ASRA

AUSTRALIAN SPORT ROTORCRAFT ASSOCIATION INC.

ABN: 53 412 417 012

BASIC AERONAUTICAL KNOWLEDGE

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VERSION NUMBER	PUBLISHED DATE	AUTHOR	REVISION NOTES
Version 1.0	28/12/2024	M.Robertson	Initial version for Part 149

INTRODUCTION

This Manual is produced to introduce the basics of gyroplane aeronautical knowledge to first-time flyers who have no previous experience in or with aircraft. For this reason, we have deliberately made it simple and hopefully easy to read and understand. It is intended that having read and absorbed the contents within, the candidate for a Gyroplane Pilot Certificate will have basic knowledge required to pass the Basic Aeronautical Knowledge Examination and be capable of applying this knowledge to assist the pilot's practical training.

This is not a flying training manual and for that reason, techniques used in specific flying sequences will not be covered. Some cross-referencing may occur and where it does, it is for demonstration purposes only.

Diagrams used may not be to scale and angles depicted may be exaggerated in order to clearly explain what is intended.

Errors or omissions noted should be brought to the attention of the ASRA Training Manager for rectification. All criticism, both positive and negative is welcomed and appreciated.

ABBREVIATIONS and DEFINITIONS

Airfoil (aerofoil): the shape of a wing or blade as seen in cross-section. It is designed to produce a reaction from the air that it moves through, these reactions being termed “lift” and “drag”.

Typical airfoil

Altitude: the distance above the mean sea level pressure datum.

Angle of attack: for a rotor blade (airfoil), refers to the angle between the chord line and the relative airflow affecting the blade. For a rotor disc, it refers to the angle between the tip path plane of the disc and the relative airflow affecting the rotor disc. Angle of attack can be controlled by the pilot through the cyclic.

ASI: airspeed indicator.

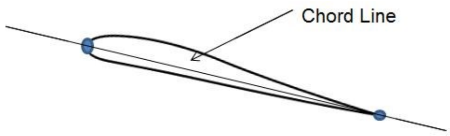
Autorotation: a state of flight where the rotor of a gyroplane turns by the action of air moving up through the rotor.

Axes (pronounced “axees”): the plural of axis and refers to the axle or spindle about which an object rotates.

C: Celsius.

CASA: Civil Aviation Safety Authority.

Chord line: a line joining the centre of the leading edge to the centre of the trailing edge of an airfoil.



Cyclic (stick, control stick, joystick): all refer to the lever that the pilot uses to control a gyro in the fore/aft and lateral planes. The cyclic is able to move in any direction at any time and is connected to the rotor head mechanically.

Density: the mass per unit volume of a medium. For example, compare 1 kg of lead and 1 kg of feathers. Both have the same mass, but the volume of the lead is much smaller than that of the feathers. Therefore, the lead is more dense than the feathers.

Discing: as rotor RPM increases, there comes a point where individual rotor blades can no longer be distinguished. At this point the rotors are said to be “discing” or “blurring”.

Elevation: distance of a ground feature above mean sea level.

Height: distance above the ground.

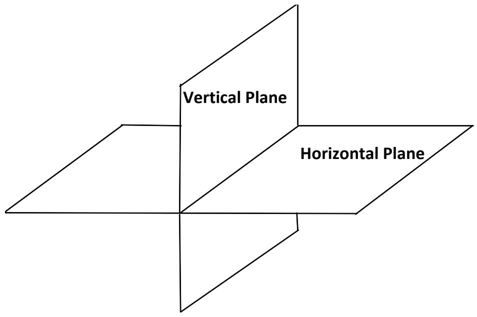
hPa: hectopascals.

Hub-bar: a component of the rotor system that joins two rotor blades. It is normally manufactured from a specific grade of solid aluminium extrusion.

IAS: indicated airspeed.

ISA: international standard atmosphere.

Plane: a level or flat surface. It is two dimensional and may be orientated at any angle. The horizontal and vertical planes are the primary references used in aviation.

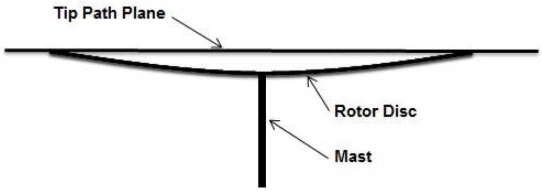


Planes

Relative airflow: the actual airflow affecting the gyroplane and on the ground is a combination of the apparent airflow caused by the forward motion of the gyro and the ambient wind blowing at the time.

Rotor disc: after the point at which the rotors start discing, the rotor system may be considered to be a rotating disc that exhibits the same properties as if it were an individual rotor blade. The chord line of a rotor disc may be considered to be the tip path plane of the blades that form the disc.

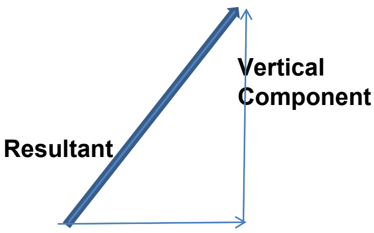
Tip path plane: the plane that contains the line joining the tips of the rotor blades. This plane can be inclined at any angle allowed by the limits of the rotor head movement.



Tip path plane

Total aerodynamic force: the sum of the forces generated by air passing over an airfoil.

Vector: a quantity possessing magnitude and direction. In other words, it can be drawn on a piece of paper. If you were asked to draw a speed of 20 knots, could you do it? No. However, if you were asked to draw a speed of 20 knots north, then it's possible. This then is a speed vector. Two or more vectors may be added together to produce a resultant. When this occurs, the vectors are referred to as components of the resultant. Conversely, a resultant can be divided into vectors acting in different directions. These vectors then become components.



_*: degrees (e.g. 30° C).

The BASICS

It is necessary to understand the primary forces that affect a gyroplane (gyro) or any aircraft in flight and the interaction between them. With this knowledge, a pilot is able to determine what *has* happened to his gyro or what *will* happen, thus eliminating to a large degree the element of surprise when the gyro reacts in a certain way.

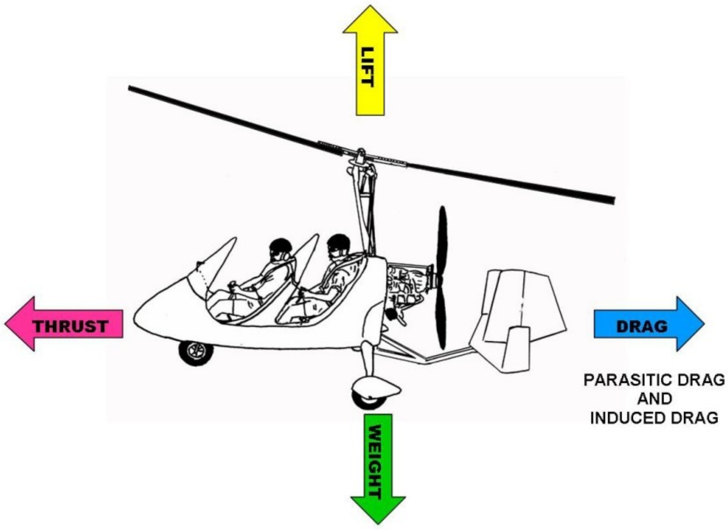


Fig. 1.1 The four basic forces

Fig. 1.1 illustrates the four basic forces affecting a gyro in stable flight. When the opposing forces are equal and opposite, the gyro remains in a stable condition. Thus, to neither climb nor descend, the lift generated by the rotor system acting vertically upwards must equal the weight acting vertically downwards. Similarly, when the thrust generated by the engine/propeller equals the total drag from the gyro, it neither accelerates nor decelerates but maintains a constant speed.
We will now consider the forces acting on the gyro in the horizontal plane.

Thrust
The power output of the engine fitted to a gyro does not automatically determine thrust. The power must be converted to thrust by the reduction drive (if fitted) and the propeller, which must be pitched so as to produce maximum thrust, usually at takeoff power settings. Having achieved this, the thrust is then governed by the power output of the engine which is determined by throttle position.
Therefore, when the throttle is opened the thrust will increase and the gyro will accelerate. Conversely, when the throttle is closed, thrust will decrease and the gyro will slow down. This is similar to a motor vehicle on the ground where opening the throttle (accelerator) will cause an increase in power (thrust) to be transmitted through the transmission train to the drive wheels, resulting in the vehicle increasing speed and vice versa. How much either vehicle accelerates is determined by the force opposing the thrust, known as “drag”.

Drag
The drag force represented in Fig. 1.1 is the total drag acting on the gyro in flight. We need to understand what comprises the total drag in order to minimise, reduce or control it.
There are three main “sub-drags” that combine to produce the total drag. They are parasite drag, profile drag and induced drag.

Parasite drag is the drag attributable to any part of the gyro that does not produce lift. These include undercarriage, pods or enclosures, exposed engines, the mast, other airframe components and similar. All provide a resistance to the airflow affecting the gyro and this resistance will increase with speed. Clever design and fairings have been used to try to streamline these components with varying degrees of success, but whenever a solid body passes through a fluid (air), parasite drag will be produced.

Profile drag is a combination of form drag and skin friction.
Form drag is produced by fluid (air) flowing past a solid object causing eddies which destroy the smooth streamlined flow. An extreme example of form drag is when a flat plate is held at right angles to a stream of air. The resistance felt is very large and is caused almost entirely by the formation of eddies. Again, an increase in speed will result in a corresponding increase in form drag. As can be seen in Fig. 1.2, the more streamlined the object passing through the airflow becomes, the less form drag is produced.

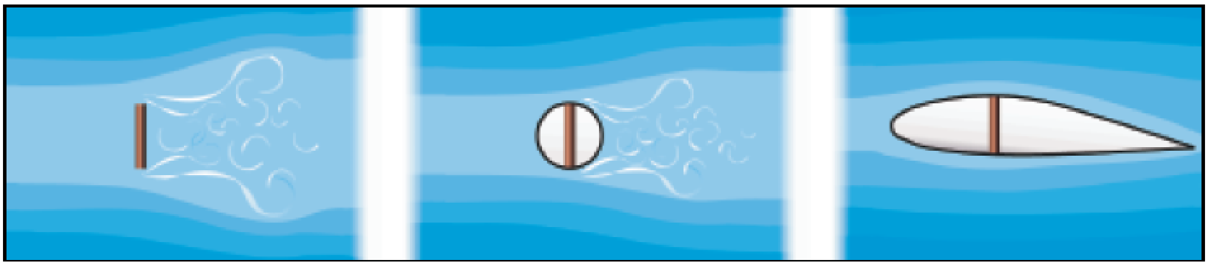


Fig. 1.2 The relationship between streamlining and form drag

Skin friction is caused by surface roughness. Even though a surface appears smooth to the naked eye, it may be quite rough when viewed under a microscope. A thin layer of air clings to the rough surface and creates small eddies that contribute to drag. Dead insects and dust on a surface increase skin friction.

Induced drag is a by-product of lift. Whenever lift is produced, so too is induced drag. In fact, induced drag is the horizontal component of the total aerodynamic force (often termed rotor thrust vector when referring to a gyro) acting on an airfoil, whilst lift is the vertical component of that force. As we will see later, lift can be controlled by the gyro pilot, so it follows that the induced drag can also be controlled. There is a formula to calculate the induced drag produced by an airfoil in given circumstances and this will be referenced later on in this section.
Fig. 1.3 graphically depicts each of the above types of drag together with the total drag.

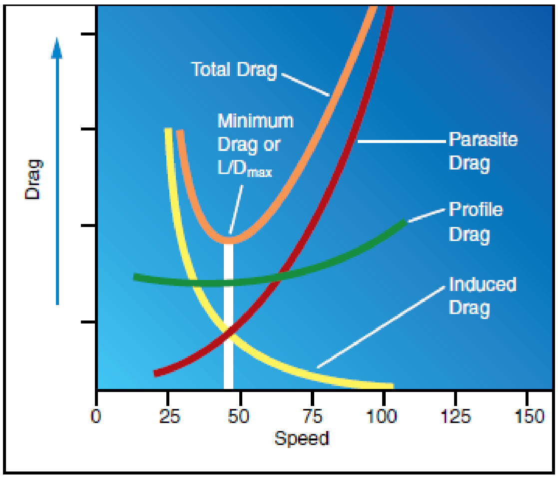


Fig. 1.3 Total drag and components

Thrust/Drag relationship
Now that thrust and drag have been described, we need to understand their relationship. When thrust is increased, speed is increased and as a result total drag increases. When the thrust force that is propelling the gyro forward equals the drag force acting to retard the gyro in the opposite direction, acceleration will cease and the gyro will stabilise at a higher speed. Ultimately then, once maximum thrust has been achieved at full throttle and the gyro has accelerated until such time as the drag causes acceleration to cease, the gyro has reached its maximum in-flight level speed. The opposite occurs when the thrust is reduced. Initial excessive drag will cause the gyro to decelerate until a speed is reached where the thrust force again equals the opposite drag force.

From the above, we now understand that thrust can be controlled by the pilot and drag is generated automatically, its value depending on the speed of the gyro which is determined by the thrust selected by the pilot.

Weight
Weight is simply the force acting vertically down on a body due to gravity. It is often referred to as "mass" and in this context the terms have the same meaning. The weight of an operational gyro generally is a definitive value that may be determined by adding together the weight of the empty gyro, the weight of its occupants and luggage and the weight of the fuel on board. Again in general, this will only change in flight when fuel is consumed.

Lift
Lift is the force (or component of a force) that is generated by the rotor system of a gyro that allows it to become airborne and remain so. From Fig.1.1, we see that lift opposes weight in the vertical plane and we know that when lift and weight are equal, the gyro neither climbs nor descends. It is most important to understand what affects lift and how it can be controlled.

Consider the following formula:

$$L = \frac{1}{2} \rho V^2 CL \llcorner a S$$

Where: L = Lift
½ ρ = ½ atmospheric pressure
V^2 = airspeed squared
CL = coefficient of lift
∟a = angle of attack
S = total airfoil surface area.

Knowing this formula, it is possible to eliminate those factors that remain constant during a given flight, thus leaving the variables that can be controlled by the pilot.

