8.4 Flight Stability

Flight Stability and Dynamics

The stability of an aircraft means its ability of return to some particular condition of flight (after having been slightly disturbed from that condition) without any efforts on the part of the pilot.

An aircraft may be stable under some conditions of flight and unstable under other conditions. Control means the power of the pilot to manoeuvre the aircraft into any desired position.

As already stated, an aircraft which, when disturbed, tends to return to its original position is said to be stable. If on the other hand, it tends to move farther away from the original position, it is unstable.

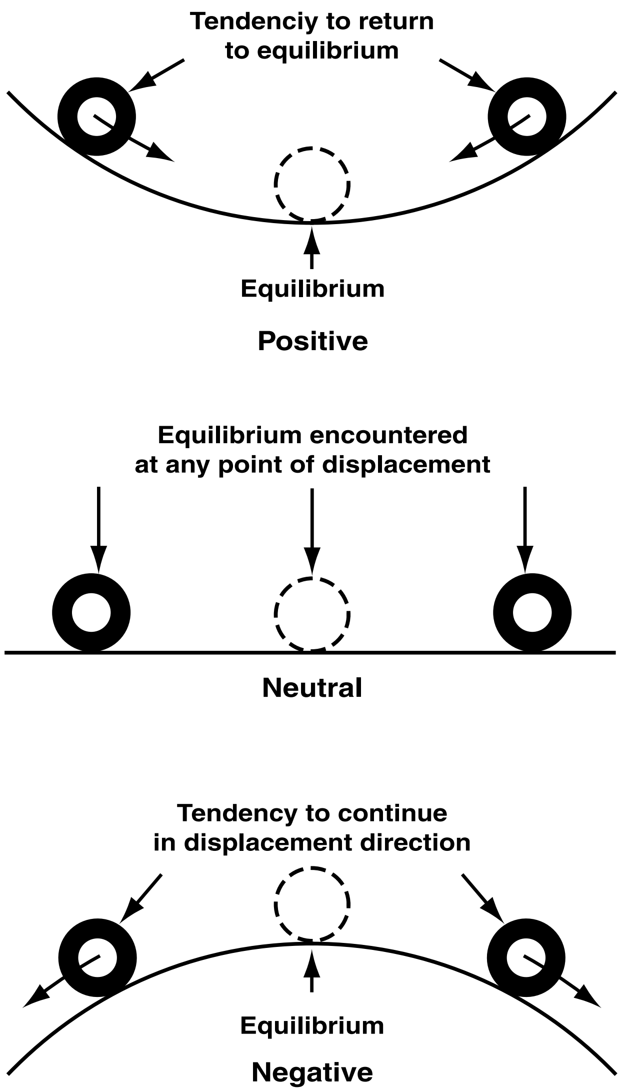
But it may tend to do neither of these and prefer to remain in its new position. This is called neutral stability, and is sometimes a very desirable feature.

Static Stability

This means that when disturbed from its flight path, forces will be activated which will initially tend to return the aircraft to its original position.

The returning forces may be so great that the aircraft will pass beyond the original position and continue in that direction until stability again tries to restore the aircraft into its original position. This will continue with the oscillations either side of the original becoming larger.

