# BASIC FLIGHT TRAINING - THEORY OF FLIGHT

## *Forces Acting on the microlight*

An aircraft has four forces acting on it.

| | |
|---|---|
| **LIFT** | The upward force |
| **WEIGHT** | Gravity the downward force |
| **THRUST** | The forward force. |
| **DRAG** | The rearward force. |

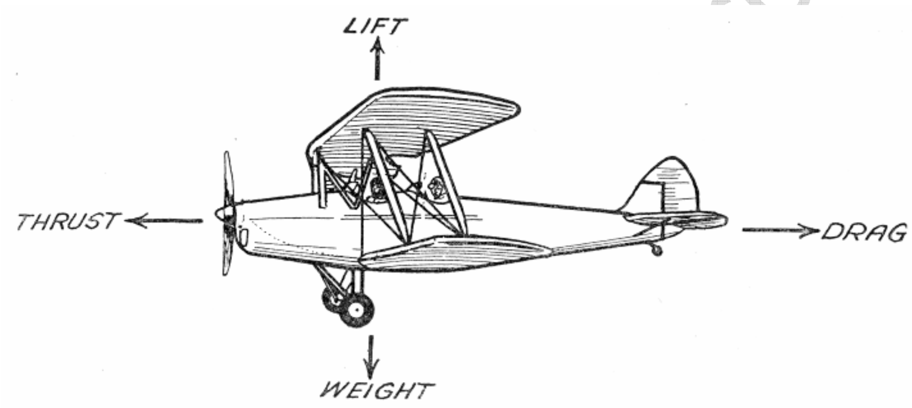



Fig.2.2.1 *Forces acting on an aircraft in flight*

As can be seen in Figure 2.2.1 lift opposes weight and thrust opposes drag. Drag and weight are natural forces to be found in anything to be lifted from the ground and moved through the air. Thrust and lift are artificially created forces that allow the microlight to fly by overcoming the natural forces of Drag and Weight. The engine and propeller produce the Thrust to overcome the Drag. The wing produces Lift to overcome the Weight or gravity. During straight and level flight at a constant speed:

**LIFT = WEIGHT and THRUST = DRAG**

Inequality between weight and lift will result in the microlight entering a descent or climb. Inequality between thrust and drag will result in speeding up or slowing down until the two forces become balanced.





## *Terms in use*

**Aerofoil**
An Aerofoil is a device that gets a reaction from air moving over its surface. When it is moved through the air it produces lift. Wings, horizontal and vertical tail surfaces and propellers are all examples of aerofoils. See Fig. 2.2.2 for a cross sectional view of an aerofoil. Microlights can have either a single surface or a double surface wing.

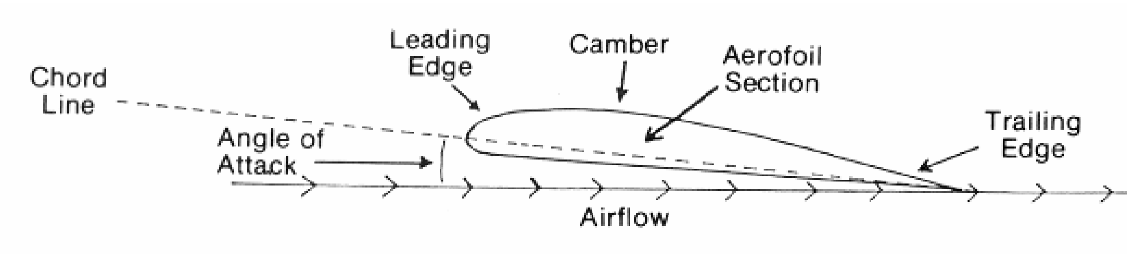
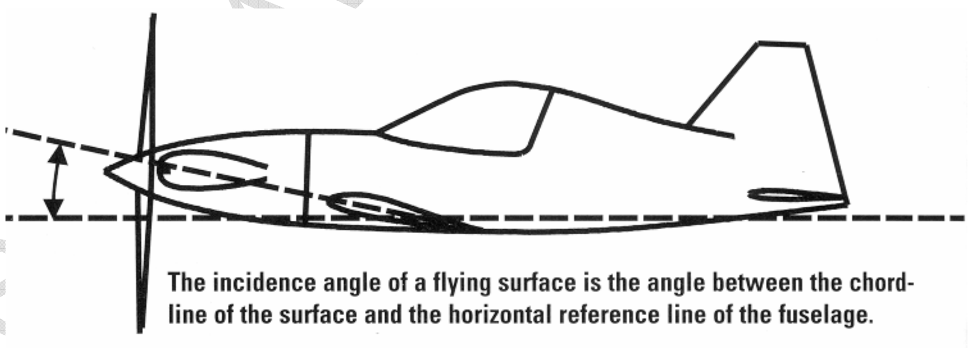



Fig.2.2.2. *The aerofoil*

The forward part of an Aerofoil is blunt and rounded and is called the leading edge. The aft part is narrow and tapered and is called the trailing edge.

**Angle of attack**
The angle of attack is the acute angle between the Chord Line of an aerofoil and the relative wind. Refer Fig. 2.2.2 above. The angle of attack should not be confused with the angle of incidence. The angle of incidence is normally fixed, but the angle of attack may be varied by the pilot and is relative to the flight path.

**Angle of Incidence**
The angle of incidence is the angle formed by the chord line and the longitudinal axis of the microlight. The angle of incidence is determined by the aircraft designer and has no effect on the flying of the aircraft. See Fig. 2.2.3




Fig, 2.2.3 *Angle of Incidence*

**Atmospheric Effects on Lift and Drag**
The **DENSITY** of the air affects lift and drag.
As air density increases (cold weather) both lift and drag increase.
As air density decreases (hot weather) lift and drag decrease.
The density of the air is governed by **TEMPERATURE**, **HUMIDITY**, and **PRESSURE**.

**Aspect ratio**
Is the ratio between the span and the chord (span/chord).



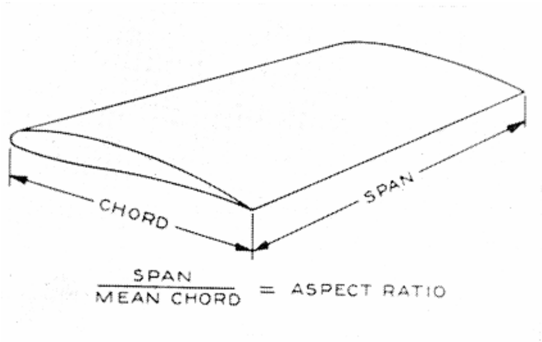



Fig 2.2.4 *Aspect Ratio*

**Axis of Rotation**
Intersect at the centre of gravity – are imaginary lines about which the aircraft may rotate about in flight.

