DOCUMENT
GSM-G-CPL.003

DOCUMENT TITLE

AERODYNAMICS 2

CHAPTER 4 – LATERAL STABILITY

Version 1.2
October 2013

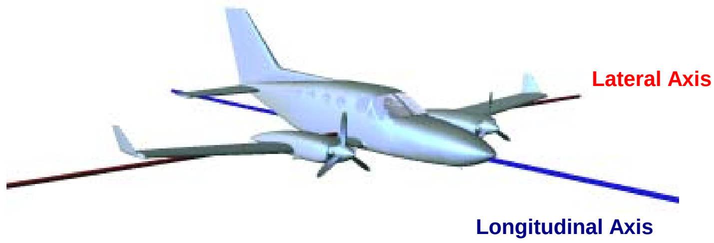
CONTENTS .... PAGE

LATERAL STABILITY

INTRODUCTION

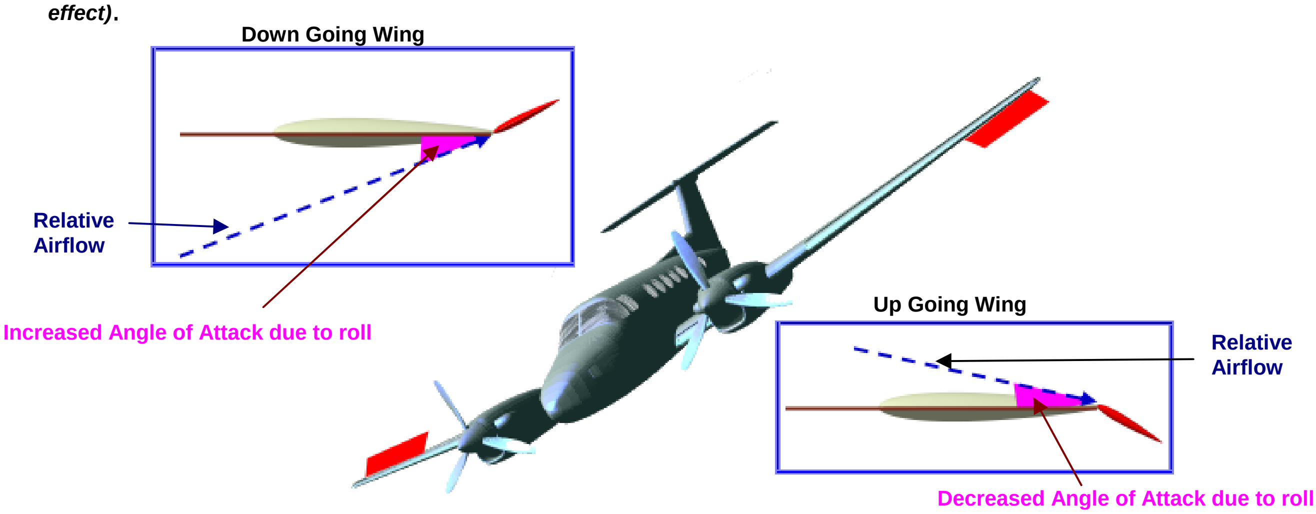
Lateral stability and control refer to aircraft behaviour in the rolling plane or, in other words, movement of the lateral axis as it is rotated about the longitudinal axis and CG.

Although roll and yaw are coupled (yaw produces roll and roll produces yaw), this lesson is only concerned with pure roll and lateral stability.



DAMPING IN ROLL

When aileron is applied, a rolling moment is created about the longitudinal axis of the aircraft, which is opposed by damping in roll moment. The greater the rolling moment, the greater the damping moment. ***(Until the rate of roll reaches a steady value as dictated by the damping in roll effect)***.



As an aircraft starts to roll about its longitudinal axis, an additional component of the free stream flow is created that changes the relative angle of attack of the wings. When an aircraft is rolling about its longitudinal axis, the angle of attack of the down-going wing will increase.

As the wing starts to rotate, an additional component of the free stream flow is created that changes the relative angle of attack of the wings. The down-going wing experiences an increase in angle of attack due to the rolling component.

The up-going wing on the other hand experiences a decrease in its angle of attack due to the rolling component imparted to the RAF.

Damping in roll will oppose any rolling moment (α increase at down-going wing, while α decrease at up-going wing) that is produced due to a displacement in roll.

