Flight Dynamics

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Outline

1. Theory of Flight
   - Relationship between lift, weight, thrust and drag
   - Steady state flight, Performance
   - Theory of Turn
   - Influence of Load factor: Stall, flight envelope and structural limitations
   - Lift Augmentation
2. Flight stability and dynamics
   - Longitudional, Lateral and Directional stability

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Axes of rotation

The aircraft position in the space is defined by three axes perpendicular to eachother and passing through center of gravity of the aircraft.

Longitudional axis

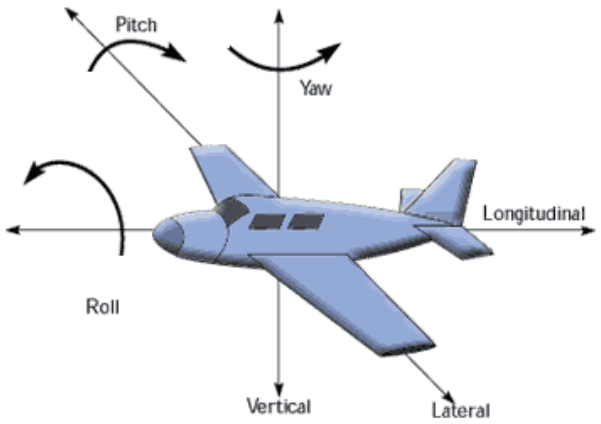
- It runs from the aircraft nose to tail.
- The aircraft movement around this axis is called roll.

Lateral axis

- It runs parallel to the line joining the two wingtips.
- The aircraft movement around this axis is called pitch.

Vertical axis

- It is perpendicular to the other two axes.
- The aircraft movement around this axis is called yaw.

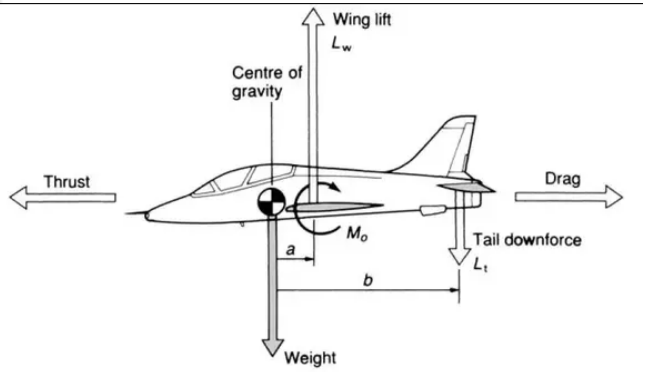


Four forces

Ideal position of the four forces

- The center of gravity is located in fornt of the center of pressure → creation of a movement tending to lower the nose of the aircraft.
- The line of thrust is lower than the center of resistance, creating a torque tending to raise the nose (nose up moment)

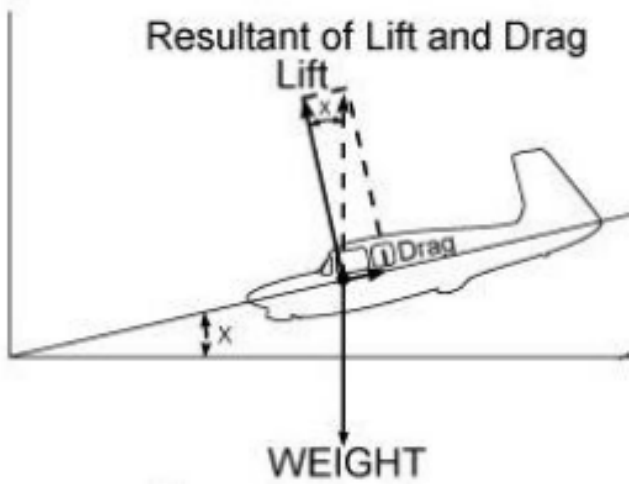
- An advanced center of gravity → improvement the stabile of the aircraft.
- The center of thrust is usually positioned behind the center of gravity → a moment tending to lower the aircraft nose → horizontal tails with airfoils producing a slight negative down lift.

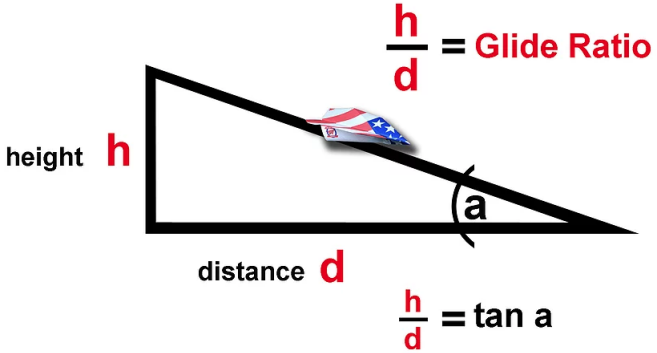


Note: the weight always acts in the vertical line !

Glide

- Aircraft performs sail flight during engine failure.
- In case of sail flight, it isn't possible to keep a uniform rectilinear motion.
- Aircraft needs to cover greatest distance in case of glide.
- Weight needs to be exploited by lowering the aircraft nose.
- A component of weight vector produces a force directed to the desired direction.
- This component replaces the thrust vector.

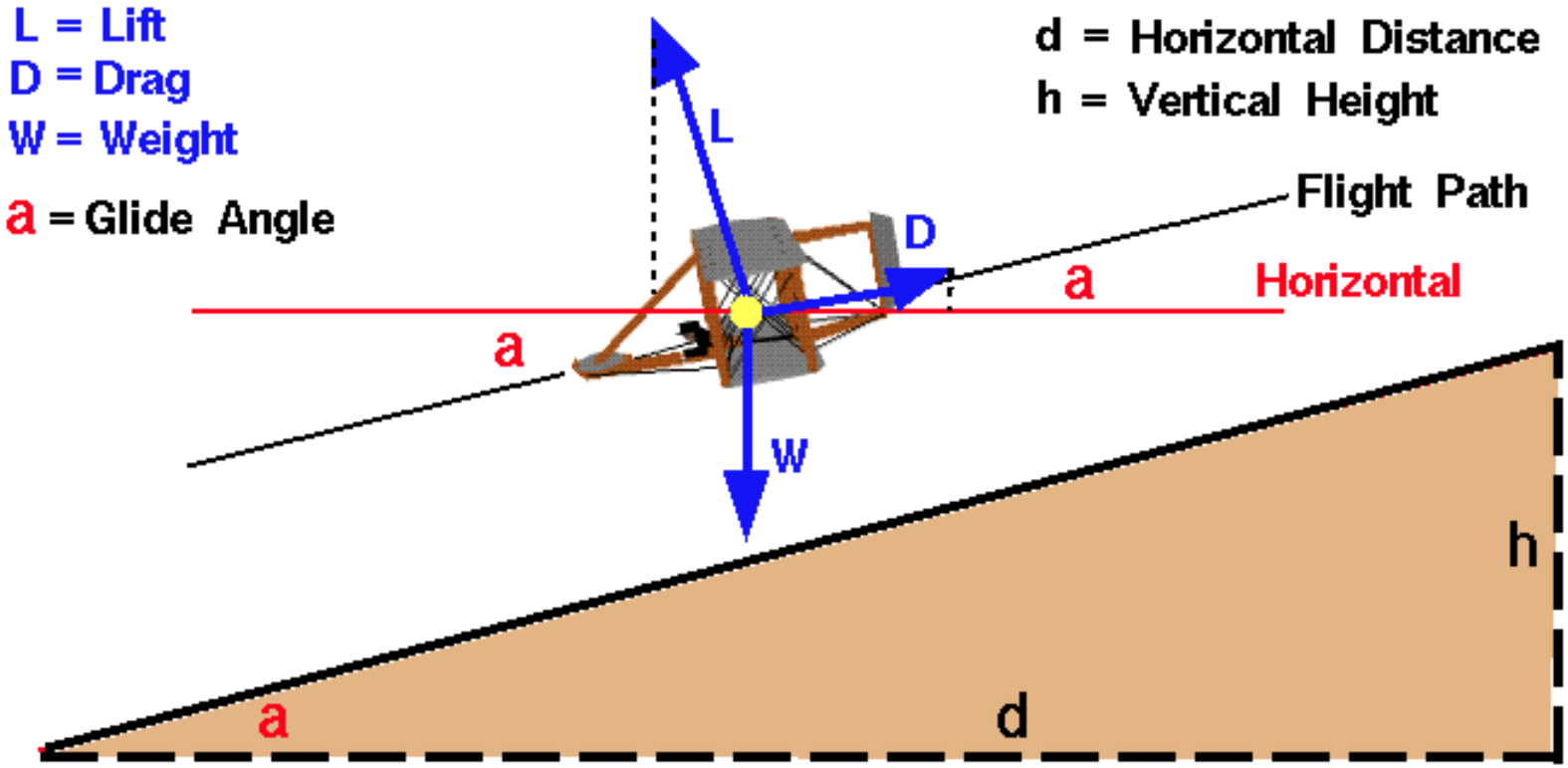




$$L = W\cos\beta = \frac{1}{2} C_l \rho V^2 S$$

$$D = W\sin\beta = \frac{1}{2} C_d \rho V^2 S$$

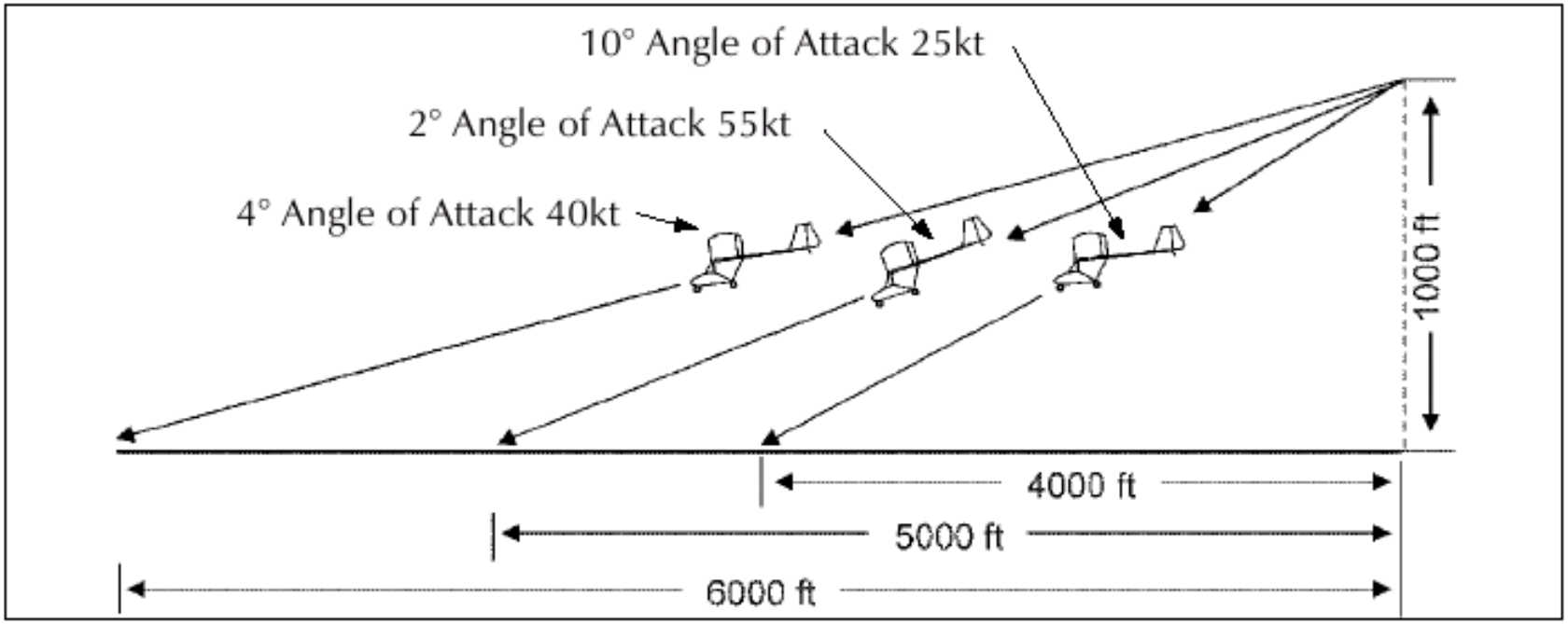
Glide ratio



Horizontal Force Equation: $L \sin(a) = D \cos(a)$

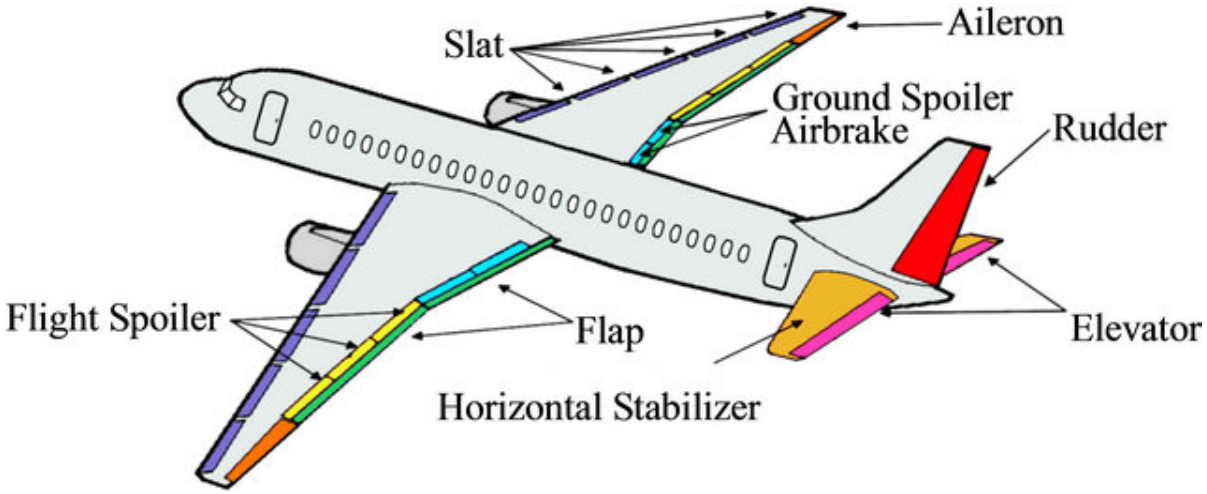
$$\text{ratio} = \frac{\text{Lift}}{\text{Drag}} = \frac{L}{D} = \frac{cl}{cd} = \frac{1}{\tan(a)} = \frac{d}{h} = \frac{\text{distance}}{\text{height}}$$

Glide ratio



- The efficiency is defined as the ratio between lift and drag.
- It is equal to the opposite of tangent of the glide angle.
- If ratio is bigger $\rightarrow$ less drag or great lift.
- Maximum glide distance depends on L/D.
- The best ratio L/D is 4° AOA for light aircraft.

Flight control surfaces



Ailerons → Roll → lift variation

- Aileron down → increase in lift.
- Aileron up → decrease in lift.

Elevator → Pitch → variation on tail lift

- Elevator down → increase in tail lift (decrease in tail load).
- Elevator up → decrease in tail lift (increase in tail load).

Rudder → Yaw → vertical tail load

- Rudder on right → yaw on right.
- Rudder on left → yaw on left.

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Straight horizontal flight

The four forces are equal and opposite, where opposite not necessarily implies that they are aligned with one another.