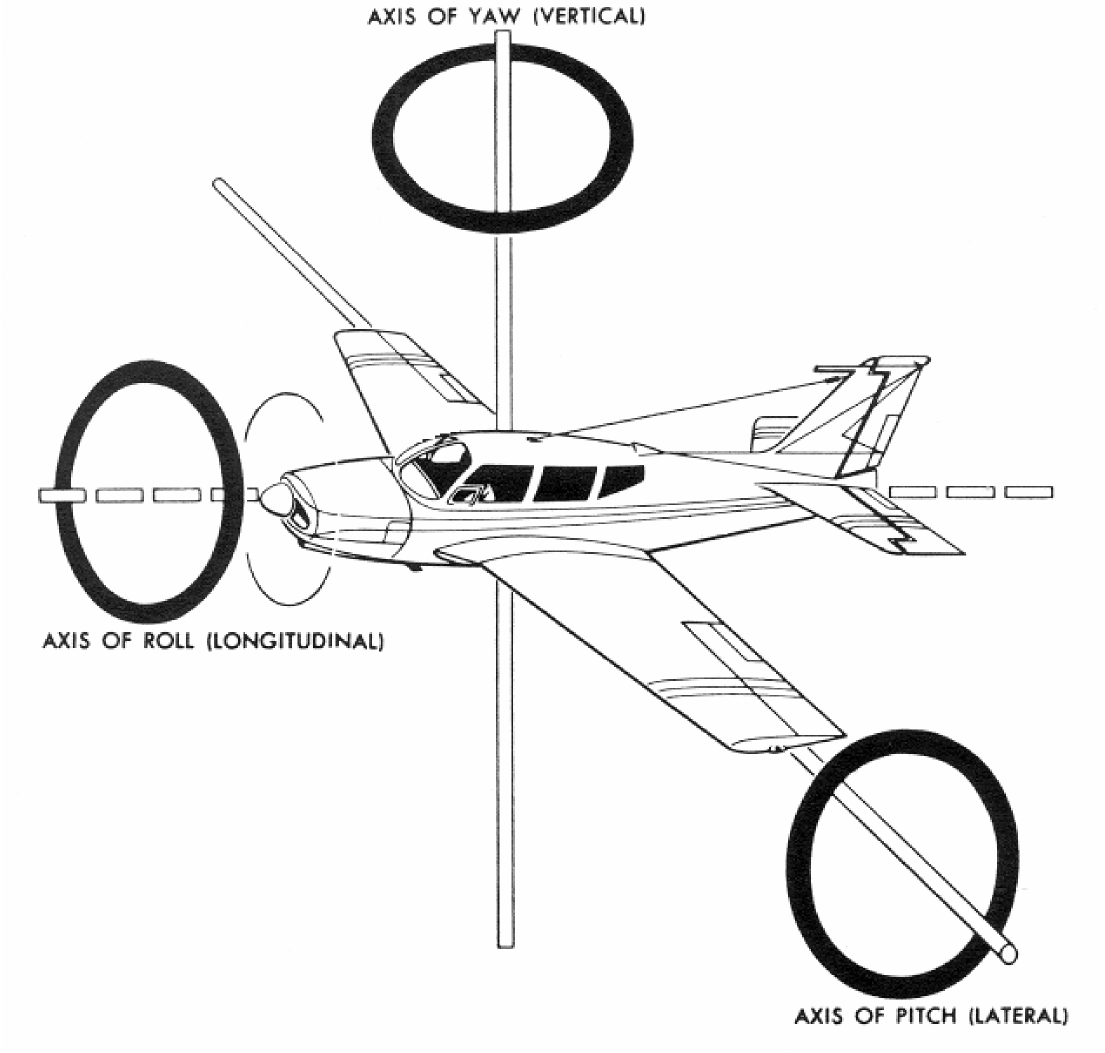



Fig. 2.2.5 *Axis of rotation*

**Bernoulli's Principle**
In the 18th Century, the Swiss mathematician Mr. Daniel Bernoulli discovered that the pressure of a fluid decreases at point where the speed of the fluid increases. This means that the high-speed flow creates low pressure and low speed flow creates high pressure. As the molecules of air behave just like molecules of fluid this principle applies to air. In the case of an aerofoil a molecule hitting the leading edge will speed

up as it goes over the large curved surface, this will create a low-pressure area because the molecules are further apart. The molecule that hits the leading edge and goes underneath will be travelling slower as it has less distance to cover, which means the molecules, will be denser. Both upper and lower molecules will meet at the same time at the trailing edge. (Refer Fig.2.2.6).

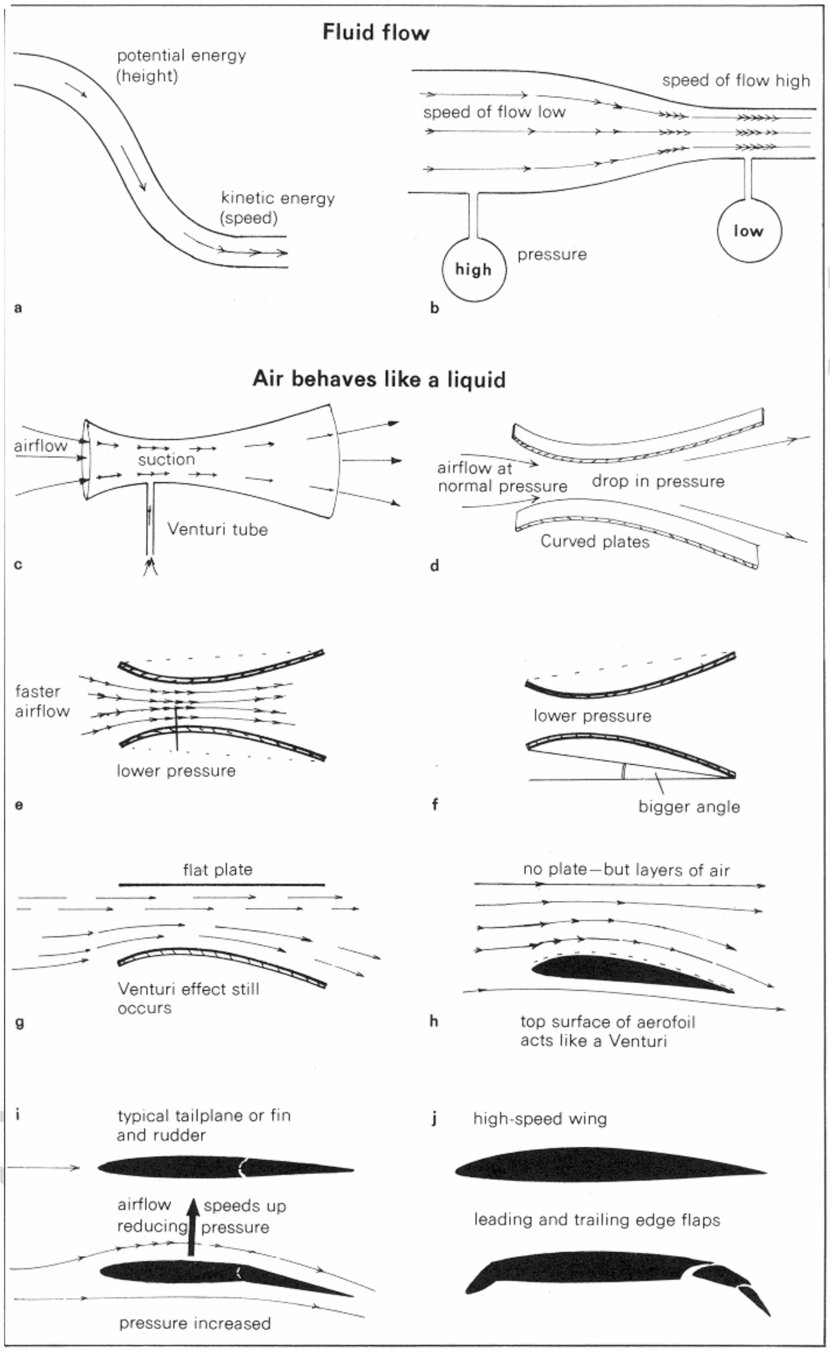



Fig.2.2.6 *Bernoulli's Principle*

**Centre of Pressure**

Is the imaginary point where the resultant of all aerodynamic forces of an aerofoil is considered to be concentrated at any given time.


Fig. 2.2.7 *Centre of Pressure*

Since the distribution of the lift forces varies, then it follows that the centre of pressure moves back and forth along the chord with changes in angle of attack.

For normal flight conditions the centre of pressure moves forward with increase in angle of attack and rearward with decrease in angle of attack.
As the stall takes place the Centre of Pressure moves rapidly backwards, resulting in the nose of the aircraft dropping swiftly.

**Chord Line**
The Chord Line - is the straight line between the centre of the leading edge and the centre of the trailing edge. The Chord Line is shown as the dotted line in Figure 2.2.2 above.

**DRAG**
Is the force which tends to resist an aerofoil's passage through the air. Drag is always parallel to the relative wind and perpendicular to lift. Drag varies as the square of the velocity.


Fig. 2.2.8 *Drag*

The total DRAG on the microlight as seen in the four forces is made up of two types of DRAG - PARASITIC DRAG and INDUCED DRAG.

***Induced Drag*** - is the result of the production of lift by the wings. At high angles of attack the induced drag is high. At low angles of attack the induced drag is low. Factors that help in the reduction of induced drag are the long slender wings (high aspect ratio) such as found on sailplanes, which minimise induced drag. The design of the wing can also reduce induced drag.

Induced drag is a result of wing tip vortices.

Wing tip Vortices are caused by the span wise flow of low-pressure air from above the wing meeting with the high-pressure air from below the wing creating a spiralling airflow from each wing tip and this is induced drag.
(Refer Fig. 2.2.9)

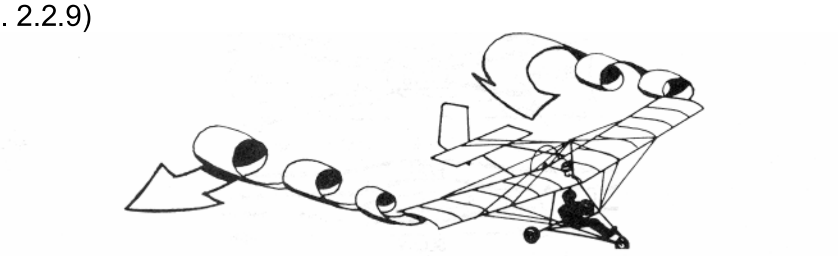


FIG.2.2.9 *Wingtip Vortices (Induced drag).*

***Parasitic Drag*** – (also known as form drag) is the drag created by the form of the microlight airframe, undercarriage, rigging, fuel tanks etc. As the speed increases Parasitic Drag increases rapidly. In fact if the speed is doubled the drag is four times as much as at the previous speed. The use of streamlining of the airframe results in significant reductions in parasitic drag.

The interaction of induced drag and parasitic (Form drag) is shown in the following Figure 2.2.10.

