The Four Forces

Airfoil design characteristics

Turns

Load Factor

Adverse Yaw

Turning tendency (torque effect)

Airplane Stability and Controllability

Ground Effect

Wingtip vortices and precautions to be taken

Understanding the effect of true airspeed on propeller efficiency and engine performance

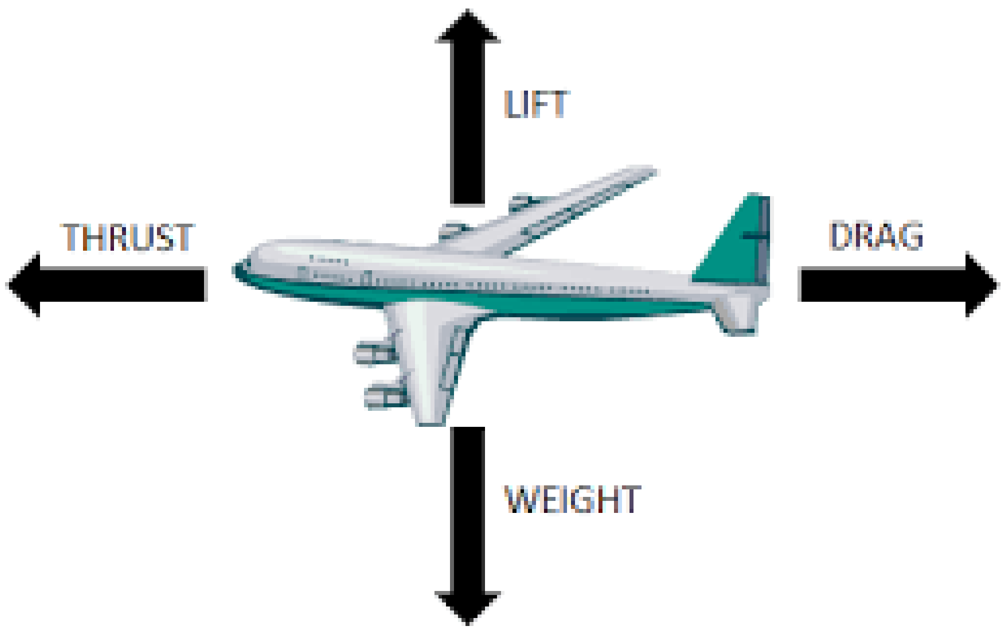
The Four Forces

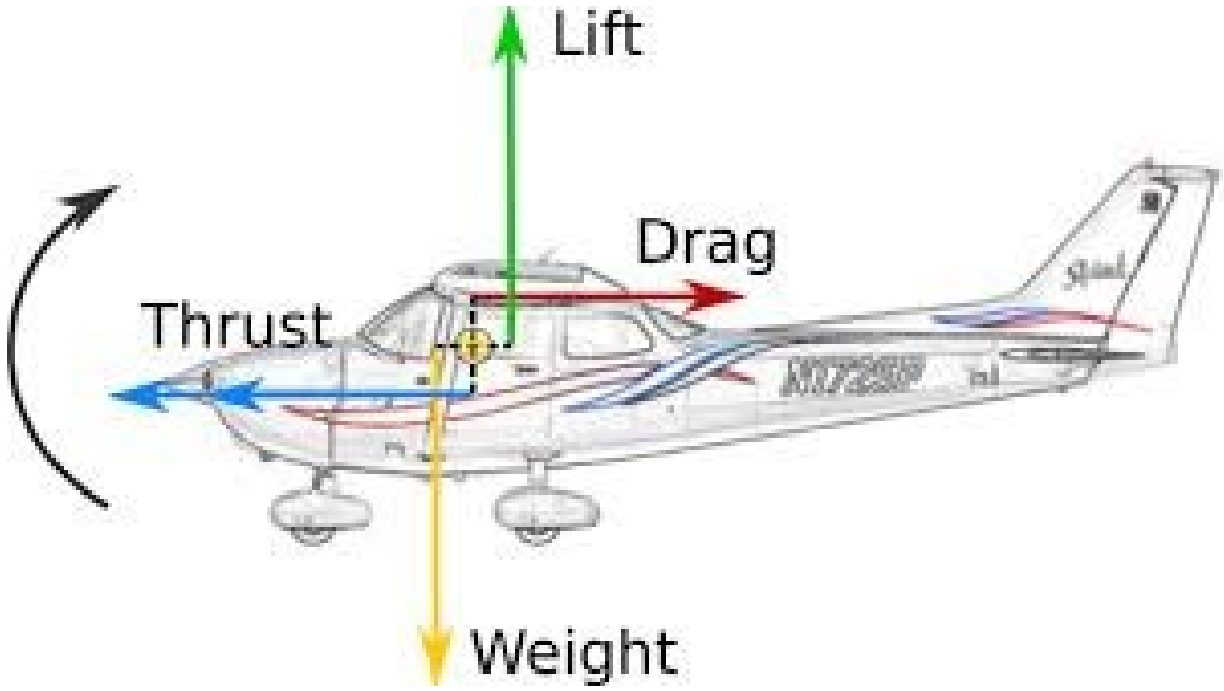
Cleared For the Option!

Lesson Objective

To develop understanding of the forces that act on an airplane. Everything in the air relates back to this.

First the Diagrams





Weight

A plane like anything else has weight.

The Earth has **gravity**.

The force of gravity acts through the **center of gravity** on the plane in a **vertical direction** towards the Earth.

Weight On the Ground vs Air

While the airplane is on the ground, its weight is supported by the force of the ground on the airplane, which acts upward through the **wheels**.

During the takeoff roll, the task of supporting the weight of the airplane is **transferred from the ground to the wings**.

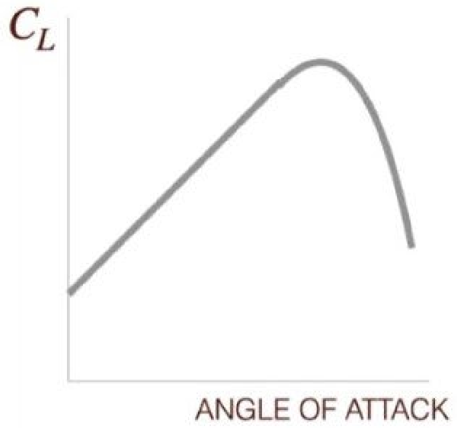
Lift

While in level flight, the weight of the airplane is supported by the lift force, which is generated **aerodynamically by the flow of air around the wings**.

Once you take off, you can not control weight, but you can control lift by Angle of Attack.

Lift

$$L = \frac{\overset{\text{AIR DENSITY}}{\rho}}{2}\ \underset{\text{WING AREA}}{S}\ \overset{\text{VELOCITY}}{V^2}\ \underset{\text{LIFT COEFFICIENT}}{C_L}$$



Notice that Velocity is squared

Weight <-> Lift

Lift > Weight

Aircraft will **climb** to higher altitudes

Weight > Lift

Aircraft will **descend** to lower altitudes

Thrust and Drag

Thrust, whether caused by a propeller or a jet engine, is the aerodynamic force that pushes or pulls the airplane forward through space.

As the airplane moves through the air it will experience a **retarding force** known as **drag**, which, unless counteracted, will cause the airplane to decelerate and lose speed.

In unaccelerated straight-and-level flight, the drag is neutralized by the thrust.

