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DOCUMENT TITLE
AERODYNAMICS 2

CHAPTER 2 – STABILITY & DYNAMIC STABILITY

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AN INTRODUCTION TO STABILITY

INTRODUCTION

Stability is the nature (by design), of an aircraft which is in flight to want to return to a state of equilibrium (or steady flight), after it has been disturbed from such a state. An aircraft which is stable, and is disturbed from straight and level flight, will have the tendency to return to the same attitude.

STABILITY BUILT INTO THE DESIGN

Although no aircraft is completely stable, all aircraft are designed and built with desirable aspects of stability and handling characteristics. A stable aircraft is easier to fly, and makes the pilots workload easier to handle. This is especially true for the climb, descent, and while turning. **HANDLING CHARACTERISTICS ARE DIRECTLY RELATED TO STABILITY.**

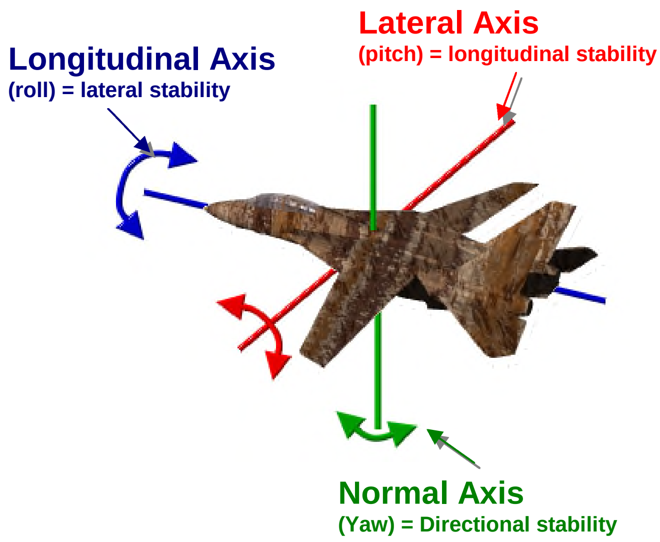
DIFFERENT AIRCRAFT AND DIFFERENT LEVELS OF STABILITY

Large passenger carrying aircraft are designed with high levels off stability in mind; while light training aircraft are designed with more manoeuvrability in mind, and are likely to be less stable.

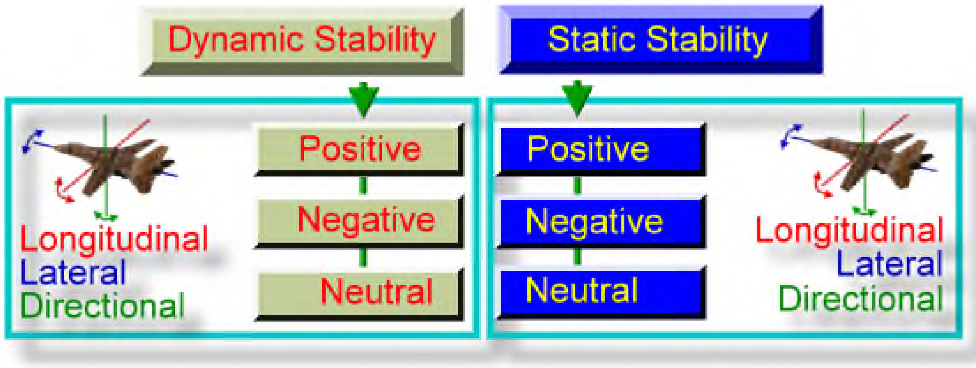
CLASSIFICATION OF STABILITY

The two major categories of stability are ***Static, and Dynamic Stability.*** Both static and dynamic stability can either be positive, negative or neutral. Because the aircraft is operated around three axis of movement (longitudinal, lateral and normal) any of these types of stability can be applicable to any one of the axis.

- **If an aircraft is stable/unstable along the longitudinal axis (roll), it is said to have lateral stability/instability.**
- **If an aircraft is stable/unstable along the lateral axis (pitch), it is said to have longitudinal stability/instability.**

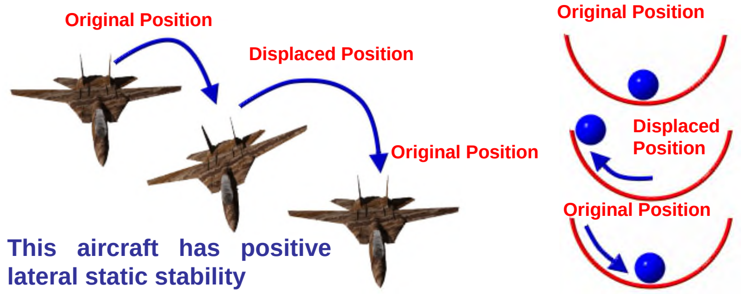


- **If an aircraft is stable/unstable about the normal axis (yaw), it is said to have directional stability/instability.**