Atmospheric pressure will not change significantly, nor can it effectively be changed by the pilot during a given flight, so it may be ignored. The coefficient of lift is a figure that is attributable to the shape of the airfoil. In the strictest terms, the coefficient of lift also incorporates the angle of attack, but they have been deliberately separated for this exercise as will become obvious. The gyro pilot cannot change the shape of the airfoil during flight, so it too may be ignored. Similarly, the total surface area of a gyro rotor system cannot be altered in flight and so cannot be controlled by the pilot. From the previous discussion we learned that speed (in this case airspeed) can be controlled by the pilot by varying the throttle position and consequently thrust. So the ability to vary the airspeed in flight will affect the lift generated and this is controlled by the pilot. Angle of attack can be controlled by the pilot through the cyclic. By the process of elimination then, we find that the lift from the rotor system on a gyro can be controlled in flight by the pilot who can control speed and angle of attack.

Lift/Drag relationship
You will recall that the section on drag stated that induced drag can be controlled by the pilot in flight. The formula for calculating induced drag is very similar to the lift formula differing only in that instead of the coefficient of lift in the lift formula, the coefficient of drag is used in the drag formula. It also is determined by the shape of the airfoil and cannot be varied in flight. So we now realise that both lift and drag are controlled by the pilot in flight. An increase in either airspeed or angle of attack will increase both the lift and the drag of the rotor system and vice versa.
When the angle of attack reaches a point where the airflow can no longer flow smoothly over the airfoil section it starts to separate from airfoil surface. At this angle, lift begins to decrease rapidly, but drag continues to increase. This is not so much from induced drag anymore, but from form drag as the airfoil is tending to become more like the flat plate used as an example in the section on form drag. At this point, the airfoil is said to be stalled. It follows then that there must be an angle of attack that produces maximum lift for minimum drag, the best lift/drag ratio. We know that speed and angle of attack control both lift and drag so the relationship between these now is what determines the best lift/drag speed for the gyro. This speed may be determined mathematically, or as occurs more commonly in practice by flying at differing speeds to determine the maximum performance speed which produces the minimum total drag and the maximum lift. In practice,

climbing at the best lift/drag speed produces the maximum rate of climb available, whilst descending at the best lift/drag speed produces the minimum rate of descent.

AERODYNAMICS – GENERAL

As an airfoil moves through air, the cross-sectional shape of the airfoil causes the airflow to separate. Some air passes over and around the top surface of the airfoil, whilst some passes underneath the airfoil.

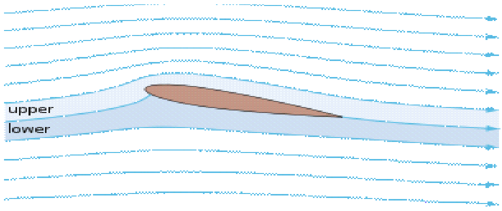


Fig. 2.1 Airflow

Referring to Fig. 2.1, let's consider two particles of air which are side by side before encountering the airfoil, one directly above the other. One passes over the top surface of the airfoil whilst the other passes below. These particles join company again after passing the airfoil. It can be seen then, that the upper particle must travel further than the lower one to achieve this. To do so it must increase speed. The laws of physics tell us that when the speed of an airflow increases due to it passing over an object, the pressure of this air decreases. This results in a differential air pressure between the upper and lower airfoil surfaces, the pressure below being greater than that above. In an attempt to equalise these pressures, the air below tries to join the air above resulting in the airfoil being "lifted" upwards. The magnitude of this lift force (lift vector) depends on many factors as explained in Chapter 1 (The Basics).

This phenomenon was discovered by a gentleman named Bernoulli who developed a theorem, or principle, often called the venturi effect. You will be aware that if water is passing through a garden hose such that it produces a solid column of water and the end of the hose is squeezed, the speed increases and the pressure decreases. (That's how you get the poop off your car isn't it?). This is the Venturi effect and can be illustrated as shown in Fig. 2.2.

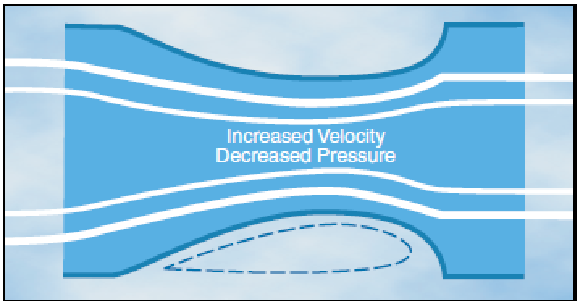


Fig. 2.2 The Venturi effect

Imagine the set-up in Fig. 2.2 is the end of the hose and the indentations that cause the restriction are your finger and thumb. If we substitute an airfoil section for the constricting force causing the bottom indentation, then replace the upper half of the venturi with layers of undisturbed air, the effect is the same. The air flows upwards and over the airfoil, the speed increases and the pressure decreases.

If this lifting force is a vector, then it must have direction as well as a value. The direction of the lift vector is always perpendicular (at an angle of 90*) to the relative air (airflow) affecting the airfoil. In normal straight and level flight, the airfoil of a gyro rotor system is inclined to the horizontal plane as indicated in Fig. 2.1. As the flight path is horizontal, it may be reasonable to expect that the airflow affecting the airfoil is also horizontal. However, this is not the case due to a factor called inflow. Inflow is the vertical component of the force that strikes the bottom of the airfoil because it is inclined at an angle of attack to the apparent airflow. Inflow also produces a small amount of lift.

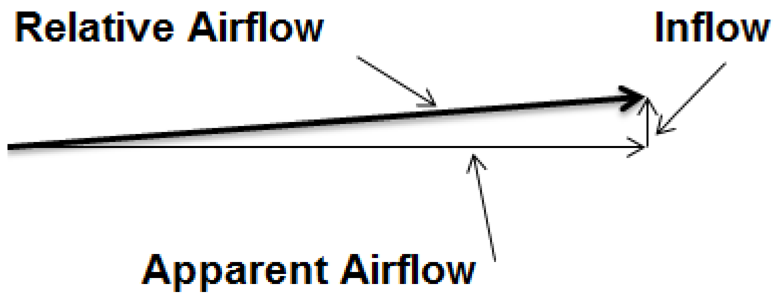


Fig. 2.3 Relative airflow high speed

Fig. 2.3 shows the relationship between these forces. The speed of the apparent airflow is that of the gyro through the air. Although not to scale, it is obvious that the speed of the inflow is much less and the change in angle between the apparent airflow and the relative airflow is small. Not that significant in this example, but if the speed of the apparent airflow was to decrease significantly, and the inflow remained the same, the angle between the apparent and relative airflows would be much greater. Refer Fig. 2.4.

Fig. 2.4 Relative airflow low speed

AERODYNAMICS – GYROPLANE

Disc regions

Part of the CASA definition of a gyroplane states that “it is supported in flight by the reaction of the air on one or more rotors which rotate freely on substantially vertical axes”. It is important that this “reaction of the air” be understood, together with how the rotors rotate freely without visible propulsion being applied to them.

From the definition of autorotation, there must be air passing up through the rotor system for this to occur. It follows then, that in straight and level flight, the rotor disc must be inclined to the flight path, thus allowing air to pass upward through the system. This will also occur if the gyro is in a vertical descent. As long as air is passing upwards through the rotor system, autorotation will happen.

Let’s consider a plan view of the rotor disc in a vertical descent.

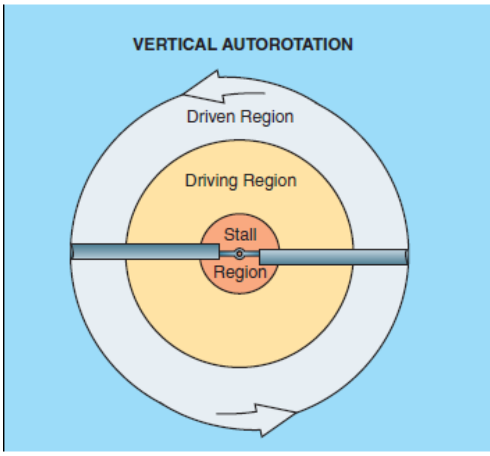


Fig. 3.1 Disc regions

There are three distinct disc areas or regions as shown in Fig. 3.1. The driving area comprises about 70% of the disc area and includes a small area surrounding the axis of rotation known as the “stalled region”. This area, because of the manner in which the air flows around the airfoils within it, contributes nothing to either the driving forces or the lifting forces, but contributes to the drag associated with the rotor system. This area also includes the hub-bar which is not an airfoil section. The outer 30% is driven by the driving area and produces almost all of the lift attributable to the rotor disc.

The rotor blades on a gyro rotate anti-clockwise when viewed from above. The rotational speed at each point along the blade will vary, being fastest at the rotor tip, and slowest at the innermost point. So the average rotational speed of the driving area will be less than that of the driven area. By referring to figures 2.2 and 2.3 in Section 2, it can be seen that the relative airflow in the low speed area has a greater angle of attack than that of the high speed area, primarily because the relative airflow direction is determined by the speed of the apparent airflow together with the inflow.

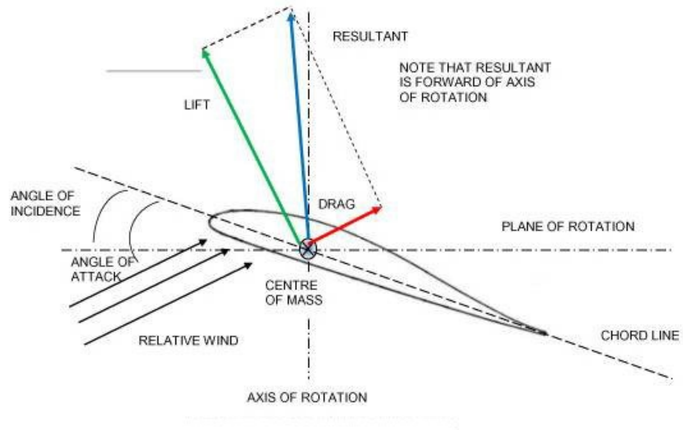


Fig. 3.2 Forces in the driving area

Fig. 3.2 depicts the forces acting on the airfoil in the driving area. Note that the lift generated is perpendicular to the relative air, drag acts perpendicular to the lift vector and the resultant is the total aerodynamic force (TAF) acting on the airfoil. Notice also, that the TAF is acting forward of the axis of rotation, thus causing the airfoil to accelerate forwards.

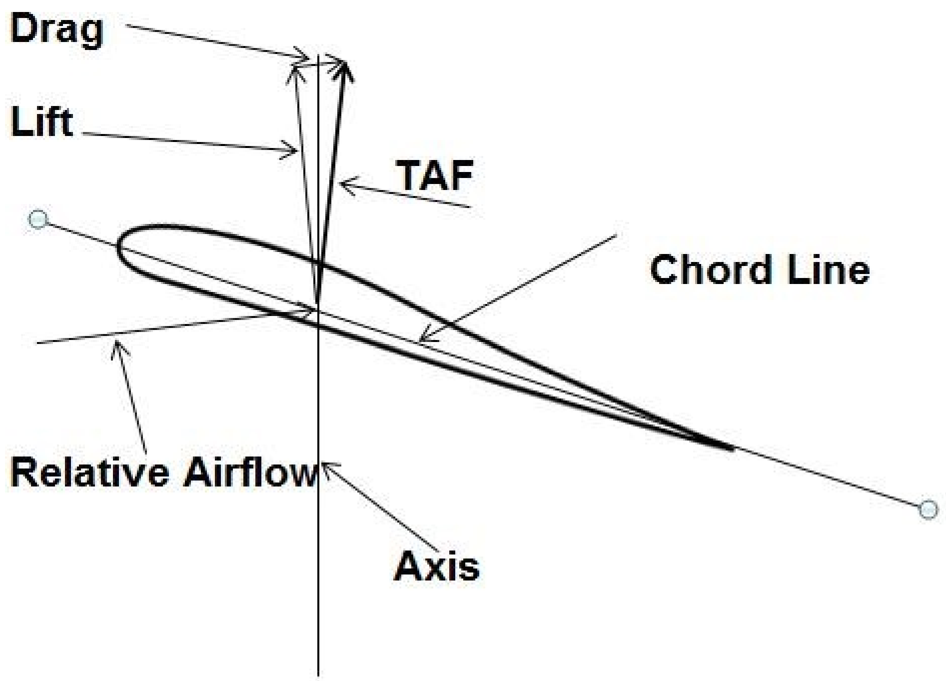


Fig. 3.3 Forces in the driven area

In Fig. 3.3 we see that the angle of attack of the relative airflow has decreased due to the higher rotational speed in that area. As a result, the TAF now acts aft of the axis of rotation. This causes a decelerating force that is now opposing the accelerating force of the driving area and as a result, the rotor speed self governs. Notice also from Fig. 3.3 that the lift vector in the driven area is more vertical than it is in the driving area. This contributes the most lift between the two areas. Due to the higher rotational speed in this driven area, the lift vector is also greater than it is in the driving area (Lift = V^2).

Dissymmetry of lift
We must now consider what happens to the disc areas when the gyro moves forward as in normal flight. Refer to Fig. 3.4. This is a snapshot of a gyro rotor system in normal forward flight. To differentiate between each blade as they rotate, the blade that occupies the semi-circle on the right-hand side of the centre-line of the gyro is termed the “advancing blade” as it is advancing into the oncoming airflow. Conversely, the blade on the left-hand side is moving away from the oncoming airflow and is termed the “retreating blade”.

From Fig. 3.4 it can be seen that when forward flight is introduced, the driving area of the disc moves further towards the retreating blade, taking the stalled area with it. As a result, the driven area on the advancing blade side is larger than that on the retreating blade side and will produce more lift. So, if there is more lift on the advancing blade side than there is on the retreating blade side, the rotor disc and the attached gyro will roll to the left at a rate commensurate with the lift differential. This differential is termed “dissymmetry of lift”.