Thrust <-> Drag

Thrust > Drag

Aircraft will **accelerate** to a greater speed

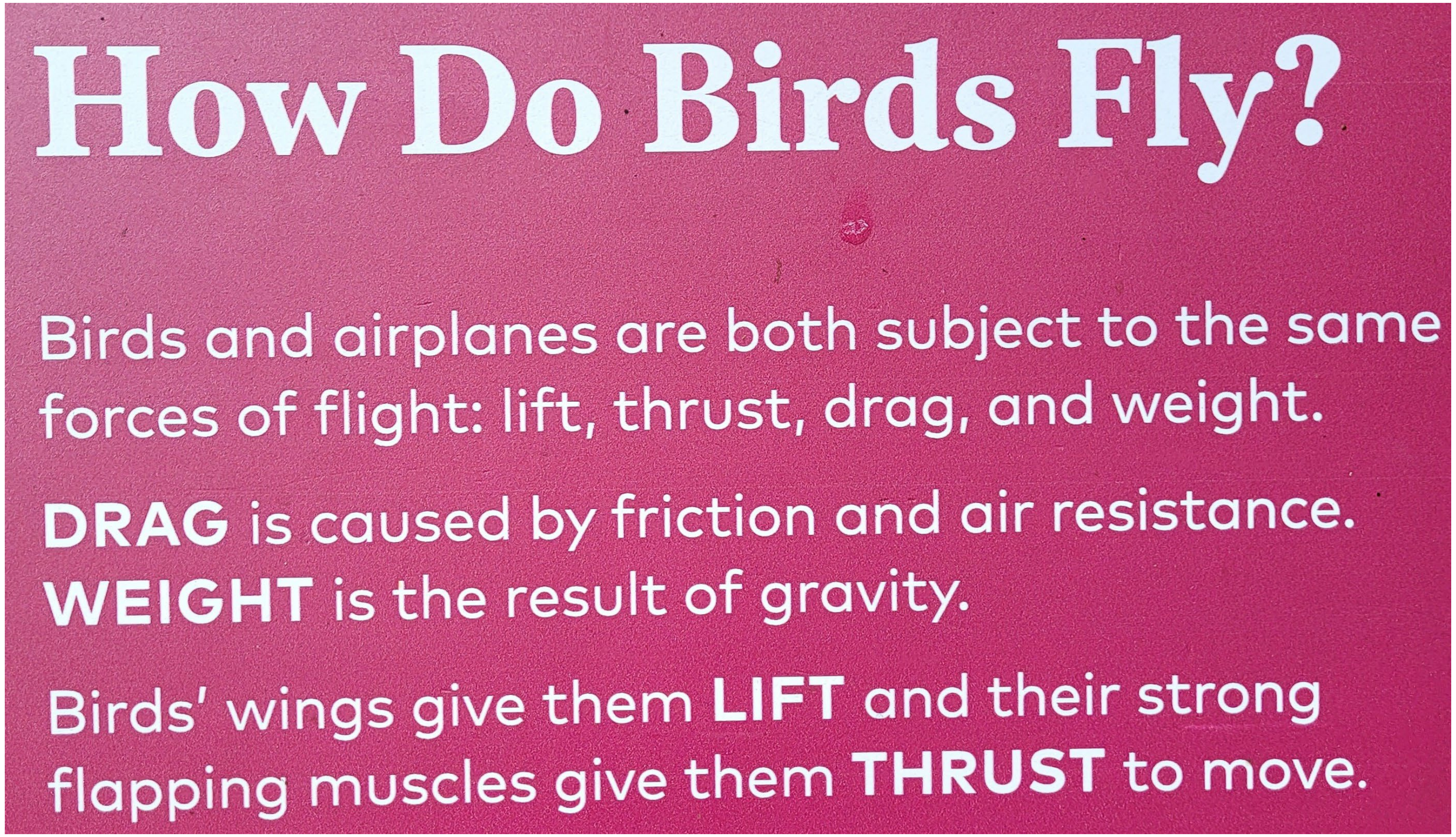
Drag > Thrust

Aircraft will **decelerate** to a slower speed

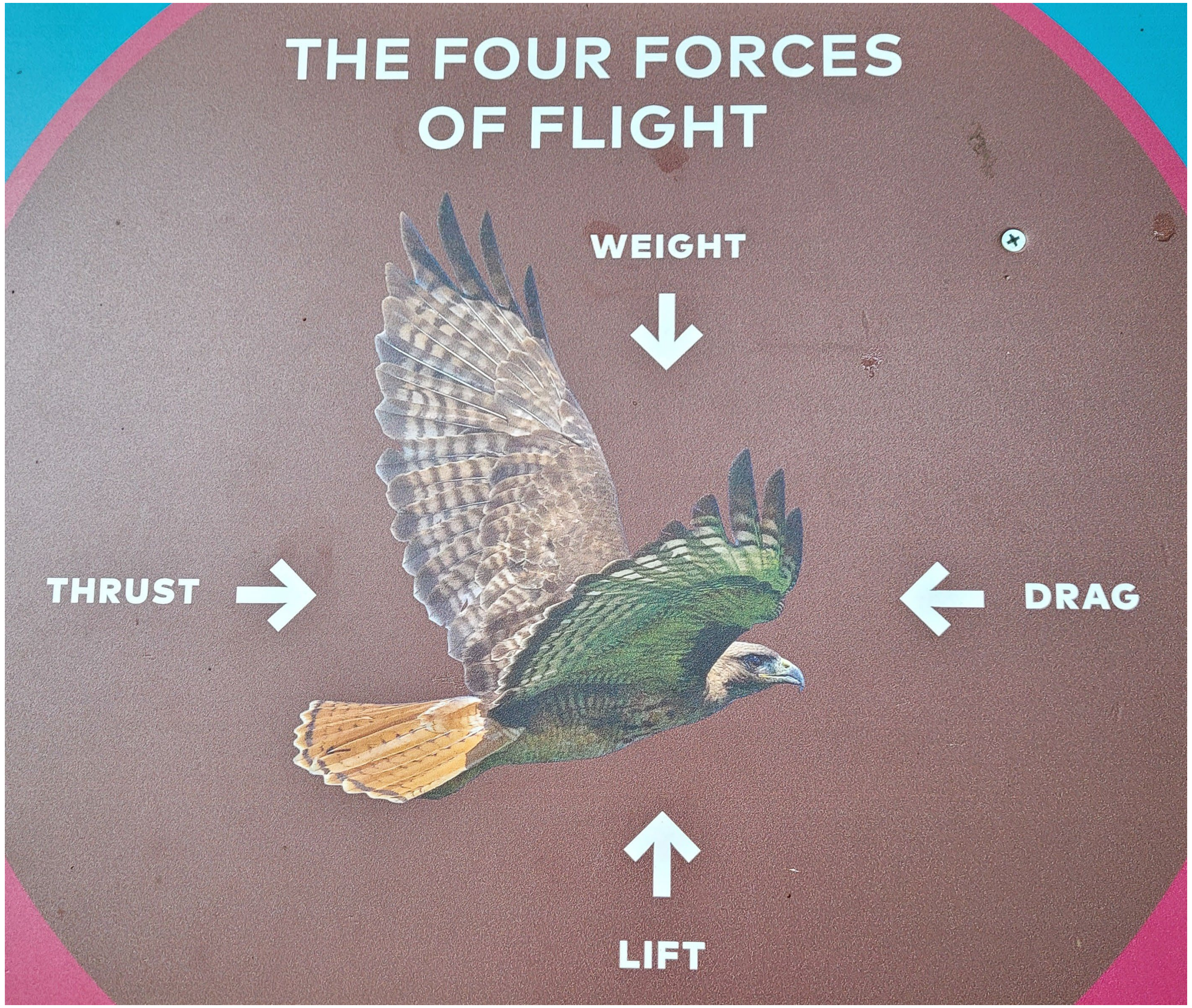
Birds and Planes

Aviation pioneer Wilbur Wright observed the flight of turkey vultures while designing the Wright Flyer—the world's first controllable airplane—in 1903.