Figure 1: Static Stability

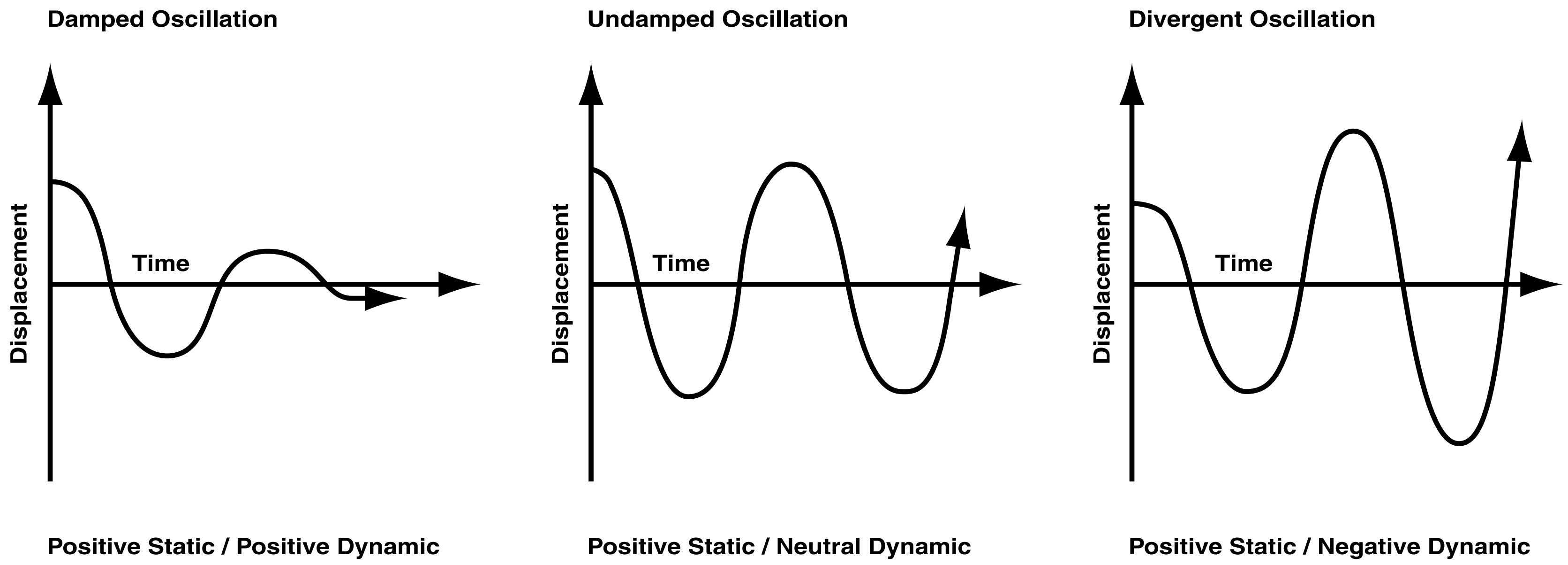


Dynamic Stability

Static stability, as was stated, creates a force that tends to return the aircraft to its original angle of attack, but it is the dynamic stability of the aircraft that determines the way it will return. It is concerned with the way the restorative forces act with regard to time.

In other words, it is the property which dampens the oscillations set up by a statically stable aircraft.

Figure 2: Dynamic Stability



When the oscillations become smaller and eventually return the aircraft to its original position the aircraft has positive static and positive dynamic stability.

Figure 2 on page 3 illustrates some of the ways in which an aircraft may behave when it is left to itself. Only a pitching motion is shown; exactly the same considerations apply to roll and yaw, although a particular aircraft may have quite different stability characteristics about its three axes.

Longitudinal Stability about the Lateral Axis

There are two important factors which will affect Longitudinal Stability. These are:

- The Position of the Centre Of Gravity

  This must never be too far back or a strong nose up tendency will exist. This is the most important consideration and is controlled by correct aircraft loading.

- The Pitching Moment on the Wings

  If the aircraft is disturbed nose up, the angle of attack is increased. This causes the centre of pressure to move forwards. The effect of this is to pull the nose up further away from its original position.This is static instability which can be controlled by wing design but will never completely disappear.

The Horizontal Stabilizer

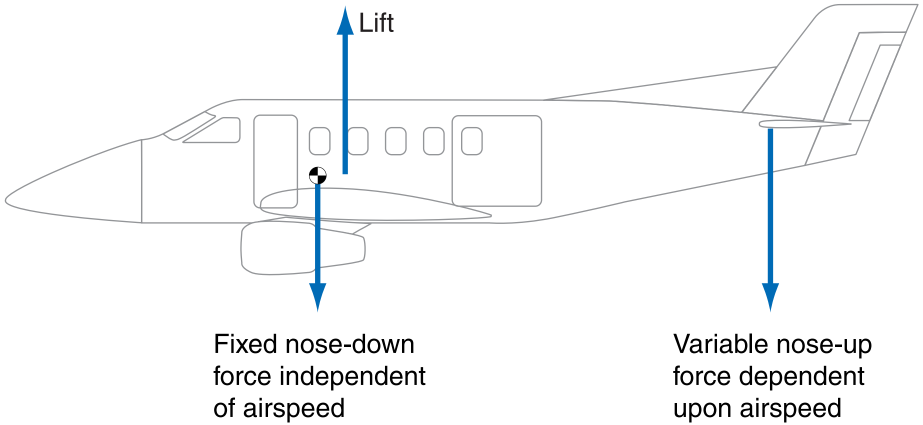
In the same situation with the nose displaced upwards, the angle of attack of the horizontal stabilizer will alter. This will change the force produced by the stabilizer. This change of force will be a restoring moment.

The amount of restoring moment will depend on:

1. The Area of the stabilizer: A larger stabilizer will supply more force.
2. The Length of the Fuselage: For a given size of stabilizer, a longer fuselage will give more leverage and more restoring moment.

The nose-down force caused by the CG's position ahead of the center of lift is fixed and does not change with airspeed. But the tail load is speed dependent the higher the airspeed, the greater the downward force on the tail. If the aeroplane is trimmed for level flight with the pilot's hands off the controls, and a wind gust causes the nose to drop, the aeroplane will nose down and the airspeed will increase. As the airspeed increases, the tail load increases and pulls the nose back to its level flight condition. If the nose is forced up, the airspeed will drop off, and the tail load will decrease enough to allow the nose to drop back to level flight. (see “Figure 3” on page 4).