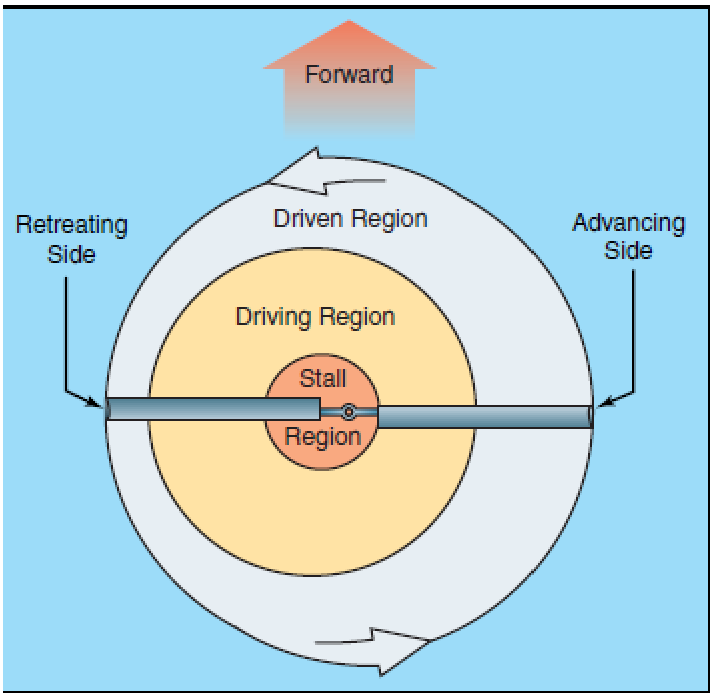


Fig. 3.4 Forward flight

Let’s consider a theoretical situation to illustrate dissymmetry of lift.

Assume that the rotational speed of the rotor system is 250 knots, and the gyro is moving forward at a speed of 50 knots. The speed of the airflow experienced by the advancing blade at the position shown in Fig. 3.4 will be 300 knots (rotational speed + forward speed), whereas, the speed experienced by the retreating blade opposite will be 200 knots (rotational speed – forward speed). We have learned that lift is proportional to speed squared, so there will be significantly more lift produced on the advancing blade side than that on the retreating blade side.

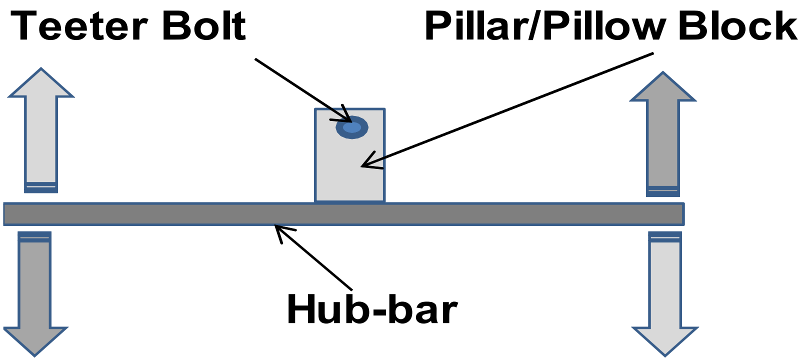


Fig. 3.5 Teetering

To eliminate the dissymmetry of lift, a system was developed that allowed the hub-bar, with attached rotor blades, to teeter or seesaw about a pivot or hinge point as shown in Fig. 3.5. In practice, when a blade becomes the advancing blade, it generates more lift than the retreating blade and thus will move upwards, teetering around the teeter bolt; and, the retreating blade will move downwards. How is it then, that dissymmetry of lift is eliminated?

We have learned that lift in a gyro is controlled by speed and angle of attack. It is not possible to change the speed of the advancing blade without a corresponding change to the speed of the retreating blade, so speed cannot be used to change the uneven lift between the advancing and retreating blades.

Let's consider angle of attack. Recall that angle of attack is the angle between the chord line of the airfoil and the relative airflow affecting it and the relative airflow is determined by the apparent airflow and the inflow. If either changes, so too does the relative airflow.

The advancing blade moving upwards is still subjected to apparent airflow and inflow. However, this upward movement reduces the inflow vector which changes the direction of the relative airflow and therefore reduces the angle of attack and lift generated.

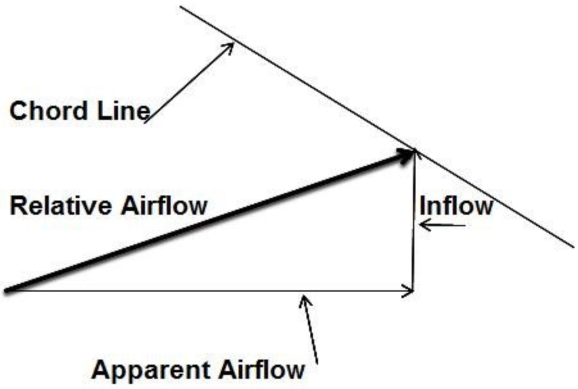


Fig. 3.6 Static

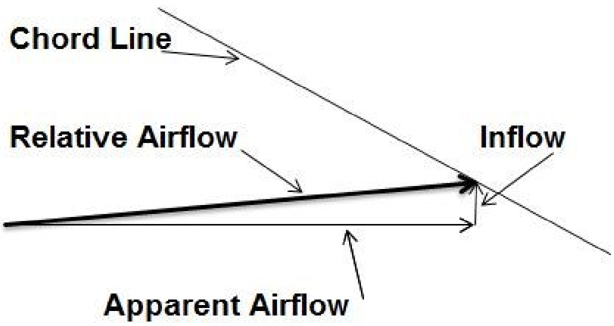


Fig. 3.7 Advancing blade

Fig. 3.6 represents a situation where the airfoil is static. Note the angle of attack. In Fig. 3.7, the airfoil is moving upwards which reduces the inflow effect, the direction of the relative airflow and the angle of attack. Lift is therefore reduced.

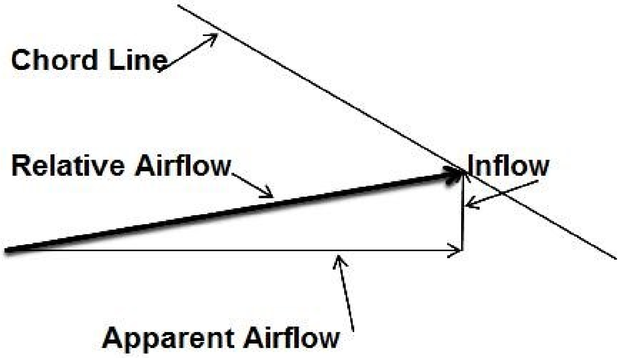


Fig. 3.8 Retreating blade

Just as the advancing blade develops more lift, the retreating blade develops less. It is however moving downwards, opposite to the advancing blade. This has the effect of increasing the effect of the inflow as shown in Fig. 3.8, increasing the angle of attack and therefore the lift produced.

So now we have the lift on the advancing blade being reduced and the lift on the retreating blade being increased. In this manner, dissymmetry of lift is eliminated.

Coning angle
When a gyro is on the ground at rest, it can be seen that the rotor blades droop downwards. This is due to the weight of each blade and the fact that the blades themselves are flexible. See Fig. 3.9.

Fig. 3.9 Blades at rest

In flight however, the blades actually bend upwards because they produce lift that is supporting the total weight of the gyro. See Fig. 3.10.

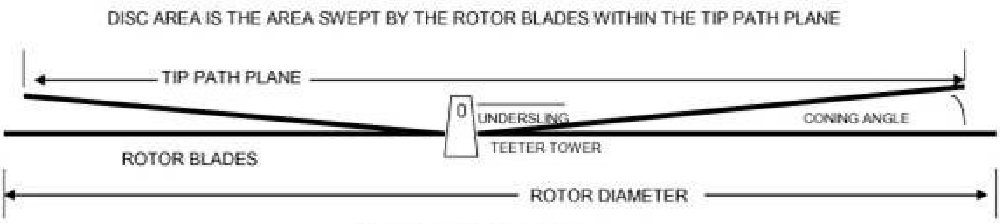


Fig. 3.10 Blades in flight

The angle at which they bend upwards is termed the "coning angle". The reason for coning is that lift generated by each blade acts through the centre of mass of each blade and the centre of mass is located some distance outboard from the axis of rotation. Logically, this would tend to continue to bend the blades upwards until they snap. However, this force is countered by the "centrifugal force" which is defined as the force exerted outwards by a body (mass or weight) moving in a curved path. The centrifugal force can be demonstrated by hanging a weight from a piece of string about 500 mm long. At rest the weight hangs straight down. Rotating the weight via the string causes the weight to move upwards and outwards by an amount that is proportional to the speed of rotation. This is centrifugal force (try this for yourself). So, as the blades of a gyro rotate, they move from a drooping state to one that is level with the plane within which they are rotating. As the speed increases, lift is generated and the blades want to flex upwards. This however is countered by the centrifugal force which resists the upward flexing. Remember here, that in stable flight the lift generated is equal to the total weight of the gyro. Thus, coning angle is the angle between the plane of rotation of the blades (tip path plane) and a line extending from the axis of rotation to the tip of a blade. The actual measured angle results from a balance between the weight of the gyro and the centrifugal force acting on the blades. See Fig. 3.11.

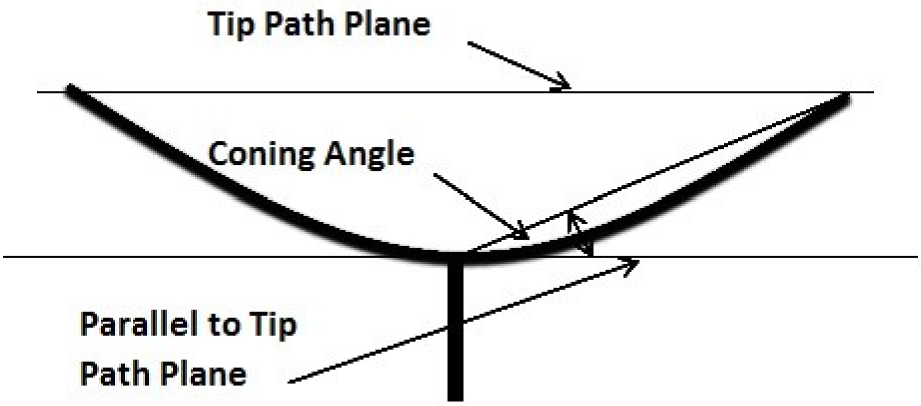


Fig. 3.11 Coning angle

Rotor thrust vector

We have learned that in flight, the rotor blades may be considered to be a disc. Let's look at this disc in more detail remembering that the cord line of the disc may be represented by the tip path plane of the rotor blades forming the disc.

In normal flight, the rotor disc is always inclined to the flight path and therefore the relative airflow affecting the disc. It is generally in the vicinity of 9 degrees but the actual measurement is immaterial and not important in this exercise. See Fig. 3.12.

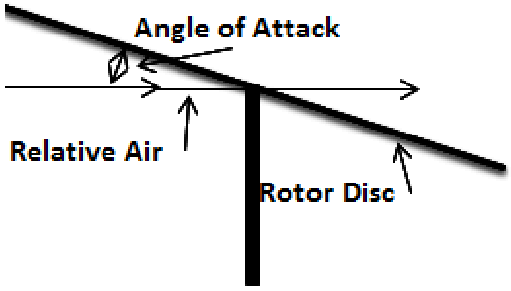


Fig. 3.12 Rotor disc in flight

We know that the TAF generated by the disc will be at 90 degrees to the chord line of the disc. See Fig. 3.13.

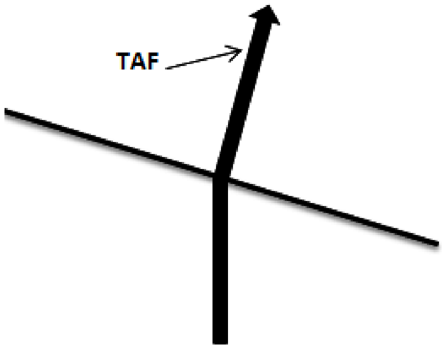


Fig. 3.13 Disc total aerodynamic force

This total aerodynamic force is also referred to as the rotor thrust vector as it is the total thrust or force generated by the disc.
As it is a vector, it can be separated into one or more components. For our purposes we'll consider the components that act in our old friends, the horizontal and vertical planes, remembering that lift is the component acting in the vertical plane and drag is acting in the horizontal plane. Refer to Fig. 3.14.

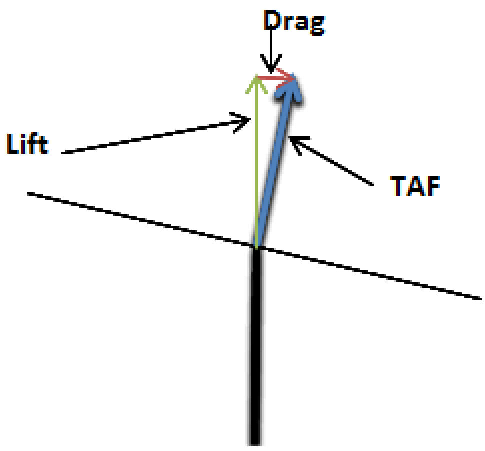


Fig. 3.14 Components of total aerodynamic force

It can be seen that when the disc angle of attack is small, the lift component is large and the drag component is small. However, if we increase the angle of attack of the disc, lift lessens and the drag increases. See Fig. 3.15.

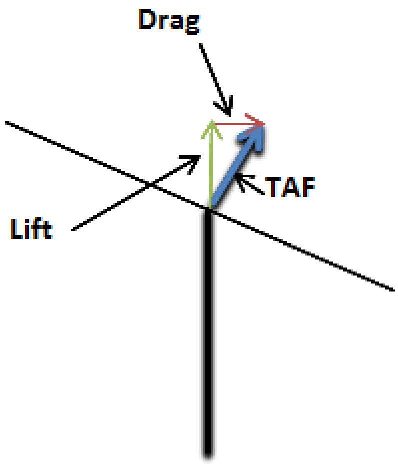


Fig. 3.15 Components of total aerodynamic force

This becomes significant during takeoff and landing when the drag component tends to rotate the gyro backwards around the main wheel axles. If we consider the drag to act through the centre of the hub-bar, this creates a clockwise moment about the main wheel axles (Fig. 3.16). The size of this moment is the force being applied multiplied by the distance from the axis (or axle in this case). This is the same principle that a torque wrench uses. So, in Fig. 3.16 it can be seen that the drag vector acting horizontally backwards creates a clockwise moment about the main wheel axles. Opposing this is the weight of the gyro acting through the centre of mass of the gyro. As this force is vertically downwards and is forward of the main wheel axles, it creates an anti-clockwise moment about the main wheel axles. These are the only two significant forces in play at this time. Therefore the gyro will remain on the main and nosewheel until the drag vector increases to the extent that the clockwise moment of the drag vector exceeds the anti-clockwise moment of the weight, at which point the gyro will rotate aft about the main wheel axles causing the keel to pitch up. This is what happens during takeoff as the rotor blades “load up” (produce more total aerodynamic force). The keel pitch up is limited by the tailwheel of the gyro riding on the ground. The gyro may remain in this attitude until the drag vector equals the thrust of the drive unit when acceleration will cease. In extreme conditions, it is possible for the gyro to rotate about the tailwheel as a result of the increasing drag moment. This is undesirable and pilots are taught during their training how to prevent this situation.