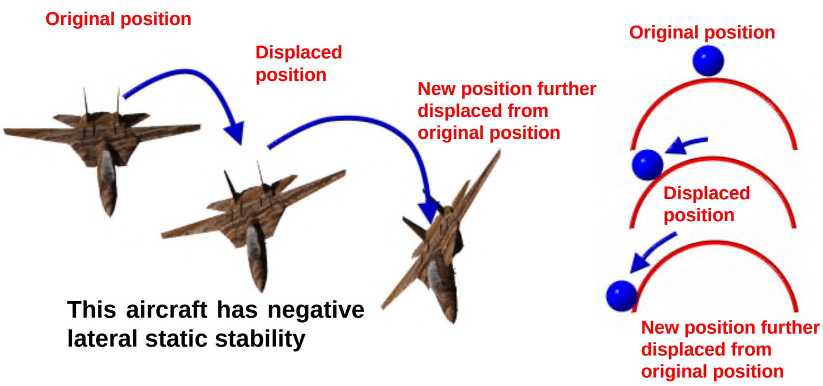
STATIC STABILITY

Static stability refers to the behavioural tendency that an object (aircraft), displays after its state of equilibrium has been disrupted.



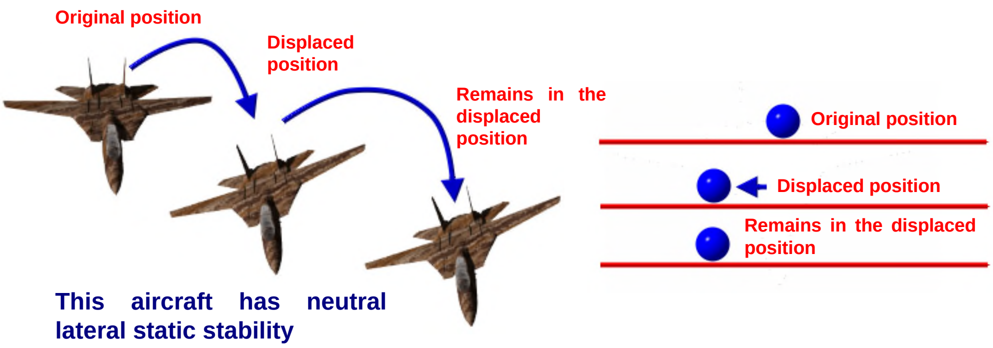
Positive Static Stability

When an object is displaced from its position by an external force, and then returns to its original position after the force is removed, it is said to have positive static stability.



Negative Static Stability

When an object is displaced from its original position by an external force, and then moves even further away from the original position, it is said to have negative static stability.



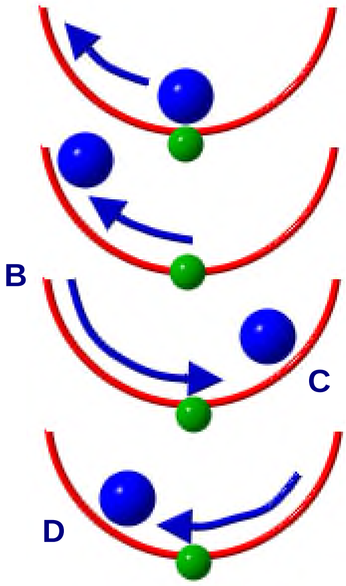
Neutral Static Stability

When an object is displaced from its original position by an external force, and then tends to remain in this displaced position, it is said to have neutral static stability.

Positive Static Stability is the most desirable, as the aircraft attempts to move back to its original trimmed position. Neutral and Negative Stability are undesirable.

DYNAMIC STABILITY

Whereas static stability is the tendency of movement of an object or aircraft after an external force has been applied to it, ***dynamic stability represents the manner in which the object or aircraft achieves it static stability.*** Dynamic stability describes the time required for an aircraft to respond to its static stability.

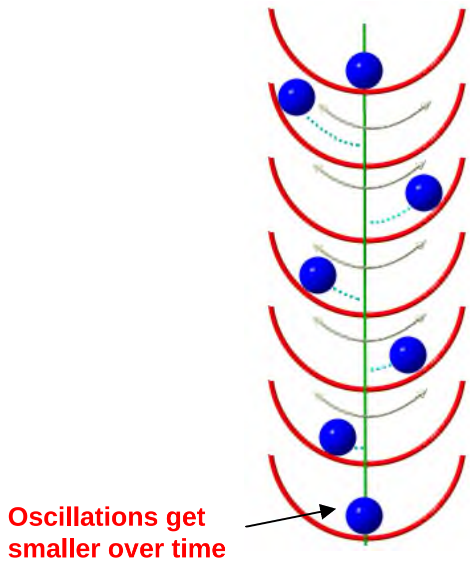


To explain dynamic stability, let us use the bowl and ball, which in this case would indicate positive static stability (the ball will tend to return to its original position).