Figure 3: Longitudinal Stability



Flying wing aeroplanes usually have a large amount of sweepback, and since they have no tail, their longitudinal stability is produced by washing out the tips of the wing. The speed-dependent downward aerodynamic force at the wing tip is behind the center of lift, and it produces the same stabilizing force as that produced by a conventional tail.

Lateral Stability About the Longitudinal Axis

An aircraft that tends to return to wings level flight after it has been disturbed is considered to be laterally stable.

The many factors that effect lateral stability are:

Dihedral Angle

This is the upward and outward slope of the wing. If the wing tip is higher than the wing root relative to the horizontal plane, the aircraft has positive dihedral. Negative dihedral is termed anhedral.

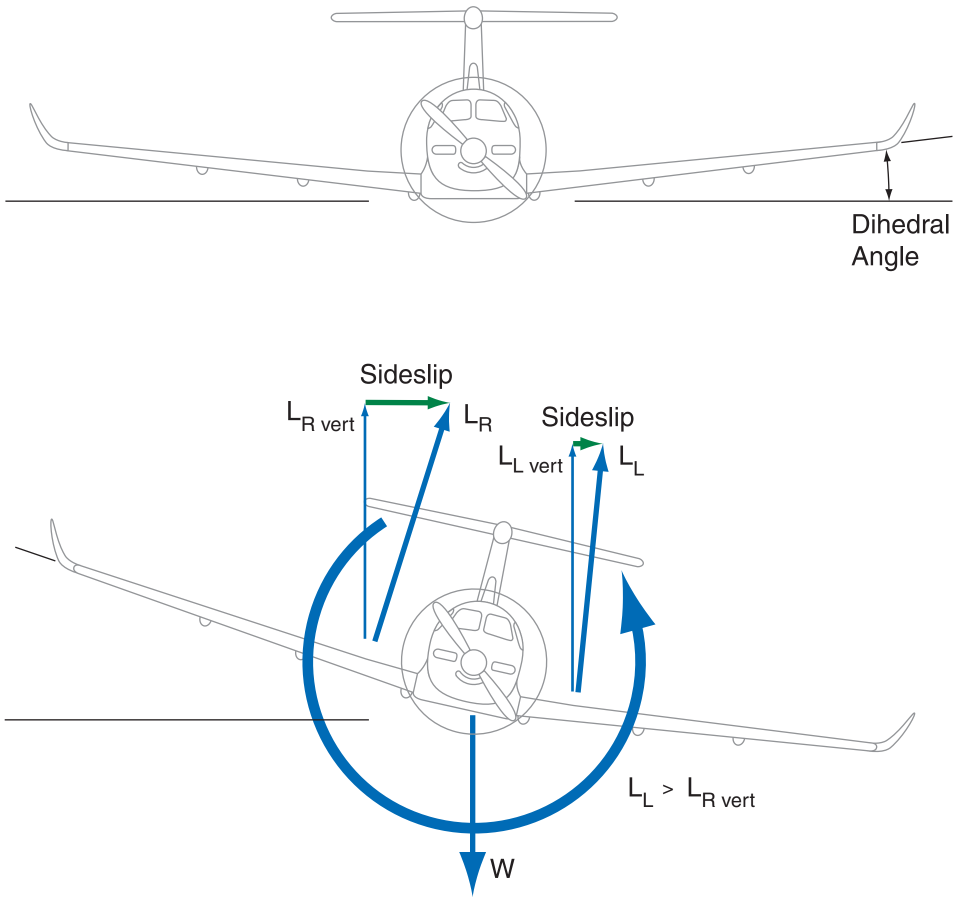
When an aircraft rolls, the lower wing presents a larger span as seen from the direction of the approaching air, the effect is to roll the aircraft back towards the horizontal. This will always be a restoring moment.

If the restoring moment is insufficient to restore level flight the aircraft will begin to sideslip.

Now the effect of dihedral comes into effect. In a sideslip the lower wing has increased angle of attack while the upper wing has a reduced angle of attack.

The greater lift on the lowered wing will restore level flight.