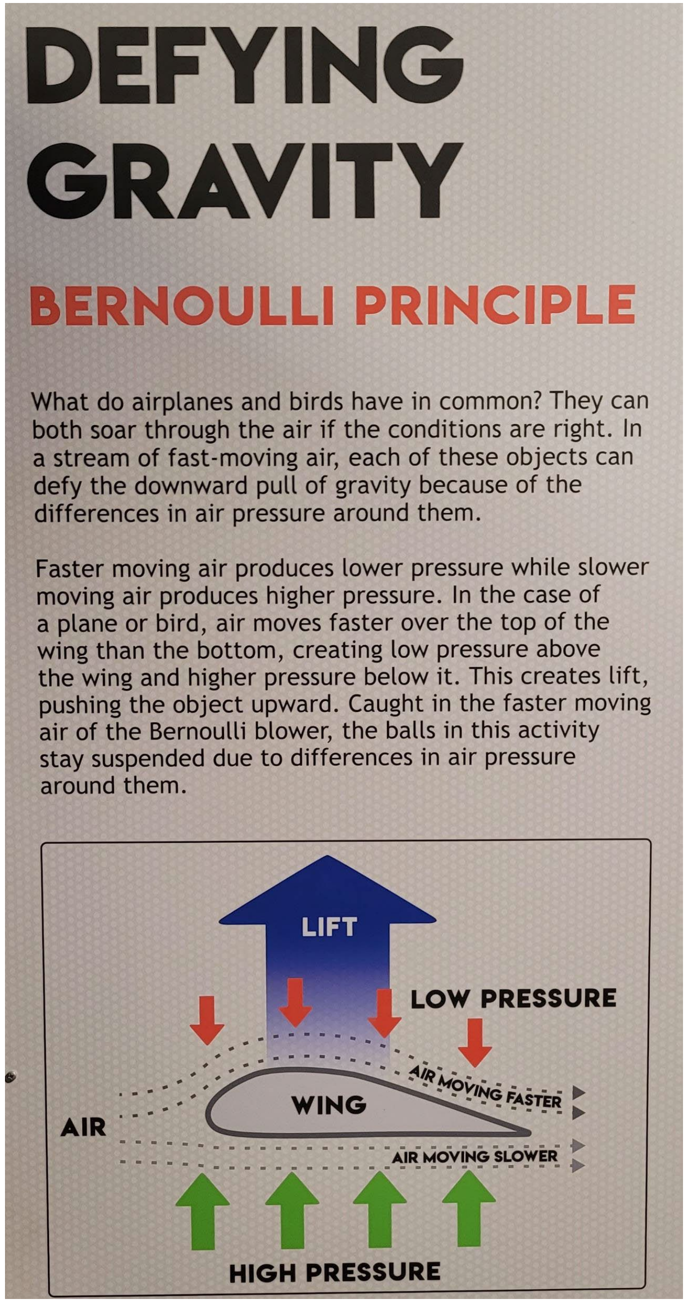
Birds and Planes

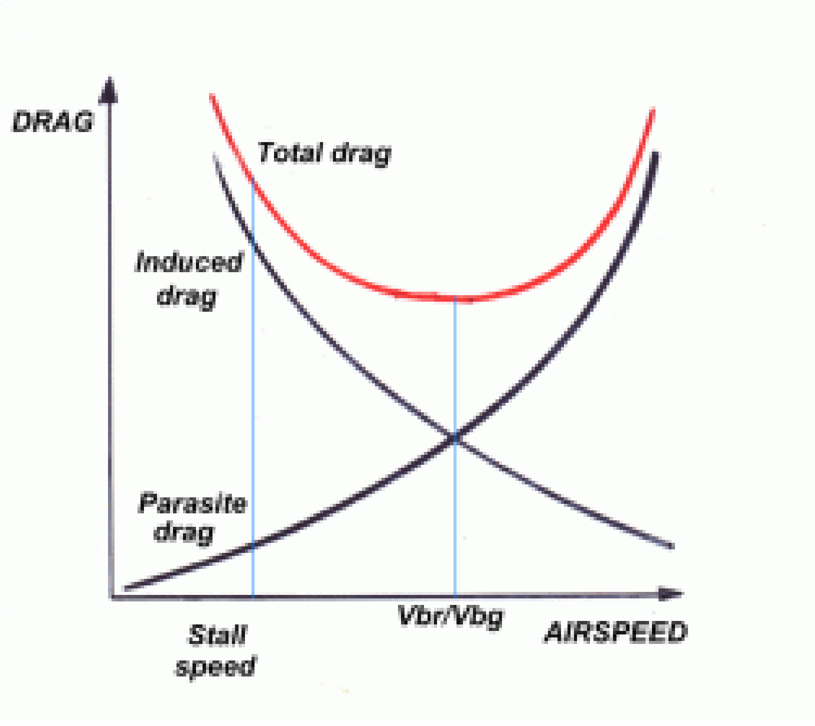


Birds and Planes



Birds and Planes





Types of Drag

Drag is the force that resists movement of an aircraft through the air.

There are two basic types:

Parasite drag greatly affects when going **fast**

Induced drag greatly affects when going **slow**

Parasite Drag

Parasite drag is comprised of all the forces that **work to slow an aircraft's movement**.

As the term parasite implies, it is the drag that is **not associated with the production of lift**.

This includes:

Displacement of the air by the aircraft

Turbulence generated in the airstream

Hindrance of air moving over the surface of the aircraft

There are three types of parasite drag: form drag, interference drag, and skin friction.

Form Drag

Form drag is the portion of parasite drag generated by the aircraft **due to its shape and airflow around it**.

Examples:

Engine cowlings

Wheels

Antennas

Aerodynamic shape of other components.

Think of a moving truck vs a sports car

Interference Drag

Interference drag comes from the **intersection of airstreams** that creates currents, turbulence, or restricts smooth airflow.

For example, the intersection of the wing and the fuselage at the wing root has significant interference drag.

Skin Friction Drag

Skin friction drag is the **aerodynamic resistance** due to the contact of moving air with the surface of an aircraft. Every surface, no matter how apparently smooth, has a rough, ragged surface when viewed under a microscope.

Induced Drag

Induced drag is the consequence of lift and is produced by the passage of an airfoil (wing or tail) through air.

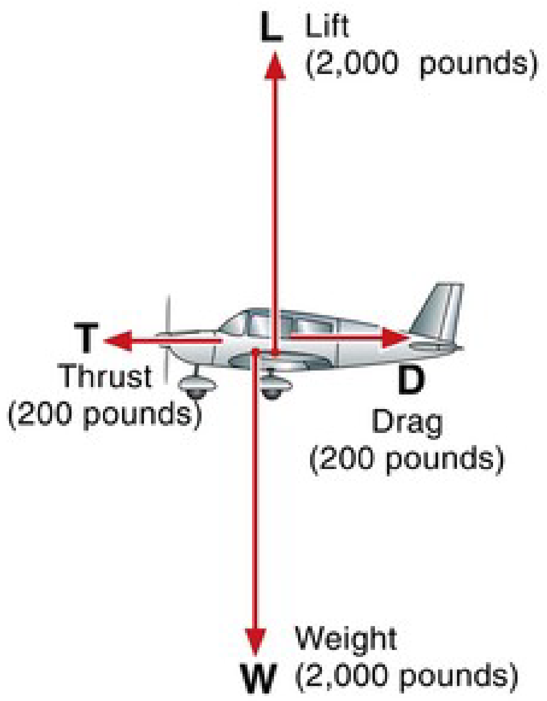
<u>If you induce lift…you induce drag</u>

High pressure air below the wing seeks equilibrium with the lower pressure air above the wing.

This creates a vortex flow from the bottom of the wing to the top.

Air flowing over the <u>top</u> of the wing tends to flow <u>inwards</u>.

Air flowing <u>below</u> the wing tends to flow <u>outwards</u>.



State of Equilibrium

In unaccelerated straight-and-level flight, forces are equal and opposite, canceling each other out.

The resultant force acting on the airplane is zero, and it will neither accelerate nor decelerate.

Weight = Lift

Drag = Thrust

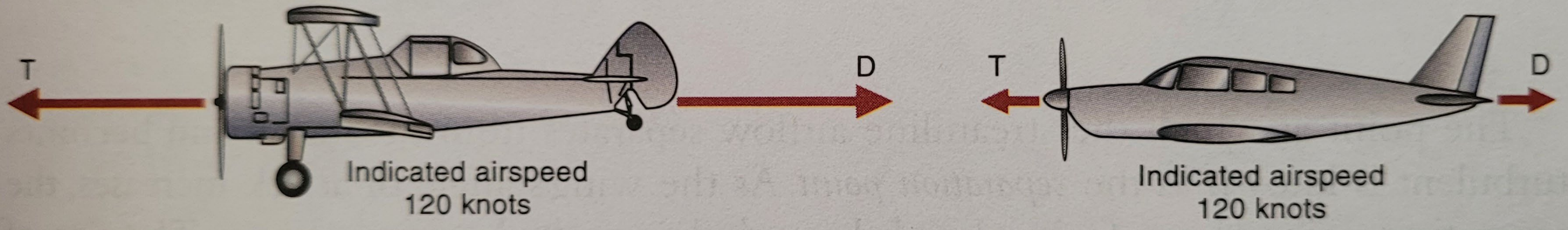


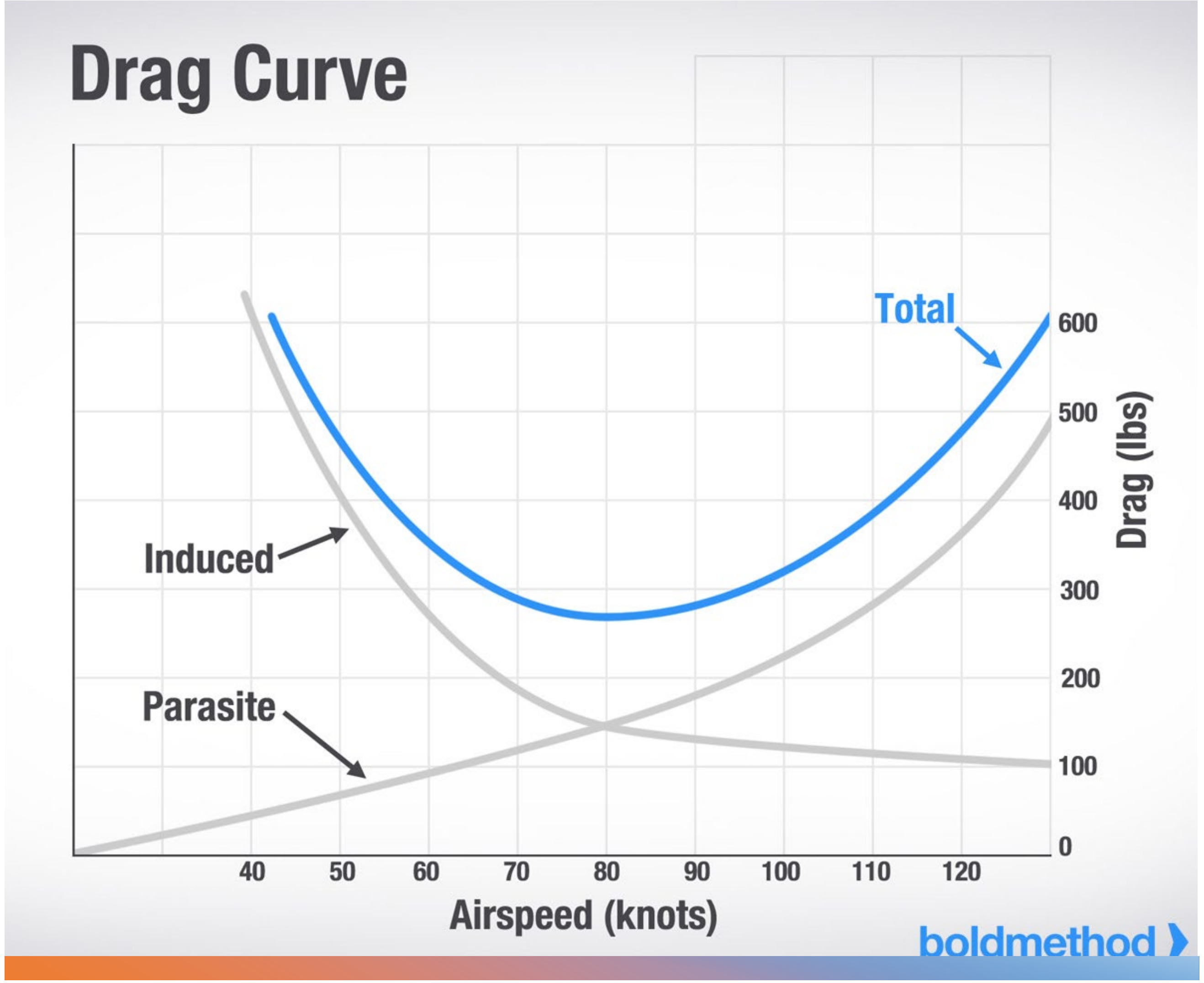
Figure 1-34 Low drag requires only low thrust to counteract it.