EFFECT OF FORWARD SPEED

The effect of forward speed on the response of ailerons is two fold with the one affecting the other.

$$F = C_L \, \tfrac{1}{2} \, \rho \, V^2 S$$

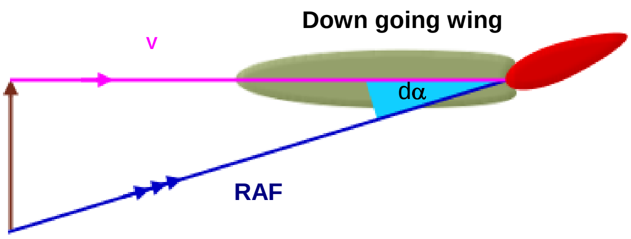
- Firstly, **F *(moment) is proportional*** **($\propto$)** to **V^2.** This applies to the rolling velocity due to aileron power as well ***(the more aileron is deflected, the higher the rolling power).*** This moment would result in the aircraft continuously rolling about the longitudinal axis as speed increases. In reality this does not happen, and the reason for this is the damping in roll, which is also affected by speed.

- The damping in roll effect is as a result of the change in angle of attack (dα) of the down going wing, ***(which is caused by the rolling velocity in forward flight).*** Therefore, for a given aileron deflection, a steady roll rate depends on the damping angle (dα).

  If, for a given aileron deflection, a steady roll rate depends on damping angle (dα) and:

$$\boxed{\text{Tan } \mathbf{d}\alpha = \frac{\mathbf{V^2}}{\mathbf{V}}}$$

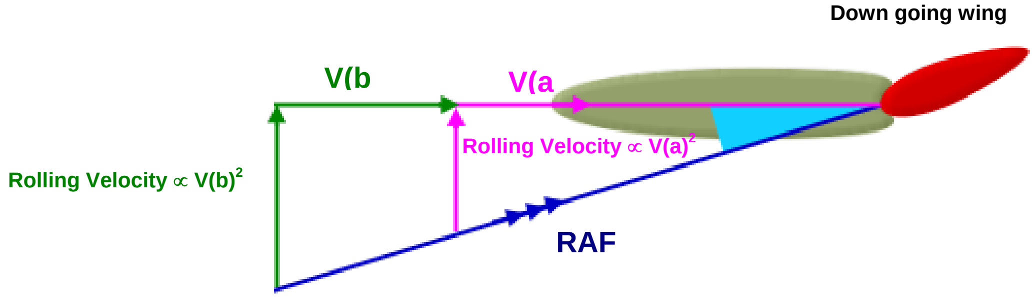
Rolling Velocity $\propto$ **V^2**



From the formulae $\text{Tan } \mathbf{d}\alpha = \frac{\mathbf{V^2}}{\mathbf{V}} = \mathbf{V}$ This means that the relationship between

Damping in roll and forward speed is linear.

However, where the damping moment increases as the first power of V, the rolling moment increases as **V^2**. This means that if aero-elasticity and compressibility are ignored, ***the rate of roll increases in the same ratio as the forward speed for a given aileron deflection.*** It is because of this that the aircraft does not roll uncontrollably as speed increases.



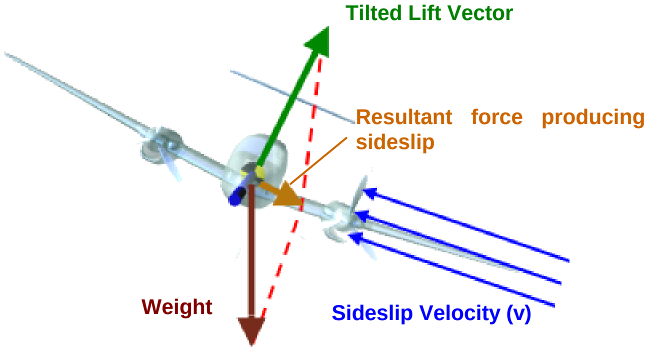
Due to the

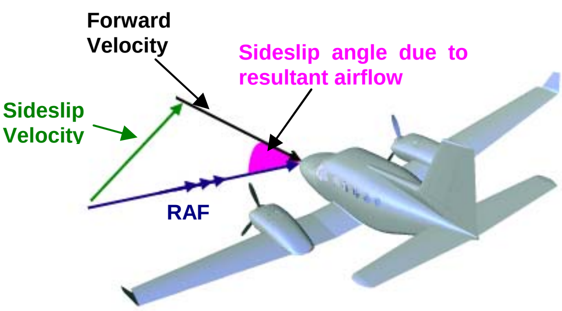
damping in roll being proportionate to the roll rate, it cannot return an aircraft back to the wings-level attitude. In the absence of any levelling force, an aircraft that is disturbed in roll, will maintain its attitude with wings banked representing neutral stability. It is clear that an aircraft possesses **neutral static stability with respect to a disturbance in roll** (angle of bank).