Figure 4: Dihedral Angle



Sweepback

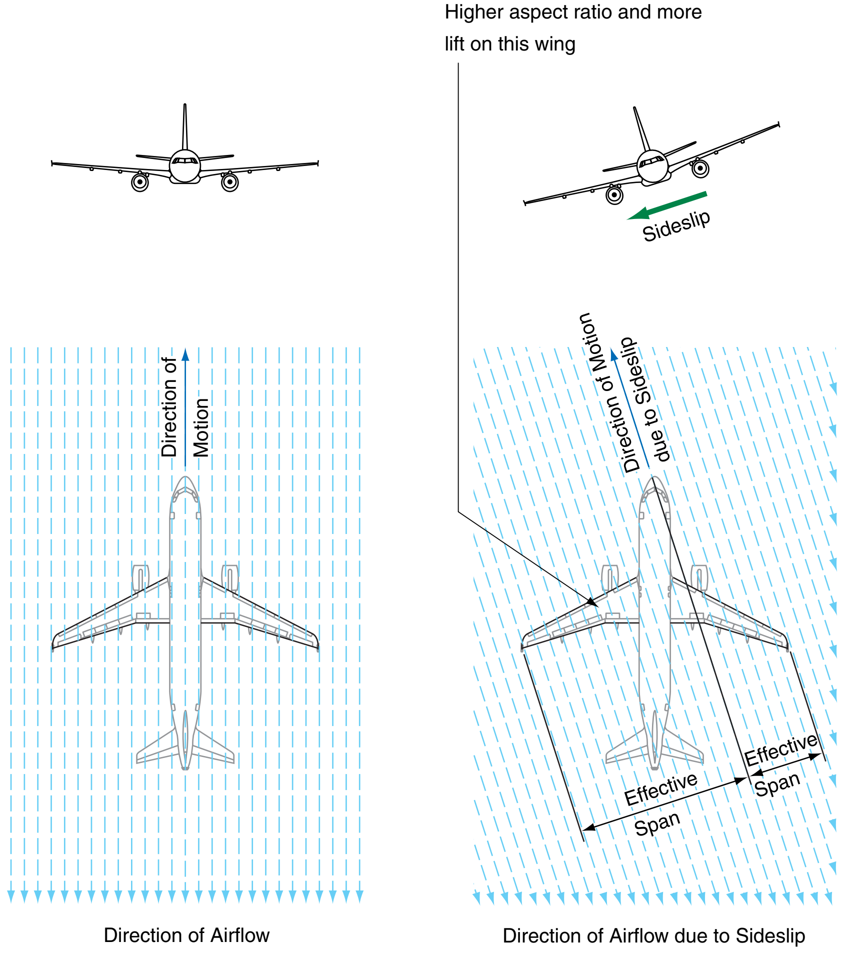
Sweepback Angle is the angle at which the wing points backwards from the root to the tip.

Sweepback is used mainly on high-speed aircraft and its primary purpose is to delay the formation of sonic shock waves which are produced at high speeds and cause a large increase in drag.

The secondary effect of sweepback is to improve lateral stability. When a side-slip occurs, the lower wing presents a larger span as seen from the direction of the approaching air, and as with dihedral, the effect is to roll the aircraft back towards the horizontal.

In general, as the sweepback angle is increased the dihedral angle will be reduced.

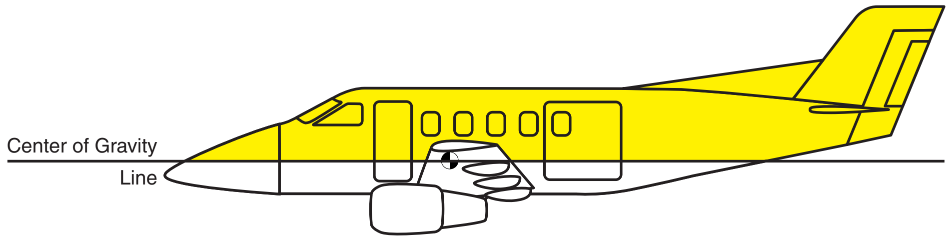
Figure 5: Sweepback and Lateral Stability



Keel Effect

If an aircraft begins to sideslip, all of the keel surface above the centre of gravity will be presented to the relative airflow which will give a force to help in correcting the roll.

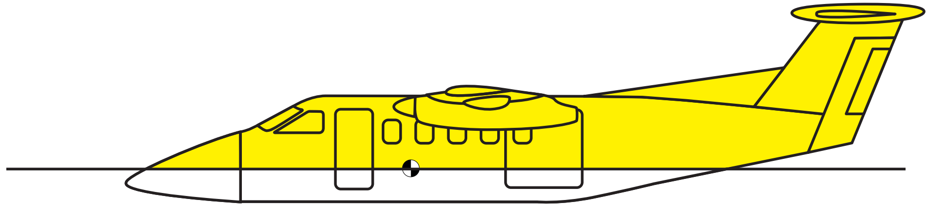
Figure 6: Keel Effect



High Wings

Mounting the wings above the centre of gravity aids lateral stability because the weight of the aircraft will act as a pendulum to restore level flight.