On landing, provided the cyclic is moved fully aft gently, it is possible to use the drag vector as a kind of speed brake. With little thrust being produced and the rotors still generating a large total aerodynamic force, gently moving the cyclic aft will cause the disc angle of attack to increase. This results in the drag vector increasing significantly, thus rotating the gyro aft onto the tailwheel. Again, in extreme cases, the gyro may continue to rotate about the tailwheel. Techniques will be taught to counter this undesirable possibility.

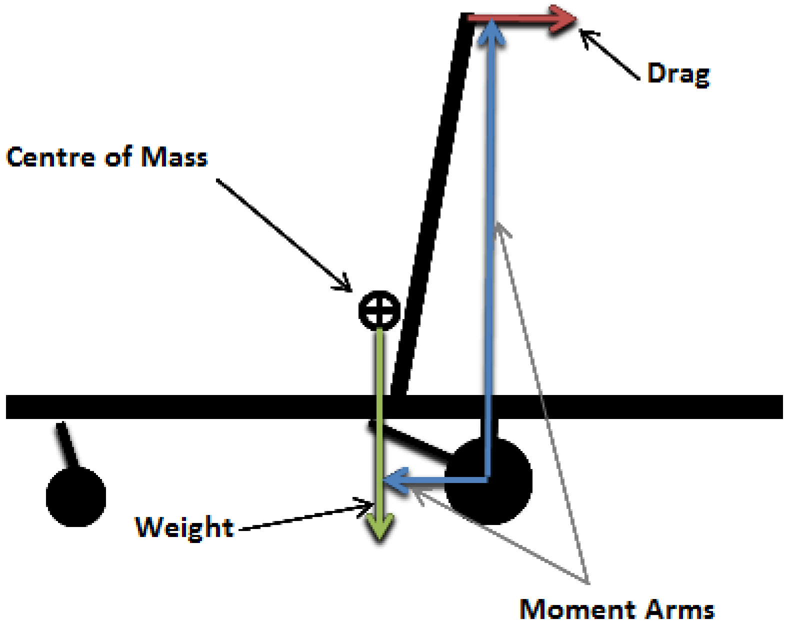


Fig. 3.16 Moments about wheel axles on ground

Angle of incidence
Angle of attack was covered in Chapter 1 (The Basics) and now we'll investigate "angle of incidence". Originally, angle of incidence was called "the riggers angle of incidence" and referred to the early days in aviation when the "rigger" attached the wings to an aeroplane at a specific angle to a nominated datum or reference, usually the horizontal plane. The rigger could change this angle to optimise performance for specific tasks. As an example, an aeroplane operating such that the majority of the flights were heavy weight climbs followed by descent to a nearby destination would likely be rigged for maximum climb performance by adjusting the angle of incidence. Conversely, an aeroplane that spent most of the time operating long cruising flights would be rigged to optimise its cruise performance, at some penalty to the climb performance. Note that this angle of incidence cannot be altered by the pilot in flight as the angle of attack can be.
Well you may ask "what is the significance of this to a gyro?". The rotor blades are attached to the hub-bar via blade straps which are merely strips of metal bolted to both the blades and the hub-bar. Careful inspection of an assembled set of rotor blades will reveal that the cord line of the each blade is inclined slightly relative to the flat upper and lower surfaces of the hub-bar itself (Fig. 3.17). This slight inclination is known as the "angle of incidence" of the rotor blades and it cannot be altered by the pilot in flight. Different manufacturers rig this angle using various methods including pitch wedges and actually twisting the hub-bar. The method and actual angle is at the discretion of the manufacturer.

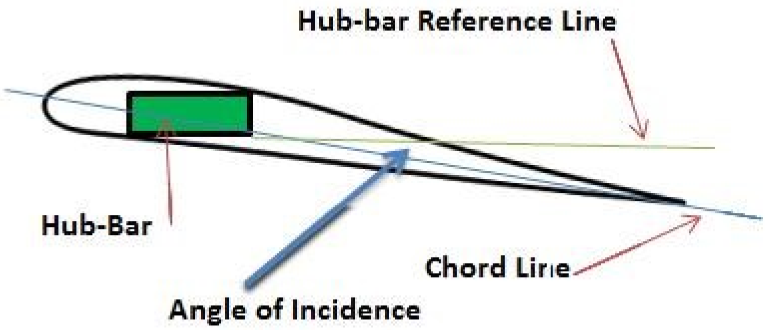


Fig. 3.17 Angle of incidence

Gyroplane controls
The controls of a gyroplane allow the pilot to manoeuvre the gyro in three different planes, one horizontal and two vertical, the latter being at right angles to each other. The horizontal plane is referred to as the yawing plane. The pitching plane is one of the vertical planes that passes through the keel of the gyro, whilst the rolling plane is the other vertical plane that is orientated at right angles to the pitching plane (Fig. 3.18).

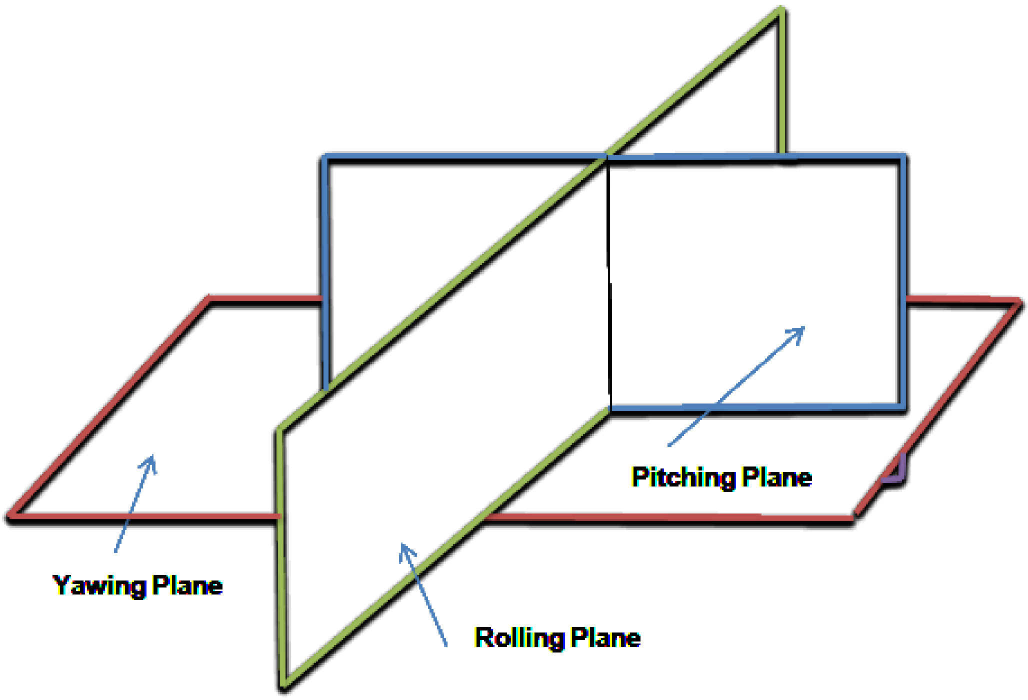


Fig. 3.18 Planes of control

In normal flight, control in the yawing plane is normally effected by using rudder pedals which are installed such that depressing the left rudder pedal will cause the rudder to deflect to the left and the gyro to yaw to the left. The opposite occurs when the right rudder pedal is depressed. As the rudder is an aerodynamic surface, there must be airflow over the rudder for it to be effective. Control in both the pitching and rolling planes is effected by manipulation of the cyclic control. In order to understand how this occurs, it is necessary to understand the characteristics of a gyroscope. A gyroscope is an apparatus consisting of a rotating wheel so mounted that its axis can turn freely in all directions and is capable of maintaining the same absolute direction in space despite movements of the mountings and surrounding parts. Put simply, the axis of the rotating wheel of a gyroscope will continue to point towards the same point in space despite the movements of its mounting mechanism. Fig. 3.19 depicts a basic gyroscope. By definition, regardless of the movement of the gyroscope frame, the spin axis will remain aligned vertically.

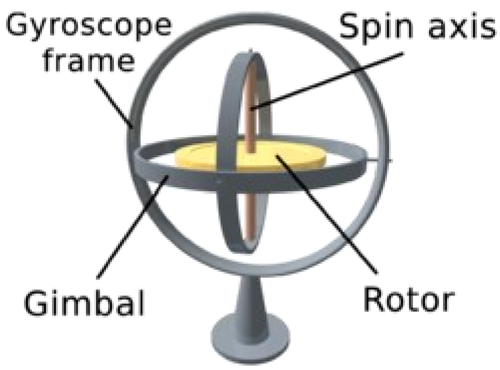
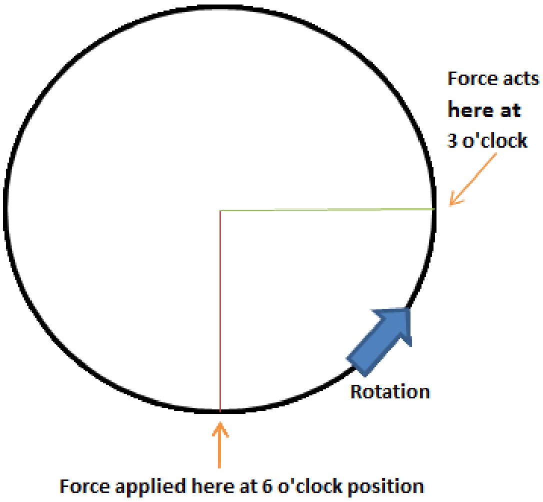


Fig. 3.19 Typical gyroscope with gimbal

The rotor of a gyroscope exhibits an unusual characteristic known as "precession". Precession means that when a force is applied directly to the spinning rotor of a gyroscope, this force acts at a point 90 degrees away from the point at which it was applied, in the direction of rotation of the rotor.

In Fig. 3.20, if we imagine that that nearest point of the rotor disc to us is the 6 o'clock position and the disc is rotating anti-clockwise, a force applied at this point on the disc will not have effect until that point reaches the 3 o'clock position. It is this feature that allows motorbike riders to turn corners at speed simply by leaning the bike one way or the other. Imagine the motorbike being viewed from the right-hand side. The front wheel is rotating clockwise. When the bike is leaned to the left for example, a force is applied to the top of the wheel in a direction away from us. This force affects the wheel 90 degrees from where it was applied in the direction of rotation. This causes the wheel, or more correctly the axis of the wheel, to rotate left, thus executing a left-hand turn.



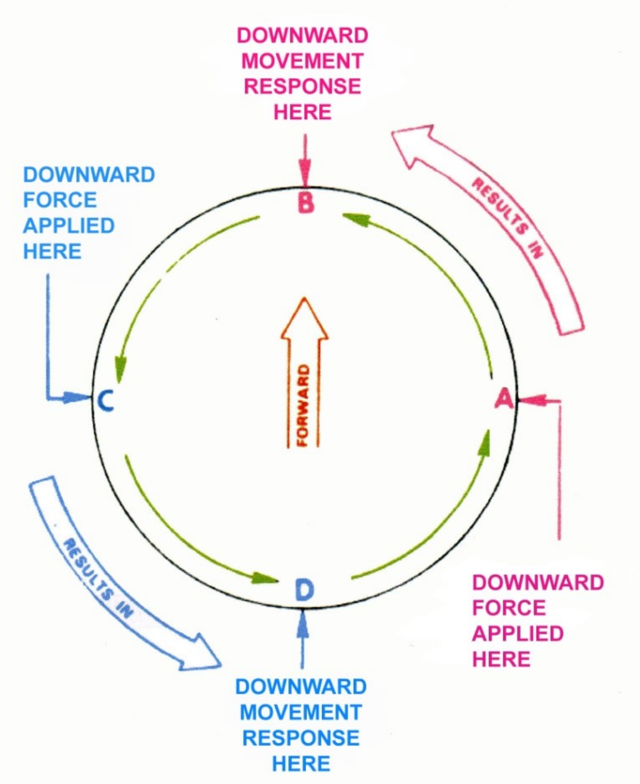


Fig.3.20 Gyroscopic precession

Again you may well ask “what has this to do with gyroplanes”? In flight the rotor disc is a rotating body and by definition must have the characteristic of a gyroscope rotor. There is no complicated gimbal arrangement associated with a gyro rotor, but it does have an axis of rotation that is fixed via the torque tube to the rotor head. When movement is imparted to the head via the cyclic, the head together with the components attached to the head move in the commanded direction. The rotor blades are attached to the head via the hub-bar, so they too will move resulting in aerodynamic forces being applied to the rotor.

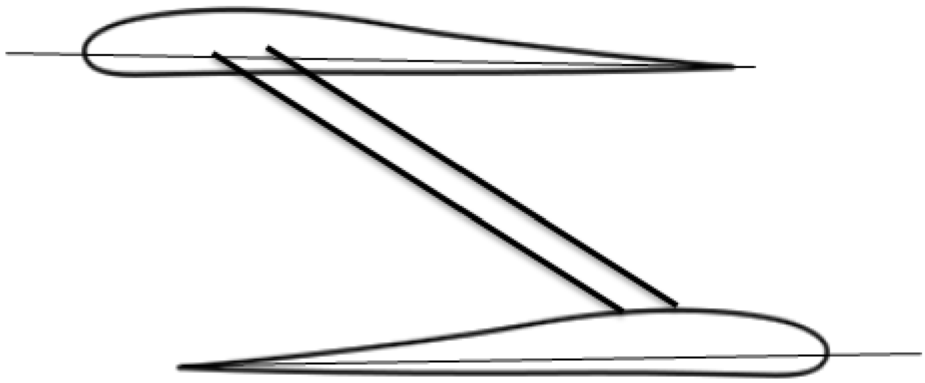


Fig.3.21 Rotor tips centralised cyclic

Fig. 3.21 represents the tips of the rotor blades joined by the parallel lines which represent the remainder of the blades and hub-bar. This view is from the rear of the rotor system looking forward, so the closest tip is in the 6 o’clock position. Rotation direction is standard anti-clockwise. When the cyclic is moved to the left, the rotor head tilts left causing the tips to move in the directions shown in Fig.3.22.

