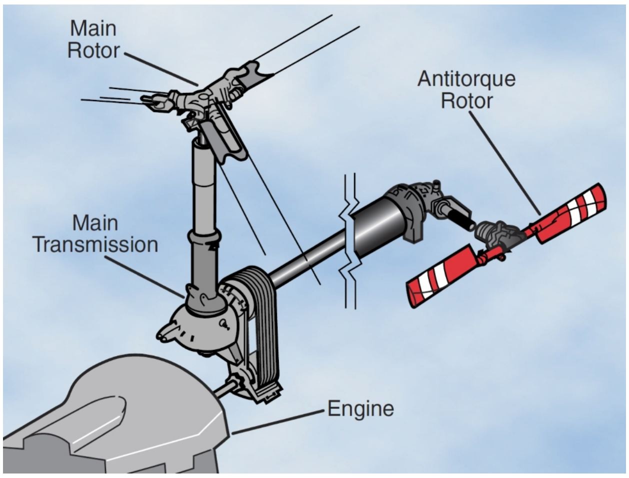


Figure 2.16. Main and Rotor Transmissions

43. The centrifugal clutch's spring-loaded shoes control contact between the inner part and outer part of the clutch. The inner part is connected to the engine while the outer part is connected to the main rotor drive shaft. At low rpm, the shoes are held away from the outer part of the clutch by the tension of the springs but as rpm increases, centrifugal force moves the shoes out and contact is made with the outer part. The clutch also acts as a freewheeling unit so that the engine is disconnected from the rotor if the engine stops.

44. The freewheeling unit automatically disengages the engine from the main rotor when the engine rpm is less than the main rotor rpm, preventing engine "drag" from affecting the rotor rpm. The most common freewheeling units are the sprag clutch and the engine-to-gear box centrifugal system. A sprag clutch is a one-way freewheel clutch. It resembles a roller bearing and when the unit rotates in one direction, the rollers stand up and bind, so doing braking the movement. When the unit is rotated in the opposite direction, the rollers slip or freewheel.

Controls

45. The Collective Lever controls the helicopter in the vertical plane. Raising the lever, moves the swashplate vertically thus increasing the pitch collectively on all the rotor blades which causes an increase in rotor thrust resulting in the helicopter climbing. Increasing the pitch also increases the rotor drag causing the rotor rpm to decay. Lowering the lever will have the reverse effect. To facilitate the maintenance of rotor rpm, a mechanical cam mechanism which automatically increases or decreases the power is fitted. In addition, a twist-grip type throttle is fitted to the end of the collective lever which is used to fine tune the engine rpm.

46. The Cyclic Stick controls the helicopter in the horizontal plane. Movement of the cyclic in any direction, left/right, fore/aft, changes the blade angle of individual blades and will cause the rotor disk to tilt. The amount of total rotor thrust is not affected, the cyclic merely points the total rotor thrust in any required direction.

47. When in powered flight in a single-rotor helicopter, the main rotor tries to remain stationery while the fuselage is subject to a torque couple trying to rotate it in a direction opposite to that of the main

Figure 2.17. The Collective Lever, the Cyclic Stick and the Yaw Pedals

rotor rotation. The greater the power output, the greater the tendency to yaw. Since the potential yaw is caused by a torque couple it is logical that an opposing couple should be used to counteract it. Thrust from the anti-torque rotor (tail rotor) is produced on the same principle as thrust from the main rotor, therefore the correct amount of tail rotor thrust will produce the required moment (anti-torque) to oppose the torque couple. This is achieved by the pilot moving the yaw pedals which collectively change the (angle of attack) on the tail rotor blades. When the movement of the tail rotor thrust equals the torque reaction, the fuselage will maintain a constant direction. The tail rotor is also used for; changing heading in the hover, to maintain a balanced condition in forward flight and to prevent the fuselage rotating in autorotation.

Landing Gear

48. A landing gear system consisting of skids, is the most common type of undercarriage and is suitable for landing on all types of surface. Some are fitted with dampers so that touchdown shocks are not transmitted to the main rotor system. Shocks can also be absorbed by using a system which allows cross tube fittings to bend on impact. In order to manhandle the helicopter on the ground, small wheels are fitted into the skids and the helicopter is then raised of the ground onto the wheels so that it can be moved by hand. Another common type of landing gear can be a three or four wheel configuration. This type of undercarriage normally incorporates oleo-pneumatic shock struts (oleo legs) to absorb shock loads. Normally the nose wheel is free to swivel as the helicopter is taxied on the ground. Wheeled undercarriages can be retractable to reduce aerodynamic drag in flight. Some helicopters are fitted with special types of landing gear such as floats for water operations or special skis for landing on snow.

Airframe loads

49. Each flight you undertake will involve at least one take-off, some form of cruise, one landing (hopefully!), and some taxying. During each of these stages the aircraft will be subjected to external loads. When in the air, these loads will come from the air itself in the form of turbulence or manoeuvring loads, and from the ground during take-off, landing and taxying. These loads play an important part in the design of the aircraft, and in the choice of material to construct the aircraft.

50. In determining the “safe” load to be carried or transported in an aircraft, the static strength, that is bearing strength of the aircraft airframe, while standing static, which will ensure that the airframe will not be damaged by the weight and stress, is determined. A safety factor is added to the static strength bearing capability to prevent the stress being exerted by a load, from reaching the point of ultimate strength, which is when failure will occur. The effect of the stresses experienced when the aircraft is in motion is also considered and hence, a maximum dynamic strength datum determined. As the cumulative effect of the stress caused by operating the aircraft causes fatigue of the construction material, it forms a very important consideration when the operating limits are determined.

51. Air loads will be discussed in Chapter 2, and here we will look only at the ground loads. The loads experienced during landing, which are usually higher than those during take-off, will usually determine the design of the undercarriage structure and attachment. This in spite of the fact that the aircraft usually weighs more during take-off than on landing. The rate of descent during approach will determine what kind of shock absorption is needed when the aircraft makes contact with the ground. Care must be taken to stay within the limits specified, or else there is a danger of undercarriage failure during a landing with an excessive rate of descent. Structural loads during landing can be larger than those developed in flight.

52. Ground handling is also important. Taxying at too high a speed over rough and uneven ground, or turning at high speeds will impose unnecessary loads on the undercarriage structure.

53. When on the ground, an aeroplane may be left unattended for days, and even weeks at a time. Always ensure that control locks are in place to prevent any damage to controls in the event of high speed winds that could be experienced. Tie the aircraft down if necessary.

Powerplant

Engines - general

54. The basic principle of the piston engine (or four stroke internal combustion engine, to give it a more correct title) is that it produces power by converting the energy contained in fuel into mechanical energy. The fuel is mixed with air and is burned to release this energy. This all takes place in the cylinder.

55. The energy that is released is transferred to the air in the form of heat. The hot gas causes the air to attempt to expand, but because it is enclosed in the cylinder, there is a pressure build up in the cylinder which causes movement of a piston which is in the cylinder. The piston is attached to a crankshaft by a connecting rod (see Fig. 2.18), and the linear (straight line) movement of the piston is converted into a rotary motion. In the aeroplane engine the crankshaft is connected to the propeller, and the rotation of the propeller causes the thrust which allows the aeroplane to move forwards.

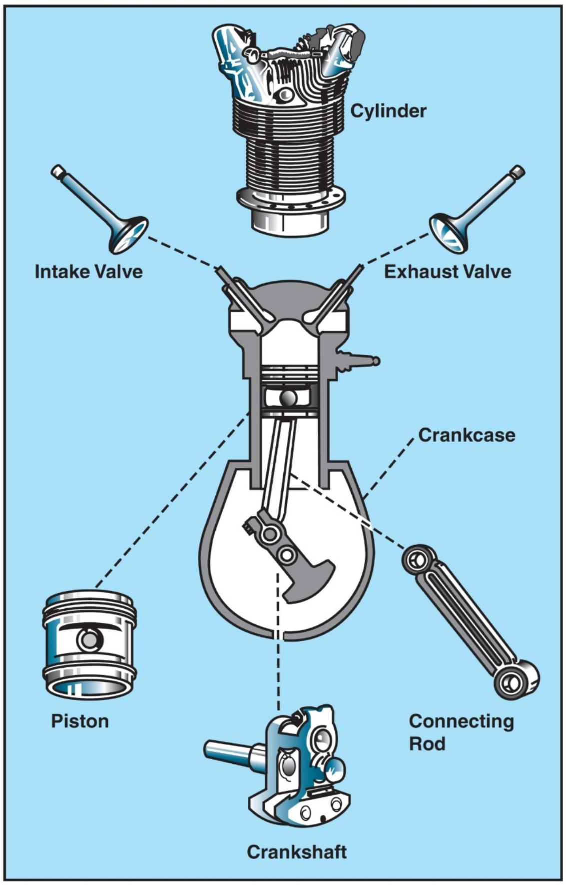


Figure 2.18. Basic Components of a Four Stroke Engine

Principles of the Four Stroke Internal Combustion Engine

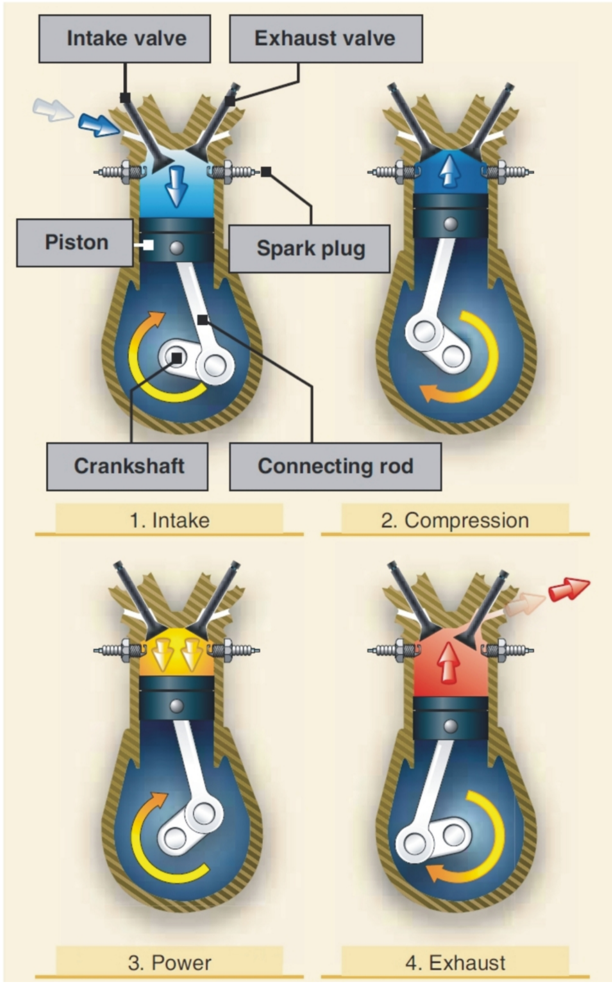


Figure 2.19. The Four Stroke Cycle

56. Starting at the top of Fig. 2.19, you will see an inlet and an exhaust valve. The air/fuel mixture enters the cylinder through the inlet valve as the piston travels downwards in the cylinder. This is called the Induction Stroke. The piston fits tightly into the cylinder, so none of the air/fuel mixture can escape past the piston when it moves up into the cylinder. The air/fuel mixture is compressed by the upward movement of the piston. This is called the Compression Stroke. As the piston reaches the top of its travel, the fuel/air mixture is ignited by the spark plug. The heated gas expands and the piston is forced down the cylinder. This is called the Power Stroke. The piston then travels back up the cylinder, the exhaust valve opens, and the burnt gases are expelled out of the cylinder. This is the Exhaust Stroke. During the four stages the piston moves up and down the cylinder twice, and the term Four Stroke Cycle comes from these four phases of the piston movement

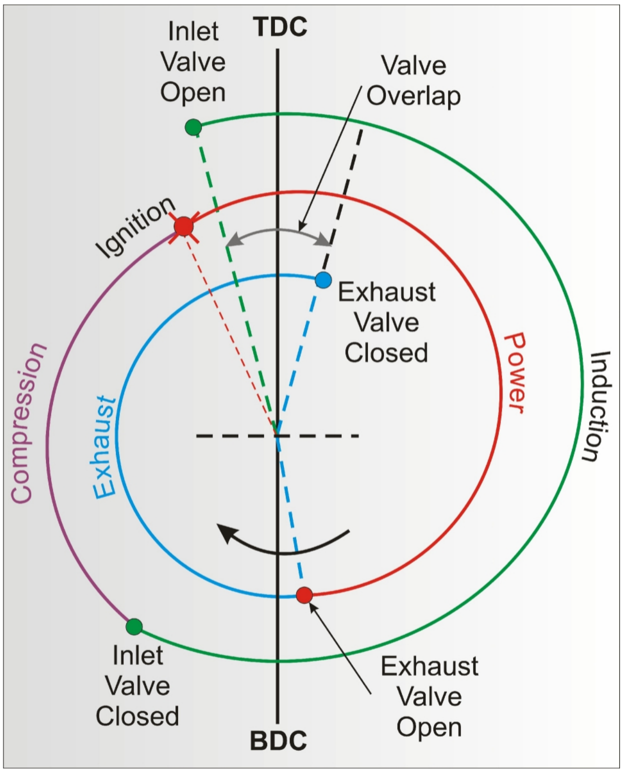


Figure 2.20. The Timing Cycle

Detonation and Pre-ignition.

57. The rate at which the fuel/air mixture burns is very important for the efficiency of the engine. The burn must be a progressive one, causing an increase in pressure in the combustion chamber which forces the piston down the cylinder in the power stroke in a smooth manner.

58. Detonation is when the burn is not progressive, but because of a temperature and pressure rise in the cylinder is too great, it is explosive. This can cause damage to the pistons themselves, as well as the valves and spark plugs. It will cause a decrease in power and can even lead to engine failure. The cause of detonation can be attributed, amongst others, to a fuel which is of a lower grade than is recommended; a mixture which is too lean; excessive temperature of the air into the carburettor; or an engine which is running too hot.

59. As a pilot you will pick up the possibility of detonation when cylinder head temperatures are high. Once this has been detected, richen the mixture, throttle back to reduce the pressures in the cylinder head, or increase speed which will help in reducing the cylinder head temperatures. By richening the mixture, the extra fuel acts as a coolant. Aircraft engines are usually run a little on the rich side to help prevent detonation.

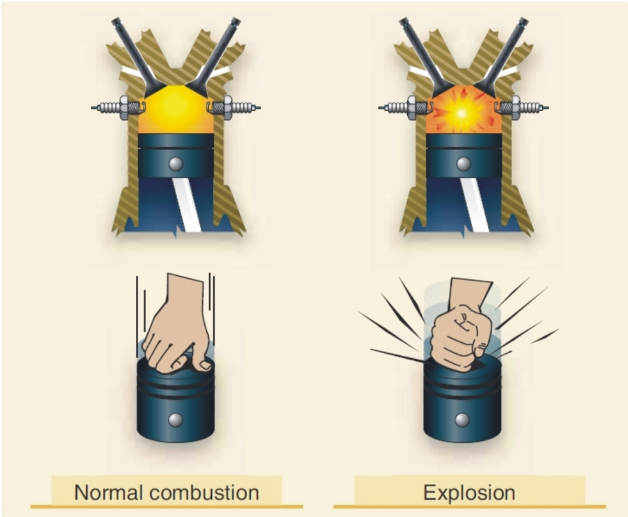


Figure 2.21. Detonation.

60. Pre-ignition is exactly what the word implies - the fuel/air mixture is ignited too early. If there is a carbon deposit in the cylinder, this can become red hot from previous ignitions, and this results in the mixture igniting before the spark plug comes into operation. Pre-ignition results in the pressures in the engine reaching a peak before they are supposed to be doing.

61. The cause of pre-ignition can be attributed, amongst others, to a carbon deposit, or hot spot in the cylinder; or using a power setting which is too high when the mixture is too lean, leaving no extra fuel for cooling purposes.

62. The results of pre-ignition are a rough running engine, with possible back-firing; a sudden rise in cylinder head temperature; and possible damage to the engine in the form of a broken cylinder head, a burnt piston, and damage to the spark plugs and valves.

63. If detonation occurs it usually occurs in all cylinders simultaneously because the fuel/air mix is the same in all of them, but pre-ignition might only occur in one if a single hot spot exists.

64. Both can be prevented by sticking to the recommended fuels and engine operating limitations which can be found in the Aircraft Operating Manual.

Engine cooling

65. If an engine were perfectly efficient all the heat produced in it would be turned into useful work, and the problem of cooling would not arise. This is impossible, however, and in practice less than 30% of the heat generated during combustion is converted into mechanical energy; about 40% passes out with the exhaust gases, while the reminder finds its way into the engine and, if no steps were taken to get rid of it, would cause mechanical deterioration and break-down of the oil.

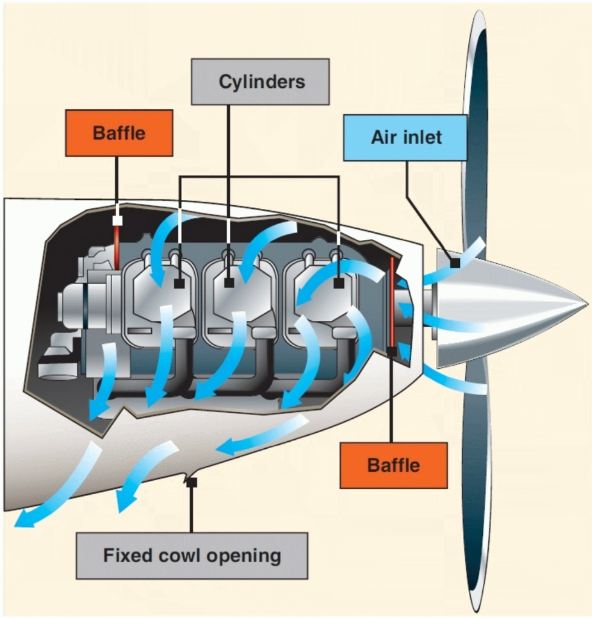


Figure 2.22. Engine Cooling.

66. There are two methods of cooling the cylinders, air cooling and liquid cooling, the difference being that in one case heat is transferred directly to the air through which the engine moves, whereas in the other a liquid coolant circulates continuously between the cylinders and a radiator as in a car. Each system has its merits, and each tends, though not exclusively, to a distinctive arrangement of the cylinders. Whichever method is used, however, a considerable degree of cooling is achieved by the lubricating oil circulating in the engine. The oil is pumped through an oil cooler to dispose of this absorbed heat.

67. In small aircraft installations, the cooling air inlets and exits are usually fixed. The inlet area can be seen directly behind the propeller. the cooling air exits from the engine compartment through the openings on the bottom of the nacelle. The exact position of these inlets and outlets are determined during flight testing by measuring cylinder head and oil temperatures. The fins on the cylinder heads increases the surface area of the cylinder exposed to the airflow and acts as heat-sinks. In aircraft where speed ranges and power variations are greater, the cooling-air exit areas are adjustable from the cockpit for the control of the cooling airflow. The adjustable portions of the exit on an air-cooled engine are called cowl flaps, the name coming from the fact that they form part of the engine cowling. Cowl flaps will increase the drag on the aircraft.

68. Cowl flaps are usually open during take-off due to the high power and low airspeed requiring more cooling air; they may be partially open or closed during the climb and the cruise, and closed when descending with low power. During taxiing they should be open to assist the cooling. The final choice as to when they must be open will depend on the cylinder head temperature which is measured at the cylinder which tests have proven to run the hottest.

Engine Lubrication

69. The primary purpose of a lubricant is to reduce friction between moving surfaces and to cool the surface. It is also used to dissipate heat from the moving parts, pistons and cylinders are particularly dependent on oil for cooling. Any contaminants which find their way into the engine are also carried away by the engine oil and removed in the oil filter. Oil filters must be cleaned regularly as they may become blocked, resulting in dirty oil circulating in the system. Oil also produces a seal between the cylinder walls and the pistons which increases the effectiveness of the expanding gases during combustion.

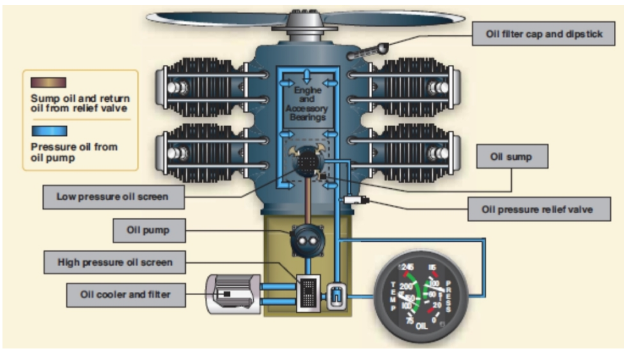


Figure 2.23. The Lubricating System.

70. The internal friction of a fluid, its resistance to flow, is called viscosity. Viscosity varies not only between oils, but between the same oil at differing

temperatures. When oil is cold it flows slowly and has a high viscosity making circulation extremely difficult. If the oil gets too hot the viscosity may become so low that the film between the bearing surfaces breaks down, metal-to-metal contact occurs and rapid wear and heating results.

71. Your engine must always have sufficient oil available. A dipstick is available for you to check the level, and a filling point is provided if more oil is needed. The correct grade of oil must be used at all times. Mineral oil has no additives and is used to break-in new engines. Detergent oil has various additives which assist in the cleaning, dispersion and suspension of particles. Never mix the two. Mineral oil must be drained before detergent oil is added. Motor car engine oil is not an option. The Aircraft Operating Manual will usually show the grade to be used. Aviation oil has a commercial aviation number such as 80 grade or 100 grade. The SAE rating is half of the grade value - SAE 40 is 80 grade oil, and SAE 50 is 100 grade oil. The higher the number, the greater the viscosity.

72. You will find an oil pressure gauge and an oil temperature gauge in the cockpit which allows you to monitor the status of the oil system. if pressures are too low, oil is not being delivered to all parts of the engine, and the flight should be terminated. If the temperature is too high, the oil may not be viscous enough to provide lubrication all the parts of the engine. the correct range of pressures and temperatures can be found in the Aircraft Operating Manual. Some aircraft are fitted with a cylinder head temperature gauge as well.

Oil System Operation

73. After doing its work in the engine, the oil gathers in the sump which is a reservoir attached to the tower part of the engine casing. A wet sump engine has a sump attached to it in which the oil is stored. Most light aircraft engines are wet sump engines. A dry sump engine has scavenge pumps that scavenge the oil from the sump attached to the lower part of the engine casing and pump it back into the oil tank, which is separate from the engine. It is usual to have a dry sump on aerobatic aeroplanes for continuous lubrication in extreme attitudes. Radial engines have dry sump oil systems. The scavenge pumps is normally stronger than the pressure pumps.

74. There is usually an engine-driven oil supply pump (Both scavenge- and pressure pumps are gear type pumps) that supplies oil from the sump or the tank through oil lines, passages and galleries to the moving parts of the engine. Within the oil pump is a spring-loaded oil pressure relief valve. If the pressure set on the pressure relief valve is exceeded, it will open and relieve the pressure by allowing oil to be returned to the pump inlet.

75. An oil pressure gauge in the cockpit indicates the oil pressure provided by the oil pump. The oil pressure sensor is situated after the oil pump and before the oil does its work in the engine.

76. Oil filters and screens are placed in the system to remove any foreign matter such as dirt or carbon particles in the circulating oil. The oil filters should be inspected and replaced at regular intervals, as required in the maintenance schedule. The foreign matter collected may give an indication of the condition of the engine - for instance, small metal particles might indicate an impending engine failure. Within the oil filter housing is the oil filter bypass valve. This permits the oil to bypass the filter in the event of the filter becoming clogged. Dirty and contaminated oil is preferable to no oil at all.

77. Because the oil absorbs engine heat, the cooling that occurs in the sump is often insufficient, so most engines have an oil cooler. The oil is pumped from the sump through the oil filter to the oil cooler. If the oil is already cool, a thermally operated valve allows it to bypass the oil cooler, as further cooling is unnecessary. If the oil is hot (as it is when the engine has warmed-up), the thermally operated valve directs the oil through the cooler. Should the cooler become blocked, a pressure bypass valve allows the oil to bypass the cooler.

78. The oil cooler is usually positioned in the system so that the oil cools a little in the sump and then passes through the oil cooler for further cooling just prior to entering the main parts of the engine.

79. As part of your daily/preflight inspection you should check the condition of the oil cooler for:

a. freedom from insects, birds* nests and other contamination, to ensure free air passages; and

b. any oil leakage or fatigue cracks.

80. There is an oil temperature gauge in the cockpit. It is connected to a temperature probe that senses the temperature of the oil after the oil has passed through I the oil cooler and before its use within the hot sections of the engine. Also, some aeroplanes have a cylinder-head temperature (CHT) gauge to provide another indication of engine temperature, this time in the cylinder head.

Malfunctions in the Oil Lubrication System

81. Incorrect Oil Type. The incorrect type of oil will possibly cause poor lubrication, poor cooling and engine damage. Oil temperature and oil pressure indications may be abnormal. For instance, mixing detergent and mineral oils can lead to engine damage.

82. Incorrect Oil Quantity. The oil level should be checked and corrected if necessary prior to flight. There will be an oil dipstick in the tank for this purpose. The dipstick is calibrated to show maximum and minimum oil quantities. If the oil quantity is below the minimum, then you will find that the oil overheats and/or the oil pressure is too low or fluctuates. If the oil quantity is too great, then the excess oil may be forced out through various parts of the engine, such as the front shaft seal. The oil quantity needs to be checked before each flight, as it gradually decreases because of:

a. being burned with the fuel/air mixture in the cylinders;

b. loss as a mist or spray through the oil breather; and

c. leaks.

83. Low Oil Pressure. At normal power, a low oil pressure may indicate an impending engine failure caused by:

a. insufficient oil;

b. lack of oil because of a failure in the oil system;

c. a leak in the oil tank or oil lines;

d. failure of the oil pump;

e. a problem in the engine, such as failing bearings; or

f. the oil pressure relief valve (PRV) stuck open.

84. Where an indication of low or fluctuating oil pressure occurs and is associated with a rise in oil temperature while in flight - play it safe and land as soon as possible, as it could indicate a serious problem in the lubrication system.

85. High Oil Temperature. Too little oil being circulated will also be indicated by a high oil temperature, therefore a rising oil temperature may indicate a decreasing oil quantity. Prolonged operation at excessive cylinder head temperatures will also give rise to a high oil temperature indication. This would be most likely to occur in situations of high power, low airspeed (climbing), especially in high ambient air temperatures.

86. Gradual Loss of Oil. If the engine is gradually losing oil, the oil temperature will gradually rise as less oil is available for cooling and lubricating the engine. If oil is lost, the oil pressure will probably be maintained, until the oil quantity reaches a critically low level. This may be indicated by rapidly rising oil temperature with a sudden drop in oil pressure occurring just before engine seizure. If you suspect a problem concerning oil, then you should plan a landing before the time you estimate the oil problem will become serious. This is a matter of judgement, especially if the choice of nearby landing areas is not great.

87. High Oil Pressure. A pressure relief valve in the system should ensure that the oil does not reach an unacceptably high oil pressure. a high oil pressure may cause some part of the system to fail, rendering the whole system inoperative.

Oil Cooling Methods.

88. The oil is sprayed onto the pistons from the bearing side to remove the heat that the pistons have absorbed from the engine. This will naturally result in the oil itself becoming hot. Because the oil is always circulating, the hot oil will pass from the pistons to an oil cooler which is exposed to the airflow. Here it is

cooled, and then continues the cycle of lubricating and cooling the engine, before coming back to cool off in the oil cooler once again.

Ignition systems

89 The aircraft engine ignition system is required to provide a rapid series of sparks of an intensity sufficient to ignite the weakest fuel/air mixtures normally used, correctly timed in rotation to each compression stroke, and arranged to fire each cylinder in the desired sequence. The following paragraphs describe briefly the main components of a simple system as shown in Fig. 2.24.

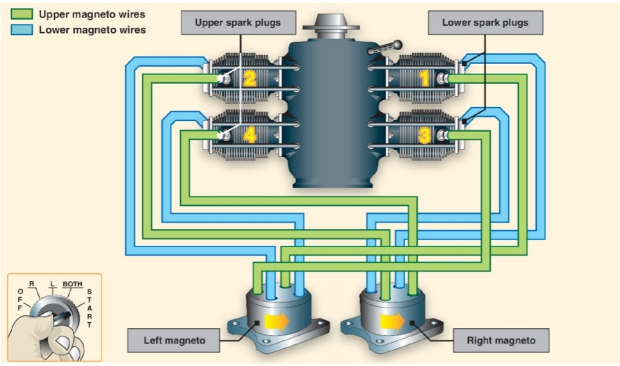


Figure 2.24. The Ignition System.

90. Sparking Plugs. The sparking plugs provide the air gap which produces the spark for ignition of the fuel/air mixture in the combustion chamber. There are two plugs to each cylinder, so that burning of the charge from two points will give more efficient burning and greater power and also provide an alternative source of ignition should one fail.