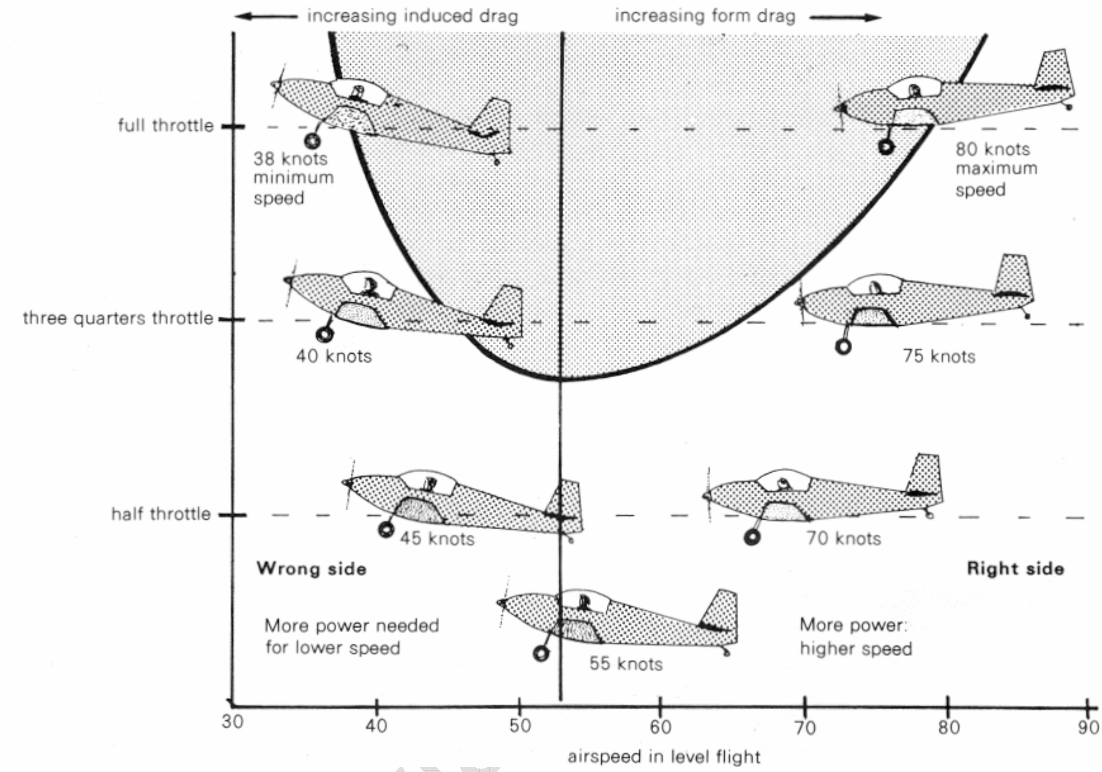



FIG.2.2.10 *The Drag Curve*

**Effect of Angle of Attack on Lift and drag**
Increasing the angle of attack increases both the lift and drag up to a point where the wing stalls.

**Effect of Airspeed on Lift and Drag**
Increasing the speed of the air passing over the wing increases the lift and drag. This is because of the increased relative wind on the lower surface produces a greater positive pressure, as well as the increased speed of the relative wind over the upper surface produces a lower pressure above the wing which sucks it up.

If we double the speed, the lift and drag quadruple (this is assuming the angle of attack remains the same).

**Effect of Aerofoil Shape on Lift and drag**
By increasing the upper curvature of the aerofoil (up to a point) the lift produced will be increased. Thus, a wing designed for high lift will have a deep wing section and possibly a concave lower surface. High lift wings are generally not suited to high-speed flight.

Lowering an aileron has the affect of increasing the curvature of the wing thus increasing the lift on that portion of the wing. Unfortunately this also results in an increase in drag on that wing.

Raising an aileron effectively reduces the camber of that part of the wing reducing the lift.

The tail surfaces change their curvature by movement of the elevator and rudder, causing the direction of the lift to change.

Any damage to the contour of the wing will have a serious effect on the production of lift on that part of the wing. The stall characteristics will also get worse. If the wing of your aircraft relies on battens for its shape, DO NOT fly with sail battens deformed, damaged, or missing as the aerofoil shape is vital to the production of lift.

**Factors affecting Lift and Drag**
Many factors alter the lift and drag e.g. aerofoil shape, wing shape, air speed over the wing, angle of attack, wing area and air density.

**LIFT**
Is the force produced by an aerofoil perpendicular to the relative wind. (The vertical component of the resultant vector is that which opposes gravity).

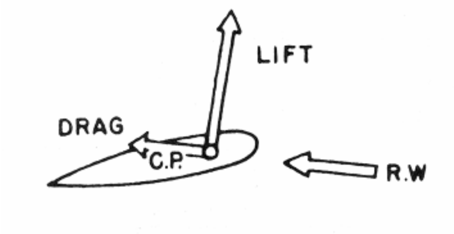



Fig. 2.2.11 *Lift*

**Moist Air** - is less dense than dry air. Performance decreases in moist air.

**Pressure** - An increase in altitude brings a decrease in pressure that makes it less dense air. In order to produce the same lift at altitude, the air speed over the wings or the angle of attack must be increased. Take-offs from an airfield at a high altitude require a much longer take-off distance.

**Relationship between Lift and Angle of Attack**
As mentioned before, the angle of attack is the angle made by the chord Line of the wing and the relative wind. If the angle of attack was zero, the pressure underneath the wing would be the same as the atmospheric pressure. All of the lift therefore would be produced by the decrease in pressure over the upper surface of the wing. At small angles of attack most of the lift would be produced by the decreased pressure above the wing, and only a small amount of positive pressure below the wing.

By increasing the angle of attack, the effective camber (curvature) of the wing is increased. Thus the air is required to travel a greater distance in the same time as mentioned earlier. In order to travel this greater distance Mr. Bernoulli's principle tells us it must therefore accelerate, producing a greater decrease in pressure. Therefore increasing the angle of attack results in an increased pressure differential, meaning greater lift. It also results in increased drag.

With the angle of attack increased to around 18 to 20 degrees or so on most aerofoils, the air can no longer flow smoothly over the upper surface of the wing because a large change of direction is needed. With the increasing angle of attack a break up of the airflow begins at the trailing edge and moves forward. Refer Fig. 2.2.12

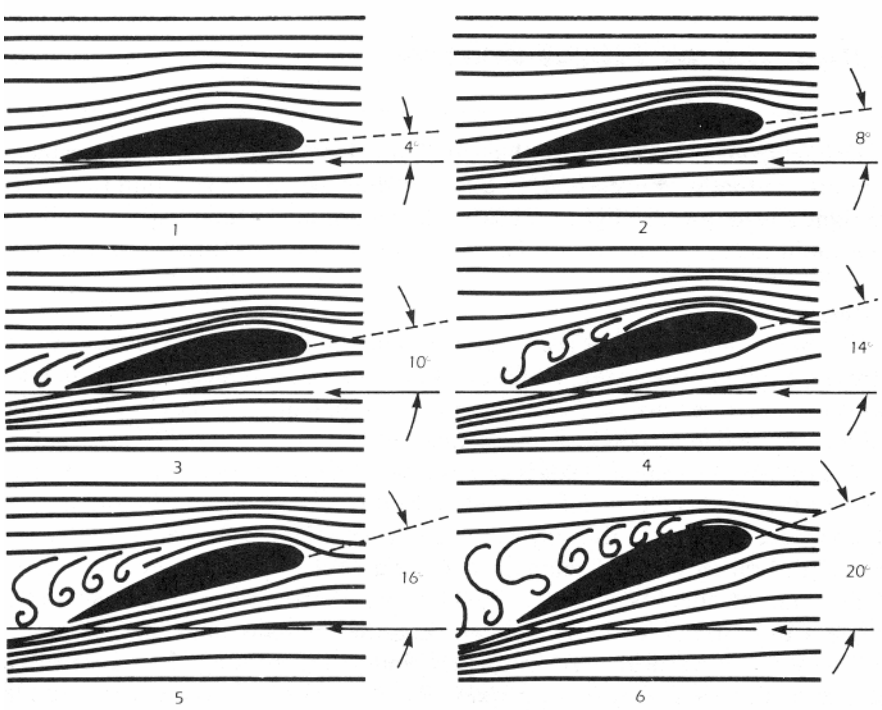



FIG.2.2.12 *Airflow at high angles of attack over an aerofoil*

At the critical angle of attack, the turbulent flow, which has appeared at the trailing edge at lower angles of attack, suddenly spreads forward over the whole upper surface of the wing. This action of the airflow increases the pressure on the top surface of the wing, along with an equally sudden increase in drag. Lift is greatly reduced and the wing is said to have stalled.