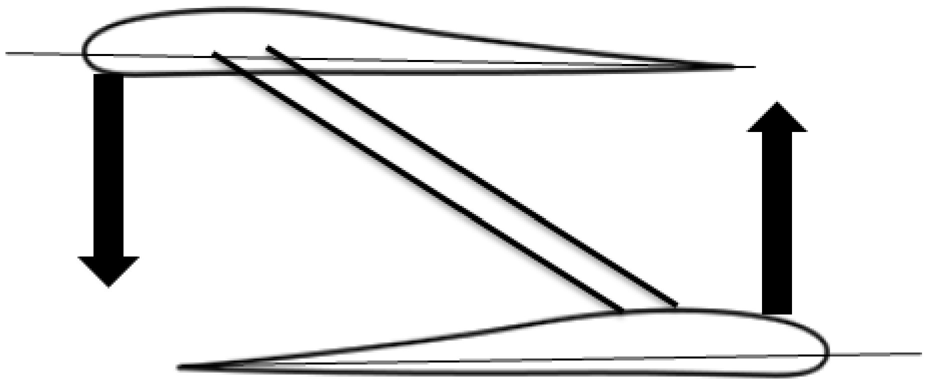


Fig. 3.22 Rotor tip movement with cyclic left

This results in an increase in angle of attack on the closer blade tip, and a decrease in angle of attack of the furthest blade tip. We know that an increase in angle of attack results in an increase in lift and vice versa, so the closest blade wants to rise and the furthest blade wants to descend. We also know that this force will not act on this rotating body until 90 degrees removed from the point of application of the force in the direction of rotation. In other words, the 3 o’clock position. When the force finally acts, it causes the entire rotor system to tilt left and the gyro to which it is attached turns left.
In a similar fashion, with the blades in the 3 o’clock/9 o’clock position, moving the cyclic forward or aft will impart aerodynamic forces to the disc, these acting when the tips reach the 12 o’clock/6 o’clock position, causing the rotor system to tilt forward or aft and the gyro to descend or climb.

GYROPLANE FLIGHT INSTRUMENTS

General

There are only three mandatory flight instruments required for gyroplanes listed with ASRA, these being a yaw indicator, an altimeter and an airspeed indicator. This section will deals with these instruments. The operators of gyroplanes fitted with additional flight instruments are encouraged to become familiar with their required inputs, expected outputs, indications of failure and the potential errors associated with each.

Yaw indicator

The yaw indicator provides a means by which to tell the direction and in some circumstances, the approximate strength of the relative airflow affecting the gyroplane. During ground operations, it provides an indication of the actual wind blowing at the time, provided that the gyro is motionless. During ground manoeuvring, the indicator shows the relative airflow affecting the gyro and is useful for rotor management techniques.

Most yaw indicators consist of a piece of wool or similar material affixed to a vertical post that is aligned within the pilot's line of vision on the centre-line of the gyro. In many cases, the vertical post is a radio antenna. It is essential that the yaw indicator be located in clean, undisturbed air in order to be effective. In flight, the yaw indicator provides an indication of whether or not the gyro is flying in balanced flight, that is, it is not slipping or skidding. Balanced flight produces the least drag and is essential for efficient flight. Balanced flight occurs when the yaw indicator is aligned with the fore and aft axis of the gyro. Where this does not occur, rudder input is necessary to return the gyro to balanced flight. Fig. 4.1 shows a typical yaw indicator installation.

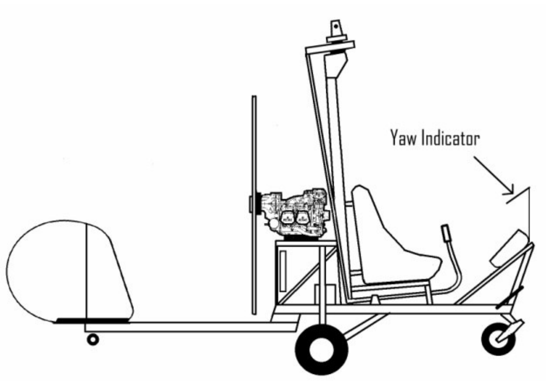


Fig. 4.1 Yaw indicator

Airspeed indicator (ASI)

The ASI displays the speed of a gyroplane through the air by comparing ram air pressure with static air pressure — the greater the pressure differential, the greater the airspeed. Ram air pressure is normally taken from a pitot tube which is a rigid tube aligned with the direction of the wind affecting the gyro in flight. Static pressure is measured at a source on the gyro that is unaffected by the airflow around or over the gyro and its location is critical if an accurate airspeed is desired.

The pitot tube is connected to a diaphragm within the casing of the ASI by tubing. The otherwise sealed case is then connected to the static source. As the airspeed increases, the diaphragm expands because the ram or pitot pressure exceeds the static pressure surrounding it. This movement of the diaphragm is transferred by mechanical linkages to the face of the ASI where the differential pressure is displayed by a needle overlying a scale. The scale may be calibrated in knots, miles per hour, kilometres per hour of a combination of these three. Australian aircraft including gyroplanes must have the ASI dial marked in knots. The ASI now displays indicated airspeed (IAS).

Air pressure is affected by both ambient temperature and pressure (altitude). However, as the pressures being sensed lie in the same parcel of air, any changes due to temperature or pressure are sensed by both the pitot and the static sources. When an IAS is given for a particular situation, that speed is used without making corrections for temperature or altitude. Fig. 4.2 shows a typical ASI.

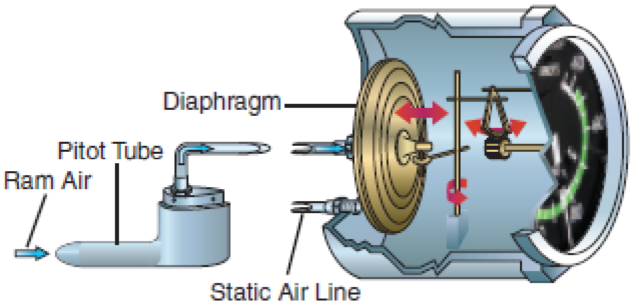


Fig. 4.2 Cutaway view of typical airspeed indicator

Pre-flight checks
Pre-flight checks for the ASI should include a check of the pitot and static sources to ensure that they are free of foreign materials that may inhibit the normal function of the instrument. Common contaminants include insects and their nests, water, dust and the like. In still conditions on the ground, the ASI should read 0. Early in the takeoff run, the ASI should be checked to ensure that it is increasing as power is applied. If this is not the case, the takeoff should be abandoned and the lack of IAS investigated.

Errors
Errors in the ASI are most commonly caused by poor sighting of the pitot and/or static sources or contamination in the pitot and/or static lines. The latter can be reduced by using suitable covers that prevent contaminants entering the system while the gyro is not in use. When in use, these covers should be highly visible so as to be obvious during a pre-flight inspection. Many commercially available covers incorporate long tapes of a conspicuous colour that include a warning to remove the cover before flight.

Many basic systems use the inside of a cockpit enclosure as the static source. Inevitably, this results in an IAS that is higher (up to 15 knots) than it really is. The cause is that in flight, the air separating to pass around the enclosure creates a vacuum inside the enclosure which is reflected at the static source as a lower-than-normal static pressure. The higher the actual airspeed, the greater the error will be. Careful sighting of the static source will eliminate this error.

Contamination of the pitot system is commonly caused by insects and their nests. This is most common when covers are not fitted to the pitot tube. Such contamination manifests itself during takeoff when increasing air pressure is not being transferred to the ASI due to the contamination. At best, the IAS will be low and often erratic. When the pitot system is totally blocked, the IAS will increase with increasing altitude. Persistent operation of a system contaminated in this manner may result in damaging the ASI as contaminants are forced into the instrument itself.

A blockage of the static line does not become obvious until the gyro climbs to altitude because the pressure trapped in the static line is the same as at the takeoff position and cannot reduce with altitude as it should. This results in a steady decrease in IAS with altitude. This is due to the pitot pressure decreasing because of the thinner air at altitude and the static source still measuring the pressure at the departure point. Over the years such blockages on airliners have resulted in crashes and many fatalities.

The early recognition of these errors will lead to rectification of the problem before a serious in-flight situation arises.

Altimeter
An altimeter senses atmospheric pressure and displays this in feet on a suitably graduated scale. The scale may be graduated in metres but Australian aircraft are required to use altimeters that are graduated in feet.
The only input into an altimeter is static pressure. This pressure is fed into the airtight case of the altimeter which contains a sealed aneroid capsule that expands and contracts with changes in atmospheric pressure. Mechanical connections between the aneroid capsule and the indicating pointers transmit the movements of the capsule to the pointers. The basis for the calibration of an altimeter is the international standard atmosphere (ISA), a theoretical idealistic atmosphere where temperature, pressure and changes to these have standard values. As the actual atmosphere is rarely the same as ISA, the altimeter incorporates an altimeter setting adjustment knob that is used to adjust for changes in actual atmospheric pressure both before and during flight (Fig. 4.3).

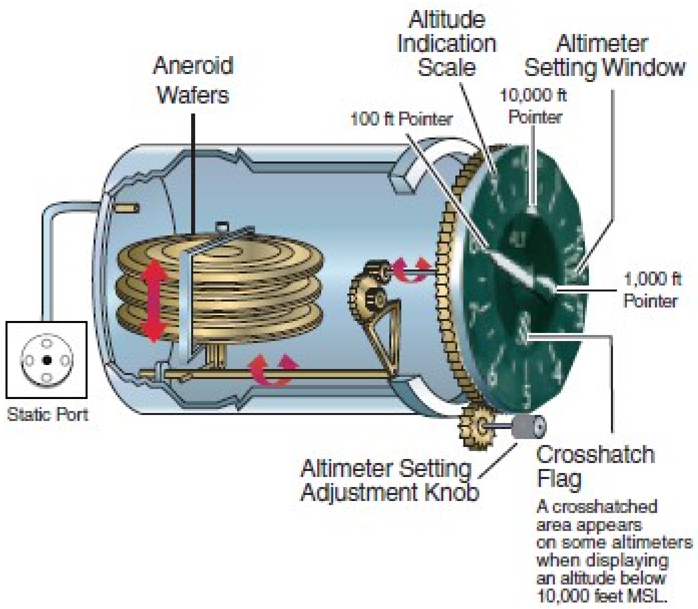


Fig. 4.3 Cutaway view of typical sensitive altimeter

The altimeter setting knob is used in conjunction with the altimeter setting window, also known as the altimeter sub-scale. This window dispalys a scale graduated in hectopascals. Rotating the setting knob moves the pointers on the face of the instrument and the display in the window. This compensates for variations between the actual atmosphere and ISA. Changing the altimeter setting window indication by 1 hectopascal changes the altimeter reading by approximately 30 feet.

Although there are several datums (references) that may be used in aviation, gyroplane operations normally use QNH which means “barometric pressure adjusted to sea level”. Thus the normal datum for gyro operations is sea level. When the sub-scale is set to the atmospheric pressure of the airfield, the altimeter will display the airport elevation above sea level. Alternatively, if the airfield elevation is known, adjusting the altimeter to read this figure will display the atmospheric pressure at the airfield at that time in the sub-scale window. As a general rule, the atmospheric pressure at any given point will be valid within a 100 NM radius of that point.

Broadly speaking, there are two types of altimeters used in gyro operations, sensitive and non-sensitive. A non-sensitive altimeter usually incorporates only one pointer on its face that indicates on a scale of 1 to 10,000 feet. They may incorporate an altimeter setting window. Sensitive altimeters use three pointers which indicate hundreds, thousands and tens of thousands of feet. They will always incorporate an altimeter setting knob and window and are calibrated up to 20,000 feet. Sensitive altimeters can be read more accurately and are the preferred of the two.

Pre-flight checks

In order to check the servicability of an altimeter before takeoff, it is necessary to know the atmospheric pressure and the airfield elevation. When the atmospheric pressure is set in the sub-scale window, an altimeter is considered servicable if it reads airfield elevation +/– 75 feet.

Errors

Errors are usually caused by a blocked static source or failure of the internal mechanical components. A blocked static source will manifest it by failing to register an increase in altitude as the gyro climbs. Mechanical failures may be indicated by the sluggish operation of the pointers or failure of the adjusting knob to move the pointers and/or the sub-scale. Such failures require expert knowledge to rectify and should not be attempted without that knowledge.

Pitot/Static system

The pitot/static system refers to the lines that transmit pressure data to the ASI and altimeter. The pitot line is connected to the ASI only, whereas the static line is connected to both. It is common to use one static line from the source to the vicinity of the instruments, then split the line to feed both instruments. Therefore, a fault in the static line will manifest in both instruments. A low or erratic airspeed alone may indicate a blocked or partially blocked pitot line, whereas a blocked static line will show as no increase in altitude during a climb and decreasing IAS as the gyro climbs.

When internal contamination for the pitot or static lines is suspected, compressed air is often used in an attempt to clear the contamination. In this case, the lines must be removed from the instruments and the compressed air applied at these ends of the line. Blowing compressed air from the opposite direction may lead to serious internal damage to either or both instruments.

GYROPLANE PERFORMANCE

General

There are many factors that affect the performance of a gyroplane: pilot techniques and ability, takeoff weight, propeller thrust, atmospheric pressure, atmospheric temperature, airfield surface, surface gradient (slope), humidity and ambient wind. Each will be discussed in turn but first we should establish a datum (reference or standard) by which to measure performance.
If the entire surface of the earth was at the same elevation and the temperature and atmospheric pressure were also equal, these same conditions would affect the performance of all gyros regardless of where on the surface they were located. As we know, this is not the case as all three of the above varying depending on the location. In order to create a “level playing field” as such, a hypothetical standard atmosphere was created together with formulae by which to convert actual ambient conditions to the same standard. This hypothetical atmosphere is known as the “international standard atmosphere” (ISA). Refer to Fig. 5.1.