91. Magneto. The magneto is an engine driven electrical generator designed to supply high voltage current to the plugs in sequence, and at a precise time in the compression stroke. A magneto contains a small magnet which rotates between two coils. One coil, the primary coil, is connected at one end to the ignition switch. The magnet within the magneto is rotated by a mechanical linkage to the engine crankshaft and as the magnet rotates, a flow of electrical current in the primary circuit is produced. As the flow reaches a maximum, a set of breaker points open causing the flow of electric current in the primary coil to stop. When this happens the magnetic field surrounding the primary coil collapses which induces a very high voltage in the secondary coil. This electric current travels to a distributor from where it is directed along the high tension leads to each spark plug.

92. Distributor. The distributor consists of two parts, a rotor and a distributor block. The rotor is attached to a distributor gear and rotates at a fixed ratio with respect to the magneto and crankshaft. As it rotates it comes opposite to, but does not actually make contact with, each of a number of electrodes in turn. These electrodes, which are insulated from each other and from the body of the magneto, are connected one to each of the plug leads. The rotor receives the high current from the magneto and passes it, via the electrodes and leads, to the appropriate sparking plug.

93. To guard against engine failure due to a defect in the ignition system, two entirely independent magnetos, with two sets of sparking plugs and connecting leads are fitted to each engine. The provision of two sparking plugs in each cylinder also ensures more efficient ignition of the charge, and it is for this reason that a small drop in rpm occurs when one magneto is switched off to test the ignition.

94. To aid starting, the magneto may be fitted with an impulse coupling. When the engine is turning over slowly such as starting the engine on a cold morning with the starter motor turning slowly, a spring loaded impulse coupling in one magneto, usually the left one, operates to provide a spark at the spark plugs which is more powerful than normal. Once the engine is running the impulse coupling automatically disengages. This spark occurs later than normal (ie 25 before TDC) and is said to be "retarded". Once started, the timing would advance automatically to 25E before TDC. This is to prevent knock-down of the piston in the opposite direction of the crankshaft rotation.

95. In order to ensure proper operation of the ignition system, the High Tension leads are to be checked for secureness and fraying.

96. The ignition system is controlled by the magneto switches in the cockpit and when the magneto switches are set to "Off", the switch in the primary circuit is closed and the primary circuit is earthed. This means even if the magneto is rotated, it cannot induce a voltage in the secondary circuit. There is no practical way for the pilot to check this earthing during the pre-flight checks and therefore the magnetos are checked for "dead-cut" during the shut-down procedure. This will ensure that the pilot is reasonably sure that the mags

are not alive, it is however a very good idea to treat all engines and propellers as being alive.

97. During the power check, the engine is run up to near cruise power and the magnetos are individually checked. The resultant decrease in power must be within the limits stated in the POH/FM.

Carburation

98. Carburation is the process by which air and fuel vapour are mixed in suitable proportions and the supply of this mixture regulated according to the requirements at any given operating condition.

99. The mechanical means by which this mixture is achieved is by the use of a carburettor or fuel injector. Their purpose is to supply a well atomised and correctly proportioned mixture of fuel and air to the engine, and to provide a method of limiting the power output by limiting the flow of the mixture.

100. Liquid fuels will not burn unless they are mixed with oxygen. For the mixture to burn efficiently in an engine cylinder, the air/fuel ratio must be kept within a certain range, around 15:1 by weight. The ratio is expressed in weight because volume varies considerably with temperature and pressure.

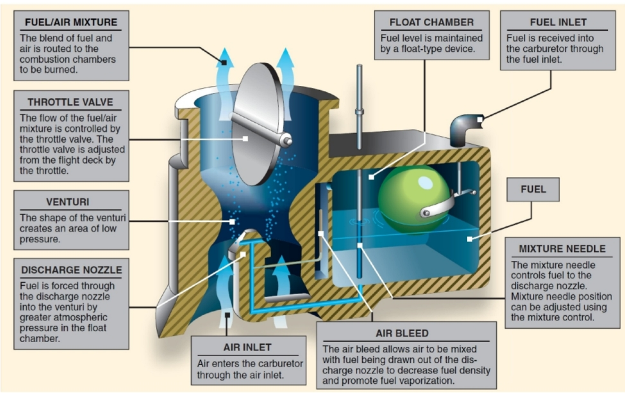


Figure 2.25. The Float-Type Carburettor.

101. The throat of the carburettor is designed in a venturi shape, and as you will see in the chapter addressing Principles of Flight, airflow in a venturi causes an increase in speed, and at the same time, a reduction in pressure. this allows the fuel to flow through jets in the carburettor from the float chamber. As the fuel enters the venturi it vaporizes and mixes with the air. from there it continues into the cylinder where it is compressed and ignited. The pilot has control over the amount of air in the mixture by using the throttle lever which opens or closes the butterfly valve, while the strength of the fuel/air mixture is controlled by the mixture control level.

102. Carburetors are normally set to deliver the correct air/fuel mixture (air/fuel ratio) at sea level. This air/fuel ratio is the ratio of the weight of fuel to the weight of air entering the cylinder. This ratio is determined by the setting of the mixture control in both fuel injection and carburetor-equipped engines.

103. When climbing, the mixture control allows the pilot to decrease the fuel flow as altitude increases (air density decreases), thus maintaining the correct mixture (air/fuel ratio). If the fuel flow is allowed to remain constant by not leaning the mixture, the fuel/air ratio becomes too rich, as the density (weight per unit volume) of air decreases with increased altitude, resulting in a loss of efficiency. Operating with an excessively rich mixture may cause fouling of spark plugs.

104. When descending, air density increases. Unless fuel flow is increased, the mixture may become excessively lean; i.e., the weight of fuel is too low for the weight of air reaching the cylinders. This may result in the creation of high temperatures and pressures. The best power mixture is the air/fuel ratio from which the most power can be obtained for any given throttle setting. Various methods are employed to correct the mixture strength as altitude changes. In aircraft fitted with small engines, the mixture control consists of a hand operated mixture control lever. High power engines usually employ automatic mixture control which can either be of the vacuum control or the diffuser air bleed type.

105. The carburettor allows the fuel flow to be adjusted. When the throttle is set to idle and the butterfly valve nearly closed, there may be an insufficient velocity of air through the venturi to draw fuel into the induction system. To overcome the problem, a slow running or idling jet is fitted which sprays fuel into the venturi when the engine is idling and the throttle is nearly closed. Additional fuel jets that may be found in the float-type carburettor are the Power Jet and the Enrichment Jets. They are respectively fitted for the purpose of ensuring full power delivery during cruise and maximum permissible power during take-off. In both cases extra fuel is injected into the induction system.

106. Another such an adjustment is the accelerator pump which may be required when the throttle is rapidly moved from idle to full power. There is a delay between the butterfly opening and sufficient fuel entering the venturi to maintain the correct fuel/air mixture. This can cause the engine to falter before delivering full power. To solve the problem an accelerator pump can be connected to the throttle linkage which squirts additional fuel into the venturi when the throttle is opened rapidly. This action will avoid the delay in obtaining full power.

107. When the ignition is switched off while the engine is running, due to the engine being hot and the availability of fuel at the slow running jet, the engine may continue to run for quite a time. To prevent this, a device, the so called cut-out valve is fitted. When moving the mixture control lever to the fully lean position, a valve, in the slow running passage closes, preventing any fuel from being drawn into the induction system.

108. The induction system brings together the air and the fuel, mixes them in the correct proportions, allows the pilot to select the amount of fuel-air mixture entering the engine and delivers the mixture to the cylinders. Air enters the induction system via an air filter which removes dust and other unwanted debris. The filtered air then travels via an inlet pipe to the venturi inside the carburettor throat. The amount of power developed by a piston engine is dependant on the weight of the fuel-air mixture delivered to the cylinders. As already explained, the density of the air decreases as an aeroplane climbs, that is the weight of the fuel-air mixture reduces as altitude increases. Two ways of preventing a loss of power as altitude is increased, are making use of supercharging or turbocharging.

109. A supercharger is basically an engine-driven fan or impeller which is positioned between the carburettor and the induction manifold. The supercharger is driven through gearing from the engine crankshaft and it may be single or multi-staged. The impeller revolves nine to ten times faster than the engine rpm. It is important to realise that the supercharger absorbs an appreciable amount of power from the engine. The fuel-air mixture is drawn in through the carburettor by the supercharger and enters the eye of the impeller, the rotational speed of the impeller then throws the mixture outwards with increasing velocity. The mixture leaves the supercharger through a diffuser which smoothly decelerates the flow of the mixture and increases the pressure as it enters the inlet manifold. Thereby restoring the loss of pressure due an increase in altitude and thus restoring the loss of power.

110. As already stated, the supercharger relies on a gear drive from the crankshaft of the engine, the turbo-charger however, utilises the exhaust gases of the engine to drive a compressor, the product of which is used to pressurise the inlet manifold in a similar manner as the supercharger. The use of exhaust gases from the engine has thus provided a useful source of energy which otherwise would have been lost and no no engine power is lost during the process.

Carburetor Icing

111. As air flows through a carburetor, it expands rapidly. At the same time, fuel entering the airstream is vaporized. Expansion of the air and vaporization of the fuel causes a sudden cooling of the mixture which may cause ice to form inside the carburetor. The possibility of icing should always be considered when operating in conditions where the outside air temperature is between -10EC and 20℃ and the relative humidity is high.

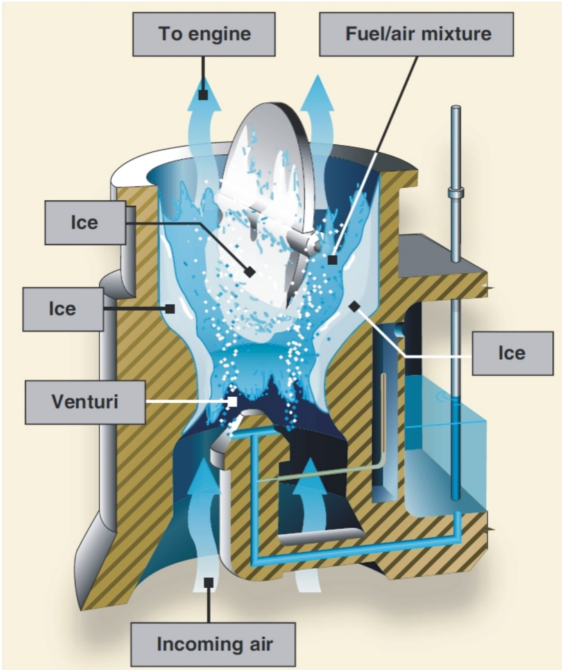


Figure 2. 26. Carburetor Icing.

112. Carburetor heat preheats the un-filtered air before it enters the carburetor and either prevents

carburetor ice from forming or melts any ice which may have formed. When carburetor heat is applied, the heated air that enters the carburetor is less dense. This causes the air/fuel mixture to become enriched, and this in turn decreases engine output (less engine horsepower) and increases engine operating temperatures.

113. During engine run-up, prior to departure from a high-altitude airport, the pilot may notice a slight engine roughness which is not affected by the magneto check but grows worse during the carburetor heat check. In this case the air/fuel mixture may be too rich due to the lower air density at the high altitude, and applying carburetor heat decreases the air density even more. A leaner setting of the mixture control may correct this problem.

114. In an aeroplane with a fixed-pitch propeller, the first indication of carburetor ice will likely be a decrease in RPM as the air supply is choked off. Application of carburetor heat will decrease air density, causing the RPM to drop even lower. Then, as the carburetor ice melts, the RPM will rise gradually.

115. Fuel injection systems, which do not utilize a carburetor, are generally considered to be less susceptible to icing than carburetor systems are. A fuel injection system metres the amount of fuel required by the engine and then injects it directly into the induction system of the intake valve of each individual cylinder. This increases the engine's efficiency and eliminates most of the carburettor's defects. The fuel injection system has no carburettor heat control but employs an alternate induction air control in case the normal air inlet becomes blocked. When alternate air is selected, the air is fed into the induction system from a separate warmer source within the engine cowling.

Aero Engine Fuel

116. Aviation fuel, or AVGAS (AViation GASoline) comes in various grades to cater for different types of piston engines. Jet engines use AVTUR (AViation TURbine fuel) or Jet A1, and this must not be used in piston engines. The various grades of AVGAS are colour coded to make it a little easier to check that you have the correct fuel . Normal fuel used in light aircraft is blue (100 LL octane) or green (100/130 octane). There is also a 80/87 octane fuel which is red in colour. AVTUR is usually clear and smells quite different. Fuel bowsers or drums are marked in distinct colour codes as well, AVGAS decals being white lettering (100/130 or AVGAS) on a red background, while AVTUR has a black background with white lettering (Jet-A1). Fuel hoses and nozzles also have the same colour as the fuel grade for both AVGAS and AVTUR.

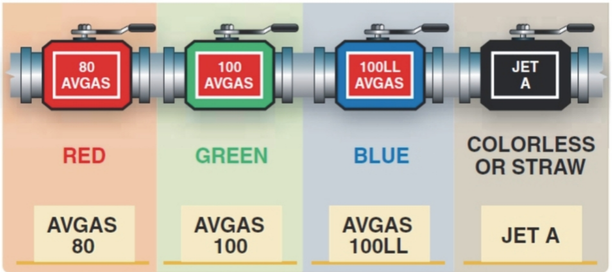


Figure 2.27. Fuel Colour Codi ng

117. The octane rating of fuel is an indication of its anti-detonation (or anti-knock) qualities. The higher the octane, the greater the compression that can be achieved before detonation occurs. Higher grade fuels also have higher lead content which also improves the anti-detonation capability of the fuel. To minimise the risk of detonation, a very small amount of tetraethyl lead (TEL) is added by the fuel company to AVGAS. The Aircraft Operating Manual will indicate which grade must be used, and make sure that you know which one is required, and make sure that any fuel which is being loaded is the same as that already in the tanks.

118.Using the wrong grade of fuel will cause problems for you. If the grade is too low, you can expect excessive engine temperatures, and detonation can occur, especially if power settings are high. This will result in a loss of power, and there is a good possibility of engine damage. If the grade is too high, spark plugs may become fouled by lead deposits from the higher lead content, and exhaust valves and seals can become eroded during the exhaust cycle.

119. If you are forced to use the wrong grade, err on the higher side. This will be less dangerous than using a lower grade fuel. A higher grade of fuel may be used as a short term solution, but not a lower grade. AVGAS is subject to higher quality control than motor car fuel, and motor car fuel has very different burning characteristics. If used in an aeroplane, motor car fuel will result in a lower power output, fouling of spark plugs and the risks of detonation increase. Motor car fuel vaporizes easier and this could result in a vapour lock which would starve the engine of fuel.

120. Fuel can be contaminated by water and/or dirt. The air inside the aircraft fuel tanks can cool at night, which allows the formation of water droplets, through condensation, on the insides of the fuel tanks. These droplets then fall into the fuel. To avoid this problem it is always a good idea to fill the tanks completely when parking the aeroplane overnight.

121. Dirt can get into the fuel if refuelling equipment is poorly maintained or if the refuelling operation is sloppy. Use care when refuelling an aeroplane. If there is any reason to doubt the quality of the fuel about to be put in the aircraft, filter it with a piece of chamois leather cloth or get it checked by an expert. If there is any doubt, don't use it.

122. The fuel must be checked before flight for any water or contaminants, and your instructor will show you how this is done.

123. The density of fuel, like other liquids, will be affected by changes in temperature. The most significant change that occurs is that as temperature increases, the fuel expands and as the size of the fuel tank remains unchanged, the amount of fuel in real terms in your tank, decreases. This phenomenon only becomes significant at temperatures above +15℃.

ENGINE HANDLING

124. When preparing for starting an engine, it is best to follow the instructions in the POH/FM. Using a checklist will avoid dangerous and expensive mistakes. Most carburettor engines are fitted with a primer which is a small plunger operated from the cockpit which is used to "prime" the engine by squirting fuel directly into the induction system at the inlet valve and cylinders, by-passing the carburettor. Once priming has been completed the primer must be locked closed again.

125. Once the engine is primed and the checklist completed and the propeller is clear, the ignition key is turned to the position marked "Start". An electric starter motor will engage and turn the engine until it fires and runs of its own accord. As soon as the engine starts the key is released and a spring will return the key to the "Both: position.

126. Once the engine has started, the first task is to set the engine to idling rpm which is normally between 1000 and 1200rpm. As the engine needs time to warm up, care must be taken not to idle at too high a rpm as it may cause long term engine damage. With the proper rpm set it is important to check the starter warning light if fitted. This indicates if the starter motor is engaged to the engine and should it remains lit, the engine should be shut down immediately in order to prevent damage to the starter and electrical system.

127. Shortly after start, the oil pressure gauge must be checked, a positive oil pressure must be indicated within 30 seconds of starting and if no oil pressure is indicated, the engine should be shut down immediately.

128. Malfunctions during start may of course occur and a little trouble shooting or fault finding will then be necessary. As a piston engine basically requires fuel, air and ignition to operate, it is a good idea to run through the checklist to make sure that nothing was left out. If everything seems to be in order the most likely problem will be either too much (over-primed) or too little (under-primed) fuel in the induction system. An under-primed engine cannot start as it has insufficient fuel. An over-primed engine may fire intermittently but fail to start properly while emitting copious amounts of smoke from the exhaust. In either case, care must be taken not to overheat the starter motor, do not turn the motor longer than 20 seconds at a time and allow a minute to cool down after an attempt.

129. Based on the behaviour of the engine, decide whether it is under-primed and requires more fuel or if its flooded. If it is flooded, the excess can be cleared away by moving the mixture control lever to the fully lean position, set the throttle to about half-way open and turn the engine until it starts where-upon the throttle and mixture must quickly be reset to the original starting positions.

130. Throughout and whenever the aircraft engine is running, whether during starting, or idling, during ignition/power checks, climbing, cruising, descending or shut down, engine gauges (cylinder-head, EGT , oil temperatures and pressures, fuel pressures, fuel quantity, engine rpm limits and manifold pressure limits) must be checked for normal readings within the specified limits in the checklist or POH/FM.

131. The aircraft checklist and POH/FM will prescribe the sequence of the power check. Before commencing with the power check, ensure temperatures and pressures are within limits. At the prescribed power

check setting, the carburetor heat function is checked by moving the carburettor heat control lever to "Hot". There should be a smooth reduction in rpm, refer to the POH/FM for the exact figures and when the control is returned to the "Cold" position, the rpm should return to the original setting.

132. After the carburettor heat check, the magnetos are checked. The normal sequence for the key-type magneto switch is as follows. From the Both position move the key to the "Left" position, only the left magneto will now be operating and a smooth drop of 100 - 150 rpm should indicate that the right magneto has been taken out of the loop. After a few seconds return the key to the "Both" position and the rpm should return to the original settings. The process is repeated by the key being moved to the "Right" position for checking the right magneto. The difference in rpm between the two indications (when the magnetos are operating on their own) should not exceed 50 rpm.

133. Rapid power changes should be avoided for three specific reasons namely; firstly, if an accelerator pump is fitted, a rapid throttle movement can cause an over-rich mixture which can in turn cause the engine to falter or cut. Secondly, the engine crankshaft is fitted with counterweights to reduce vibration and damp out potentially damaging resonant frequencies, sudden throttle movements can cause just the sort of vibration the counterweights are designed to avoid. Thirdly, sudden throttle movements may make it difficult for the carburettor to supply the correct fuel-air mixture throughout the rpm range, possibly resulting in a "flat spot" where the throttle movement cause the engine to falter.

PROPELLERS

134. The propeller is a means of converting the power developed by an aircraft's engine, into a propulsive force. A propeller is merely an aerofoil rotated by the engine, it creates lift along the horizontal axis of the aircraft, referred to as thrust, and it is the thrust that provides the motion to move the aircraft forward. With the aircraft's engine running and the propeller blade moving through the air, forces known as thrust and torque, are generated. The magnitude of the thrust and torque produced will be dependent on the size, shape and number of blades, the blade angle, the speed of rotation of the propeller, the air density and the forward speed of the aircraft. As each blade is basically a cross-section of an aerofoil, thrust will be produced most efficiently at a particular angle of attack. The angle of attack being the angle between the chord lime of the propeller blade at a particular blade station, or position along the blade, and the relative airflow.

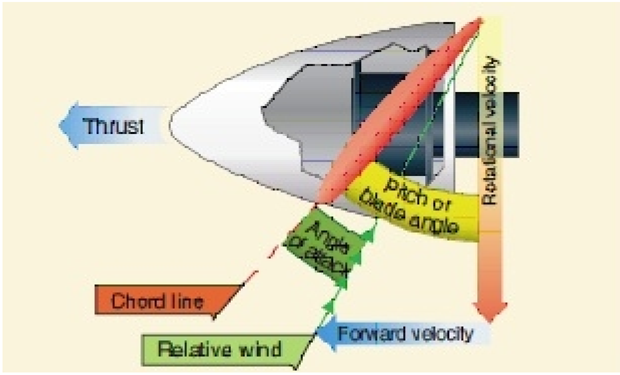


Figure 2.28. Propeller Blade Angle

135. The angle of attack will vary both with operating conditions and the camber of the blade section. However, for a given blade and given in-flight conditions, the angle of attack will be relatively constant along the blade length. The rotational speed of a speed of a particular cross-section of the blade will increase, the farther it is from the axis of rotation (the propeller hub). As the forward speed of the of all parts of the blade is the same, the relative airflow will vary along the length of the blade. It is therefore necessary to decrease the blade angle from the root to the tip of the blade (blade twist) in order to generate the same (balanced) thrust conditions along the blade length.

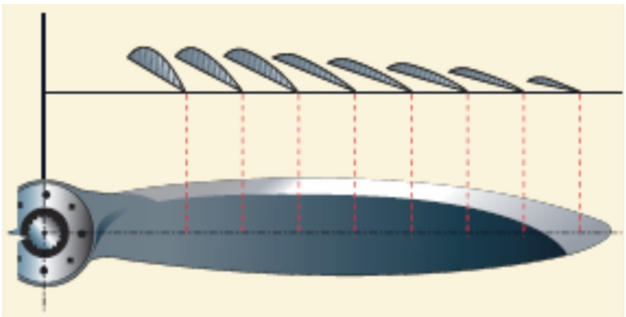


Figure2. 29. Aerofoil Sections of Propeller Blade

136. Most training aircraft have a fixed pitch propeller whose pitch angle is fixed and cannot be altered in flight or on the ground. Fixed pitch propellers are set to a optimum operating angle which confines it to a small section of the aircraft's operating speed.

137. Forces acting on a propeller blade. The aerodynamic force produced by setting the blade at a small positive angle attack may be resolved with respect to the direction of motion of the aircraft.

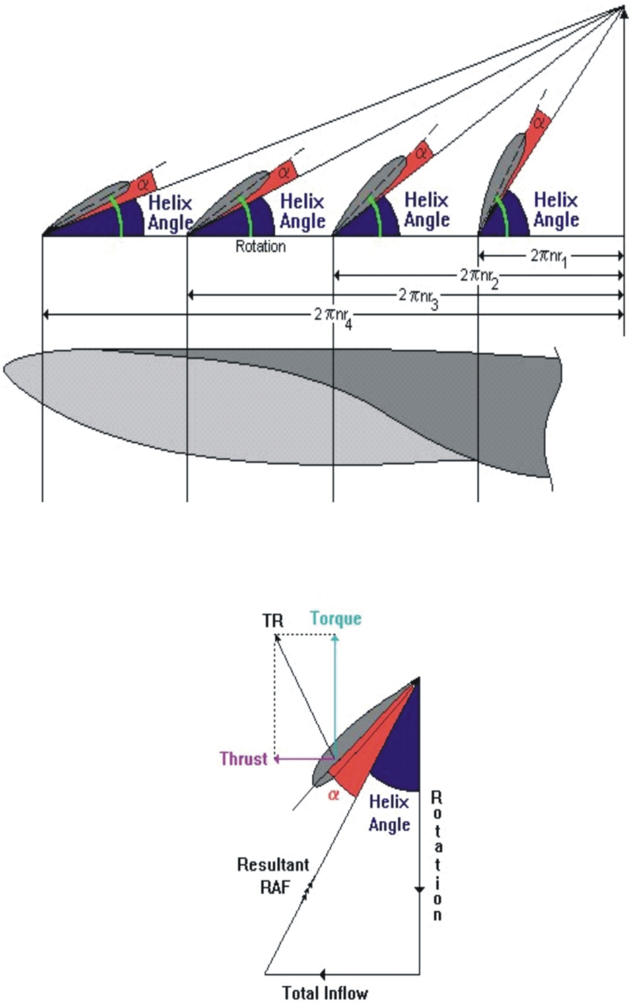


Figure 2.30. Forces on Blade Element

138. As can be seen from Fig. 2.30, the reaction thus resolved, is in the form of lift and drag vectors. Whilst the drag component is important when considering retardation effect on the blade, the breakdown of the resultant into thrust and torque is more useful. It can be seen that part of the total reaction in the direction of flight, whilst torque is the component vertical to thrust and opposing the rotational velocity. The thrust is therefore the propulsive force, whilst the torque tends to rotate the aircraft in the opposite direction to that produced by the rotational velocity. Centrifugal forces, exerting bending and twisting forces, acts on a propeller during flight and can be severe at high rotational speeds. Centrifugal forces induce radial stress and a twisting moment. The radial force acts parallel to the blade axis and produces radial stress whilst the other acts at 90 degrees to the blade axis and tends to bend or twist the blade to a finer pitch. The wider the blade, the greater will be the twisting moment. Thrust will tend to bend the blade in the direction of flight whilst torque forces tend to bend the blades against the direction of rotation. Air loads tend to oppose centrifugal twisting and try to coarsen the blade pitch.

139. Variation of Propeller Efficiency with Speed. Fig. 2.31 demonstrates the effect of speed on a fixed propeller travelling at different flight speeds at a constant rpm. If the blade angle is fixed, the angle of attack can and will only change with a variation of speed. Thus as the speed increases, the angle of attack decreases and with it, the thrust. It can therefore be seen that at high speed the angle of attack will be close to zero degrees reducing the thrust value to zero and therefore the propeller efficiency will also be close to zero. On the other hand at low speeds the angle of attack is at a large angle and therefore the thrust being produced will also be large, however as the speed is low the efficiency is also low. There will only be one speed at which the propeller is operating at its optimum and efficiency be a maximum.

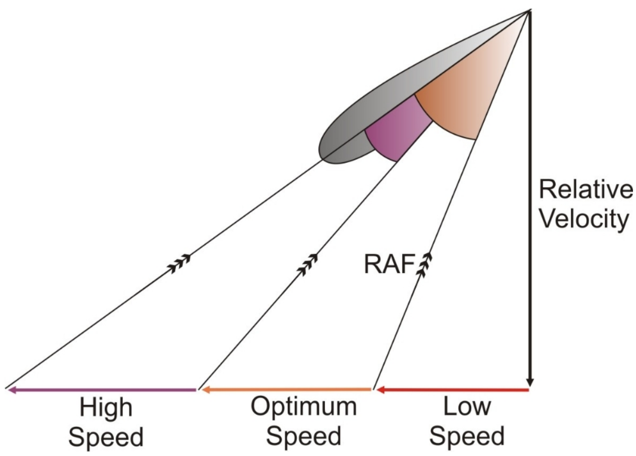


Figure 2.31. Variation of Propeller Efficiency with Speed

140. Variation of RPM with Change of Airspeed. A fixed pitch propeller can be likened to a car with one gear. The speed of the engine/propeller is measured with a tachometer and rather like a car stuck in one gear, as an aircraft with a fixed pitch propeller increases its speed, so the engine/propeller increases its speed even though the throttle position is unchanged. Vice versa if the aircraft slows down, the engine/rpm decreases. Simply explained, whereas the torque and the rotational speed normally act opposite

to one another, at high speed, they act in the same direction.

141. As already explained, a change in airspeed will alter the effective angle of attack of the propeller blade. It follows if the pilot can alter the propeller blade angle in flight, it will be possible to maintain the effectivity of the propeller of a wide range of speeds. This can be done by using the variable pitch propeller. The variable pitch propeller achieves this function using a mechanism which rotates the blade where it is attached to the propeller hub, effectively changing the propeller blade angle for different flight conditions. Using a pitch control lever inside the cockpit, the pilot can select and change the propeller blade angle, when flying at relatively low speeds or for take-off and climb, a fine pitch or small blade angle will be selected and a coarser pitch, large blade angle for faster or cruise speeds. Early variable pitch propellers did indeed operate with only a take-off/climb and a cruise setting (the two-pitch airscrew). However the modern-day variable pitch propeller incorporates a constant speed unit.