SIDESLIPPING

When an aircraft experiences a lateral disturbance, it not only experiences a rolling motion, but also a **sideslippping motion**.

The sideslipping motion is due to the fact that when an aircraft is banked, the lift vector tilts in the direction of the bank.





A rolling moment that tends to restore the aircraft to the wings-level attitude ***(positive lateral static stability)*** is produced by the forces that act on different parts of the aircraft due to the sideslip. The lateral static stability of an aircraft reacts to the sideslip velocity (v) or a displacement in yaw. The reaction of the aircraft has a considerable influence on the lateral dynamic stability ***(long-term response)*** of the aircraft.

Restoring Moment Due To Sideslip

The sideslip causes the flow of air to move in the opposite direction to the slip. The air will now strike the lower (leading) wing at a greater angle than the upper (trailing) wing. As far as the sideslip is concerned, the tip of the lower wing will become, as it were, the leading edge. As the CP is always closer to the leading edge, the pressure distribution along the span of the aircraft will now be on the lower wing. The lower wing will therefore produce more lift and therefore tend to roll the aircraft back to the level-flight attitude.

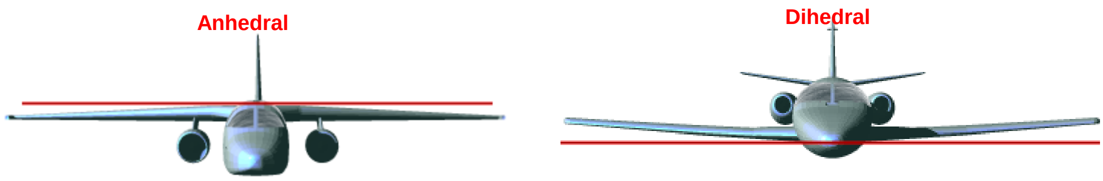
FACTORS CONTRIBUTING TO LATERAL STABILITY

All the different parts of the aircraft contribute towards the overall lateral static stability value of the aircraft. Depending on the condition of flight and the configuration of the aircraft, the magnitude of the contributions will differ. The main factors that contribute to lateral static stability are:

- Effect of Dihedral
- Effect of Sweepback
- Wing/Fuselage Interference
- Fuselage/Fin Contribution
- Undercarriage, Slipstream and Flap

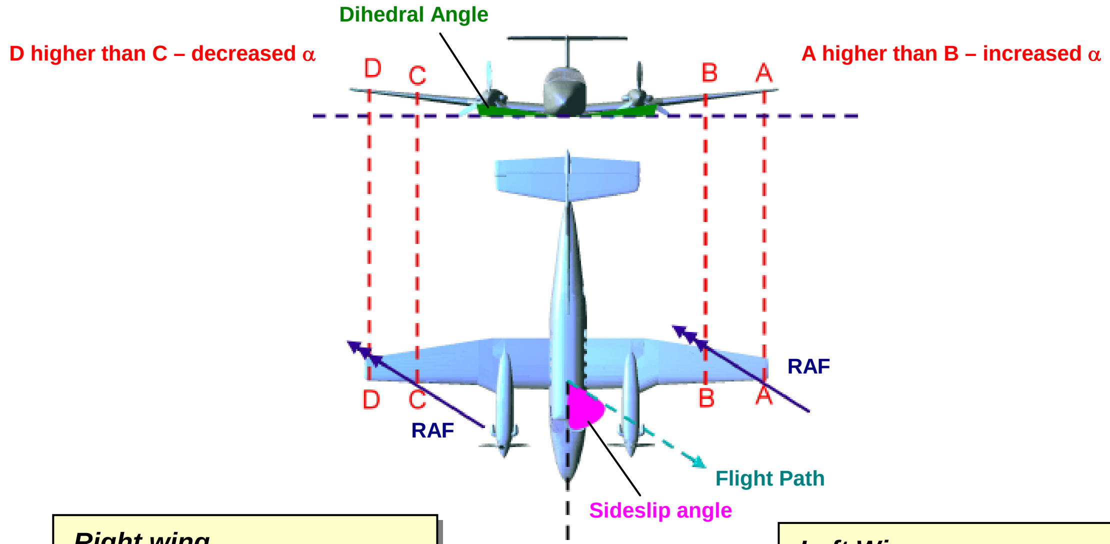
DIHEDRAL

Dihedral is defined as the spanwise inclination of a wing or horizontal stabilizer to the horizontal, or a plane equivalent to the horizontal. Upward (towards the canopy) inclination is known as positive dihedral and downward (towards the undercarriage) is known as negative dihedral or anhedral.