Total Drag

Total drag =

Parasite Drag + Induced Drag

The airspeed at which **total drag is lowest** will determine the **best glide speed** of that plane.



Now the Deep Dive

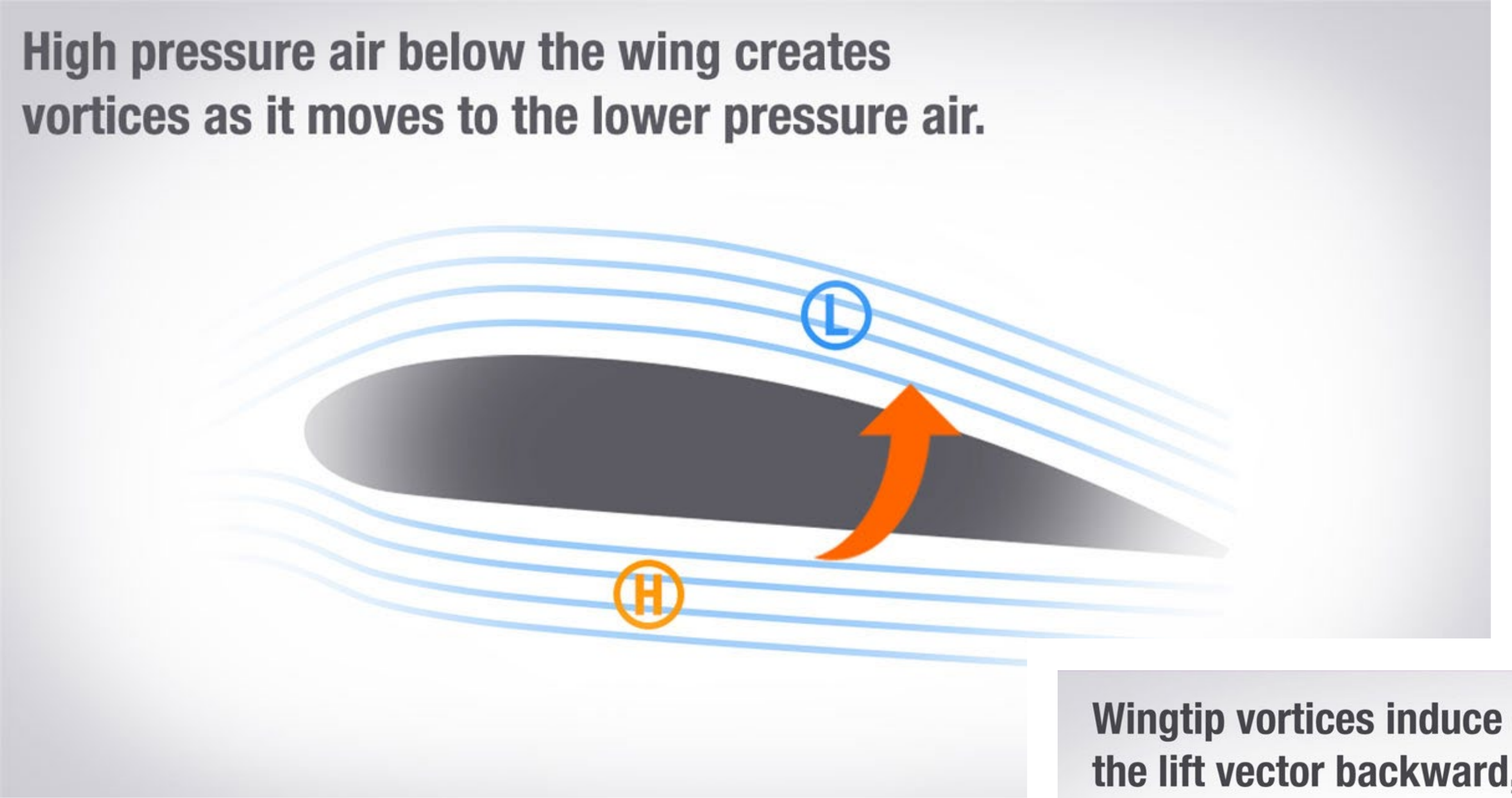
Induced Drag and Aspect Ratio

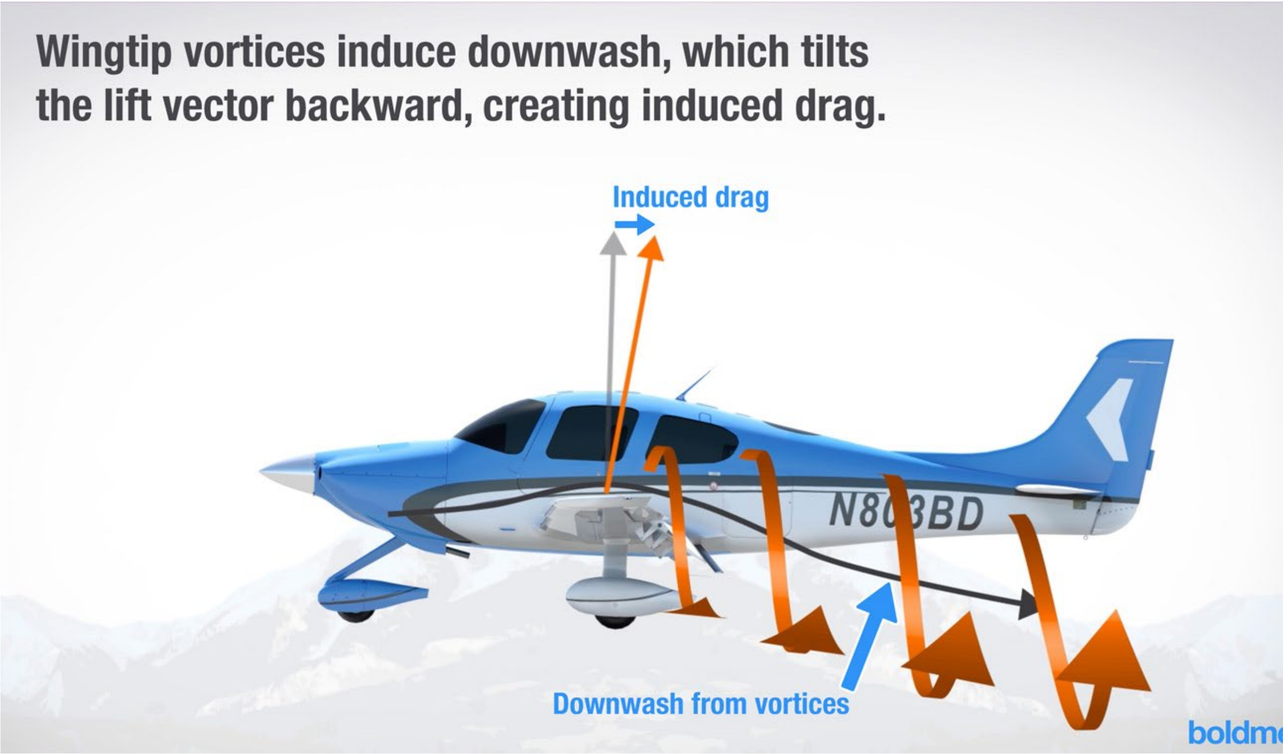
A high aspect ratio wing is better as the proportion of air which moves in this way is reduced so it generates more lift.

The higher the aspect ratio, the less disturbance at the tip.

As the air (and vortices) roll off the back of your wing, they angle down, which is known as downwash.

When you have more downwash, your lift vector points back more, causing induced drag.


High pressure air below the wing creates vortices as it moves to the lower pressure air.
L
H


Wingtip vortices induce downwash, which tilts the lift vector backward, creating induced drag.
Induced drag
Downwash from vortices

Induced Drag

By definition lift is said to act at right angles to the remote free stream of air. It is the vertical component of the total reaction. At lower airspeeds, the angle of attack is higher, and the total vector is tilted rearwards. The increasing horizontal component is induced drag. It is an unavoidable cost for the generation of lift.