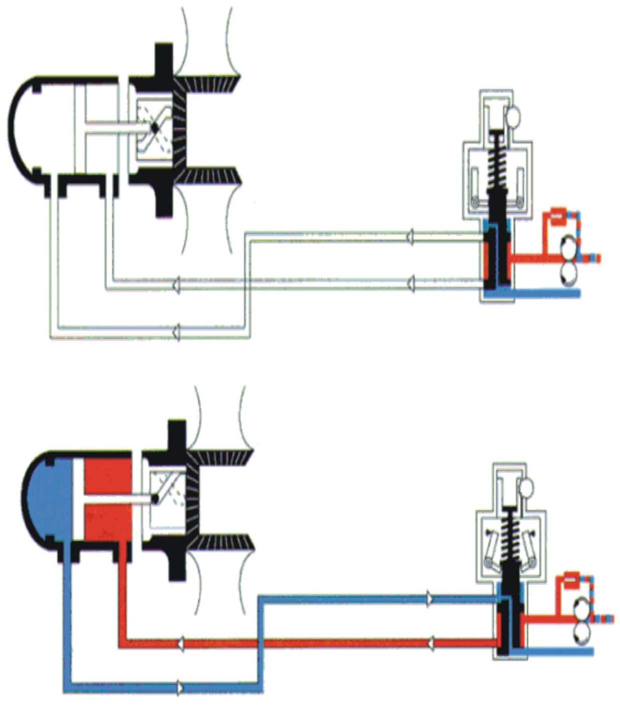


Figure 2.32. The Simple Constant Speed Unit .

142. The constant speed unit is a mechanical device connected to a pitch change mechanism on the propeller hub and the propeller blade mountings. When the propeller is rotating, the centrifugal twisting force tries to twist each blade to a fine pitch. This force is opposed by a piston/cylinder assembly fixed to each propeller blade which tries to move the blades to a coarse position. This assembly is powered hydraulicly by oil from the engine oil system. The balance between these forces are controlled by the CSU itself in that a spring-loaded fly-weight assembly controls the oil pressure in the piston/cylinder assembly. Pumping oil in, increases the propeller blade angle (a coarser pitch will load the blade preventing an increase in rpm), allowing the oil to flow out decreases the propeller blade angle (a finer pitch will decrease the load on the blade preventing a decrease in rpm. The CSU is controlled by the pitch control lever in the cockpit which sets the spring/fly-weight assembly at a particular rpm. If the rpm tries to increase as the aircraft flies faster or if the throttle is opened, the fly-weights spin faster and opens a valve which pumps oil into the piston/cylinder to increase the blade angle and therefore maintain the pre-set rpm. If the aircraft slows or the throttle is closed, the fly-weight spin more slowly and the valve allows oil to flow out of the piston/cylinder so that the centrifugal twisting force reduces the blade angle and so maintain the pre-set rpm. Thus it can be seen that the pilot selects the required rpm using the pitch control lever and the csu will then maintain this rpm over a wide range of throttle settings and airspeeds. Typically a fine pitch is selected for low speed operations like take-of and climb and a coarser pitch for cruise and high speed operations. The pitch control is used to set the required rpm and the throttle controls the amount of fuel/air mixture supplied by the carburettor via the manifold system to the engine cylinders. This is measured in terms of manifold pressure. Pushing the throttle in will increase the manifold pressure and pulling the throttle out, will decrease the manifold pressure. In order to operate the engine at optimum power settings, care must be taken to adhere to the limits set by the FM. As a rule, the rpm is set to fully fine for take-off and initial climb and just prior to landing. A very important limitation never to be ignored, as it may cause detonation if ignored, is to always increase rpm first before increasing the manifold pressure and always decrease the manifold pressure first before decreasing the rpm. In other words;

Rev up
And
Throttle down.

143. A Windmilling propeller is caused by loss of positive torque (engine cut) and the propeller pitch

fining off in an attempt to maintain the rpm selected at the time. Thus the propeller is being rotated by the relative airflow rather than by the engine causing a huge amount of drag and no appreciable thrust.

144. Propeller-driven tail wheel aircraft have a tendency to swing to the side during take-off, if it is assumed that the propeller is turning clockwise when viewed from the cockpit, the swing will be to the left.

This is caused by:

(a) Asymmetric blade effect. This effect is caused by the fact that the axis of rotation of the propeller is inclined to the horizontal path of the aircraft when the tail wheel is on the ground. In Fig. 2.33 it can be seen how the angles of attack and the resultant velocities are changed when the axis of rotation is inclined. The down-going blade having a higher angle of attack and therefore producing more thrust than the up-going blade. It can also be seen that the down-going blade has a greater distance to travel in the same unit of time as the up-going blade, therefore the down-going blade will be travelling at a higher speed than the up-going blade, thus for a given angle of attack, will be producing more thrust. As the propeller is turning clockwise as seen from the cockpit, the right-hand half of the propeller will be producing more thrust than the left-hand side causing the aircraft to swing to the left.

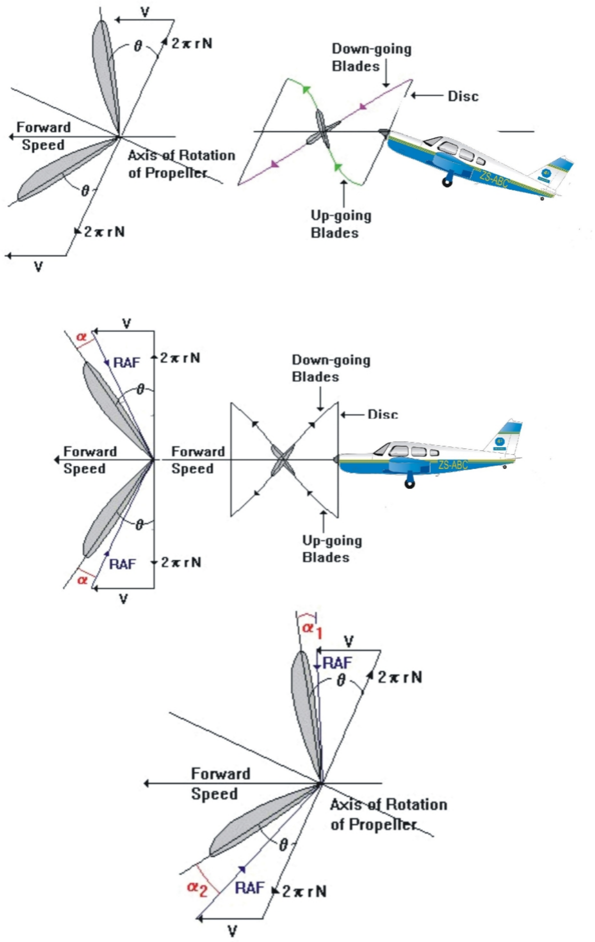


Figure 2.33. Asymmetric Blade Effect.

(b) Torque reaction. As the propeller is rotating clockwise as observed from the cockpit, the torque reaction will tend to rotate the aircraft fuselage in opposite direction, ie roll to the left. As the aircraft's undercarriage is in contact with the ground, it will result in more weight being supported by the left-hand undercarriage than the right-hand side. This will increase the rolling resistance of the left-hand undercarriage again causing the aircraft to swing to the left.

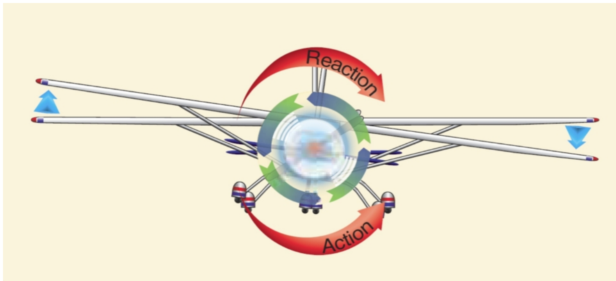


Figure 2.34. Torque Reaction

(c) Slipstream effect. A propeller rotating clockwise will impart a rotation to the slipstream in the same sense. This rotation causes an asymmetric flow on the fin and rudder so as to cause the relative airflow to approach the fin from the left resulting in a aerodynamic force produced to the right. Again resulting in a swing to the left.

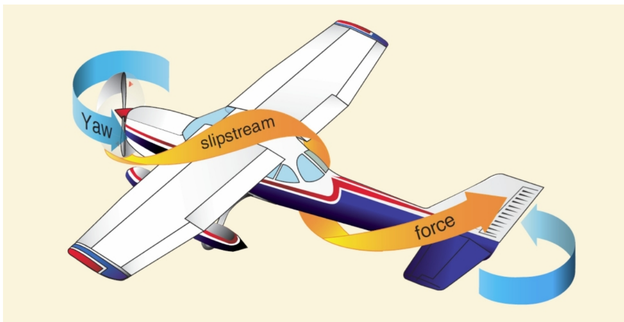


Figure 2.35. Slipstream Effect

(d) Gyroscopic effect. As the tail wheel gets lifted of the ground, a torque is applied to the rotating propeller in a nose-down sense. The effect of this torque on the angular movement of the disc is like that of a precessing gyroscope, ie the torque appears 90 degrees removed from the point of rotation in the direction of rotation. Again the result is a swing to the left. See Fig.2.36.

(e) Cross-wind (weathercock) effect. Depending on the direction of the cross-wind, the above effects can either be aggravated or lessened as a cross-wind from the left, will cause a further swing to the left and a cross-wind from the right will cause the aircraft to want to swing to the right.

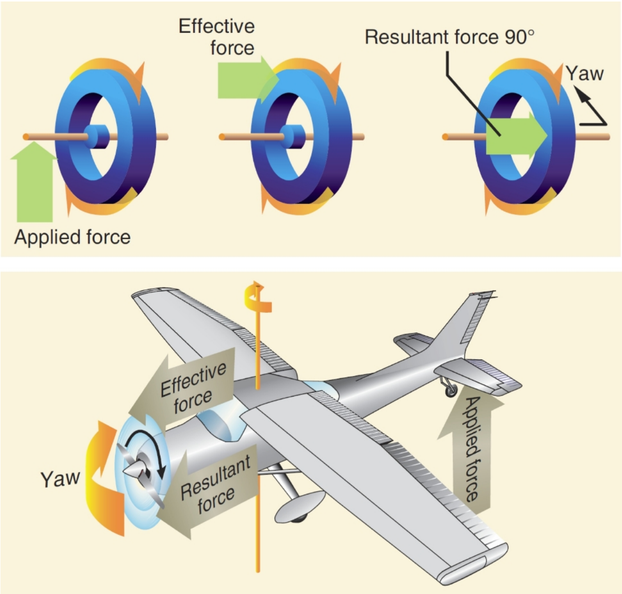


Figure 2.36. Gyroscopic Effect

SYSTEMS

Electrical Systems

145. Light aircraft electrical systems are either 12 or 24 volts, direct current (DC). Either a generator or alternator is incorporated to supply electrical current to the system and re-charge the battery. The Cherokee system includes a 12 volt, 60 ampere alternator. The advantage of an alternator is that it supplies electrical current at low rpm, while the older generator requires high rpm to function adequately.

146. A generator is a machine which converts mechanical power into electrical power. It consists of a magnetic field in which conductors are rotated in such a manner that they cut the lines of force. If a conductor is moved in a magnetic field in a manner such that it cuts lines of force, an electromotive force is induced in that conductor. The simplest form of generator consists of a loop of wire, known as an armature, rotating in a permanent magnetic field. Connection to the external circuit is made by brushes pressing on two slip rings connected to the ends of the coil. The magnitude of the emf depends on the number of conductors, the speed of rotation and the strength of the magnetic field. A generator produces direct current as the current flows in the same direction in the external circuit. When necessary, direct currant can be converted to alternating currant by the use of a inverter. To prevent a battery from discharging back through a non-current producing generator, a reverse current cut-out relay is included in the circuit.

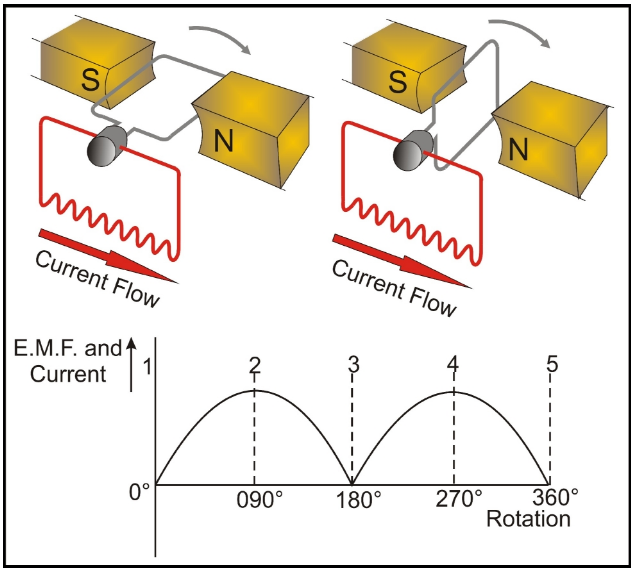


Figure 2.37. Simple Generator

147. Alternators are also known as alternating current generators. The main difference between a dc and an ac generator is that ac generators, unlike dc generators, do not incorporate permanent magnets and are not self excited. They therefore require a supply of direct current from an independent source for the initial excitation of the rotor field windings. This is normally provided from the battery or external power source. Thus making use of electromagnetic instead of a permanent magnetic flux. As it is possible to convert dc to ac, a rectifier is used to convert ac to dc. Reverse flow in an alternator is prevented by diodes in the alternator.

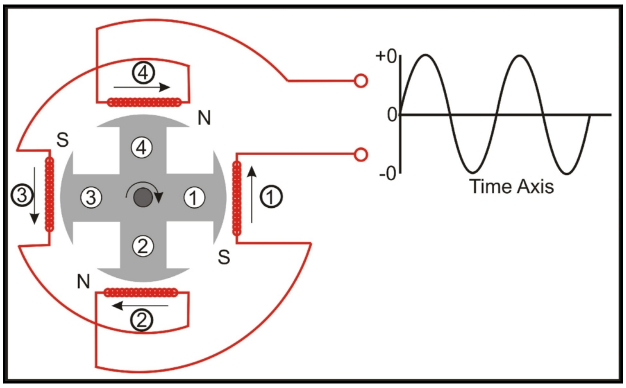


Figure 2.38. Alternator

148. Generators however have a number of disadvantages, as already previously stated, the alternator will supply sufficient electrical power at low rpm while the generator requires high rpm to function adequately. Furthermore generators are very large and heavy compared to alternators. Alternators are more reliable, efficient and cost effective to maintain.

149. Power is supplied through one or more busbars, and the master switch controls this power to all circuits. All electrical circuits are protected by fuses or circuit breakers. An ammeter indicates the flow of current, in amperes, from the alternator to the battery or from the battery to the electrical system. When the engine is operating and the master switch is on, the ammeter shows the charging rate applied to the battery. If the alternator is not functioning or the electrical load exceeds the output of the alternator, the ammeter shows the battery discharge rate. The ammeter should always show on the "+" side of the "0" mark.

150. There are two types of ammeter, the "Left-Zero" type, and the "Centre-Zero" type. The Cherokee is fitted with a "Left-Zero" type which measures the output of the alternator. All readings are right of the "0" mark. It will indicate the load on the alternator when the engine is running, and the alternator is turned on. The "Left-Zero" type is installed between the alternator and the main busbar to show the flow of current from the alternator to the electrical system.

151. The other type, the "Zero-Centre" indicator, shows the electrical flow to and from the battery as it is installed between the battery and the main busbar it indicates the charging rate of the battery. If the needle is in the "-" side, electrical energy is being drawn from the battery instead of the alternator.

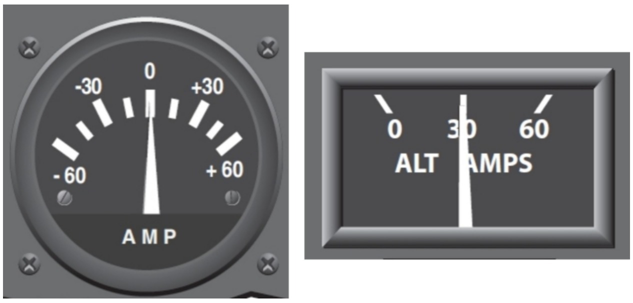


Figure 2.39. Ammeters

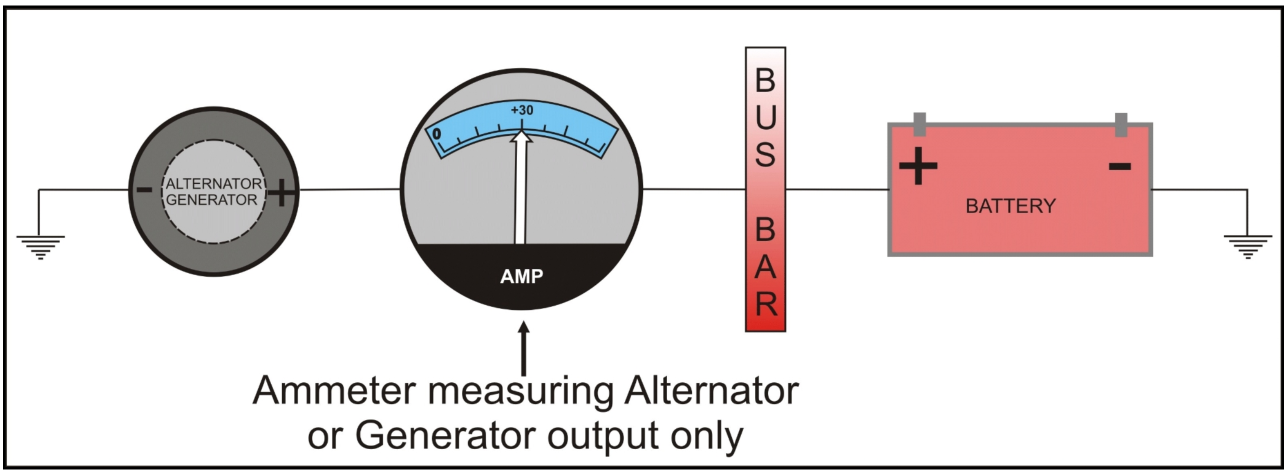


Figure 2.40. Left Zero Type Ammeter.

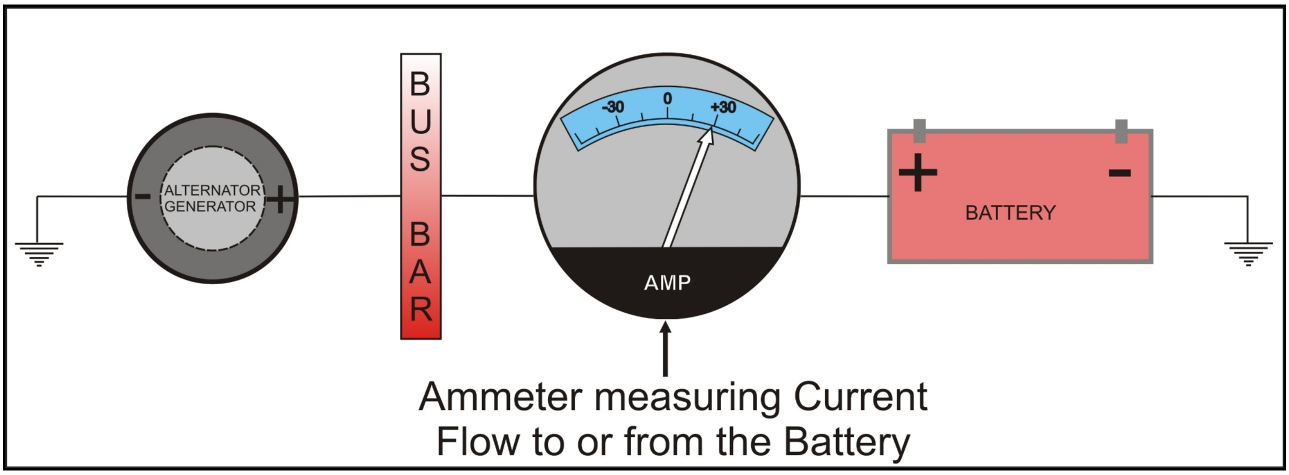


Figure 2.41. Centre Zero Type Ammeter

152. The aircraft battery is intended to supply current in the event of generator failure. Under normal operating conditions, with the generator output at its correct level, the battery takes a small charging current and the entire load is supplied by the generator. In the event of generator failure and the generator voltage falling below that of the battery voltage, the entire load will be taken up by the battery and the generator will be subjected to a reverse current which will cause damage to the armature windings. To prevent a reverse current flowing to the generator and protect the generator from being damaged, a cut-out switch or reverse current relay is fitted which will open and prevent the current from reversing its flow.

Figure 2.42. Voltmeter and Master/Battery Switch.

153. An over-voltage sensor is a warning light which, when illuminated. Indicates that the alternator has been shut down due to an over-voltage condition, and the battery is supplying all electrical power the over-voltage sensor may be reset by turning the master switch off and then back on again. If the warning light does not illuminate. Normal alternator charging has resumed; however, if the light again illuminates, a malfunction has occurred and the flight should be terminated as soon as possible. The over-voltage warning light may be tested by momentarily turning off the ALT side of the master switch and leaving the BAT side on.

154. A voltmeter indicates the voltage (the electromotive force) in the electrical system. The voltage regulator prevents the battery from being over-charged or the generator or alternator from overloading the system.

155. Prior to start, all electrical systems (flap, radios, instruments, lighting, etc) are powered by the battery. After start, all electrical systems are powered by the generator or alternator, as the case may be. When starting, the starter switch activates a solenoid, which in turn activates a flow of current to the starter motor, which causes the engine to turn over.

156. An aircraft battery is a device for storing electricity. It converts chemical energy into electrical energy. The majority of light aircraft use lead-acid batteries in which electricity is produced by chemical action between pieces of lead (the plates) and sulphuric acid (the electrolyte). The battery is kept in a vented box often in the engine compartment but it may be located in a more convenient place. Because the sulphuric acid electrolyte is extremely corrosive, any spillage should be immediately doused in plenty of water and sodium bicarbonate (baking powder) if available.

Figure 2.43. Battery.

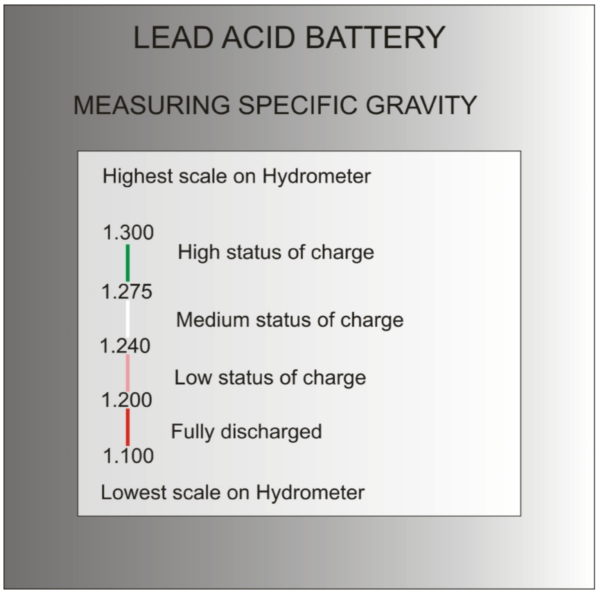


Figure 2.44. Hydrometer

157. Batteries are rated in voltage and number of ampere-hours. One ampere-hour is the flow of one ampere for a duration of one hour. The ampere is a measure of electrical current. A typical light aircraft battery will have a rating of 20 to 30 ampere-hour. This means that a battery a rating of 30 ampere-hour, will be able to produce 30 amps for one hour, or one amp for 30 hours or 10 amps for three hours. As volts are the measurement of the electromotive force (the pressure pushing the current through the system), a typical light aircraft will use a 12 or 24v rated battery.

158. The state of charge of a battery depends on the condition of its active materials, that is the lead plates and the electrolyte. Care must be taken not to overcharge or discharge batteries as this may lead to damage and shorting of the lead plates. The state of charge of a battery is indicated by the density of the electrolyte and is checked with a hydrometer. A hydrometer is an instrument which measures the specific gravity (weight as compared to water) of the electrolyte. In a new fully charged battery, the electrolyte is approximately 30 percent sulphuric acid and 70 percent distilled water, and is therefore 1.3 times as heavy as pure water. During discharge the electrolyte becomes less dense and its specific gravity drops below 1.3. specific gravity a reading between 1.3 and 1,275 indicates a high state of charge. A reading between 1.24 and 1.2 indicates a low state of charge. It is seldom necessary to add sulphuric acid to the electrolyte and if required to top-up the electrolyte level of a fully charged battery, only distilled water is added.

159. A battery may be charged by passing direct current through the battery in a direction opposite to that of the discharge current. Batteries are either charged by the constant voltage or constant current method. In the constant voltage method, as is the case when the battery is being charged by the aircraft generator or alternator, a motor generator set to a constant regulated voltage forces the current through the battery. In this method the current at the start of the process, is high but automatically tapers off reaching the value of approximately one ampere when the battery is fully charged. In the constant current method which is used by battery maintenance facilities, the current remains constant during the entire process and care must be taken towards the end of the process not to overcharge the battery.

160. Each electrical component must have a protection device to isolate it from the system in the event of excessive current. Fuses are safety devices employed for circuit protection purposes. A fuse consists of a glass or ceramic tube surrounding a strand of wire with metal caps at each end which allow current to flow through. The wire within the fuse is rated so that it can carry a certain current. If this current is exceeded, the wire will overheat and melt thus breaking the circuit. If it is suspected that a fuse has burned through and must be replaced, the fuse must be removed and checked. A blown fuse can be replaced with a fuse of the same rating,

marked on the fuse and the fuse holder. It is important to know that a fuse may only replaced once, if it blows again, do not replace the fuse a second time. Never replace a fuse with another fuse with a higher rating.

161. The modern trend is to protect electrical devices with circuit breakers. A circuit breaker also acts to isolate an electronic component if a predetermined current is exceeded. A circuit breaker makes use of a bi-metallic strip and if excessive current flows through the strip, the heat being produced will distort the strip causing it to unlatch, breaking the circuit. The “popped” circuit breaker can then be seen and easily located as the top of the circuit breaker cap will stick out of the circuit breaker panel. If the circuit breaker is allowed to cool, it can be reset by pushing it back into the panel. As with the fuse, it must not be reset if it “pops” again.

Figure 2.45. Circuit Breaker Panel

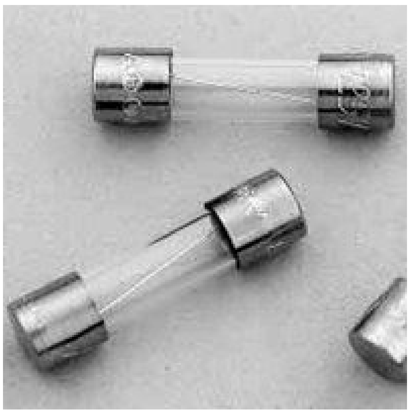


Figure 2.46. Fuses

162. In light aircraft the instruments may be powered by electricity but in most cases make use of an engine driven suction (vacuum) system. The avionics, (radio, transponder etc.) however, are normally supplied via a separate “avionics” busbar. These items are particularly vulnerable to damage caused by sharp fluctuations in voltage and current which may occur during engine starting. By making use of a separate busbar, they can be isolated and protected during engine start. If a separate avionics busbar is not installed, all the avionics must be switched off during start-up.

163. In the case of generator/alternator failure, it will be indicate by either a low voltage and “gen” light if fitted, or ammeter. As mentioned before, it may be possible to reset the generator/alternator by turning the master switch off for a few seconds and then turning it back on. If the generator can not be restored, the electrical system will be powered by the battery alone and it must be realised that there is only a finite amount of battery life available. Your first priority should be to get into visual flying conditions and to inform the air traffic control. As each electrical component draws a certain amount of electric power, it is important to prioritise as which systems can be considered as essential as to non-essential services. The POH/FM will normally have some excellent suggestions in what to do to reduce the electrical services to the absolute minimum for safe flight. The POH/FM will also give an indication as to how much battery life in units of time will be available, allowing you to plan accordingly.