When the ball is released in B, it will move past its original position, to C, and then again past its original position in D.

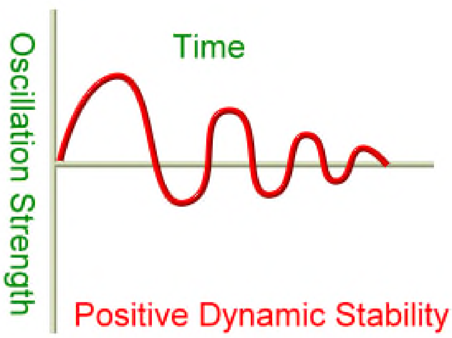
This will continue until the ball comes to rest at its original position. In other words it achieves its static stability over a period of time by oscillations and damping (much the same as a pendulum will come to rest after a number of oscillations.

Dynamic Stability



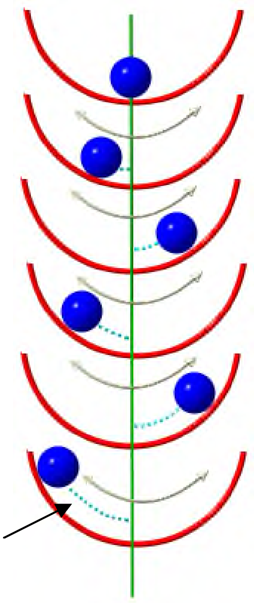
Positive Dynamic Stability

If the aircraft tends to realize its positive static stability, by means of a series of decreasing oscillations, it has positive dynamic stability.

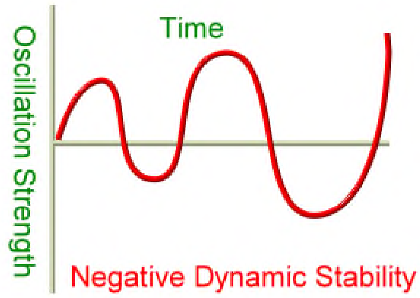


Negative Dynamic Stability

If the aircraft tends to want to return to its original state, but the oscillations increase, then it is said to have negative dynamic stability.

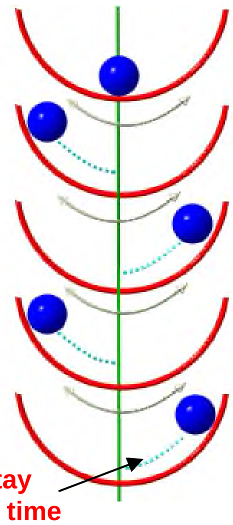


Oscillations get bigger over time

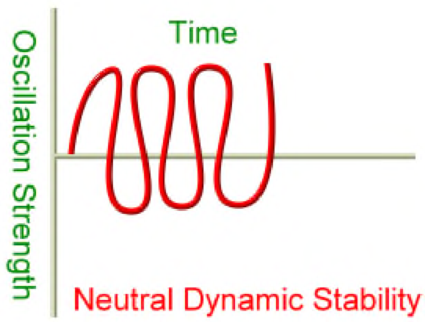


Neutral Dynamic Stability

If the aircraft tends to want to return to its original state, but the oscillations neither increase or decrease, then it is said to have neutral dynamic stability.



Oscillations stay the same over time



The most desirable stability, is a combination of positive static stability, and positive dynamic stability.

DYNAMIC STABILITY

OSCILLATION

As the aircraft oscillates about the original position, the indicated values of speed, height and load factor will vary continuously. With an aircraft that possesses positive dynamic longitudinal stability, the oscillations will gradually die away and the aircraft will eventually return to the original trimmed flight condition.

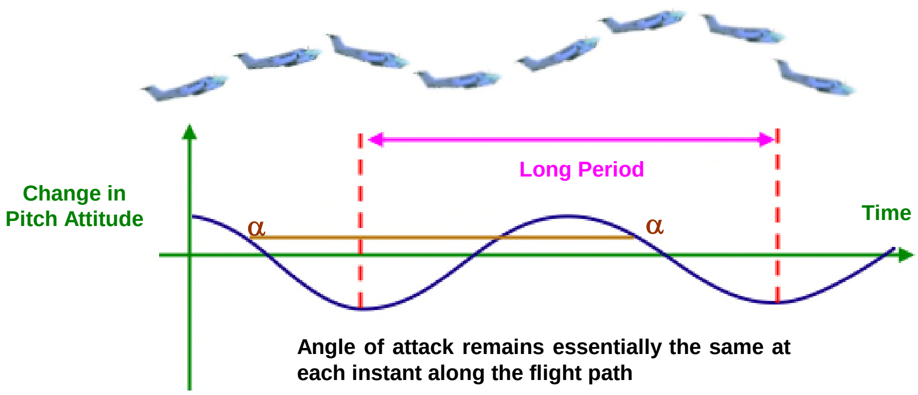
The oscillatory motion of an aircraft which has been disturbed in pitch, consists of two separate oscillations. These two different oscillations have widely differing characteristics and are known as the phugoid and the short-period oscillations.