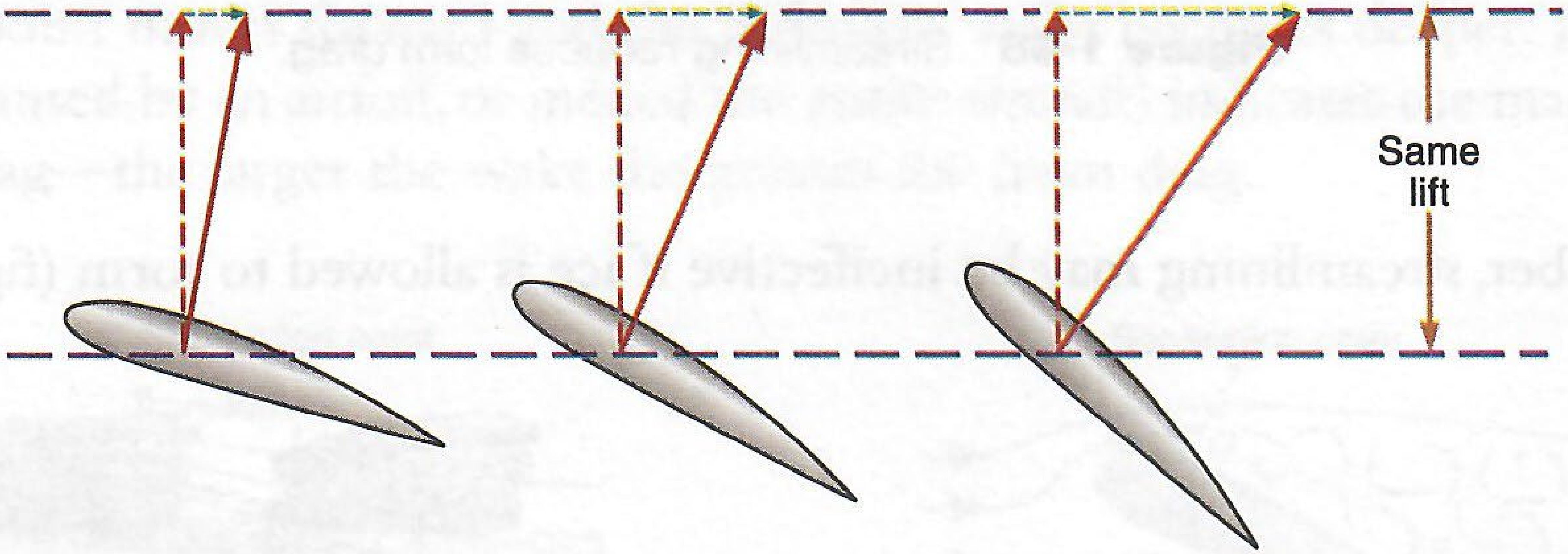


Figure 1-41 Induced drag increases as angle of attack increases.

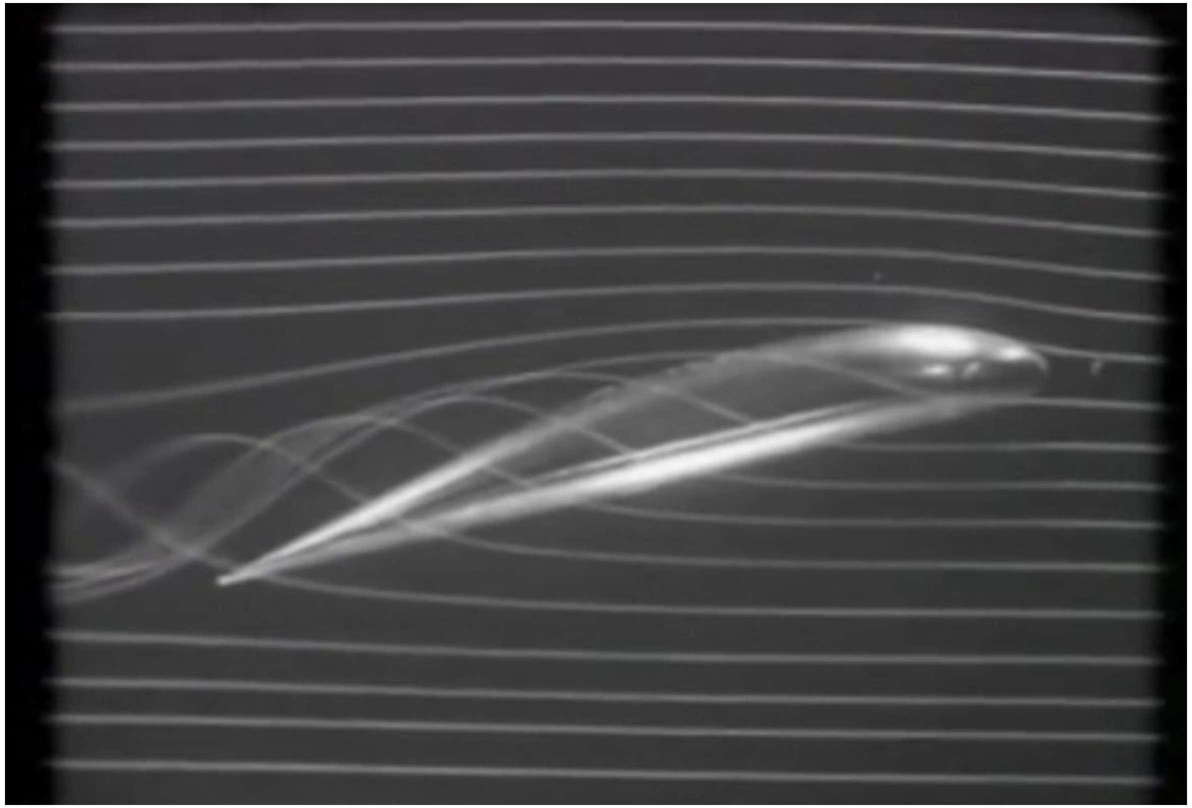
Induced Drag

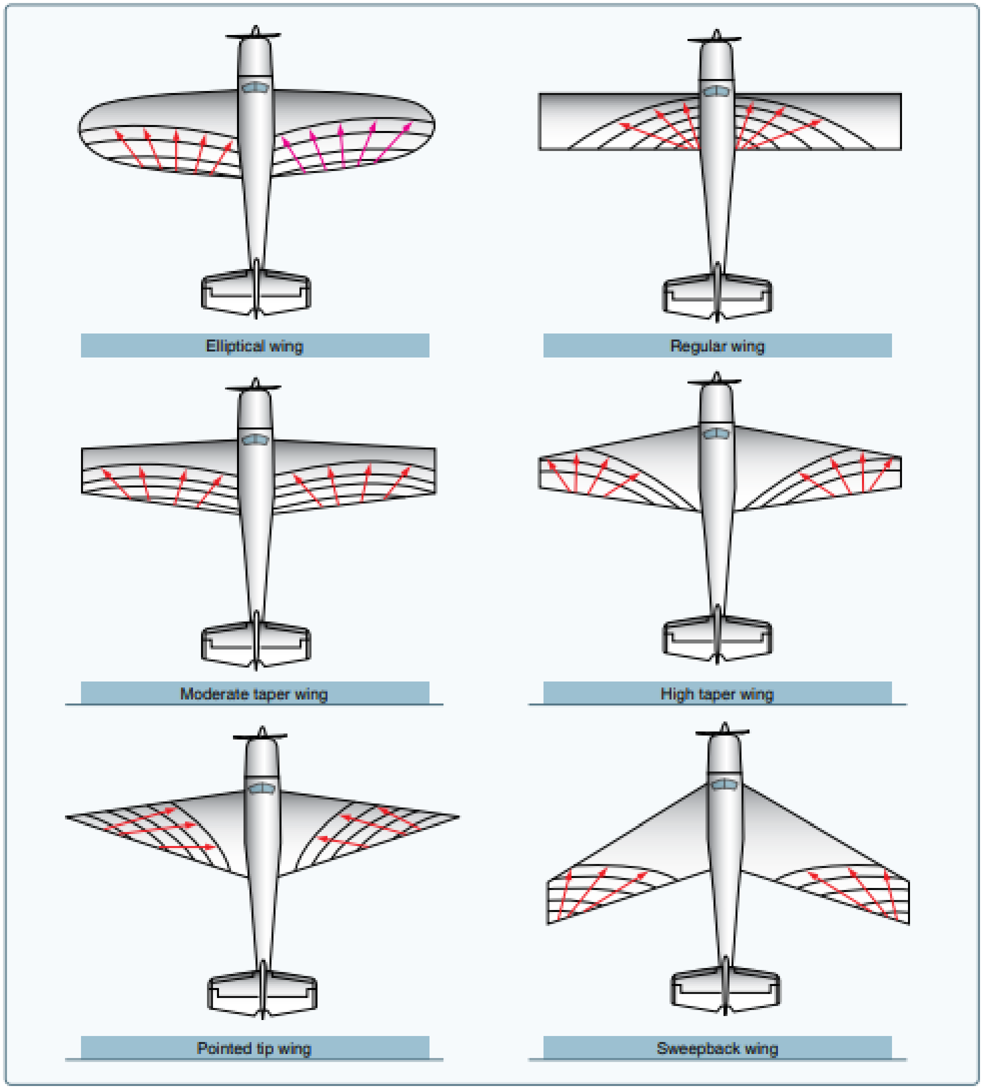
Other ways to reduce induced drag and tip vortex strength in a wing design are also based upon reducing the amount of air movement upwards at the wing tip by aiming to generate relatively more of the lift away from tips.