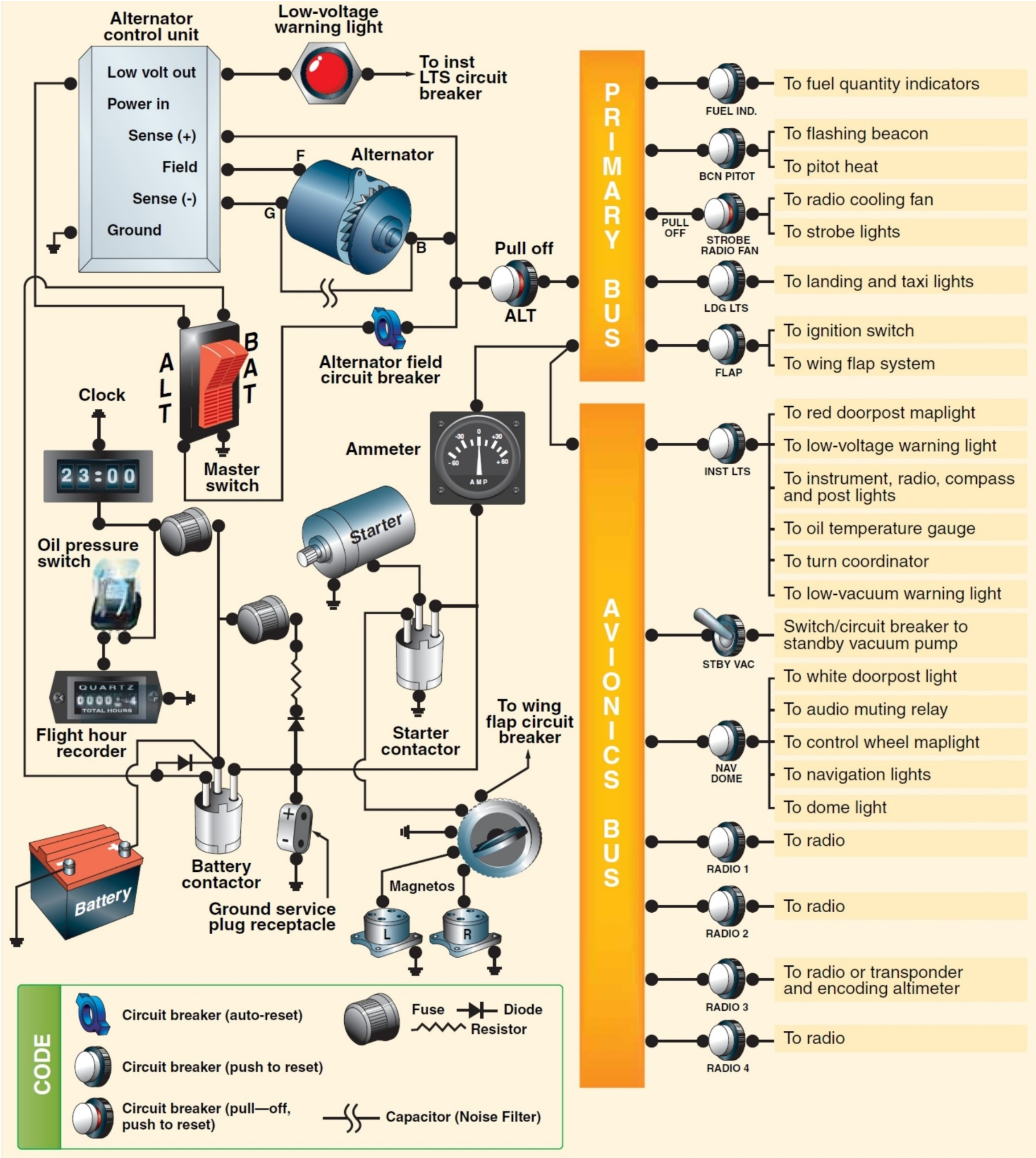


Figure 2.47. Electrical System .

Vacuum System.

164. In order to provide suction to drive the non-electrical gyroscope-based instruments like the Heading Indicator, the Attitude Indicator and the Turn Indicator, light aircraft often make use of an engine-driven vacuum pump. In a typical installation, the pump draws air through an inlet and a filter. The air is then drawn through a system of pipes to each individual instrument, where it is again filtered before being sucked into the instrument and directed over the periphery of the rotor of the gyro. The air stream impinges on little buckets carved into the rim of the rotor causing it to spin at very high speed. The air is sucked through a regulator, allowing the suction force to be regulated before being pumped overboard. Some aircraft are fitted with dual vacuum pumps providing the pilot with a back-up system in case of a pump failure. Older aircraft use a venturi instead of an engine-driven system. Suction is

created by the air moving through the venturi which is tapped and fed to the instruments. The system only becomes efficient and reliable once the aircraft is airborne. It is also susceptible to icing as it is not heated. The pilot can ascertain the serviceability of the system by regularly checking a suction gauge. Most vacuum systems operate at a suction of between 3 and 5 inches of mercury. If the reading falls to 2 inches of mercury, one could expect the instruments to move erratically. If it falls to 0 you know that you lost your vacuum system and thus the instruments that it supplies. It is important to note that the Turn and Slip indicator is normally electrically driven and it would act as back-up for the other systems.

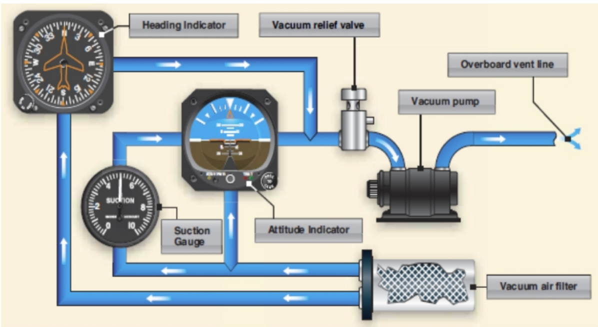


Figure 2.48. Typical Vacuum System

Hydraulic System.

165. The purpose of the hydraulic system is to use fluid under pressure with the aid of a number of essential components to operate aircraft services such as landing gear, flaps, wheel brakes and primary control surfaces. In order for a hydraulic system to operate as a complete system and to be able to move a service like the undercarriage up and down, each of the components must be studied. The reservoir mainly provides storage space for the hydraulic fluid but it also contain sufficient air space to allow for variations in volume caused by thermal expansion and movement of the fluid in the system. It also contains a reserve of hydraulic fluid to compensate for minor leakages.

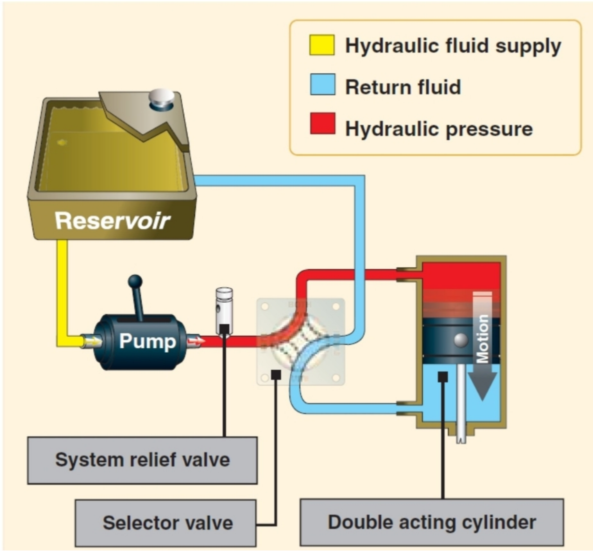


Figure 2.49. A Typical Hydraulic System.

166. A very basic hydraulic system would incorporate a double-acting hand pump which when operated by hand will draw fluid from the reservoir and supply it to a control valve. Selection of the control valve will determine to which end of a jack the pressure is delivered. Larger systems use engine-driven pumps which provide a continuos flow of hydraulic fluid to the system. It has no direct control over the system pressure but operates at a constant rpm and delivers a continuos or constant volume of fluid. The system pressure is controlled by an automatic cut-out valve.

167. The purpose of an accumulator is to, together with the cut-out valve, store hydraulic fluid under pressure. Additionally, accumulators also assist in damping any pressure fluctuations caused by the pumps, allow for thermal expansion and assist the pumps in maintaining line pressure when several hydraulic systems are operated together. Accumulators provide an emergency supply of hydraulic fluid to the system in case of pump failure.

168. An accumulator consists of a container where the one side is charged with either air or nitrogen to a predetermined pressure (usually half system pressure) through a charging valve which is a non-return valve. The other half of the container is filled with hydraulic fluid. As hydraulic pressure builds up in the system, the gas is further compressed until the fluid and gas pressures equalise at the normal system pressure. The cut-out

valve will then allow the pump to go into an idle circuit and the system pressure will be maintained by the accumulator. When a service is selected, the accumulator supplies fluid under pressure until the system pressure has dropped sufficiently for the pump to be brought back onto line.

169. The purpose of the actuator is to convert hydraulic pressure into mechanical energy. It comprises a cylinder in which is fitted a piston and a piston rod. The piston is fitted with seals which prevent the hydraulic fluid leaking from one side of the piston to the other. An actuator (jack), normally has two pipe connections through which the fluid is fed under pressure from a control valve. If it is assumed that the system in Figure 2.49 is operating an undercarriage jack, then, when the undercarriage is selected down, fluid will enter the pipe connection at the left hand side of the jack and the pressure of the fluid will exert a force on the piston to move the undercarriage down by forcing the piston and jack to move to the right. The fluid to the right of the piston, which is not under the high pressure generated by the pump, will be forced out of the jack cylinder by the piston moving to the right, this is termed the return fluid as it is forced back to the reservoir.

170. Pressure relief valves are designed to protect hydraulic systems from damage (over pressurisation) when the normal system operating pressure is exceeded. Pressure relief valves are typically installed after the pump, set to a pre-set pressure and in case of a pump failure, will reduce the pressure by releasing a quantity of the fluid and direct it to a return line. Another type of pressure relief valve is found in the high pressure filter and will, when the filter becomes blocked, open and allow unfiltered fluid to by-pass the filter element.

171. Hydraulic systems are fitted with two types of filters namely; low pressure and high pressure filters. The low pressure filter is to found before the pump and is installed between the reservoir and the pump for both hand and engine driven-pumps. The high pressure filter, as the name implies, requires high pressure to force the hydraulic fluid through the filter. It is therefore necessary that the filter be installed after, on the output side of the pump. Additional high pressure filters may also be fitted to individual circuits to prevent contamination and damage.

172. Three types of hydraulic fluids are commonly in use, they are manufactured using different base materials and are either vegetable based, mineral based or phosphate ester based. Take care, it is dangerous to intermix the different fluids as they do not mix. The most widely used hydraulic fluids are the mineral based fluids. They are red in colour and systems using it require synthetic rubber seals. The vegetable based fluids are blue in colour and require systems to be fitted with natural rubber seals. Skydrol is a phosphate ester based fluid, purple in colour and highly toxic. Hydraulic fluids are all highly resistant to compression and virtually no reduction in volume takes place with a increase in pressure. To prevent foaming of the hydraulic fluid, the fluids all have good anti-foaming properties. To prevent spontaneous combustion taking place, the fluids must have a high fire and flash point. The fluid must be chemically stable to resist oxidization and deterioration over long periods. The fluids must be dense enough to give good seal at pumps and pistons yet not be too thick so as to resist flow, hence it must retain good viscosity properties.

173. In order to operate the hydraulic system to fully, it is necessary to understand the critical aspects and servicing requirements of the system an be able to diagnose faults that may arise. It is necessary and possible to check the fluid level by either using a “sight glass” which is a small window mounted in the casing of the reservoir which indicates the actual fluid level, or a cockpit indicator if fitted. If necessary, first checking the fluid for correctness of type, the fluid level must topped up. Most modern filters are equipped with red tell-tale button which indicates that the particular filter is blocked. In some aircraft a cockpit indicator may be fitted. Leakages may also pose a problem but can be detected firstly by the need to top-up the system more often than normal and an increase in the fluid temperature as indicated by the temperature sensors. Engine-driven pump failure in a system utilising a two pump supply system will be indicated by a supply flow rate that will be halved and operating times will be doubled. Note that the system pressure will remain the same.

174. The hydraulic system consists of Primary and Secondary services. The primary services are known as essential services. Essential services are those that in case of failure, will result in the aircraft

being unable to remain in controlled flight. Such services include primary control systems such as flying control services operating the elevators, ailerons and rudder. Secondary services are termed non-essential services in the context of hydraulic fluid supply. For example although it may be essential to be able to operate the undercarriage, flaps and wheel brakes, in an emergency, it can be operated by other methods.

Fuel Systems.

175. The function of a fuel system is to store fuel and deliver it to the carburetor (or fuel injection system) in adequate quantities at the proper pressures. It should provide a continuous flow of fuel under positive pressure for all normal flight conditions, including:

a. changes of altitude;

b. changes of attitude; and/or

c. sudden throttle movements and power changes.

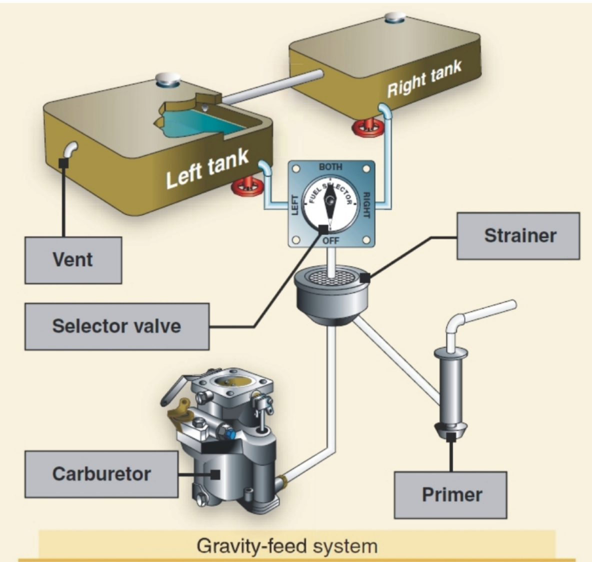


Figure 2.50. Gravity Feed Fuel System

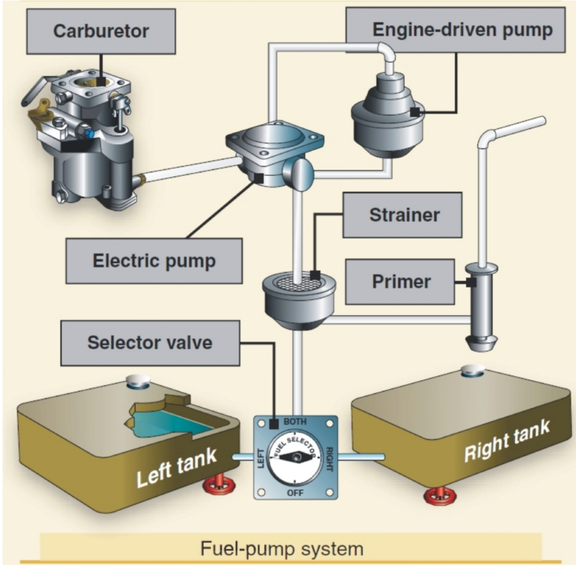


Figure 2.51. Fuel Pump System

176 Fuel is stored in fuel tanks, which are usually installed in the wing. Fuel tanks may be of the rigid, bag or integral type tank. Rigid tanks are of the metallic type which are inserted as units into the fuel bays and connected to the fuel lines. Bag type tanks are lightweight crash proof bags made of thin rubber and housed in smooth-sided compartments within the wing. Integral tanks are formed in the wing construction itself and are situated within the spars and ribs of the main-plane. A sump and a drain point at the lowest point of the tank allows heavy impurities (such as water or sediment) to gather, be inspected and drained off. The tanks often contain baffles to prevent the fuel surging about in flight - especially during large attitude changes or uncoordinated manoeuvres, or in turbulence.

177. The fuel supply line (pipe) inlet is higher than the sump to prevent impurities (water or sludge) from entering the fuel lines to the carburetor, even though there is a fuel filter in the line to remove any small impurities from the fuel as it passes down the supply line. Because the fuel enters the supply line through a standpipe at the bottom of the tank, there will always be some unusable fuel in the tanks.

178. The top of the fuel tank is vented to the atmosphere so that the air pressure above the fuel in the tank remains the same as outside as altitude is changed. Reduced pressure in the tank caused by ineffective venting could reduce the rate of fuel flow to the engine and also cause the fuel tanks to collapse inward. Fuel vents should be checked in

the preflight external inspection, to ensure that they are not blocked or damaged.

179. An overflow drain prevents excessive pressure building up if fuel volume increases because full tanks have been warmed in the sun.

180 A high-wing aircraft with the tanks in the wings will generally allow the fuel to be gravity-fed to the carburetor without the need for a fuel pump. If there is no carburetor but a fuel injection system, then electric boost pumps are necessary.

181. In a low-wing aircraft, the tanks, being lower than the engine, need a fuel pump to lift the fuel to the carburetor. Prior to start-up, an electric auxiliary (boost) pump is used to prime the fuel lines and to purge any vapour from them. Once the engine is started, the engine-driven mechanical fuel pump takes over. Correct functioning of the pump can be monitored on the fuel pressure gauge.

182. For many aeroplanes, the Aircraft Operating Manual recommends that the electric fuel pump be switched on for critical manoeuvres such as the takeoff, landing and low flying. This will prevent fuel starvation in the event of the engine-driven mechanical fuel pump failing.

183. It is important, especially on low-wing aircraft with fuel carried in tanks below the level of the engine, that the fuel strainer drain valve in a low part of the fuel system is checked closed during the pre-flight external inspection. If it is not closed, the engine-driven fuel pump may not be able to draw sufficient fuel into the engine (it will be sucking air instead), and the engine may be starved of fuel unless the electric pump is used.

The Priming Pump.

184. The fuel primer is a hand-operated pump in the cockpit which the pilot uses to pump fuel into the induction system of the engine in preparation for engine start-up. This fuel does not pass through the carburetor, but is hand-pumped directly into the inlet manifold just before the cylinders.

185. Priming the engine is especially useful when starting a cold engine on a cold day, when the fuel in the carburetor is reluctant to vaporize.

186. The primer must be locked when the engine is running to avoid excessive fuel being drawn through the priming line into the cylinders, especially at low power settings, which could stop the engine if the fuel/air mixture is too rich.

Fuel Selection.

187 A fuel line runs from each tank to a selector valve in the cockpit, which the pilot uses to select the tank from which fuel will be. taken or to shut the fuel off. Incorrect fuel tank selection can result in fuel starvation, and has been the cause of many accidents - so study your Aircraft Operating Manual very closely on this matter. The sounds of silence while you still have fuel in one tank, but not the tank that you have incorrectly selected, can be very loud indeed!

Figure 2.52. Fuel Pump System

198. You should not run a tank dry in flight before switching tanks, because the fuel pump may draw air into the fuel lines, causing a vapour lock which may stop the fuel flow, even from another tank, into the engine. Once a vapour lock has formed, it may be very difficult to restart the engine. Furthermore, most fuel pumps are lubricated by the fuel itself and if allowed to run dry, the pump may seize.

199. It is advisable when changing tanks to switch on the electric auxiliary or booster fuel pump (if installed) to guarantee fuel pressure to the carburetor, and then to positively monitor the fuel pressure as the tanks are changed.

200. Any sudden and unexpected loss of power should bring two possible causes immediately to mind:

a. lack of fuel to the engine; or

b. carburetor icing.

201. If the cause is incorrect fuel selection, your actions should include:

a. close the throttle (to avoid a sudden surge of power as the engine restarts);

b. set the mixture control to full-rich;

c. turn the electric fuel pump on; and

d. check fuel tank selection and tank quantity - change tanks if necessary.

202. If the cause of the engine problem is carburetor ice, then apply full carburetor heat. Refer to your Aircraft Operating Manual for the correct actions to be taken in the event of any power loss.

Fuel Booster Pumps (or Auxiliary Pumps)

203. The reasons for installing electric fuel boost pumps are to:

a. provide fuel at the required pressure to the carburetor or to the fuel metering unit of a fuel injection system;

b. purge the fuel lines of any vapour to eliminate the possibility of a vapour lock;

c. prime the cylinders of fuel-injected engines for start-up; and

d. supply fuel if the engine-driven pump fails.

204. If an electric fuel pump is installed, it is usual to also have a fuel pressure gauge to monitor its operation.

Fuel Gauges

205. Most light aircraft have fuel gauges in the cockpit, which may be electrical, so the master switch will have to be ON for them to register. Some older aircraft have direct-reading fuel gauges which do not require electrical power.

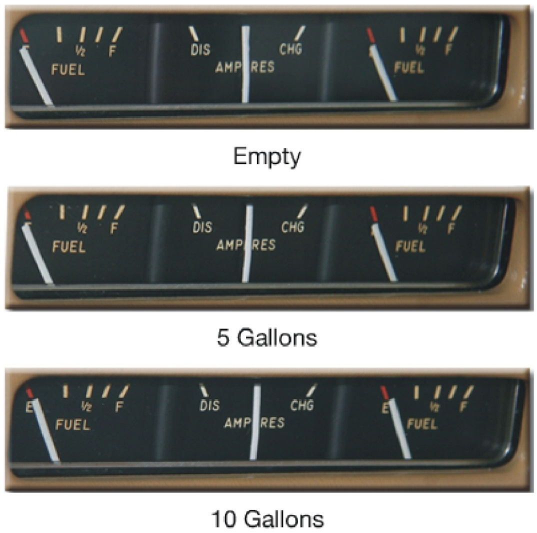


Figure 2.53. Fuel Gauges .

206. It is good airmanship and common sense not to rely on the fuel gauges, since they can read quite inaccurately, especially when the aircraft is not straight and level. always carry out a visual check of the contents in the fuel tanks during the pre-flight external inspection by removing the fuel caps, visually checking the contents of the tanks, then replacing the caps securely.

207. The fuel consumption rate specified in the aircraft operating manual assumes correct leaning of the mixture which, if not done, could lead to a fuel burn of about 20% in excess of the book and the fuel gauges consequently reading much less than expected because of the excessive fuel burn.

Ground Fuelling (Re-Fuelling and De-Fuelling)

208. For safety during re-fuelling or de-fuelling, the aircraft should be positioned well away from other aircraft or buildings, the engine should not be running, and the ignition switches and parking brake should be in the OFF position. The location of fire fighting equipment should be noted in case of it being needed. A NO SMOKING rule should be enforced, and any passengers should be kept well clear of the aircraft.

209. To prevent the possibility of a spark of static electricity igniting the fuel vapour that is present in any fuelling operation, you should connect ground wires between the aircraft, the fuelling equipment and the ground to ensure that they are at all at the same electrical potential. This should be done prior to commencing fuelling - even before you remove the fuel caps, when fuel vapour could be released into the atmosphere.

Fuel Checks

210. Fuel which is about to be loaded should be checked first for contamination. The most common contamination is water. It can leak into ground fuel tanks, and from there be loaded into the fuel truck and into the tanks of an aircraft.

211. Fuel naturally contains a small amount of water and this can condense with a drop in temperature, contaminate the fuel system, block the fuel passages in the carburetor, and possibly cause a loss of engine power.

212. There are certain fuel test pastes and fuel test papers available which react when water is present, and the fuelling agent will use these on a regular basis to guarantee the purity of the fuel in his storage tanks.

213. Other impurities besides water can also cause problems in the fuel. Rust, sand, dust and micro-organisms can cause problems just like water. Filtering or straining the fuel should indicate the presence of these and hopefully remove them prior to fuelling.

214. Be especially careful when fuelling from drums because they may have been standing for some time. Always check drum fuel with water-detection paste, for date of expiry, and for correct grade of fuel. Additionally, it is a good idea to check the release note for the fuel. Filter the fuel through a chamois cloth prior to loading into the aircraft tanks if the drum pump has no filter.

215. Water, because it is more dense than fuel, will tend to gather at the low points in the aircraft fuel system. After fuelling has been completed, a small quantity of fuel should be drained from the bottom of each tank and from the fuel strainer drain valve (gascolator) to check for impurities, especially water, which will sink to the bottom of the glass. Fuel drains are usually spring-loaded valves at the bottom of each fuel tank, and the fuel strainer drain is usually found at the lowest point in the whole fuel system.

INSTRUMENTS

Pitot/static System.

216. Aircraft instruments operate either by measuring air pressure, be it static or dynamic air pressure or by making use of the properties (rigidity and precession) of a gyroscope. The instruments using the measurement of air pressure, must firstly be able to measure the ambient or surrounding atmospheric (static) air pressure, and secondly the pressure created by movement (dynamic) pressure. By implication it must be able to measure any changes in static and dynamic pressure.

217. Static pressure is the pressure being exerted by the earth's atmosphere. The weight of the atmosphere is all surrounding and is experienced by everybody, every object and therefore every instrument. It varies from place to place and with changing weather conditions. It also varies with an increase in altitude as it decreases with an increase in altitude. Static pressure is measured by means of small holes called static vents or ports. These vents (two) are connected to the aircraft's pressure system and are located on both sides of the fuselage of an aircraft. Two vents are used as it minimises errors which arise from several factors such as manoeuvres. Static vents can also be located in a pressure head. Static systems are usually fitted with an alternate static source allowing, in the event of the blockage of the static vents, allowing the pilot to select an alternate supply of static pressure. This will allow static pressure from within the cabin/cockpit of an un-pressurised aircraft, to be fed into the static system. Small errors, usually causing the altimeter and airspeed indicator to over-read may occur.

218. Dynamic pressure, on the other hand, which is measured by a pressure head, is the pressure caused by the forward movement of the aircraft through the air. Therefore the faster the movement through the air, the greater the dynamic pressure. As static pressure is experienced by everything, it is impossible for the pressure head to sense only dynamic pressure therefore the pressure head pressure is known as total pressure, ie static pressure + dynamic pressure =

pressure head pressure. The pressure head, also called the pitot head, is an open-ended tube facing forward in the direction of aircraft movement. It is affixed parallel to the fore and aft axis of the aircraft and may be heated for use in icing conditions.

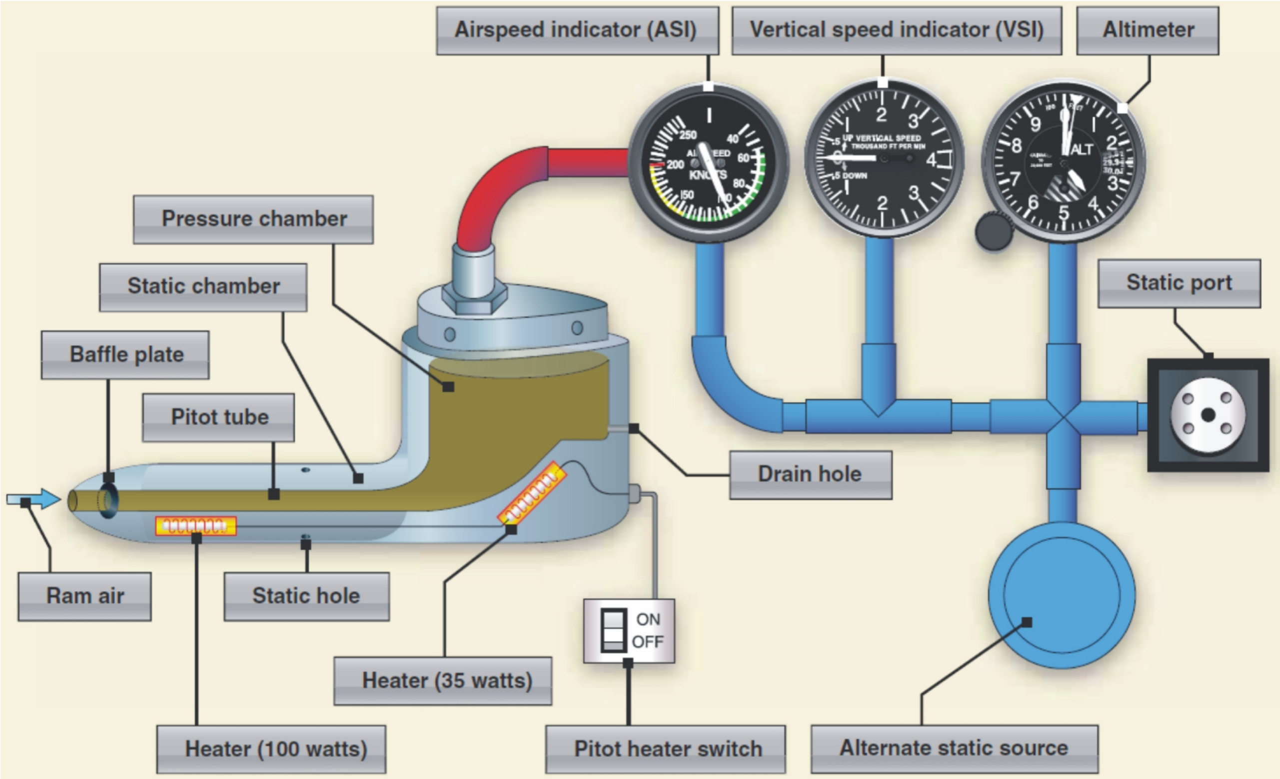


Figure 2.54. Pitot Static System

219. Pressure Head Errors. Because of the movement of the aircraft, eddy currents and turbulence are created around the static vents and pressure head which lead to errors in the instruments using the information. Therefore the placement of the static sensors and the pressure head in order to minimise errors because of their position is very important. In an effort to reduce the position errors, the static vents are installed on the sides of the fuselage as far away as possible from the leading edge of the dynamic wave. Similarly the pitot head is positioned ahead or safely away from the leading edge or surfaces of the wings and fuselage. Position error will vary according to the location of the pressure head, airspeed, angle of attack/attitude and configuration - flaps, undercarriage and slats. Whenever a aircraft is not in level flight the sensed pressure will be inaccurate because of the aerodynamic disturbances caused by manoeuvre. Manoeuvre error is not predictable and cannot be calibrated. It is influenced by the position of the sensors and time lag which results from delays in the transmission of pressure changes to the instruments.

220. Blockage of the sensors will cause errors. It is therefore important to use pitot head and static vent covers to prevent insects from nesting in the inlets. It also just as important to make sure that the pitot and static vents are unblocked and the covers removed before flight. A drain-hole, to allow water and water vapour or condensation to drain from the pitot system is supplied at a low point in the tube. Pitot systems of aircraft certificated to be used in icing conditions are also fitted with a heater system to prevent sensors icing closed.

