

## Stability

Fwd cg more stable- tail has more leverage to counteract pitch

Rear cg less stable- more manuverable

Lateral stability is the aircraft's ability to return into wings level state after disturbance.

Achieved by:

Dihedral- down going wing sideslip causes lower wing to generate more lift, pushing it up and levelling the plane

Sweepback-swept back wings also contribute, when a wing drops it becomes less swept relative to airflow, increasing its lift and creating a restoring rolling motion.

High wing: wings atop fuselage mean cog is below, creating a pendulum effect that naturally pulls the aircraft back towards a stable wings level position.

Negative tail force=downforce, in stable flight produced a negative force to counteract nose down pitching moment

Positive force achieved by rapid pitch down, causing an upwards force causing tail to rise

Dutch roll at high Mach

Can also occur when lateral stability is large compared to directional stability

Initial yaw- ac yaws to right, left wing advances forward, right wing retreats.

An asymmetric shock wave moment occurs. On the advancing left wing, the airflow perpendicular( $90^\circ$  to) to the leading edge speeds up. This causes the shockwave to move rearward. Causes airflow separation behind the shockwave, causing loss of lift on wing tip.

On the right wing, the airflow perpendicular to leading edge slows down, the shockwave moves forward, the lift remains unchanged.

This creates a rolling moment. The loss of lift on the advancing wing creates a left roll, demonstrating strong lateral (roll) stability.

At the same time, yaw correction is attempted, however, at high alt and Mach, the tail fin is less effective and has weak aerodynamic damping.

Swept wings

When an aircraft with swept wings yaws, it creates side slip where the relative airflow is no longer aligned with the aircraft's longitudinal axis.

Wing sweep also causes an increase in AoA of advancing wing, causing an increase in lift on the advancing wing/upwind. This also increases directional stability

This misalignment effects each wing differently

Asymmetric drag: let's say the aircraft yaws to the left, the right wing advances into the relative airflow. This reduces its effective sweep angle (swing wing jets!), making it more

perpendicular to advancing air (so basically straightening it), the left wing retreats, thus increasing sweep angle. A straight wing has a  $0^\circ$  sweep angle.

The advancing right wing experiences a significant increase in drag because it's now less swept. A greater sweep causes a reduction in drag - higher speed but reduced lift. The retreating wing experiences left drag, creating a yawing force, pulling the aircraft nose back to the right, correcting the initial yaw.

The magnitude of this stabilising effect is directly proportional to the angle of sweepback.

**Static directional stability:**

When an aircraft yaws, it creates a sideslip where relative airflow is no longer aligned to the aircraft's nose. This sideslip produces forces on the side of the fuselage and fin.

**The aft fuselage and fin:** the area behind the cg- particularly the fin acts like a weathervane. The side force in this area creates a stabilizing moment that pushes the tail back into alignment, correcting the yaw. A larger fin or a longer arm (dist to cg), increases the stabilising effect.

The forward fuselage creates a destabilising effect, the side force acting on the fuselage area ahead of the cg creates a destabilizing moment. This force pushes the nose further away from the relative airflow, making the initial yaw worse.

The importance of the CG position is critical because it defines the length of the moment arm.

A rearward cg would increase the size of the destabilising forward fuselage area and its moment arm

It however decreases the size of the stabilising arm for the vertical stab, thus reducing its effectiveness.

Thus a rear cg significantly reduces static directional stability.

**Static lateral stability** is the aircraft's tendency to level its wings after a disturbance. Too little makes the aircraft slow to correct, too much makes control harder.

**Phugoid oscillations**

A long, slow pitching oscillation where an ac repeatedly climbs and dives.

In this cycle, the ac trades airspeed for altitude, then reverse. Exchanging kinetic energy for potential energy (height). However, aircraft AoA does not change and remains constant.

In terms of aircraft cog, the aft cog decreases stability. The neutral point is the most aft position the cog can have before the aircraft becomes longitudinally unstable. For an ac to be stable, its cog must always be ahead of the metal point. A larger distance between cog and neutral point means greater stability.

Dorsal and ventral fins.

Dorsal and ventral fins are small airfoils added to the aircraft's rear fuselage, enhancing directional stability.

When an aircraft yaws or side slips, the side of the fuselage is exposed to the relative airflow, this then creates a side force on the fins. Because they're located far behind the cog, they generate a strong corrective yawing moment that pushes the nose back into alignment with the airflow, providing a stabilising effect. They're most effective at high sideslip angles. They're very resistant to stalling also, thus, can provide a stabilising force at extreme sideslip angles.

In terms of lateral stability, the dorsal fin contributes positively to both directional and lateral stability.