Wing taper towards the tip assists this as does wing twist.

The Boeing 767 is a example of a twisted wing.

Induced Drag




Elliptical wing
Regular wing
Moderate taper wing
High taper wing
Pointed tip wing
Sweepback wing


NMA
N797FL

Angle of Attack

AOA = **angle between the chord line of an airfoil and the oncoming air/relative wind**

"The angle between the direction the plane is moving in and the direction the plane is pointing"

Credit to Yoel Gilman

https://youtu.be/3OEWguuPEPE&t=240

Induced Drag

The inner wing is set at a higher Angle of Attack (AOA) than the outer wing and thus generates proportionately more lift whereas the tip, at a very small Angle of Attack generates very little.

Winglets (sharklets) have also become popular, both the usual up-turned versions and the older Airbus A320 series two-way ‘wingtip fence’ versions.

Well designed winglets can prevent about 20% of the airflow spillage at the tip - and therefore 20% of the induced drag.

Induced Drag

Induced drag and its wing tip vortices are a direct consequence of the creation of lift by the wing.

Since the Coefficient of Lift is large when the AOA is large, induced drag is inversely proportional to the square of the speed whereas all other drag is directly proportional to the square of the speed.

Induced Drag

The effect of this is that induced drag is relatively unimportant at high speed in the cruise and descent where it probably represents less than 10% of total drag.

At slow speeds just after take off and in the initial climb, it is of maximum importance and may produce as much as 70% of total drag.

When looking at the potential strength of wing tip vortices, all this theory on induced drag must be moderated by the effect of aircraft weight.

Induced drag will always increase with aircraft weight.

The Propeller

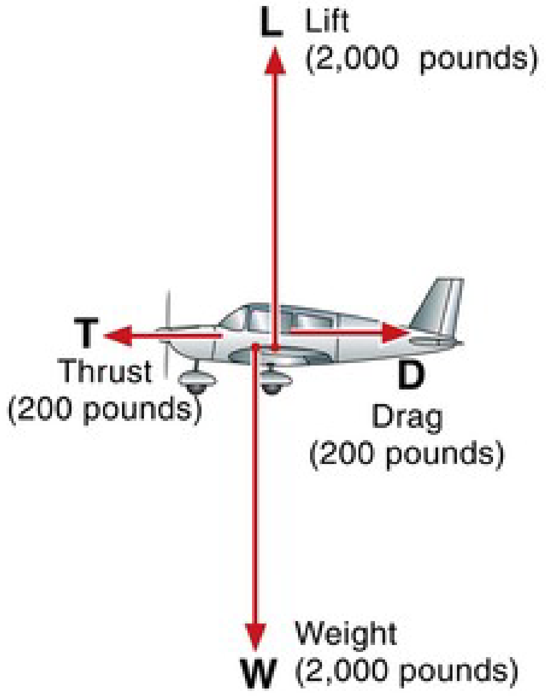
Also an airfoil. Wings produce lift, a propeller produces "horizontal lift" or thrust to propel an airplane forward.

Propeller Twist: To produce uniform thrust along the entire length of its blades.

Why is this Necessary?

Because the propeller blades are spinning faster at the tip and slower at the hub. Hence, the tips will need a lower angle of attack and the hub will need a greater angle of attack.

Lift/Drag Ratio



The lift-to-drag ratio (L/D) is the amount of lift generated by a wing or airfoil compared to its drag.

A ratio of L/D indicates airfoil efficiency.

Aircraft with **higher L/D ratios are more efficient** than those with lower L/D ratios.

For the plane in the diagram:

2000/200 = 10 --> L/D = 10

Lift and Drag Coefficients

The rates of change of lift and drag with angle of attack (AOA) are called lift and drag coefficients CL and CD.

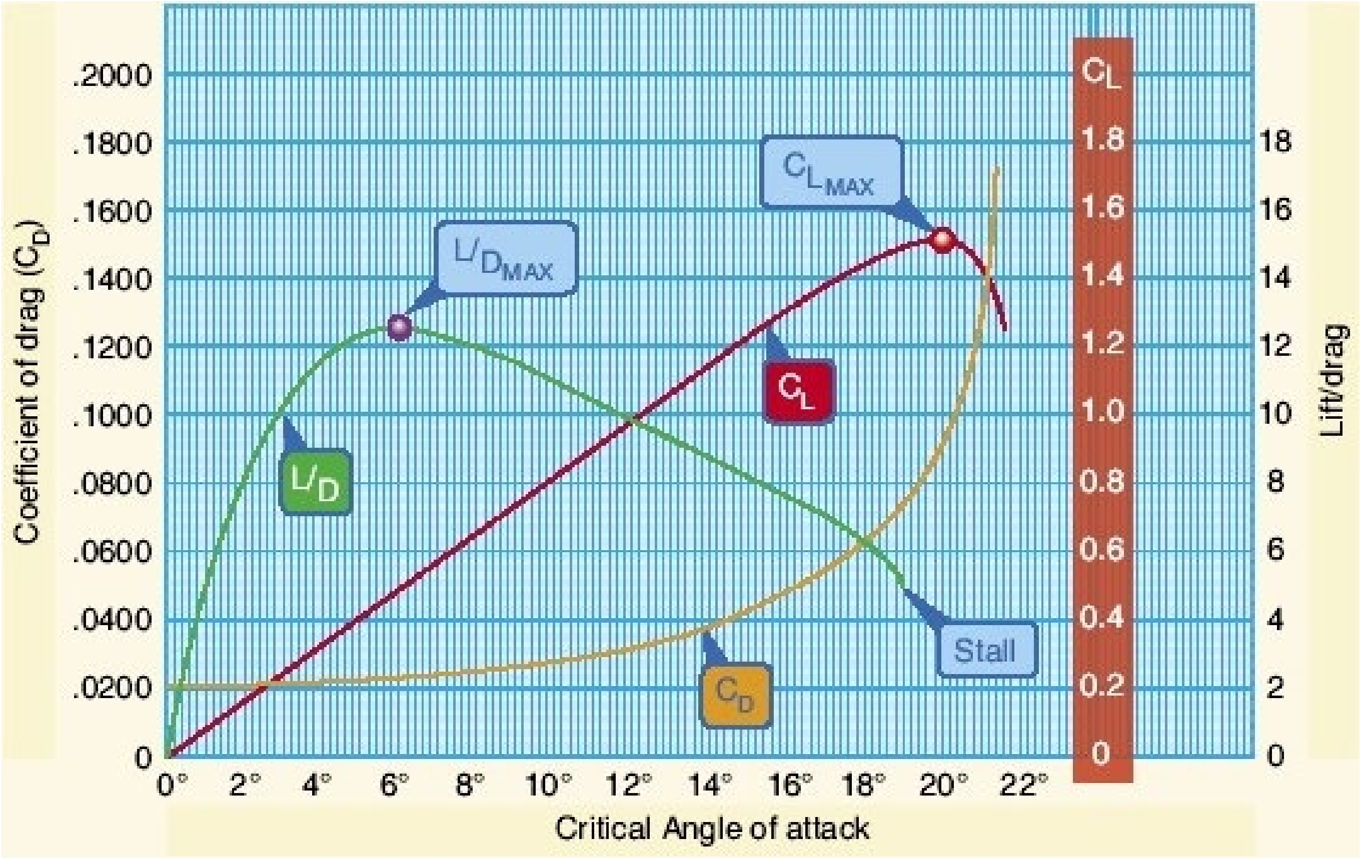
In unaccelerated flight with the lift and drag data steady, the proportions of the coefficient of lift (CL) and coefficient of drag (CD) can be calculated for specific AOA.

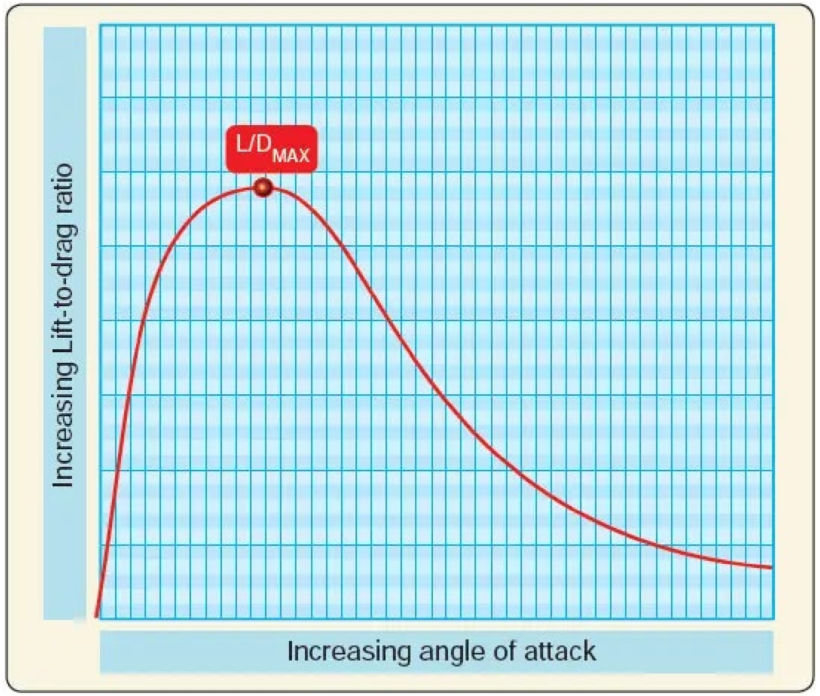
Typically, at **low AOA**, the coefficient of drag is low and small changes in AOA create only **slight changes in the coefficient of drag**.