ALTITUDE		TEMP.	PRESSURE		PRESSURE RATIO	DENSITY	SPEED OF SOUND
(Feet)	(Meters)	(℃)	(hPa)	(in. Hg.)			(kt)
40,000	12,192	-56.5	188	5.54	0.1851	0.2462	573
39,000	11,887	-56.5	197	5.81	0.1942	0.2583	573
38,000	11,582	-56.5	206	6.10	0.2038	0.2710	573
37,000	11,278	-56.5	217	6.40	0.2138	0.2844	573
36,000	10,973	-56.3	227	6.71	0.2243	0.2981	573
35,000	10,668	-54.3	238	7.04	0.2353	0.3099	576
34,000	10,363	-52.4	250	7.38	0.2467	0.3220	579
33,000	10,058	-50.4	262	7.74	0.2586	0.3345	581
32,000	9,754	-48.4	274	8.11	0.2709	0.3473	584
31,000	9,449	-46.4	287	8.49	0.2837	0.3605	586
30,000	9,144	-44.4	301	8.89	0.2970	0.3741	589
29,000	8,839	-42.5	315	9.30	0.3107	0.3881	591
28,000	8,534	-40.5	329	9.73	0.3250	0.4025	594
27,000	8,230	-38.5	344	10.17	0.3398	0.4173	597
26,000	7,925	-36.5	360	10.63	0.3552	0.4325	599
25,000	7,620	-34.5	376	11.10	0.3711	0.4481	602
24,000	7,315	-32.5	393	11.60	0.3876	0.4642	604
23,000	7,010	-30.6	410	12.11	0.4046	0.4806	607
22,000	6,706	-28.6	428	12.64	0.4223	0.4976	609
21,000	6,401	-26.6	446	13.18	0.4406	0.5150	611
20,000	6,096	-24.6	466	13.75	0.4595	0.5328	614
19,000	5,791	-22.6	485	14.34	0.4791	0.5511	616
18,000	5,486	-20.7	506	14.94	0.4994	0.5699	619
17,000	5,182	-18.7	527	15.57	0.5203	0.5892	621
16,000	4,877	-16.7	549	16.22	0.5420	0.6090	624
15,000	4,572	-14.7	572	16.89	0.5643	0.6292	626
14,000	4,267	-12.7	595	17.58	0.5875	0.6500	628
13,000	3,962	-10.8	619	18.29	0.6113	0.6713	631
12,000	3,658	-8.8	644	19.03	0.6360	0.6932	633
11,000	3,353	-6.8	670	19.79	0.6614	0.7156	636
10,000	3,048	-4.8	697	20.58	0.6877	0.7385	638
9,000	2,743	-2.8	724	21.39	0.7148	0.7620	640
8,000	2,438	-0.8	753	22.22	0.7428	0.7860	643
7,000	2,134	1.1	782	23.09	0.7716	0.8106	645
6,000	1,829	3.1	812	23.98	0.8014	0.8359	647
5,000	1,524	5.1	843	24.90	0.8320	0.8617	650
4,000	1,219	7.1	875	25.84	0.8637	0.8881	652
3,000	914	9.1	908	26.82	0.8962	0.9151	654
2,000	610	11.0	942	27.82	0.9298	0.9428	656
1,000	305	13.0	977	28.86	0.9644	0.9711	659
0	0	15.0	1013	29.92	1.0000	1.0000	661
-1,000	-305	17.0	1050	31.02	1.0366	1.0295	664

Fig. 5.1 International standard atmosphere table

The second bottom line represents mean sea level (MSL). The table shows that the standard MSL temperature is 15*C and the pressure is 1013 hPa. (hectopascals and millibars mean the same). As altitude increases, the temperature decreases by 2*C per 1000’ and the pressure decreases by approximately 30 hPa per 1000’ or 1 hPa per 30’. Although the figures quoted are approximate, they are sufficient for “rule of thumb” calculations.

Pilot

A pilot must be capable of accurately flying the speeds and profiles applicable to a particular gyro in order to maximise its performance. Sloppy airspeed control will degrade performance, as will poor decisions in respect of takeoff/landing direction, obstacles on the intended flight path and the like. At a given weight, a gyro has an airspeed that maximises lift and minimises drag (best lift/drag speed). Maximum performance during climbs and glide approaches will only be achieved if the recommended speed is flown accurately. This is particularly important during low level operations, takeoff and landing. A disciplined pilot will always get better performance from a gyro than one who does not pay attention to accurate flying.

Takeoff weight
Takeoffs at high weights require more lift to be generated in order to become airborne, compared to takeoff at a lower weight. In order to generate more lift, the takeoff speed must be increased. This requires a longer takeoff ground run to reach the higher speed. The rate of acceleration is also degraded further extending the ground run required. In general, the combination of all these factors means that if the takeoff weight is increased by 10%, the takeoff speed increases by 5% and the takeoff ground run increases by 20%. Furthermore, the climb performance will be degraded proportionately.

Propeller thrust
Propeller thrust is often overlooked during discussions on gyroplane performance and the term "engine power" used instead. It is immaterial what horsepower the engine is developing, if this power cannot be efficiently turned into thrust produced by the propeller. Propeller thrust can only be optimised using a suitable reduction drive and a propeller set up to produce maximum thrust at maximum static engine RPM. Formulae that purport to produce the correct combination of these for a particular engine may exist, but the proof is in practical thrust tests where the actual thrust is measured using a suitable device. As a general rule, to achieve adequate performance the thrust produced should be at least half the weight of the gyro. Too little thrust will have a significant effect on takeoff distances and climb performance.

Atmospheric pressure
Atmospheric pressure at sea level is the result of the weight of the air in a column of the atmosphere directly above the measuring point. The ISA table (Fig. 5.1) shows that this pressure decreases with altitude due to there being less air above as altitude increases. In other words, the density of the air (mass per unit volume) decreases with altitude. Air density is a factor in the amount of lift and drag produced by a gyro rotor system as learned earlier in this manual. So if the air density decreases, so too does the lift and drag. Therefore, at an airfield at an elevation of 2000', the takeoff and climb performance can be expected to deteriorate compared to the same situation at sea level.

As the propeller is also an aerofoil, its performance will also deteriorate.

For the efficient operation of an internal combustion engine, the fuel/air mixture that is burned in the cylinders must be at or close to ideal. The exact ratio of this mixture is not important here, but it must be understood that the ratio is by weight, not volume. So, in a given volume of air, the heavier (more dense) it is, the more fuel can be mixed with it and the more power the engine produces. Thus with increasing altitude and lowering air density, less fuel will be burned and less power will be produced. The combined factors above result in a takeoff ground run approximately 10% greater per 1000' elevation than that at sea level for the same weight, together with a similar degradation in climb performance.

Atmospheric temperature
Atmospheric temperature directly affects the atmospheric pressure at a given point. Suffice it to say that in an unconfined volume of air (not a sealed container), an increase in temperature causes the molecules that comprise air to become more active resulting in fewer molecules being contained within that volume. So, with fewer molecules of air there is less weight of air, less pressure and less density. Performance-related temperatures are often referred to by reference to ISA. As an example, at sea level if the actual temperature is say, 25*C then that temperature is 10*C above ISA and is described as ISA + 10, or the ISA deviation is +10. At sea level, an ISA deviation of + 10 will result in an approximate 20% increase in takeoff ground run.

From the above, it would appear that numerous calculations may be required to determine the approximate ground run required to become airborne from a specific airfield. However, temperature and pressure effects can be combined to simplify the calculation. For this we use a nomograph (Fig. 5.2).

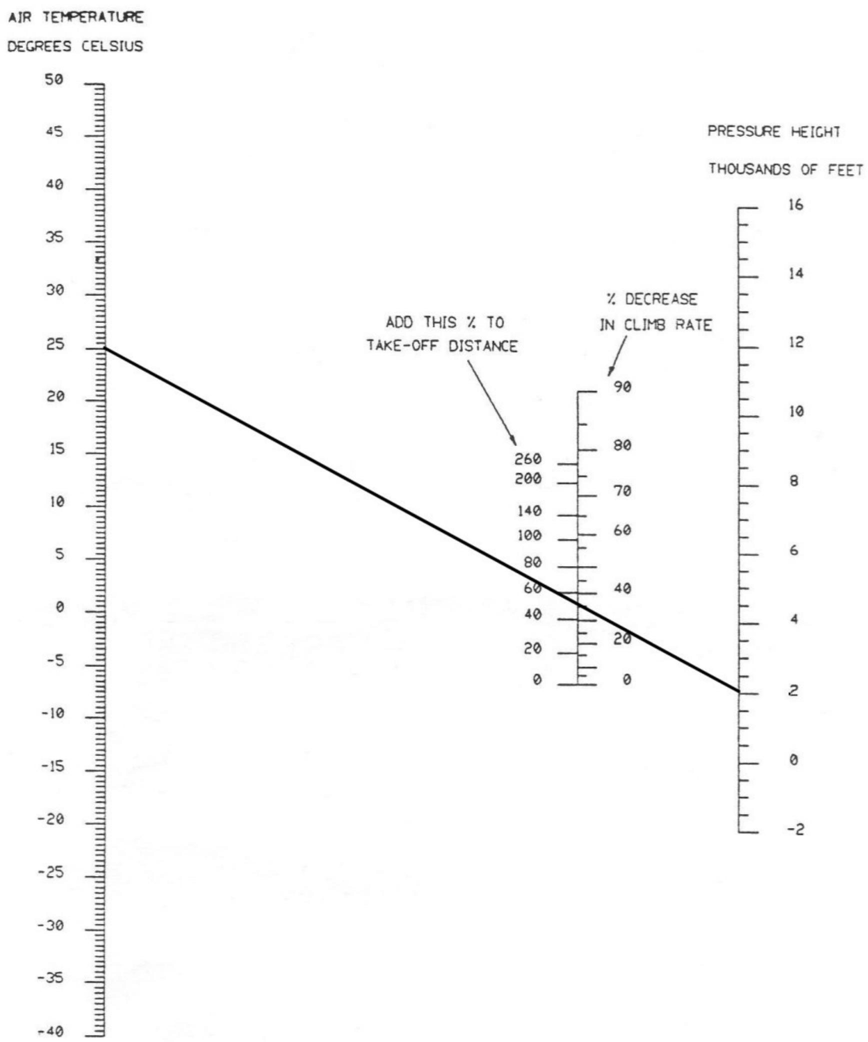


Fig. 5.2 Nomograph

Note that the left-hand scale is temperature in *C and the right-hand scale is pressure height. Pressure height means the equivalent height in ISA and is found by setting 1013 on the altimeter sub-scale and reading off the indicated altitude. Using pressure height accounts for ISA deviations due to pressure.

In the example above, we have selected a 2000’ pressure height obtained from an altimeter and drawn a line to the actual air temperature. Where this line crosses the centre scales, we can determine that the takeoff distance required will increase by a little more than 50% and climb performance is degraded by 35%.

Airfield surface
Most takeoff distance figures in manuals assume a hard, level runway. Where the takeoff surface is other than this, takeoff distances may be prejudiced. Short, dry grass can add approximately 15% to the takeoff distance, whereas long, wet grass or very soft ground can add 25%. A combination of long, wet grass and soft ground may result in insufficient runway to achieve liftoff.

Surface gradient
An uphill slope on a runway will degrade takeoff distances due to a component of the force of gravity acting to retard acceleration. An uphill slope of 2% up will extend the takeoff distance by about 10%. Additionally, the climb gradient after takeoff is effectively reduced by 2% and may result in less than desirable clearance of obstacles along the takeoff path.

Conversely, in a downhill takeoff, a component of gravity assists in accelerating the gyro, thus reaching liftoff speed sooner. However, in extreme conditions this rapid acceleration may place the gyro in a situation where blade flap is a real possibility. Understanding the situation and caution are advised in such a situation. The advantage is the probability that the ground and obstacles on it will drop away from the gyro with the slope on takeoff, thus providing more obstacle clearance than would normally be the case.

Humidity
Humidity refers to water vapour that is held in suspension in the air. Under humid conditions, the water vapour replaces some of the air molecules in a given volume of air thus reducing the air density. We know that lower air density means less performance, so in humid conditions the pilot can expect an all-round degradation in performance. Despite humidity affecting performance, there are no formulae that take this into account.

Wind
The wind is a significant factor in takeoff distance and climb gradient considerations. A headwind component of 10% of the normal liftoff speed will result in a reduction in takeoff run of about 20%. Conversely, a tailwind component of the same magnitude will increase the takeoff distance by a similar amount. Obviously then, taking off into a headwind is the more desirable of the two options. After takeoff, performance can be affected by a phenomenon known as “windshear”. Windshear means a change in the strength and/or direction of the wind from place to place. It is usual for the wind to increase in strength with increasing altitude. This is caused by friction between the ground and the wind which slows the wind down near the ground. Climbing into an increasing headwind results in an increase in IAS which should be countered by the pilot by adjusting the attitude upwards. This increases the climb gradient and provides for increased obstacle clearance.

It follows then that the opposite occurs during a tailwind takeoff. Additionally, during a downwind takeoff, a novice pilot may feel the need to liftoff when the groundspeed is what he normally sees at liftoff. This can lead to the gyro becoming airborne behind the power curve and attempting to climb into an increasing tailwind. The consequences of this are potentially disastrous. Pilots should exercise extreme caution if considering a downwind takeoff.

Regulations preclude downwind takeoffs unless the capability to do so is specified in the gyroplane flight manual.

METEOROLOGY

General

A knowledge of the atmosphere, its properties and characteristics, is as important to the pilot as a knowledge of the sea and its behaviour is to the sailor. Meteorology has been described as an inexact science, no doubt because so many unpredictable factors are involved in forecasting. Nevertheless, forecasting techniques continue to improve and insofar as the pilot is concerned, an understanding of the subject is mandatory.

The atmosphere

The atmosphere is composed of a number of gases, which for practical purposes can be called air. It is however, the properties of air, principally temperature, pressure and humidity, which chiefly concern the pilot studying meteorology.

Temperature

A great deal of the movement of air masses is a result of temperature. Heat from the sun warms the surface of the earth and the radiation from the hot earth causes air to rise and in turn cooler air moves into take the place of that which is displaced. Circulation of this kind may be local or it can extend over hundreds, even thousands of kilometres. Air which is heated in this way will continue to rise until it cools and reaches an altitude where the air is of similar temperature. Generally air temperature changes with height at a rate of 2°C per 1,000ft, and this is known as the “lapse rate”. It is well known that gases heat up when compressed (e.g. a bike pump becomes hot whilst pumping). Conversely when gases are allowed to expand there is a temperature drop. The drop in temperature due to expansion, together with the lapse rate of 2°C per 1,000ft gives a total lapse rate (known as the “dry adiabatic lapse rate”) of 3°C per 1,000ft.

