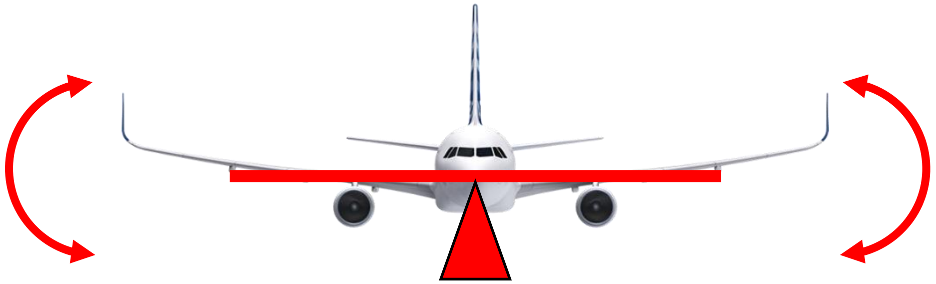
11 - Stability

Introduction

Stability is the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition.

The aircraft stability is studied about three axis.

Longitudinal stability



Lateral stability

Directional stability

Introduction

There are two types of stability:

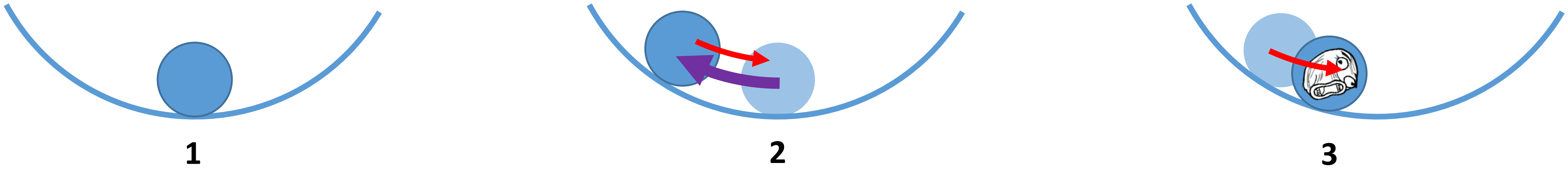
The static stability: it is the tendency or the reaction of the body when the disturbance is removed

The dynamic stability: it the result over time caused by the static stability.

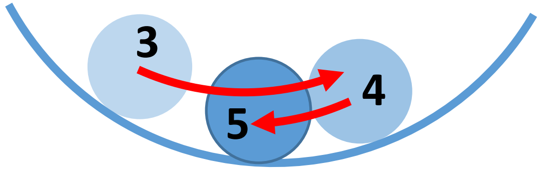
When the static stability increases, the body tends to come to initial conditions, thus makes it harder to move, so the maneuverability decreases. Inversely, when the static stability decreases, the maneuverability increases.

Introduction

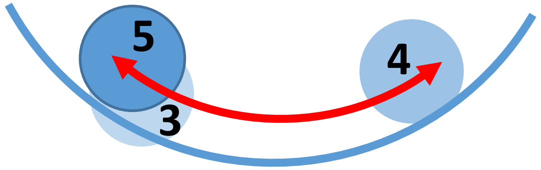
In this configuration, when a **disturbance** is applied on the ball, the weight of the ball makes a **tendency** to bring it back, which will create a certain resistance to the **disturbance**. After removing the **disturbance**, the **tendency** will try to bring the ball to its initial condition. This is a configuration of **positive static stability**.



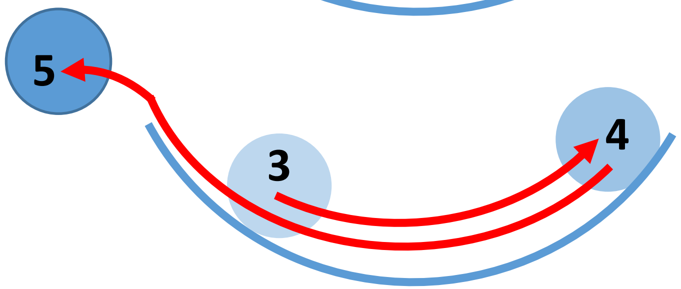
By trying to stabilize the ball to its initial condition, the tendency will generate oscillation that could:



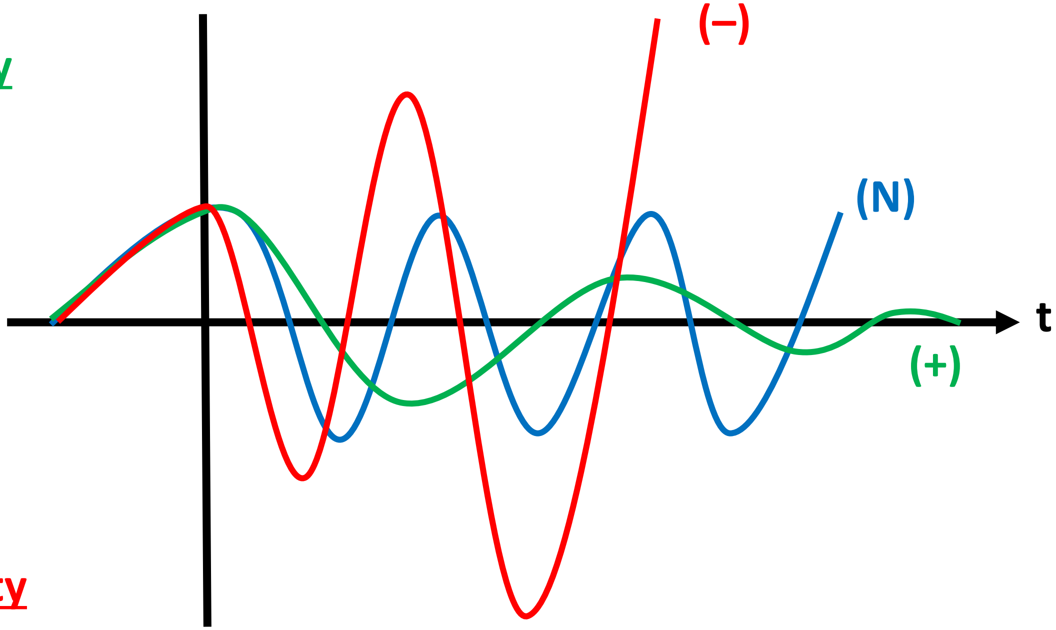
- Be damped overtime (convergence).
This is called **positive dynamic stability**



- Remain overtime (same amplitude).
This is called **neutral dynamic stability**

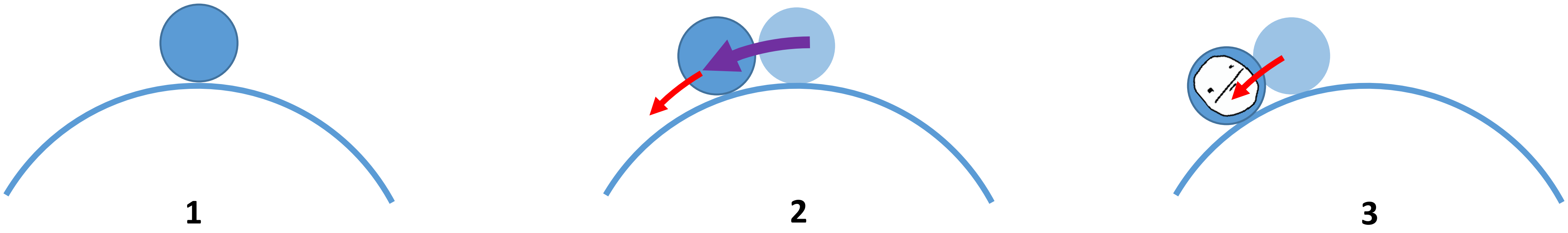


- Be amplified overtime (divergence).
This is called **negative dynamic stability**

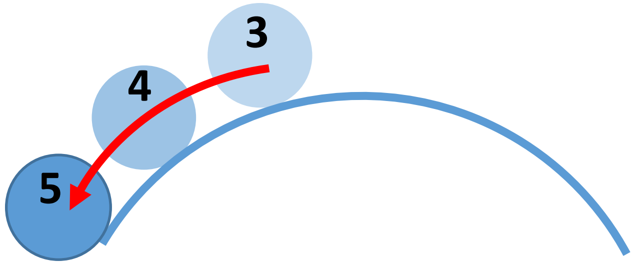


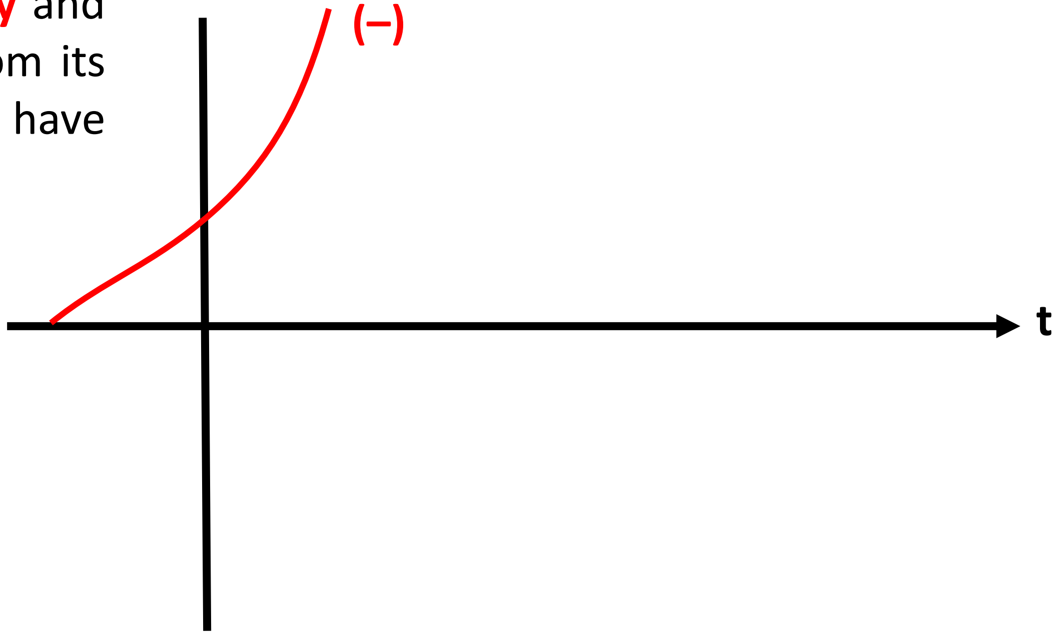
Introduction

In this configuration, when a **disturbance** is applied on the ball, the weight of the ball makes a **tendency** to move it further, which will create a certain assistance to the **disturbance**. After removing the **disturbance**, the **tendency** will keep moving the ball away from its initial condition. This is a configuration of **negative static stability**.



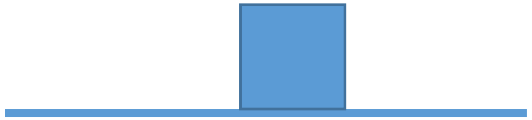
Since there's a **tendency** to move it further from its initial condition, it will amplify the effect of the **disturbance** that will amplify this **tendency** and so on, which overtime it will only keep moving the ball further from its initial condition. A **negative static stability** configuration, will only have **negative dynamic stability**.





Introduction

In this configuration, when a **disturbance** is applied on the box, there is no force acting against or in the same direction of the **disturbance**. After removing the **disturbance**, the box will maintain its new condition since there's no tendency to move it further from or bring it back to its initial condition. This is a configuration of **neutral static stability**.



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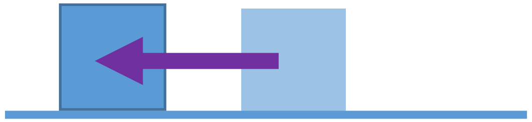

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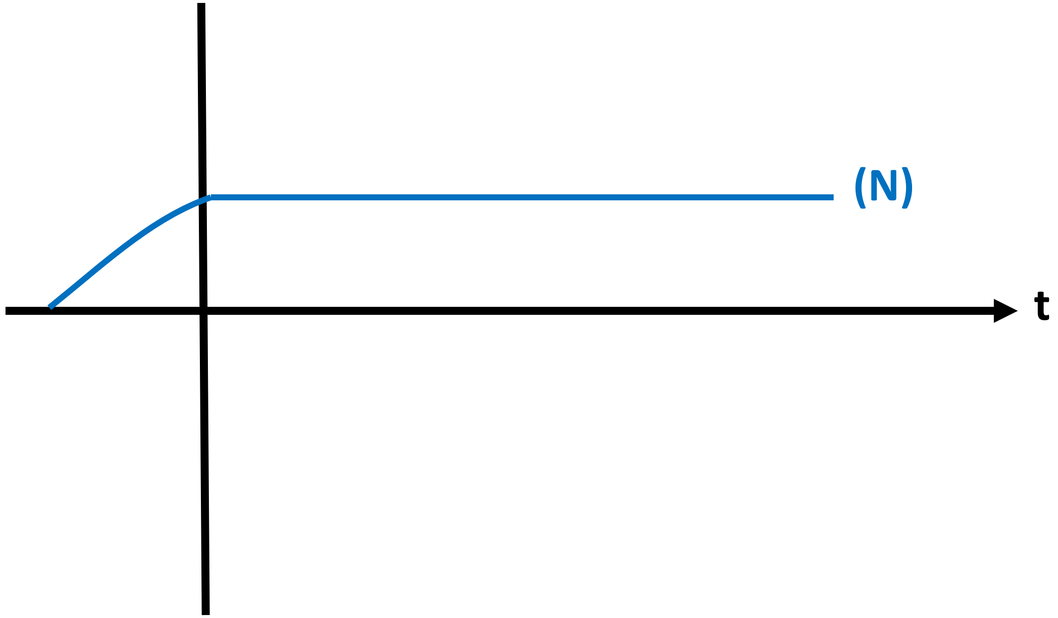
Since there's no tendency to move it further from or bring it back to its initial condition, overtime it will maintain the same condition. A **neutral static stability** configuration, will only have **neutral dynamic stability**

4



Introduction

Summary

Dynamic \ Static	Positive (+)	Neutral (N)	Negative (-)
Positive (+)	X		
Neutral (N)	X	X	
Negative (-)	X		X

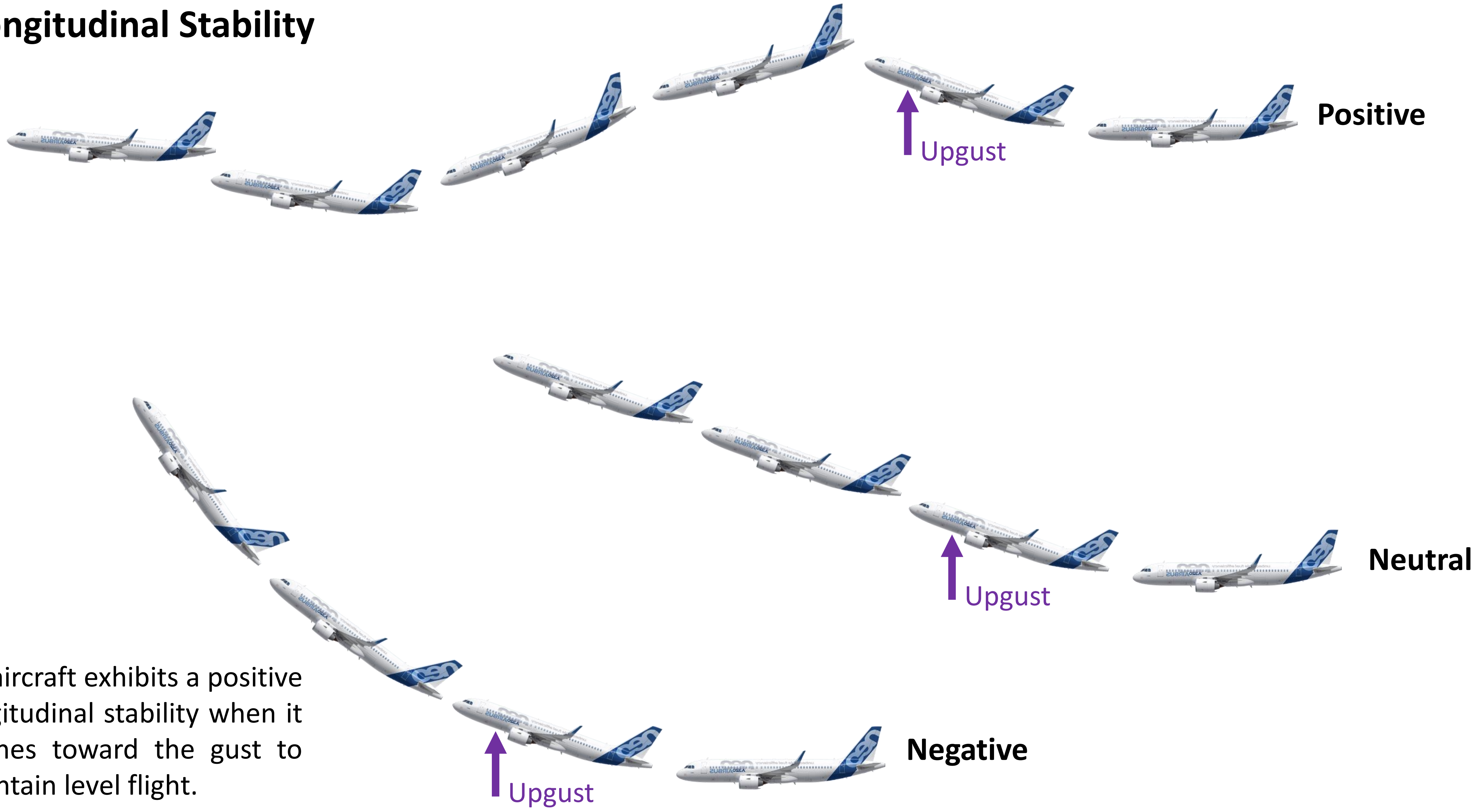
A **positive static stability** configuration can exhibits **a positive OR neutral OR negative dynamic stability.**

A **neutral static stability** configuration can exhibits **ONLY a neutral dynamic stability.**

A **negative static stability** configuration can exhibits **ONLY a negative dynamic stability.**

When the static stability increases, the maneuverability decreases, and when the static stability decreases, the maneuverability increases.