If a plane performs a straight horizontal flight at constant speed means that all forces acting on an aircraft are in balance.
W = L and T = D

- W is the weight
- L is the lift
- T is the thrust
- D is the drag

Lift and drag equations

$$L = W = \frac{1}{2} C_l \rho V^2 S$$

$$D = T = \frac{1}{2} C_d \rho V^2 S$$

Speed of aircraft

$$V = \sqrt{\frac{2W}{\rho S C_l}}$$

Stall speed

Stall speed is slowest speed a plane can fly to maintain level flight.

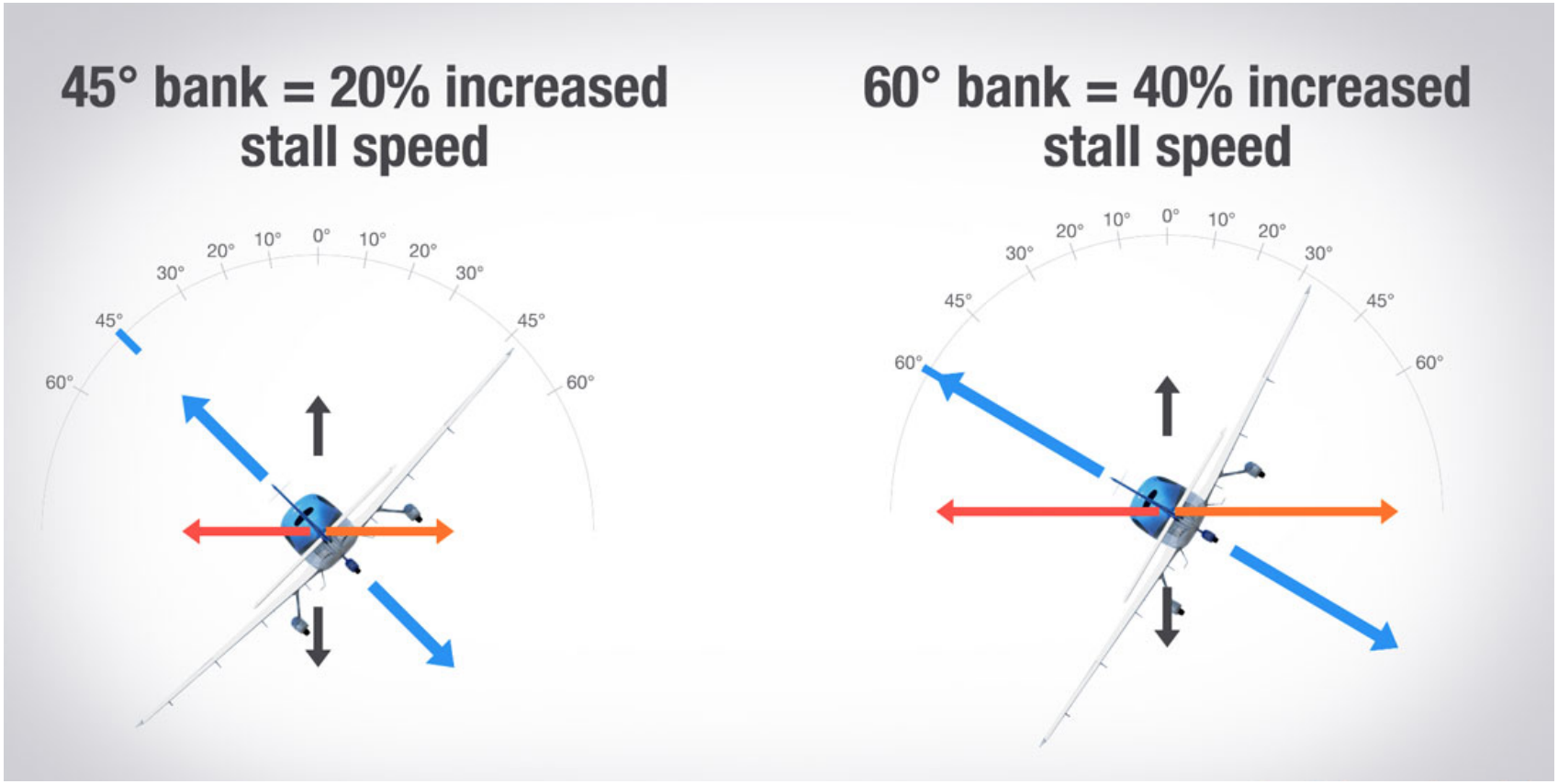
- Increase in AOA $\rightarrow$ increase in lift.
- At critical AOA $\rightarrow$ no longer increase in lift.
- Aeroplane stalls when it wings exceeds critical AOA.
- Critical AOA at which a specific aerofoil stalls is constant.
- Stall speed varies based on weight and other factors.

Speed of aircraft

$$L = W = \frac{1}{2} C_l \rho V^2 S \qquad V = \sqrt{\frac{2W}{\rho S C_l}}$$

- In level flight we cant change the air density or wing area.
- Air density and wing area are constant.
- To inspect stalling speed $\rightarrow$ set lift coefficient at critical AOA.
- Lift = Weight in level flight
- Increasing weight results increase in the minimum velocity required to support that weight.
- Thus, stall speed increase with an increase weight.

Stall speed



$$L = W = \frac{1}{2} C_l \rho V^2 S \qquad V = \sqrt{\frac{2W}{\rho S C_l}}$$

Stall speed (Further observations)

why does stall speed increase in a banked level turn?
→Stall speed increases in a banked level turn because the g-force on the plane increases the effective weight of the plane, and stall speed increases with weight.

- Since the weight of the plane affects the stall speed, that is one reason why it is said that an airplane can stall at any airspeed.
- A heavier aircraft will stall at a higher speed than a lighter one.
- Stall speed will increase with the steeper turn.
- As aircraft gains altitude, the stall speed increases. since at higher altitudes the air pressure decreases.
- On hot days, stall speed will increase since hotter air has a lower air pressure than colder air.
  - But again, the indicated airspeed at which you stall remains the same regardless of air temperature.
- As you fly and burn off fuel your stall speed will decrease.
  - In this case, the indicated airspeed at which you stall will change since the weight of the plane is decreasing.

Some other types of speed

Cruise speed

- The minimum consumption per flown kilometer and therefore the maximum flight range.

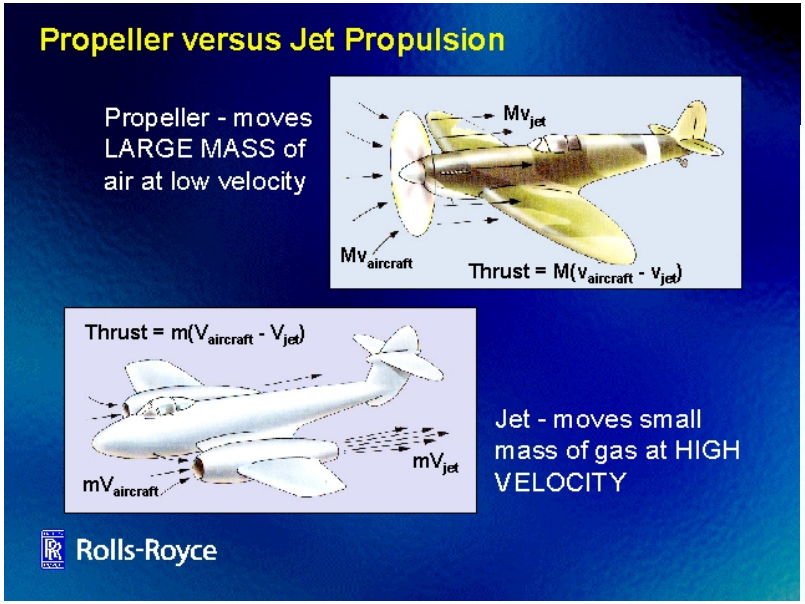
Economy Cruise

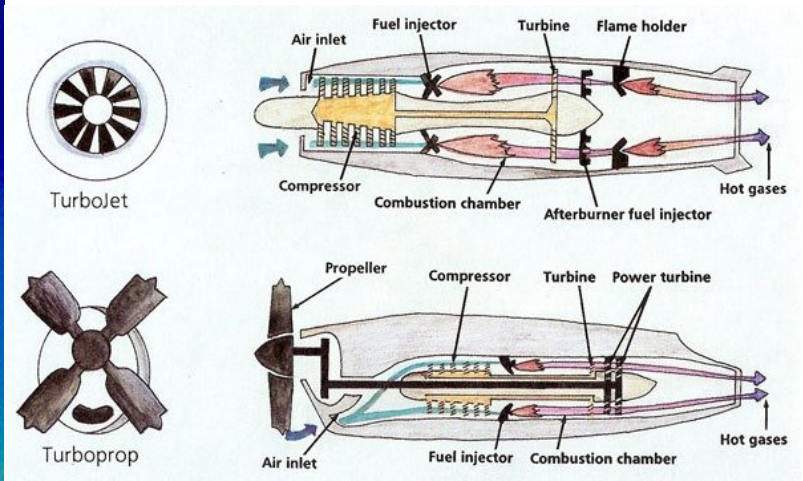
- The minimum consumption per hour and thus maximum endurance.

Best speed

- The maximum value of engine thrust, which corresponds to the maximum power of the engine.

Propeller Vs Jet aircrafts



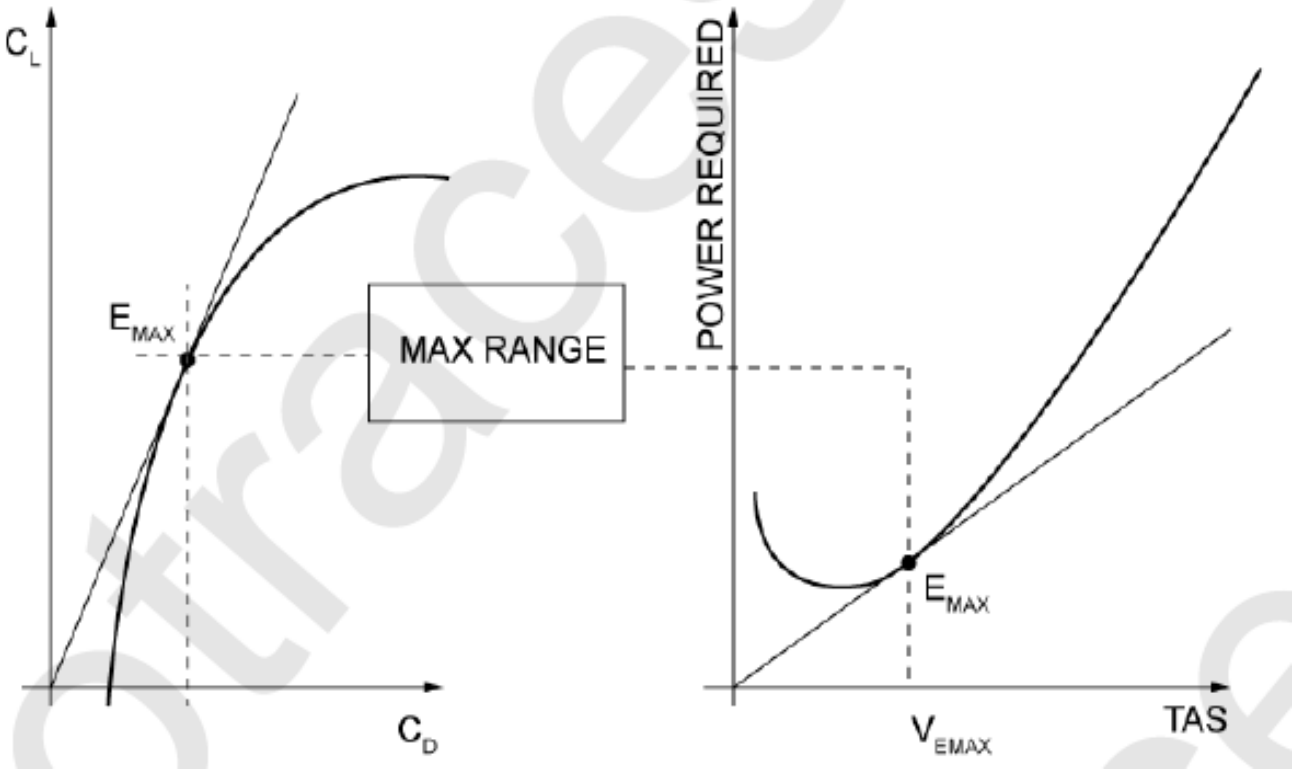


- All aircraft must produce thrust to overcome the drag of the aircraft.
- In turbojets and in other thrust-producing aircraft, this thrust is produced directly from the engine.
- In aircraft that have propellers (or rotors), the engine does not produce thrust directly.
- The power turns the propeller and the propeller, in turn, develops an aerodynamic force when it is turned through the air; this force is thrust.
- Fuel consumption of power-producing aircraft is roughly proportional to the power produced, rather than the thrust produced.
- Range and endurance performance are functions of fuel consumption, and so the power required to fly the aircraft is of prime importance.

Propeller aircraft

Range

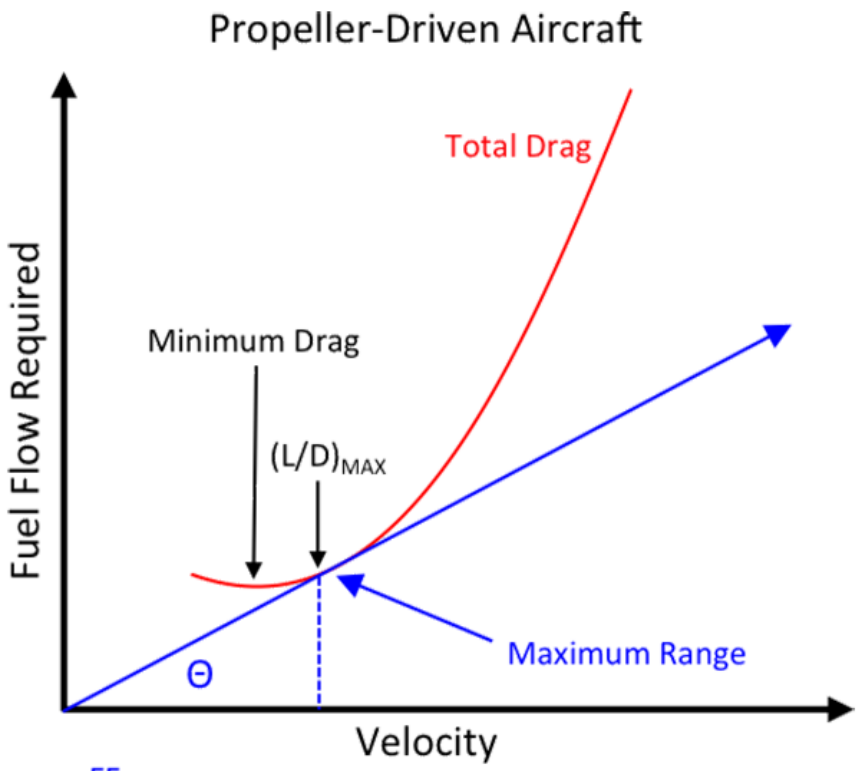
- Maximum range: The point that represents maximum efficiency (E_{max}) and that is calculated from polar curve, corresponds to the point of maximum range.