At **high AOA**, small changes in the AOA cause **significant changes in drag**.

The shape of an airfoil, as well as changes in the AOA, affects the production of lift.

Lift and Drag Coefficients





L/D Max and Glide Speed

The best glide airspeed is used to maximize the distance flown. This airspeed is important when a pilot is attempting to fly during an engine failure.

The best airspeed for gliding is one at which the airplane travels the greatest forward distance for a given loss of altitude in still air.

This best glide airspeed occurs at the highest lift-to-drag ratio (L/D).

Why Do Planes Takeoff Into the Wind?

All airplanes generate lift. Most of an airplane's lift is generated by its wings. As air flows under the wings, it pushes the airplane up.

Against-the-wind takeoffs allow airplanes to generate more lift. Airplanes must achieve a fast enough speed when taking off to maintain airflow under their wings. If there's little or no air moving under an airplane's wings, it may fail to generate a sufficient amount of lift. This is why airplanes accelerate when taking off. While an airplane's engines create most of the propulsion needed to accelerate an airplane, against-the-wind takeoffs — also known as headwind takeoffs — can help as well.

Why Do Planes Takeoff Into the Wind?

Most airplanes take off against the wind to generate more lift. The speed at which the air moves under an airplane’s wings affects the amount of lift it generates. The faster the air moves, the more lift the wings will generate. By taking off against the wind, air will move faster under the airplane’s wings, resulting in more lift.

If the engine goes out on the takeoff roll, the wind might be a little help to stop before the end of the runway.

Any questions I can answer or follow up later on?

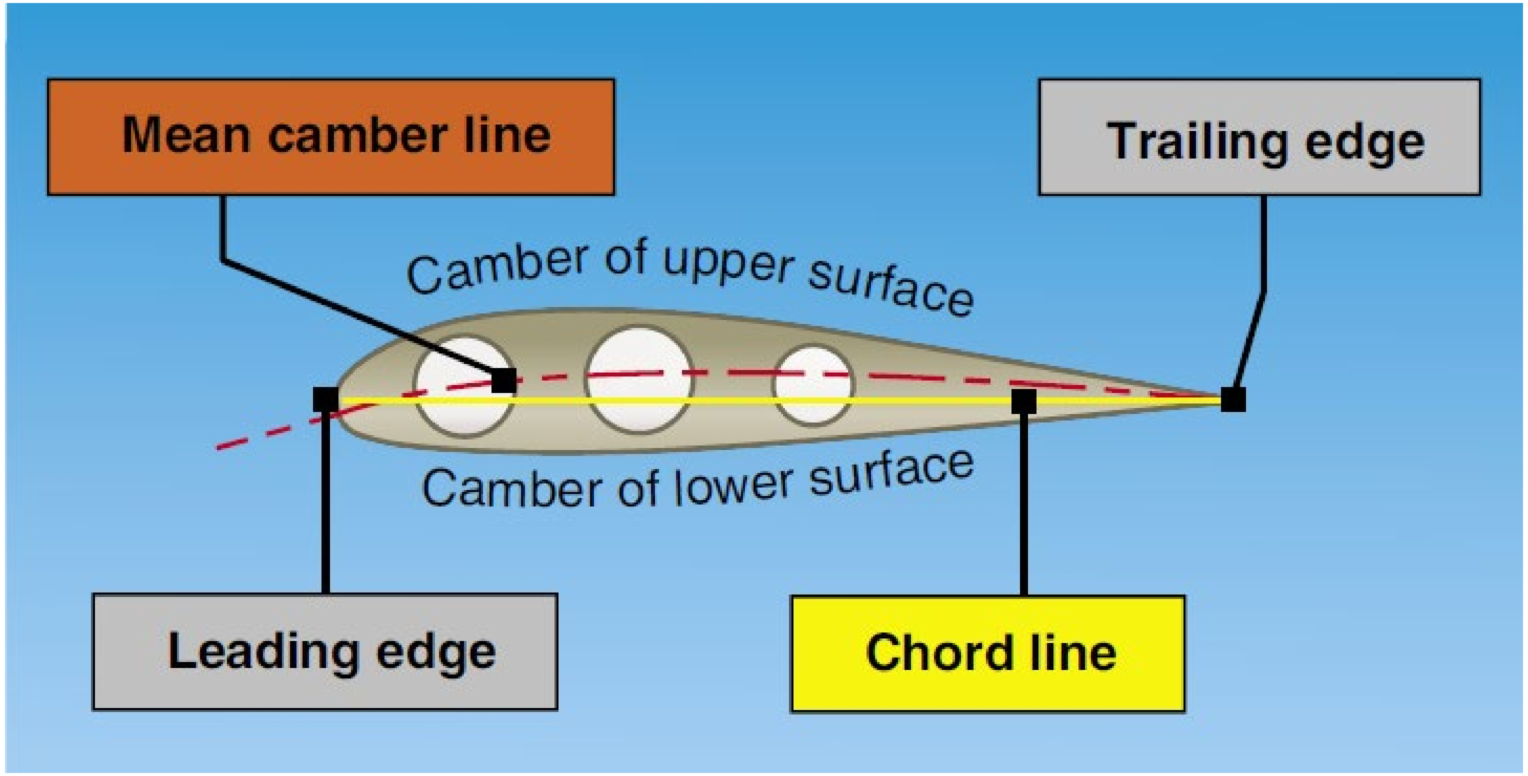
Airfoil design characteristics

Cleared For the Option!

Lesson Objective

To develop understanding why wings look the way they do

Diagram to Start With

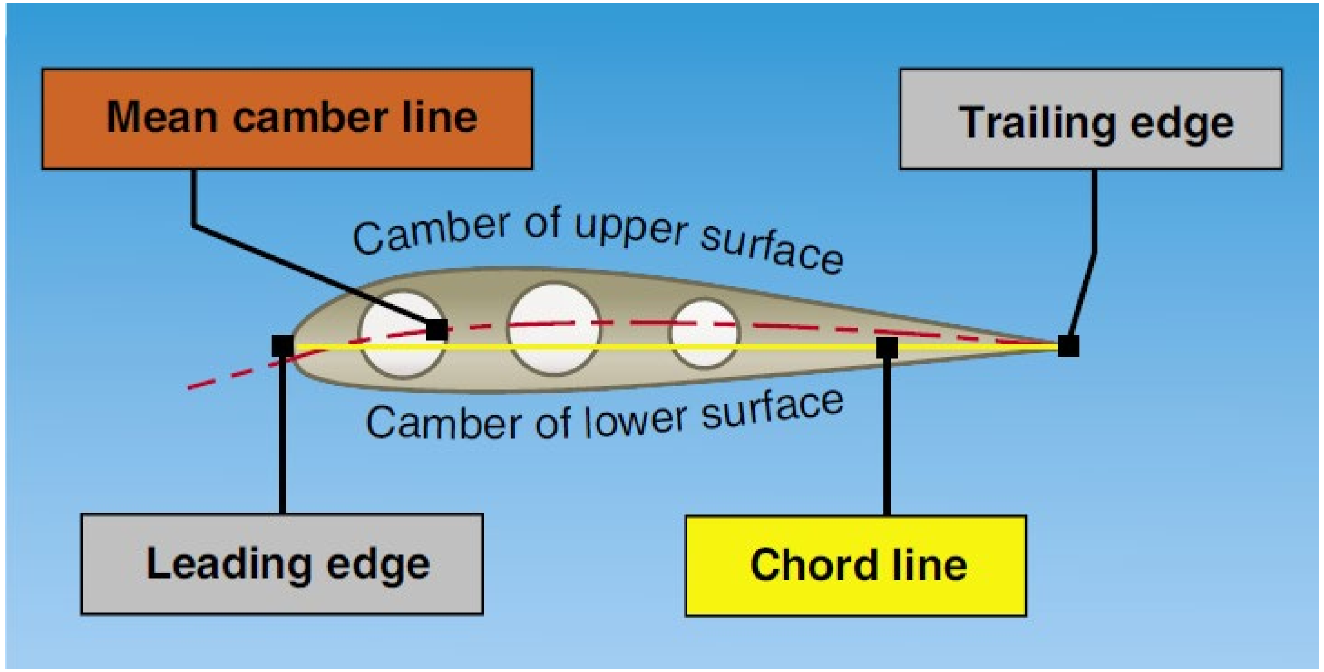


Leading Edge

The leading edge of an airfoil is the **portion that meets the air first**.