Due to the dihedral on the wings, a point nearer to the wing tip will be higher than a point that is located further inboard. A sideslip to the left will thus produce different effects on the leading ***(low)*** and trailing ***(high)*** wings.

SIDESLIP TO THE LEFT



Right wing

On the right wing point C is lower than point D due to dihedral. The effect is to decrease the angle of attack and therefore lift will be reduced.

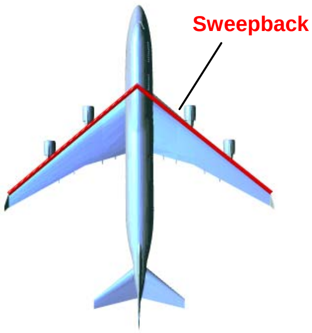
Left Wing

The RAF crosses the left wing from A - B at an angle that is equal to the sideslip angle. Due to dihedral, point A is higher than point B. This produces the same effect as raising the leading edge and lowering the trailing edge (i.e. increasing the angle of attack). So, as long as the aircraft is not flying near its stalling speed, **the lift on the left wing will increase**.

Whenever sideslip is present (such as after a disturbance in yaw), lift increases (increased angle of attack) on the leading wing and lift decreases (decreased angle of attack) on the trailing wing, **a stable rolling moment will be produced**.

This stable contribution will depend on the dihedral angle and the slope of the C_L-curve. Although there are a number of important contributions, **dihedral is one of the most important contributions to overall lateral stability and, for this reason, lateral static stability is often referred to as the "dihedral effect".**

SWEEPBACK



Sweepback is a design feature that is mainly used on high- speed aircraft and has an important influence on lateral stability.

The geometry or planform of a wing has a large influence on the lateral static stability characteristics of an aircraft. Sweepback on a wing has the effect of increasing the stabilizing contribution to lateral static stability by increasing the "effective" dihedral.

The effect of a swept wing planform on stability can be divided into three sections that are covered under sweepback:

- The sweep angle
- The aspect ratio and,
- Wing taper are all aspects

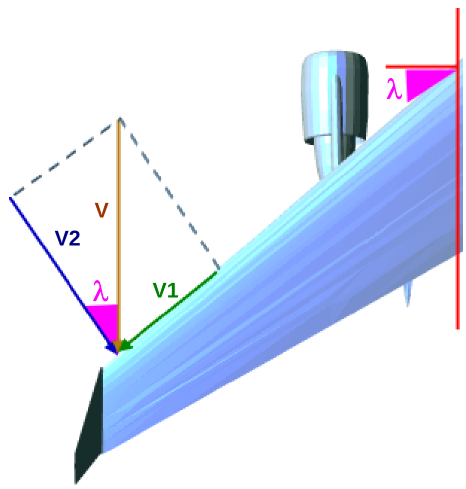
Rule of thumb for effective dihedral

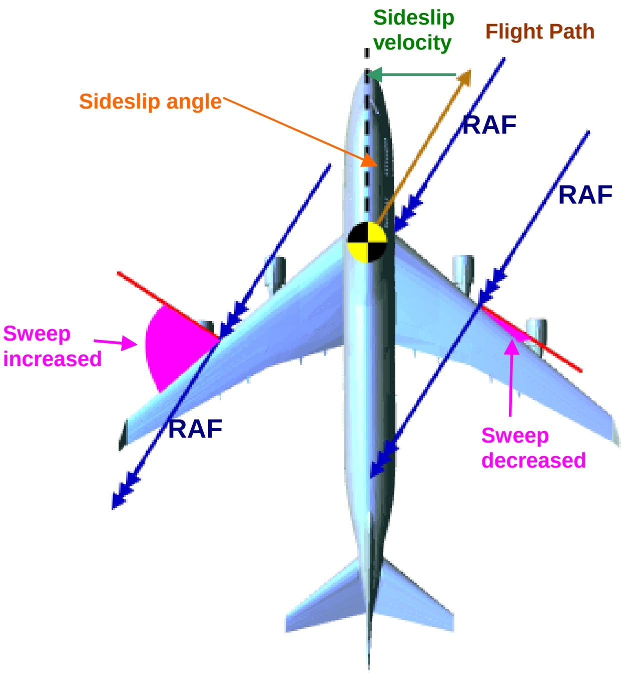
A very good rule of thumb to remember is that 3 degrees of wing sweep has the same effect as 1 degree of dihedral.