Propeller aircraft

Range

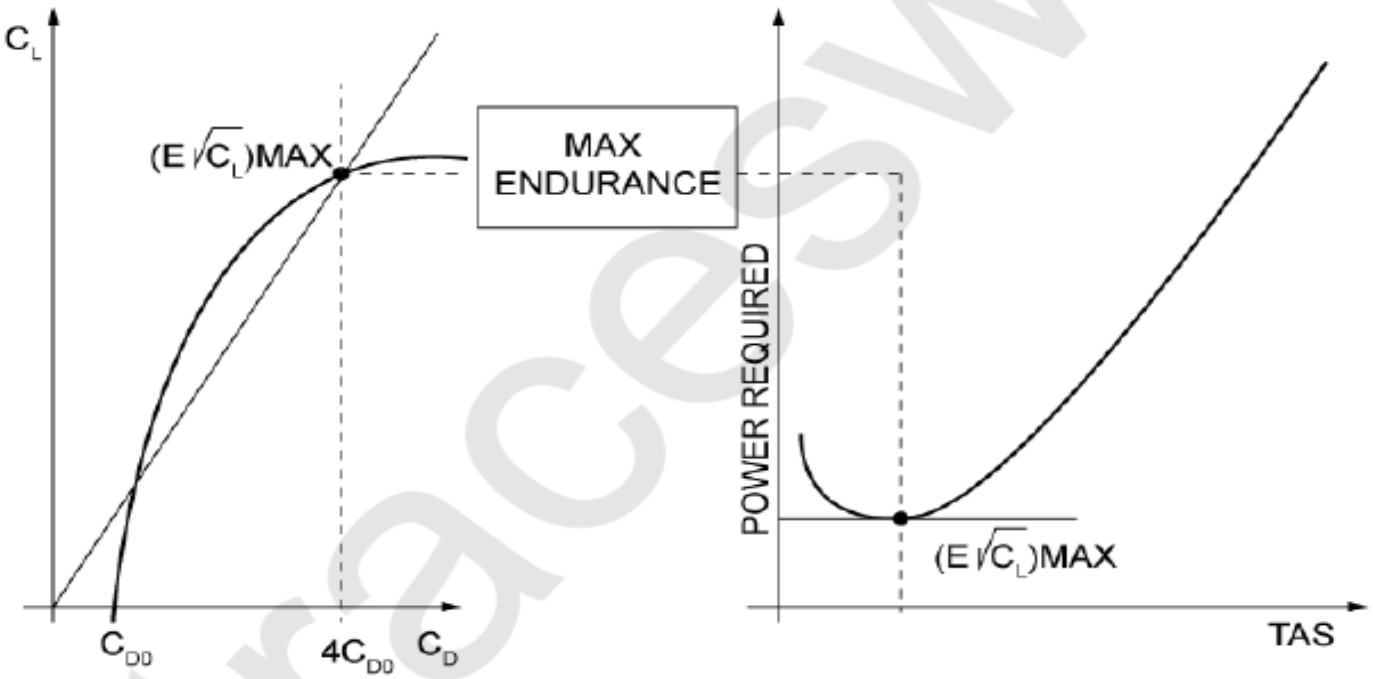
- Maximum range occurs when you get the greatest distance (D) for a given amount of fuel (F). The specific range is equal to (D/F), which can also be written (nm/lbs. of fuel).
- To obtain maximum range, flight must be conducted at maximum $(L/D)_{MAX}$.



Propeller aircraft

Endurance

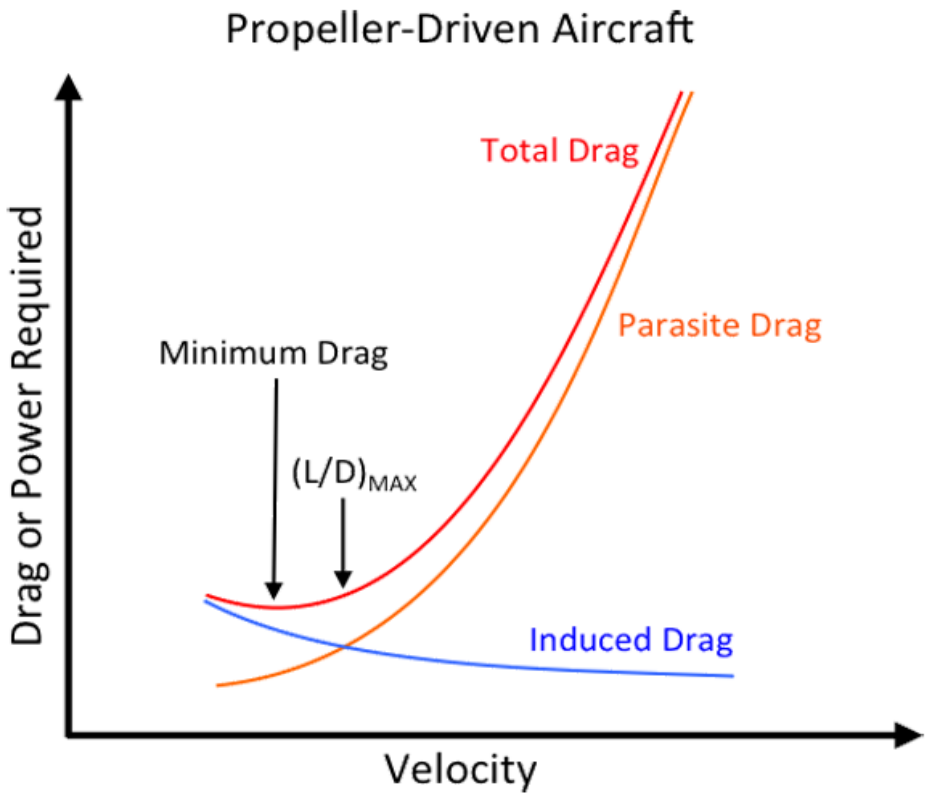
- To obtain the maximum endurance, the flight must be performed at altitude that corresponds to the maximum value of $E\sqrt{C_l}$.
- The altitude that provides maximum value of $E\sqrt{C_l}$ corresponds to the particular values of lift and drag coefficients.
- $C_l = \sqrt{3\pi\lambda C_{d0}}$ and $C_d = 4C_{d0}$



Propeller aircraft

Endurance

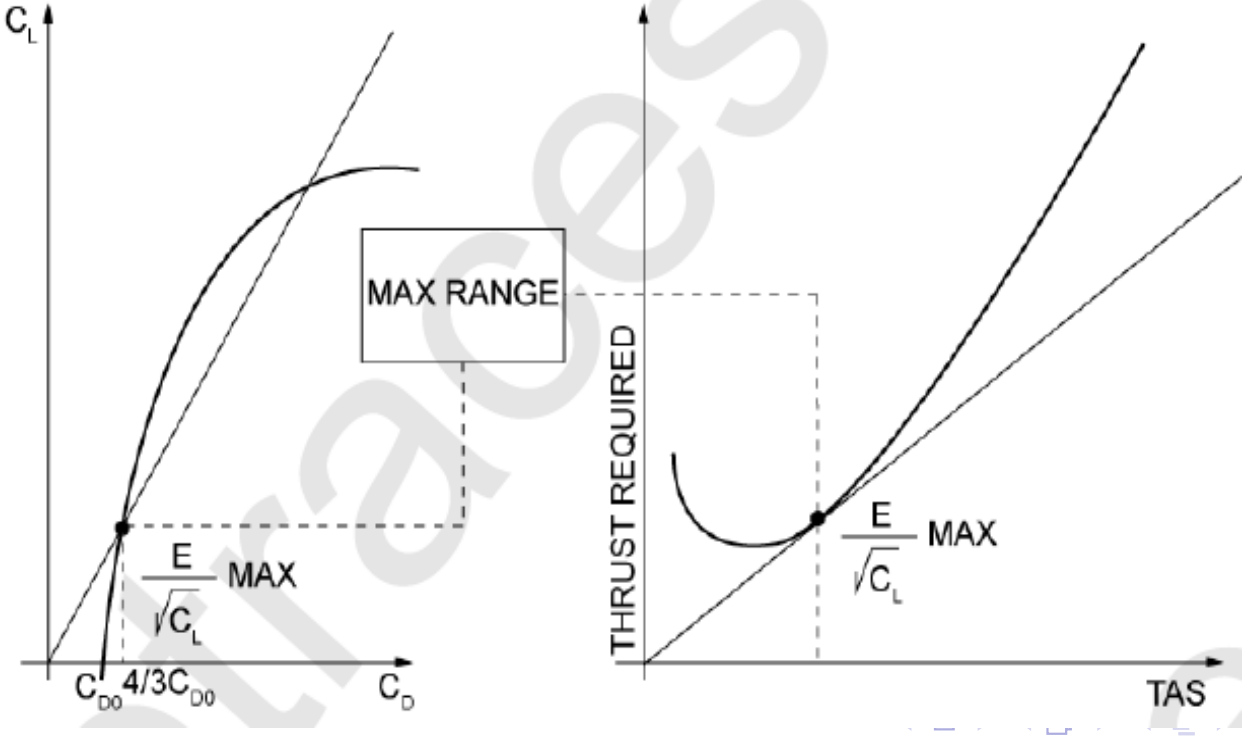
- Maximum endurance occurs when you have the greatest amount of flying time (T) for the least amount of fuel (F). T/F is at a maximum.
- The flight must also be performed at low altitude.
- The aircraft must be characterized by low value of wing load (W/S).



Jet aircraft

Range

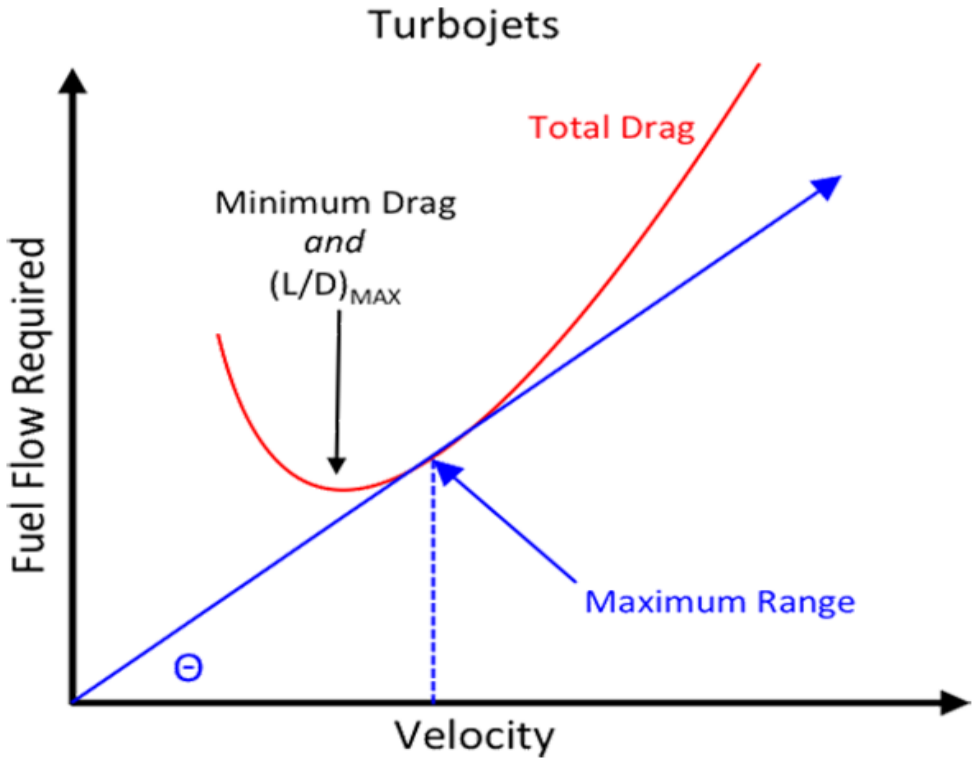
- To obtain the maximum range, the flight must be performed at the altitude that corresponds to the maximum value of: $\frac{E}{\sqrt{C_l}}$.
- The altitude that provides the maximum value of $\frac{E}{\sqrt{C_l}}$ corresponds at particular values of lift and drag coefficients.
- $C_l = \sqrt{\frac{\pi \lambda C_{d0}}{3}}$ and $C_d = \frac{4}{3} C_{d0}$.



Jet aircraft

Range

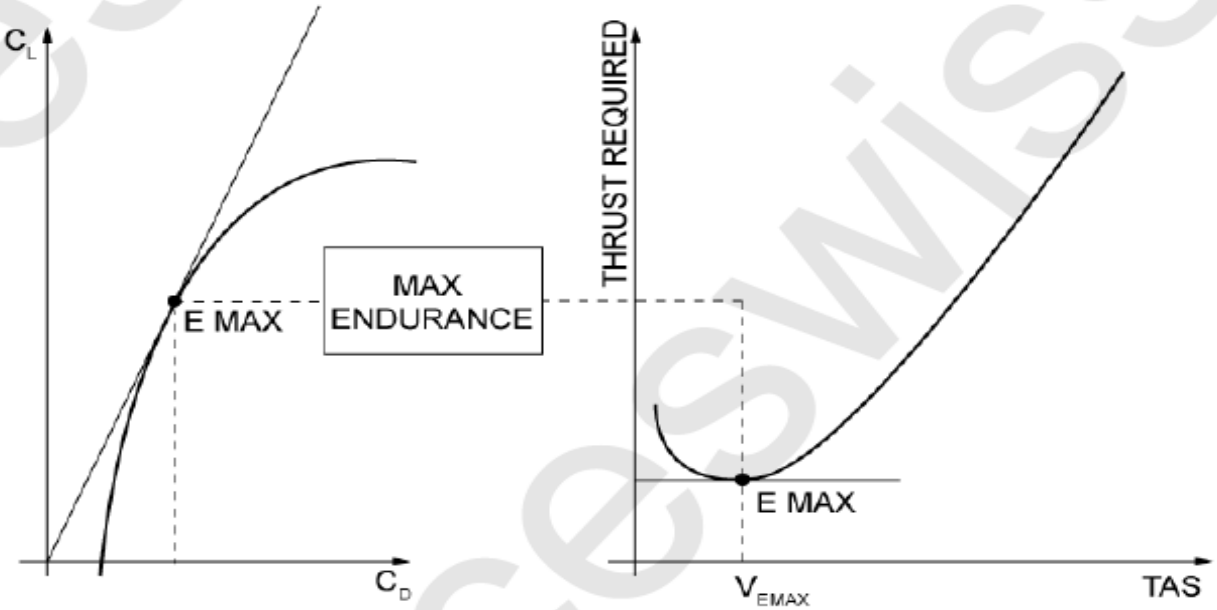
- The flight must be performed at high altitude.
- The aircraft must be characterized by high value of wing load (W/S).
- In a turbojet, maximum range also occurs at the tangent point described for propeller-driven aircraft, but this point will not be at $(L/D)_{MAX}$, it will be at a higher speed.



Jet aircraft

Endurance

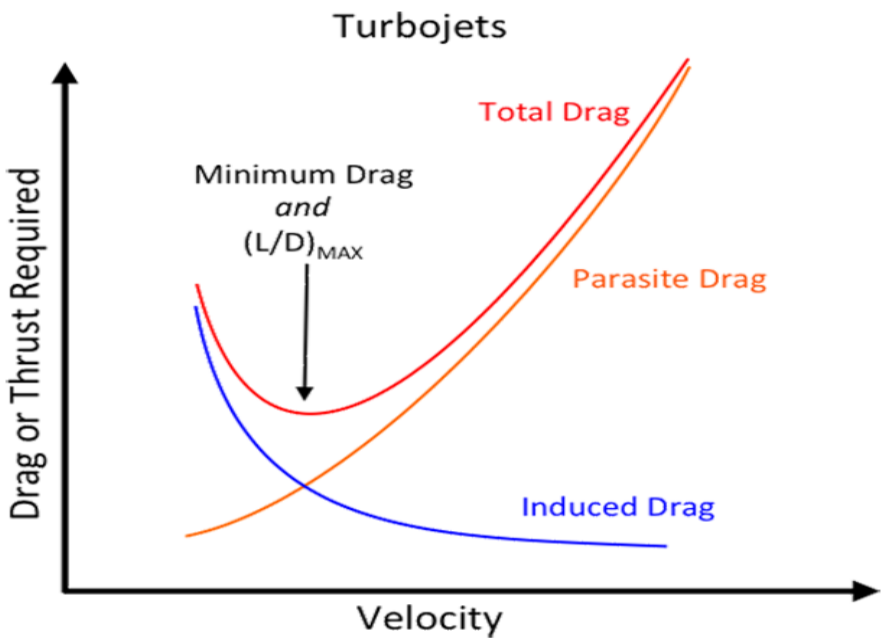
- The point that represents the maximum efficiency (E_{MAX}) and that is calculated from the polar curve, corresponds to the point of maximum endurance.
- The endurance is independent from wing load (W/S) and from the flight altitude.
- The point where the total drag is at a minimum will also be the point where the lift-to-drag ratio will be at a maximum. For a turbojet, this point is known as $(L/D)_{MAX}$.