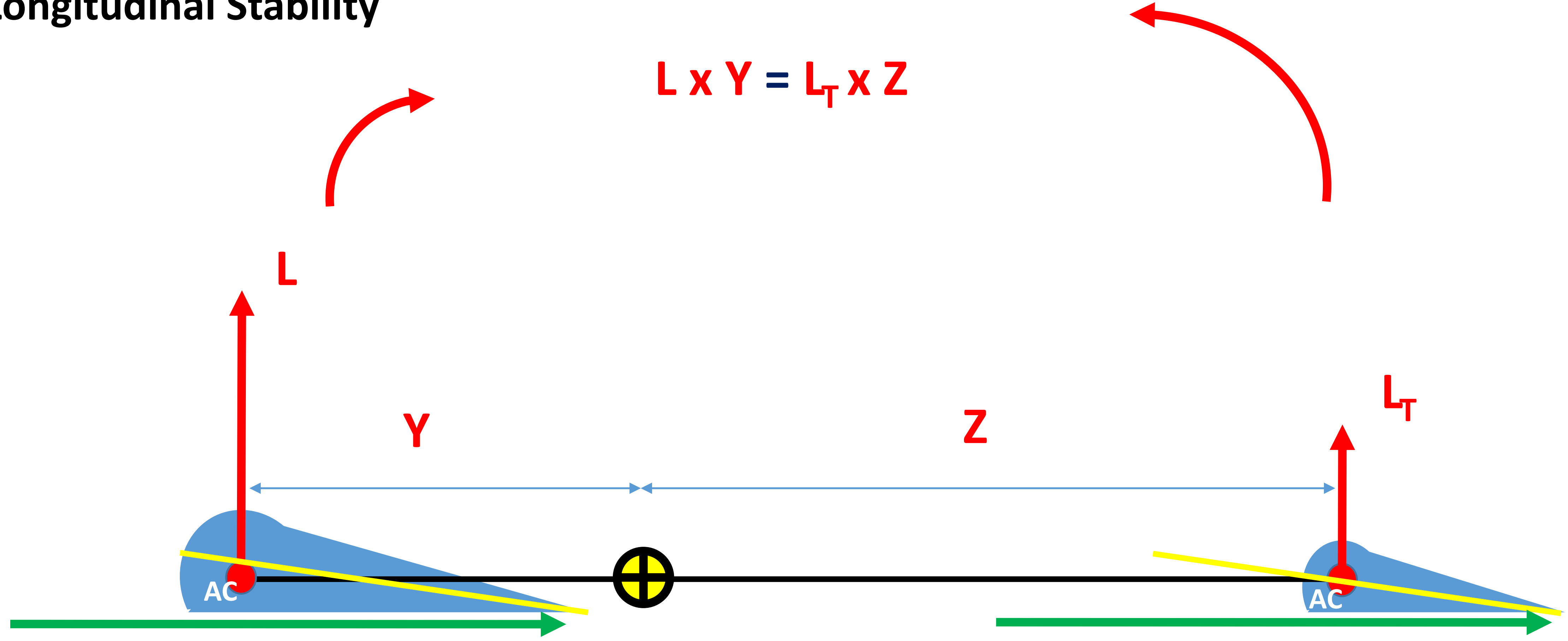
Longitudinal Stability



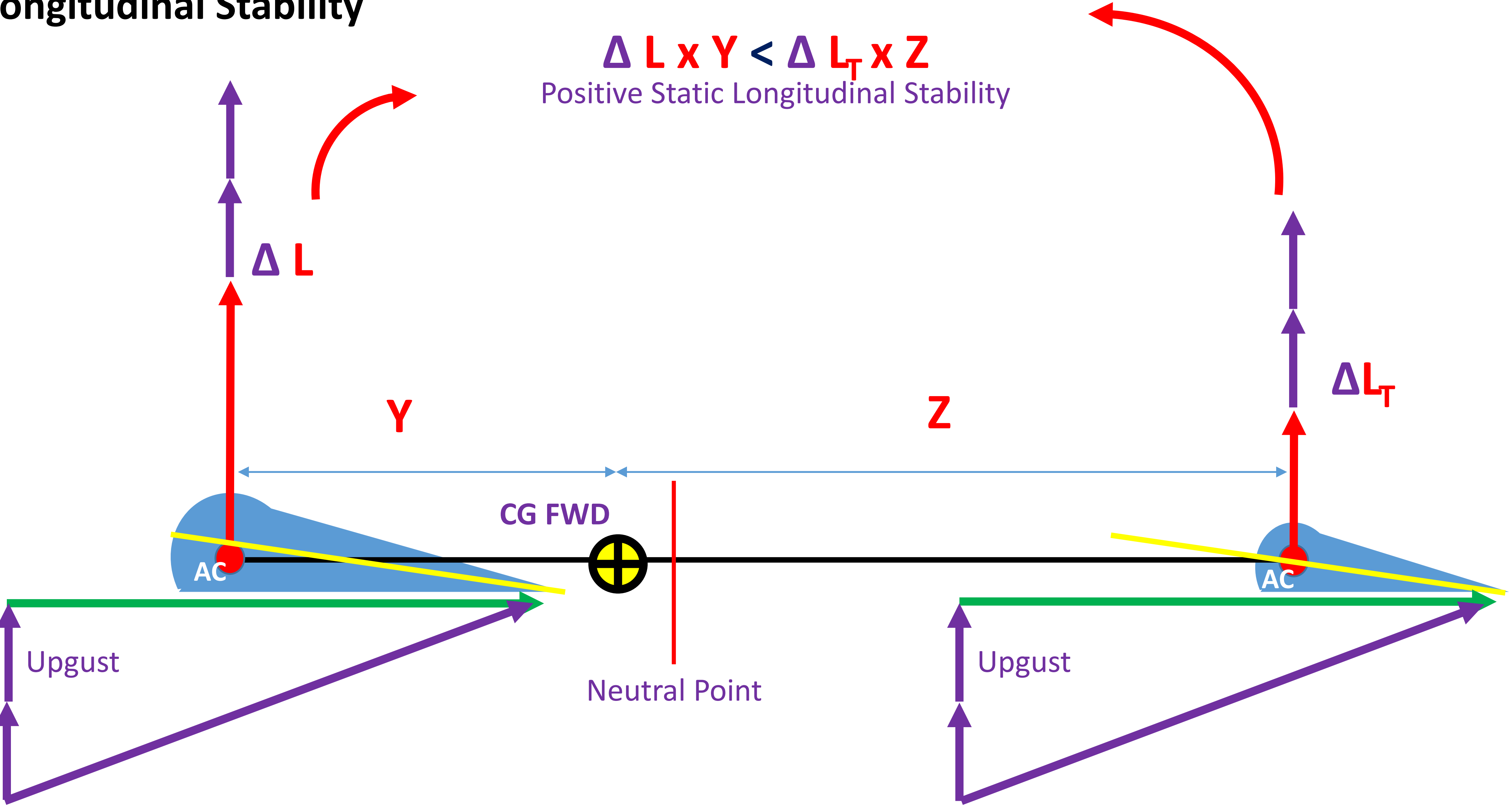
An aircraft exhibits a positive longitudinal stability when it pitches toward the gust to maintain level flight.