PHUGOID

A phugoid is normally a **long period**, **poorly damped** motion, which involves **large changes in speed and height** of the aircraft, but with **small changes in load factor**.

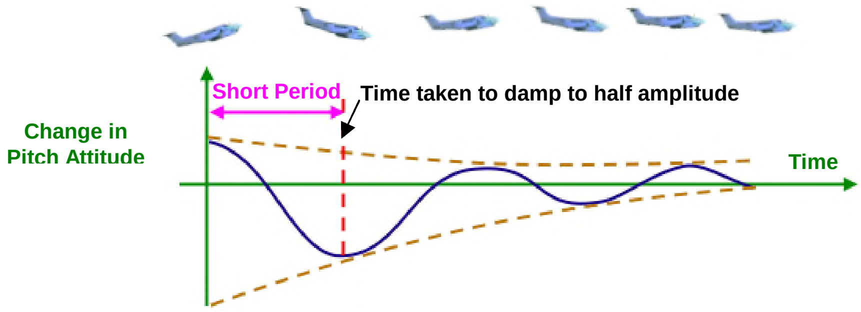
A phugoid can be regarded as a constant energy motion where kinetic and potential energy are exchanged constantly and the angle of attack of the aircraft will more or less remain the same at each instant along the flight path (α at the same points on the curve are the same).

Normally a phugoid oscillation is poorly damped and the degree of damping depends on the drag characteristics of the aircraft. With modern aircraft designs, which tend to produce the minimum of drag, the phugoid oscillation is becoming more of a problem.



SHORT PERIOD OSCILLATIONS

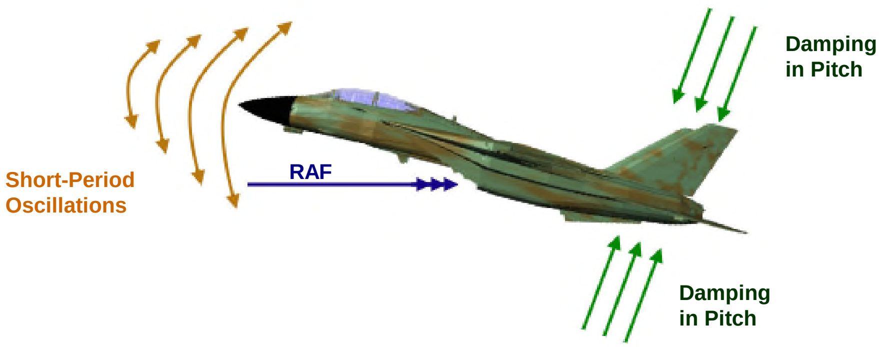
A **short-period oscillation** is usually **heavily damped** and involves **small changes in speed and altitude**, but **large variations of load factor**. It can be regarded as a simple pitching oscillation with only one degree of freedom.



From the graphic the very short periodic time of one cycle and the time required to damp the oscillation to half its original value, can be seen.

Extreme caution must be exercised when attempting to damp out these short-period oscillations. Pilot reaction time is close to the natural periodic time of short-period oscillations and the pilot may inadvertently reinforce the pitching motion instead of damping it.

With a slow, light aircraft it might not present much of a problem. With high performance aircraft, it may lead to pilot induced oscillations and eventual disaster, as the aircraft can be destroyed in a matter of seconds.



Short-period oscillations usually develop due to sharp gusts, but the aircraft's natural damping in pitch will damp out the oscillations in a relatively short period if the controls are left in a neutral position.

DYNAMIC LONGITUDINAL STABILITY

The dynamic longitudinal static stability of an aircraft was defined as the manner in which it returns to the original condition of equilibrium and is dependent on the following factors:

- Longitudinal static stability
- Aerodynamic damping in pitch
- Moments of inertia in pitch
- Angle of pitch
- Rate of pitch
- Effect of altitude

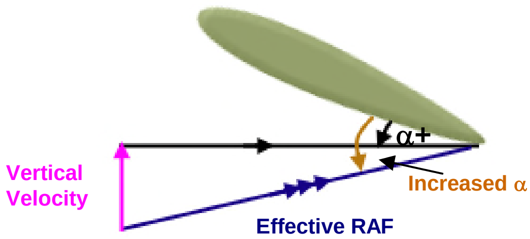
LONGITUDINAL STATIC STABILITY

As the degree of static stability has a direct influence on the periodic time ***(greater degree of stability - shorter periodic time)***, it stands to reason that as the oscillations become shorter due to the shorter periodic time ***(due to greater degree of static stability)***, an aircraft will regain its original position of equilibrium in a shorter time.