Jet aircraft

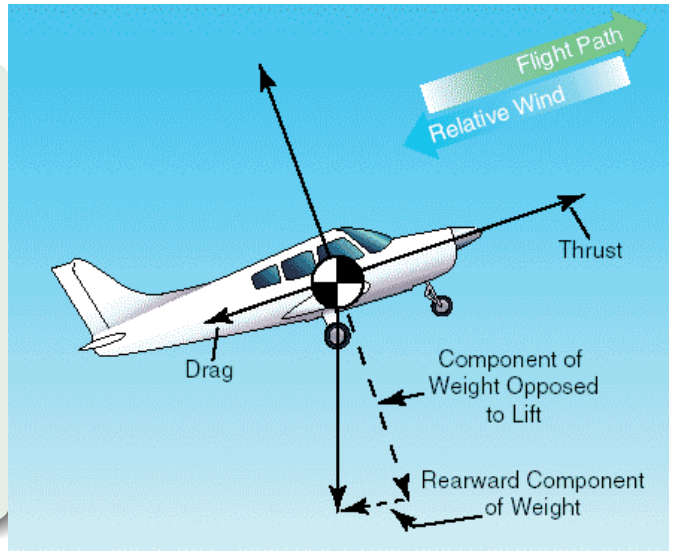
Endurance

- Unlike a propeller-driven aircraft, a turbojet produces thrust directly from the engines.
- As a result, the drag or thrust required versus velocity graph looks different.
- A turbojet typically has the pronounced "u" shape because the induced drag is very high at slow speeds (it takes a high angle of attack) and again at high speeds (the parasite drag becomes restrictive).



Climb

- When aircraft has climb attitude, all vectors rotate with the aircraft except weight (directed downwards).
- To keep the airspeed constant during the climb, it is necessary to increase the engine power to obtain the total thrust vector.



Vector components

Weight vector can be split into two components:

- $W_1 = Wcos\beta$ and $W_2 = Wsin\beta$
- To keep the airspeed constant during climb, W_2 component is added to the drag. It is necessary to increase engine power to obtain a total thrust vector equal to: $T = D + Wsin\beta$
- The lift instead is given by the formula: $L = Wcos\beta = W_1$

Aircraft Ceiling

- The aircraft ceiling is that altitude beyond which the aircraft have no more propulsive balance in straight horizontal flight.
- Or, a ceiling is the maximum density altitude an aircraft can reach under a set of conditions, as determined by its flight envelope.

- The thrust (power) generated by an aeronautical engine decreases as the altitude increases, due to the air rrefaction (reduction of density).

- The thrust (power) requested to perform a straight and level flight increases as altitude increases.

Aircraft Ceiling

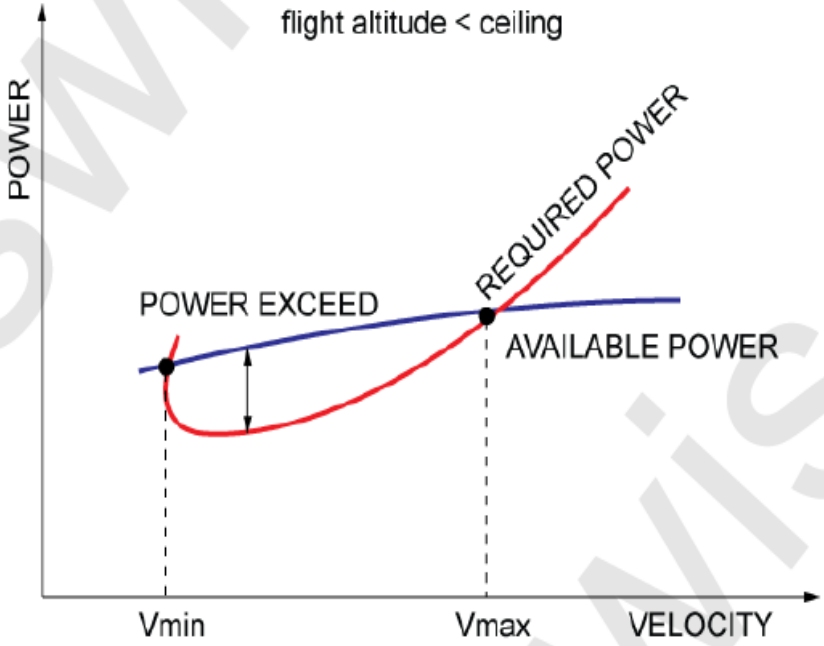
Absolute Ceiling

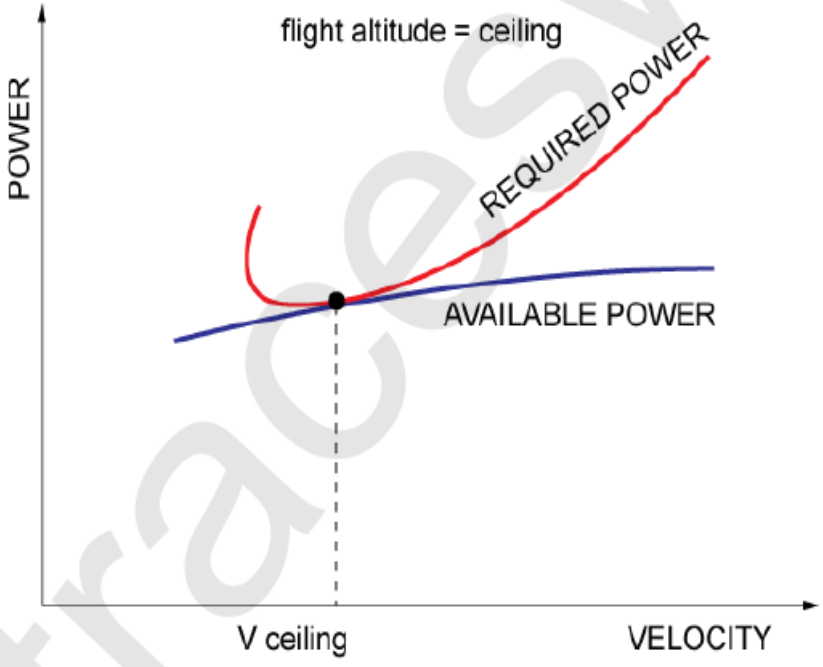
- Absolute ceiling is the height at which rate of climb drops to zero.
- It is the highest altitude at which an aircraft can sustain level flight.
- the engines operats at maximum thrust, yet only generates enough lift to match the weight of the aircraft.
- Hence, the aircraft will not have any excess capacity to climb further.
- It is a theoritical altitude in which the curves of the required power and the available power are tangent.

Service ceiling

- The maximum height at which a particular type of aircraft can sustain a specified rate of climb.
- Service ceiling is where the rate of climb drops below a prescribed value.
- It is the height above sea level, measured under standard conditions, at which the rate of climb of an aircraft has fallen to a specified amount.
- It is the altitude at which under standard air conditions a particular aircraft can no longer rise at a rate greater than a small designated rate (such as 100 feet per minute).

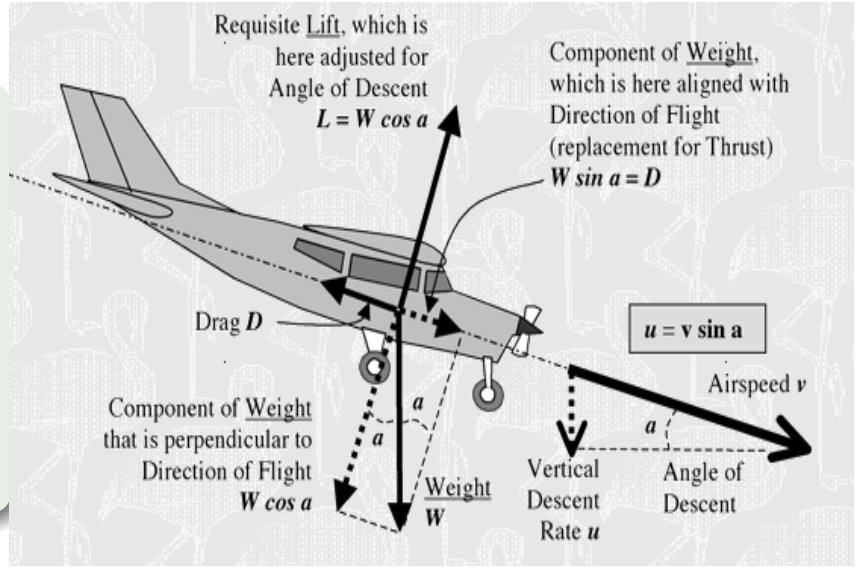
Absolute Ceiling





Descent

- When the aircraft preforms a descent, all vectors rotate with the aircraft (except the weight always directed downwards).
- The descent is supported by the propulsive engine thrust.



Vector components

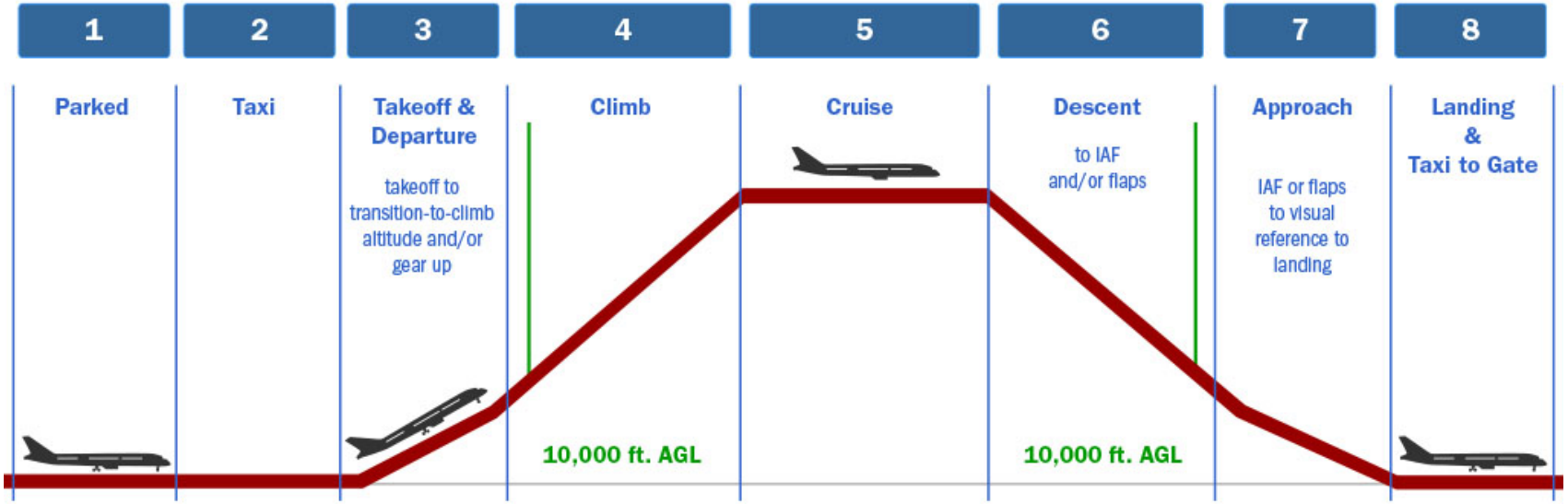
If the descent is supported by the propulsive engine thrust, it can obtain the following relations:

- $L = Wcos\beta = \frac{1}{2}\rho C_l V^2 S$
- $D = T + Wsin\beta = \frac{1}{2}\rho C_d V^2 S$
- Fron the first relation, we can obtain the airspeed during the descent: $V = \sqrt{\frac{2W}{\rho S C_l}}\sqrt{cos\beta}$

Take-off

The aircraft take-off can be split into 3 main phases:

- Take-off run phase: The aircraft move and accelerating reaches the take-off speed.
- Maneuver phase: The aircraft passes from the taxiing altitude to the one corresponding to maximum C_l and leves the ground.
- Climbing phase: The aircraft reaches the altitude required for the flight.



Take-off

During the take-off run phase, the forces acting on the aircraft are:

- The thrust (T)
- The total weight at takeoff (W)
- The lift (L)
- The inertia force ($a\frac{w}{g}$)
- The aerodynamic drag ($D = D_a = \frac{1}{2}\rho C_d V^2 S$)
- The friction D_f due to the contact of the wheels with the runway, which results proportionally to the difference between weight and lift, according to the constant of proportionality f:

$$D_f = f\left[W - \left(\frac{1}{2}\rho C_l V^2 S\right)\right]$$

- In this phase the equation of the aircraft motion in the horizontal plane is:

$$a\frac{W}{g} = T - D_t$$

Where g is the acceleration due to gravity and D_t is the total drag sum of D_a and D_f.

Take-off

- The total drag D_t is given by the following equations:

$$D_t = \frac{1}{2}\rho v^2 S C_d + f(W - \frac{1}{2}\rho V^2 S C_l)$$

$$D_t = fW + \frac{1}{2}\rho V^2 S(C_d - fC_l)$$

- The total drag can be written as:

$$D_t = fW + \frac{1}{2}\rho V^2 S(C_{d0} + \frac{C_l^2}{\pi\lambda} - fC_l)$$

- As the airplane accelerates, the relative airspeed increases and the lift starts to generate, prportional to the square of speed.
- In taxing phase, total drag must have minimum value.

$$(C_{d0} + \frac{C_l^2}{\pi\lambda} - fC_l)$$

Take-off run phase

- From the equation of aircraft motion during taxing phase,

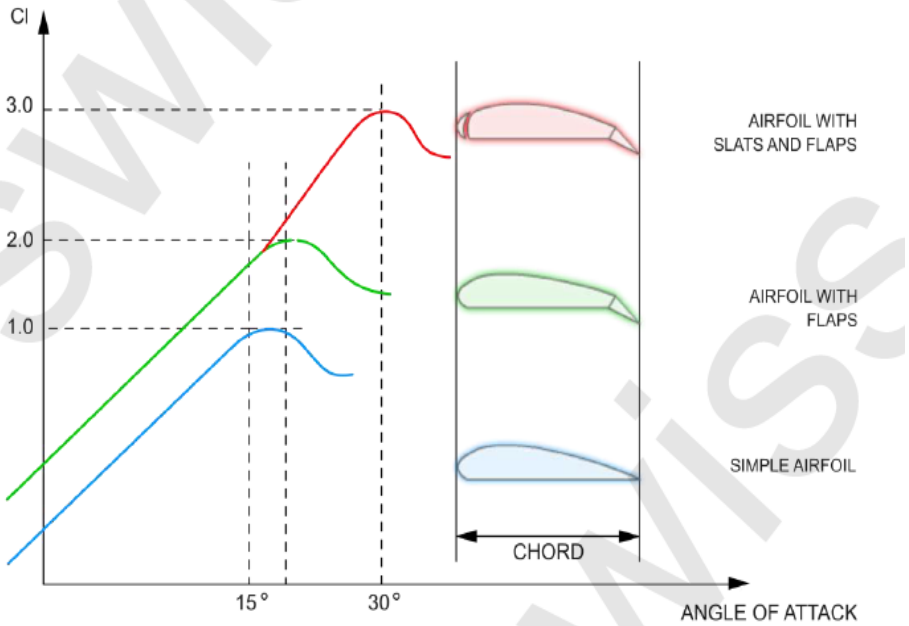
$$S_r = \frac{\frac{W}{S}}{\rho g h C_l} = \frac{\frac{W}{S}}{\rho g h C_l(\frac{T}{W} - f)}$$

- Take-off run space increases at the wing load increases (W/S).
- More thrust $\rightarrow$ shorter take-off run pahse.
- Heavier aircraft $\rightarrow$ more firction on runway $\rightarrow$ longer take-off run phase. For conventional aircraft,
- On cement runways $\rightarrow$ AOA corresponding to the best attitude are 3°-6°
- On grass runways $\rightarrow$ Increase friction coefficients $\rightarrow$ more calibrated attitudes are needed.