Longitudinal Stability

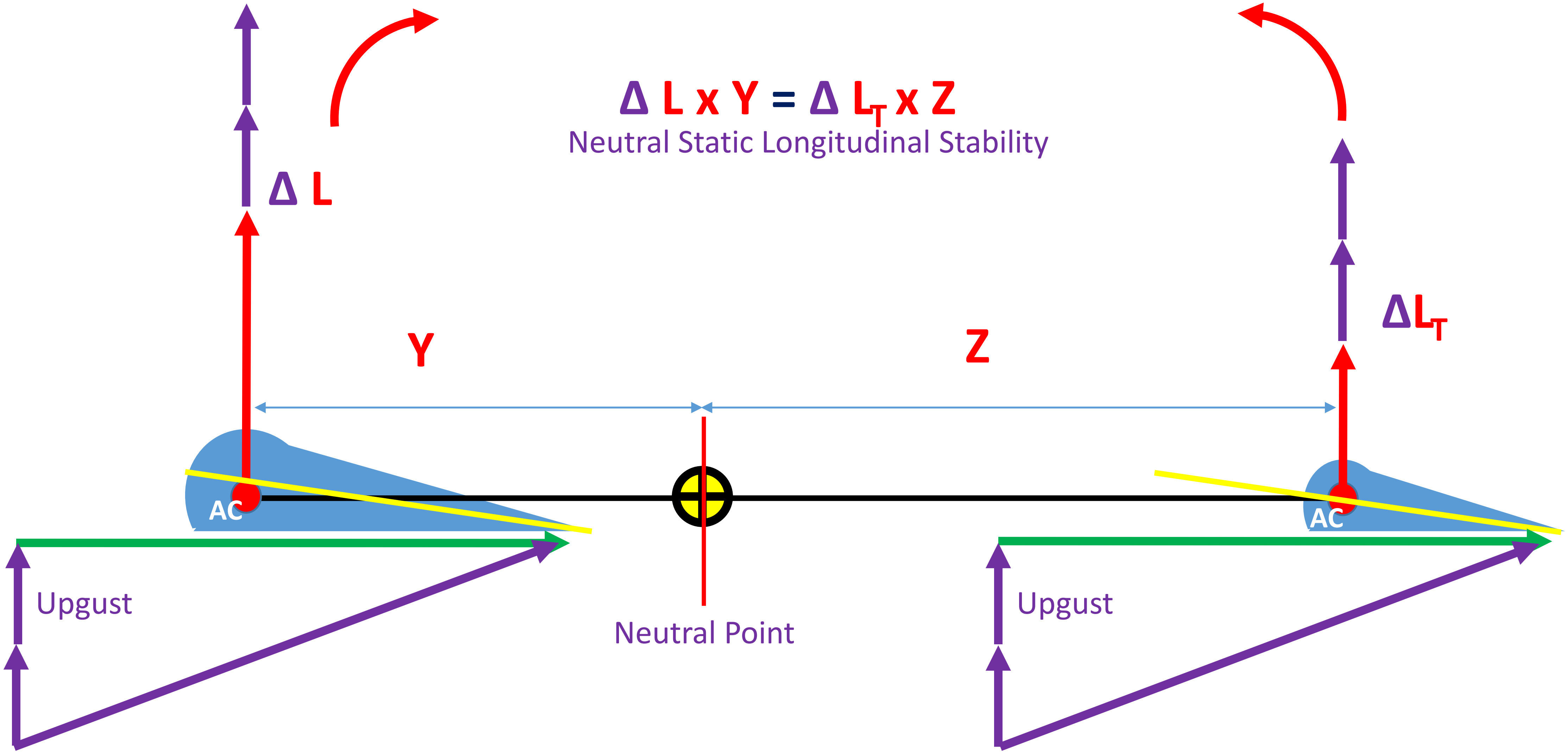
$$L \times Y = L_T \times Z$$



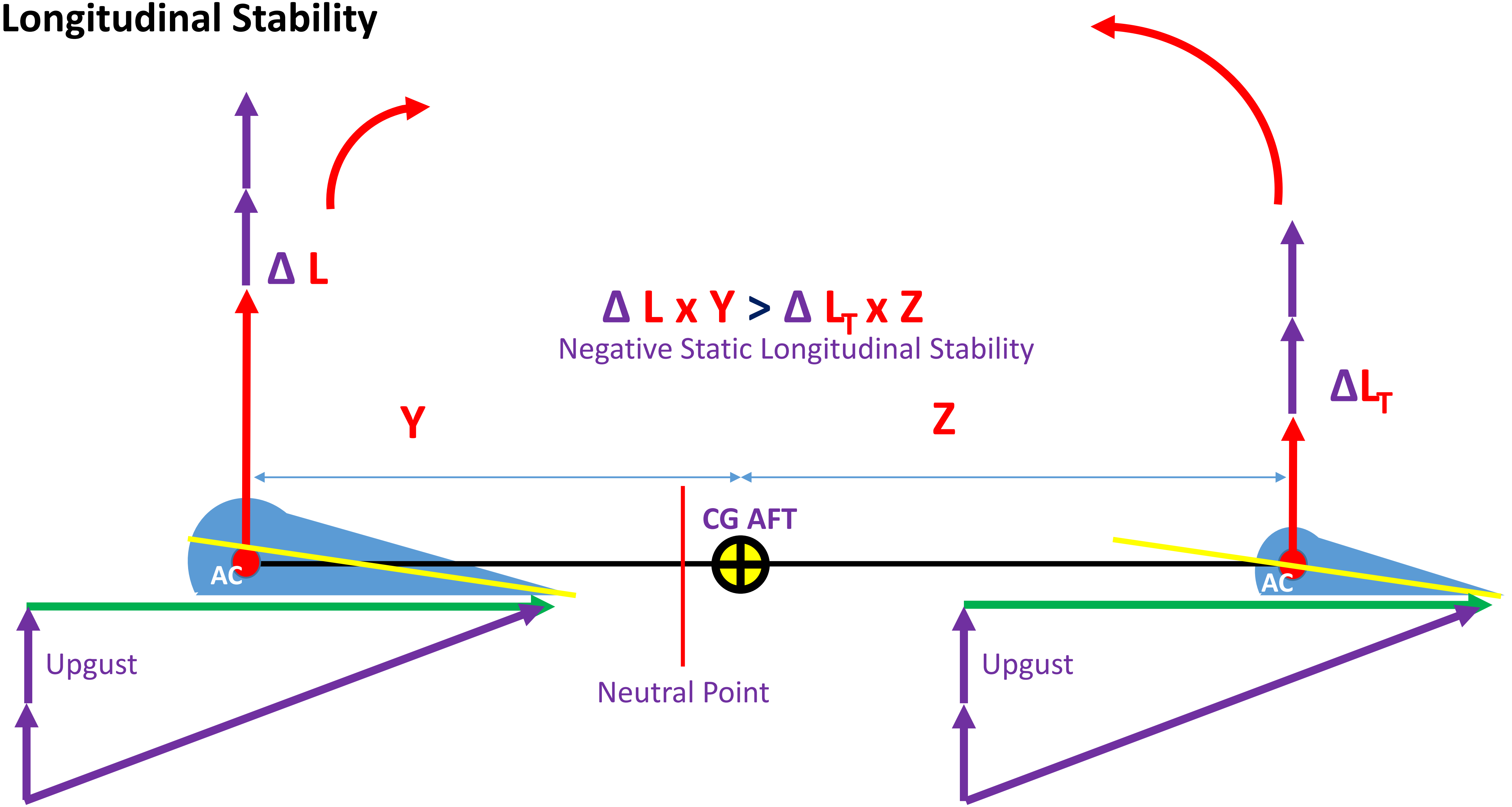
Longitudinal Stability



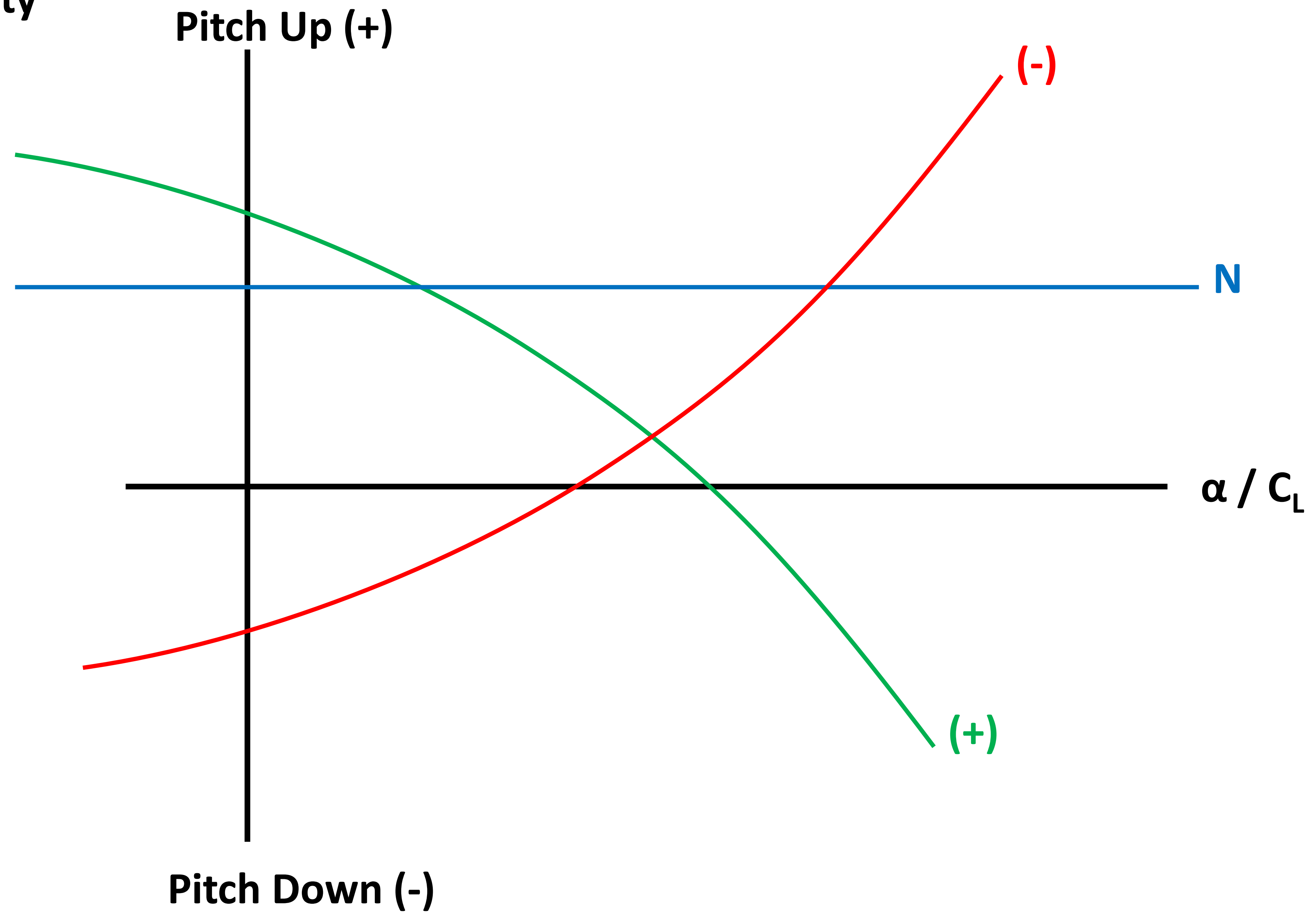
Longitudinal Stability



Longitudinal Stability



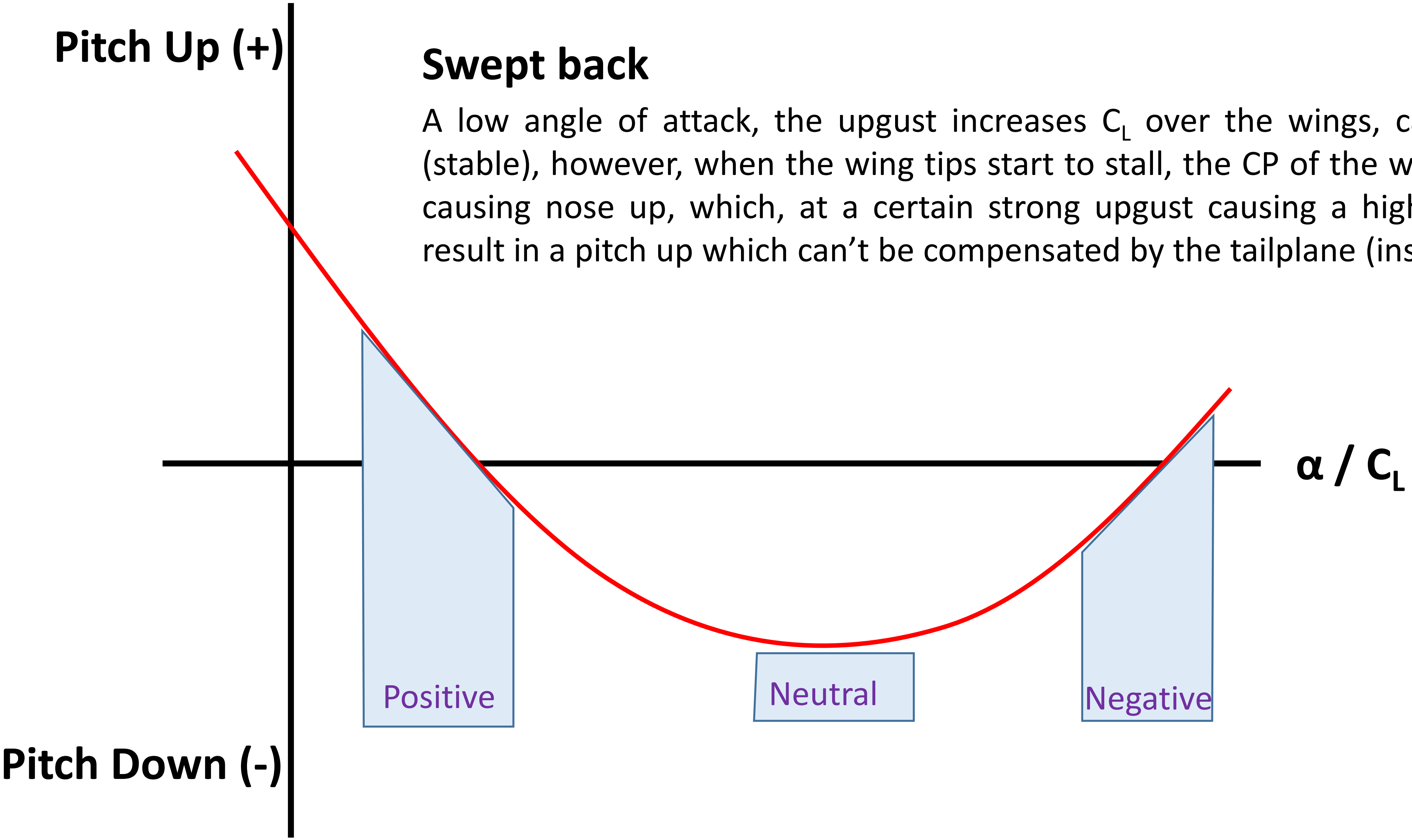
Longitudinal Stability



Longitudinal Stability

Swept back

A low angle of attack, the upgust increases C_L over the wings, causing a nose down (stable), however, when the wing tips start to stall, the CP of the wing moves foreword, causing nose up, which, at a certain strong upgust causing a high increase in C_L, will result in a pitch up which can't be compensated by the tailplane (instable)



Longitudinal Stability

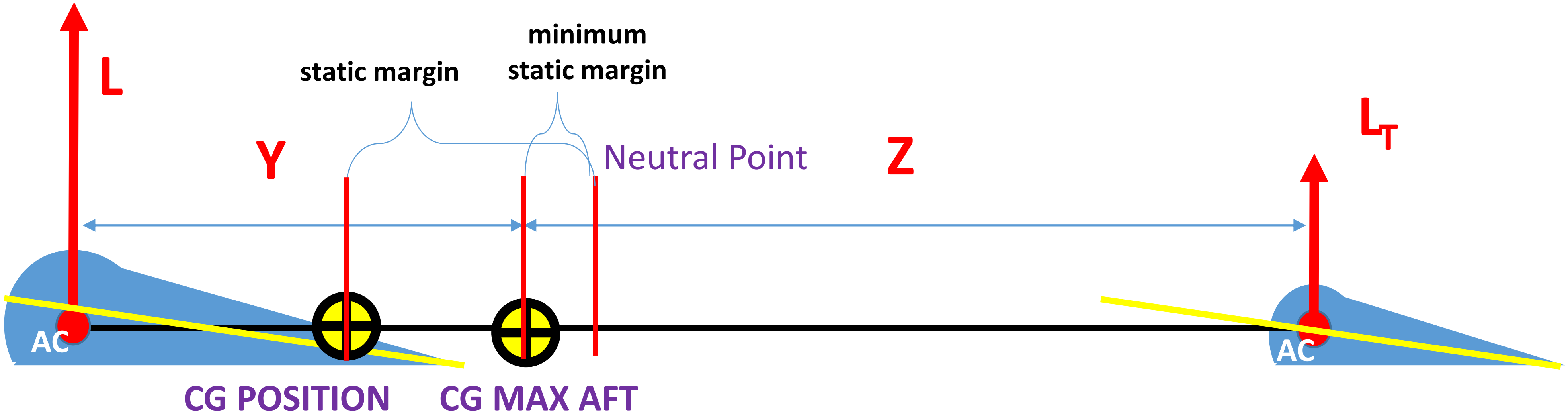
When the CG is on the neutral point, the aircraft will have a neutral static longitudinal stability.

If the CG is slightly forward, the aircraft longitudinal static stability increases. The further forward the CG, the higher the static stability.

The neutral point is an important point of reference in the study of static longitudinal stability. In practice the CG will never be allowed to move so far AFT that it reached the neutral point. The aircraft would be much too sensitive to the controls.

So the CG must be forward of the neutral point, the distance the CG is forward of the neutral point will give a measure of the static longitudinal stability. This distance is called the **static margin**, the greater the static margin, the greater the static longitudinal stability.

A certain amount of static longitudinal stability is always required, so the AFT CG limit will be positioned some distance forward of the neutral point. The distance between the neutral point and the AFT CG limits gives the required **minimum static margin**



Longitudinal Stability

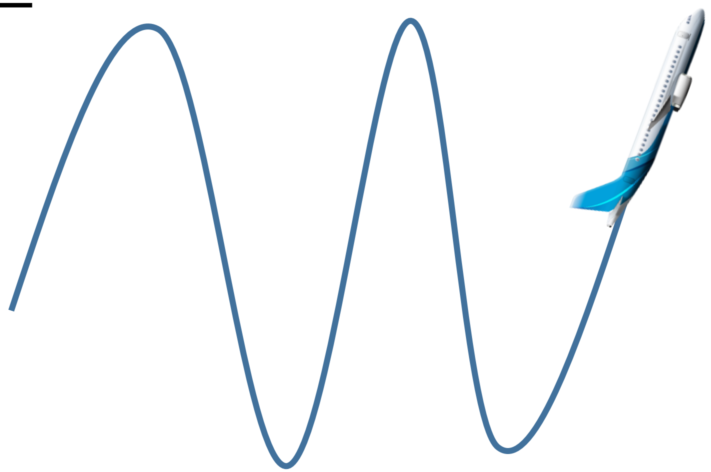
CG Effect and Limit

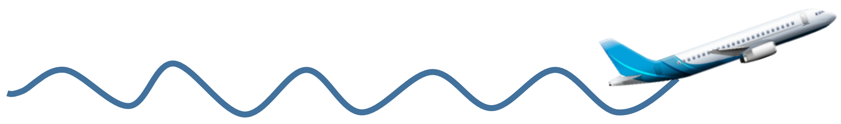
FWD CG	AFT CG
- Increase longitudinal stability - Decrease maneuverability - Increase stick force per g	- Decrease longitudinal stability - Increase maneuverability - Decrease stick force per g

Most FWD CG limit	Most AFT CG limit
- Max upward deflection of the stabilizer - Max nose wheel capability - Acceptable maneuverability (Excessive stick force per g) - Insufficient maneuverability - Insufficient flare/rotation capability	- Max downward deflection of the stabilizer - Aircraft balance on the ground - Acceptable static longitudinal stability (Acceptable stick force per g) - Excessive maneuverability - Risk of stall during take-off

Longitudinal Stability

Oscillation





Long Term Oscillation (phugoid)

- Large change in:
  - Speed
  - Altitude
  - Attitude
- Small change in:
  - Load Factor

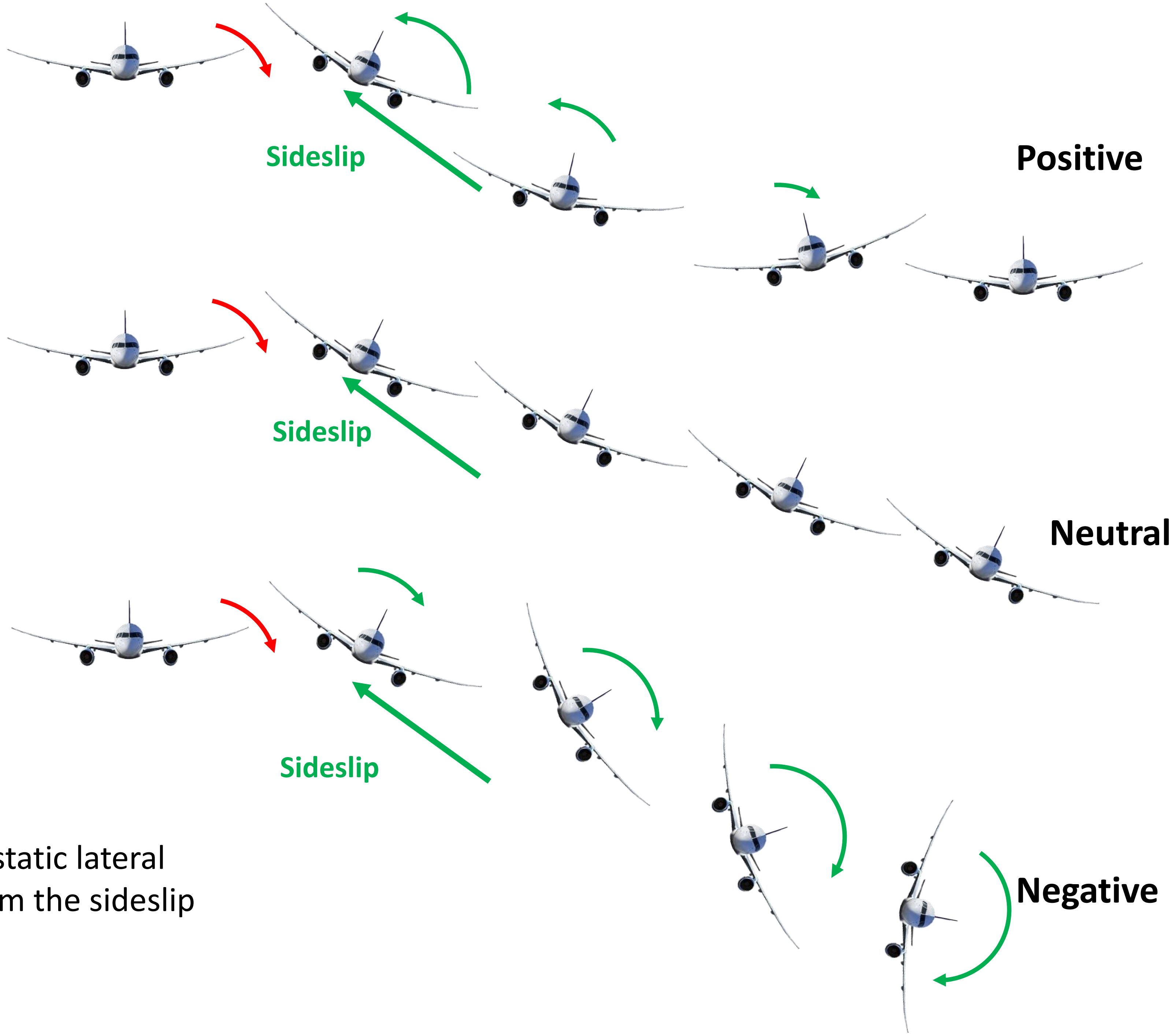
→ Easy to recover

Short Term Oscillation

- Small change in:
  - Speed
  - Altitude
  - Attitude
- Large change:
  - Load Factor