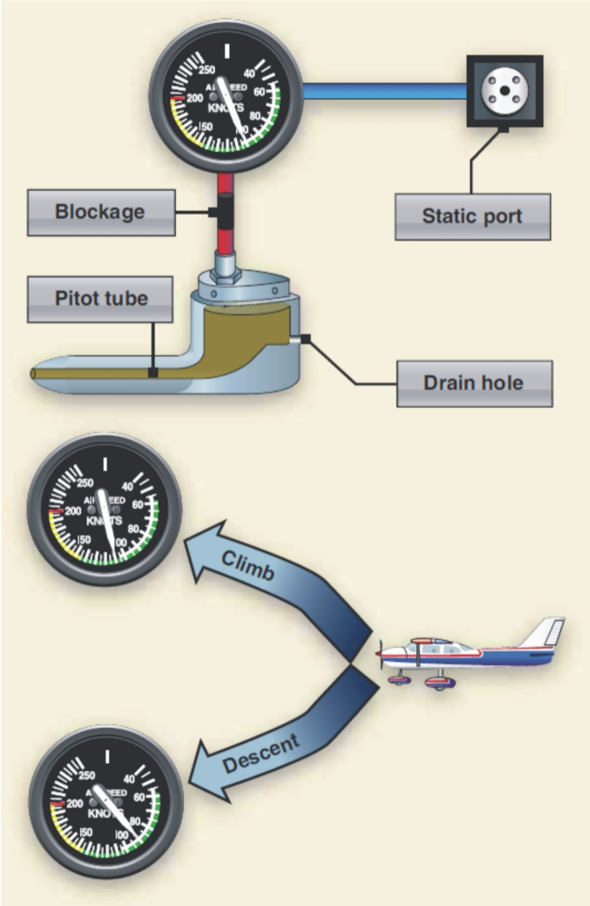


Figure 2.55. Blocked Pitot System

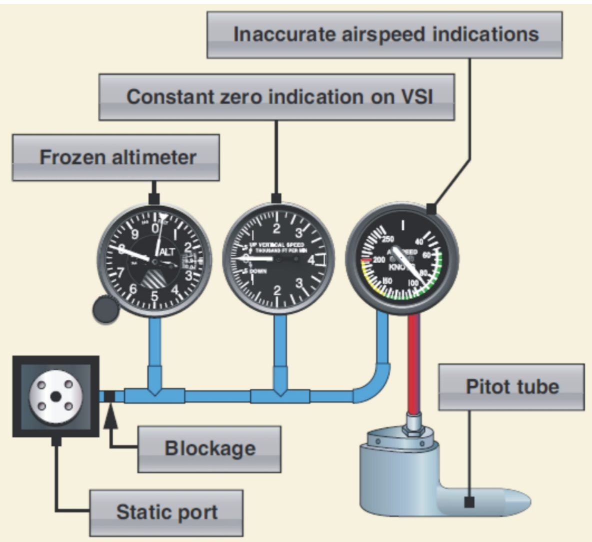


Figure 2.56. Blocked Static System

Airspeed Indicator.

221. As previously stated, an aircraft will, as it moves through the air, experience additional dynamic pressure. The magnitude of the dynamic pressure is directly proportional to the speed of the aircraft and therefore the indicated airspeed (IAS). When stationery, the aircraft will only experience static or atmospheric pressure only when the aircraft starts moving, the additional dynamic pressure will be experienced. The pitot head senses the total pressure, ie pitot pressure (P) which is the sum of static (T) and dynamic (D) pressure. So in order to be able to measure the dynamic pressure only, static pressure must be subtracted from the pitot pressure.

222. The ASI consists of an airtight container which is supplied with pitot and static pressure. The system is designed that the difference between pitot and static pressure is measured and indicated as airspeed. The simple ASI is divided by a flexible diaphragm. One side of the diaphragm is supplied with pitot pressure while the other side is supplied with static pressure. This gives rise to the simple mathematical equation of D+S/S. The pressure difference across the diaphragm is thus detected and with the use of linkages and levers, displayed on the face of the instrument. The speed may be indicated in knots, mph or km/h.

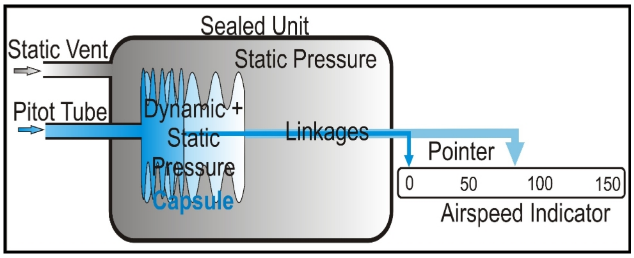


Figure 2.57. Simple Airspeed Indicator.

223. In the more sophisticated instrument, total pressure is supplied from a pitot source to a capsule within the ASI and static pressure is fed from the static sources into the instrument casing surrounding the capsule. In this way, a change of static pressure alone will not cause the capsule to expand or contract - only a change in dynamic pressure will effect the capsule. An increase in dynamic pressure will cause expansion of the capsule and a reduction in dynamic pressure will cause the capsule to retract. The movement of the capsule is transmitted to the needle of the ASI via a mechanical linkage to indicate an increase or decrease in the airspeed.

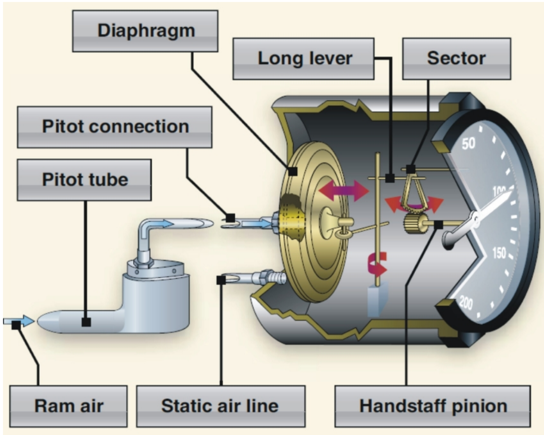


Figure 2.58. Airspeed Indicator

224. As can be seen from Fig. 2.58, the ASI is colour-coded so as to present key indicated speed limitations and ranges to the pilot. The following colour-code applies to single-engine light aircraft

White Arc	Extends from V_{SO}(Stalling speed in the landing configuration) to VFE (Flap limiting speed).
Green Arc	Extends from V_S1 (Stalling speed with landing gear and flap up) to VNO (Maximum normal operating speed).
Yellow Arc	The "cautionary" airspeed range, flight in smooth conditions only.
Red Line	The VNE (Never exceed) speed.

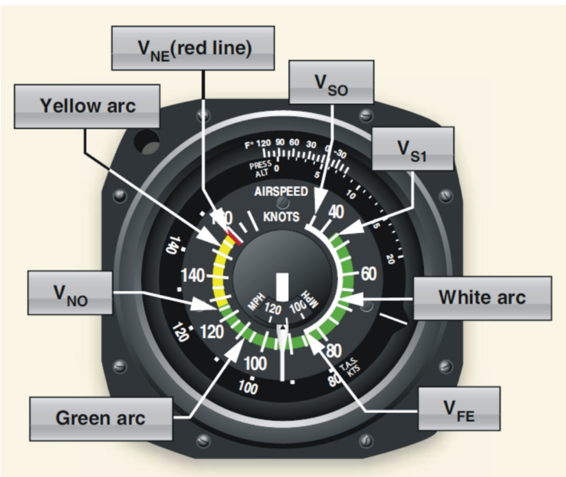


Figure 2.59. A colour -coded ASI

225. The dynamic pressure is dependant not only on the speed of the aircraft, but also on the density of the air. Density = ½ ñV ²Where ñ is the ambient air density and V is the true airspeed. The ASI can be calibrated for only value of density and the density selected is the density at sea level in ISA, 1225gm/m³ . Therefore, only when the air is at this density, will IAS be equal to TAS. At any other value of density, a density error will be evident and therefore the TAS will differ from the IAS.

226. The ASI suffers from a variety of errors. Imperfection in manufacturing leads to Instrument Errors which can be combined with errors due to the position of the pressure sensors. A correction for instrument and position errors are normally applied by means of a correction graph or table found in the aircraft manual. When these correction are applied to the IAS, the result is known as Rectified Airspeed (RAS) or as used in the USA, as Calibrated airspeed (CAS).

227. As already stated, if the ambient air density is other than standard, the IAS will need to be corrected to obtain TAS. As altitude increases, pressure decreases and the IAS will be lower than the TAS. Thus in less dense air, a greater speed (TAS) is required to register the same dynamic pressure. The error (Density Error) is corrected by a navigational computer using RAS, pressure altitude and outside air temperature. For example if the IAS= 200 kts, the pressure altitude= 10 000 ft and the outside air temperature (OAT) = -5 ⁰C, the true airspeed (TAS) = 231.5 kts.

228. Compressibility is only significant above 300 kts TAS. Because air is compressed above 300 kts it causes the ASI to over-read because of the greater dynamic pressure, this is called the Compressibility Error.
The error will increase with an increase in height as less dense air is more easily compressed than dense air. When RAS is corrected for compressibility error by navigation computer, the result is known as Equivalent Airspeed (EAS). The correction is always negative.

229. As the ASI obtains its information from the pitot and static sources, it will also be subjected to the same errors that are present in those sensors. Therefore errors due to manoeuvres, as in sideslips, will lead to static pressure fluctuations which can give errors.

230. Blockage of either the pitot tube or static ports, due to icing during flight, may lead to inaccurate indications. A blockage in the pitot tube will mean that whatever pressure is in the capsule, will be trapped there. Therefore the dynamic and static pressure inside the capsule will not be able to change. Thus, as long as the aircraft remains at a constant altitude, the ASI reading will remain constant. A change of altitude will however cause a change of static pressure inside the casing. In a descent for example, the static pressure inside the case will increase while the static pressure inside the capsule remains the same, resulting in the ASI under-reading. A climb will cause the ASI to over-read. A blockage in the static line will again cause a constant ASI indication in level flight. In this case the static pressure in the case will be trapped and a change in altitude will mean that the static pressure in the capsule will change. During a descent this will cause the ASI to over-read, a dangerous situation, and during a climb the ASI will under-read.

231. The importance of checking that the pitot head and static openings are unblocked and uncovered has already been described in the pitot system. As part of the serviceability checks before flight, the instrument dial glass must be intact and the airspeed indicator should read zero while stationery. The pitot heater should be checked for serviceability if fitted and the instrument should start to indicate in correct sense shortly after the start of the take-off run.

Altimeter.

232. The altimeter is, in essence, an aneroid barometer and measures changes of static pressure and relates these to changes of vertical distance from a chosen datum.

233. The simple altimeter is housed in an airtight case and ambient atmospheric pressure is supplied to the inside of the case via a tube from the static line. The sensing element is a partially evacuated aneroid capsule inside the case. The capsule is secured to the side of the case and is prevented from collapsing under the pressure of the surrounding static pressure by a leaf spring. If the static pressure decreases, as happens when the aircraft climbs, the leaf spring will expand the capsule. The movement will be transmitted through a system of levers and linkages causing the pointer to rotate over the instrument dial. When the aircraft descends, the leaf spring will allow the capsule to contract.

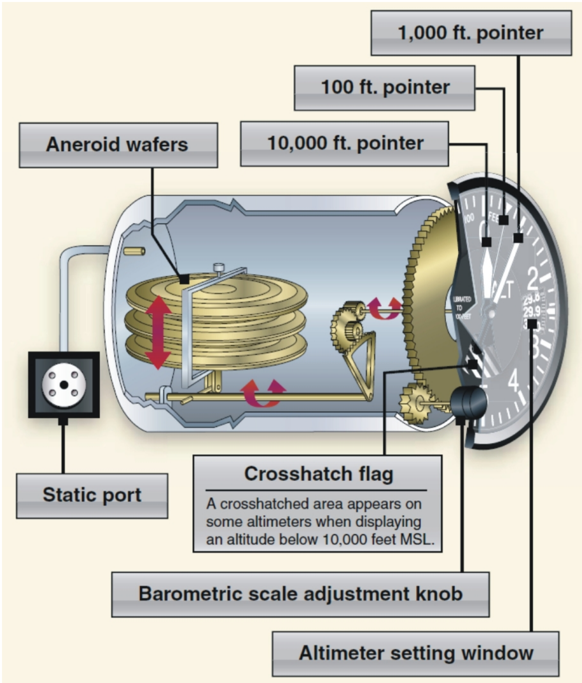


Figure 2.60. The Altimeter.

234. The sensitive altimeter works on the same principle as the simple altimeter but in order to improve sensitivity, a bank of two or three capsules is used rather than one. Sensitive altimeters incorporate friction reducing devices such as jewelled bearings and temperature compensators to allow for expansion and contraction of the linkages. A variable datum mechanism and a sub-scale setting knob are fitted to allow the pilot to set a datum in order to indicate the height above a desired pressure datum.

235. As the altimeter really only measures changes in pressure, for it to provide a meaningful indication, it must be provided with a pressure datum from which to measure. The sub-scale setting knob provides this facility. Any difference between the sub-scale setting and the actual pressure at, for example mean sea level, will cause the altimeter to be in error. This error is called Barometric Error. If the actual pressure is lower than the one set on the sub-scale, it will cause the altimeter to over-read. This is dangerous situation and to be avoided. On the other hand, if the actual pressure is higher than the one set on the sub-scale, the altimeter will under-read an the aircraft will be higher than indicated. Several altimeter settings for

varying situations are in use.

236. QFE is the barometric pressure at aerodrome level. When set on the sub-scale, the altimeter of an aircraft on the ground will indicate zero. In flight the altimeter will indicate the height above the airfield. QFE is used mainly for circuit flying and gives a good indication of height above the aerodrome.

237. QNH is a setting indicating the equivalent mean sea level (msl) pressure calculated by ATC from the aerodrome pressure. With QNH set on the sub-scale, the altimeter of an aircraft on the aerodrome will indicate the aerodrome elevation, that is the height above mean sea level. In flight the altimeter will indicate altitude but it will still be indicating the altitude above msl.

238. Standard Setting. When 1013.25 hPa is set on the sub-scale, the altimeter reading is called “Pressure Altitude” or “Pressure Height” to indicate Flight Levels. Thus flight levels are surfaces of constant pressure related to the standard pressure datum and separated by specified pressure intervals. Generally these correspond to 500 ft intervals up to F290. Above F290 the separation correspond to 2 000 ft intervals. A flight level is expressed as the number of hundreds of feet which would be indicated at the level concerned by an altimeter set to 1013.25 hPa. For example with 1013.25 hPa set and 25 000 ft indicated, the flight level would be 250, abbreviated to F250. With 4 500 ft indicated the aircraft should be at F045.

239. Regional QNH is also the Lowest Forecast QNH which is provided by the Met Office to ensure safe terrain clearance. It is the value below which the QNH is forecasted not to fall in a given period of time. The value should always be lower than the actual QNH anywhere in the area. If set on the sub-scale, the regional QNH should make the altimeter under-read, which is safe.

240. Changes in Density result because of changes in pressure and temperature. As pressure increases, the density will also increase but as temperature increases the density will decrease. Thus is practise the effect will be noted rather as an increase or decrease in pressure and temperature as an increase or decrease in density.

241. When flying from an area of high pressure (1030 hPa) to an area of low pressure (1010 hPa), the altimeter will over-read if the sub-scale setting is not changed. This happens because the aneroid capsule senses the reduction in pressure, expands and indicate an increase in altitude. The pilot on noticing the increase in altitude, will fly down to the correct altitude and by doing so will be descending. When calculating altimetry problems, assume 1 meter = 3.28 ft and 1 hPa = 30 ft.

242. When flying from an area of high temperature to an area of low temperature, the altimeter will again over-read, even if the surface pressure remains constant. It must be remembered that the altimeter measures pressure differences and therefore will indicate the height above a pressure datum. When comparing two columns of air, the one with a relative high temperature, will, because of the reduced density, occupy a relative large space compared to the colder column of air. Thus flying at a constant pressure level, from an area of high temperature to an area of low temperature, the aircraft will again be descending

Figure 2.61. The Altimeter

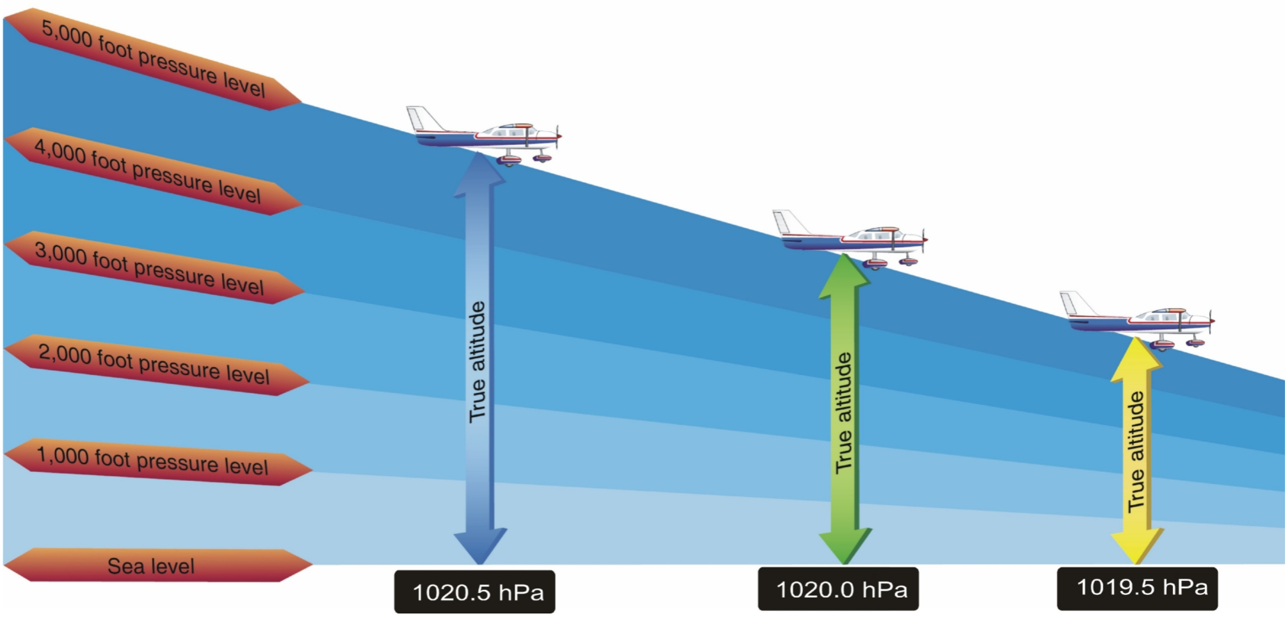


Figure 2.62. Change of Pressure.

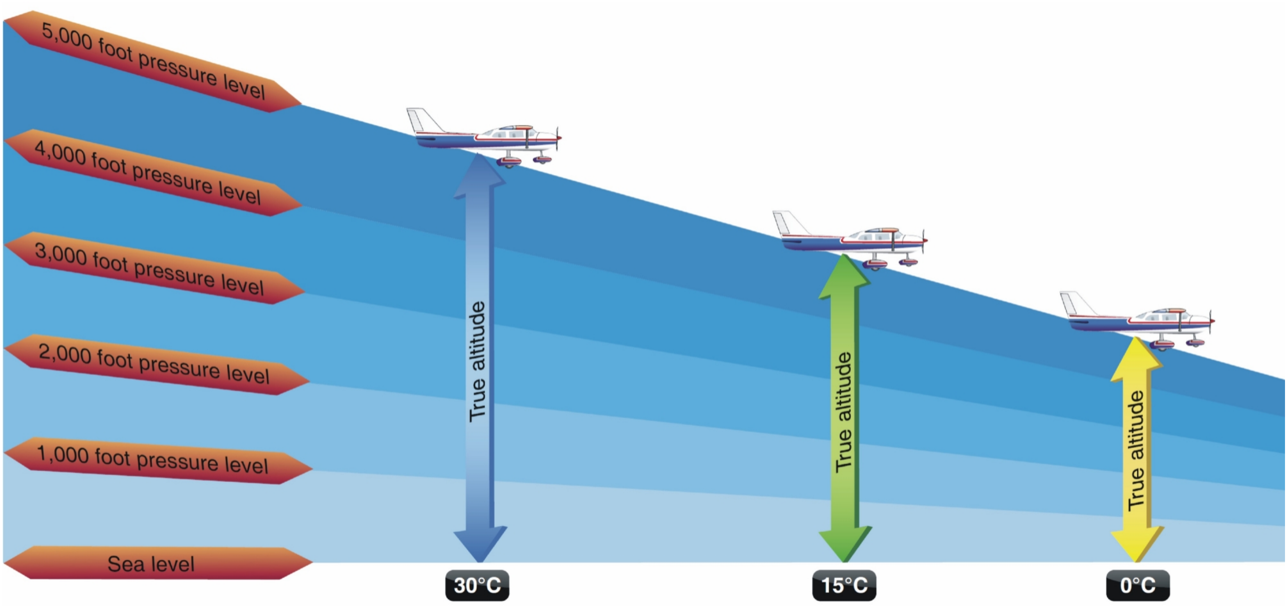


Figure 2.63. Change of Temperature.

HIGH TO LOW CAREFUL GO

HOT TO COLD DON'T BE BOLD

243. The altimeter is adjusted for pressure changes in the atmosphere but is not corrected for non-standard temperatures. Therefore when flying in air that is colder than the standard temperatures, the true altitude will be lower than indicated altitude and vice versa. Calculating the true altitude can only be done with a flight computer.

244. The calculation is done with the ASA E6-B Flight Computer or "Whiz-wheel". Using the Altitude Window on the "slide rule" side of the computer, pressure altitude is set against the Outside Air Temperature in the "Altitude Window". Using the "slide rule" side of the computer, the position of the value of the QNH altitude is found. The True Altitude is read from the outside scale against the QNH

altitude on the inside or slide rule scale (Refer to Chapter 4 Page 7 Paras 29-36).

Example: An aircraft is cruising at Flight Level 170. The altitude shown with QNH set 17500 ft. The OAT is -10^{0}C. What is the True Altitude? Method: Using the altitude window, set the pressure altitude (Flight Level) against the OAT. Refer to the inside scale to find the QNH altitude and read the corresponding Figure on the outside scale. This Figure is the True Altitude (18100 ft).

245. The most common instrument presentation used in light aircraft is the three-pointer dial. In this presentation the long pointer shows hundreds of feet, the shorter pointer shows thousands of feet and the third pointer, with a triangle at its periphery, indicates ten of thousands of feet. On most altimeters found in light aircraft, a rotatable inner disk forms part of the dial. The disk rotates to uncover a striped area on the instrument face. Below 10 000 ft the entire striped area is visible but above 10 000 ft the rotation of the disk starts to cover the area and by about 15 000 ft the striped area is completely covered. The striped area serves as a warning to pilots operating at 10 000 ft or above that lack of oxygen may become a consideration.

Altimeter Errors.

246. Imperfections in manufacture are present in most instruments, it can give rise to errors in the indication and together with normal wear and tear, manifest as instrument errors. As the altimeter receives static pressure from the common source, it will also be affected by pressure errors arising from position and manoeuvring error. The altimeter is calibrated to operate correctly at a pressure of 1013.25 hPa at sea level. Therefore, in order to compensate for barometric error, a variable datum mechanism together with a sub-scale setting knob is installed. The instrument is also calibrated for a temperature lapse rate of a decrease of 1.98 C^0/1 000 ft. therefore a temperature error will be present and can be corrected by navigational computer. Time lag errors are pronounced after long or rapid climbs or descends as a change of pressure takes to reach the instrument from the static source. The problem can be solved by using more sophisticated servo-assisted altimeters. As the altimeter operates by sensing the change of static pressure, a blockage of the static line will cause the instrument to indicate the altitude where the blockage occurred.

247. The altimeter can be checked for serviceability by checking the altimeter indication against the known aerodrome elevation with the QNH set on the subscale. The altimeter reading should be within the manufacturers permissible reading errors.

Vertical Speed Indicator.

248. The vertical speed indicator measures the rate of change of the static pressure. It does this by measuring the pressure difference between each side of a restrictive choke. This instrument is also known as the only instrument which “theoretically” has no errors. This is because the static pressures on each side of the restrictive choke, ie inside the case and the open capsule, are from the same static source. During straight and level flight the two pressures are the same but during a climb or descend the pressure fed to the capsule immediately responds to the pressure change but the change in pressure inside the case is delayed by the restrictive choke. The rate of change is displayed on the VSI in feet per minute.

249. The VSI consists of a capsule inside a sealed case to which static pressure is fed. Static pressure, from the same source, is also fed to the inside of the sealed case, but via a restrictive choke (metering device). Thus the pressure inside the case, surrounding the capsule, will change at the same rate. Thus when an aircraft climbs or descends the change of pressure will be sensed almost instantaneously by the capsule while change will reach the inside of the case after a slight delay. During the delay the capsule will either contract or expand depending on the pressure differential surrounding the capsule, the movement of the capsule is transmitted via a system of levers and linkages to cause a needle to move over a calibrated dial. The faster the aircraft climb/descent, the greater will be the movement of the capsule and therefore the needle. The VSI indications can be either linear or logarithmic. With the linear scale, the scale graduations are the same for all rates of climbs or descents while with the logarithmic scale the presentation is more easily readable at lower rates of climb or descent.

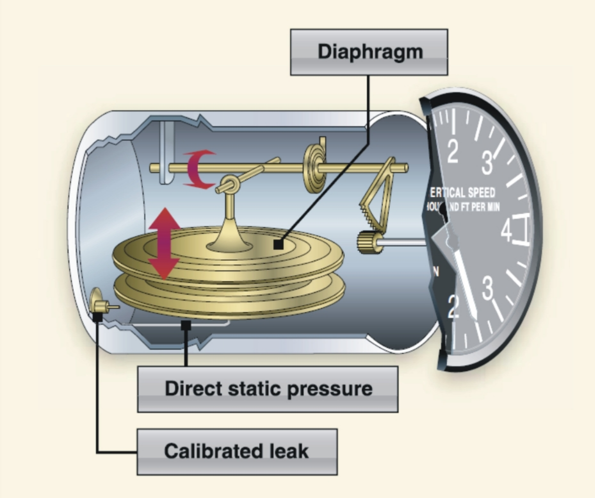


Figure 2.64. Vertical Speed Indicator (VSI)

250. The VSI suffers from all the basic source errors like Instrument Error, Manoeuvre Error and Position Errors. The VSI additionally suffers from Instrument/Time Lag Error because the time taken to build up a steady pressure difference during a climb or descend. On levelling out the time taken for the pressure to equate also results in a lag in indication.

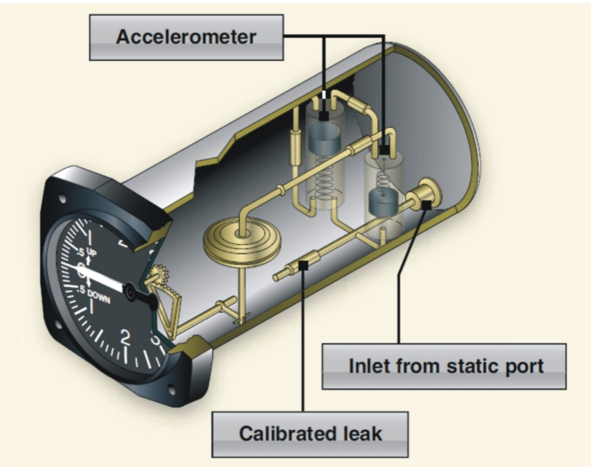


Figure 2.65. Instantaneous VSI

251. To overcome the problem of lag, the Instantaneous VSI , which incorporates two accelerometer units in the static line to the capsule, is used. The accelerometers comprise two small cylinders which are held in balance by springs and their own weight. One spring is stronger than the other allowing an immediate and follow-up change of pressure in the capsule. When a change of vertical speed occurs, the pistons are displaced because of their inertia causing in, for example a descent, an immediate increase of pressure in the capsule. The pressure change created by the accelerometers dissipates after a few seconds but by then the actual static pressure has taken over and the pressure differential is established by the metering unit.

252. The VSI can be checked for Serviceability while on the ground when the indication should be zero or within the permissible limits: ± 200 fpm at -20^{0}C to +50^{0}C or ± 300 fpm outside these temperatures and there must be no apparent damage to the instrument. The accuracy of the instrument can also be checked while airborne. The rate of climb or descend can be checked against the altimeter and a stopwatch and the instrument should indicate zero while flying straight and level.

Gyroscopes.

253. A gyroscope is a rotating mass with freedom of movement in one or more planes, at right angles to its plane of rotation. This freedom is provided by mounting the rotating mass in a system of gimbals which are pivoted at right angles to each other.

Figure 2.66. Gyro with Gimbals

254. Any wheel that spins on its axis, e.g. bicycle wheel and aircraft propeller is a gyroscope. A gyroscope possesses two fundamental properties: Rigidity and Precession.