The degree of longitudinal static stability has a direct influence on the dynamic longitudinal stability of an aircraft. The greater the degree of static stability, the quicker an aircraft will regain its original position of equilibrium.

AERODYNAMIC DAMPING IN PITCH

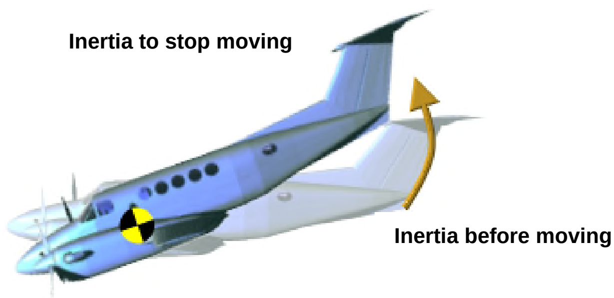
Any pitching motion of an aircraft takes place about the CG ***(the aircraft rotates about its own CG).*** This means that the tailplane can be considered to be moving downwards relative to the air flow ***(or the airflow moves upwards relative to the tailplane).*** The increase in effective angle of attack of the tailplane produces a resistance to pitch - damping in pitch.



If the damping in pitch moment changes, the duration of the oscillations will be affected. If the damping increases, the oscillations are damped out far quicker (time for amplitude to be reduced to half of the original value is reduced) which means that the aircraft is dynamically more stable.

MOMENTS OF INERTIA IN PITCH

Newton 1 states that a body will tend to remain in the state it is in unless disturbed by an external, unbalanced force. Due to the longitudinal weight distribution of the aircraft, moments of inertia are produced when it is disturbed in pitch.



When an aircraft is disturbed in the pitching plane, it wants to rotate about the CG. Due to the inertia ***(resistance to move)*** of the tailplane, it might remain unaffected if the displacement ***(due to light turbulence)*** is not large enough.

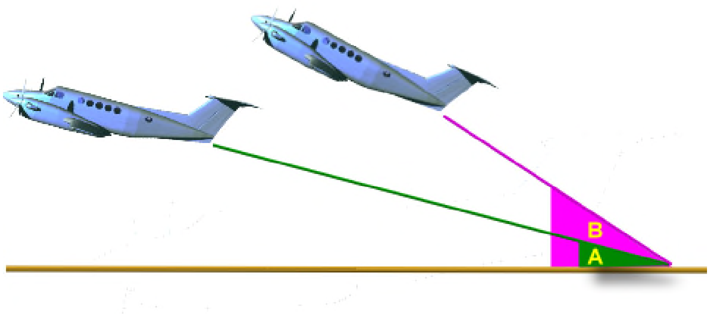
On the other hand, if the displacement is large enough and the tail started to move, it will experience a certain resistance to stop, which is also due to inertia. The inertia displayed by the tailplane has a definite effect on the periodic time of any oscillation in pitch.

ANGLE OF PITCH

Consider two aircraft; both being disturbed in pitch, but the one on the right (B) pitches to a higher angle than the one on the left (A).

The tailplane of the aircraft on the right (B) will be subjected to damping in pitch for a longer time than the aircraft on the left (A), but on the other hand, the moment of inertia of that aircraft will also be more.

The increased damping effect will tend to reduce the amplitude of the oscillations, while the inertia moment of the tailplane (due to downwards/upwards movement) will tend to increase the amplitude of the oscillations. However, in most cases, the **aerodynamic damping has the overriding effect** and the oscillations will reduce in size.

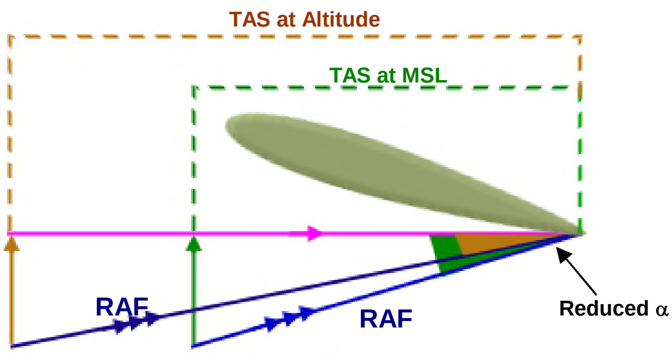


RATE OF PITCH

The effect of an increased rate of pitch is the same as for Angle of Pitch. Both the damping effect and inertia moments will increase with an increase in rate of pitch, but the damping in pitch effect will again have the greatest effect.

EFFECT OF ALTITUDE

The increase in TAS with an increase in altitude reduces effective α of the tailplane, which in turn reduces the aerodynamic damping effect and therefore the static stability.



As the aerodynamic damping effect is reduced, the periodic time of the oscillations will increase. Thus, dynamic stability will be reduced at higher altitudes due to the longer time required to damp the oscillation to half its original value.