**Flaps**
Are normally attached to the inboard portion of the wing and carry out three basic functions:

- generate lift at a lower speed by increasing the effective camber of the wing, reducing landing speed.
- increase drag allowing a steeper path of descent on landing.
- improve forward vision during landing approach and in slow speed flight.

**Flaperons**
A surface combining roll-control function of aileron with increased lift and drag function of a flap. Can be differentially operated.

**Relationship of Lift and Weight (Gravity) in Straight and Level Flight**
The upward force of lift on the wing always acts perpendicular to the direction of the relative airflow. In straight and level flight lift opposes the microlights weight.
With lift equal to weight, the machine will neither climb nor descend. If lift becomes more than weight, the microlight will enter a climb. If lift becomes less than the weight the microlight will descend.

**Relationship of Thrust and Drag in Straight and Level Flight.**
In straight and level flight at a constant airspeed, thrust and drag are equal.



If the thrust output of the propeller is increased, thrust will momentarily exceed drag and the airspeed will begin to increase (assuming that straight and level flight is maintained).
An increase in speed will cause an increase in drag and at some new higher speed drag and thrust will again be equal. The speed will again be constant.

At full power, the speed will increase until drag equals thrust. The new constant speed this results in will be the top speed for the microlight in that configuration and attitude. If thrust is reduced to less than the drag, the microlight will decelerate to a lower airspeed (assuming that straight and level flight is maintained). The thrust and drag become equal.

**Relative Wind**
The relative wind, or relative airflow, is the direction of the airflow in relation to the wing. If a wing is moving forward horizontally, the relative wind moves backwards horizontally. If a wing is moving forward and upward, the relative wind moves rearward and downward. The flight path and relative wind are always parallel but travel in opposite directions. A microlights wing moving through the air in flight has relative wind, as also does a microlights wing when the aircraft is sitting on the ground with the wind blowing over it. (Refer Fig.2.2.13.)
Relative wind is caused by the motion of an aerofoil through the air, by the motion of air past an aerofoil, or by a combination of the two.

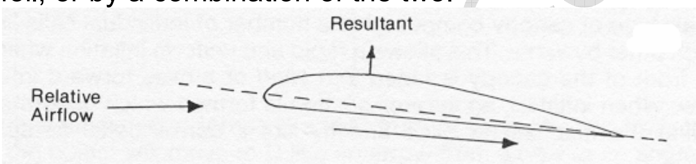



Fig.2.2.13 *Relative Wind (airflow)*

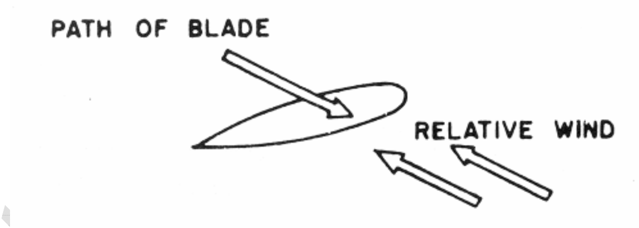



Fig. 2.2.13a *Relative Wind (rotor blade)*

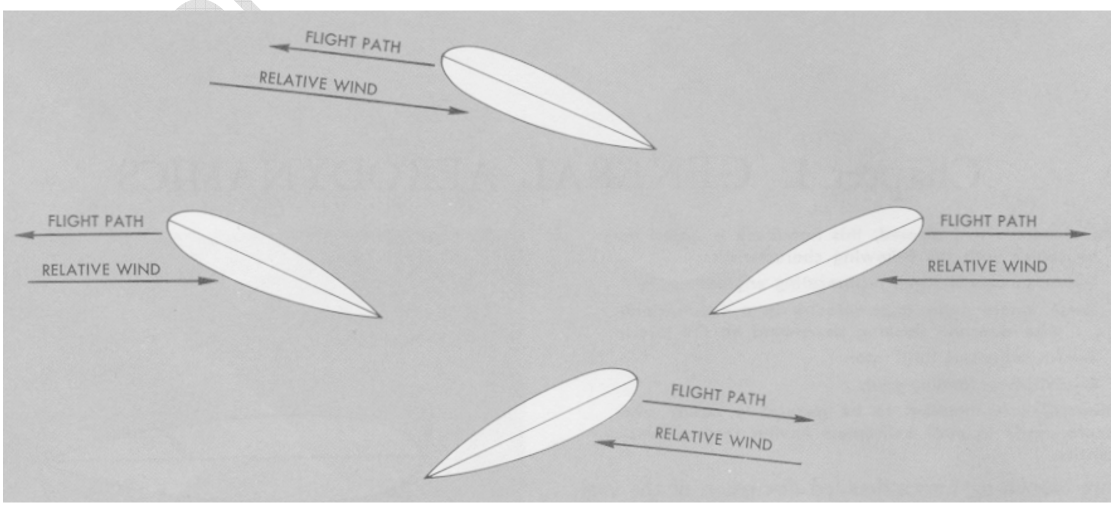



Fig.2.2.13b *Relative wind. Showing relationship between the flight path of an aerofoil and relative wind. Relative wind is parallel and in the opposite direction to the flight path.*

**$V_{NE}$** Velocity never to be exceeded. Maximum allowable speed.
**$V_A$** Design Maximum Manoeuvring speed. Up to this speed full or abrupt control deflection will not exceed the aircraft limit load factor.
**$V_{FE}$** Maximum Flaps Extended Speed. Maximum speed flaps can be used at.
**$V_s$** Minimum steady flight speed at which the aircraft is controllable

**Warm Air** - is less dense than cool air. Performance decreases in warm air.

The most difficult scenario for a microlight would be to take off from a high altitude airfield on a hot, humid day.

**Washout**
Is a term used where the incidence of a mainplane is lesser at the wingtip than at the wingroot. The effect of washout is to delay the stall of the wing at the wingtip reducing the tendency for the wingtip to drop and to maintain the effectiveness of the ailerons.

**Notes:**

## *Effects of Controls*

Microlight Aircraft are deemed to have three axis of movement. Whenever the microlight changes attitude in flight, it will rotate around one or more of these axis. The three axis intersect at the centre of gravity and each one is at right angles to the other two. (Refer Fig 2.2.5).