- Thrust decreases very much with the altitude.
- Density decrease $\rightarrow$ thrust deccrease.
- over a certain altitude, the takeoff can't be performed.
- Therefore, in gas turbine engines the thrust decreases.

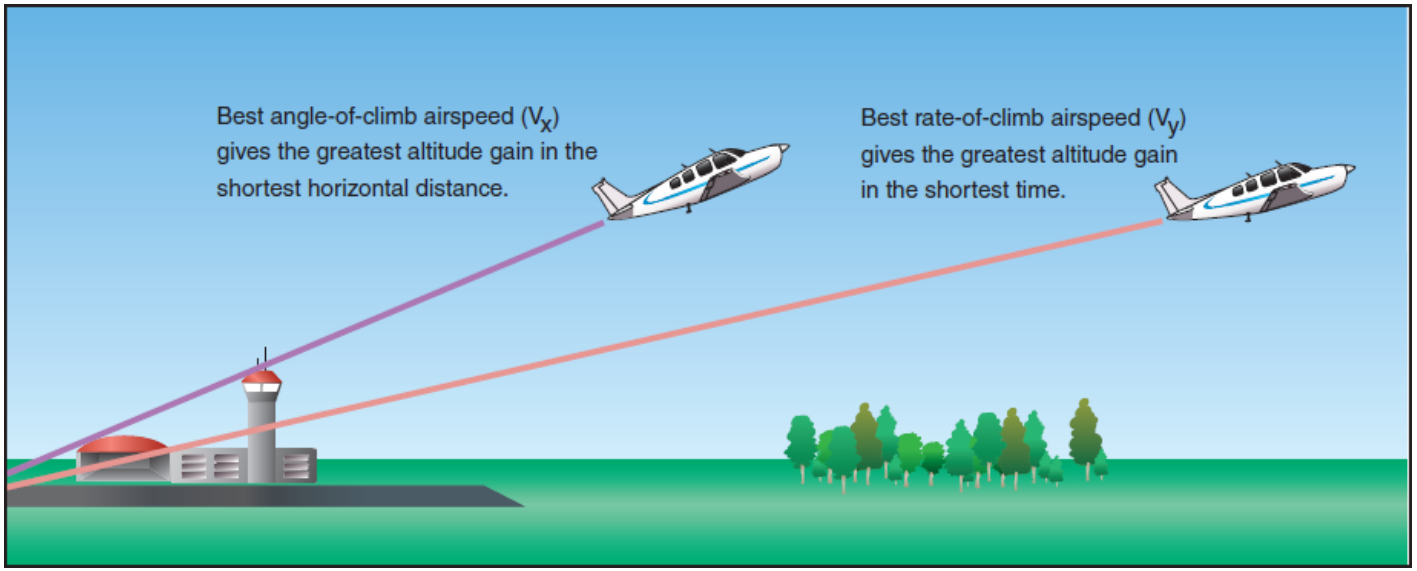
Maneuvre phase

- Once reached take-off speed → pilot pulls the contol stick to lift the elevator.
- Aircraft rotates about the main landing gear and increasing the AOA about 30° (with extended slats and flaps).
- Enought lift is generated to overpass the weight vector and the aircraft take-off.
- The maneuver phase lasts a pair of seconds → in this phase the maximum value of C_l is reached.



Climbing phase

- Once reached maximum value of C_l $\rightarrow$ aircraft leavs the ground and starts to follow a parabolic trajectory until it reaches the necessary altitude.
- Reaches the correct speed, flaps and slats are retracted, together with landing gear (if retractable).
- Aircraft keeps on accelerating until the pilot reduces the throttle
- Or the speed reaches a value at which the drag balance the engine thrust $\rightarrow$ the aircraft airspeed remain constant.

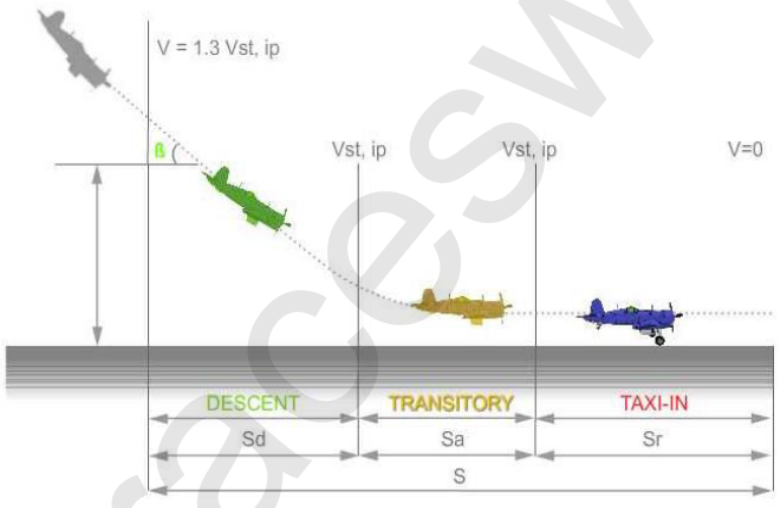


Landing

The aricraft lading can be split into 3 main phases:

Descent Phase

- The aircraft start to dive with a certain angle β anda certain velocity V.



Transitory Phase

- The pilot changes the aircraft altitude in a one corresponding to the aircraft on the ground.
- Modifies the desending trajectory, passing through the straight horizontal one.

Taci-in Phase

- Where once put the wheels on the runway, the thrust is null.
- The pilot acts on the brakes (or thrust reverser) to stop the aircraft.

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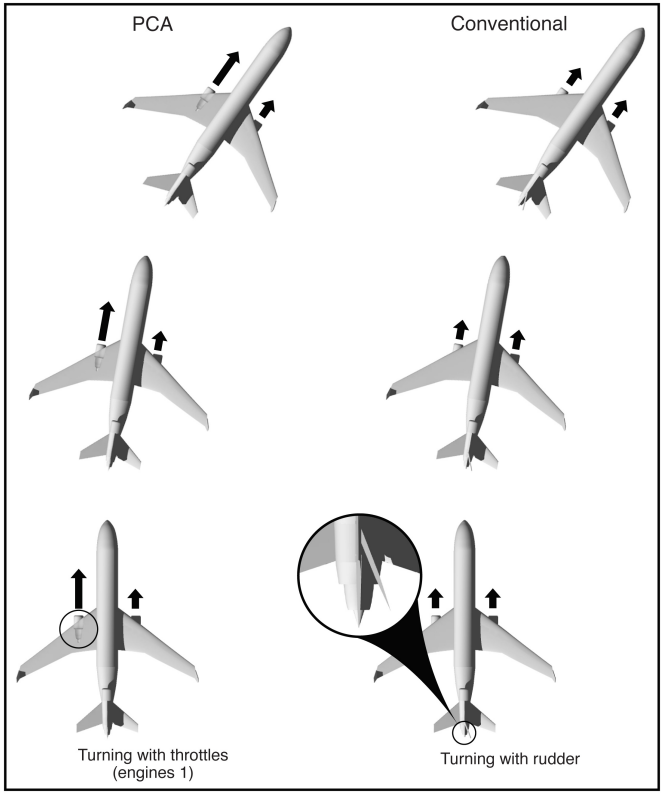
   - Longitudional, Lateral and Directional stability

Turn

There are two types of turn:

- Flat turn
- Banked turn

- In both cases, the centre of gravity of the aircraft draws a curve in a horizontal plane, but with different maneuvers and characteristics.
- To perform turn, the aircraft has to produce a force directed towards the turn centre (centripetal force)



Flat turn

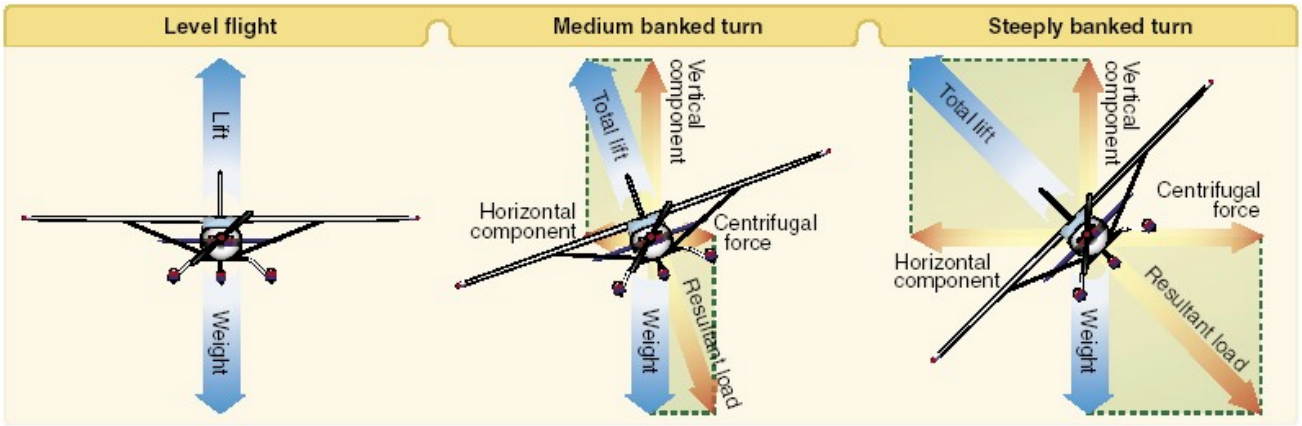
- The maneuver is performed using the rudder.
- The rudder creates a perpendicular component to the velocity direction.
- The aircraft remains in a horizontal plane (without roll).

Turn

Banked Turn

Banked turn (at constant altitude)

- Act on ailerons to bank the lift vector and create a centrifugal component.
- Use the rudder to help the aircraft rotate.
- Act on the elevator to increase the lift.
- Increase the engine power to increase the lift.



- To mantain the altitude, during a turn, it is necessary to increase the lift.
- This is obtained by increasing AOA and the airspeed.
- Otherwise the aircraft makes a slideslip.

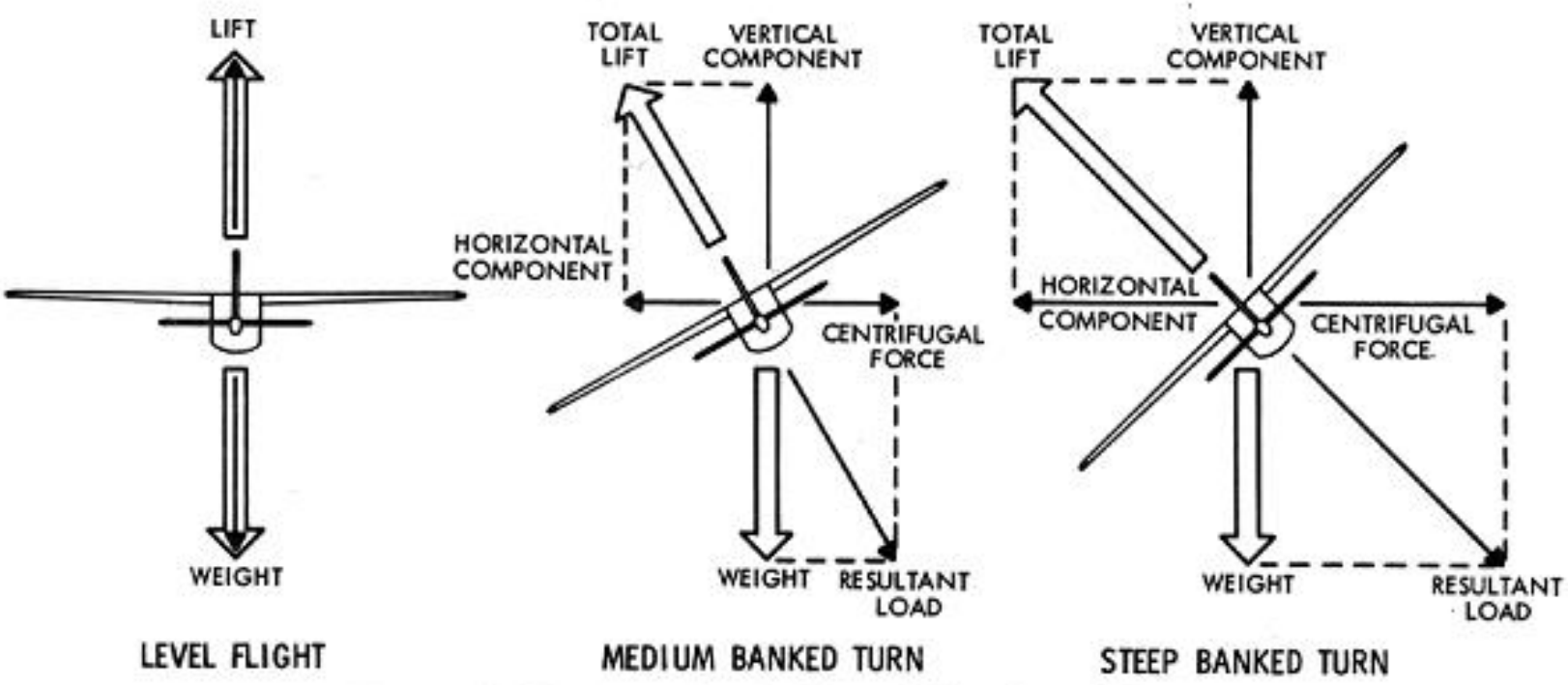
- The horizontal component of the lift when an aircraft is banked, it will tend to make th aircraft follow a circular path.