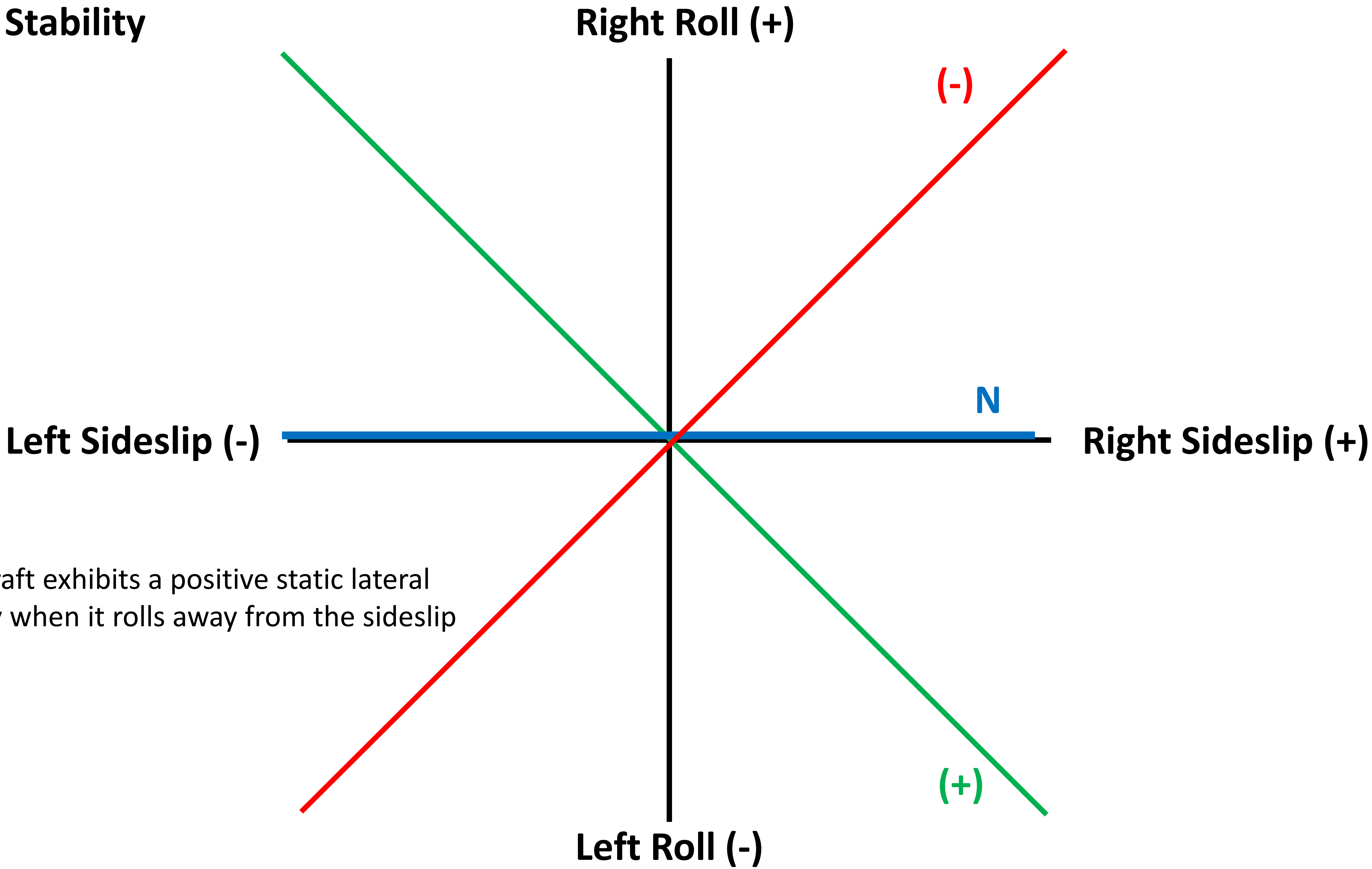
→ Hard to recover

Lateral Stability



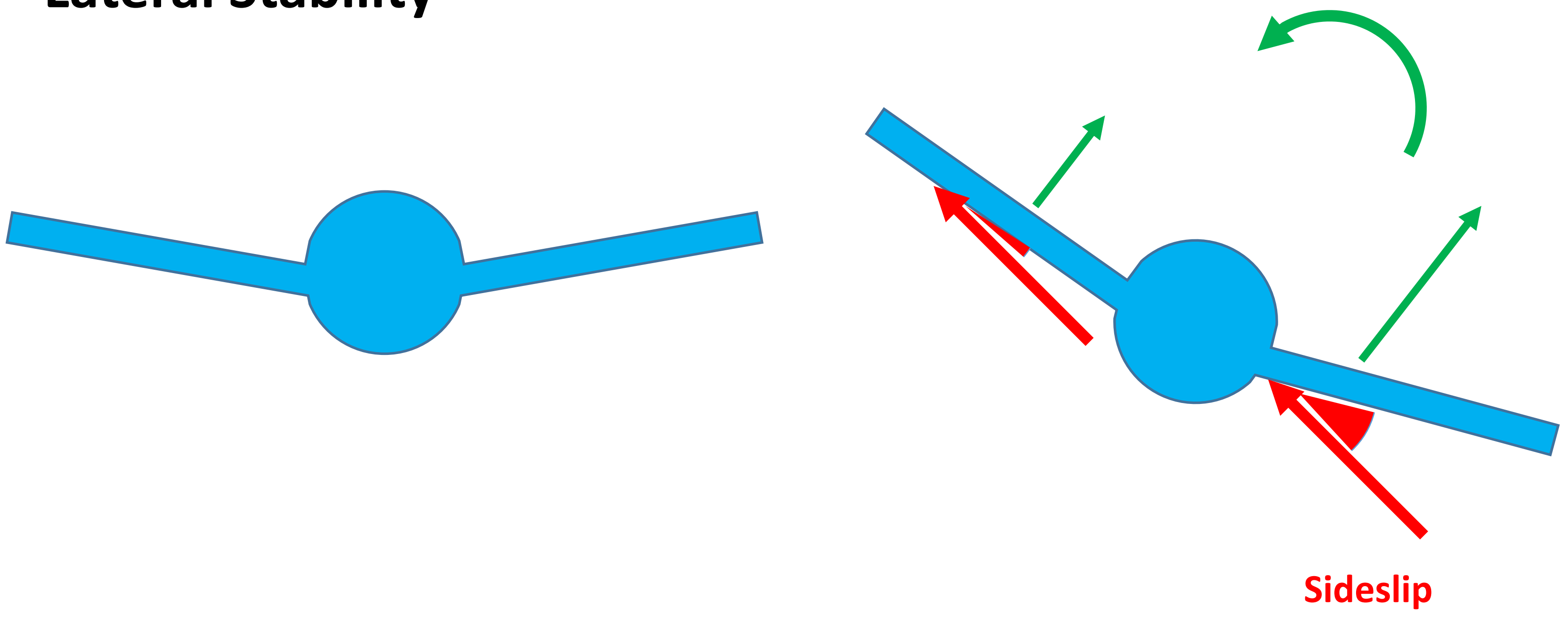
An aircraft exhibits a positive static lateral stability when it rolls away from the sideslip to maintain straight flight.

Lateral Stability

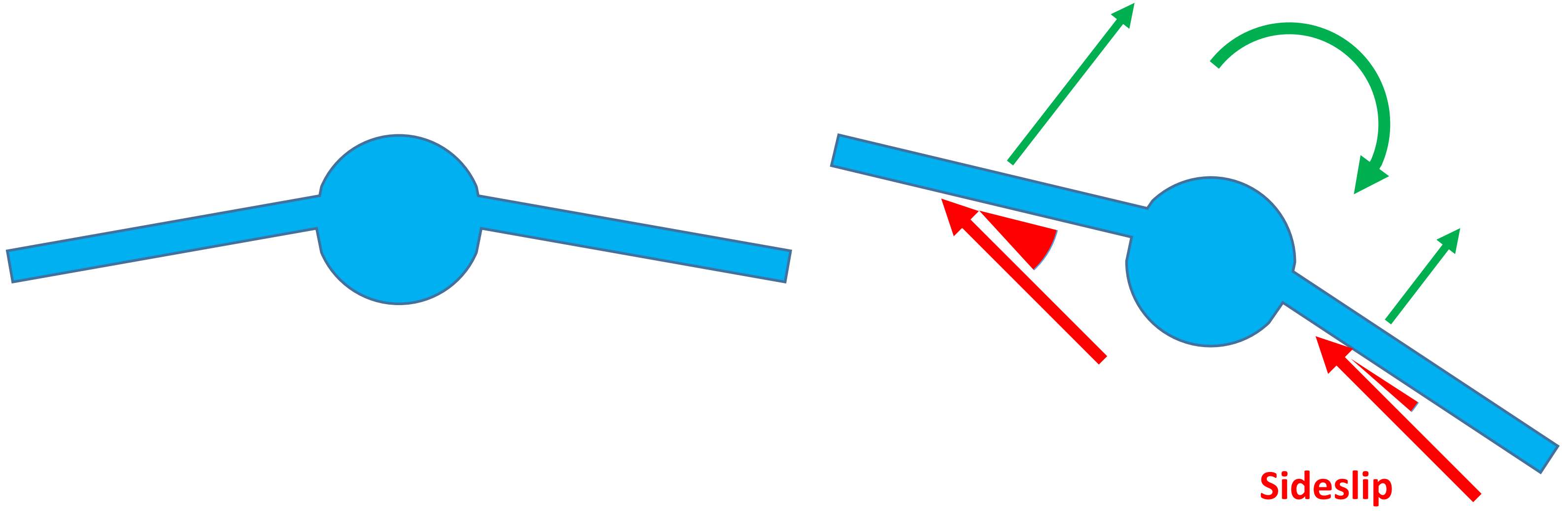


An aircraft exhibits a positive static lateral stability when it rolls away from the sideslip

Lateral Stability

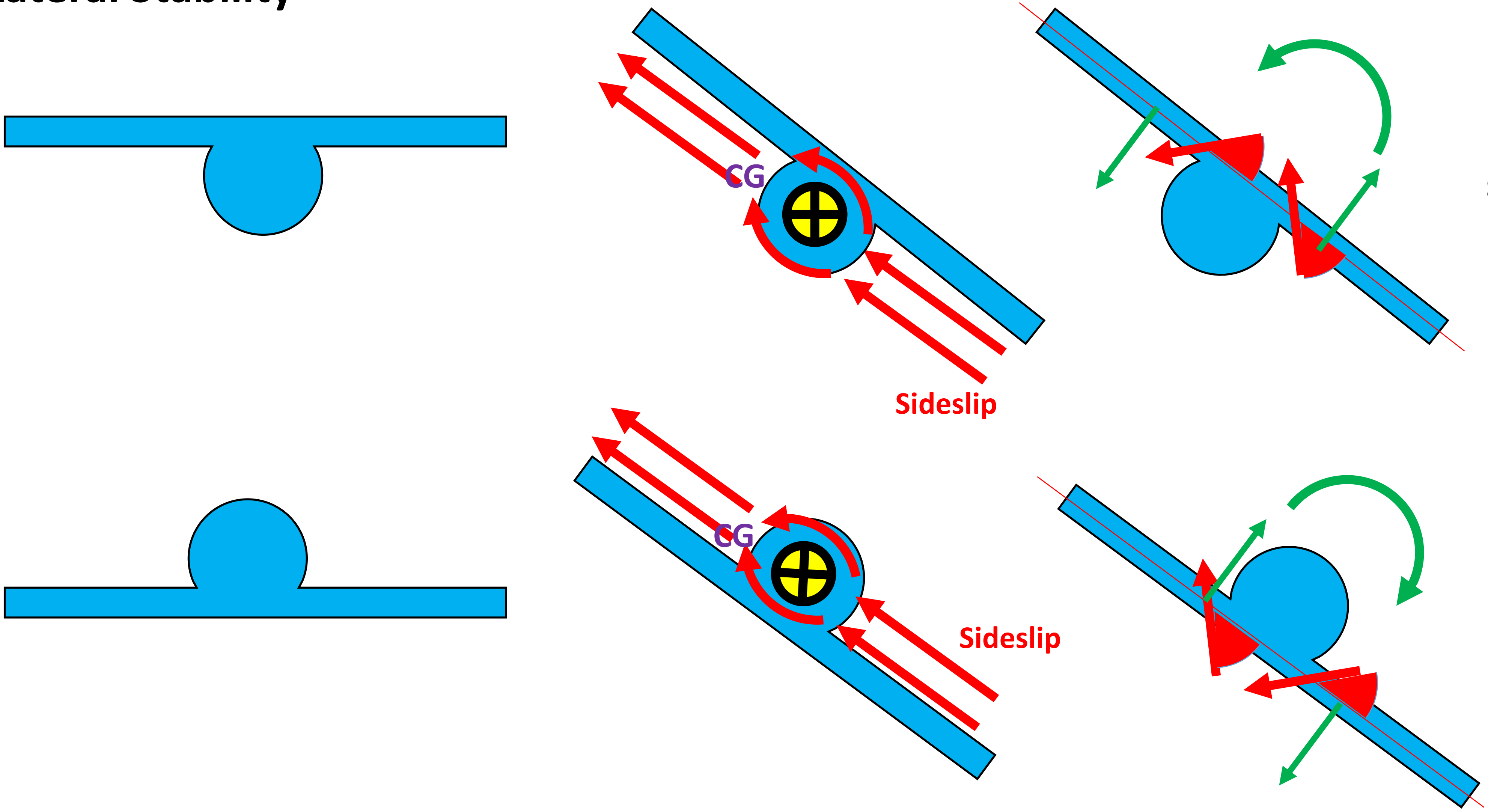


Dihedral wing config increases lateral stability (increase Dihedral effect)