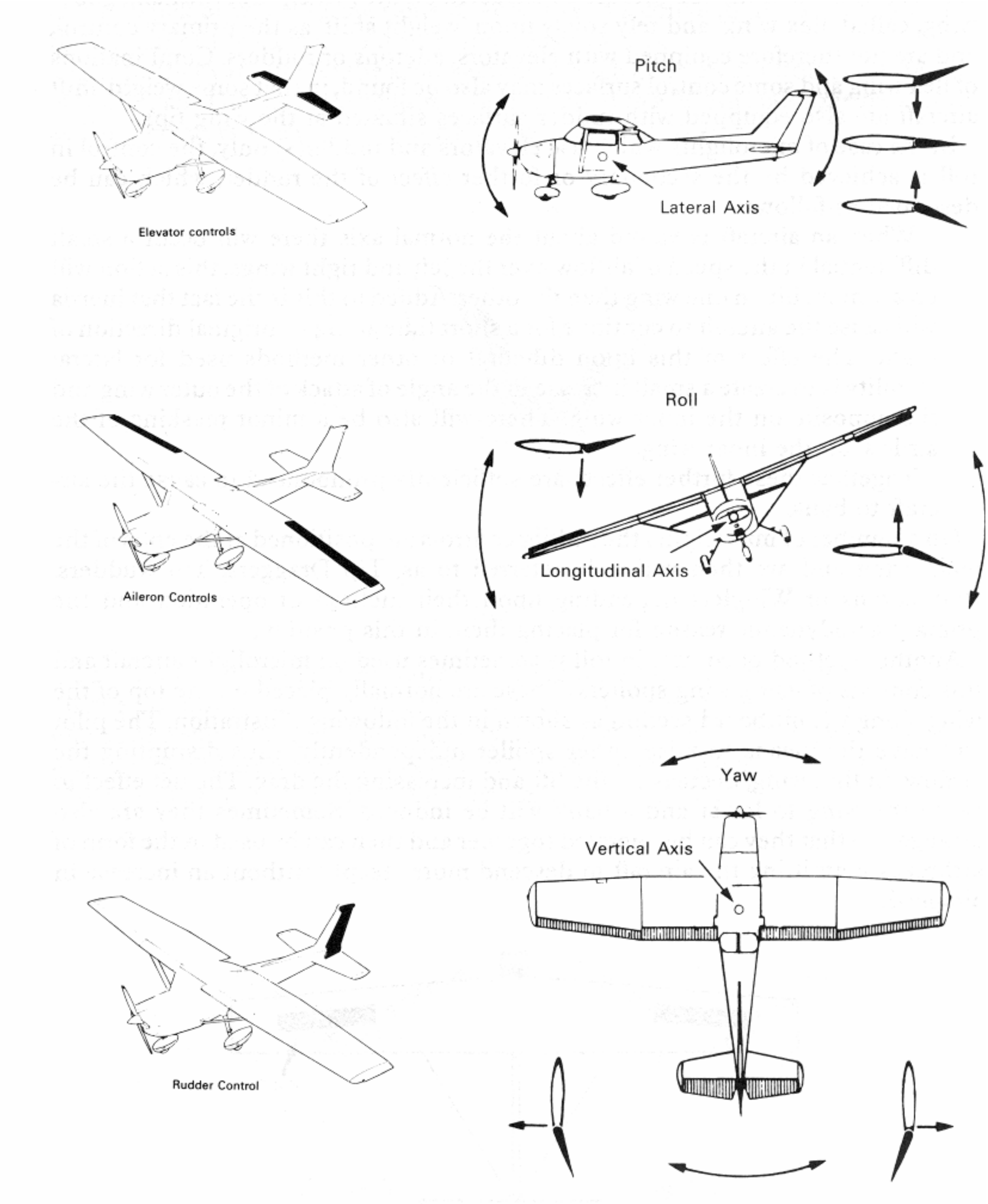



FIG. 2.2.14 *Effects of Controls*

## *The three axis*

**The Longitudinal Axis**

This is an imaginary line running length wise through the microlight from bow to stern. Movement around this axis is called rolling and it is achieved with the ailerons on a three axis control (Refer Fig. 2.2.14) and also by sail billow shift induced by weight shift e.g. a Trike (Refer Fig. 2.2.20). On a two axis control e.g. Kasper Wing, Pterodactyl, Quicksilver MX, etc. the roll is induced by a drag rudder which when deployed creates drag on the that wing while the opposite wing has full lift thereby rolling the microlight. (Refer Fig. 2.2.19)

**The Vertical Axis**
This is a line through the centre of gravity going downwards and at right angles to the longitudinal axis. Movement around this axis is called yawing and is achieved with the rudder on a three axis microlight (Refer Fig.2.2.14). On a weight shift microlight (Trike) yawing can be induced by axial twisting of the control bar. (Refer Fig. 2.2.21)

**The Lateral Axis**
This is sometimes called the pitch axis. This is the line through the centre of gravity and running span wise from wing tip to wingtip and at right angles to the longitudinal axis. Movement around this axis is called pitching and is achieved with the elevators on a three axis microlight (Refer Fig. 2.2.14). On a weight Shift microlight (Trike & Kasper Wing) this is achieved by moving the body forward or back. (Refer Fig. 2.2.23)

## *Control Surfaces*

**Ailerons**
Ailerons are located at the trailing edge of the wings, and are movable surfaces that control movement about the longitudinal axis. On some types these surfaces span the entire trailing edge of both wings.

*Roll Control - Ailerons - Spoilers*

As one surface is lowered the other is raised. The wing with the raised aileron goes down because of its decreased lift, the wing with the lowered aileron goes up because of increased lift. Moving the control stick to the right moves the left aileron down and the right aileron up. This rolls the microlight to the right. This happens because the down going left aileron increases the wing curvature (camber) and this increases the angle of attack. The right aileron moves downward and increases the camber. This results in an increased angle of attack. This increases the lift on the right wing and decreases the lift on the left wing causing a roll and the microlight will bank to the left. (Refer Fig. 2.2.15)



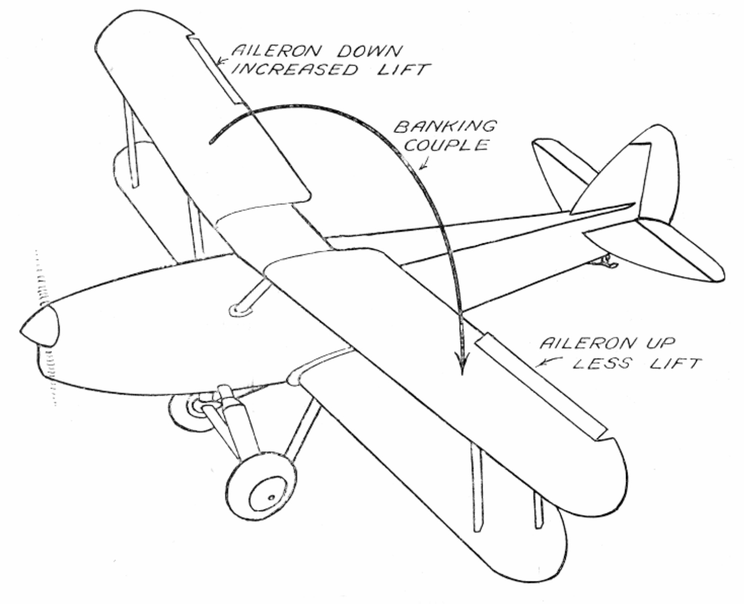



Fig.2.2.15 *Aileron controls*

**Elevators**

The Elevators control movement about the lateral axis, this is called pitch. The elevators are hinged to allow the surface to swing up and down. On some microlights the entire horizontal tail surface may move, but usually it is only the aft portion that moves. The horizontal tail surface, along with the elevators, make up a single aerofoil. Changing the position of the elevators alters the camber of the aerofoil and this increases or decreases the lift it produces. The elevators are connected to the control stick and fore and aft movement of the stick moves the elevator surface up or down. Moving the stick forward moves the elevators down, moving the stick aft moves the elevator up. Forward stick therefore increases the lift of the tail surface and causes the nose to drop. Aft stick reduces the lift on the tail surface and causes the nose to rise. The elevators control the angle of attack of the wings. When the nose is lowered the angle of attack is reduced. When the nose is raised the angle of attack is increased. (Refer Fig.2.2.16)

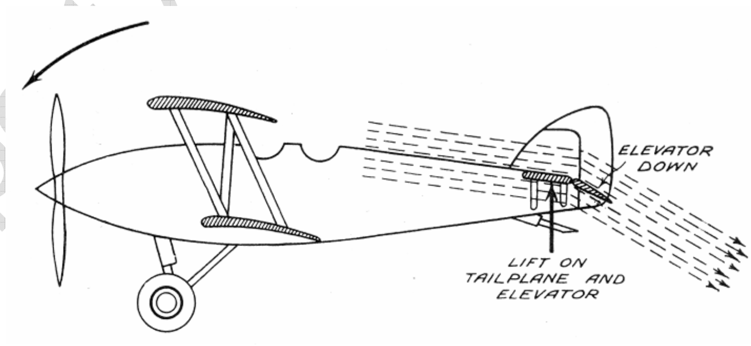



Fig.2.2.16 *Elevator control*

**Rudder**
The rudder surface controls movement of the microlight about its vertical axis. This is called yaw. The rudder is a hinged surface which swings from left to right and is attached to the vertical stabiliser or fin. Its action is similar to the elevator except that it produces movement in the yaw axis, swinging the nose from side to side. Yaw is controlled by the rudder pedals. Application of the left pedal starts a yaw to the left and the right pedal to the right. The rudder is not used to initiate turning the microlight but rather to balance the turn. (Refer Fig. 2.2.17)

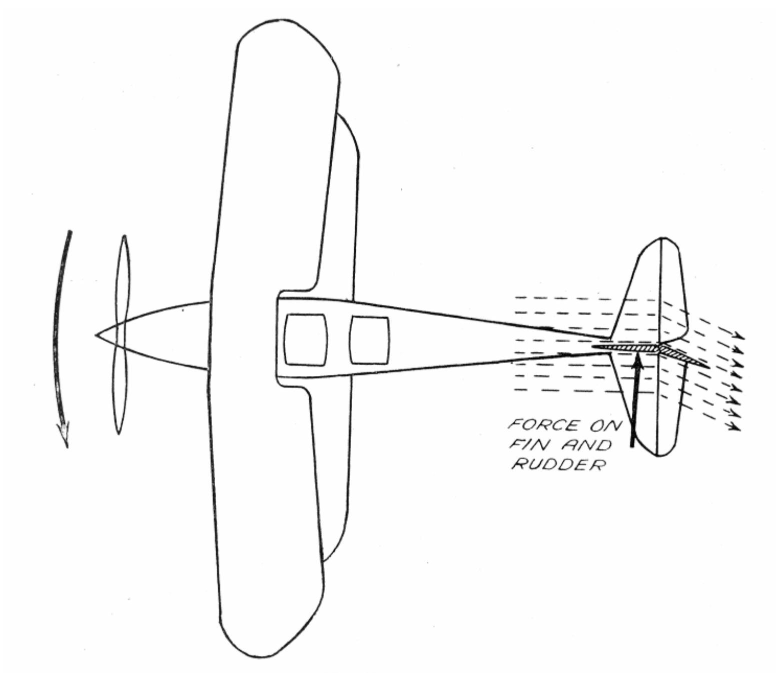



Fig.2.2.17 *Rudder control*

**Spoilers**
Spoilers are located in the outer third of each wing. When deployed a spoiler kills the lift over that portion of the wing while the other wing retains full lift and induces roll. (Refer Fig. 2.2.18)