Turn

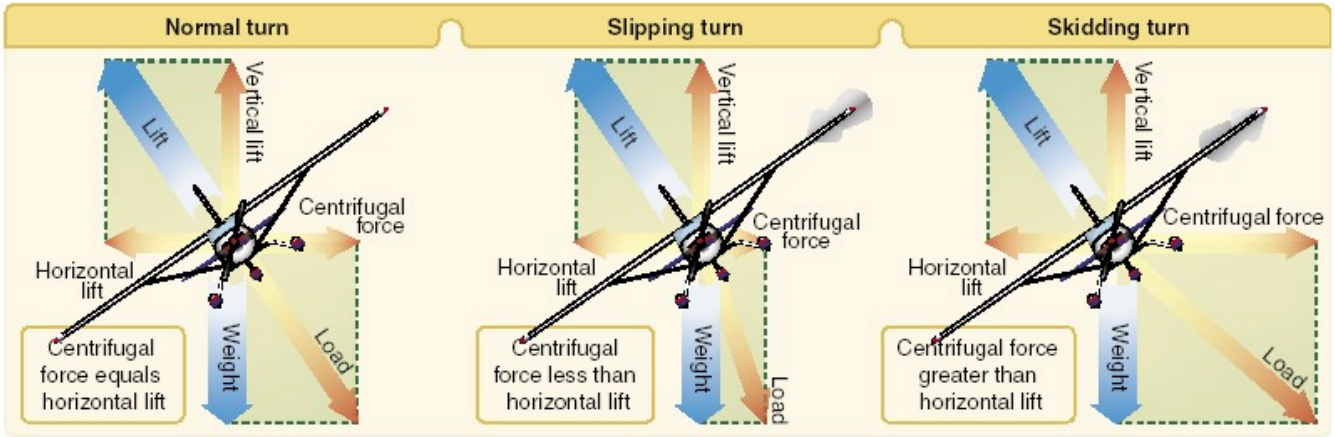
Banked Turn

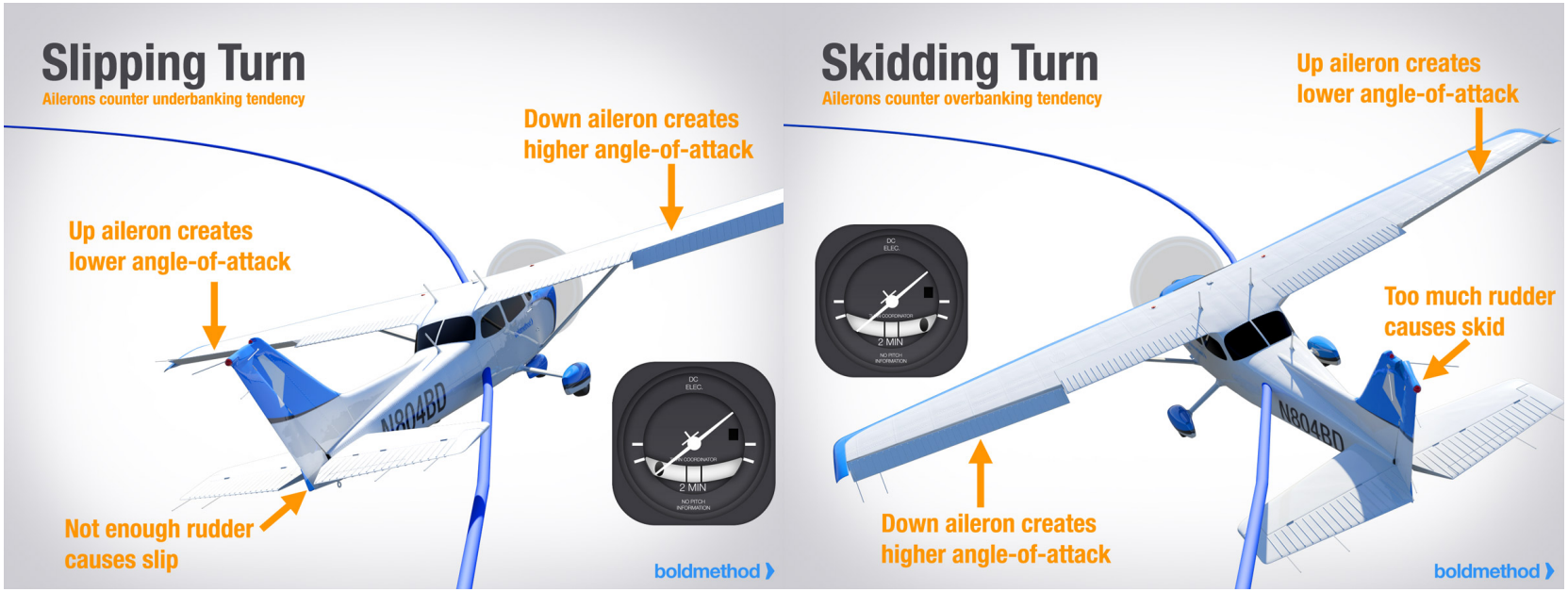
During a banked turn, the forces acting on the aircraft are the following:

- The weight(W), acting in the vertical direction
- The centripetal force (F_c), acting in the horizontal plane of the trajectory
- The thrust (T) that is tangent to the trajectory
- The lift (L)
- The aerodynamic drag (D)



Turns





https://www.youtube.com/watch?v=_cA-AxUIuY

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   - Relationship between lift, weight, thrust and drag
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Load factor

- The load factor is defined as the ratio of the lift of an aircraft to its weight.
- It represents a global measure of the stress ("load") to which the structure of the aircraft is subjected.

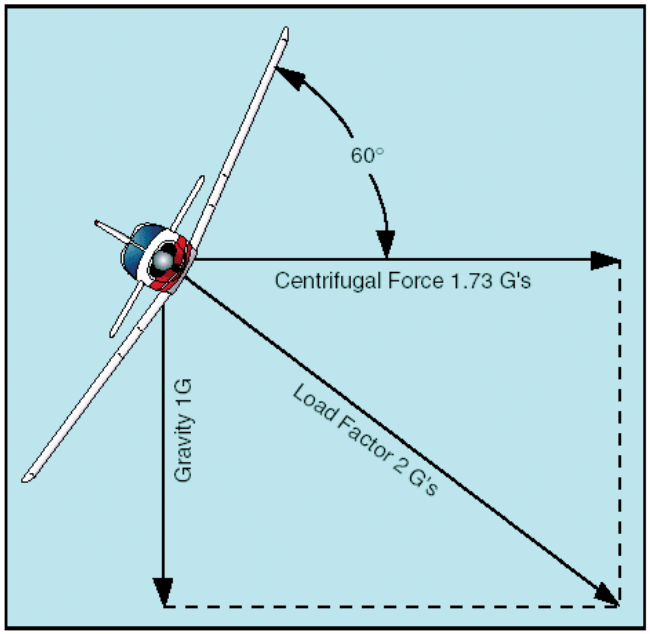
$$n_z = \frac{Lift}{Weight} = \frac{L}{W}$$

Positive value ($n_z > 0$)

- The nose of aircraft is up with high angle of attack.
- Pilot feels acceleration from head to feet.
- People may suffer from black vison.

Negative value ($n_z < 0$)

- The case of dive or upside down.
- Pilot feels negative acceleration from feet to head.
- People may suffer from red vison.



Load factor in different maneuvers

Straignt and Level flight

During a cruise in straight and level flight, the load factor in the vertical direction felt by the aircraft and pilot is equal to 1.

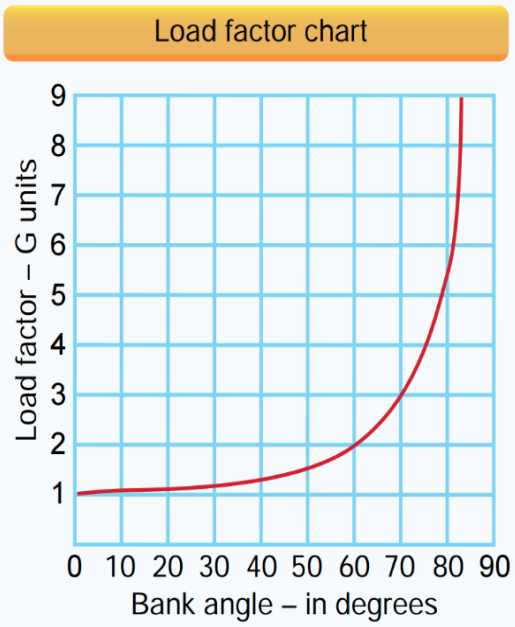
$$n_z = \frac{L}{W} = 1$$

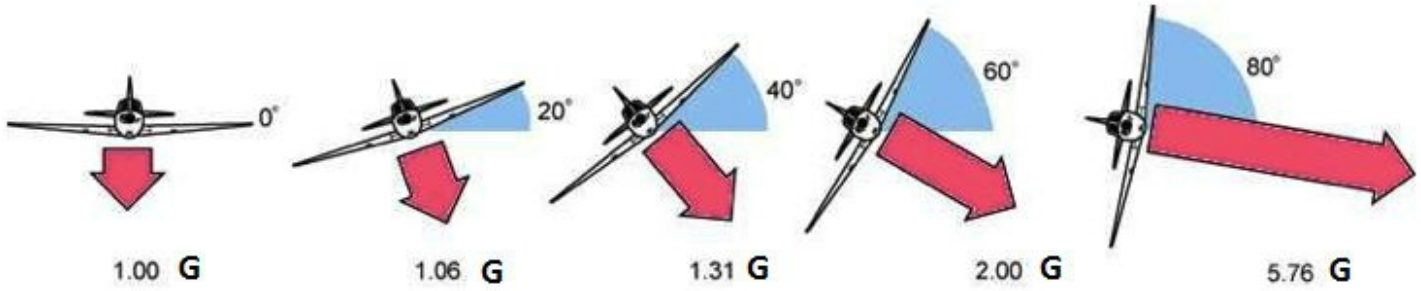
Turn

During a turn, the load factor in the vertical direction felt by the aircraft and pilot can be indicated as:

$$n_z = \frac{L}{W} = \frac{1}{Lcos\theta} = \frac{1}{cos\theta}$$

Angle of bank φ	Load factor n
0°	1.0
10°	1.015
30°	1.154
45°	1.414
60°	2.000
70°	2.923
80°	5.747
85°	11.473
90°	∞

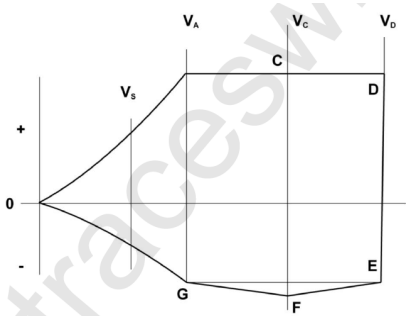


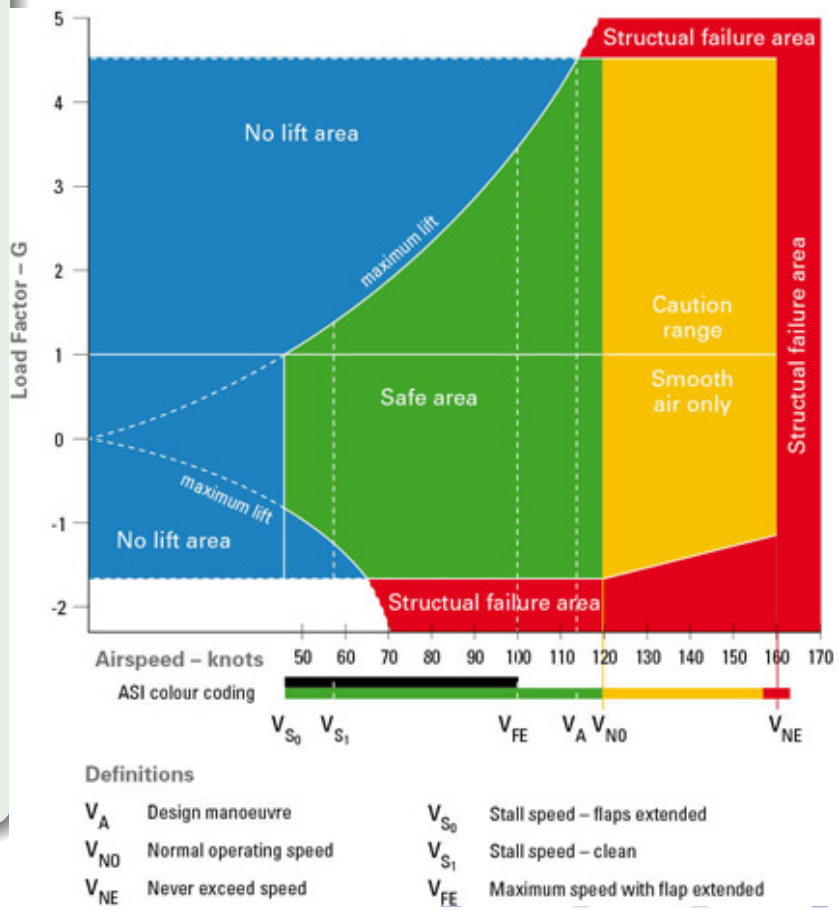


V-n diagram

The V-n diagram provides a snapshot into the operating envelope of the airplane, that is, the load factor that the airplane might see at any given airspeed.

- The determination of V-n diagram is the base for the structural analysis.
- It is for different airspeeds, and different flight attitudes.
- It provides the limit acceleration for the aircraft.
- V_S = Stall airspeed $\rightarrow$ V_A = Maneuver airspeed
- V_C = Cruise airspeed $\rightarrow$ V_D = Dive airspeed





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Lift augmentation

Augmentation system (High lift systems)

- Takeoff and landing distances are strongly influenced by aircraft stalling speed.
- With lower speeds requiring lower acceleration or deceleration and corresponding shorter fields.
- It is always possible to reduce stall speed by wing area, but it is not desirable.
- Stalling speed can be reduced by reducing weight, increasing air density, or increasing wing C_{Lmax}.
- More efficient to use movable leading and/or trailing edges.
- Movable parts at LE and TE helps to obtain good high speed performance while achieving a high C_{Lmax} at take-off and landing.
- The primary goal of a high lift system is a high C_{Lmax} .

Augmentation system

- Increase the circulation around the system.
- Increase C_L coefficient.

Lift augmentation

Augmentation system.... WHY?

- To reduce take-off and landing speed (and thus runway length).
- It is necessary to reduce the wing load (W/S) or to increase the lift coefficient and sometimes the wing surface.
- Unfortunately, a very fast flight, in economy conditions require a reduced wing area (to reduce at the minimum drag and thus a heavy load wing).

- It is necessary to increase the wing lift instead to vary the wing area $\rightarrow$ purpose of the augmentation systems.

Lift augmentation

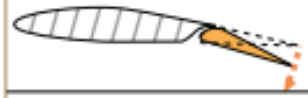
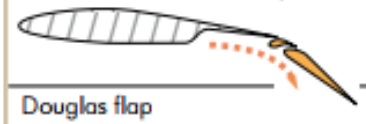
Augmentation system

The mos of augmentation system are based on.

- Downward deflection of the fluid flow
- Control of the boundary layer
- Slot effect

Lift augmentation systems

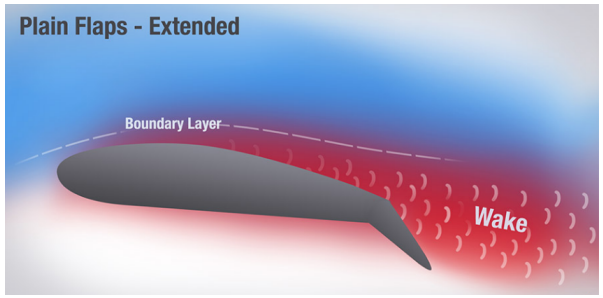
- Flaps → trailing edge → downward deflection → increase in lift coefficient (reduces stalling speed).
- Slats → leading edge → slot effect and control of boundary layer → airflow over the top of the wing regenerates the boundary layer.