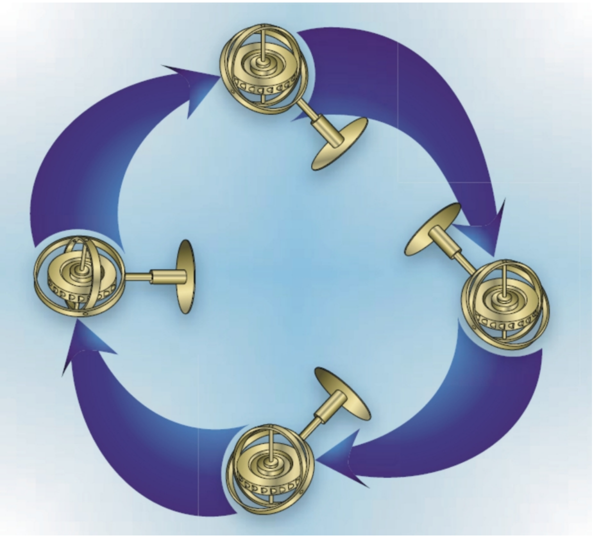


Figure 2.67. A gyro tends to remain rigid in space

255. Rigidity is the reluctance of a gyroscope to change the direction of its plane of rotation. Rigidity depends on the Speed of rotation, the Mass of the rotor and the Distance of the mass from the axis of rotation. Rigidity also depends on several design features, for example, the higher the rotational speed (S) of the gyro the greater the rigidity or resistance to deflection. The greater the Inertia (I) the greater the rigidity. Therefore to obtain maximum inertia the mass of the gyro must be concentrated near the rim rotating at high speed also the greater the mass the greater the rigidity of the gyroscope.

256. It can therefore be said that Rigidity is directly proportional to the rotational speed (S) and the movement of Inertia (I). Rigidity is inversely proportional to an external force (F) applied to the gyro.

$$Rigidity = \frac{Speed\ X\ Inertia}{Force}$$

257. Precession occurs when a force is applied to a gyroscope in such a manner as to disturb the plane of rotation. When such a force is applied, the force will not act at the point of application but at a point, which is 90^0 removed from it in the direction of rotation.

258. It can therefore be said that Precession is directly proportional to force applied and inversely proportional to the rotational speed and the moment of inertia.

$$Precession = \frac{Force}{Speed\ X\ Inertia}$$

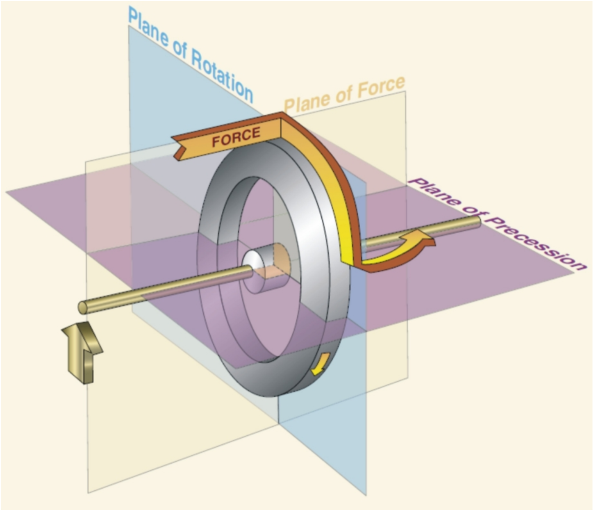


Figure 2.68. Precession.

259. Gyroscopic Wander is known as any movement of the gyro away from its initial orientation. If the spin axis is moved in the horizontal plane, the wander is known as drift. If the spin axis is moved in the vertical plane, the wander is known as topple.

260. Wander can be further divided in Real Wander and Apparent Wander. Real wander is the actual movement of the spin axis away from its original position and it can be drift, topple or a combination of the two. Random (real) wander is caused by imperfections in the gyro such as friction or imbalance of the rotor or the gimbals. Apparent Wander occurs when the spin axis of the gyro appears to move in relation to an observer. It is in fact not that the gyro is moving but that the observer's view of its changing. Apparent wander can also be drift, topple or a combination. Apparent wander is induced by the rotation of the earth and by movement of the observer over the earth. Transport Wander is caused by transporting the gyro just as the movement of the earth under a space orientated gyro will cause wander. Movement with an easterly component creates apparent drift in the same sense as in apparent wander due to earth rotation. A westerly component causes the drift to be in the opposite sense. Apparent wander due to earth rotation and transporting the gyro will be discussed in detail when considering the Heading Indicator. Turn and Slip Indicator.

261. The Turn and Slip indicator consists of two independent instruments. One, (Turn) measures and indicates the rate of turn while the other (Slip) detects whether a turn is coordinated or not.

The Turn Indicator.

262. The Turn Indicator employs the principle of a Rate Gyro which has freedom of movement in only one plane (in addition to its plane of rotation) and is constructed so as to measure rate of movement about an axis which is at right angles both to the spin axis and the axis of freedom.

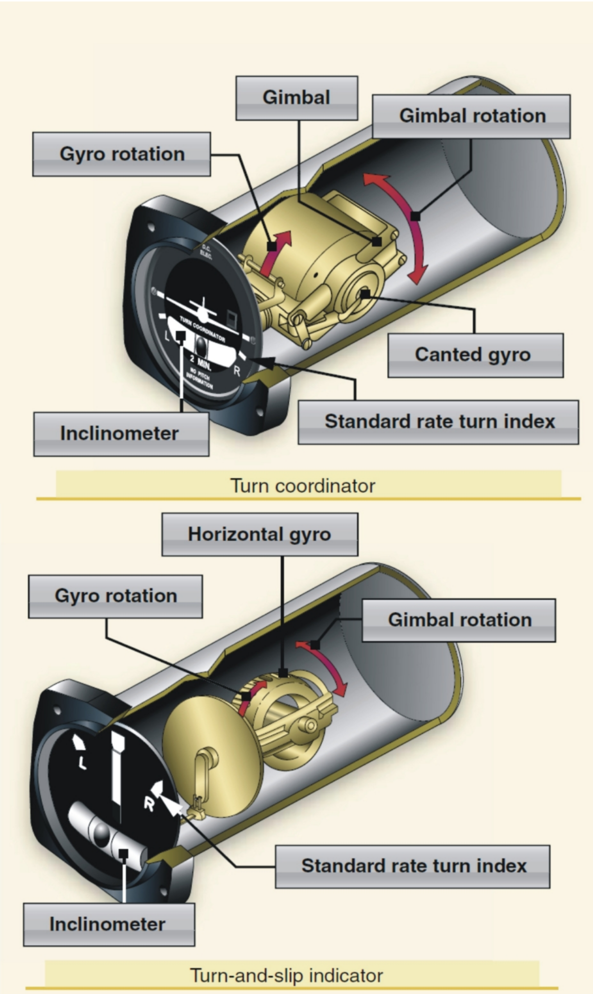


Figure 2.69. The Turn and Slip Indicator .

263. The Turn indicator uses the interaction between Primary and Secondary precession to indicate the rate of turn. The Turn Indicator measures rate of change of heading, it mainly measures movement in the yawing plane. It consists of a horizontal axis gyro positioned with its spin axis athwartships in the aircraft (Figure 2.70).

264. The gyro is mounted in a single gimbal which is pivoted fore and aft in the instrument case. The gimbal is attached to the instrument case by two calibrated coiled springs, one on each side. The rotor spins “up and away” from the pilot to make the turn relative to the earth. The gyro therefore has freedom in the rolling plane and plane of rotation. Turn Indicators are normally electrically driven and rotate at approximately 9 000 rpm.

265. Refer to Fig. 2.70 which shows the Turn Indicator operation.

266. In straight and level flight the coiled springs hold the gyro axis horizontal preventing unwanted precession. The pointer attached to the gimbal, indicating the rate of turn, will indicate zero rate of turn or the central position of the printed scale. If the aircraft enters a turn to the left, the gyro’s orientation in the fore and aft axis being fixed, the gyro will be forced to turn with the aircraft by force A. The force will be precessed through 90° in the direction of rotation, hence a torque which tilts the rotor clockwise from the pilot’s point of view. This is 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 and would give no indication of the rate of turn.

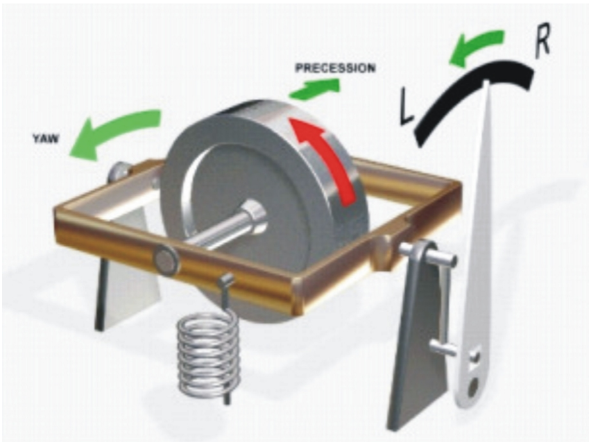


Figure 2.70. Turn Indicator Operation

267. However because springs are fitted, as the rotor begins to tilt, the spring on the left is stretched while the opposite spring is forced down. The stretched spring exerts a balancing force downwards on the gyro axis. This vertical force will also be precessed through 90° in the direction of rotation acting on the rotor in the horizontal plane

acting in the same direction as the turn. This secondary force is called Secondary Precession. The gyro which was initially reluctant to move with the aircraft because of its rigidity, is now precessing with the aircraft at the rate of turn.

268. When a steady rate of turn has been established, all forces are constant and in balance and the gyro is tilted at a constant angle proportional to the rate of turn.

269. The Turn Indicator has been calibrated to accurately and correctly indicate a rate one turn only at one datum speed. This speed can be found in the POH/FM and is usually the speed for that particular used in holding and race course patterns. It is important to realise that the bank angle depends on the rate of turn and the TAS. Turns executed whilst flying at a TAS other than that for which the instrument is calibrated will produce a small error. If the TAS is higher than the datum TAS, a proportional higher angle of bank is required to achieve a rate one turn and conversely a lower TAS will require a lower angle of bank.

270. A rule of thumb for a rate one turn is:

$$Angle\ of\ Bank = \frac{TAS}{10} + 7^\circ$$

$(TAS\ in\ Kts)$

Example: TAS 90 Kts

$$Angle\ of\ Bank = \frac{90}{10} + 7^\circ$$
$$Angle\ of\ Bank = 9 + 7^\circ$$
$$Angle\ of\ Bank = 16^\circ$$

271. The indication of the rate of turn is presented by a needle pointing in the relevant direction to a mark on the instrument face.

272. The situation illustrated is during straight flight and no turn is taking place, hence the needle is central. In a turn the needle is displaced left or right, indicating the direction of the turn, by an amount proportional to the rate of turn. The graduated marks represent rates one, two or three, moving outwards from the centre.

Fig. 2.71. Turn and Slip Indicator.

273. The Turn Indicator only senses yaw because, with the gyro gimbal in the aircraft horizontal, it is insensitive to roll and will therefore give no indication of bank. In order to overcome this deficiency, the Turn Co-ordinator was developed. The gimbal is tilted through some 30^0 such that the foremost end is highest. It can now detect yaw and roll.

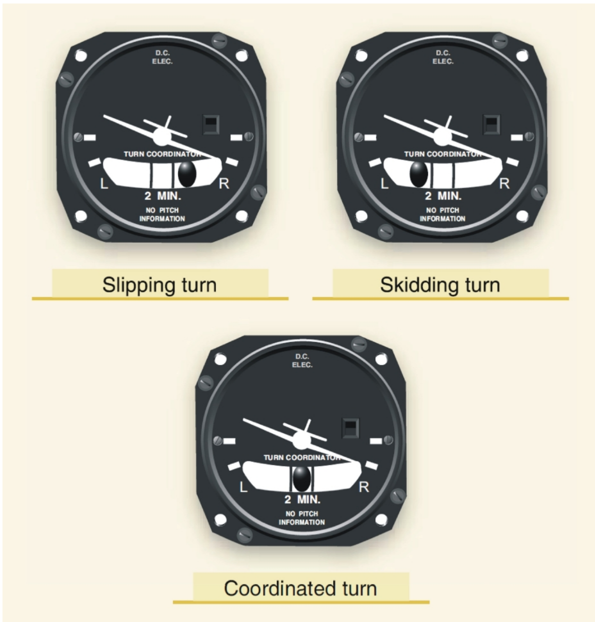


Figure 2.72. Turn Co-ordinator

274. When the aircraft turns, the aircraft symbol tilts left or right as appropriate. There are graded marks for a Rate One Turn Only. The reason being, with the gimbal tilted, the geometry is such that it "hits the stops" at about rate $1\frac{1}{2}$. The Turn Co-ordinator is therefore suitable for use in light aircraft only.

275. The Turn Co-0rdinator can be both suction

driven or electrically powered. However, traditionally the Turn Co-ordinator uses a different power source to that used by the other two gyro instruments - the Attitude Indicator and the Heading Indicator in order to provide a back-up should their power source fail. As most light aircraft use a suction driven AI and HI, the Turn Co-ordinator is usually uses electrical power and will then be equipped with a red warning flag which appears to indicate electrical power failure.

276. The Slip or sometimes called the Balance Indicator is either a pendulous weight with a pointer attached on a pivot or a ball in a liquid filled tube. The Slip Indicator portion of the instrument is a purely mechanical device and operates quite independently from the Turn Indicator. It is neither suction driven nor electrically powered and reacts only to the influence of gravity and centrifugal force. It therefore will continue to operate correctly in the event of the vacuum and electrical systems failure.

277. Consider first the aircraft in level flight. If the wings are level, the ball will be in the centre, between the two vertical lines etched on the tube (Fig. 2.73).

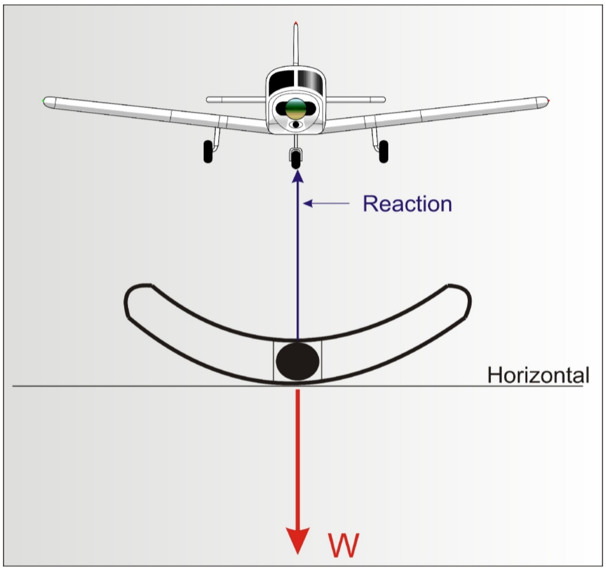


Figure 2.73. Level Flight

278. When considering an aircraft in a turn, (Fig. 2.74) it can be seen that the weight is acted upon by two forces - the gravitational force (W) acting vertically downwards and the centrifugal force (C) acting horizontally away from the centre of the turn. If the turn is balanced the resultant of the weight and the centrifugal force will act through the aircraft's vertical and the ball will remain centred.

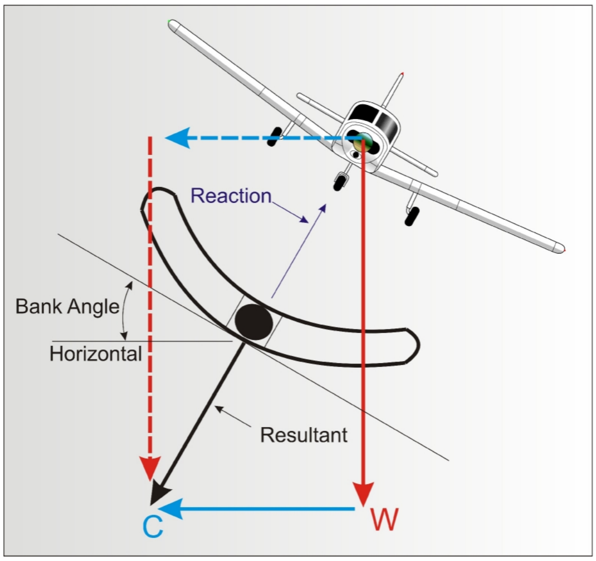


Figure 2.74. Balanced Turn to the Left

279. When an aircraft is banking excessively (Fig. 2.75) the gravitational force acting on the weight is greater than the centrifugal force and the resultant lies inside the aircraft's vertical. The aircraft is said to be slipping, the aircraft is banking to the left and the ball is also out to the left.

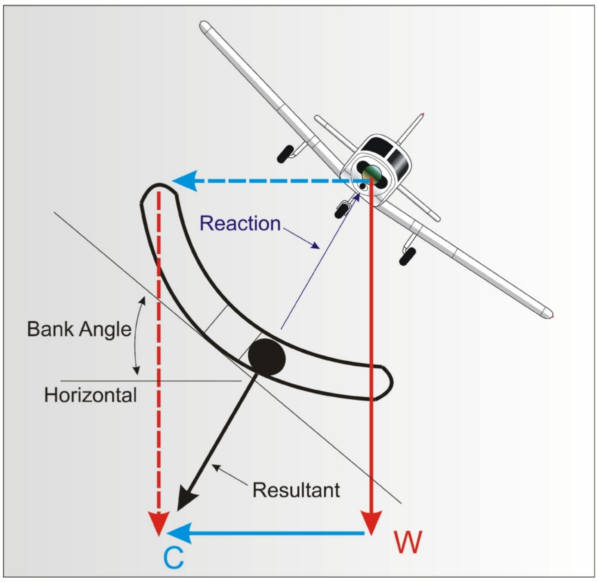


Figure 2.75. Unbalanced Turn (Slipping)

280. When an aircraft is under-banking (Fig. 2.76) the centrifugal force now exceeds the gravitational force and the resultant now lies outside the aircraft's

vertical, the aircraft is said to be skidding, the aircraft is the aircraft is banking to the left while the ball is out to the right.

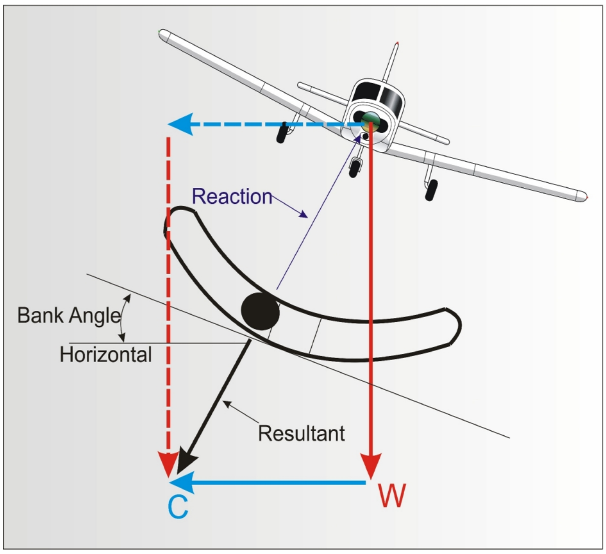


Figure 2.76. Unbalanced Turn (Skidding).

281. The rigidity of the gyro is proportional to its rotor speed, therefore any change in the rotor speed will cause an Error. Enhanced rigidity (increase in rotor speed) will produce an over-indication of the rate of turn and a reduced rigidity (reduction in rotor speed) which is the more likely to occur, will produce an under-indication of the rate of turn. Another phenomenon which may cause the instrument to over-read, is the Pitching Error in the Looping Plane. In a gently banked turn, the turn is mainly in the yawing plane.

282. However in a steep turn, there is more movement in the looping plane. Normally movement in the looping plane means that the aircraft is rotating about the rotor axis with no effect on the gyro. However if the gimbal is tilted before movement in the looping plane begins, the movement in the looping plane will cause additional precession of the rotor. The usual movement in the looping plane in a steep turn will increase the gimbal tilt making the indicator over-read.

283. The instrument can be checked for Serviceability during turns while taxying. The needle or the aircraft symbol should indicate a turn in the correct sense while the ball must show a skid in the opposite direction.

Attitude Indicator.

284. The Attitude Indicator also known as the Artificial Horizon, gives a direct and immediate indication of the aircraft attitude in the longitudinal (pitching) and lateral (rolling) planes.

Figure 2.77. Attitude Indicator (Artificial Horizon)

285. In order to have a clear understanding of the operation of the Attitude Indicator, it is important to realise that a miniature aircraft and a printed scale is fastened to the case of the instrument and moves as the aircraft moves. As the pilot needs to know his attitude in relation to the real horizon, a horizon bar is gyro-stabilised to remain parallel to the true horizon. The instrument is read as a direct interpretation of the position of the miniature aircraft in relation to the horizon bar. A vertical axis gyro is used and the force of gravity is used to “tie” the rotor spin axis to the true vertical thereby maintaining the plane of rotation horizontal. In this way, by making use of an Earth Gyro, the required stable lateral and longitudinal references are provided.

286. The gyro is mounted inside a sealed case which also serves as the inner gimbal. Suction, usually 4" Hg, is created inside the case and replacement air enters the case through a filter, spinning the rotor up to 15 000 rpm in an anti-clockwise direction when viewed from above. The air having spun the rotor, leaves the case under suction through four exhaust ports in a pendulous unit mounted at the base of the gyro. The pendulous

unit also serves to erect the rotor axis to the true vertical and maintains the alignment in flight.

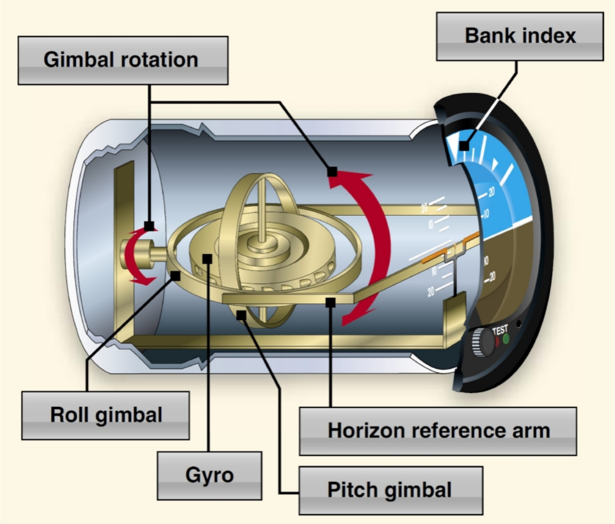


Figure 2.78. The Attitude Indicator.

287. The inner gimbal (rotor case) is mounted in the outer gimbal with its axis athwartships allowing the instrument case the freedom in the pitching plane. Mounted on the inner gimbal is a guide pin which is able to engage the horizon bar arm through a slot in the outer gimbal. The inner gimbal, guide pin and horizon bar therefore control the indications in the pitching plane.

288. The outer gimbal is mounted in the case with pivot points in the fore-aft axis of the aircraft, allowing the instrument case freedom in the rolling plane. A sky plate is attached to the outer gimbal. The outer gimbal therefore controls the indications in the rolling plane.

289. In 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 dial is in the centre of the dial behind the miniature aircraft. Any movement relative to the inner gimbal is transmitted to the horizon bar arm through the guide pin on the inner gimbal.

290. When the aircraft climbs or descends, the rotor case (inner gimbal) remains rigid whereas the outer gimbal and the instrument case move with the aircraft. The movement, relative to the inner gimbal, displaces the guide pin in the slot taking the horizon bar with it. An indication of climb or descent result.

291 Fig.2.80. shows the indications for an aircraft banking left and right while climbing, descending and in level flight. 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 printed on the glass face of the instrument. When the aircraft banks, the rotor, inner gimbal and outer gimbal remain rigid in the horizontal (level) position while the instrument, together with the printed scale and the miniature aircraft, moves with the aircraft. The position of the index on the sky plate indicates the bank angle against the scale.

Figure 2.79. Digital Attitude Indicator

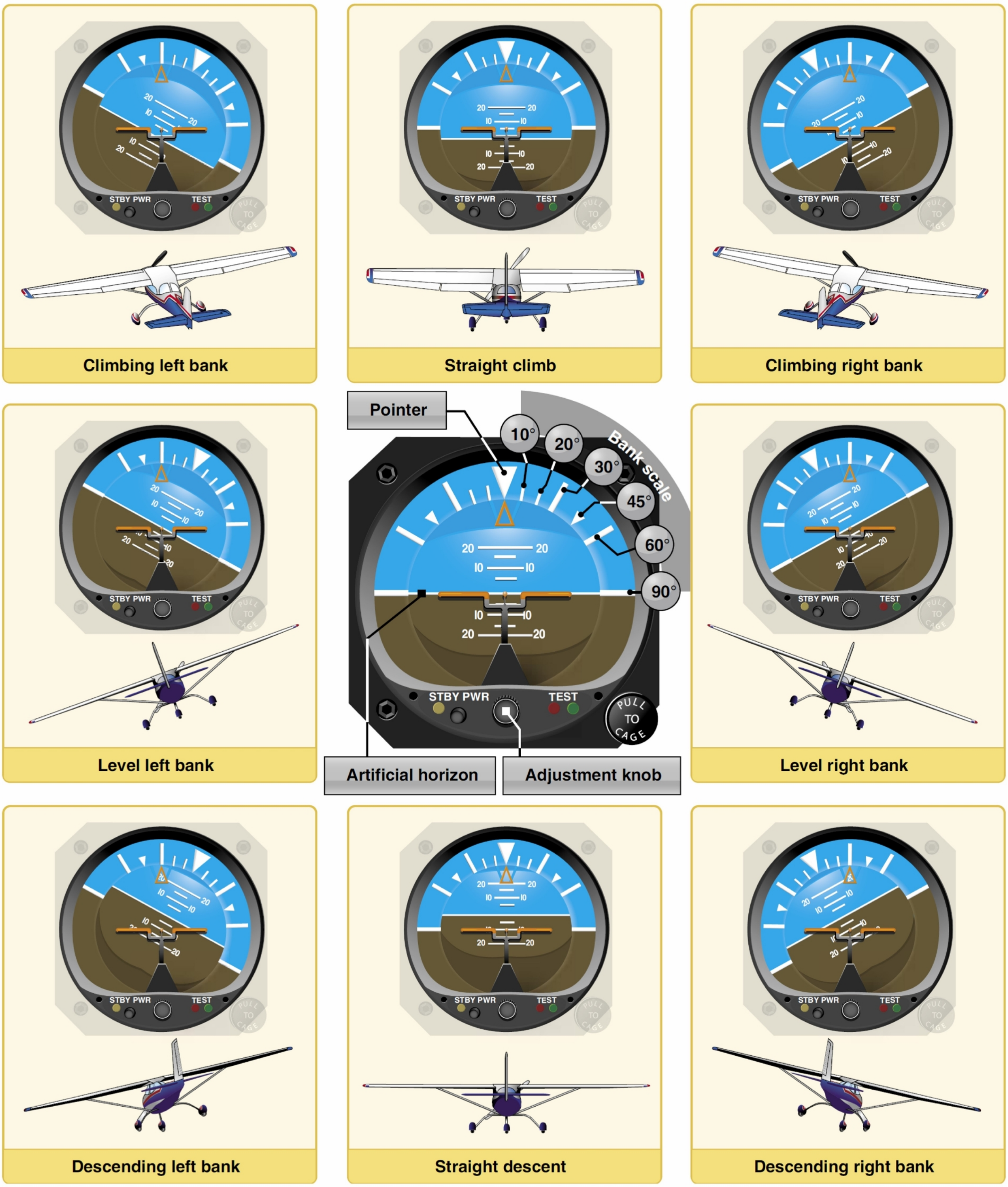


Figure 2.80. Attitude Representations.

292. As mentioned before, a pendulous unit, also called an erection chamber, which erects the gyro axis to the true vertical, is mounted below the gyro case. Four exhaust ports are cut in the sides of this chamber, two in the fore-and-aft axis (one forward, one aft) and two athwartships (one on each side). A pendulous vane is mounted over each port and when the gyro axis is vertical, each port is half closed by a vane allowing the to escape equally from all four ports and the system is in equilibrium. each pair of vanes is attached to a common spindle and is arranged in such a manner so that when one port is fully open, the opposite port will be fully closed.

293. If the rotor departs from the vertical, the pivoted vanes, under the influence of gravity, will still remain in the true vertical, resulting in one pair of

ports being out of balance. Thus one port will be more than half open and the vane directly opposite to it, more than half closed. As the airflow through the open port will be excessive, a reaction force will be set up against the closed port. This reaction force will be precessed through 90^0 in the direction of rotation and will push the gyro back to the vertical.

294. The Attitude Indicator suffers from Acceleration and Turning Errors. As the direction of gyro rotation plays a significant part in the manifestation of the errors, it must be remembered that an air-driven gyro rotates anti-clockwise when viewed from above.

295. Acceleration or Take-off Errors occur because of the Pendulous Unit and the Vanes.

296. The Pendulous Unit makes the rotor bottom heavy and as a result, when an aircraft accelerates, a force from the inertia of the unit is felt at the bottom and the unit tends to lag behind. It tends to swing the bottom of the gyro towards the pilot. This inertial force will be precessed through 90^0 in an anti-clockwise direction, lifting up the right hand side of the outer gimbal. The sky-plate attached to the outer gimbal rotates anti-clockwise and the bank indicates a false right bank.

297. During acceleration, the vanes on the right and left side are thrown rearward. The result is that the right-hand port is more than half open and the left-hand side is more than half closed. This upsets the balanced exhaust of air, more air being discharged from the right-hand side than from the left side. The reaction occurs on the left side and precesses through 90^0 and lifts up the inner gimbal from the point nearest the pilot to indicate a false climb. Thus during acceleration, a slight indication of climb and right bank are obtained.