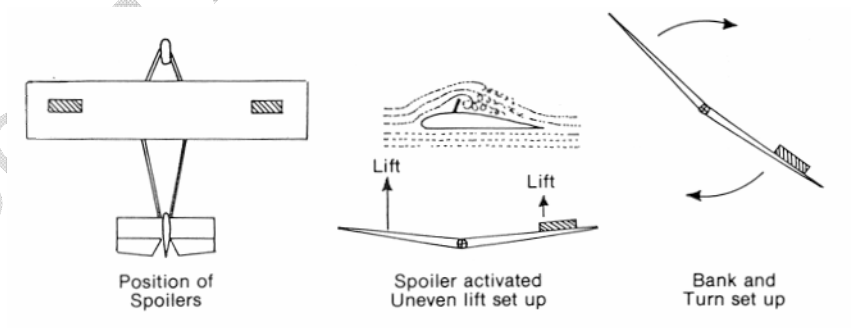



FIG. 2.2.18 *Spoiler controls*

## *Two Axis Control*
Roll is induced by activating a drag rudder on the side you wish to roll to, the rudder creates drag which causes the wing to yaw, slow down and lose lift. The opposite wing accelerates, gains lift and rolls the microlight towards the side with less lift. (Refer Fig. 2.2.19)

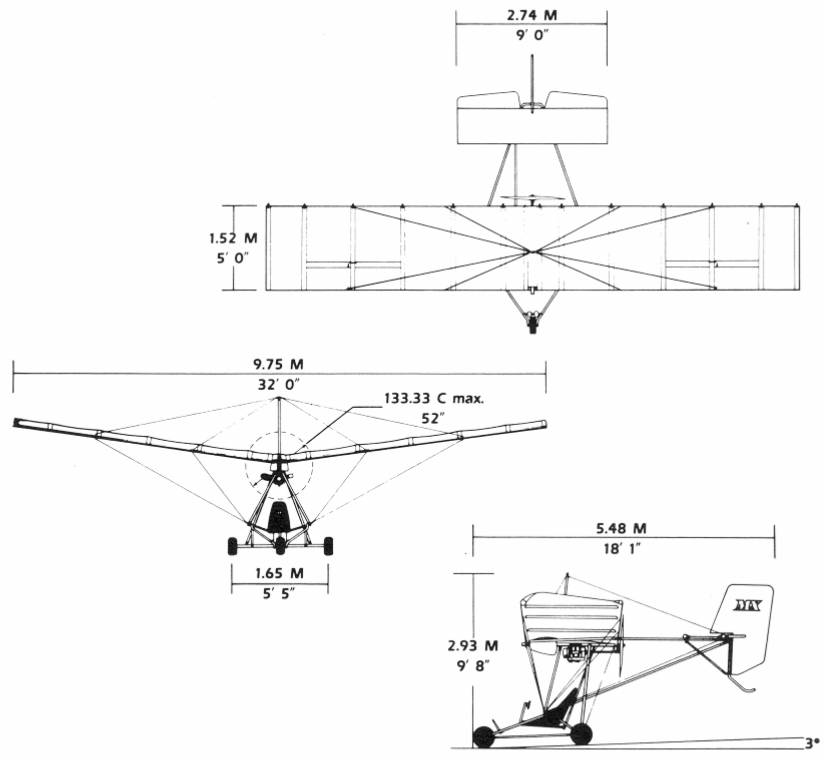



Fig. 2.2.19 *Two Axis controlled aircraft*

## *Weight Shift*

Roll is induced by pulling the your body to the side you wish to roll to, this creates a sail billow on the side of the wing you are rolling into and tightens the sail on the opposite side which creates more lift. This causes the roll. (Refer Figure 2.2.20)

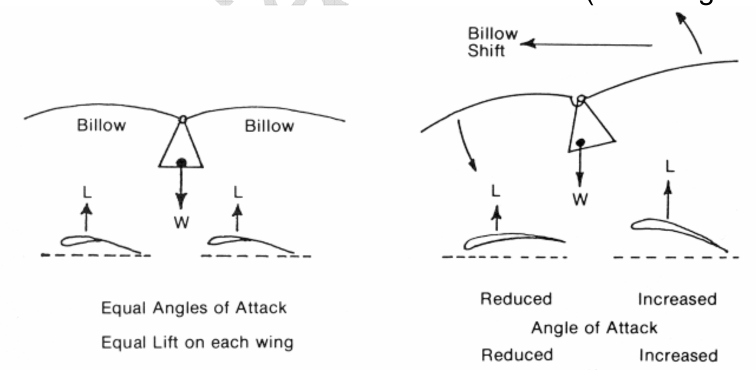



Fig. 2.2.20 *Billow shift on a trike*

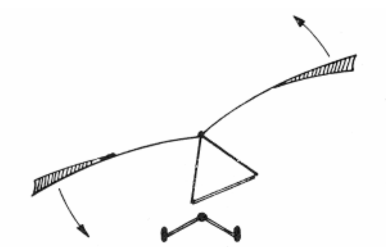


Fig. 2.2.21 *Roach effect on a trike*

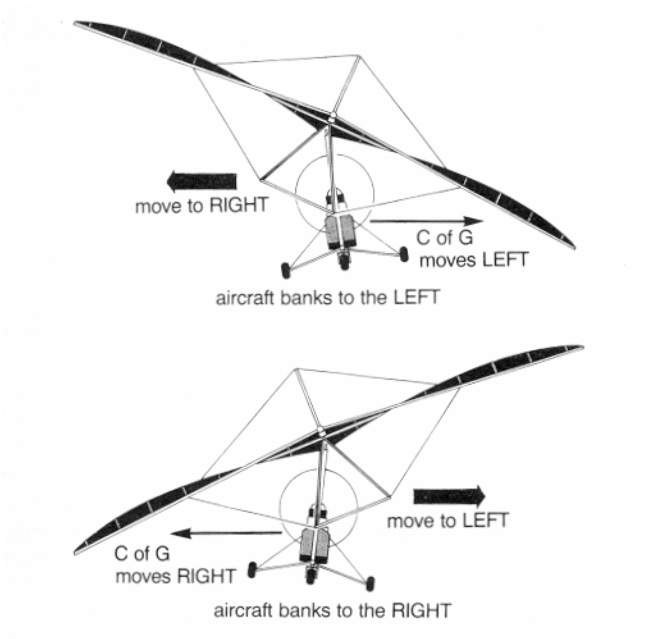



FIG.2.2.22 *Trike lateral control*

When your body is moved forward, the centre of gravity of the wing is also moved forward. This will cause the microlight to descend. When your body is moved back the centre of gravity of the wing moves rearwards and the microlight will climb. (Refer Fig 2.2.23)

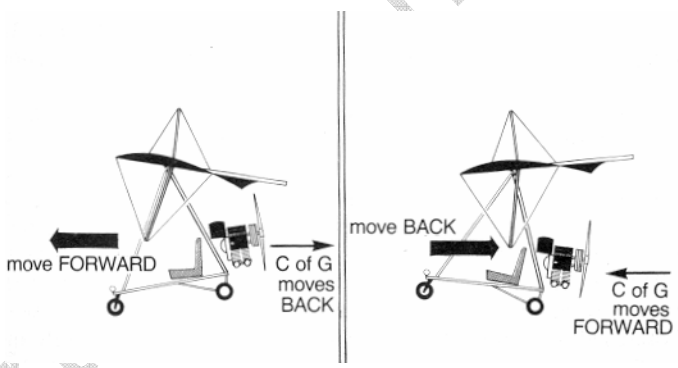



FIG.2.2.23 *Trike fore and aft control*

## *Trim Devices*

Some microlights have the means to reduce the loads felt in the controls. For example, an elevator trim can be used to ease the back pressure required to maintain a climb, or could be altered to provide 'hands off' level flight. On some microlights this may be achieved by physically moving the entire control surface to get the desired effect. Sometimes a spring tension is applied to the surface of control linkage or cable.



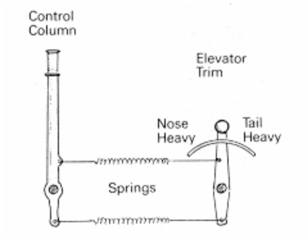



Fig. 2.2.24 *Spring trim system*

Another trim device is a trim tab which is a small movable surface attached to the control surface. Moving this tab alters the lift characteristics of the control surface it is on. This changes the stick loads and helps the pilot. On microlights with trim devices, their position must be checked before take-off as they affect the control pressure felt by the pilot.