Anhedral wing config decreases lateral stability

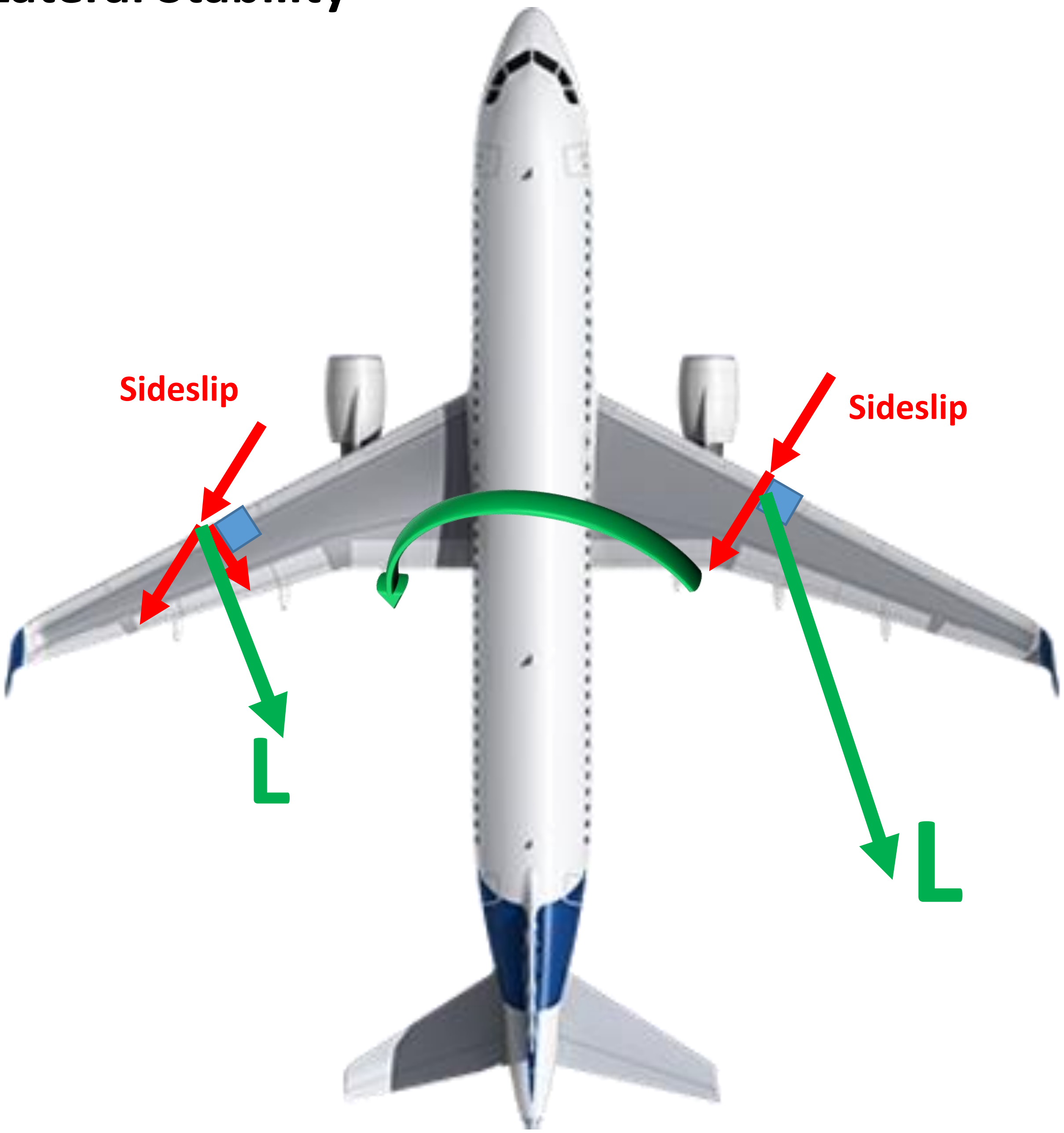
Lateral Stability



High wing config increases lateral stability (increase Dihedral effect)

Low wing config decreases lateral stability

Lateral Stability



Sweptback config increases lateral stability (increase Dihedral effect)

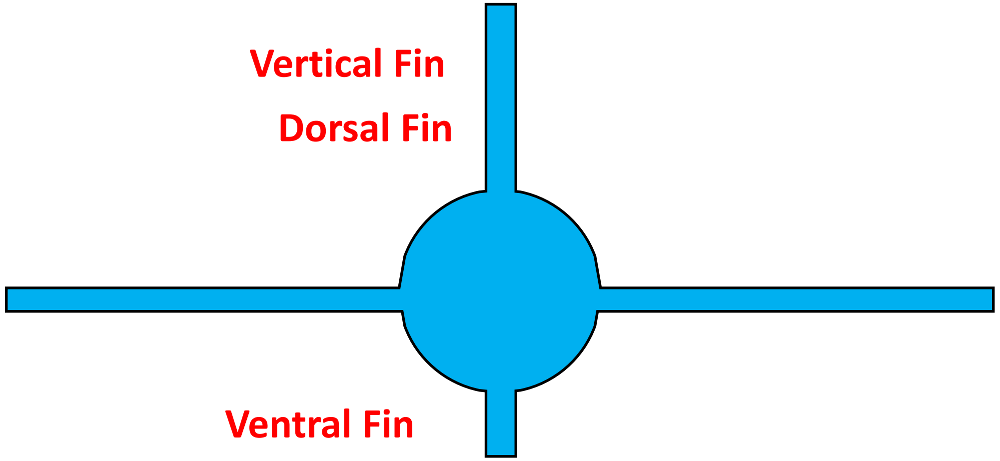
The wing into the sideslip has the airflow more effective, creating more LIFT, thus the aircraft will bank away from the sidelip.

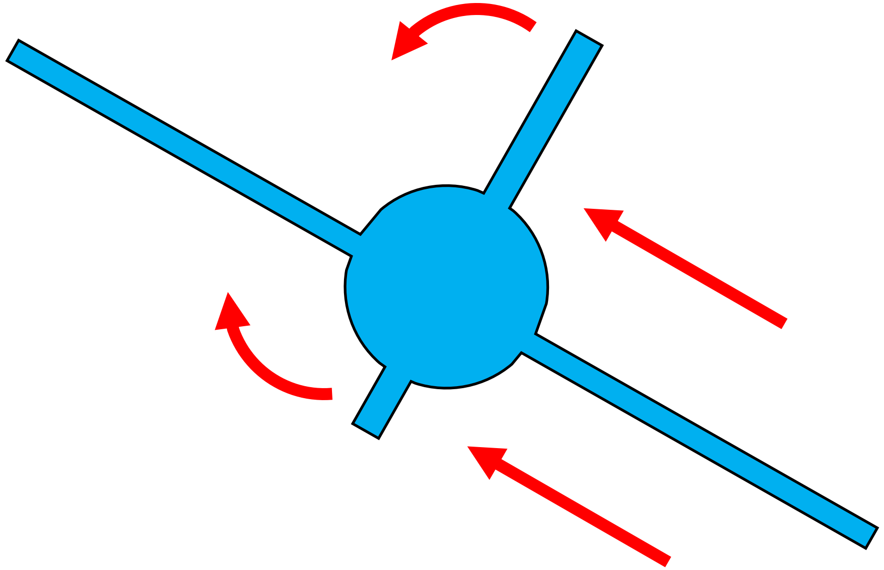
Forward sweep config decrease lateral stability (decrease Dihedral effect)

The wing into the sideslip has the airflow less effective, creating less LIFT, thus the aircraft will bank toward from the sidelip.

Lateral Stability

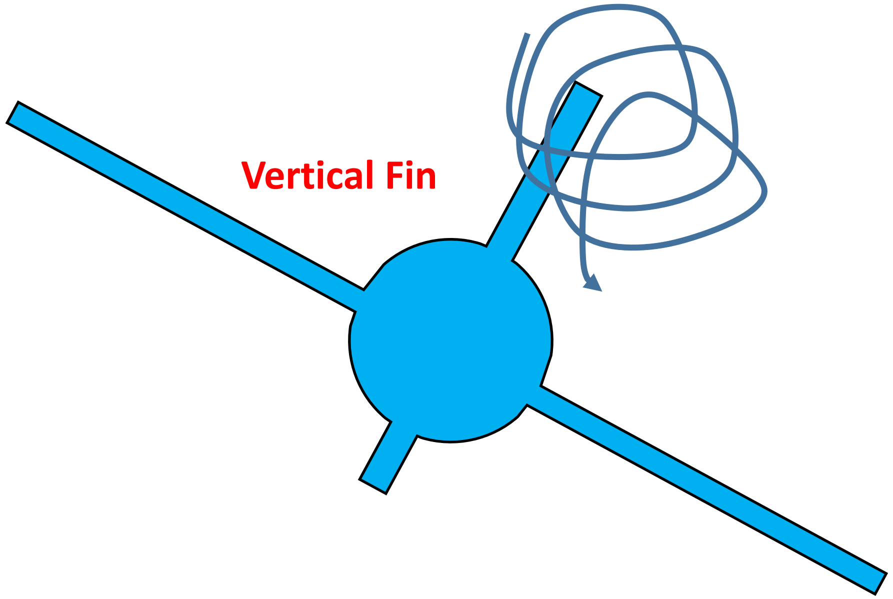
Vertical fin and the dorsal fin increase lateral stability (increase Dihedral effect)



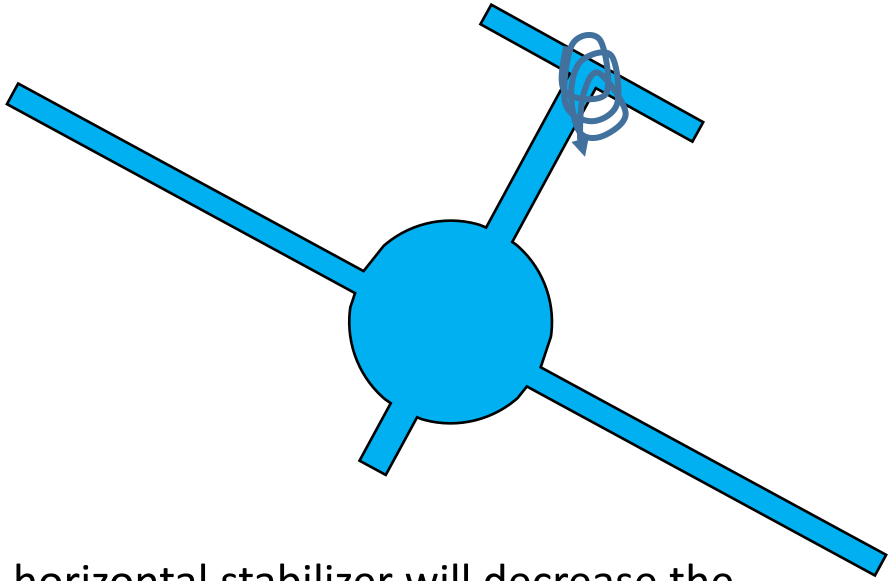


Ventral fin decrease lateral stability (decrease Dihedral effect)

Lateral Stability



T-tail config increases lateral stability (increase Dihedral effect)

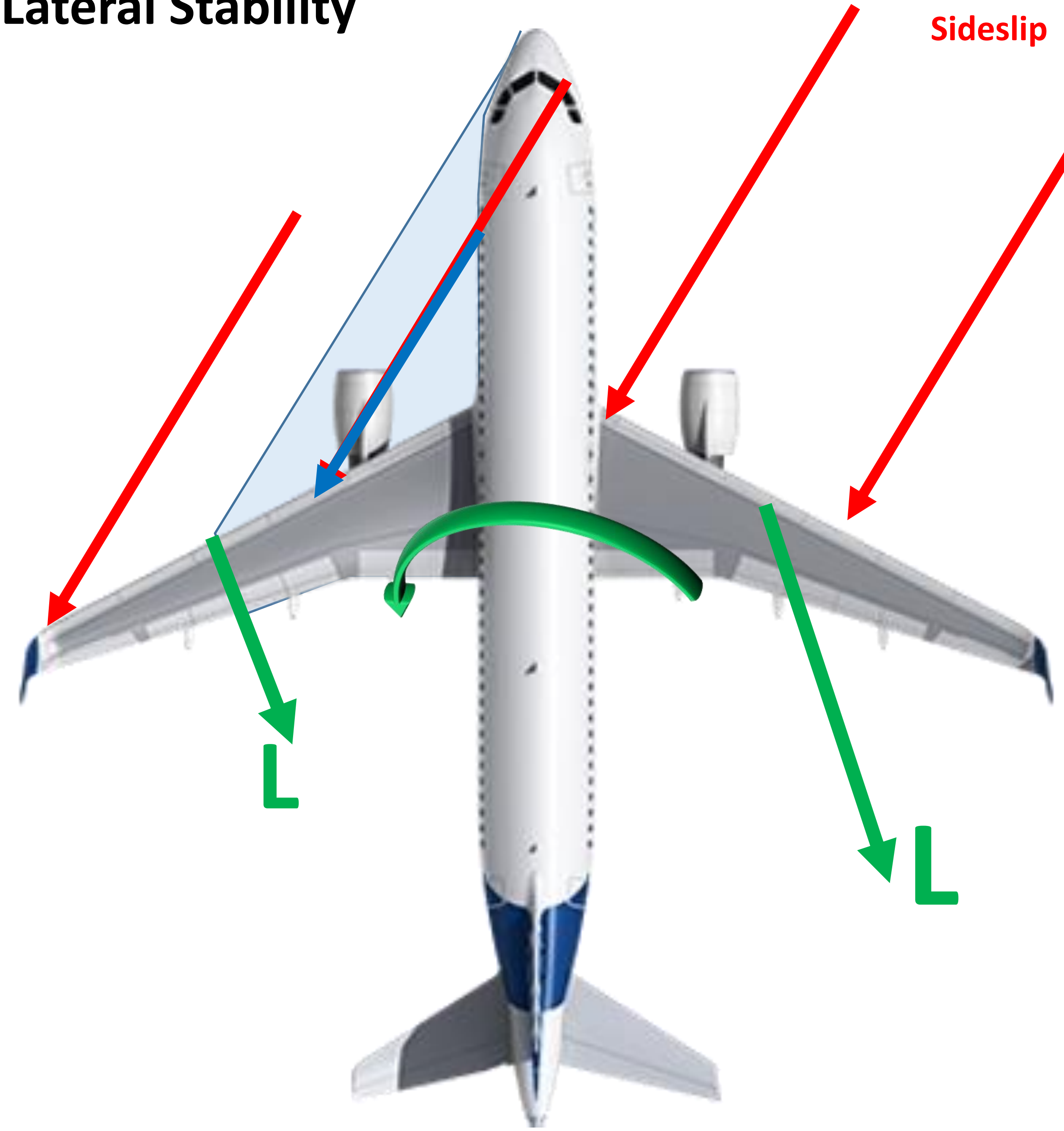


The horizontal stabilizer will decrease the vertical fin tip vortices, making the vertical fin more efficient

Increase Aspect Ratio of the vertical fin, increases lateral stability (increase Dihedral effect)

By increasing the Aspect Ratio, the vertical fin produces less tip vortices, which makes it more efficient

Lateral Stability



Fuselage shading increases lateral stability (increase Dihedral effect)

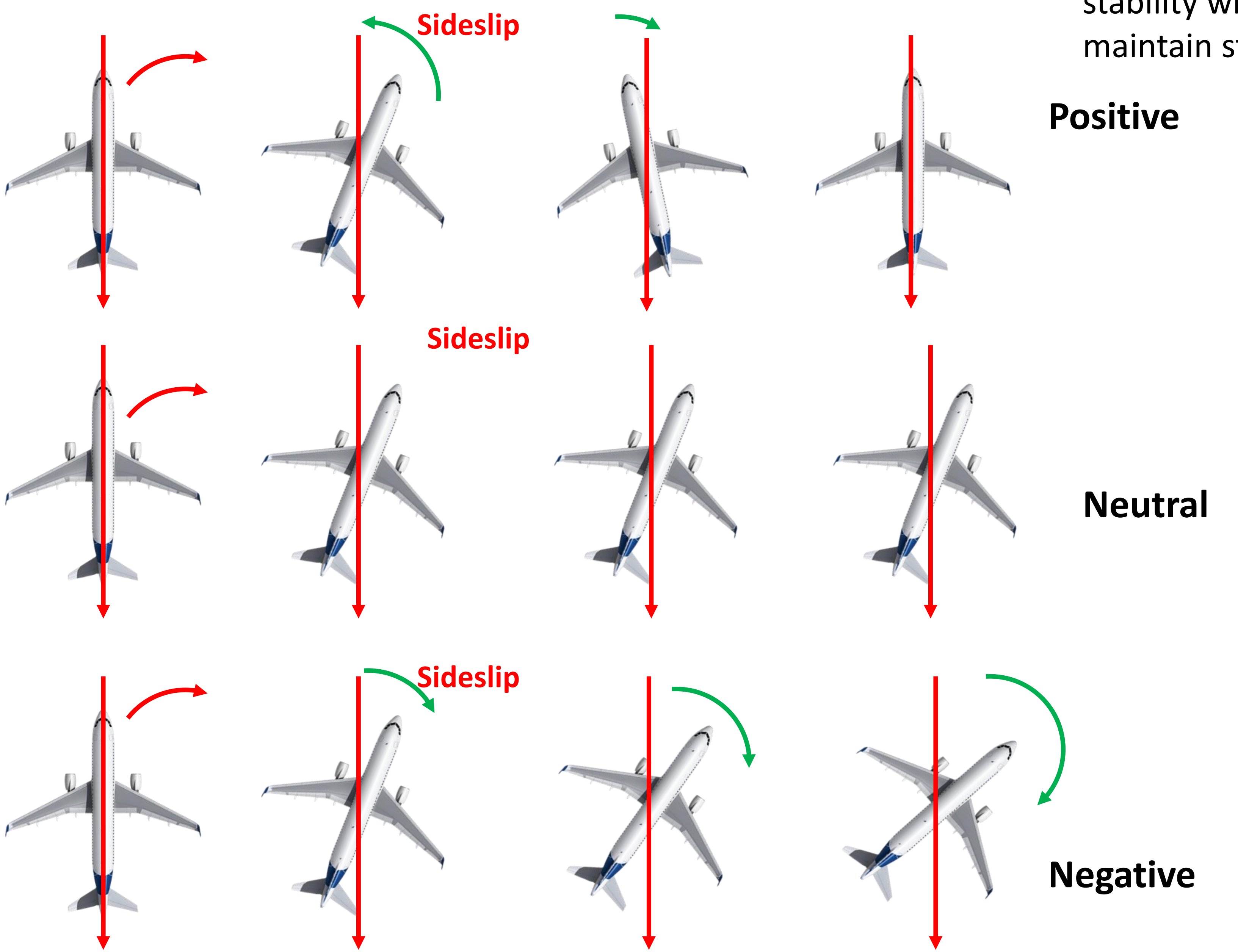
The shading of the fuselage, makes the wing outside of the sideslip less exposed to the sideslip therefore less effective. It will produce less LIFT than the wing onto the sideslip, thus a stabilizing effect