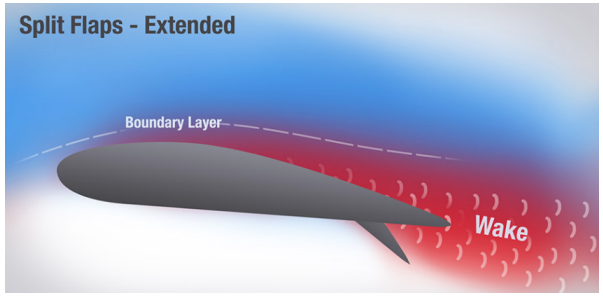
High-lift devices	Incr. of $C_{L\,max}$	a stall	Remarks
Basic airfoil	-	15°	Effects of all high-lift devices depend on the shape of basic airfoil
Plain or camber flap	50%	12°	Increased camber Much drag when fully lowered Nose-down pitching moment
Split flap	30-40%	14°	Increased camber Even more drag than plain flap Nose-down pitching moment
Slotted flap 	65%	16°	Control of boundary layer. Increased camber. Stalling delayed Not so much drag
Double slotted flap	70	18°	Same as single-slotted flap, only to a greater degree Triple slots sometimes used
Fowler flap	90%	15°	Increased camber and wing area Best flaps for lift. Complicated mechanism. Nose-down pitching moment
Double-slotted Fowler flap 	100%	20°	Same as for Fowler flap, only to a greater degree Triple slots are sometimes used
Douglas flap	-	-	Increased camber and wing area Rather simple mechanism Nose-down pitching moment
Blown flap	80%	16°	Effects depend very much on details of arrangement

Lift augmentation

Split flap

- It consist of a flap applied on lower camber part of the wing in correspondence to the trailing edge.
- The lowering of the flap causes an increase in pressure in the lower camber.
- Behind the flap there is a wake, which affects the upper side of the wing.
- Split flap lowers $\rightarrow$ aerodynamic drag of wing increases.
- It produces braking effect.
- Not ideal during take-off phase.
- Lift increase obtained with this type of flap reaches 60%.

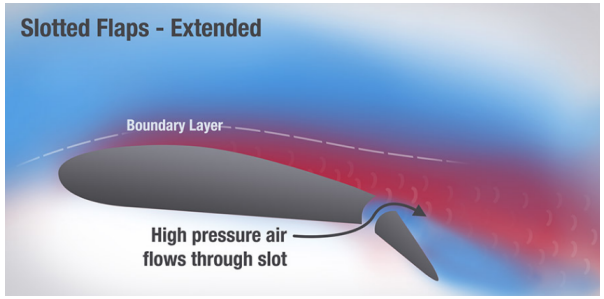


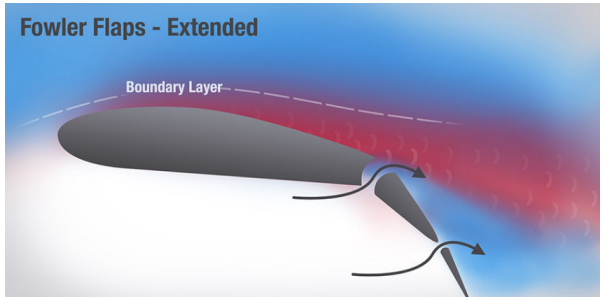


Lift augmentation

Slotted flap

- It creates an increase in the airfoil curvature and the slot in the back creates a depression.
- They increase wing camber, like other flaps.
- When extended, they open a slot between the wing and the flap.





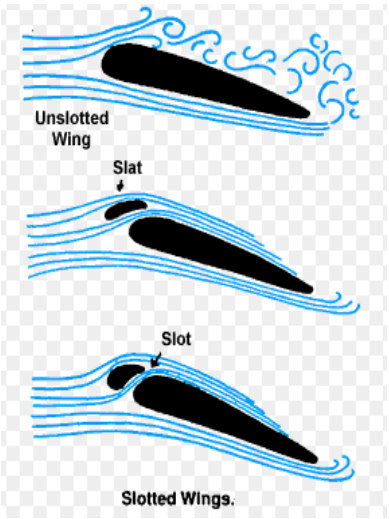
Fowler flap

- It is moved backward so that its leading edge will coincide with the trailing edge of the wing $\rightarrow$ a slot remains.
- Simultaneously the flap is tilted downward with an angle β.
- This flaps increase the surface and the curvature of the wings.
- The lift obtained reaches upto 90%.

Lift augmentation

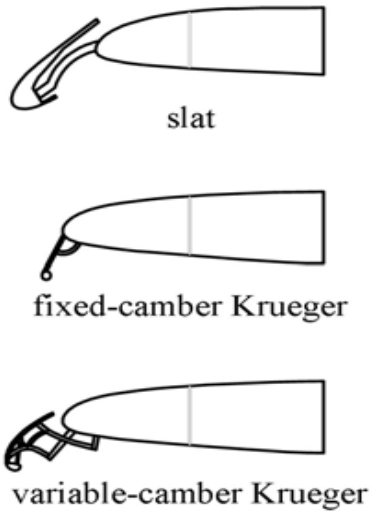
Handley page flap (Slat)

- In an automated slat, at great incidences, the deep depression is produced on the leading edge of the wing.
- This cause slat displacement forward which is otherwise closed by means of a returning spring.
- At little incidences the pressure on the edge causes the slat lock.
- The lift increase is about 60%.



Krueger flap

- It is hinged to the leading edge in order to increase the curvature of the main camber line and the wing surface.
- It's broadly present in wings inner parts of the aircraft of the main airline.
- It increases the lift about 50%, with an increase until 25° of the stall angle.



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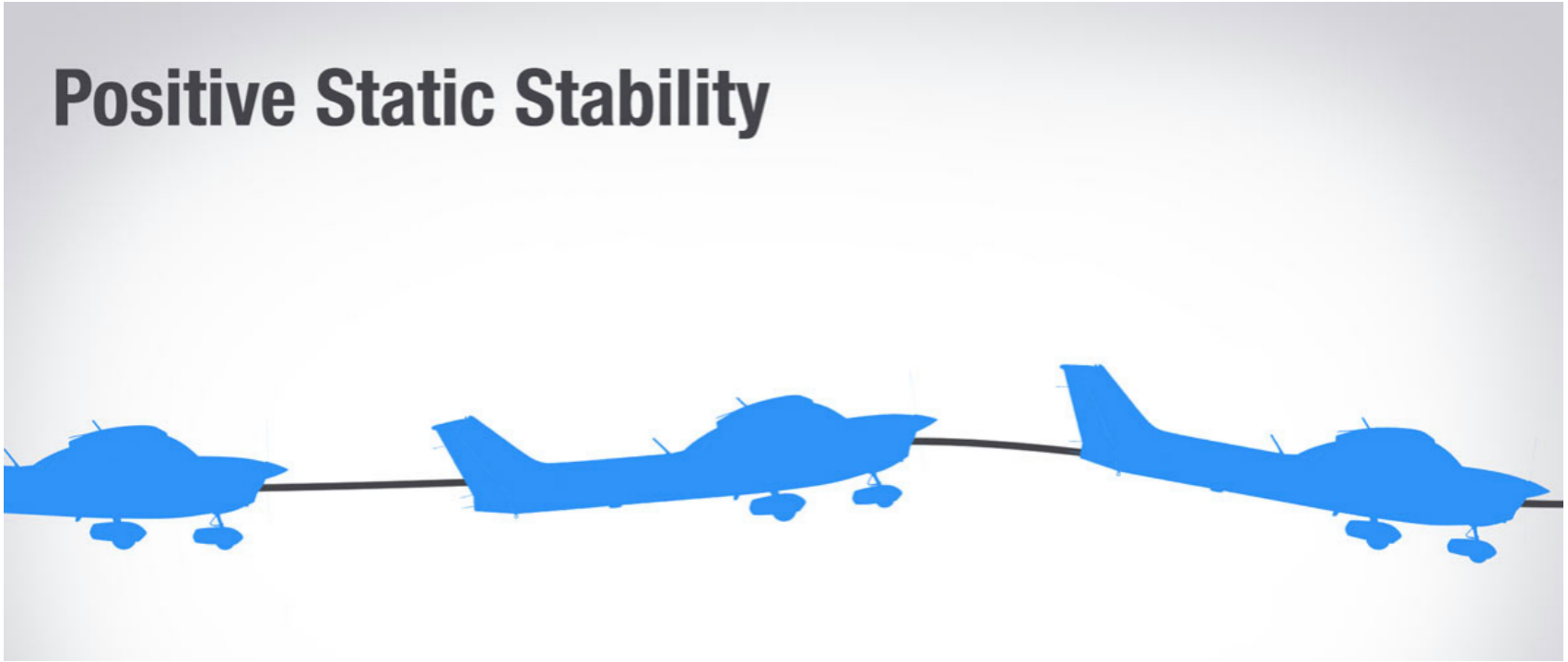
Static stability

- An aircraft is statically stable when moved form its flight altitude it returns back without variations in the airspeed or in the trajectory.

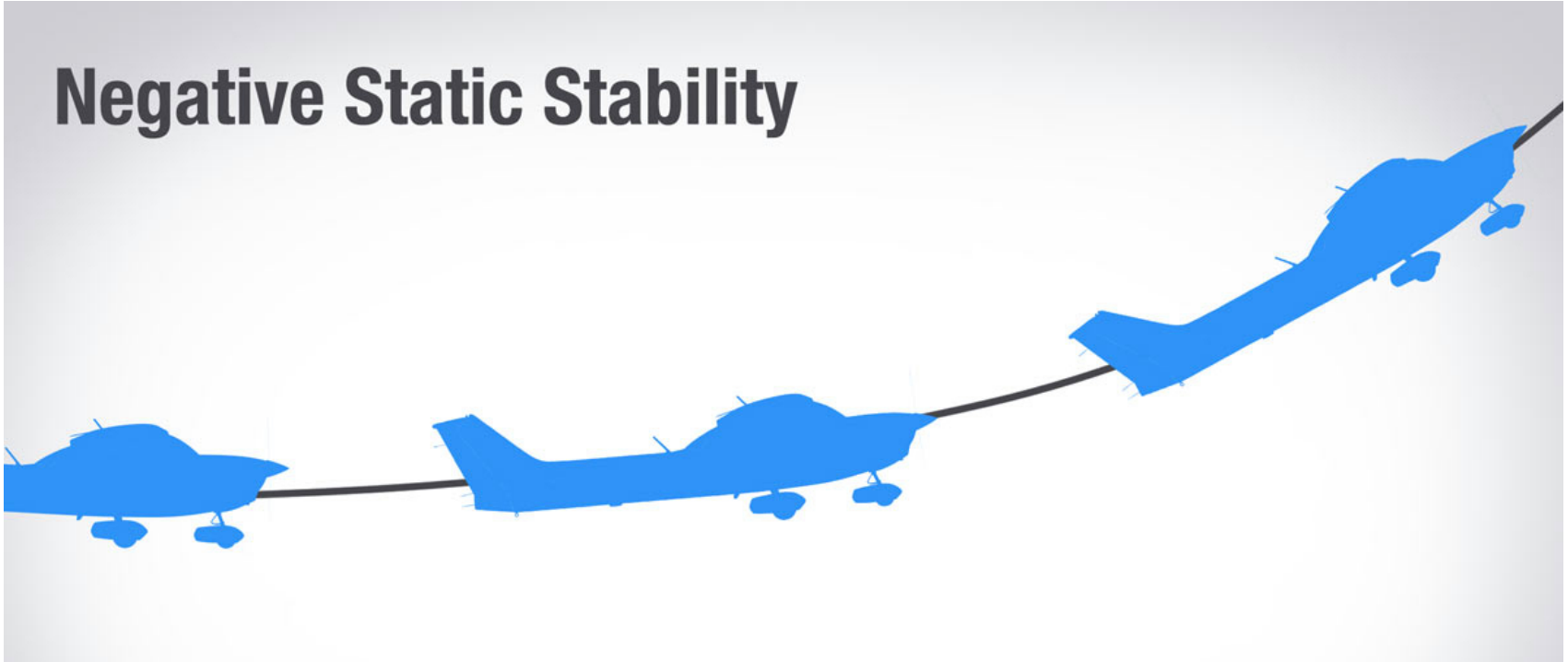
Note: The aircraft is considering as a rigid body hinged on its centre of gravity and free to rotate about its axes.

Static stability



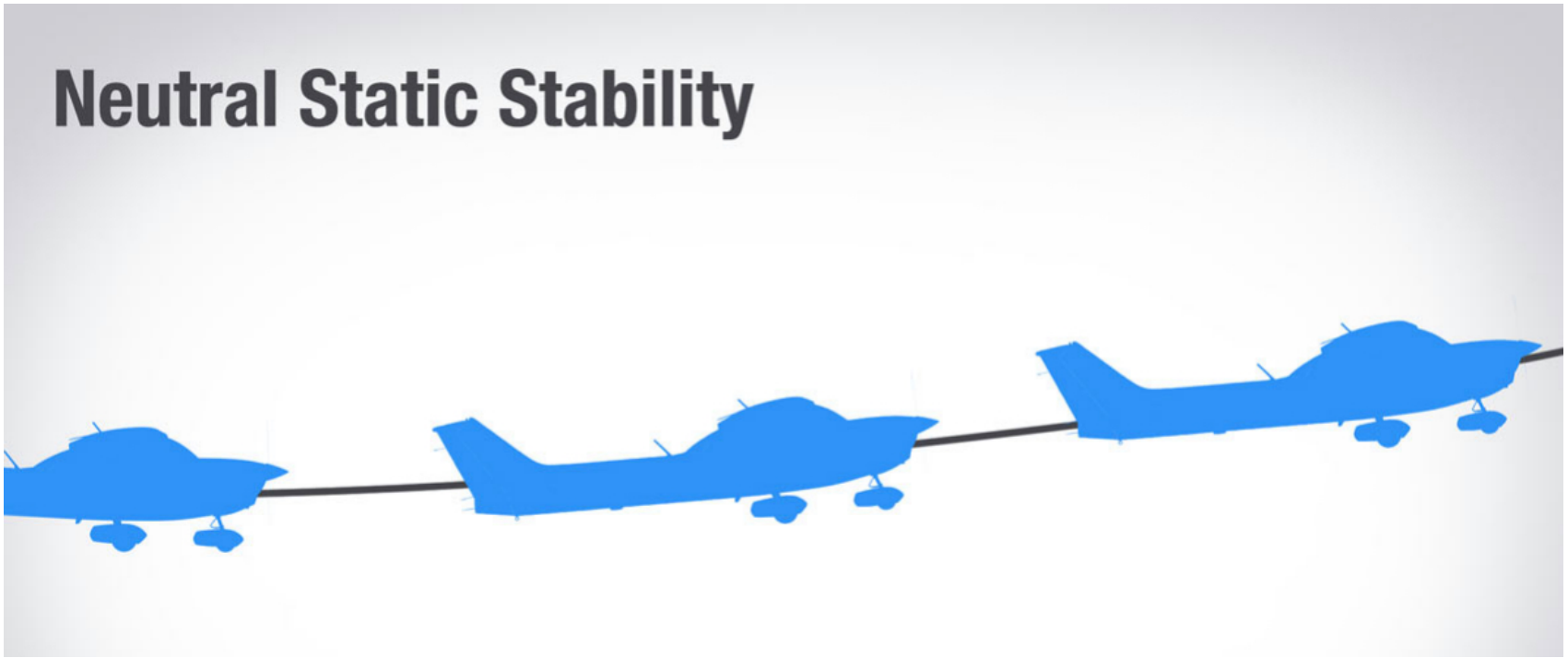
- An aircraft is called statically stable if once ended the disturbance (which has moved it away from its trajectory), it returns in its original position without variations in the airspeed or in the trajectory.