SWEEP ANGLE

The sweep angle of a wing has an important influence on lateral stability. The graphic shows an aircraft in a sideslip to the right. Due to the flight path of the aircraft, a sideslip velocity is produced.

Cosine of angle of sweep: The airflow (V) over a wing with sweepback is divided into two components, a component that is parallel to the leading edge (V1), and a component that is normal to the leading edge (V2). The V1 component has no effect on lift production, but the V2 component ($V2 = V\cos\lambda$, where λ is the angle of sweep) does affect lift production as the C_L of a swept wing is reduced in the ratio of $\cos\lambda$.



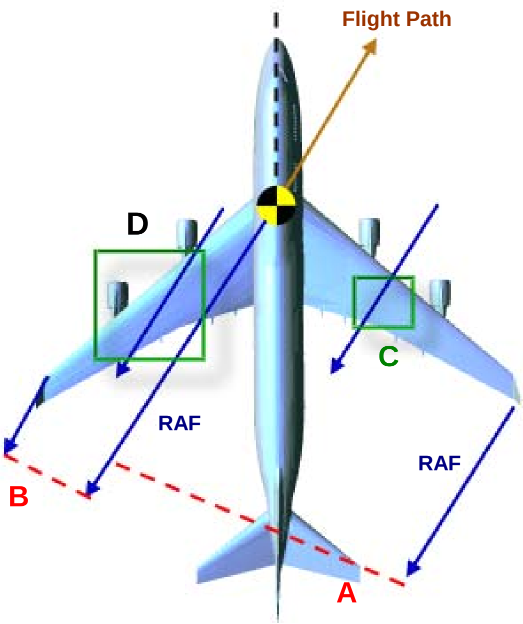


The RAF strikes the aircraft at an angle and this causes the angle of sweep on the low (leading) wing to decrease. On the high (trailing) wing the angle of sweep is increased.

As the airflow component that is accelerated by the section camber, is proportional to the cosine of the sweep angle of a wing, the airflow over the low wing accelerates more than the airflow over the high wing.

Due to the higher acceleration of airflow over the low wing, it produces more lift than the high wing. Therefore the effect of angle of sweep during sideslip is to create a lift differential, which produces a stable rolling moment out of sideslip.

ASPECT RATIO



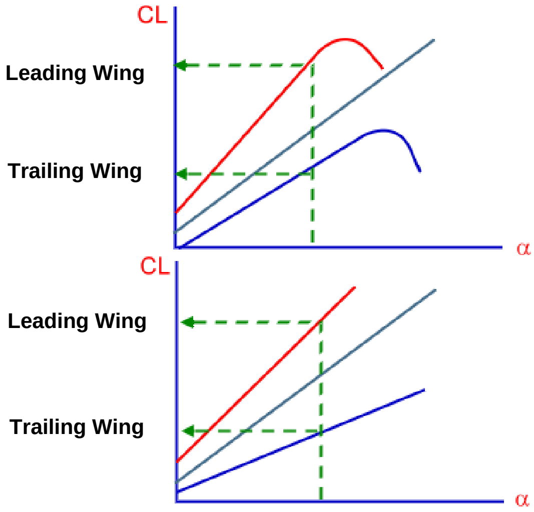
The offset relative airflow has the effect to increase the span (a) on the low (leading) wing, while the span (b) on the high (trailing) wing is decreased. The offset relative airflow also has the effect to decrease the chord (c) on the low (leading) wing, while the chord (d) on the high (trailing) wing is increased.

The result is that the aspect ratio on the low wing is increased (longer span / shorter chord) while on the high wing the aspect ratio is decreased (shorter span / longer chord). The increase in lift on the more efficient low wing (due to increased aspect ratio) produces a stable rolling moment.

THE TAPERED WING

The taper produces a slightly swept back leading edge. During a sideslip condition the slight sweepback on the leading edge (due to the taper) will produce the same effect (although to a lesser extent) as a wing with very little sweepback.

An increase in taper ratio affects the C_L and will also produce a stable rolling moment out of the sideslip.



The two graphs show how the changes in the lift curve slope that are associated with changes in sweepback and aspect ratio, result in variations in the lift forces of the leading and trailing wings.

The divergence of the graphs shows that the contribution of sweep to lateral static stability becomes more important at higher C_L values (lower speeds and higher α). This means that the "dihedral effect" varies considerably over the speed range of an aircraft.

At higher speeds the "dihedral effect" (lateral stability) will be much less than at low speeds due to the reduction in angle of attack at high speeds. Sometimes it is necessary to reduce the lateral stability at high angles of attack to a more reasonable value. This is achieved by incorporating some negative dihedral (anhedral) on a swept-wing aircraft.