DYNAMIC DIRECTIONAL AND LATERAL STABILITY

Directional and lateral static stability were discussed separately earlier in this module. However, in practice it is very difficult to ignore the interaction between directional and lateral stability, as it is this interaction which determines the dynamic stability of the aircraft in yaw and roll. The resulting motion of a trimmed aircraft in level flight which is disturbed laterally, consists of:

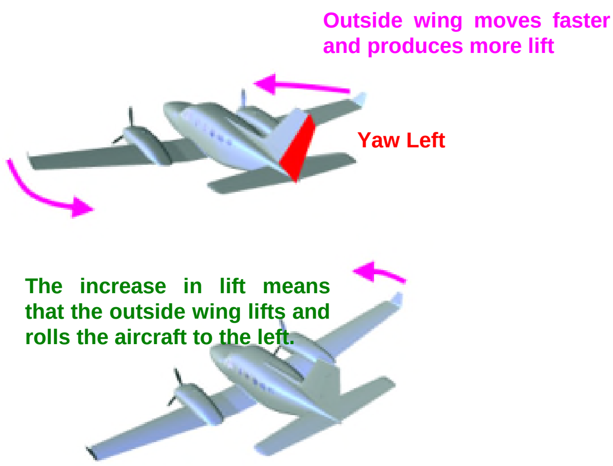
- A **Rolling Motion**. The roll will initially only change the angle of bank, which in turn will be rapidly damped.
- A **Spiral Motion**. Spiral is a combination of bank and yaw and if an aircraft is unstable in this mode, it will result in a gradually tightening spiral.
- **Oscillatory Motion**. This is a poorly or undamped oscillation which involves roll, yaw and sideslip and which has a very short periodic time. An example of dynamic instability due to oscillatory motion is Dutch Roll.

The motion of an aircraft due to dynamic stability in the rolling and yawing planes is affected by the following:

- Roll due to yaw
- Adverse yaw
- Spiral divergence
- Directional divergence
- Dutch roll

ROLL DUE TO YAW

Deflecting the ailerons in the desired direction can produce a rolling moment, but an aircraft can also be rolled by means of the rudder. An aircraft yaws about the normal axis (which passes through the CG). If an aircraft is yawed to the left, the EAS on the right wing increases, and due to the higher EAS the right wing produces more lift than the left wing, which causes a rolling moment in the same direction as the yaw.



Keep in mind that in this case the roll is initiated by a pure yawing moment with the aircraft in trimmed, level flight. There are a few aspects which cause the rolling moment.

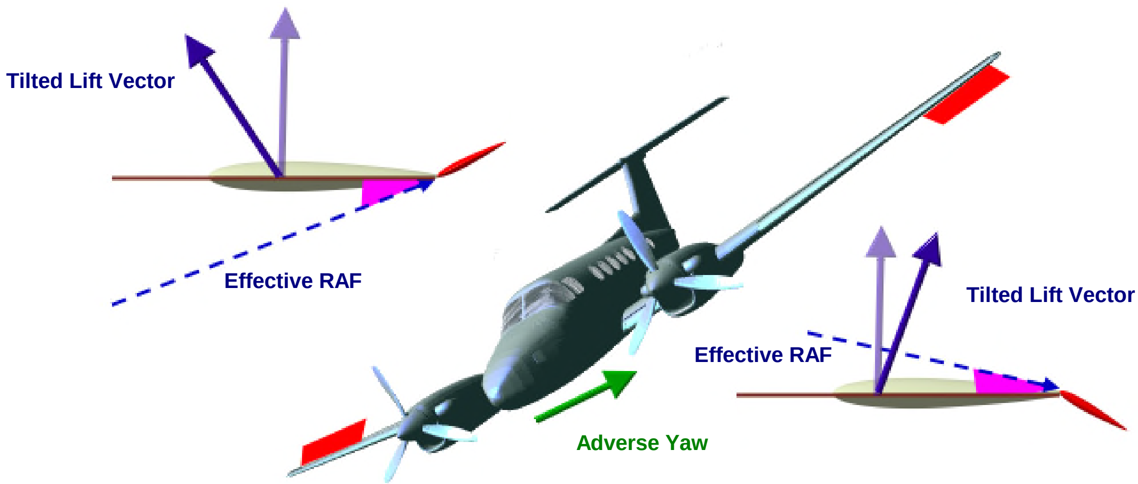
During the yaw ***(rotation about CG),*** an initial rolling moment is only produced for as long as the speeds of the wings differ.

Negative Sideslip: Normally the effect of sideslip is to roll the aircraft out of the turn or wings level. As this is indicative of positive stability, it can be termed as a positive sideslip. However, in this case the sideslip increases the bank angle and rolls the aircraft further into the turn, which is negative stability; hence it is termed as a negative sideslip.