When warm moist air rises it cools until it reaches its dewpoint, that is a temperature where any further cooling will cause condensation to take place forming cloud. When this occurs latent heat is released which causes the temperature to drop at a lower rate. This is known as the ‘”saturated adiabatic lapse rate”, which is 1.5°C per 1,000 ft.

Pressure

In meteorology, pressure is measured in millibars. By drawing lines on a chart joining places of equal pressure the weather pattern emerges in much the same way as contour lines on a map will show the shape, formation and gradient of the land. These lines are called isobars (“iso” means same and “bar” means pressure). These are the lines you will commonly see on the synoptic charts used in TV weather reports.

Atmospheric pressure is in a continual state of change. Locally, the changes may be small, but over a large area they can be considerable, particularly when intensely high (anticyclone) or low (depression) pressure weather systems are active.

Clouds

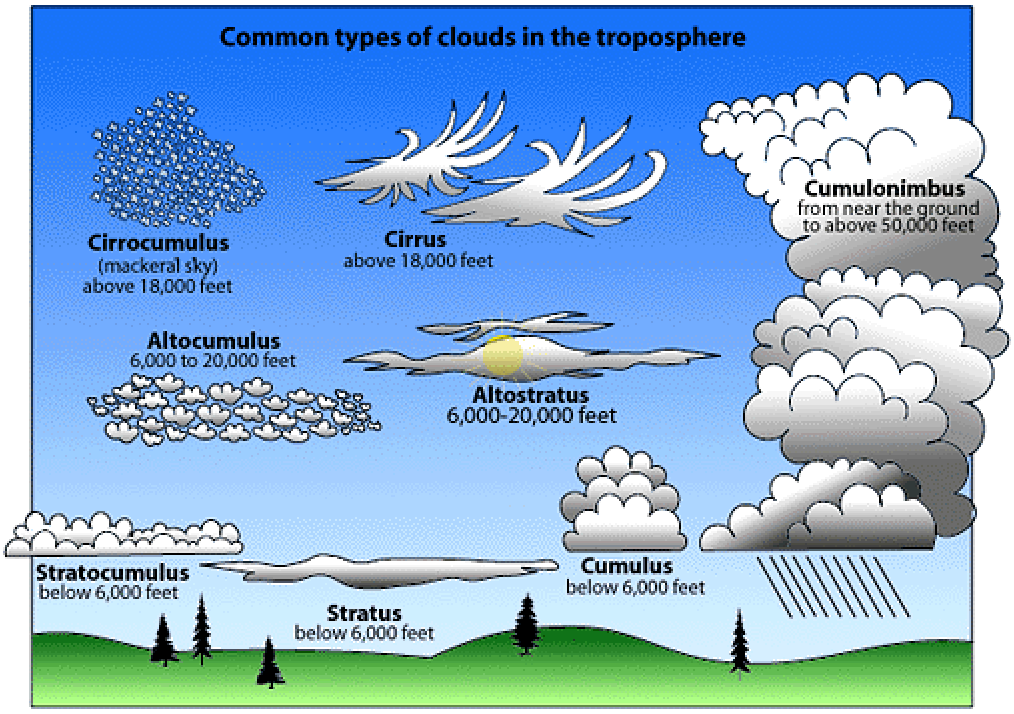


Fig. 5.1 Common types of cloud

Fig. 5.1 illustrates the types of cloud commonly observed together with the altitudes where they are most likely to occur.

In this manual clouds are referred to by type name and the following list gives a brief description of each classification. Clouds are classified into four main groups according to their height and appearance. (The bracketed letters that appear after each cloud type are abbreviations used in aviation weather forecasts to describe the type of cloud forecast. They emanate from a bygone era when weather forecasts were transmitted using morse code.)

1. HIGH CLOUDS. Height above 20,000 ft. These clouds are normally composed of ice crystals.

a) Cirrus (CI): shapeless or wispy, white clouds (Fig. 5.2). “Cirrus” means high and thin. Sometimes referred to as "mare’s tails".

Fig. 5.2 Cirrus

b) Cirrocumulus (CC): has the appearance of ripples, white in colour and known as a "mackerel sky" (Fig. 5.3). “Cumulus” means rounded heaps, so when “cirrus” and “cumulus “are combined into cirrocumulus, this means high, thin clouds with some rounded heaps. These heaps are generally small.

Fig. 5.3 Cirrocumulus

c) Cirrostratus (CS): a thin, white veil-like cloud (Fig. 5.4). They often cause a halo to appear around the sun or the moon. “Stratus” means layer, so cirrostratus means high, thin clouds in layers.

Fig. 5.4 Cirrostratus

2. **MEDIUM CLOUDS**. Heights between 7,000 ft and 20,000 ft. Although “alto” literally means high, this term is used in meteorology to describe mid-level clouds.

a) Altocumulus (AC): resembles patches of flattened globular masses, sometimes arranged in waves or lanes (Fig. 5.5).

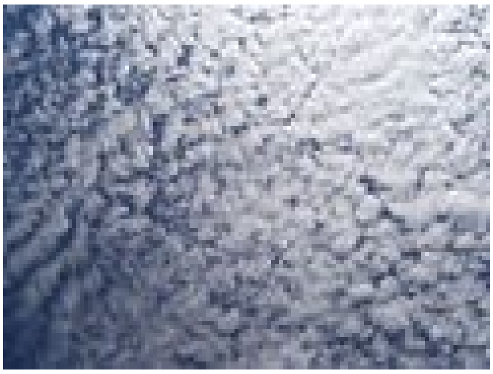


Fig. 5.5 Altocumulus

b) Altostratus (AS): layer of grey blue cloud of fibrous appearance (Fig. 5.6). They may develop to considerable thickness. The sun may be visible as if viewed through ground glass.

Fig. 5.6 Altostratus

3. LOW CLOUDS. Usually less than 5,000 ft.

a) Stratus (ST): a dirty grey cloud lying close to the ground (Fig. 5.7).

Fig. 5.7 Stratus

b) Nimbostratus (NS): a thick dark rain-bearing cloud, often covering high ground (Fig. 5.8). They may be ragged near rain-depositing areas. "Nimbo" means precipitation or rain. Nimbo clouds therefore can be expected to have a dark appearance, the degree of darkness being proportional to the amount of precipitation contained in the cloud. Combining "nimbo" and "stratus" (nimbostratus) we come up with layers of cloud containing precipitation.

Fig. 5.8 Nimbostratus

c) Stratocumulus (SC): a layer of patches or rolls of globular clouds, sometimes dark grey and light grey in colour (literally, rounded heaps of cloud in layers) (Fig. 5.9). This colouring should not be confused with nimbus clouds that contain significant concentrations of moisture. The colouring is often cause by shadows from other clouds in the vicinity. Flying conditions in and below these clouds may be bumpy, depending on the vertical growth of the formation.

Fig. 5.9 Stratocumulus

4. HEAP-FORMED CONVECTION CLOUDS: Heights between 1,000 ft. and 36,000 ft.

a) Cumulus (CU): a cauliflower appearance (Fig. 5.10). The entire sky may be dotted with these crisp clouds, and their formation is usually due to convection currents ascending on warm, sunny days. They are invariably the product of differential heating. The base of the cloud is usually flat. Flying conditions may be turbulent, especially in the middle of the day when vertical cloud growth is most likely. This type of formation is often referred to as fair weather cumulus.

Fig. 5.10 Cumulus

b) CUMULONIMBUS (CB): a cloud of great vertical extent, often seen with well developed mushroom or anvil head which can extend to 35,000 ft or higher (Fig. 5.11). Often associated with electrical storms and lightning. Violent vertical air currents in and near these clouds are very hazardous and should be avoided. During the building or growing stage of this cloud, strong, rising air currents are evident by the billowing, expanding nature of the cloud around the edges and on the top. This rapidly rising air causes strong winds at and near the surface which are eventually "sucked up" into the cloud. It is known that light flying machines (paragliders, powered parachutes etc.) have been caught in these currents and drawn up into the cloud with often fatal consequences. Conversely, when the cloud has matured and heavy rain and hail reach the ground, the resulting down drafts strike the ground and dissipate in all directions often giving rise to "micro bursts". These result in rapidly changing wind direction and speed known to cause fatal airline crashes. Heavy icing is also a source of danger and hail discharge from the anvil top can cause severe damage to aircraft.

Fig. 5.11 Cumulonimbus

Another rather common type is known as a lenticular cloud, meaning its shape is like a lens (Fig. 5.12). It cannot be classified into any of the above four categories as it can form at any level. It is formed when moist air blowing generally horizontally is forced upwards by a geological feature (such as a hill or mountain) and in the process reaches its saturation point and forms cloud. As this air passes over the feature, it again descends reaching the saturation point, although this time travelling downwards, and consequently the cloud evaporates and disappears. The presence of lenticular cloud is indicative of turbulence in the lee of the geographical feature and this area should be avoided.

Fig. 5.12 Lenticular

Wind

Wind is air in horizontal motion, caused by changes in temperature between one area and another and the resulting pressure difference.

It is usually expressed in terms of direction and speed (wind velocity). For example 270/15 indicates that the wind is from the west at 15 knots.

Windshear

Severe windshear has caused the loss of a number of aircraft, some of them large passenger aircraft.

AN EXAMPLE OF WINDSHEAR

Often when the wind is relatively calm on the ground, at several hundred feet above the ground, the light and variable wind conditions suddenly change into a strong and steady wind. If we consider an aircraft making an approach to land in these conditions, we can see the effect the windshear has as the aircraft passes through the shear (Fig. 5.13).

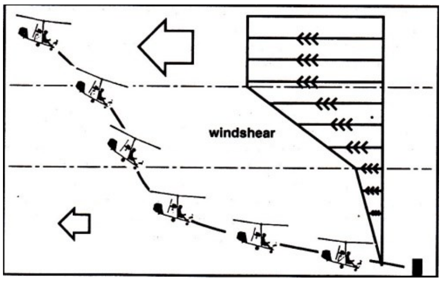


Fig. 5.13 Windshear

The causes of windshear include the wind being slowed down by ground surface roughness, abrupt changes in terrain, thunderstorms, cumulonimbus clouds, large cumulus clouds, (downbursts and gust fronts), low level jet streams, fronts, thermal activity, sea breezes etc.

As a particular warning to pilots, we strongly suggest that thunderstorms and cumulonimbus clouds be avoided. A strong downburst out of the base of one of these clouds will spread out as it nears the ground. The initial effect may be an overshoot, followed by what may be an extremely severe undershoot (Fig. 5.14).

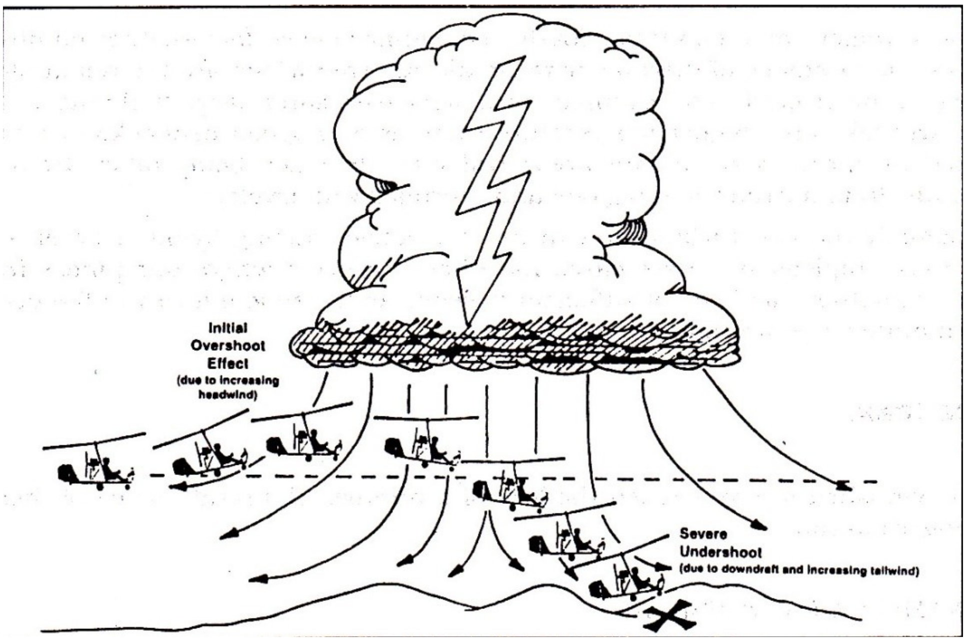


Fig. 5.14 Avoid thunderstorms

Sea breeze

Near the coast, an onshore wind frequently sets in during the late morning, rises to a maximum in the early afternoon, and then dies away in the evening. The strength of the breeze is greater on warm days, but may be weaker under cloudy conditions. It is called a sea breeze.

It is caused by the different rate of heating of the land and the sea surface when solar radiation falls on them. The layers of air above the land surface becomes warmer than that over the sea. The warmer air expands and rises and the cooler air from the sea flows in to take its place. In Perth Western Australia, the commonly known “Freemantle Doctor” is a typical sea breeze (Fig. 5.15A)

Land breeze

In coastal regions at night, land breezes may develop. These are directed in the lower layers from the land to the sea. Radiation cooling from the land surface takes place much more rapidly than from the adjacent ocean.

Eventually the temperature of the land falls below that off the sea. The air in the lower layers of the atmosphere then cools more rapidly than that over the sea. In doing so it contracts and descends. The pressure over the land then becomes higher than that over the sea. As a result the air moves from the land towards the sea (Fig. 5.15B).

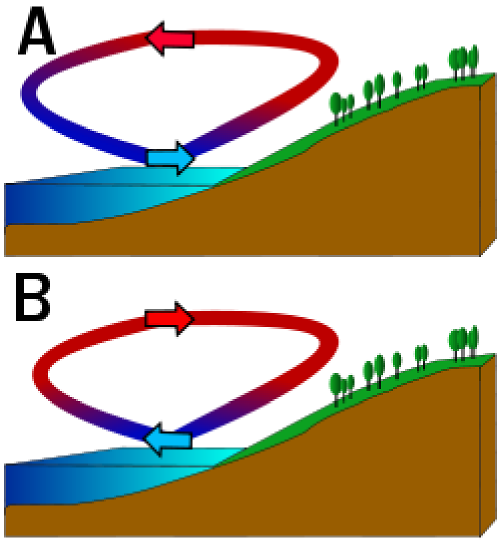


Fig. 5.15 A represents a sea breeze. **B** represents a land breeze.