The "dihedral effect" of sweepback in sideslip produces a very strong rolling moment ***(sometimes referred to as roll with yaw).*** As the effect is strongest at low speeds, two very important applications have to be considered:

Cross-wind landings:

After an approach in a cross-wind from the right (where the aircraft was headed into the wind) the pilot has to yaw the aircraft to the left to align it with the runway for touchdown. Due to the yawing moment, the aircraft will tend to roll to the left as well. The pilot has to anticipate the rolling moment and keep the wings level before touching down.

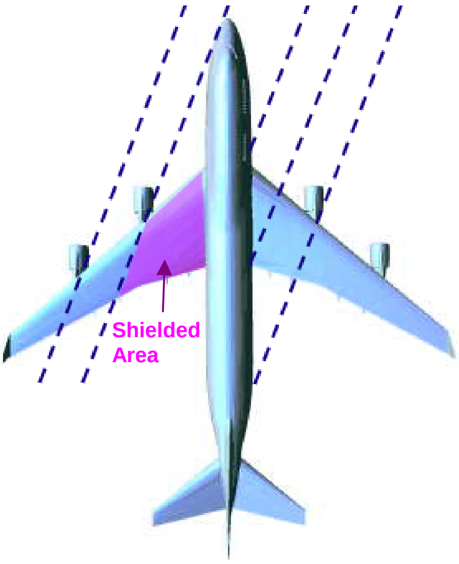
Wing drop:

Some swept-wing aircraft have the tendency to drop a wing at high α. The wing drop can be aggravated by applying large aileron deflections in an attempt to pick up the low wing. By applying rudder towards the high wing instead, the "dihedral effect" produced by the sweepback, will induce a rolling moment that will "pick up" the low wing (sideslip to left - roll to right or vice versa).

WING/FUSELAGE

When an aircraft is sideslipping, it will experience a certain amount of wing/fuselage interference due to two factors that have to be kept in mind. These factors are the shielding effect of the fuselage and the vertical position of the wings.

SHIELDING EFFECT

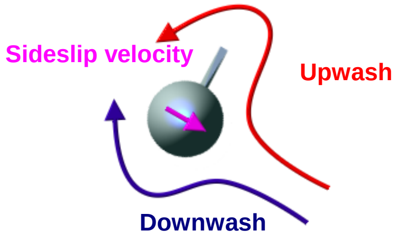


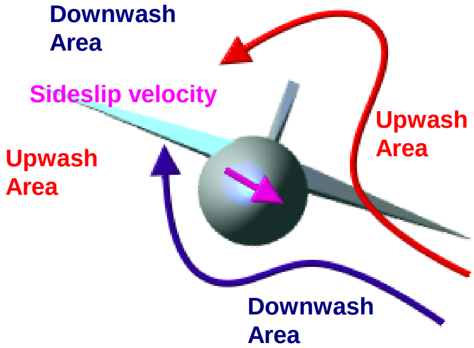
Almost all aircraft will be affected by the shielding effect of the fuselage. Consider an aircraft in a sideslip to the right. The relative airflow will come from the right.

During the sideslip, the section of wing near the root of the trailing (high) wing lies in the "shadow" of the fuselage. The dynamic pressure over this portion of the wing will be less than that over the rest of the wing. The reduced dynamic pressure leads to a decrease in lift on the trailing wing. This effect tends to lead to a considerable increase in the "dihedral effect" with some aircraft.

VERTICAL LOCATION OF WINGS

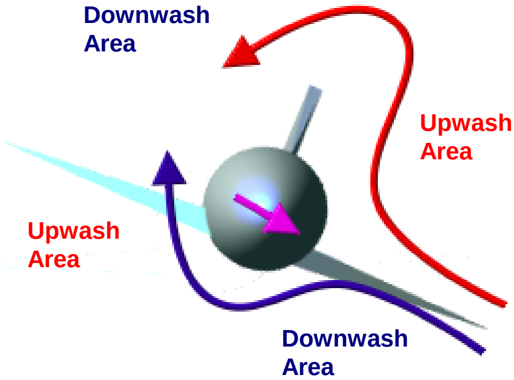
The vertical position of the wings relative to the fuselage represents a strong contribution towards lateral stability. Consider a fuselage that is cylindrical in cross-section. The relative airflow due to the sideslip velocity will flow around the fuselage; being deflected upwards over the top and downwards underneath.