The ventral fin improves directional stability, however destabilises lateral stability. During roll, it creates lift below the cog, which tends to increase roll as opposed to correcting it.

Mach tuck is effectively describing a reversal in control forces as an aircraft exceeds  $m_{crit}$ .

In normal subsonic flight, an aircraft has positive stick stability. To increase speed while maintaining alt, the pilot must lower the nose by applying a push force.

As the aircraft approaches the speed of sound, shock waves begin to form at the root, this means there is a loss of lift at the root, the shockwaves disrupt the airflow. The wingtips however keep flying as they're in the subsonic flow, producing lift.

This then causes the centre of pressure of the wings sharply rearward.

This then creates a nose down pitching moment, known as Mach tuck. The pilot must pull back on the control. This creates a decrease in stability due to the nosedive, where you go from pushing to go faster, to pulling to prevent a crash.

Increasing the size of the tail:

Increases directional stability- forced nose into wind

Increases lateral stability- helps level wings during sideslip

Increases rudder authority

Insignificant pitch change

Features that increase lateral static stability:

Dihedral

Sweepback

High wing

Large fin

Low cg

Features that decrease lateral static stability:

Anhedral

Forward swept wings

Ventral fin

Low wings

## Inboard flap extension

Neutral stability is when the aircraft damps its oscillations- will look like a sine wave with decreasing amplitude.

## Spiral dives

When an aircraft after a small disturbance slowly enters a tightening spiral dive because its directional (yaw) stability is much stronger than its lateral (roll) stability.

The aircraft banks and sideslips slightly. The vertical fin yaws the nose into wind, correcting the slip(strong directional stab), however the wings tendency to level is too weak and slow to correct the bank (weak lateral stability), as the aircraft is in a banked turn, outer wing faster moving, generating more lift, increasing the bank angle. It's a non oscillatory, slow stable spiral.

The relationship between stick force and g force must be balanced:

Stick force too heavy=aircraft too tiring to manoeuvre

Stick force too light= too easy for the pilot to pull and damage aircraft

An aircraft certified for a higher g limit can be designed with a lower stick force/g because it has a larger structural safety margin. Afm contains g limits, but not specific stick force/g.

At constant IAS, stick force per g reduces with altitude

## Aerodynamic damping-

When aircraft moves, the air pushes back against. For example if right wing rolls down, The downward moment slightly increases that wings AoA relative to the air.

This creates extra lift

This extra lift pushes up against the downward roll, resisting the motion and damping the oscillation.

At higher altitudes, it's much weaker, this is due to the thinner air. This means to stay in the air you need a higher TAS. This means due to high fwd speed, any vertical or sideways motion from an oscillation creates a much smaller change in angle of attack. This thus means a smaller resisting force from the air at high altitudes, reducing the air's ability to damp our oscillations, which increases aircraft dynamic stability.

During short period oscillations, altitude remains approx constant unlike a phugoid.

When an aircraft yaws left, the right wing is on the outside of the turn. It's got a longer distance to travel than the inner left wing. The outer right wing is faster. The right wing produces more lift, this results in a roll to the left.

Spiral divergence happens when an aircraft's directional stability is much stronger than its lateral stability.

Static longitudinal stability is an aircraft's natural tendency to return to its trimmer pitch attitude after being disturbed

This stability is provided by the tail plane which counteracts the destabilising effects of the wing and fuselage

A stable aircraft is indicated by a negative slope on a graph of pitching moment vs lift. This means if the nose pitches up unexpectedly, a corrective nose down pitching moment is automatically created to restore the aircraft to its trimmed position.

The stability can be increased by making the tail plane more effective which is achieved by Increasing the tail planes area

Increasing the distance between the tail plane and the aircraft's centre of gravity- moving the tail aft.

Positive static lateral stability is the tendency of the aircraft to roll away from relative airflow, so if wind is coming from the left of the nose, the aircraft will roll to the right with lateral stability.

The neutral point is the average of the aerodynamic centre for the entire aircraft. It's ALWAYS located behind the aerodynamic centre of the wing.

A forward cg makes the tail push down harder, to balance this the main wings must produce more lift. The reduced thrust will mean wings must pick up the slack, causing an increase in wing lift.

Static and dynamic stability are linked. An aircraft can only have any measurement of dynamic stability if it is first statically stable.

The static margin is the distance between cog and neutral point

How is directional stability effected:

Fin- increases

Swept fin- less stable at small angles, more stable at high as resists stalling.

Swept wing- stabilising- advancing wing creates more drag and straightens plane

Dorsal/vetbral- stabilising

Fuselage-destabilising

Strakes-stabilising, direct airflow over tail