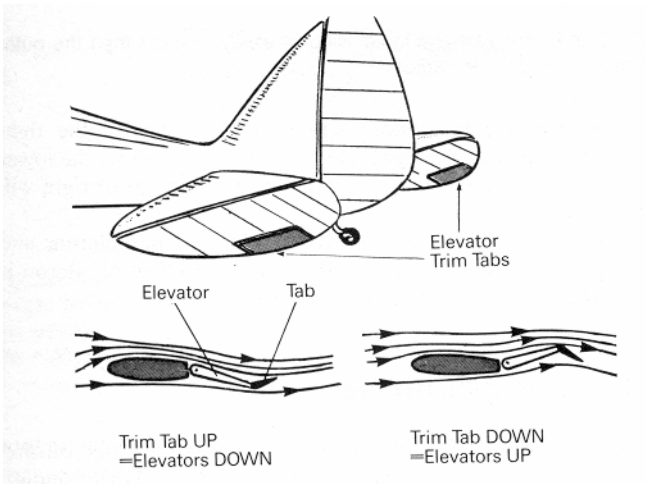



Fig.2.2.25 *Trim tab*

To provide a greater leverage, the designer normally places the control surfaces as far from the centre of gravity as possible. All control surfaces are similar.

Movement of the pilot's control alters the angle of attack with the result that the force on that control surface is altered.

## *Stability*

It is a great advantage to have an aircraft in flight demonstrate a measure of stability. The need for stability varies with the end use the aircraft is designed for.

An aircraft that is very stable would be difficult to manoeuvre while one that is unstable would be very difficult to control. The designers aim is to produce an aircraft which demonstrates an amount of stability which will not adversely effect controllability **and** manoeuvrability.

There are two types of stability in aircraft;

- Static stability; and
- Dynamic stability

## Static stability

Imagine an aircraft in straight and level flight at a constant speed. In this state, an aircraft is said to be in equilibrium with all the forces acting on it being in balance. If the aircraft encounters turbulence or a gust, these forces will become unbalanced and cause the stability of the aircraft to be effected.

When discussing static stability, there are three forms to consider;

1. Static stability
2. Neutral stability
3. Static instability

***Static stability*** can best be illustrated with a ball in a bowl. If the ball is disturbed it will move and always return to its original position in the bottom of the bowl.

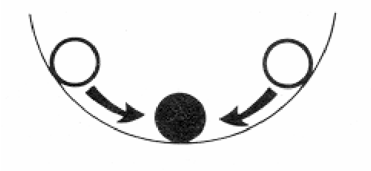


Fig. 2.2.26 *Static stability*

***Neutral stability*** can best be illustrated with a ball on a flat surface. When a force is applied to the ball, it will move to a new position on the surface and stop. There will be no tendency to move back to its original position.

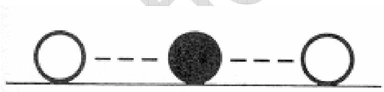


Fig 2.2.27 *Neutral stability*

***Static instability*** can best be illustrated with a ball placed on the top of an inverted bowl. Once the ball is moved it will roll down the outside of the bowl and accelerate away from its original position. This can be stated as a divergent condition.

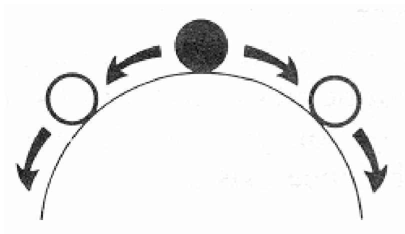


Fig. 2.2.28 *Static instability*

## Dynamic stability

When the equilibrium of an aircraft has been disturbed as mentioned above in static stability, if the aircraft is stable, it will try to return to its original state. What normally happens is that inertia and aerodynamics take over and cause the aircraft to go past its original flight attitude when it attempts to return to equilibrium. This is caused by the dynamics of the aircraft and results in a series of oscillations or ‘phugoids’.

Where the oscillations or phugoids dampen themselves out, it is said that the aircraft has some dynamic stability. This effect is called ***positive dynamic stability.***

Where the oscillations or phugoids carry on with out increasing in severity (hunting), this effect is called ***neutral dynamic stability***.

Where the oscillations or phugoids increase in severity and diverge, this is called ***dynamic instability*** – a dangerous situation for an aircraft to be in.

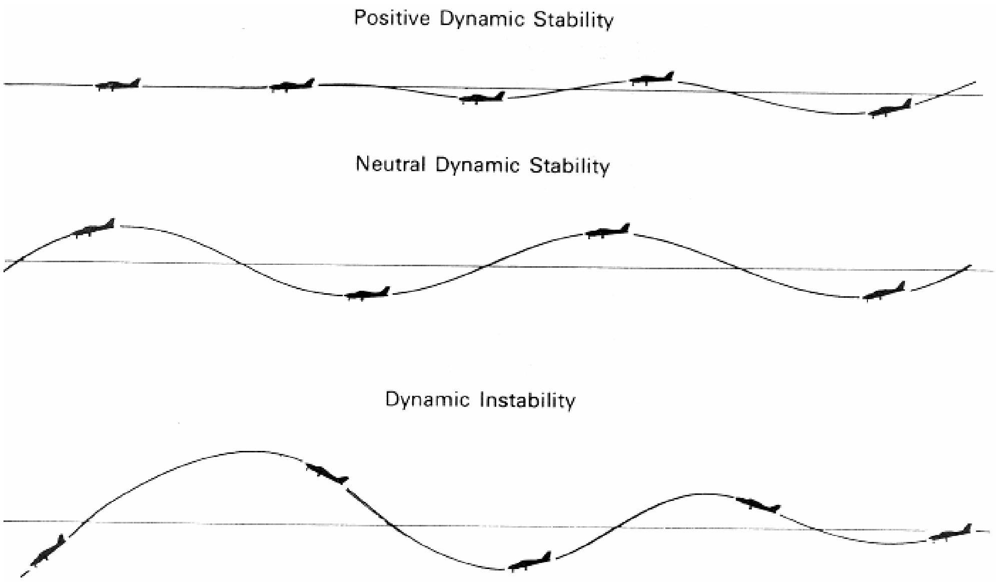



Fig. 2.2.29 *The three forms of dynamic stability*

**Directional stability**
If a gust of wind moves or yaws the nose of an aircraft to one side, say to the left (port), it will proceed to fly 'crabwise' skidding or slipping to the right (starboard).

The airflow now hits the tail fin and weathercocks the aircraft back into line on its original course back into the wind.

When there is sufficient vertical fin area to cause the aircraft to positively weathercock back into wind the aircraft is said to be statically stable directionally.

When there is insufficient vertical fin area to cause the aircraft to positively weathercock back into wind the aircraft is said to be neutrally stable directionally and the aircraft will continue to hold the yaw.

If the aircraft overshoots its original position every time and sets up an oscillation or hunting in yaw, it is said to be dynamically unstable in yaw.

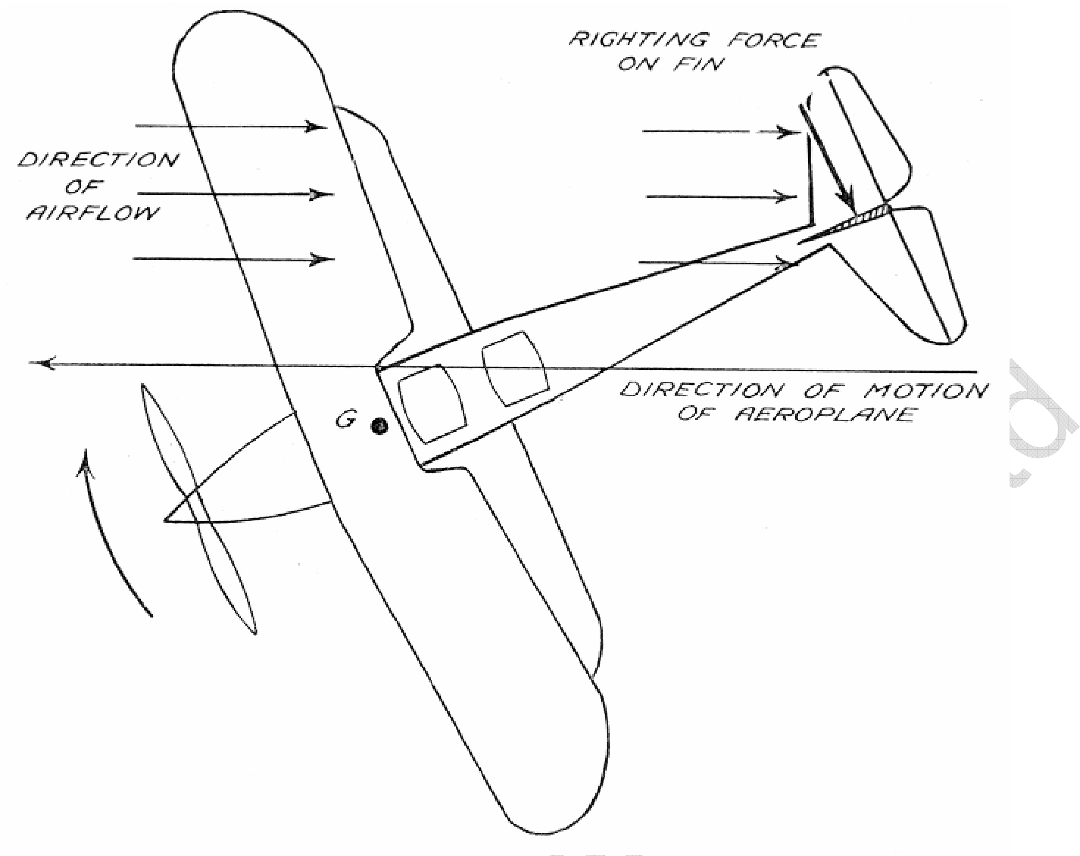



Fig. 2.2.30 *Directional stability is aided by a vertical fin that will weathercock the aircraft straight into the airflow*