Lateral Stability

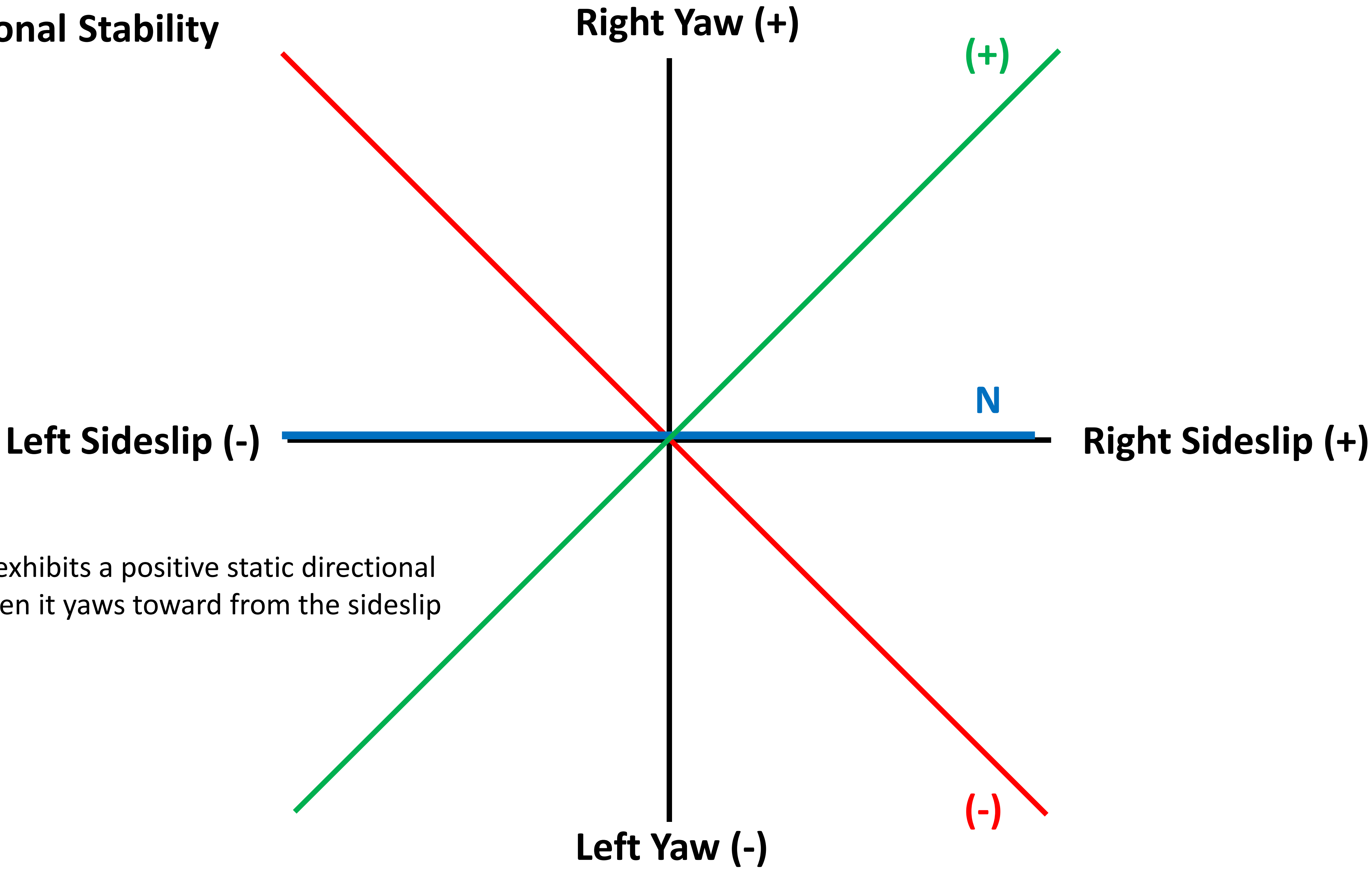
Increase lateral static stability	Decrease lateral static stability
- High wings - Dihedral - Sweep back - Fuselage shading - T-Tail - Vertical Fin - Dorsal Fin - Increase AR of the fin (vertical stabilizer)	- Low wings - Anhedral - Sweep forward - Ventral Fin - Decrease AR of the fin (vertical stabilizer)

Directional Stability

An aircraft exhibits a positive static directional stability when it yaws toward the sideslip to maintain straight flight.



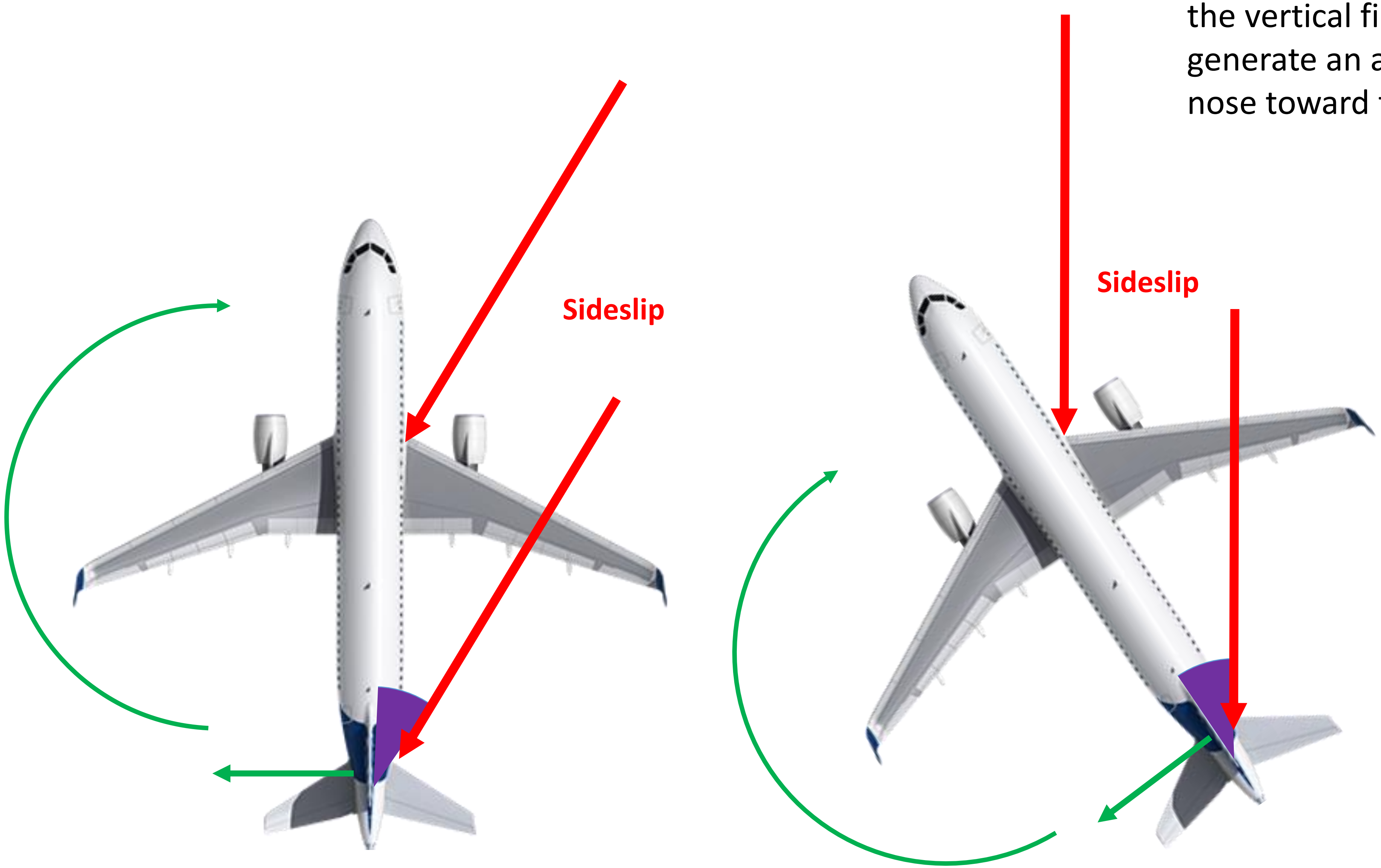
Directional Stability



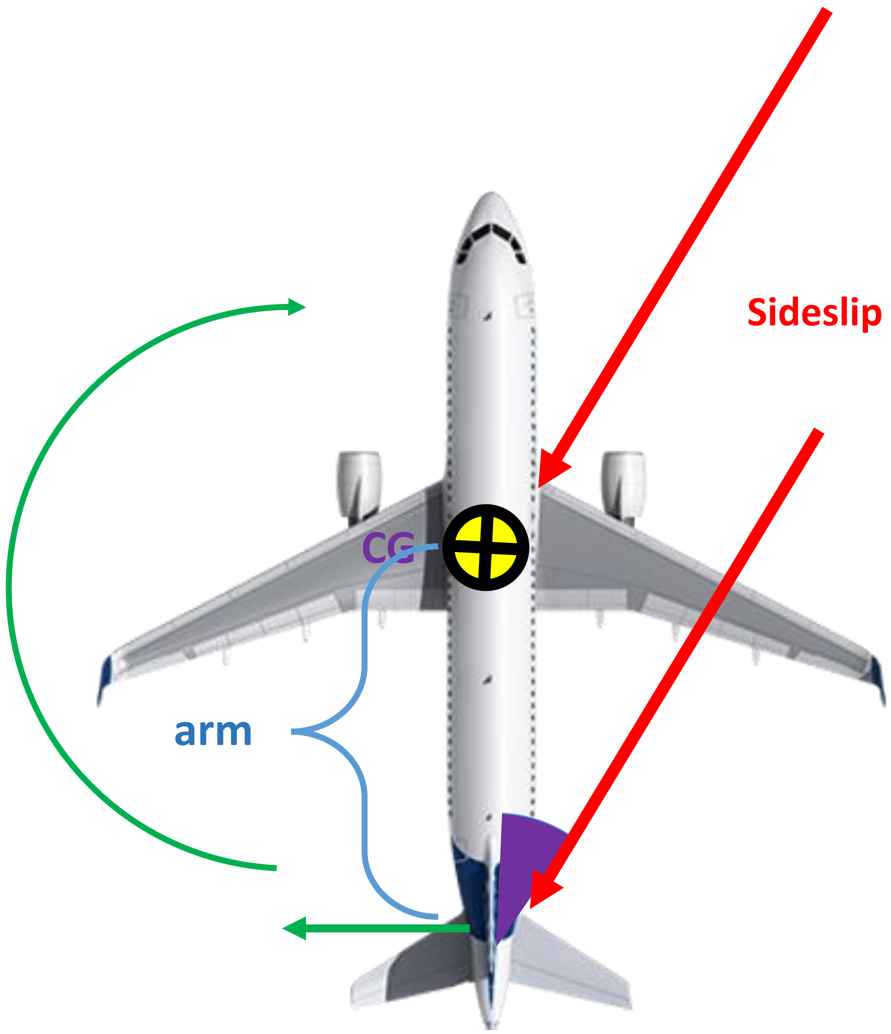
An aircraft exhibits a positive static directional stability when it yaws toward from the sideslip

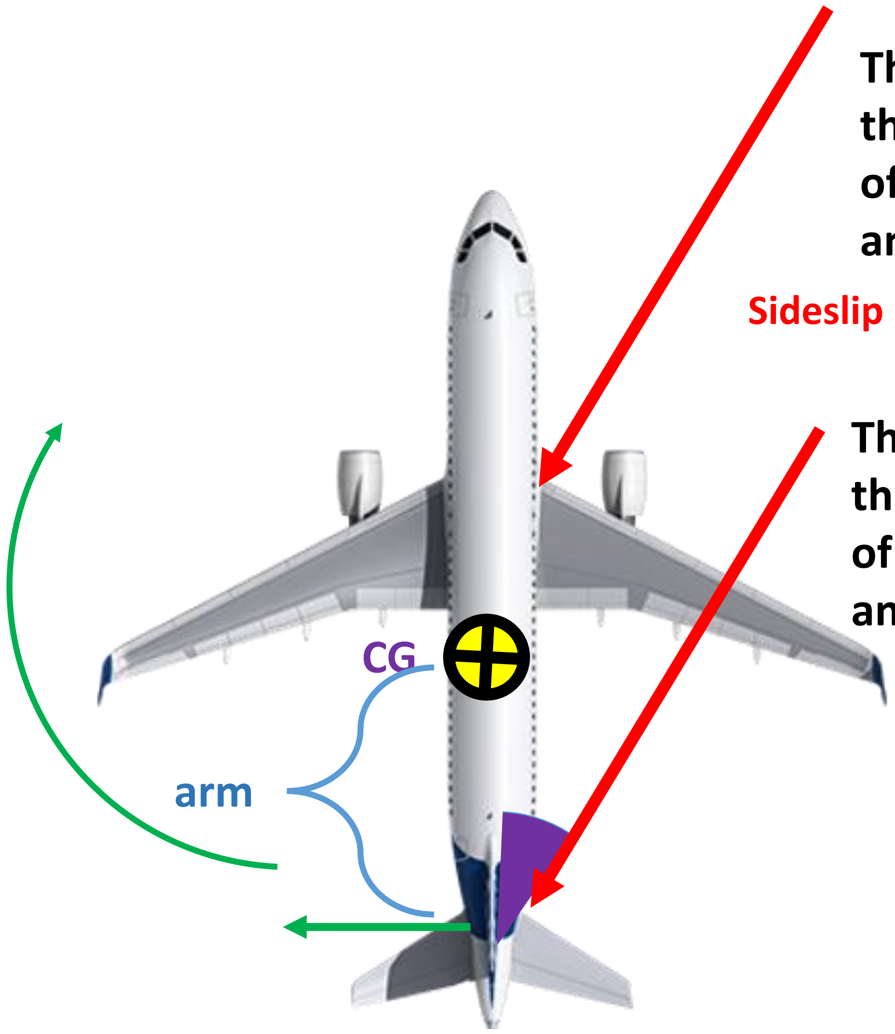
Directional Stability

The directional stability will be ensured by the vertical fin, which inti the airflow, it will generate an aerodynamic force to yaw the nose toward the relative airflow/sidelslip.