With a high mounted wing, the leading wing lies in a region of upwash (which increases the α), while the trailing wing lies in a region of downwash which decreases the α. The difference in lift so produced, causes a restoring moment and the effect is the equivalent of about 1 - 3 degrees of dihedral.

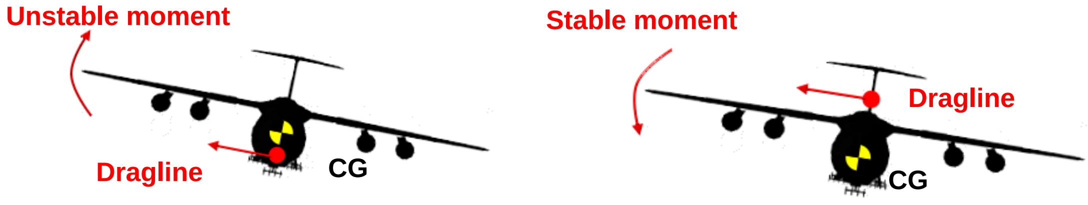
With a low mounted wing, on the other hand, the leading wing lies in a region of downwash (decreases the α) and the trailing wing in a region of upwash (increases the α). This situation produces an unstable moment that is equivalent to about 1 - 3 degrees of anhedral.



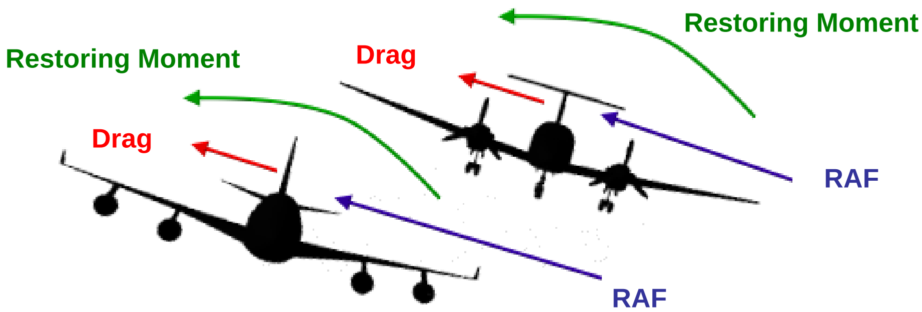
FUSELAGE/FIN

Due to the sideslip, the aircraft will experience a component of drag ***(produced by the fuselage and fin),*** which will oppose the sideslip velocity.

If the dragline is situated above the CG, it will result in a restoring moment which will tend to raise the low wing ***(positive lateral contribution - stable)***. With the drag line below the CG, the contribution will be unstable.



The position of the drag line depends on the configuration and geometry of the aircraft. In the case of an aircraft with a **high wing**, the fuselage ***(underslung engines, ordonance, fuel tanks, etc.)*** will tend to move the drag line down. To balance the unstable moment, these type of air-craft usually have a very large fin (or more than one fin) to offset the effect of the lower drag line. The resultant is usually still a stable rolling moment due to the fact that the fin produces a much larger moment than the fuselage.



On aircraft with a **high fin**, the fin produces quite a considerable drag component during a sideslip. This causes the drag line to move upwards. The restoring moment increases the lateral stability. The tendency to fit high fins is very apparent with modern high speed aircraft.

The **"T"-tail** configuration improves the effectiveness of the fin. It also produces its own bit of additional drag which moves the drag line even more upwards. This configuration also produces a large restoring moment.

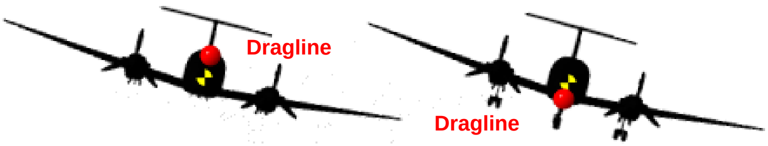
UNDERCARRIAGE/FLAPS AND POWER

Not all aspects of an aircraft increase the positive lateral stability. The three important aspects, which reduce the degree of positive lateral stability, are:

- **Undercarriage**
- **Power (Slip-stream)**
- **Flaps**

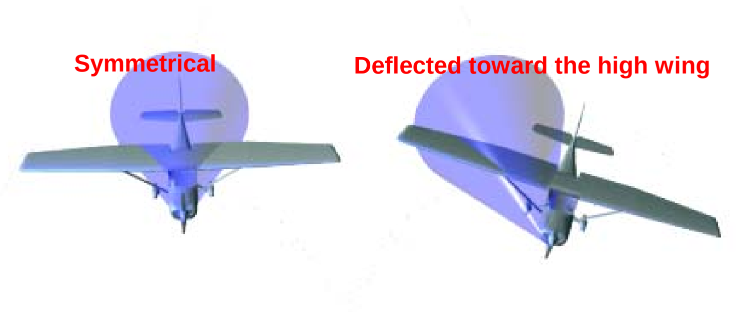
UNDERCARRIAGE

When the undercarriage of an aircraft is extended, drag increases considerably and the drag line moves due to this increase in drag. Due to the fact that the drag increase is underneath the aircraft, the drag line **shifts down** to a position below the CG. With the drag line below the CG, the **degree of lateral stability is reduced in sideslip**.