**Lateral stability**
If a gust of wind banks an aircraft over to the right (starboard)), it will start to slip to the right.
Lateral stability is normally obtained by giving the wings dihedral – that is, fitting them at a slight positive angle to the horizontal. See Figure 2.2.31

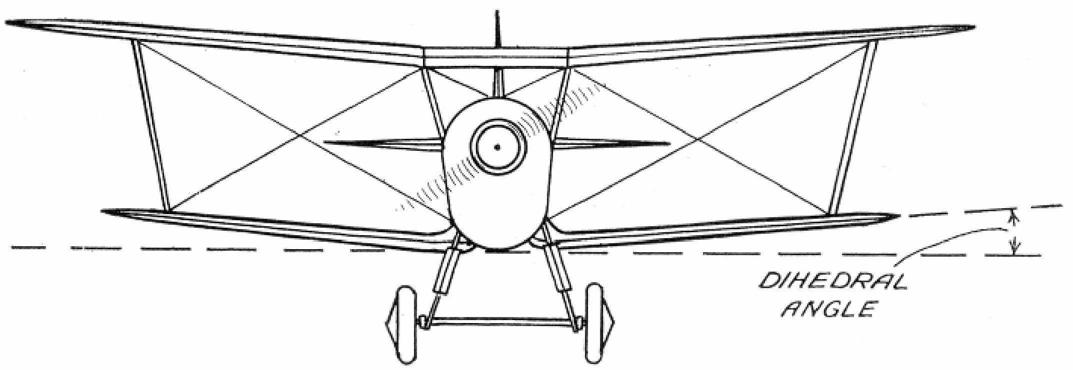



Fig. 2.2.31 *Dihedral on the wings aid lateral stability*

When the aircraft sideslips now, the air strikes the under-side of the depressed wing at a greater angle of attack that it does the elevated wing. So long as the depressed wing remains unstalled, the lift of the depressed wing is increased and a righting movement is introduced which tends to put the aircraft back on an even keel laterally.



The aircraft is now statically stable laterally.

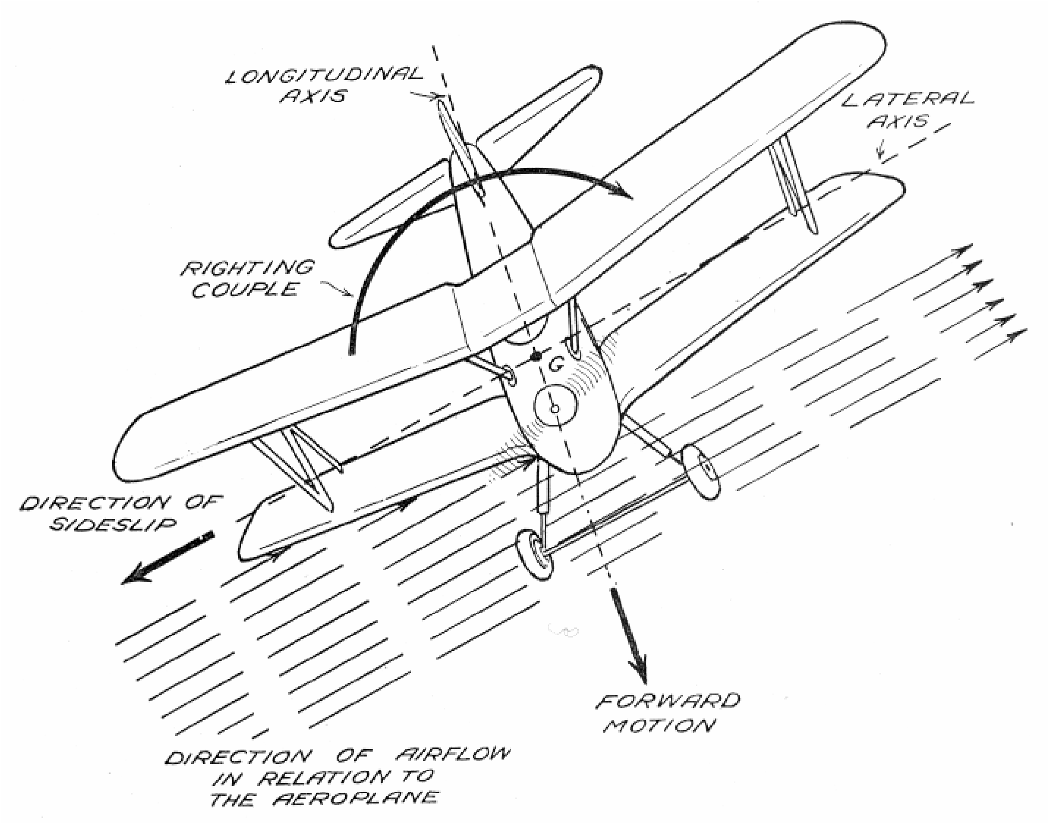



Fig. 2.2.32 *The stabilising effect of dihedral*

## *The effects of power on aircraft handling*

Microlight aircraft have engines of varying horsepower and location. The application and reduction of power will therefore have an effect on aircraft handling and control. When an engine swings a propeller, it produces thrust and torque. The propeller also produces a slipstream which is rotary in motion. The direction of this rotary motion is dependent on the direction the propeller rotates.

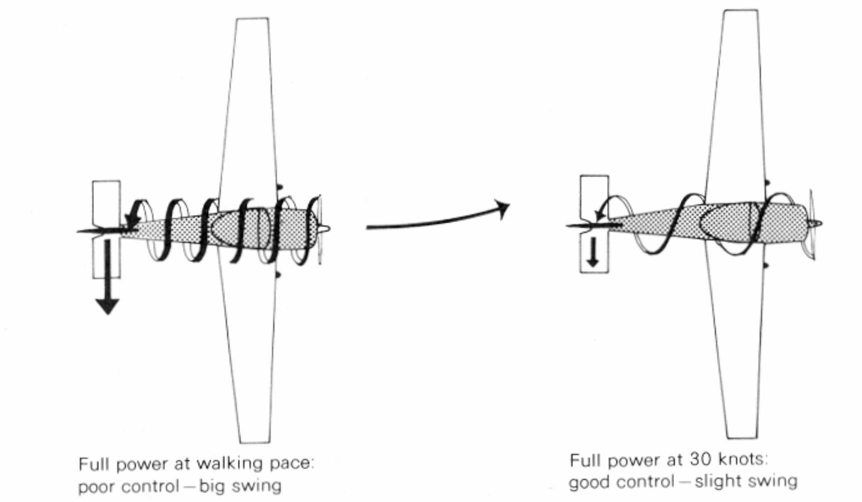



Fig. 2.2.33 *Slipstream effect on directional control*



As can be seen in Figure 2.2.33 torque is felt more at high power and low speed. This requires a larger rudder input in the early stages of take-off to keep the aircraft tracking down the runway centreline.

Another effect of torque is associated with tailwheel aircraft. Here the effect of gyroscopic precession is coupled with propeller torque to magnify the swing on takeoff.

As the tail comes up on takeoff, the propeller (which is like a gyroscope) is forced to take up a new plane. This is a vertical pitch down until the thrust line of the aircraft is horizontal. It is well known that to make a gyroscope change its plane of rotation (precess), the input must be made 90º before the required resultant.

When the tail of the aircraft rises it is putting in an input to the propeller and, as it is fixed to the crankshaft and cannot move laterally, the whole fuselage is forced to swing left or right due to the gyroscopic forces and the rotation of the propeller.

To prove this point, take a bicycle wheel in your hands by the axle and have a friend spin the wheel. Try to change its plane of rotation and feel which way the axle wants to move.

As the thrust line of an engine is rarely inline with the drag of an aircraft, there will always be a couple or turning moment created between the two.

An aircraft with a high thrust line over a low drag line will want to pitch down when power is applied. Conversely, an aircraft with a low thrust line over a higher drag line will want to pitch up in the same circumstances.

Aircraft designers sometimes try to minimise these effects by giving the engine an inclined thrust line or offsetting the fin of the aircraft.

Pilots should therefore expect a change of pitch and direction when changing power settings.

**Notes:**