Once a constant yaw angle is achieved (rotation about CG has stopped), a negative sideslip angle is created on the outside wing. This negative sideslip angle also creates a positive rolling moment in the direction of the yaw. Due to the negative sideslip angle, the effects of other factors such as wing/fuselage junction and fuselage/fin also generate a rolling moment.

ADVERSE YAW

When an aircraft does an aileron turn, the effective angle at which the RAF strikes the wings changes. Consider an aircraft turning to the right.

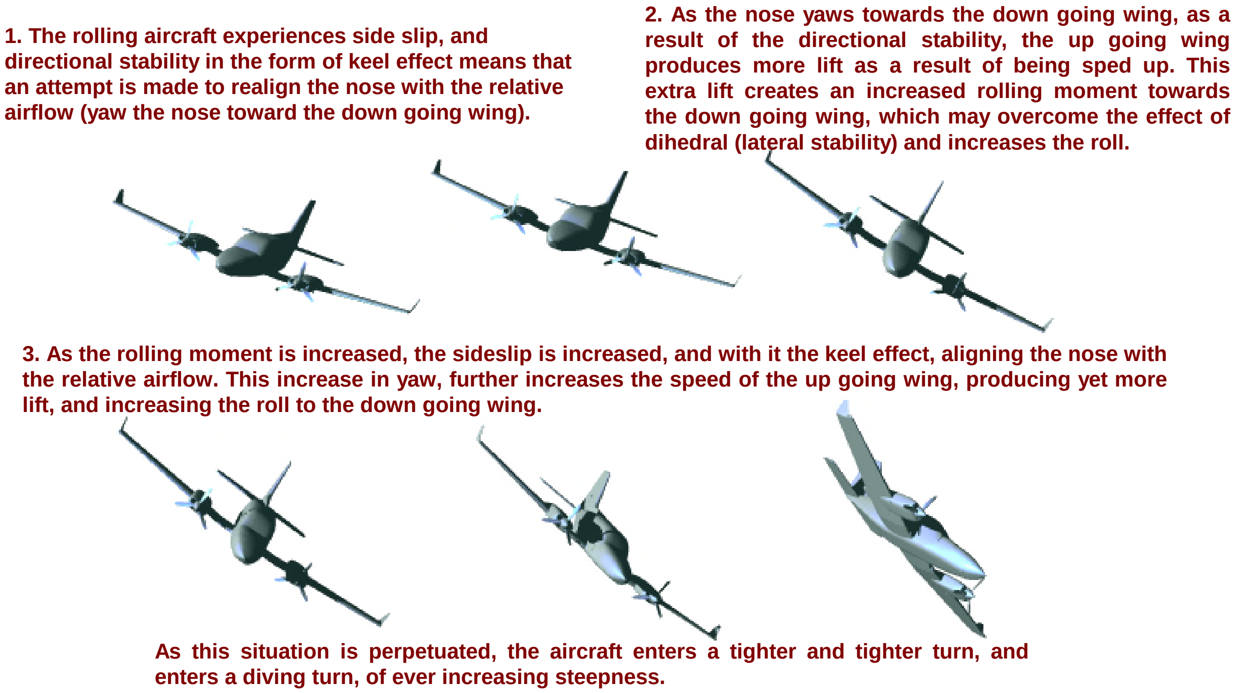


It has been stated that the lift vector is always perpendicular to the RAF. Due to the rotational velocity of the wing the resultant RAF is slightly from above and therefore the lift vector is tilted back. The tilted lift vector creates a rearward force on the up-going wing. On the downgoing wing the effective RAF will be slightly from below due to the rotational velocity. Therefore the lift vector will be tilted slightly forward and this creates a forward force on the down-going wing.

If combined, the two forces oppose the turn by producing an adverse yawing moment out of the turn. The adverse yaw is most noticeable at high angles of attack with the wings partially stalled. Adverse aileron yaw also reinforces the adverse yawing moment.

SPIRAL INSTABILITY (DIVERGENCE)

Spiral instability is associated with aircraft that have strong directional stability, when compared to lateral stability.



In general, designers attempt to minimise the tendency for an aircraft to enter the Dutch Roll, as it is considered more dangerous and intolerable than spiral instability. Due to this, most aircraft have a degree of spiral instability, which is generally considered as acceptable.

In general the overall stability of an aircraft, is related to its tendency to enter a spin after being stalled. While stable aircraft tend to resist the spin, unstable aircraft are less resistant.

Reducing the fin area of an aircraft can lessen spiral divergence. The reduction in fin area reduces the directional static stability and therefore the tendency to yaw into the new airflow. If the yawing tendency is reduced, less lift is produced by the outer wing, which in turn decreases the negative rolling moment towards the inner wing.

Therefore this effectively increases the lateral stability when compared to the now reduced directional stability.