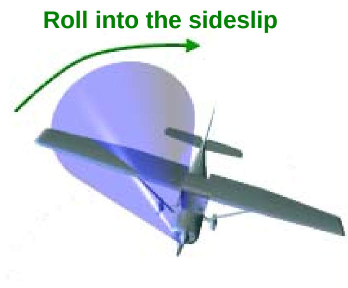


POWER (SLIP-STREAM)

With a propeller-driven aircraft, the slip-stream behind the propeller(s) is symmetrical about the longitudinal axis under normal flight conditions. During a sideslip, the slip-stream behind the propeller(s) is no longer symmetrical about the longitudinal axis, but is deflected towards the high wing. Due to the deflection, the slip-stream covers more of the high wing in a sideslip.



As the dynamic pressure in the slip-stream is higher than the free stream, the high wing produces more lift and it results in an unstable moment which tends to increase the displacement in roll in the direction of the sideslip. Use of flaps increases this unstable contribution.



With propeller-driven aircraft that are fitted with very powerful engines ***(such as aircraft used in the Reno air races)*** another factor plays a role.

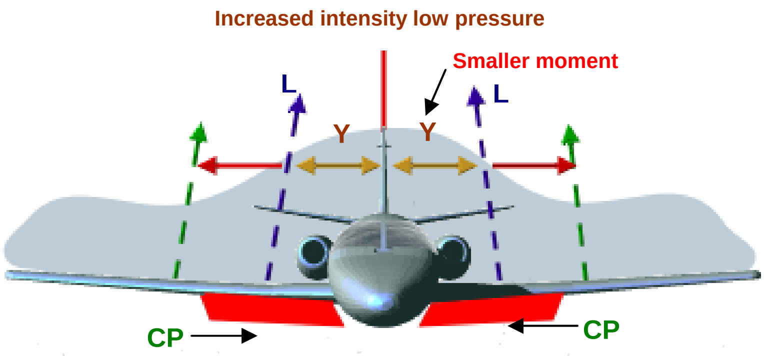
These powerful engines fitted to these aircraft, develop enormous amounts of torque.

If a lot of power should be applied ***(especially at low speeds)*** while the aircraft is in a sideslip, the torque could have either a restoring or an unstable influence; depending on the direction in which the aircraft is sideslipping.

FLAP

Flaps increase the intensity of the low pressure above the wing and partial-span flaps also **change the spanwise pressure distribution of the low pressure above the wing.**

The C_L increases over the inboard section close to the fuselage and moves the "half-span" CP of the wing closer towards the fuselage ***(in a spanwise sense).*** The moment arm (y) produced by the wing lift vector is therefore reduced and produces a smaller moment for the same C_L change with the dihedral effect in sideslip.



This means that: **lowering of inboard flaps lower the overall lateral stability,** but the effect can be reduced by certain design considerations.

DESIGN CONSIDERATIONS

The contribution produced by lowering inboard flaps can be controlled by changing the design geometry of the flaps. A swept-back flap hinge-line will decrease the dihedral effect. On the other hand, a swept-forward hinge line will increase the dihedral effect.

Although some components of an aircraft may produce a negatively stable moment, in order for that aircraft to be laterally stable, the negative moments have to be overcome by the stabilizing moments of all the other components of the aircraft. The resultant moment must be that the complete aircraft must have positive lateral static stability.

The amount of lateral stability of an aircraft depends entirely on the role of the aircraft. An air superiority fighter is useless if it possesses a slow roll rate due to excessive lateral stability; it requires a very high roll rate to fulfil its role. Transport aircraft are normally laterally very stable. Remember: **STABILITY OPPOSES MANOEUVRE**.

Thus too much static stability can lead to problems with dynamic stability such as:

- Lateral oscillatory problems (Dutch Roll),
- Large aileron deflections and forces under asymmetric conditions,
- A large rolling response due to rudder deflection which requires aileron deflection to counteract the possibility of an "autorotation" under certain flight conditions.