Katabatic winds

On cloudless nights, air often begins to flow down the slopes of mountains and hills. This downward flow becomes particularly evident as the air moves down the bottom of the river valleys that lead to lower levels. It develops at night, when the land surface loses heat by radiation.

Air that is cooled by contact with the cold land surface becomes denser than the surrounding air and tends to settle towards the ground. When the ground slopes away, the force of gravity on this dense air mass causes it to move down the slope towards the lower levels. The movement of the air mass down the slope is called a katabatic wind.

Katabatic winds are light, but they may attain a higher speed if the slope is significant, or if the surface is covered by snow and ice. When there are mountain ranges close to the coast, the katabatic wind may reinforce the land breeze at night, which may lead to strong offshore winds (Fig. 5.16).

Anabatic winds

On a fine warm day there is a gentle upward flow of air on hill slopes. On a warm cloudless day, the ground slope becomes warmed by the sun, and reaches a higher temperature than the air. Air near the slope contacts the ground and becomes warmer. The warmed air becomes unstable and rises, being replaced by the surrounding air, which is cooler and denser. As it moves up the slope it expands because of the lower pressure aloft.

Anabatic winds tend to be weak, but the pressure gradients developed by the heating differences on a warm sunny day may be large. However, the air has to be forced uphill against gravity, and this reduces the speed up the slope (Fig. 5.16).

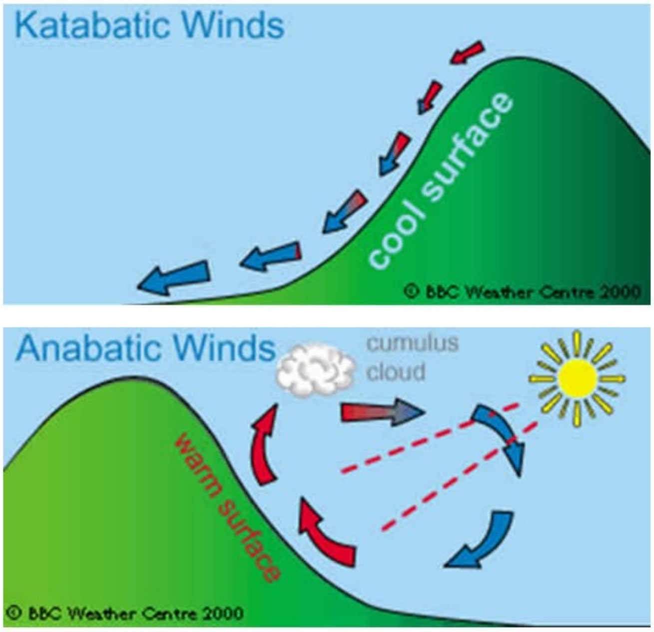


Fig. 5.16 Katabatic/Anabatic winds

Turbulence

Although cloud formation is one of the principal sources of turbulence, in windy conditions, land features will create disturbances of which the downdraft is an example. Downdrafts can be very severe, particularly on the leeward side of hills, and powerful enough to prevent a gyroplane climbing over the high ground. This should always be borne in mind when airstrips are situated near features likely to cause air disturbances of this kind.

The behaviour of wind near uneven ground may be illustrated by watching a fast flowing stream as it makes its way over a rock-strewn bed. To overcome a stone, the water must rise in a small wave and then descend leaving behind an area of foam and eddies. If the obstacle in the stream is large enough the flow may even reverse, behind the stone, encouraging flotsam to move upstream. Air in motion near the ground will behave in a very similar manner. In addition to the horizontal flow, there are up currents, down currents, eddies and gusts. These all contribute to a fluctuation in surface wind velocity. Hills, ridges and even large buildings create ground turbulence and both the windward and leeward sides of such obstacles may present a danger.

Fig. 5.17 shows the flow of air over a high ridge and the path of an aircraft attempting to fly overhead. The pilot approaches the summit with what they consider to be a safe height margin. On entering the area of downdraft, the aircraft descends and the pilot may be unable to maintain height or have sufficient speed or room to turn away from the danger. Never approach a ridge line in windy conditions head on. Always track parallel to the ridge until the severity of any turbulence is assessed as suitable for the transit. This technique means that in the event that a rapid escape becomes necessary, the gyro need only turn through 90* instead of 180* if the approach was head on (Fig. 5.17).

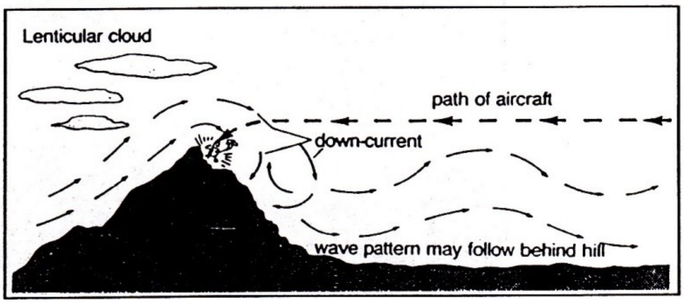


Fig. 5.17 Downdraft

In certain meteorological conditions, typically an inversion where temperature increases with height instead of decreasing and with the wind blowing more or less at right angles to the ridge or hills, the resulting air on the leeward side may continue as a wave cycle. Wave lengths are dependent on temperature and wind velocity but 4 to 5 NM is commonplace. The waves can produce local, turbulent gusty conditions which do not exist elsewhere and are difficult to forecast. It is therefore most important to clear hills and ridges by a margin of several hundred feet, when the wind is more than 15 KTS or so, remembering that the wind in flight will be stronger than the surface wind experienced during takeoff. Good terrain clearance and available thrust are excellent safeguards.

During summer, small cumulus clouds, (sometimes called “fair weather cumulus”) indicate the existence of thermal or warm air currents which are the result of uneven heating of the ground. For example, air flowing over sand, large buildings or asphalt areas will take on a higher temperature than air over green paddocks or water. Air warmed by these more radiant areas will rise, its place being taken by a flow of colder air from surrounding regions, and thermals will develop.

Occasionally thermal turbulence can be very active causing flying at lower altitudes to be most unpleasant. Rare cases have been reported where bumpiness from one cause or another has been sufficiently violent to injure the occupants of even quite large aircraft.

Synoptic charts

Lines of equal pressure (isobars) are drawn at selected intervals on a weather chart (synoptic chart). These lines delineate the areas of high and low pressure (Fig. 5.18).

The major pressure systems as shown on the diagram are as follows:

LOW PRESSURE SYSTEM

In the southern hemisphere air moves in a clockwise direction around the centre of the low pressure. Rain is normally associated with low pressure systems. Very deep or intense low pressure systems become cyclones.

HIGH PRESSURE SYSTEM

In the southern hemisphere, air moves anti-clockwise around the centre of the high. Fine weather is usually associated with high pressure systems.

COL

An open region between two highs and two lows. Any wind within a col is light and variable.

TROUGH

An extension of a low pressure system.

RIDGE

An extension of a high pressure system, which may extend for some distance.

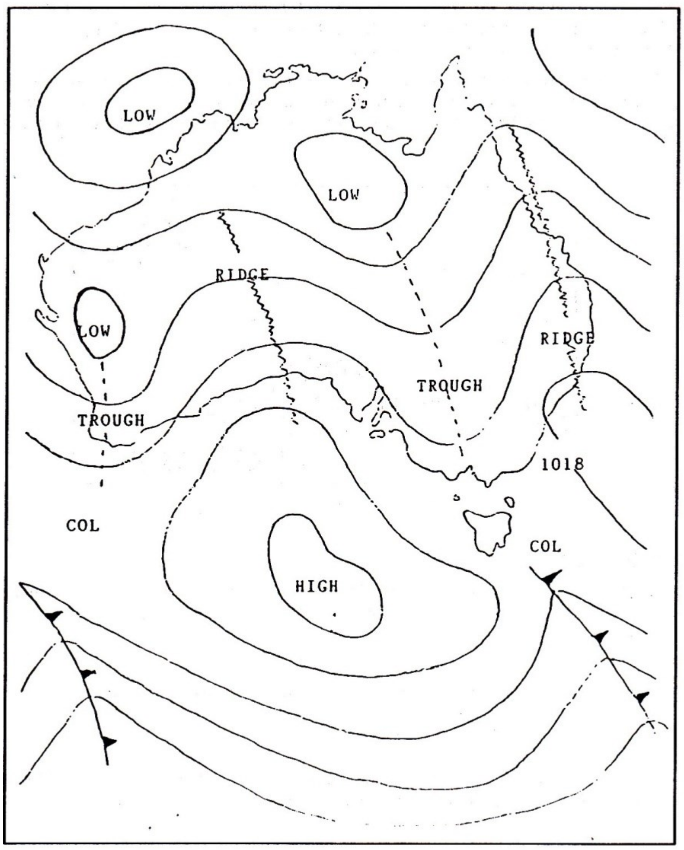


Fig. 5.18 Typical synoptic chart

The astute reader will notice two symbols in the lower left and right corners of the synoptic chart which have not been explained. These symbols represent fronts.

Fronts

A weather front is a boundary separating two masses of air of different density. Whilst there are some nine types of fronts and symbology for each, the most common in Australia are warm and cold fronts and only these two will be discussed.

WARM FRONT

A warm front results when a warm air mass, which is less dense than cold air overruns a cold air mass and is forced upwards in the process. This phenomena gives rise to unique cloud formations and surface conditions that are only associated with the approach and passage of a warm front (Fig. 5.19).

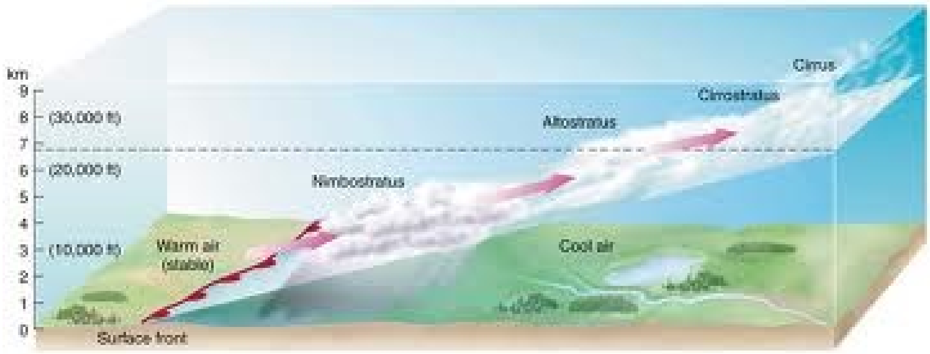


Fig. 5.19 A warm front

Fig, 5.19 illustrates how the approach of a warm front is indicated by cirrus, then stratiform clouds. The passage of the front is preceded by showers and rain if sufficient moisture is contained in the warm air mass. Generally fine weather follows the front's passage. Thus, the attentive pilot, when observing the approach of cirrus followed by cirrostratus and altostratus clouds, would expect that showers and rain would arrive shortly and plan accordingly.

A warm front is depicted on synoptic charts by the symbol indicated in Fig. 5.20.

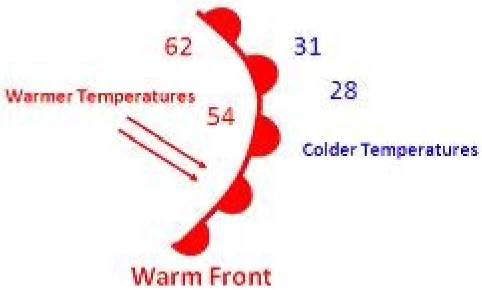


Fig. 5.20 A warm front as indicated on synoptic charts

COLD FRONT

A cold front is defined as the leading edge of a cooler mass of air that replaces a warmer mass of air at ground level (Fig. 5.21). The approach of a cold front is also indicated by cirrus cloud, but they do not occur in the same quantities as that associated with warm fronts. Altocumulus clouds, sometimes followed by cumulonimbus clouds, form behind the front. Obviously, cloud formation and its density will depend on the amount of moisture contained in the air mass that is being forced upwards, with the cumulonimbus cloud potentially becoming quite severe thunderstorms with associated heavy rain and hail.

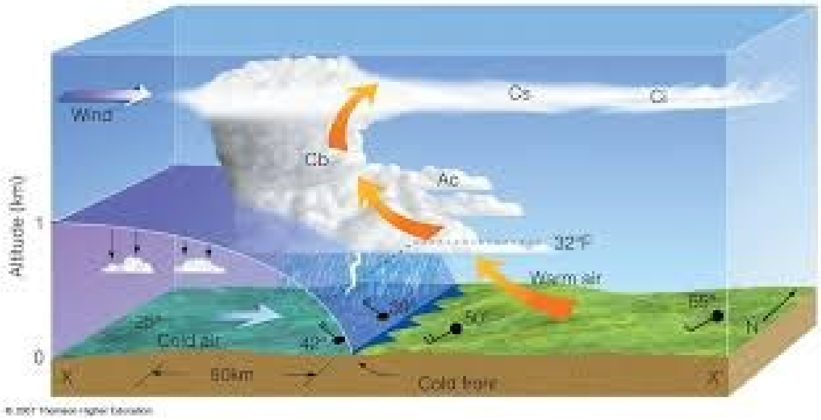


Fig. 5.21 Cold front

Cold fronts can move very quickly with gusty winds accompanying the edge of the front. Temperature decreases of up to 30*C have been recorded behind a cold front. After a warm front fine weather can generally be anticipated, however the weather behind a cold front can remain unsettled with periods and areas of rain. The commonly named “southerly buster” that is experienced by the residents in Sydney, New South Wales, is an example of a cold front.

A cold front is depicted on synoptic charts by the symbol indicated in Fig. 5.22.

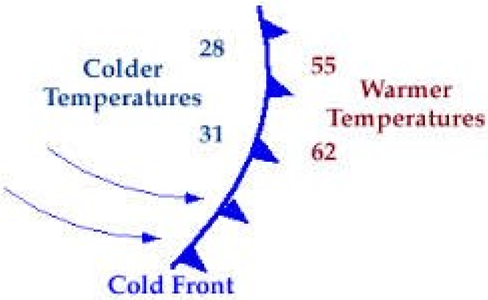


Fig. 5.22 A cold front as indicated on synoptic charts