DIRECTIONAL DIVERGENCE

In the lesson on directional static stability it was stated that on a body without a vertical stabilizer, an unstable moment is produced by the CP being ahead of the CG.

By adding a fin, the CP moves back to a position behind the CG. With the CP positioned aft of the CG, a stable moment is produced.

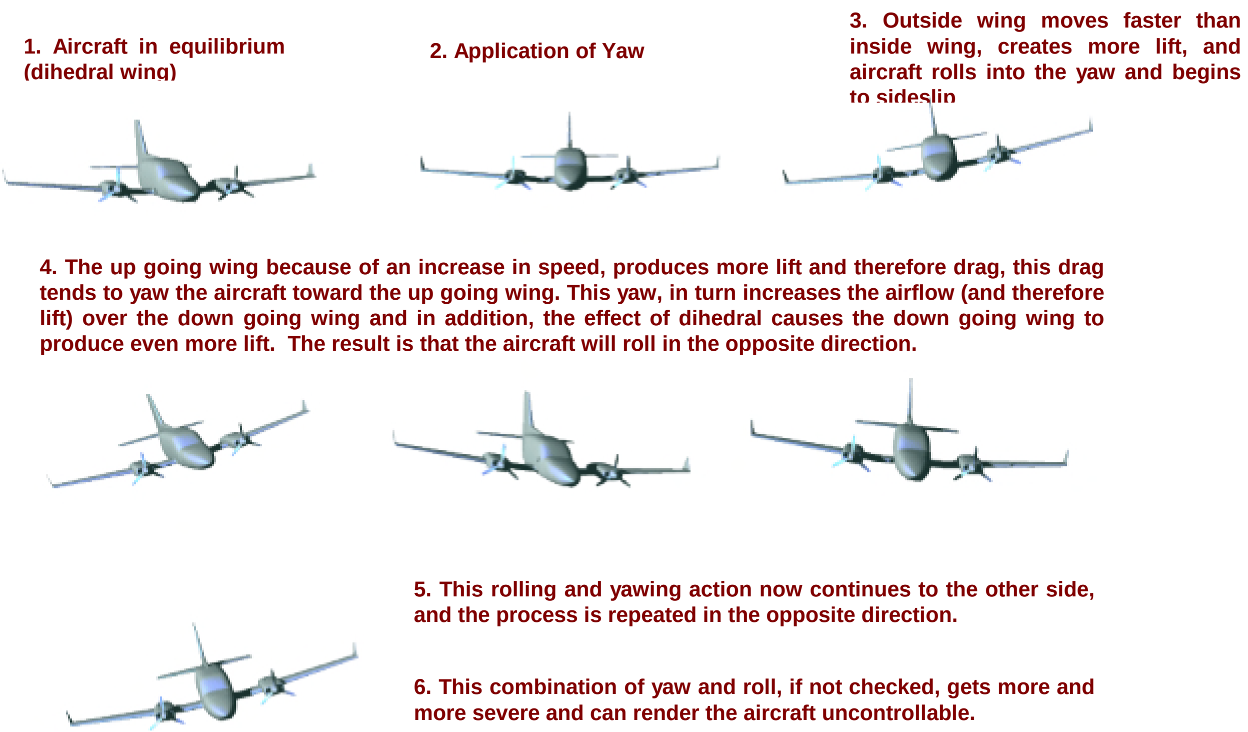
Directional divergence results from negative directional static stability and an aft position of the CG is also a factor that can lead to negative directional stability.

If an aircraft with negative directional stability sideslips due to a disturbance in either roll or yaw, it will produce a yawing moment that will cause the aircraft to yaw further in the same direction.

Once the aircraft has started to yaw, it will continue to yaw until it is presented broad-side-on to the airflow. Directional divergence is unacceptable in aircraft design and therefore aircraft are designed to prevent it.

DUTCH ROLL

The Dutch roll is a side effect of lateral- and directional stability, comprising of ***Yaw and Rolling*** oscillations, as well as sideslip. It is normally brought about by the handling of the controls by the pilot, or by gusts of wind.



A method to correct an aircraft, which exhibits Dutch Roll tendencies, is to build an aircraft, which has better directional stability, than it has lateral stability. If directional stability is improved and lateral stability reduced, the roll moment is suppressed, and hence the Dutch

Roll tendencies. However by altering the stability in this way, a new side effect may become eminent, that is ***Spiral Instability***.

TO SUMMARISE :

The lateral and directional dynamic stability of an aircraft is dependent on two aspects:

- The rolling moment due to sideslip (dihedral effect).
- The yawing moment due to sideslip (weathercock effect).

However, it has to be noted that:

- Too much lateral stability (dihedral effect) will lead to oscillatory instability such as the Dutch Roll.
- Too much directional stability (weathercock effect) will lead to spiral divergence.
- Too little directional stability will lead to directional divergence.