Figure 7: Keel Effect



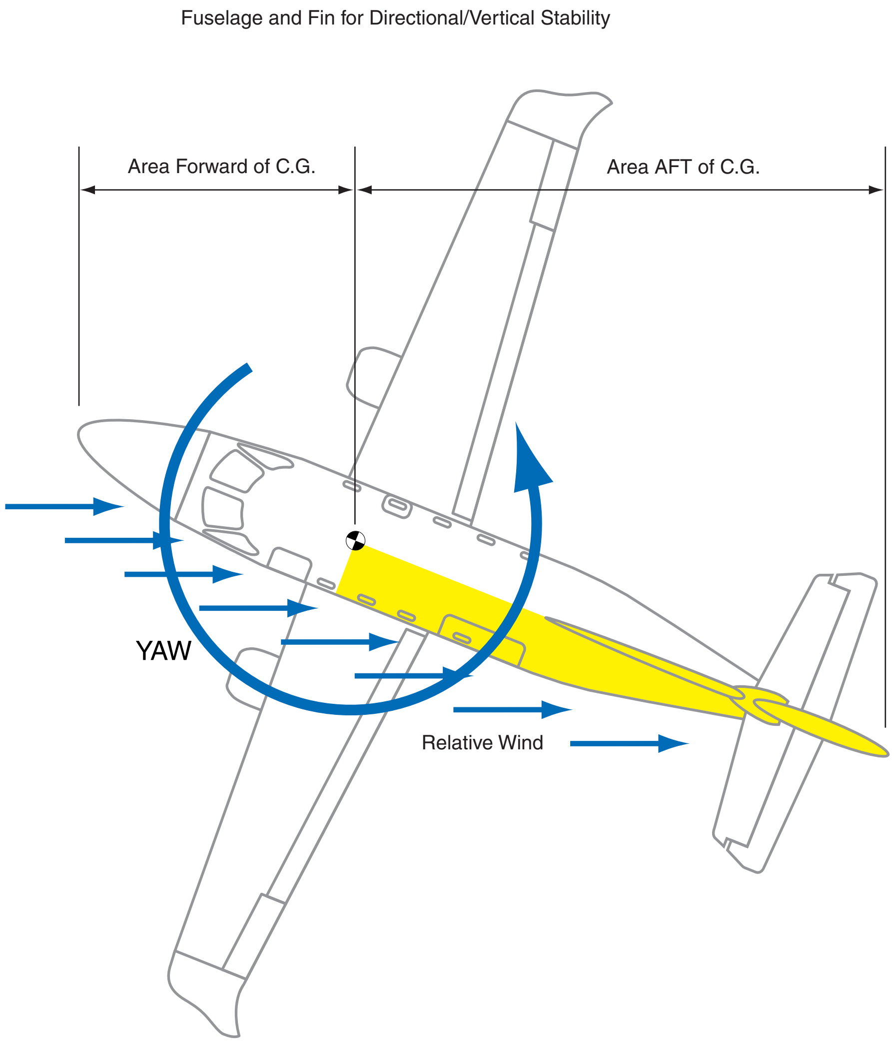
Directional Stability about the Vertical Axis

Directional Stability is displayed around the vertical axis and depends to a great extent on the quality of lateral stability. If the longitudinal axis of an aircraft tends to follow and parallel the flight pattern of the aircraft through the air, whether in straight flight or curved flight, that aircraft is considered to be directionally stable.

Directional stability is accomplished by placing a vertical stabilizer or fin to the rear of the centre of gravity on the upper portion of the tail section.

The surface of this fin acts similar to a weather vane and causes the aircraft to weathercock into the relative wind. If the aircraft is yawed out of its flight path, either by pilot action or turbulence, during straight flight or turn, the relative wind would exert a force on one side of the vertical stabilizer and return the aircraft to its original direction of flight.