298. Turning Errors, as the acceleration errors, are caused by the Pendulous Unit and the Vanes.

299. Turning Errors are also known as Pendulosity Error or Bottom Heaviness. During a turn, centrifugal force acts on the pendulous unit, the pendulous unit tends to swing away from the direction of the turn. The force being experienced, precesses through 90^0 to affect the gimbal in such a way that it indicates a false climb or descent. A left turn will result in a false descent.

300. Errors from the Exhaust Vanes is also known as Erection Error. During a turn the fore and aft vanes will be displaced by centrifugal force in a direction away from the centre of the turn. Thus one port will be more than half open and its opposite port will be more than half closed. The reaction will be set up in the fore and aft axis of the aircraft and will precess through 90^0 to lift up the gimbal at the right or left side. The result is a false indication of bank depending on the direction of turn. Initially, up to turning through 180^0 an under-indication of bank will result. If the turn is continued past 180^0, an over-indication of bank will result.

301. The combined effect of pendulosity and erection error is to displace the gyro in two planes. If a turn is made through 360^0 the error reaches a maximum at 180^0. It then reduces to zero at the completion of the turn. In modern instruments the errors are minimised by offsetting the rotor axis. The offsetting of the rotor will not affect straight and level indications as the scales on the instrument offset by a similar amount.

302. Typical Operating Limits of the instrument are 90^0 to 110^0 in bank and 60^0 pitch up/down. If these limits are exceeded, the horizon bar will sweep to and fro across the face of the instrument and it will take 10 to 15 minutes for the instrument to settle and indicate correctly after level flight has been resumed. Some instruments are fitted with a caging device which can be used to reset the instrument. Resetting can only be done successfully during straight and level flight.

303. Light and training aircraft are normally fitted with Attitude Indicators powered by an engine-driven vacuum pump. Electrically-driven Attitude Indicators are mostly found in more sophisticated aircraft but may also be found on some light aircraft and gliders.

304. The serviceability of the suction-driven AI can only be determined after approximately seven minutes after start-up as the gyro requires time to reach full operating speed. The AI should indicate straight and level flight while the aircraft is parked and sensible pitch and bank indications while taxying. It must not indicate a false angle of bank when turning on the ground.

Heading Indicator.

305. The Heading Indicator or Direction Indicator or Directional Gyro or Directional Gyro Indicator, gives a stabilised directional (heading) reference both for maintaining a required heading and for turning onto a new heading. A tied gyro is employed since its axis is tied in the aircraft yawing plane through the aircraft's vertical axis.

Figure 2.81. Heading Indicator

306. The horizontal axis rotor is mounted in two rings, which are called the "inner gimbal" and the "outer gimbal". The gimbals move independently from each other. The rotor is driven by two ait jets which impinges on small buckets carved out on the rim and spins the rotor at approximately 12 000 rpm. The rotor is mounted in the inner gimbal and the gimbal itself lies in the horizontal plane with the rotor spinning in the vertical plane. The inner gimbal is mounted on the outer gimbal and is pivoted at two points on the inner gimbal which are 90^0 from the rotor axis. This allows the rotor to move about the horizontal axis.

307. The outer gimbal is mounted in the case of the instrument and pivots about the vertical plane. This allows the gimbal 360^0 freedom of movement so that the aircraft can turn through 360^0 around it. The graduated card is attached to the outer gimbal.

308. The spinning rotor is rigid in space and therefore once the DGI rotor has attained its full rotor speed and the axis is manually aligned with a datum (usually Magnetic North) it will continue to point to that direction in space for the rest of the flight. Should the aircraft alter its heading, it will do so relative to the gyro axis and therefore the graduated scale.

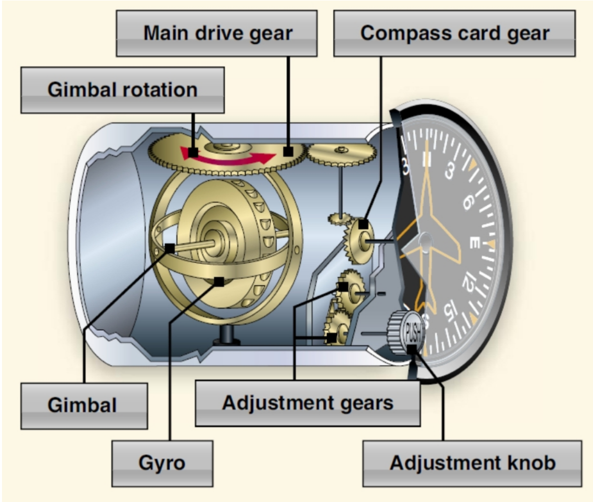


Figure 2.82. The Heading Indicator

309. When the gyro is first run-up, it will erect on any random direction whereas we need to know the direction relative to a a known datum. The HI is provided with a caging knob which when pushed in, operates an arm which locks the inner gimbal at right angles to the outer gimbal. At the same time a gear engages on the outer gimbal so that by turning the caging knob, the gyro can be rotated and aligned in azimuth to a known datum (usually with the magnetic compass). The caging system is also used to prevent damage to the instrument during manoeuvres in which pitch and roll limits may be exceeded. As a means of re-aligning with a known datum or re-setting the gyro to a new heading. To re-erect the gyro if it topples and to prevent the gyro from toppling during synchronisation.

310. The HI is limited in manoeuvring in pitch and roll. If these limits are exceeded the inner gimbal will contact a mechanical stop and the gyro will topple. The inner gimbal is free to rotate for 55^0 either side of the central position for air driven gyros and 85^0 for electrically driven gyros. Exceptions can occur, if the rotor axis is athwartships, then 360^0 of aircraft rotation in the looping plane is possible without toppling. If the rotor axis is fore and aft, 360^0 of roll is possible without toppling.

311. The Directional Gyro suffers from two types of Wander, namely Real Wander and Apparent Wander which in turn is due to Earth Rotation and Transport (a travelling gyro).

312. Real wander is caused by imperfections in manufacturing and friction in the bearings and gimbals. This may cause the gyro to wander. Real Wander is also referred to as Mechanical Wander and as it is a random error, the drift or wander has no definite drift rate. As a result, the heading will need checking against a known datum (usually the magnetic compass) at regular intervals (normally every 15 minutes).

313. In considering Apparent Wander due to Earth Rotation, (a stationery gyro), it can be seen from Fig. 2.83 that the gyro at A, at the equator, is aligned with the meridian. Because the meridians are parallel at the equator, it will maintain this alignment when the earth's rotation moves it to B. On the other hand, if we compare the alignment of the gyro with the meridian at C and its alignment after the earth's rotation has moved it to D, it can be seen that the earth turned (left) round the gyro which is seen as apparent drift. A gyro at the pole (North) would appear to drift at a rate equal to the earth's rotation rate - that is 360^0 in 24 hours or 15^0 per hour. The opposite will be true in the southern hemisphere, the earth will rotate to the right round the gyro.

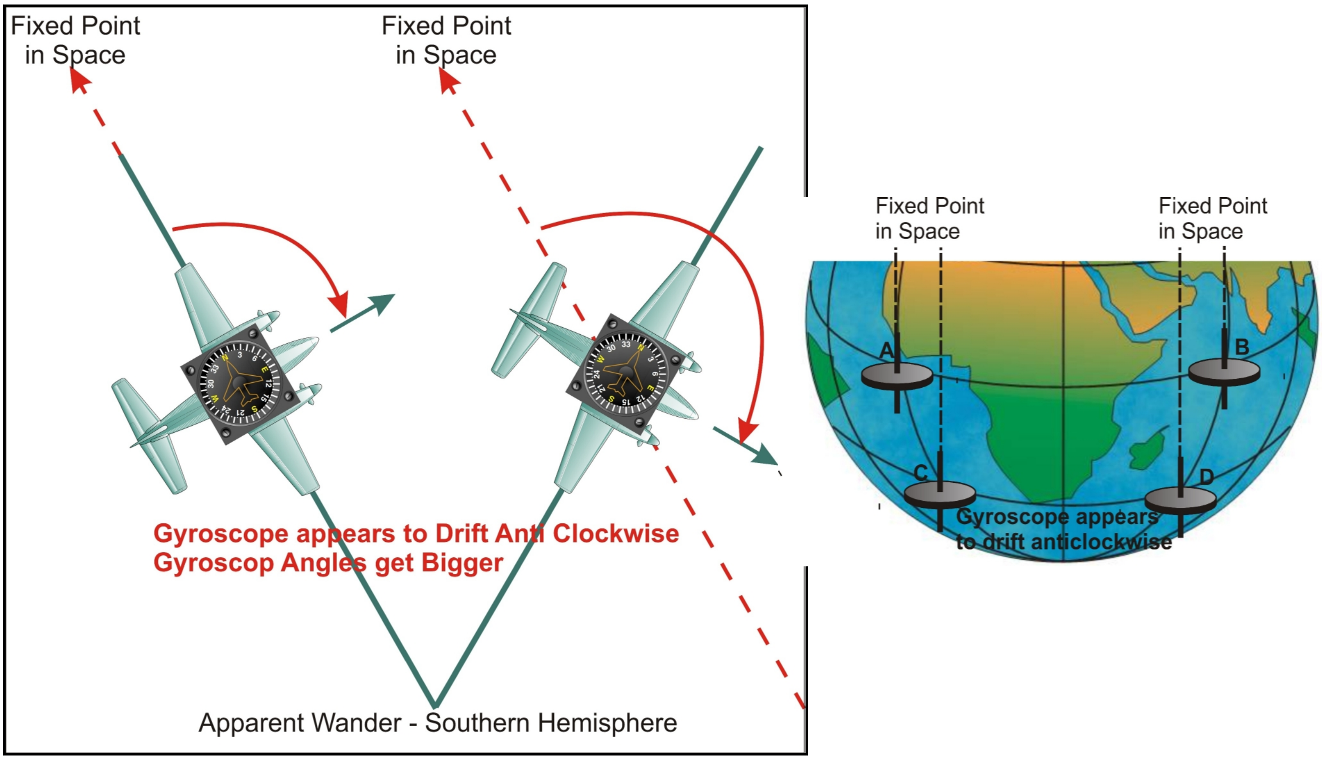


Figure 2.83. Apparent Wander

314. The effect of the drift caused by the earth's rotation can be corrected by inducing equal drift rate, but in the opposite direction. This is done by using a Latitude Rider Nut which will correct for the drift due to the earth's rotation but only at one particular latitude.

315. To achieve this correction the inner gimbal has been fitted with a screwed stud with a nut fixed on one side. On the opposite side of the gimbal is a counterbalance weight. This is sufficient to balance the gimbal when the nut is in the halfway position. Movement of the nut will therefore unbalance the gimbal. Movement of the nut away from the inner gimbal will result in the inner gimbal precessing anti-clockwise (correction for earth rotation in the northen hemisphere). Inward movement of the nut will cause clockwise precession (correction for earth rotation in the southern hemisphere).

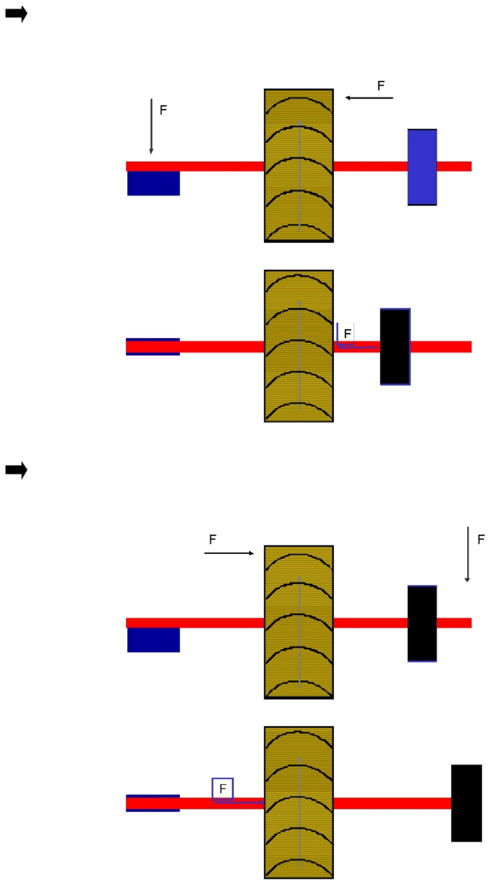


Figure 2.84. Latitude Rider Nut

316.   Transporting (travelling) the gyro over the surface of the earth will also induce apparent wander known as Transport Wander. Like the wander caused by earth rotation, it happens because of the convergency of the meridians and its magnitude is proportional to the east/west component of Ground-speed and the Latitude.

317.   The result of transporting the gyro is that an easterly travelling gyro will add to the wander caused by earth rotation, that is, in the northern hemisphere it will cause the gyro to under-read and over-read in the southern hemisphere. Westerly transportation will have the opposite effect.

318.   In addition to the drift already discussed, the instrument has a turning error known as the Gimballing Error. This is produced when the inner gimbal ring is not exactly at right angles to the outer gimbal. This makes the index card speed up in one quadrant and slow down in another. By the time the aircraft has returned to level flight, the correct heading is indicated again as the index card slows down or speeds up when levelling from a turn.

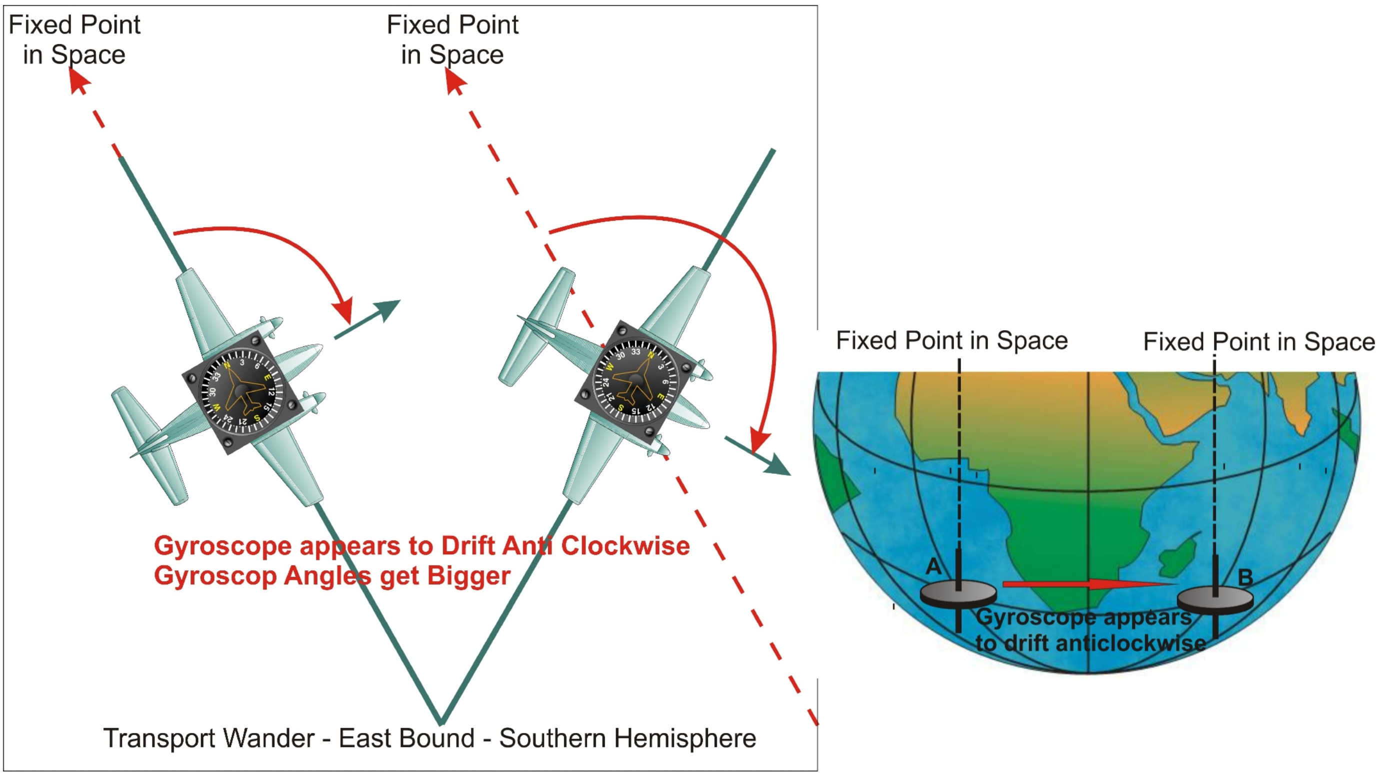


Figure 2.85. Transport Wander, Eastbound.

319. The Serviceability of the HI can be determined after the gyro has reached its full operating speed, the air-driven type may take as long as four minutes. The instrument may be considered to be serviceable when it correctly indicates a turn on the ground, a left-hand turn should cause the readings to decrease and a right-hand turn to increase, and stops turning when the aircraft stops turning.

Magnetic Compass

320. The Direct Reading Magnetic Compass in its simplest form is a magnet freely suspended in the earth's magnetic field. Such a magnet would align itself with the total component of the earth's magnetic field, that is, in the horizontal plane it would point to the magnetic north and in the vertical plane it would be out of the horizontal causing the needle to dip.

Figure 2.86. The Magnetic Compass .

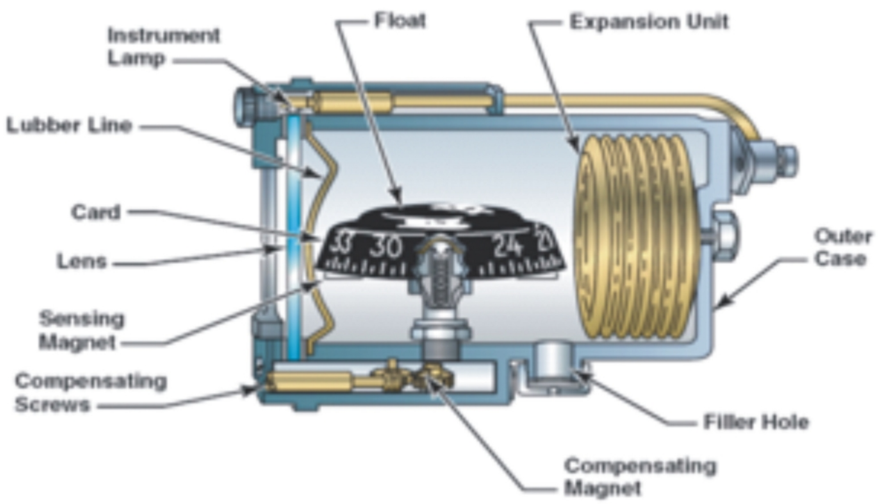


Figure 2.87. Direct Reading Magnetic Compass

321. The purpose of the magnetic compass is to indicate direction as accurately as possible in the horizontal plane, therefore the influence of the horizontal plane must be maximised as much as possible in order to keep the needle as horizontal as possible. The compass must also be as sensitive to the direction of the earth's magnetic field so as to indicate small changes in direction. If the compass needle is displaced from its direction because of the aircraft turning or turbulence, it must swiftly settle back into proper alignment without undue oscillations, that is it must be aperiodic or dead-beat.

322. The compass needle is held as horizontal as possible by using a Pendulous Suspension. The compass is so constructed that the Centre of Gravity of the magnet is below the pivot point. This cause a unbalanced couple to be formed and as the system is not in equilibrium, it will tend to balance itself out. In mid-latitudes this leaves a residual angle of dip of about 2^0 - 3^0. It is important to realise that the Centre of Gravity of the system is displaced towards the Equator. This displacement is the prime cause of acceleration and turning errors.

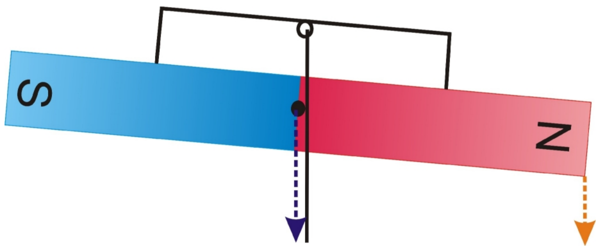


Figure 2.88. Pendulous Suspension.

323. The compass must be Sensitive enough to indicate changes of heading efficiently and quickly. This is achieved by using a strong magnet and in practice up to four magnets are used. To minimise the effect of friction, a jewelled pivot in a sapphire bowl is used. In addition the system is placed in a fluid-filled bowl, the liquid not only lubricates and has as a damping effect, but reduces the effective weight (Archimedes' theorem).

324. The compass needs to be "Dead Beat" and as far as possible be without oscillations (Aperiodic) after a heading change. In order to achieve this, the whole system is immersed in a suitable liquid which dampens the motion effectively. Additionally the magnets are made as short as possible thereby reducing their moment of inertia.

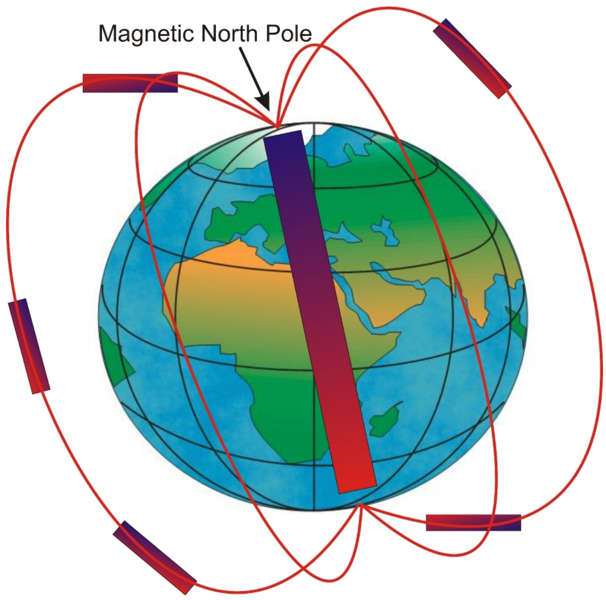


Figure 2.89. Magnetic Field of the Earth.

325. As the magnetic compass operates because of its behaviour in the Earth's magnetic field, it is necessary to understand Terrestrial Magnetism and how the magnetic compass is influenced by it. The Earth's magnetic field can be likened to a large magnet lying at the centre of the earth with the magnetic poles close to the geographic poles. The magnetic field from this earthly magnet surrounds the earth in a similar manner to that surrounding an ordinary bar magnet. A freely suspended magnet will align itself with the Earth Field. The magnetic field is represented by lines of magnetic force parallel to the earth's surface at the Equator. At the magnetic poles however, the lines will be vertical.

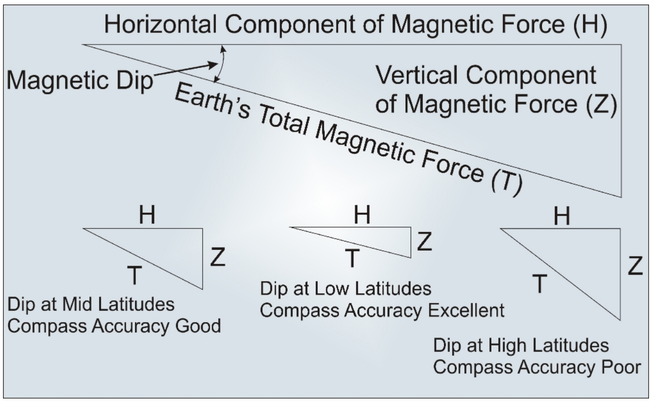


Figure 2.90. Components of the Earth's Magnetic Field.

326. At any particular point on the earth, the total magnetic force (T), resolves into two components (Fig. 2.90). One component (H) is parallel to the earth's surface, the other component (Z) is vertical. As a freely suspended magnet will indicate the Earth's total field (T), it is said to "dip" according to the vertical direction of the field. The angle between T and H is known as the Angle of Dip. The value of dip will be 90^0 at the poles and 0^0 at the Equator. At mid latitudes dip will be approximately 11^0.

327. As previously mentioned, the Magnetic poles are near but not coincident with the Geographic or True poles. Therefore at any given point on the earth's surface, the direction to Magnetic North is unlikely to be the same as the direction to True North. The difference between the two directions is known as Magnetic Variation. When the Magnetic North lies to the west of True North, the variation is said to be Variation West and when the Magnetic North lies to the East of the True North, the variation is said to be Variation East. Thus magnetic variation is the angle measured in the horizontal plane between True North and Magnetic North at a point.

328. The value of variation is shown on charts by lines joining places of equal variation, these lines are known as Isogonals. As the magnetic poles appear to move anti-clockwise around the geographic poles, the direction of the magnetic meridians will also change and therefore the value of the variation will also change. A complete cycle takes approximately 960 years. True direction can be calculated from Magnetic direction and vice versa by the application of variation. When variation is westerly, the direction of the track is greater when measured from Magnetic North than from True North, hence the saying:

VARIATION WEST - MAGNETIC BEST
VARIATION EAST - MAGNETIC LEAST

329. When placed or installed inside an aircraft, a magnetic compass will not necessarily indicate the direction of Magnetic North with absolute accuracy. The reason being that the magnetic fields emanating from the aircraft structure (Aircraft Magnetism) and from electrical equipment, cause Deviation of the compass needle.

330. The direction taken up by the compass needle is known as Compass North and the angular difference between Compass North and Magnetic North is Deviation and is measured East and West from the Magnetic Meridian. It can therefore be said that Deviation is the difference between the direction of a line measured with respect to Magnetic North and the direction measured with respect to Compass North, hence the saying:

DEVIATION WEST - COMPASS BEST
DEVIATION EAST - COMPASS LEAST

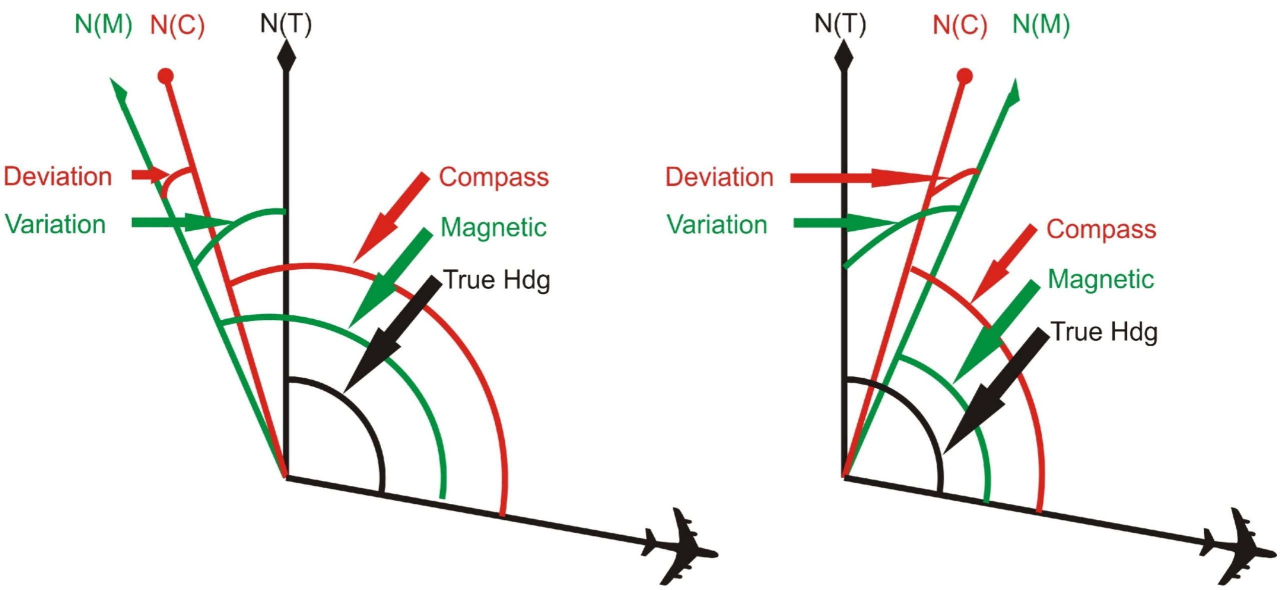


Figure 2.91. Magnetic Variation and Deviation.

331. In spite of the pendulous suspension, there is always a residual of dip. In the Northern Hemisphere the needle dips towards the North Pole and in the Southern Hemisphere the needle dips towards the South Pole. Thus in the Northern Hemisphere the CG is displaced to the South of the pivot and in the Southern Hemisphere the CG is displaced to the North of the pivot. In both cases the CG is displaced towards the Equator.

332. When an aircraft accelerates on an Easterly or Westerly heading without changing the heading, the pivot experiences the acceleration force and moves forward with the aircraft. A force equal in magnitude, but opposite in direction, is felt at the C of G of the magnet system caused by its inertia. Since the CG is not directly below the pivot, these two forces set up a couple and turn the needle. Deceleration will of course produce the opposite effect. The easy way to remember this is by the use

of the word SAND - South - Accelerate, North - Decelerate

333. On Northerly and Southerly headings NO ERROR is caused as the pivot and the CG are in alignment. The CG may move fore and aft causing the needle to dip but no apparent change of heading will occur.