Directional Stability

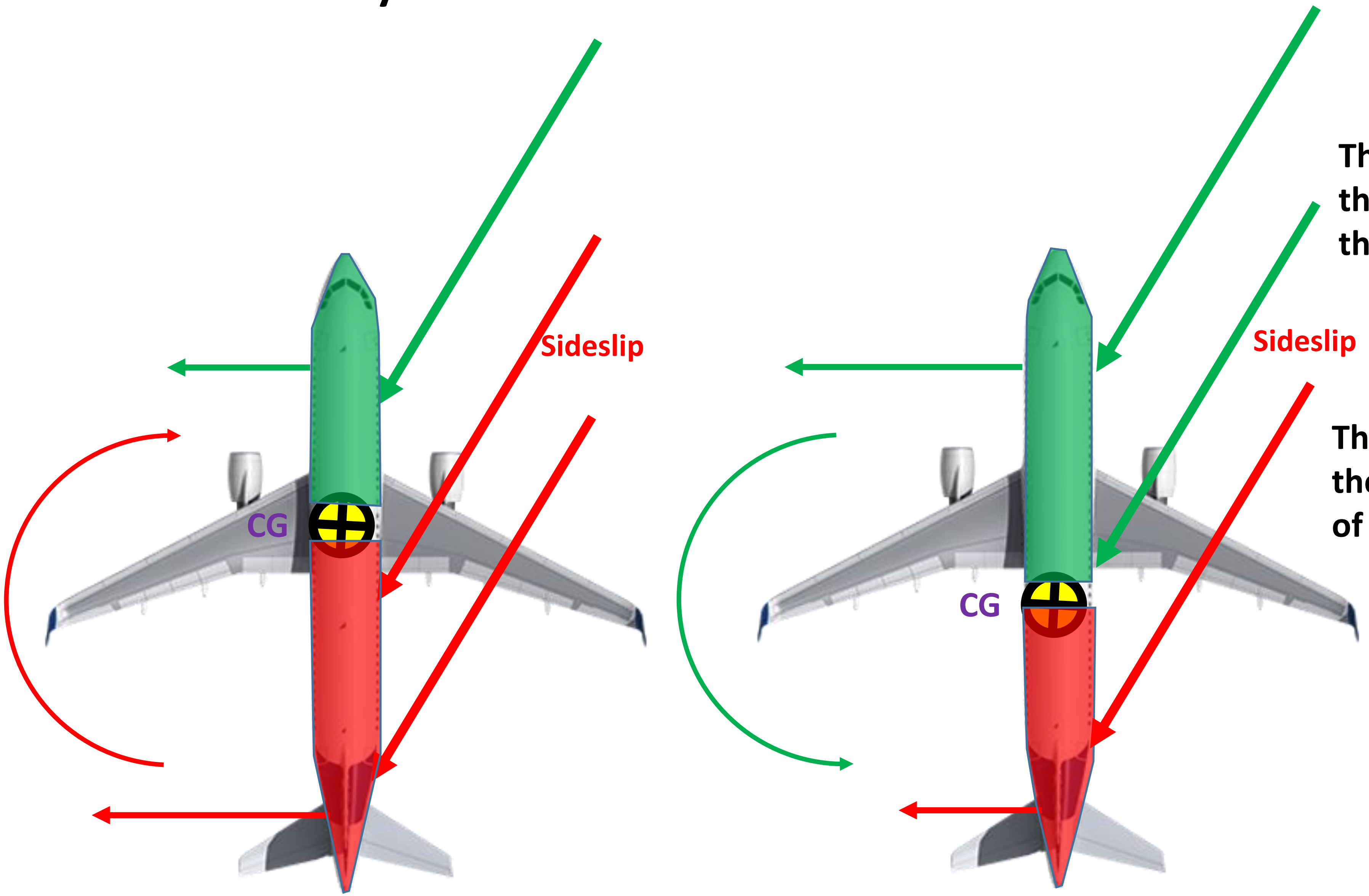




The FWD CG position, increases the directional stability, because of larger arm between the CG and the AC of the vertical fin

The AFT CG position, decreases the directional stability, because of shorter arm between the CG and the AC of the vertical fin

Directional Stability



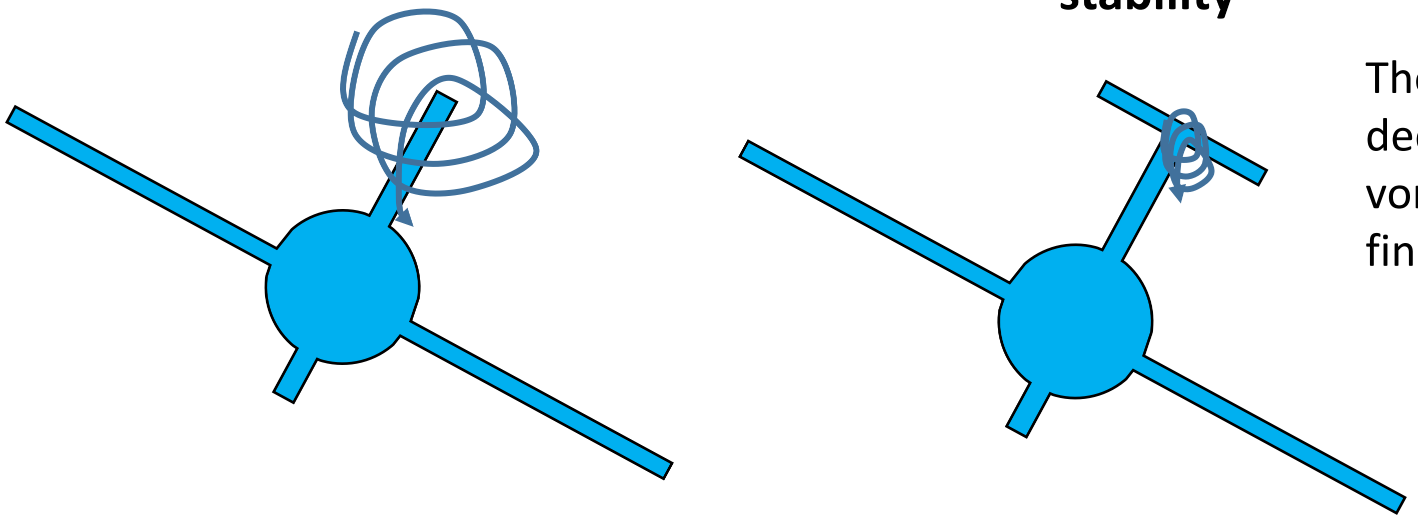
The FWD CG position, increases the directional stability, because the AFT keel is wider

The AFT CG position, decreases the directional stability, because of the FWD keel is wider

Directional Stability

Ventral fin and the dorsal fin increase the area of the vertical fin, thus the vertical is more efficient

T-tail config increases directional stability

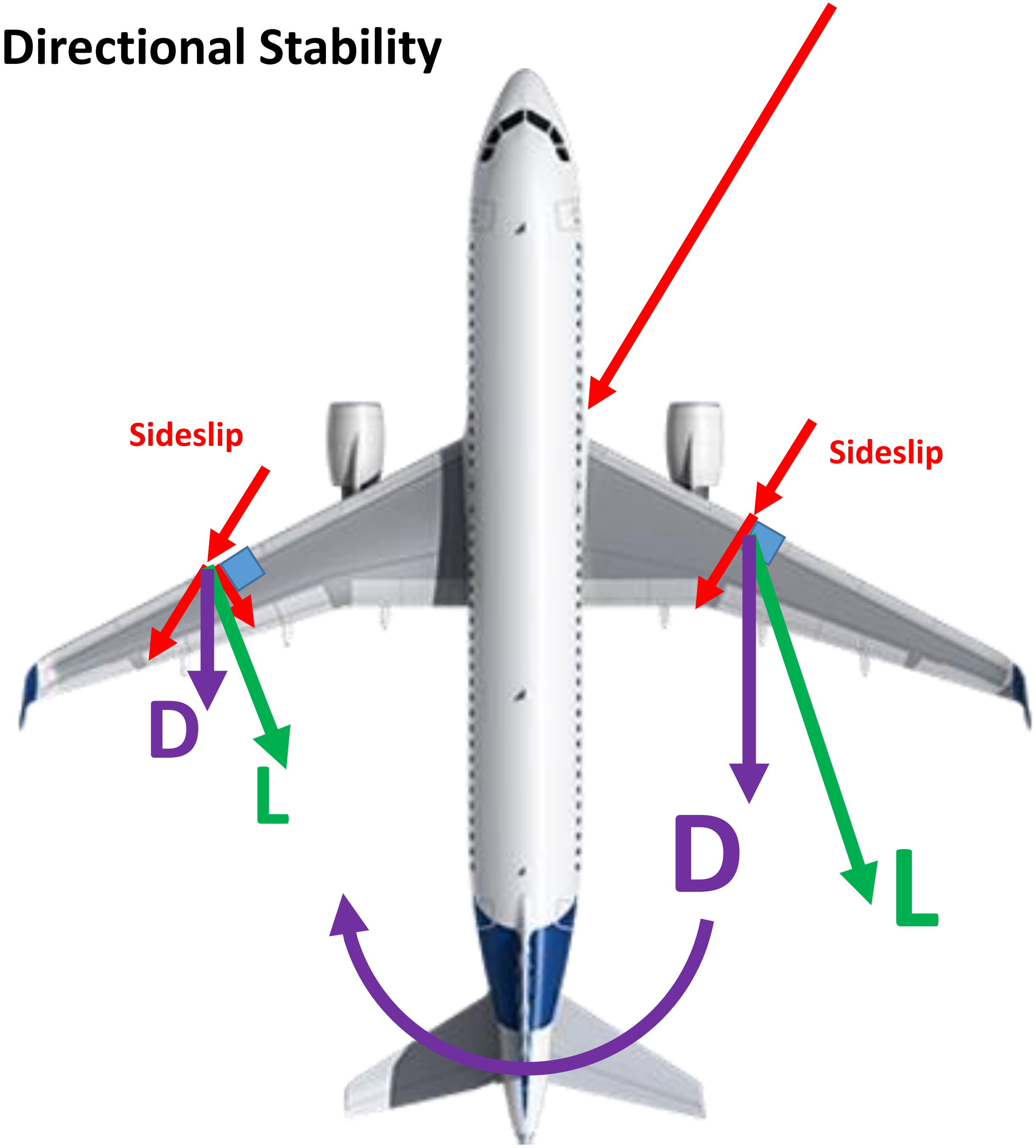


The horizontal stabilizer will decrease the vertical fin tip vortices, making the vertical fin more efficient

Increase Aspect Ratio of the vertical fin, increases directional stability

By increasing the Aspect Ratio, the vertical fin produces less tip vortices, which makes it more efficient

Directional Stability



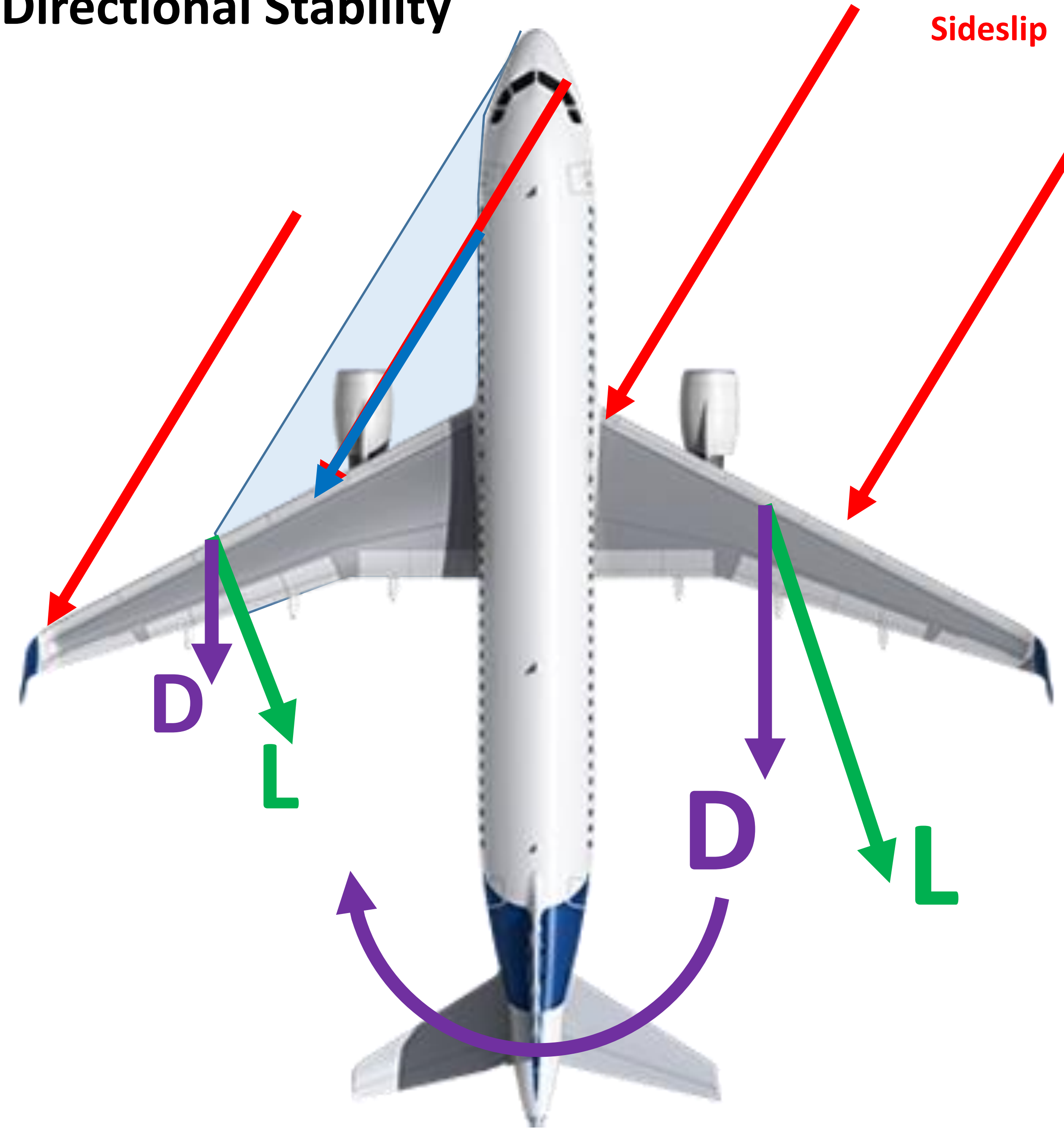
Sweptback config increases directional stability

The wing into the sideslip has the airflow more effective, creating more LIFT, also more DRAG. The differential DRAG will yaw the aircraft toward the sideslip.

Forward sweep config decrease directional stability

The wing into the sideslip has the airflow less effective, creating less LIFT, also less DRAG. The differential DRAG will yaw the aircraft away from the sideslip.