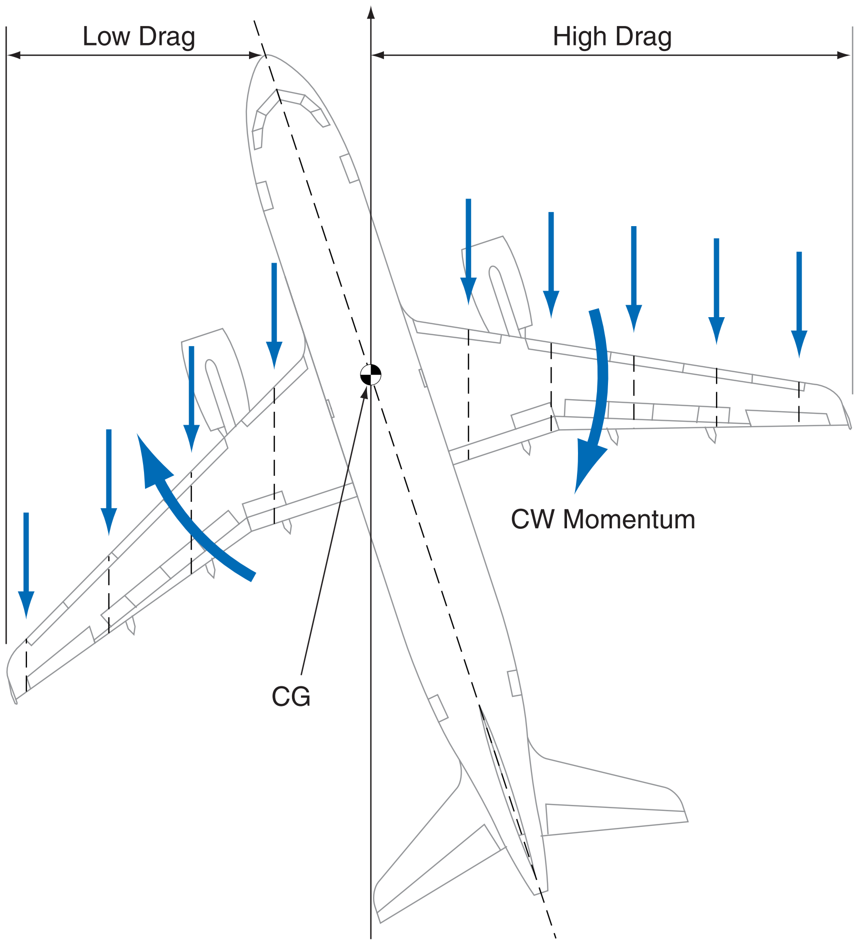
Figure 8: Directional Stability



Wing sweepback aids in directional stability. If the aircraft is rotated about the vertical axis, the aircraft will be forced sideways into the relative wind.

Because of sweepback this causes the leading wing to present more frontal area to the relative wind than the trailing wing. This increased frontal area creates more drag, which tends to force the aircraft to return to its original direction of flight.

Figure 9: Sweepback Wings Effect on Directional Stability



Even though an aircraft has inherent stability, it does not always tend to fly straight and level. The weight of the load and its distribution affect stability. Various speeds also affect its flight characteristics.

If the fuel in one wing tank is used before that in the other wing tank, the aircraft tends to roll toward the full tank. All of these variations require constant exertion of pressure on the controls for correction.

While climbing or gliding, it is necessary to apply pressure on the controls to keep the aircraft in the desired attitude.

Interaction between Lateral and Directional Stability

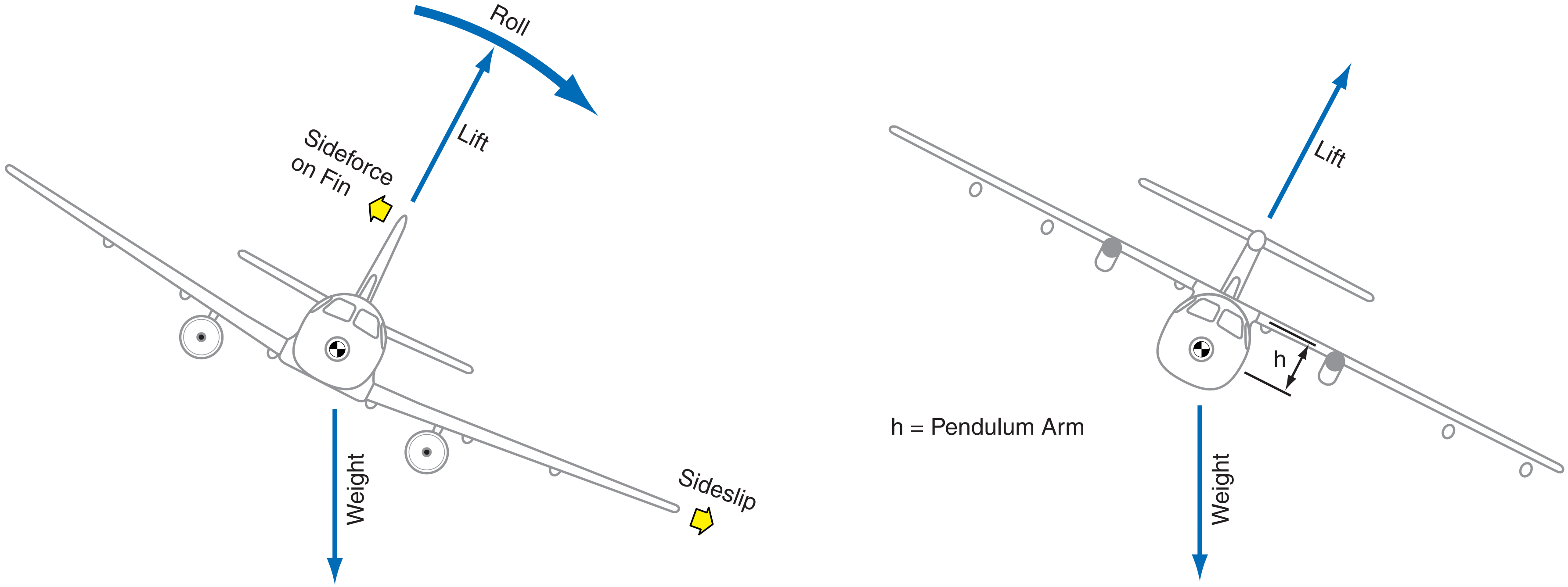
The sideslip essential to lateral stability will cause an air pressure on the side surfaces which have been provided for directional stability. The effect of this pressure will be to turn into the relative wind, i.e. in this case, towards the direction of sideslip. The aircraft, therefore will turn off its original course and in the direction of the lower wing. The greater the directional stability the greater will be the tendency to turn off course in a sideslip. This turn will cause the raised wing, now on the outside of the turn, to travel faster than the inner or lower wing, and therefore to obtain more lift and so bank the aeroplane still further.