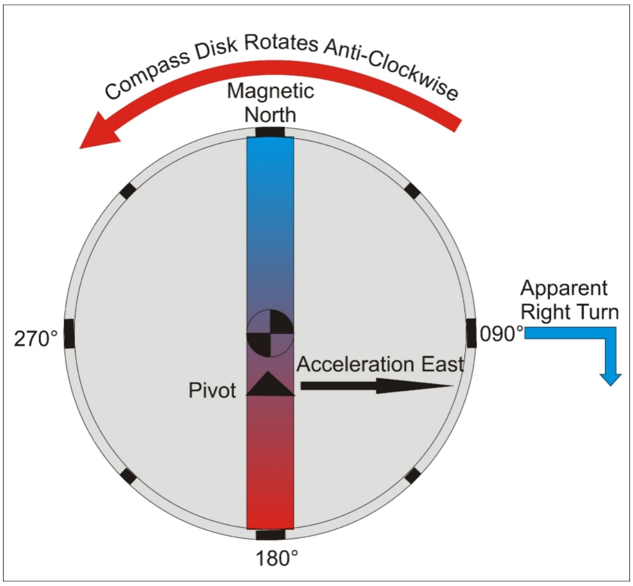


Figure 2.92. Acceleration Error In the Southern Hemisphere.

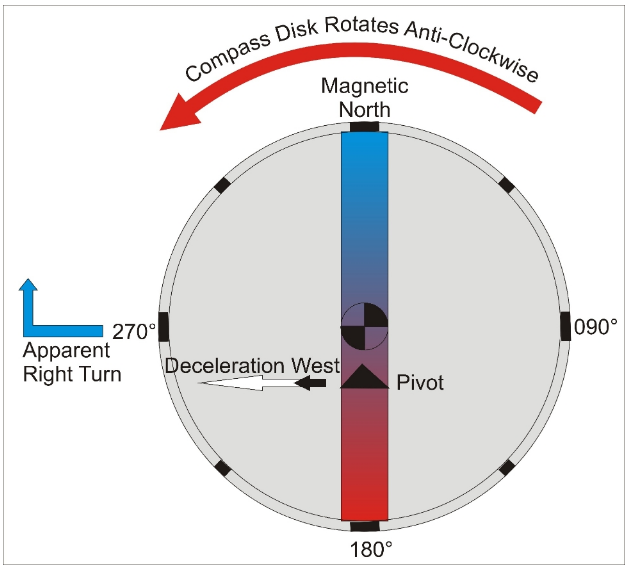


Figure 2.93. Deceleration Error In the Southern Hemisphere.

334. Turning Errors are caused magnetically and mechanically. Both errors are caused by the CG being displaced from under the pivot point towards the Equator. Maximum errors will occur during turns through North and South.

335. In a correctly balanced turn the pivot point of the magnet system is carried with the aircraft along the curved path of the turn, whilst the CG is offset, it is subjected to the force of centrifugal acceleration produced by the turn, which causes the system to rotate.

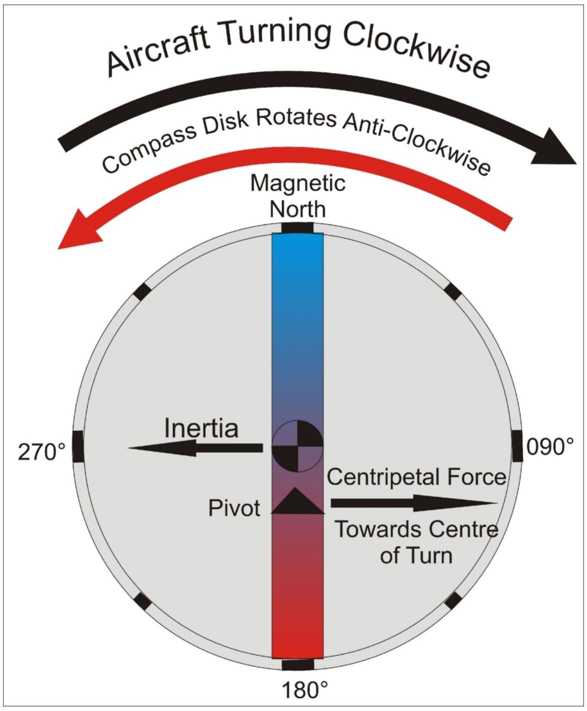


Figure 2.94. The Mechanical Turning Error.

336. The errors are opposite for the Northern Hemisphere.

337. The magnetic turning error is similar in effect to the mechanical error. in a balanced turn, the compass, pivot post, pivot and magnet system all bank with the aircraft. Weight acts in the aircraft vertical, but component Z of the earth's field acts in the true vertical and will pull the South end of the magnets down towards the South Pole (reversed in the Northern Hemisphere). As the pivot of the system is above the magnets, a turning motion occurs and a similar error to that of the mechanical error results.

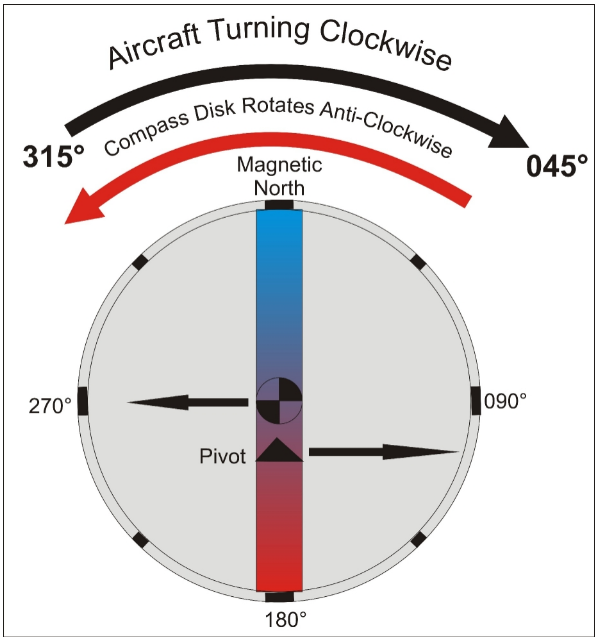


Figure 2.95. Right Turn Through North in the Southern Hemisphere.

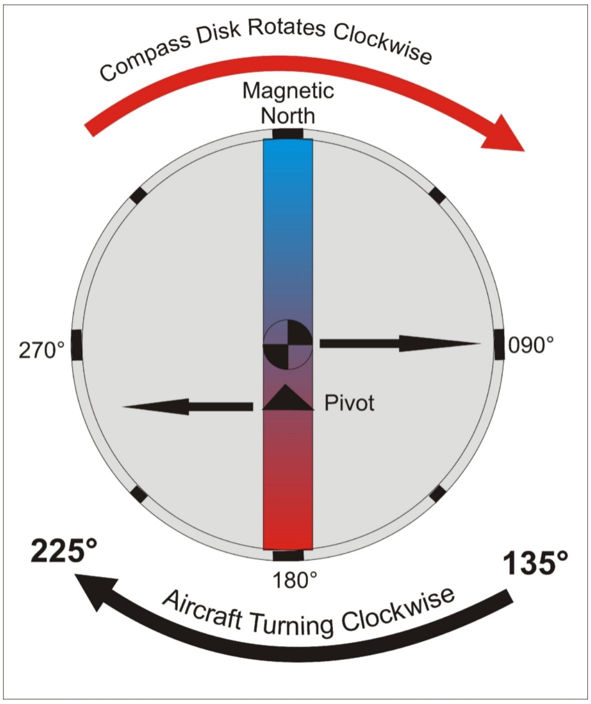


Figure 2.96. Right Turn Through South in the Southern Hemisphere.

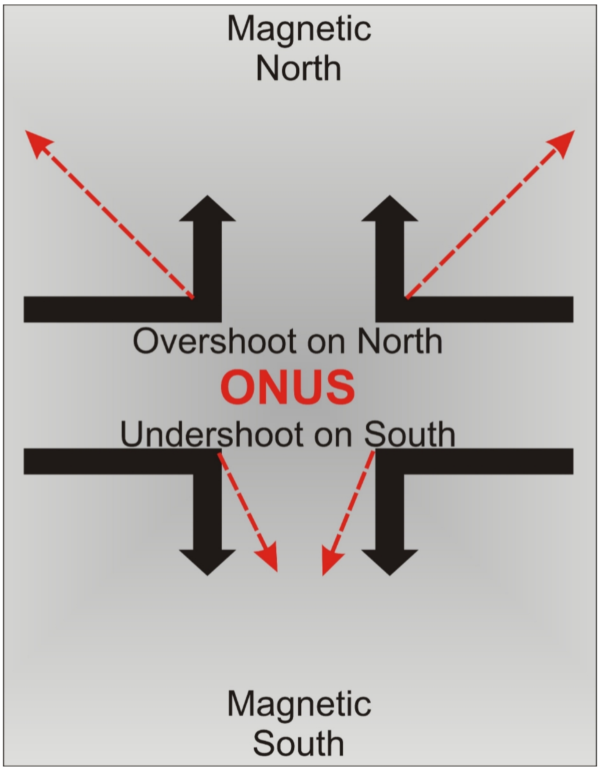


Figure 2.97. Resolving Turning Errors in the Southern Hemisphere.

SOUTHERN HEMISPHERE

ONUS

Overshoot on North
Undershoot on South

NORTHERN HEMISPHERE

UNOS

Undershoot on North
Overshoot on South

338. The Direct Reading Magnetic Compass can be checked for Serviceability in the following manner: -

- Check the liquid for discolouration, presence of bubbles or sediment.

- Check compass mounting for security

- Check the compass lighting

- Check presence of the deviation card

- PIVOT FRICTION TEST:

  * Deflect the needle by 10^0

  * Hold needle for a few seconds to allow the liquid to settle

  * Release needle and note heading at rest

  * Deflect the needle by 10 ^{0}in the opposite direction, hold and release

  * Note heading at rest

  * The two headings noted should be within 2^0

- DAMPING TEST:

  * Deflect the compass needle through 90^0

  * Hold needle until liquid settles

  * release the needle and start a stopwatch

  * The time of travel through 85 ^{0}must be within the makers limits (usually between 6 and 14 seconds).

- Also check for serviceability after:

- A hard landing.

- A lightning strike

- Replacement of major components including electrical and radio equipment.

- After carrying a magnetic load

- After standing on one heading for a long period (3 weeks or more).

Engine Instruments

339. The specific groupings of instruments required for the monitoring of power plant operation is governed primarily by the type of power plant, the size of aircraft and the space available for the location of instruments. In a single-engined aircraft this does not present too much of a problem. The small number of instruments required, may flank the flight instruments thus keeping them within a small scanning range.

340. The Oil Temperature gauge is an essential component of any oil system as it, together with the Oil Pressure gauge, give the best indication of engine health. The Oil Pressure gauge showing a drop in oil pressure and the the temperature gauge showing an increase in temperature, may be an indication of worn bearings or worse, loss of oil. The other gauges will not react to worn bearings. The oil temperature and pressure are registered at the point where oil enters the engine.

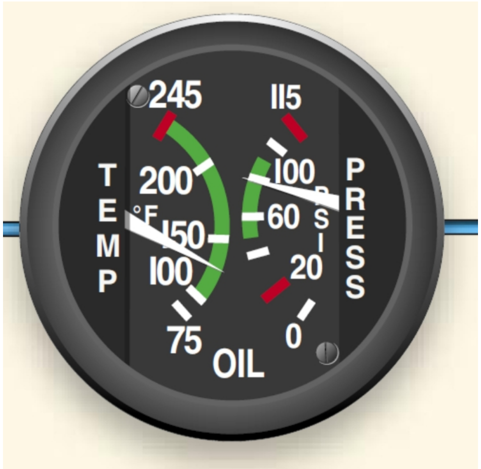


Figure 2.98. Oil Pressure and Temperature Gauges.

341. Engine handling must be done according to the FM/POH. As different manufacturers have different prescriptions as to warming-up the engine it is best to follow to the manufacturers instructions. As a general rule, oil pressure must be indicated within 30 seconds after start-up. Part of managing the oil temperature and pressure is recognising tendencies or trends, that is if for instance, the oil pressure slowly decreases over time, it can be an indication of a malfunction which, if corrected timeously, can prevent damage to the engine.

342. Controlling and managing engine temperatures is a very important part of not only ensuring the best results from your engine but also prolonging engine life. An efficient use of power application and airspeed will ensure engine temperatures staying within the limits. A Cylinder Head Temperature gauge indicates the temperature

of one cylinder head and the limits specified in the FM/POH must be observed at all times. Richening the mixture is only one option for increasing cooling. Reducing power and increasing airspeed are also good for cooling the engine.

343. More powerful aircraft engines often have additional gauges to assist with the leaning out process, commonly indicating cylinder head temperature and Exhaust-gas Temperature. The EGT gauge is specifically designed to enable very accurate leaning of the mixture to be made without the risk of damaging the engine. Procedures will be given in the POH/FM and care must be taken to follow the instructions precisely. As a general rule, the maximum power is obtained with the EGT between 90^{0} to 150^{0}F on the rich side of the peak, (hottest) EGT. The best economy mixture occurs with the EGT about 25^{0}F on the lean side of the peak.

Figure 2.99. The Cylinder Head Temp Gauge.

Figure 2.100. The Exhaust-gas Temperature Gauge.

344. Engine power settings on aircraft with variable pitch propellers are stated in terms of both Manifold Pressure (controlled by the throttle) and RPM (set with the pitch control). As a rule, the Manifold Pressure Gauge is located close to the throttle and the RPM gauge close to the pitch control lever so that power adjustments can easily be monitored. Manifold Pressure is the absolute pressure in the induction manifold expressed in inches of mercury and is measured between the throttle valve and the engine inlet valve. High manifold pressure has the effect of increased power. The power of an un-supercharged engine is directly related to its speed, so with the throttle set to a corresponding operational setting, an RPM indicator also serves as a power indicator. Normally a generator-type Tachometer is fitted to the engine and its frequency monitored. As the rotor speed and frequency are directly proportional, and since the rotor is driven by the engine, then the frequency is a measure of the engine speed.

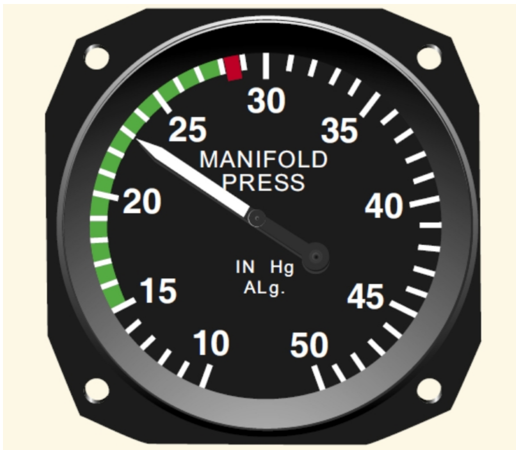


Figure 2.101. Manifold Pressure Gauge

Figure 2.102. RPM Gauge

345. Aircraft must have some sort of indication of fuel contents. Light aircraft usually use a float-type system whereby the level of the float (and the level of the fuel) is transmitted via an electrical signal to the fuel gauges in the cockpit. Light aircraft fuel gauges however, do not have a high reputation for accuracy. The measurement of fuel quantity, due to the changing attitude of the aircraft, movement of the fuel and shape of the tanks is not a simple matter, therefore the most reliable means of determining the fuel contents is by checking it visually.

Figure 2.103. The Fuel Quantity Gauge.

346. Aircraft which do not rely on a gravity-feed fuel supply will be fitted with a fuel pump and a Fuel Pressure Gauge indicating the pressure of the fuel flowing to the induction system. As the aircraft may be fitted with both an engine-driven and an electrical fuel pump, the Fuel Pressure Gauge will monitor the pressure in the system regardless if one or both pumps are operating. Fluctuating or low fuel pressure might indicate a blockage, fuel pump failure or that the fuel supply is insufficient.

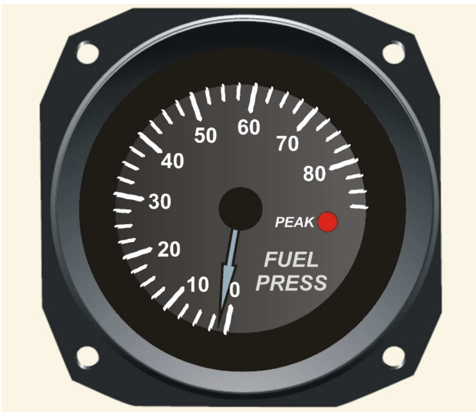


Figure 2.104. Fuel Pressure Gauge

347. Fuel Flow Gauges measure and provide visual indication of the instantaneous rate at which fuel flows to an engine. It provides a secondary indication of the quantity of fuel consumed in terms of units per hour. The gauge can also be linked to a fuel flow computer which can calculate not just the present fuel flow but also fuel remaining and endurance.

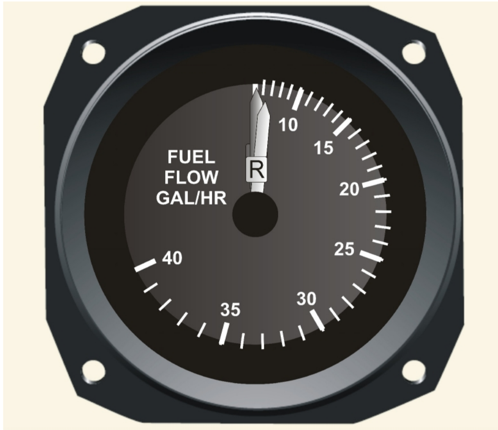


Figure 2.105. The Fuel Flow Gauge.

Other Instruments.

348. As the typical light aircraft is fitted with an engine-driven suction pump, the strength of the suction (vacuum) created within the system is measured and displayed to the pilot on a Vacuum Gauge in inches of mercury. This is the best indication of the serviceability of the vacuum system. The vacuum gauge should be checked before take-off and regularly during the flight. The POH/FM will give the acceptable suction limits but five inches of mercury is a common value at cruise power settings.

349. To enable the pilot to monitor the performance of the electrical system, an aircraft is fitted with an ammeter. The ammeter measures the flow of current in the electrical system. Two systems, the Zero-Centre or the Left-Centre system, are generally in use and the POH/FM for the particular aircraft being flown, must be checked to determine the procedures applicable.

350. The Zero-Centre ammeter (Fig. 2.41) is connected between the battery and the main busbar so as to indicate the charging rate of the battery. If the alternator is operating properly and supplying power to the electrical system via the busbar and charging the battery, the ammeter will indicate a

positive (+) charge. As the ammeter indicates the amount of current flowing in the system, a high charging rate will be indicated when a substantial number of electrical services are being used. It will also indicate a high charging rate if the battery has been somewhat depleted, as with starting on cold mornings, and must be recharged. If the alternator malfunctions or has failed, the battery will be supplying all of the required electrical power and the ammeter will indicate that the battery is discharging ie. a negative (-) charge.

351. The Left-Centre Ammeter (Fig. 2.40), also known as a Loadmeter, is installed between the alternator and the main busbar to indicate the flow of current from the alternator to the electrical system. As the alternator is supplying current directly to the main busbar, the more electrical services use, the greater the amount of current drawn from the alternator and the higher the indication will be on the ammeter. This will also be the case if the battery is being recharged after a cold start. As this ammeter cannot indicate a negative charge, should the alternator malfunction or fail, the ammeter will indicate a zero charge as no current is flowing from the alternator. It sometimes may be difficult to distinguish between a very low charging rate and no charging rate when the battery is supplying all the electrical services.

352. Generator output is directly proportional to generator voltage. A Voltmeter (Fig. 2.42) is therefore installed in some systems to facilitate the monitoring the operation (health) of the alternator.

353. A Low Voltage Warning Light is fitted to some aircraft which illuminates when the alternator fails or is off-line. This is an indication that the battery is supplying all the electrical power. Some light aircraft also have annunciator panels which is a panel of warning lights.

354. Although it is not specifically stated, the Daily Inspection (pre-flight inspection) is part of Periodic Maintenance Inspections. Others prescribed by the standards relating to maintenance are; Inspections as Recommended by the manufacturer, Mandatory Periodic Inspections, Progressive Inspections, Block Inspections, and Other Inspections.

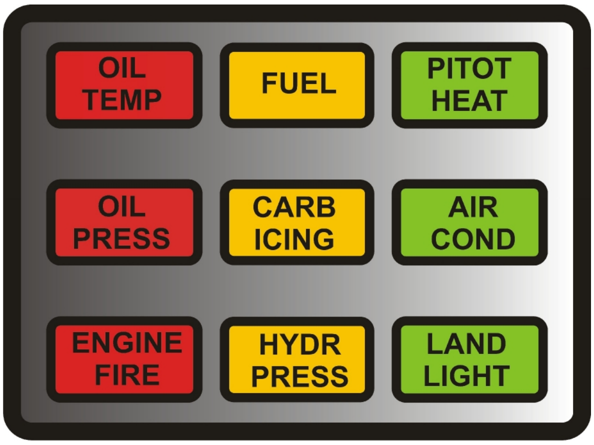


Figure 2.106. Annunciator Panel

355. The Recommended Inspections must be complied with only and in so far as it is not contradicting and will not compromise commercial air transport operations regulations as prescribed by CAA.

356. Mandatory Inspections must be accomplished in order to validate or re-validate the C of A on all aircraft imported into South Africa for the purpose of obtaining a certificate of registration. On new aircraft built in the RSA. When an aircraft has sustained damage as prescribed in CAR 43.02.5 and at any time before the next routine inspection is due.

357. A Mandatory Periodic Inspection must be carried out at 100-hours of flight time intervals since the last MPI or within 12-month period, whichever comes first.

358. An owner or operator may request permission from the Commissioner to introduce a system of Progressive Inspections to replace the 100-hours mandatory periodic inspections.

359. Block Inspection and Maintenance programmes may be used on aeroplanes with a maximum certificated mass in excess of 5 700kg and helicopters with a maximum certificated mass exceeding 3 700 kg according to an approved maintenance schedule divided in blocks.

360. Other Inspections normally comprise Duplicate Inspections in order to verify that the manufacturer’s specifications and requirements

have been met in detail

361. Non-scheduled Maintenance Inspections

may be necessary due the aircraft being subjected to hard/overweight landings, exceeding placarded speeds for flaps/undercarriage, severe turbulence, lightning strikes etc.

AIRWORTHINESS AND EMERGENCY PROCEDURES

CERTIFICATE OF AIRWORTHINESS.

SOUTH AFRICAN CIVIL AVIATION AUTHORITY

CAR21L

AW 17842

REPUBLIC OF SOUTH AFRICA

CERTIFICATE OF AIRWORTHINESS

CERTIFICATE NO: 2146/ZS-EBL/6

1. Nationality and registration marks	2. Manufacturer and manufacturer's designation of aircraft PIPER AIRCRAFT CORPORATION	3. Aircraft serial number
ZS-EBL	PA-28-140	28-20435
4. Categories :	■■Standard■■	

5. This certificate of airworthiness is issued, pursuant to the Convention on International Civil Aviation, dated 7 December 1944, the Aviation Act, 1962 (Act 74 of 1962), as amended, and the Civil Aviation Regulations, 1997 as amended, in respect of the above-mentioned aircraft which is considered to be airworthy when maintained and operated in accordance with the foregoing and the pertinent operating limitations, and has been shown to meet the requirements of the applicable comprehensive and detailed airworthiness code as provided by Annex 8 to the Convention on International Civil Aviation.

6. Special conditions : **OPERATIONAL UNDER CATEGORY PART 135**

7. Original date of issue: **14 JULY 1977**

8. **Expiry date: 13 JULY 2009**

FOR COMMISSIONER

CIVIL AVIATION

COMMISSIONER FOR CIVIL AVIATION

Figure 2.107. Certificate of Airworthiness.

362. It is very important that all Instructions and Limits as given in the Flight Manual regarding Weights. Speeds. Normal Operating Procedures, Emergency Procedures, Weight and Balance, Aircraft Systems Limitations and Placards be strictly adhered to at all times. Exceeding these limits or disregarding these procedures will invalidate the Certificate of Airworthiness.

363. The owner or operator of an aircraft shall keep a current approved aircraft Flight Manual for each aircraft of which he or she is the owner or operator. The flight crew members of the aircraft shall, on each flight, operate such aircraft in accordance with the aircraft Flight Manual, unless an unforeseen emergency dictates otherwise.

364. The following Logbooks shall be kept in respect of South African registered aircraft and in respect of other specified equipment for the purpose of recording therein the maintenance history of the equipment to which each relates; An Aircraft Logbook for each aircraft, an Engine Logbook for each engine and a Propellor Logbook for each propellor.

365. The operator of an aircraft shall establish adequate Inspection and Reporting Procedures to ensure that Defective equipment are reported to the pilot in command before take-off. The procedures shall be extended to include the reporting to the operator of all incidents or the exceeding of limitations that may occur while the flight crew are embarked on the aeroplane and of defective equipment found on board. Upon the receipt of the reports, the operator shall compile a report and shall

submit such a report on a monthly basis to the commissioner.

Figure 2.108. Warning Panels

366. The Maintenance that the holder of a Pilot licence may carry out on an aeroplane with a maximum certificated mass of 5 700 kg or less or a maximum approved passenger seating of nine, is limited to the following items;

S Changing of tyres and tubes and repairing punctures.
S Servicing landing gear shock struts with air.
S Correcting defective locking wire and split pins.
S Replenishing hydraulic fluid in the hydraulic fluid reservoir.
S Small simple repairs to fairings, non-structural cover plates and cowlings by means of stop drilling cracks and fitting small patches or reinforcements which will not change contours or interfere with proper airflow.
S Replacing side windows where such work does not interfere with the primary system.
S Replacing safety belts.
S Replacing seats or seat parts where such work does not involve any removal, dismantling or interference with a primary structure system.
S Replacing pre-fabricated fuel and oil lines, provided that a fuel flow check is carried out in accordance with TS 43.02.8, Section A.2(6) “fuel flow checks”.
S Replacing any electrical bulb, reflector, lense or fuse of navigation and landing lights.
S Replacing or cleaning spark plugs and setting spark plugs gaps.
S Cleaning fuel and oil strainers.
S Replacing batteries and checking fluid level and specific gravity.
S Replacing tail wheels and tail wheel springs.
S Changing engine oil.
S Removing and installing such dual controls as is designed for easy removal and installation.
S Replacing the following instruments by others of the same type which have such markings as may be indicated in the appropriate owners manual.:

i. Airspeed indicator.
ii. Altimeter
iii. Engine speed indicator foreach engine.
iv. Oil pressure gauge for each engine.
v. Fuel contents gauge.

Provided that a pitot static check is carried out in accordance with TS 43.02.9 for subparagraphs i and ii above.

Emergency Procedures

367. As modern aircraft’s systems are sophisticated and of high technical standards, emergencies rarely happen, their occurrence is unexpected. Pilot’s should be familiar with the procedures in POH/FM and be prepared to take appropriate action should an emergency arise.

368. Pilots should review standard emergency procedures periodically to remain proficient. Critical actions with respect to time, are indicated by the use

of bold print and these actions should be performed immediately if the emergency is not to be aggravated. The remaining procedures are not critical in the sense that the time is usually available for consulting the checklist.

369. The aviation environment encompasses many hazards and one of the ways in which the effects of an emergency situation can be minimized is by providing appropriate equipment and to be fully trained and conversant in its use. As most light aircraft carry only a First Aid Kit and a Fire Extinguisher, it should not take to much of an effort on the pilot's side to familiarise himself/herself with it.

370. The contents of First Aid Kit carried in an aircraft are specified by the TS 91.04.16. During the pre-flight checks the pilot must ascertain that the First Aid Kit is present, correctly (firmly) installed and in good order. Periodic inspections must be carried out to check the contents for completeness and that dated items are within their stated use by date.

Figure 2.109. Standard First Aid Kit

371. Various types of Fire Extinguishers are in use and the choice of use normally depends on the source of the fire. Water extinguishers are only effective for use on fires involving wood, paper or cloth. Foam extinguishers are effective for use also on wood, paper, cloth and flammable liquids. Carbon Dioxide extinguishers can be used on fires involving flammable liquids and on electrical fires. Dry Powder extinguishers can be used on fires involving flammable liquids, gases and electrical fires. They are also recommended for use on wheel fires. BCF extinguishers can be used on all types of fires.

372. The Fire Extinguisher being used in most aircraft is the BCF extinguisher containing the agent Halon 1211. As part of the pre-flight inspection, the fire extinguisher must be checked for content (the gauge needle must be within the green arc) and properly secured.

373. In the event of an engine fire on the ground (most probably due to over-priming), a BCF extinguisher can be used to try to extinguish the fire by discharging it directly into an opening or intake somewhere close to the base of the fire. It is best to let to let the professionals handle it. If an engine fire occurs during starting, the best action is to keep turning the engine over, should the engine start, the fire may well be drawn out of the induction system.

Figure 2.110. BCF Fire Extinguisher

374. If it becomes necessary to use a BCF extinguisher in the cockpit, all vents and windows should be closed before using the extinguisher. Once the fire is out, the cockpit should be well ventilated to clear out the residual fumes.

375. The pilot should be aware of the dangers of carrying goods that can be hazardous in the aircraft. Certain goods have been classified as being dangerous and where these are permitted to be carried, special conditions may apply.

376. Some items are obviously dangerous and are not to be allowed on to an aircraft. For example acids and other corrosive liquids, Flammable Liquids and Materials and gas containers. As already stated, the carriage of compressed or pressurised gas containers is prohibited, however it may be transported if empty.