Static stability



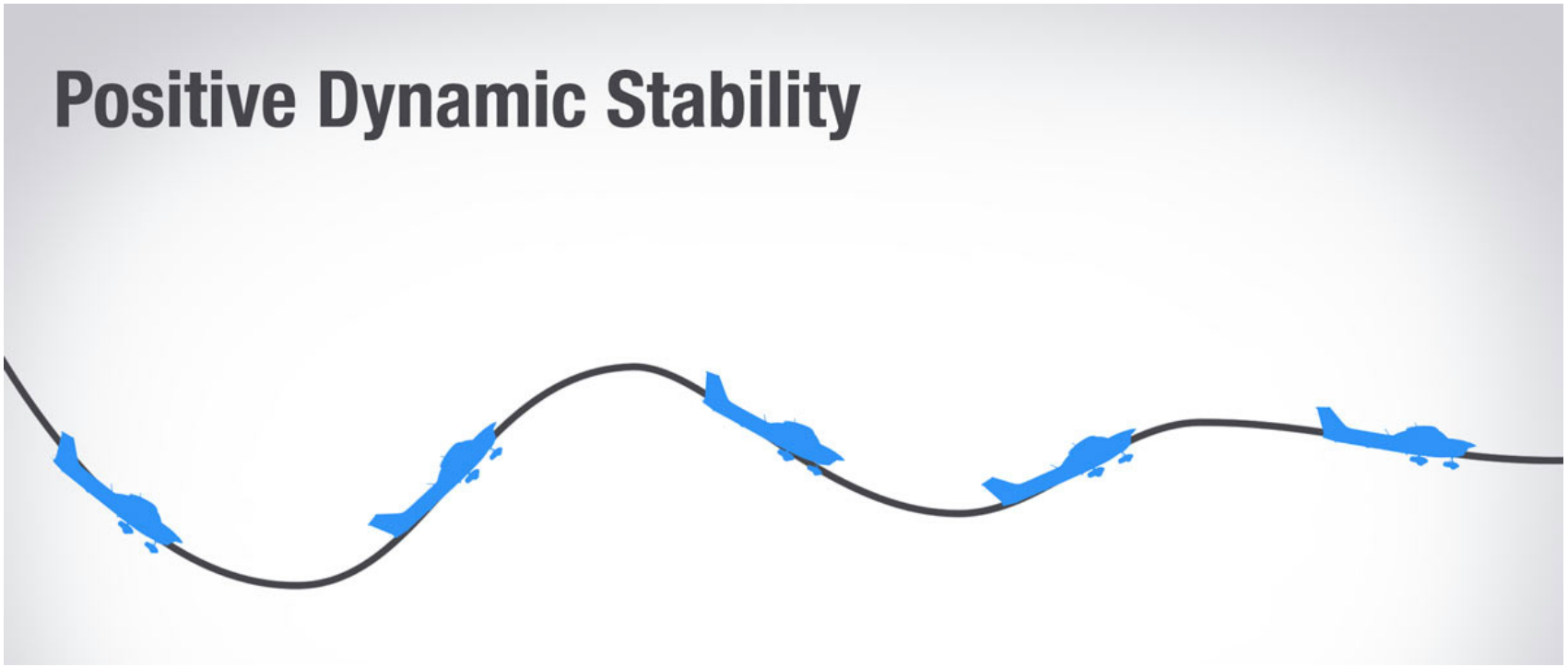
- An aircraft is called statically unstable (or negative stability) if once ended the disturbance (which has moved it away from its trajectory), it doesn't return in its original position without variations in the airspeed or in the trajectory.

Static stability



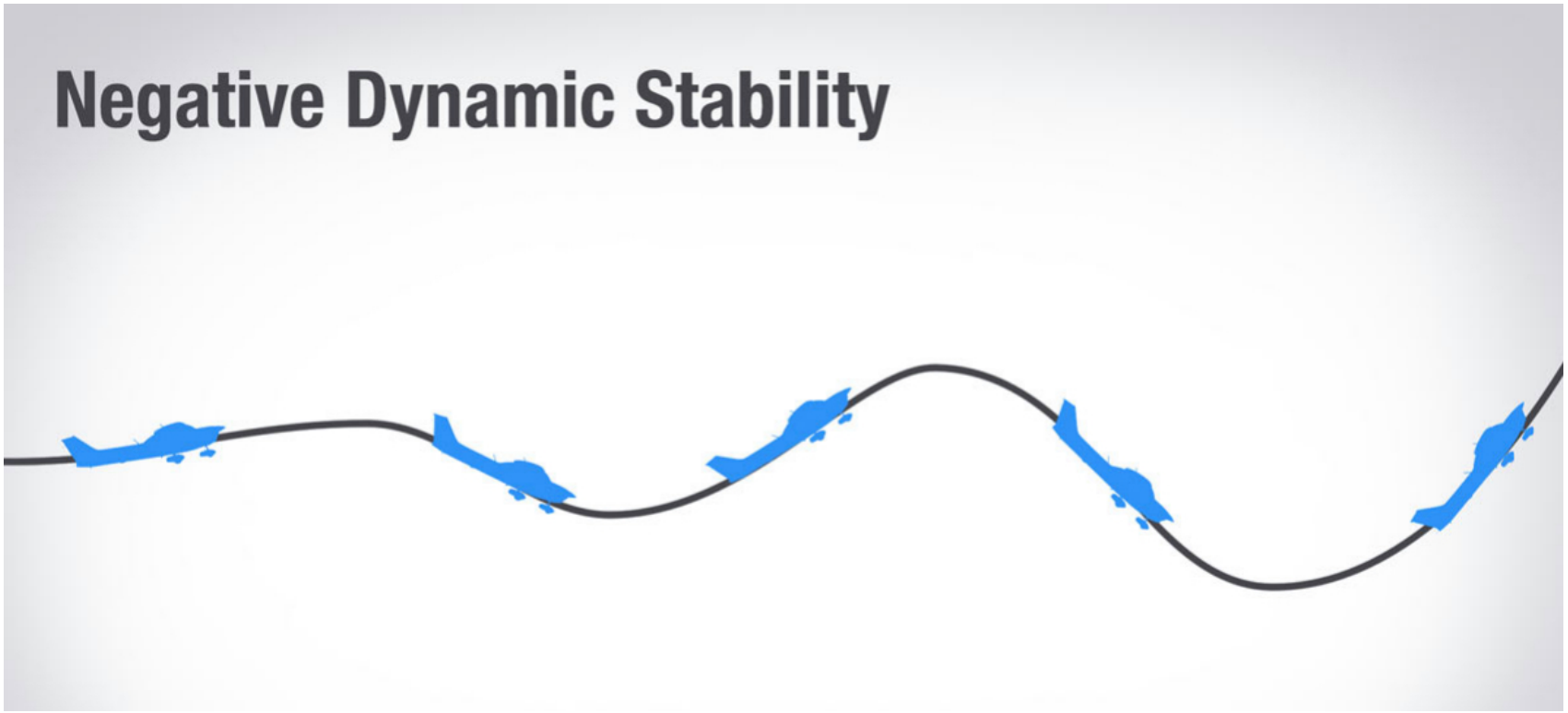
- An aircraft is called statically neutral if once ended the disturbance, it remains in its original position without variations in the airspeed or in the trajectory.

Dynamic stability



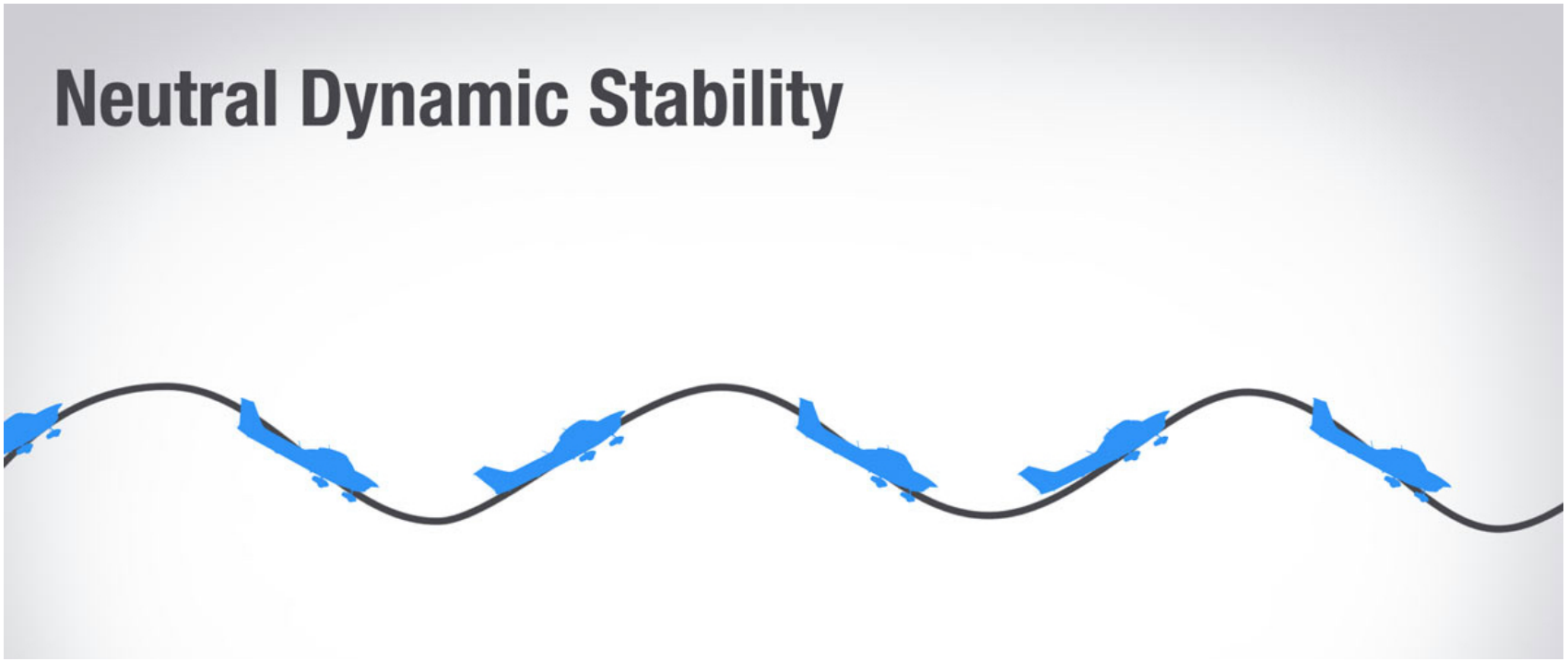
- An aircraft is called dynamically stable if once ended the disturbance (which has moved it away from its trajectory), it returns in its original position.
- That one can be reached after some damped oscillations, or in the best case, following a very damped trajectory.

Dynamic stability



- If during the returning phase, the aircraft overpass its initial position and starts an oscillatory motion about the initial trajectory with growing amplitudes, there is a dynamically unstable (negative) situation.

Dynamic stability



- An aircraft is called dynamically neutral when starts a series of oscillations about the point of equilibrium, with constant amplitude, without damp.

Active and passive stability

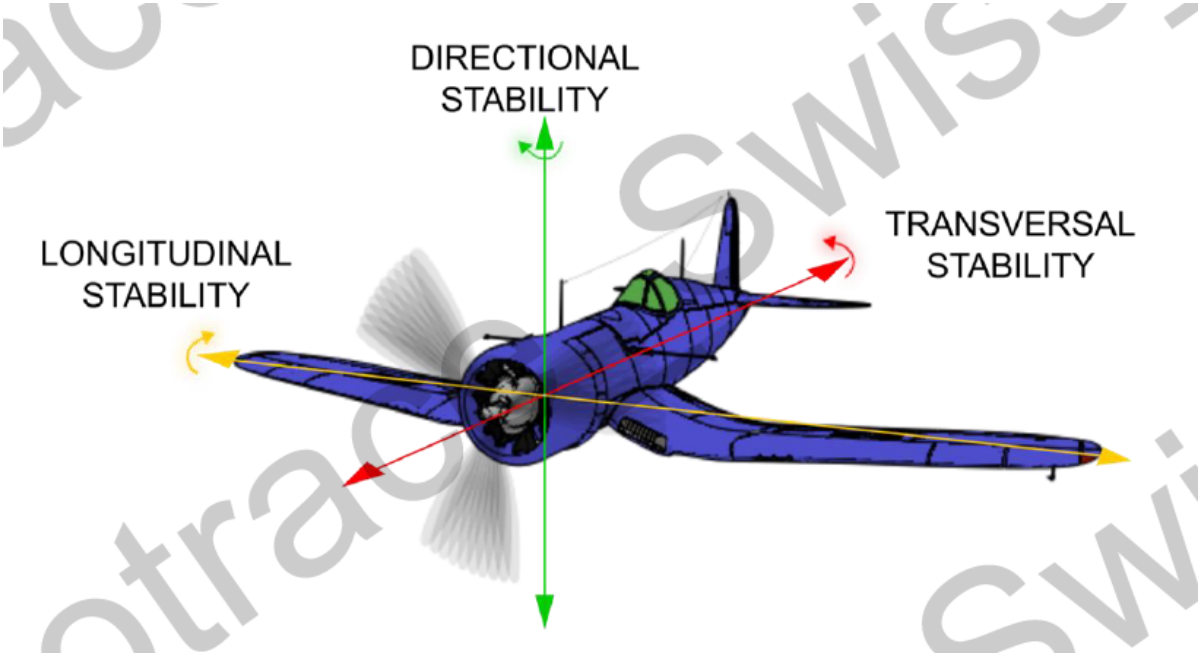
Active stability

- It is the automatic restore of the initial attitude, performed by means of the flight controls.
- The controls are activated and controlled by some computers, which detect attitude variations by means of gyroscope.

Passive stability

- It is the stability of an aircraft that at the end of the stress, recovers naturally its initial attitude thanks to its aerodynamic features.

Active and passive stability



Transversal stability

- It is respect to the longitudinal axis (roll movements).

Directional stability

- It is respect to the perpendicular axis (yaw movement).

Longitudinal stability

- It is respect to the transversal axis (pitch movement).

Lateral and Longitudinal stability

Lateral stability

- The lateral stability is the tendency to return in stable equilibrium after the rotational movements around the roll axis.
- The lateral stability is related to the directional stability.

The factors affecting the lateral stability are:

- High wings $\rightarrow$ center of thrust higher than the center of gravity $\rightarrow$ perpendicular effect $\rightarrow$ more stability than low wings
- Low wings $\rightarrow$ dihedral angle (wing tip higher than the wing root).

Longitudinal stability

The longitudinal stability is around the lateral/transversal axis.

- The longitudinal stability is the tendency to return in stable equilibrium after the rotational movements around the pitch axis
- Centre of gravity ahead of the center of pressure.
- Horizontal tail surface $\rightarrow$ longitudinal dihedral angle.

Directional stability and Dutch roll

Lateral stability

The directional stability is around the vertical axis.

- The directional stability is the tendency to return in stale equilibrium after the rotational movements around the yaw axis $\rightarrow$ as weathercock.
- The factors affecting the directional stability are: Effective keel surfaces $\rightarrow$ rudder, fin, fuselage sides after the center of gravity.

Dutch roll

- The Dutch roll is an oscillatory motion as a combination of the yaw and roll.
- If the aircraft is distrubed on the vertical axis of yaw, the tailplane moves laterally respect to the common position and the wing on the wing on the yaw side moves faster than the other one $\rightarrow$ the initial yaw towads the side cause an increase of the lift in that side and consequently a rolling motion.

Aircraft characteristics: weaker positive directional stability as opposed to positive lateral stability. Factors causes the Dutch roll:

- The most important factors is related to the seept angle, furthermore the dihedral angle could be influencing the motion.