If the left wing drops and the pilot applies rudder so as to turn the aircraft to the right, he will probably prevent it from departing appreciably from its course. We can now explain the modern technique of turning an aeroplane. Suppose, when we want to turn left, instead of applying any rudder we simply bank the aeroplane to the left, as we have already seen it will slip inwards and turn to the left.

So effective is this method that is has become unnecessary to use the rudder on some aircraft for turning purposes. So far as the yaw is concerned and a turn involves a yaw the rudder with the help of the fin is still responsible,. The difference is simply that the rudder and fin are brought into effect by the inward sideslip, instead of by application of rudder which tends to cause an outward skid. The pilot may do nothing about it but the inherent stability of the aircraft puts a force on the rudder for him.

Just: as a slight roll results in a sideslip and then a yawing motion so if an aircraft moves in a yawed position, that is if it moves crabwise (which is really the same thing as slipping or skidding) lateral stability will come into play and cause the aircraft to roll away from the leading wing. Thus a roll causes a yaw, and a yaw causes a roll, and the study of the two cannot be separated.

Figure 10: Stability Interaction



If an aircraft is very stable directionally and not very stable laterally, e.g. if it has large fin and rudder and little or no dihedral angle. or other “dihedral effect”, it will have a marked tendency to turn into a sideslip, and to bank at steeper and steeper angles, that it may get into an uncontrollable spiral this is sometimes called spiral instability, but note that it is caused by too much stability (directional).

If, on the other hand, the aeroplane is very stable laterally and not very stable directionally, it will sideslip without any marked tendency to turn into the sideslip. Such an aircraft is easily controllable by the rudder, and if the rudder only is used for a turn the aircraft will bank and make quite a nice turn. The main point to be emphasised is that too much stability (of any type) is almost as bad as too little stability.

Dutch Roll

“Dutch Roll” is an inherent characteristic of all swept wing aircraft.

Any aircraft, straight or swept, will tend to roll as the aircraft is yawed. This is due to the increased velocity of the forward moving wing and the decreased velocity of the backward moving wing.

However, swept wing aircraft, in addition to this effect while the aircraft is being yawed, will also tend to roll even in a steady state of yaw. The reason for this is illustrated on Figure 11 on page 13.

In a straight winged aircraft with a steady yaw both wings are at an equal angle to the incident air flow and will therefore lose lift to a slight extent equally. There is consequently no tendency to roll with steady yaw.

A swept wing aircraft, on the other hand, in a steady state of yaw tends to continue to roll. This is due to a loss of lift on the trailing wing (due to increased effective sweep) and an increase of lift on the forward wing due to a more direct incident air flow. (see “Figure 9” on page 9)

It follows that if a swept wing aircraft is yawed slightly. it will roll to marked degree.

The roll at first tends to create a situation of side slip, which increases the yaw. This continues until the natural stability of the aircraft and the extra drag on the leading wing comes into effect and starts to correct the yaw. The aircraft then yaws in the other direction and consequently rolls in the other direction. This leads to an unstable state of yawing and rolling from side to side in a corkscrew manner. This phenomenon is Dutch roll.