Directional Stability



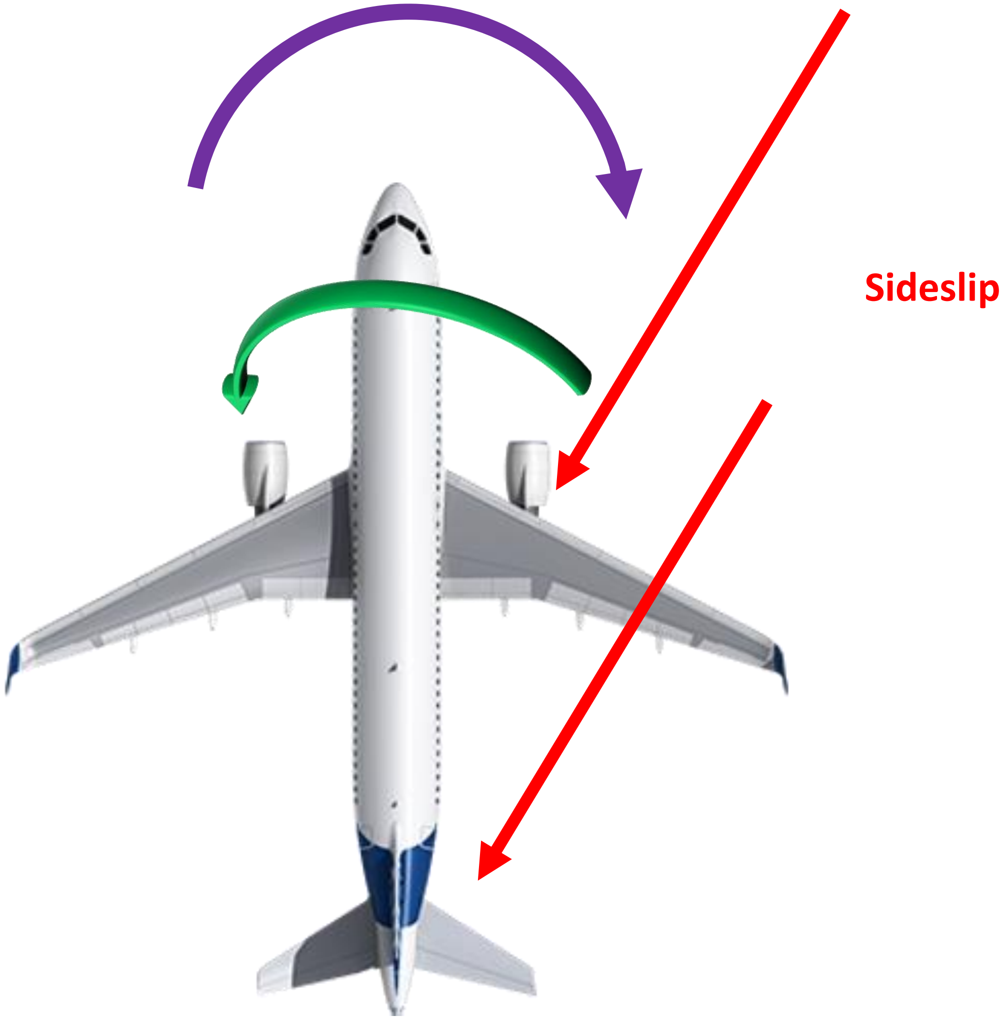
Fuselage shading increases directional stability

The shading of the fuselage, makes the wing outside of the sideslip less exposed to the sideslip therefore less effective. It will produce less LIFT, also less DRAG than the wing onto the sideslip, thus a stabilizing effect

Directional Stability

Increase directional static stability	Decrease directional static stability
- FWD CG - AFT aircraft keel - Dorsal and ventral fin - Increase AR of the fin (vertical stabilizer) - T-Tail - Sweep back - Fuselage shading	- AFT CG - FWD aircraft keel - Decrease AR of the fin (vertical stabilizer) - Sweep forward

Lateral/Directional Stability

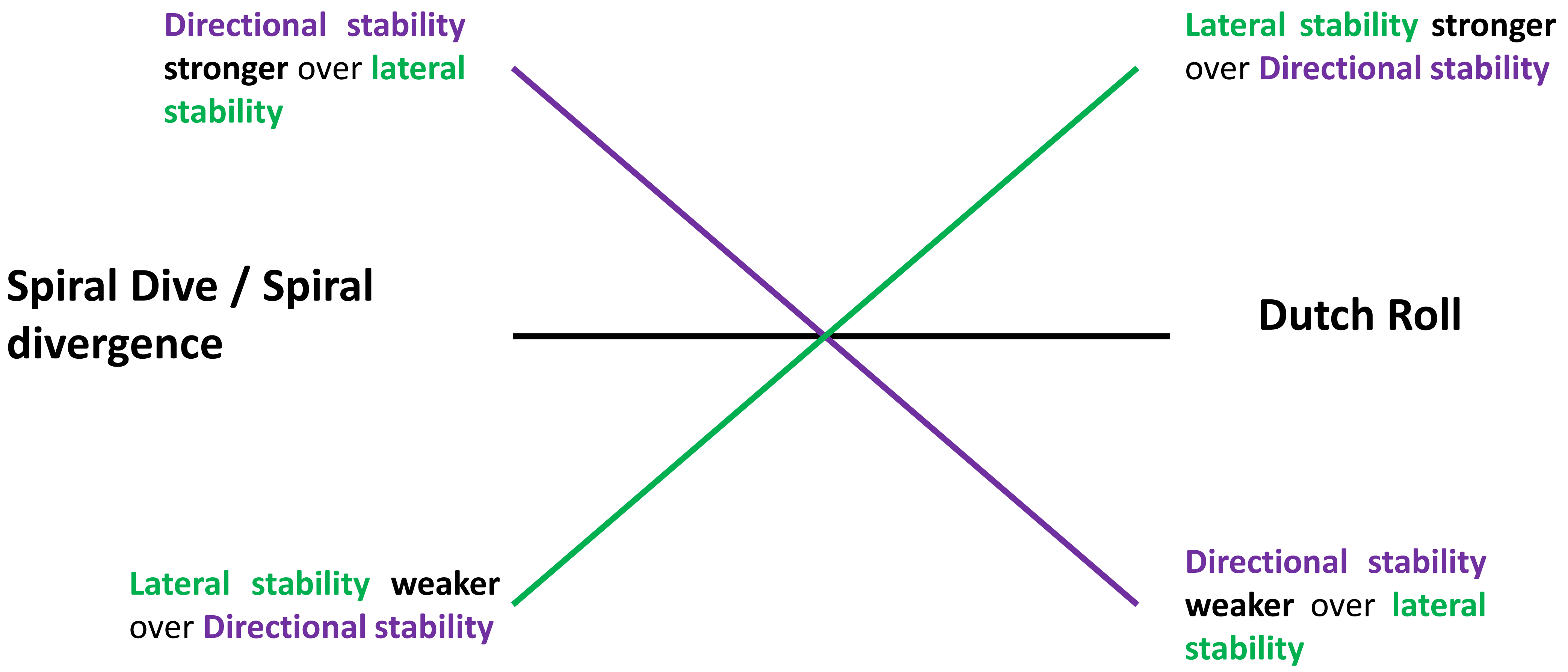


Indeed, when the aircraft experiences sideslip, the couple lateral and directional stability react together

Reminder:
An aircraft exhibits a positive static lateral stability when it **rolls** away from the sideslip

An aircraft exhibits a positive static directional stability when it **yaws** toward from the sideslip

Lateral/Directional Stability



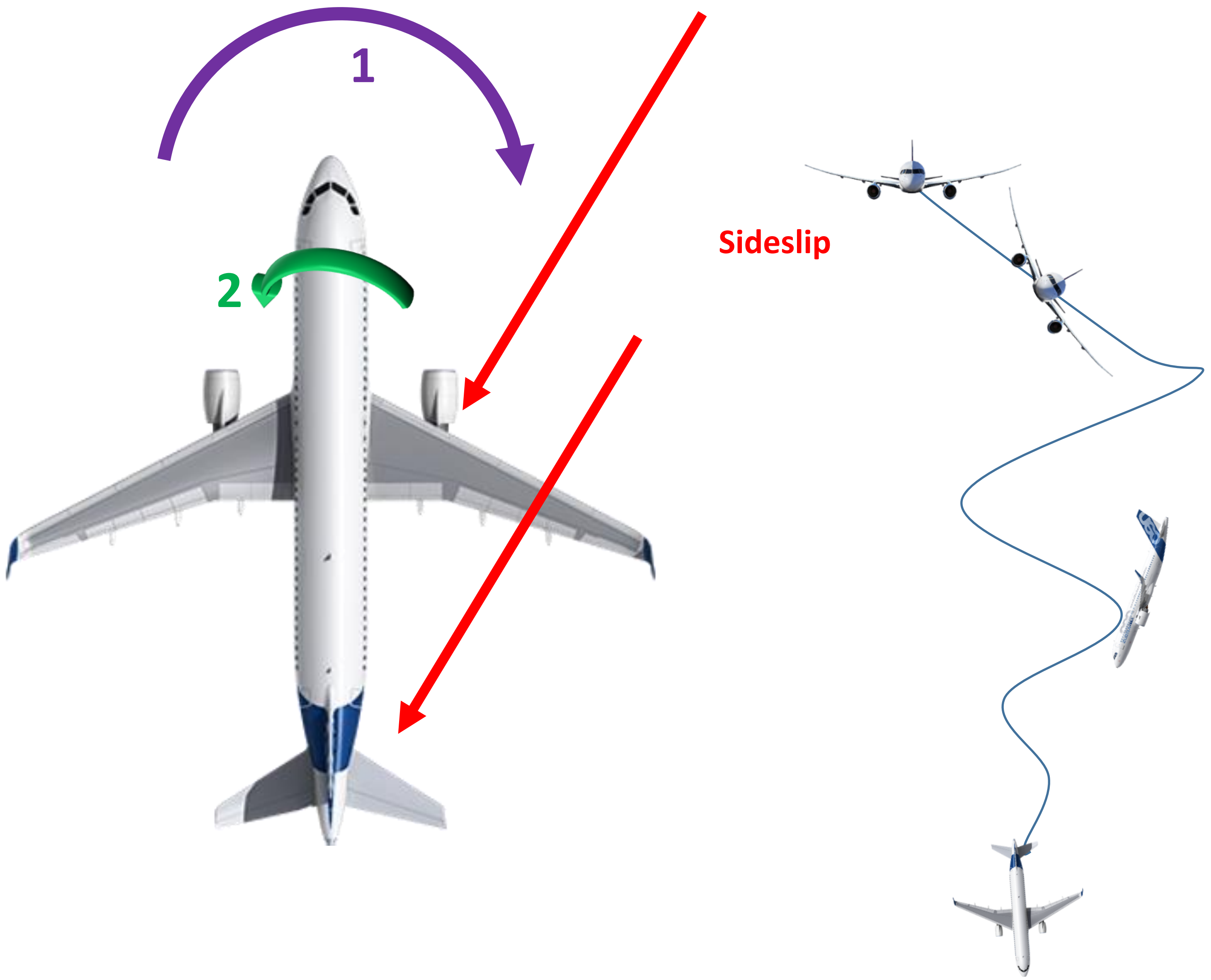
Lateral/Directional Stability

SPIRAL DIVERGENCE/SPIRAL DIVE

Spiral divergence will exist when static directional stability is very large when compared to the lateral stability (“dihedral effect”)

The character of the spiral divergence is not violent. The airplane, when disturbed from the equilibrium of level flight, begins a slow spiral which gradually increases to a spiral dive.

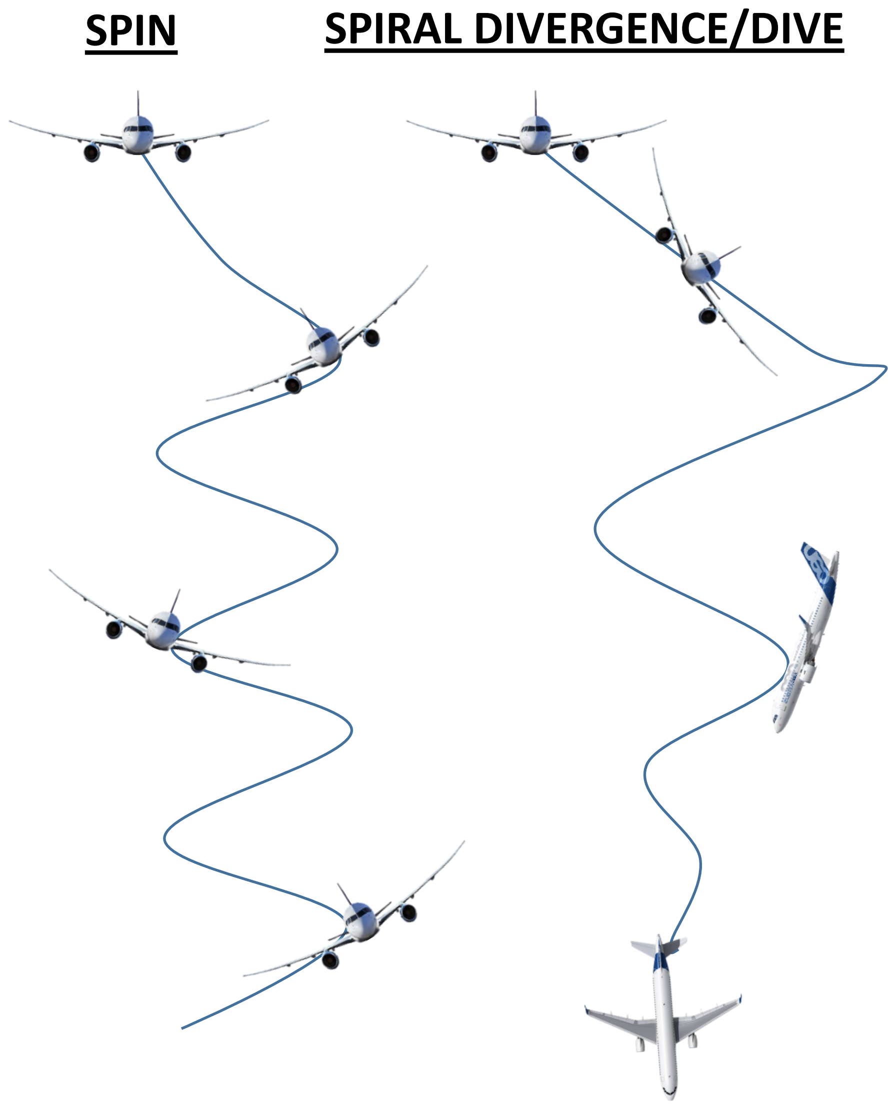
Spiral divergence is **divergent** motion that can be recovered by the pilot.



Lateral/Directional Stability

Difference between SPIN and SPIRAL DIVERGENCE/DIVE

SPIN	SPIRAL DIVERGENCE/DIVE
- Stalled condition - Rate of turn, airspeed, Rate of Descent are stabilized	- Installed condition - Rate of turn, airspeed, Rate of Descent keep increasing



Lateral/Directional Stability

DUTCH ROLL

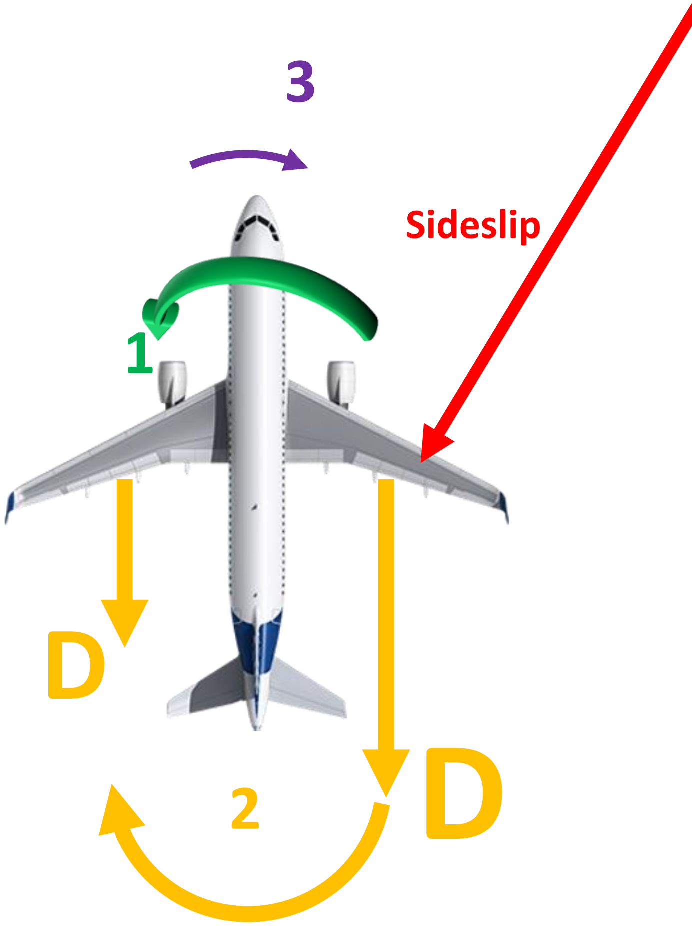
Dutch roll will occur when the lateral stability ("dihedral effect") is large when compared to the directional stability.

Dutch roll is a convergent motion that involve lateral and directional oscillation

When yaw is introduced, the strong "dihedral effect" will roll the aircraft due to the lift increase on the wing into wind. The increased induced drag on the rising wing will yaw the aircraft in the opposite direction, reversing the coupled oscillation.

Aircraft with a tendency to **DUTCH ROLL** are fitted with a **YAW DAMPER**. This automatically displaces the rudder proportional to the opposite direction, reversing the coupled oscillation.

If the YAW DAMPER fails in flight, it is recommended that the ailerons be used by the pilot to damp-out dutch roll. Because of the response lag, if the pilot uses the rudder, Pilot Induced Oscillation (PIO) will result and dutch roll may very quickly become divergent, leading to loss of control.



Swept back wings features

Benefits	Disadvantages
- Increase M_{CRIT} - Less responsive to turbulences - Increase lateral and directional stability	- Poor C_L at low angle of attack - Prone to deep/super stall - Prone to Dutch Roll

SUMMARY

MEOW!