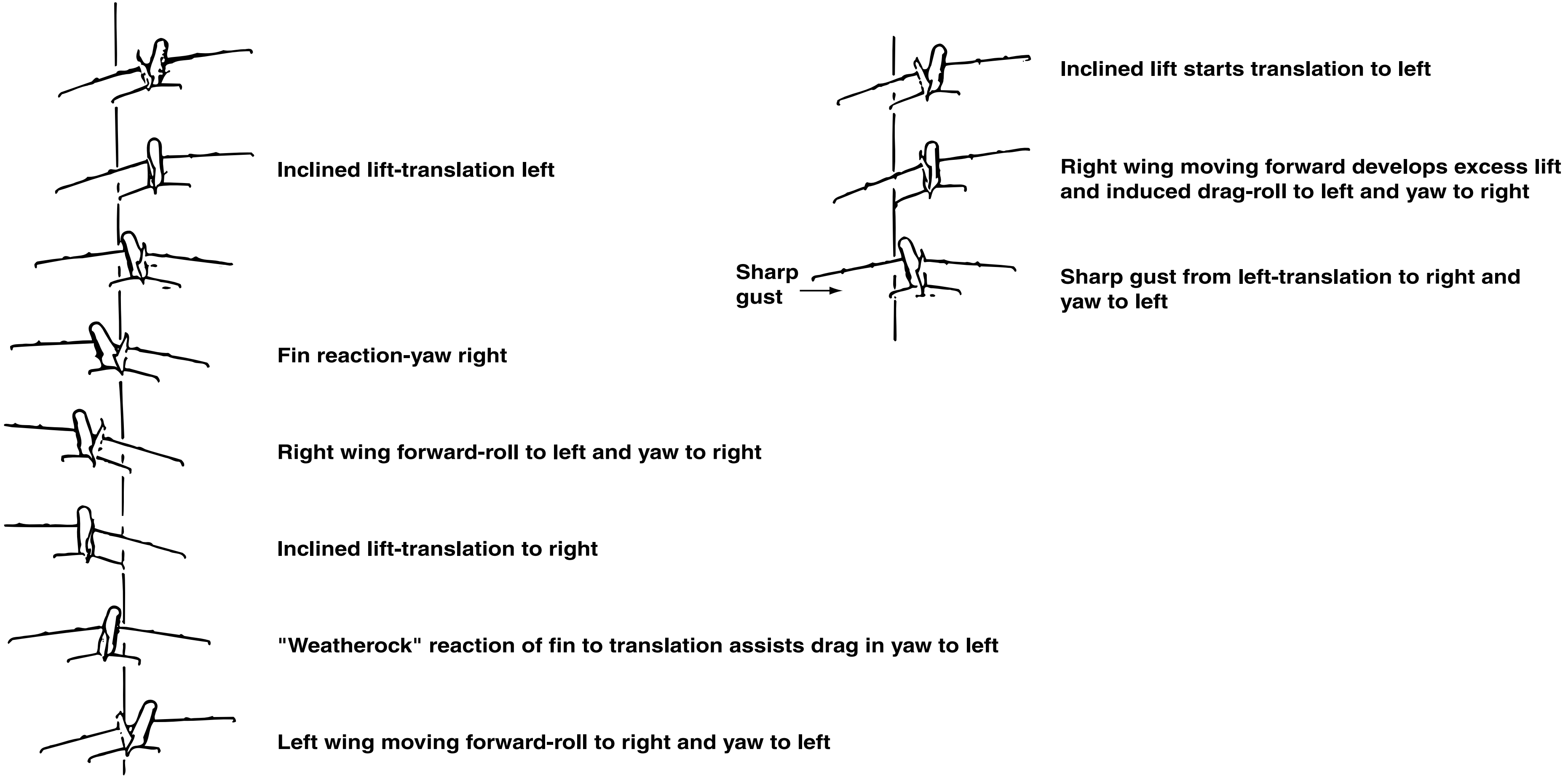
Since “Dutch Roll arises primarily from yawing of the aircraft, the rudder is the primary correcting medium. The basic method of correcting Dutch Roll is to use the rudder and the yaw damper works this way.

When correcting Dutch Roll” manually, however, the timing of rudder corrections is difficult and miss - timing can accentuate the corkscrew.

The simplest method of correction is therefore to keep wings level using the ailerons.

If all the corrections needed to dampen out Dutch Roll were accomplished manually this would put an excessive work load on the pilot. Therefore an automatic yaw damp system is required.

Figure 11: Dutch Roll



First cycle of a typical dutch roll development as viewed from AFT and above the airplane

Active Stability

Static stability is good for most aeroplanes, but not for highly manoeuvrable military fighter aircraft. These aircraft are designed with what is known as relaxed static stability, and have little or no static stability. The aeroplane must be flown at all times, an almost impossible task for the pilot. To overcome this limitation, aeroplanes with relaxed static stability have sophisticated electronic stability augmentation systems that compensate for the lack of natural static stability.

An other example are aeroplanes that have Dutch Roll problem. These are usually equipped with a yaw damper, a special automatic flight control device that senses the Dutch roll and applies corrective rudder action to prevent or at least greatly attenuate it.

System Description: aircraft yaw, pitch and roll movement along with air data or inertial reference are detected by various aircraft instruments which will send signals to a computer. The computer will then process the information and send a signal to the rudder actuators to move the rudder to dampen yaw, thus considerably reducing the effects of Dutch Roll. Manual operation of the rudder pedals has priority over yaw damp.