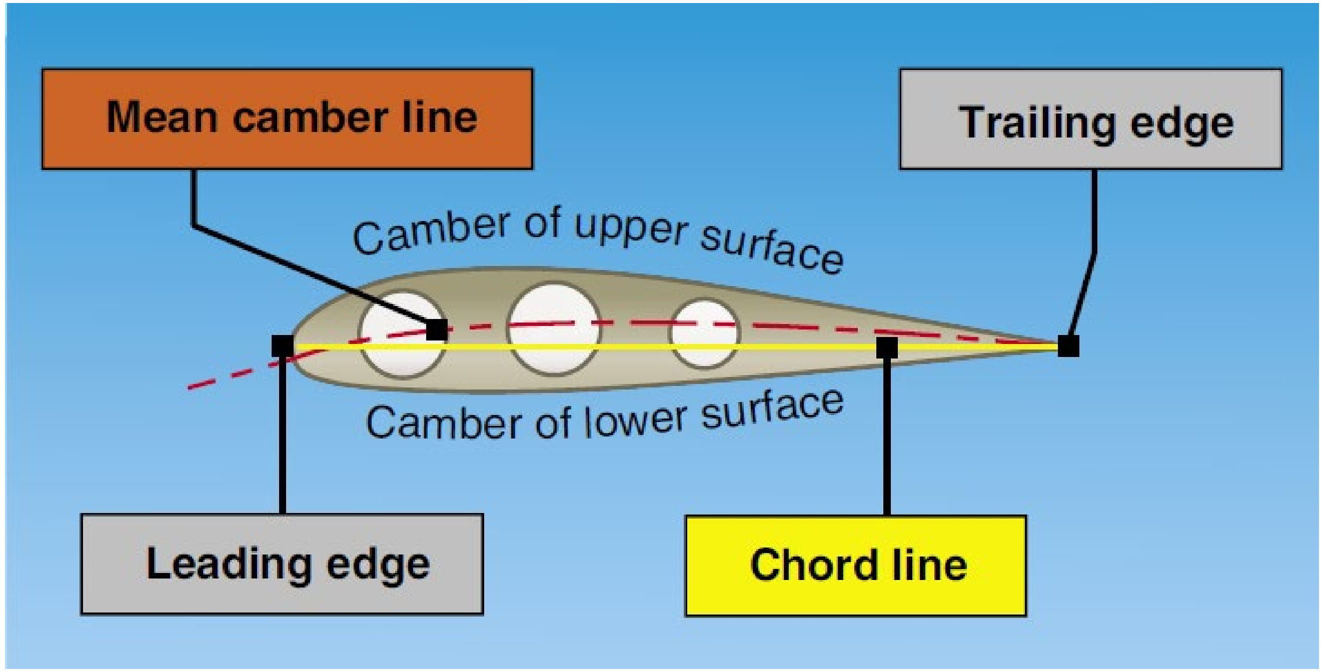
The front of the wing.

If the airfoil is designed to operate at high speeds, its leading edge will be very sharp, as on most current fighter aircraft.



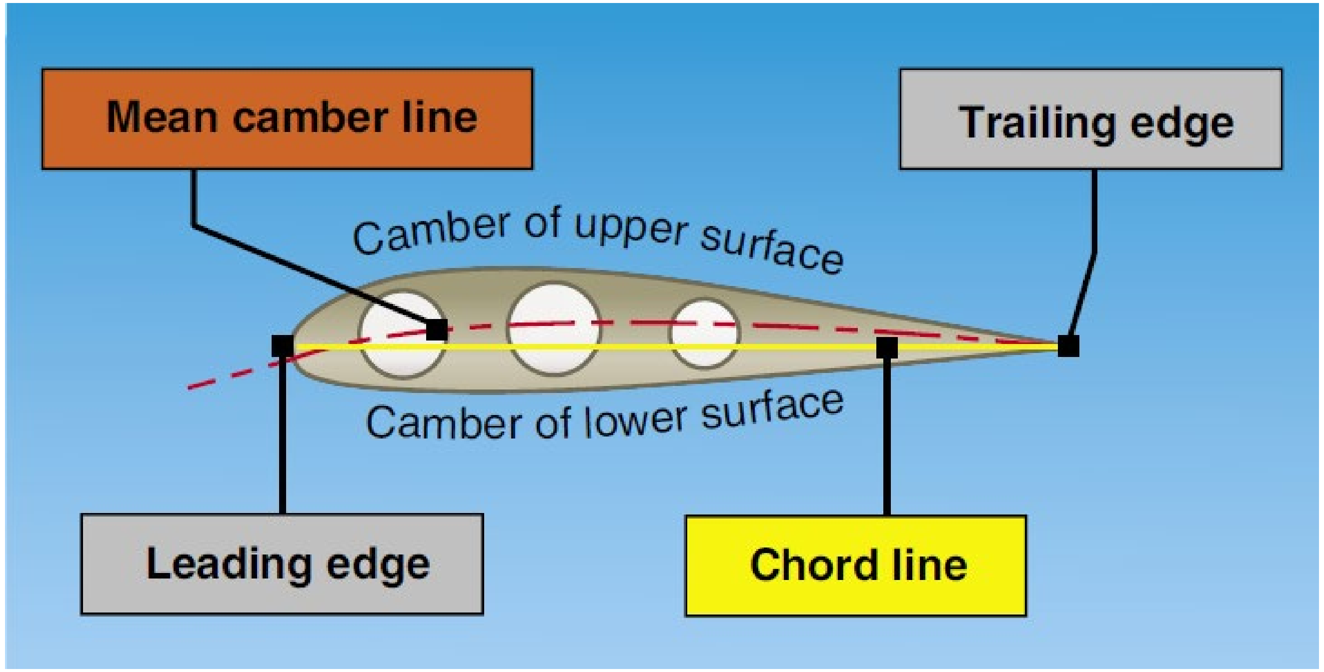
Leading Edge

If the airfoil is designed to produce a greater amount of lift at relatively low rates of speed, as in a Cessna 150 or a Cherokee 140, the leading edge will be thick and fat.



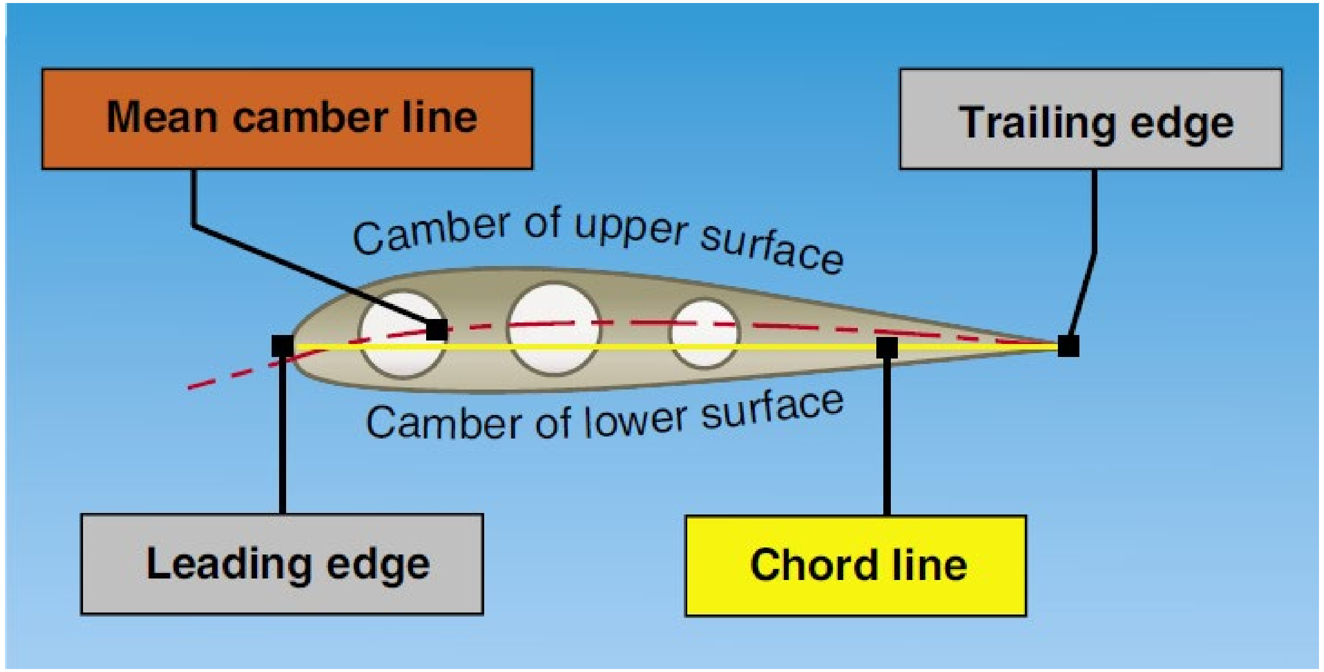
Trailing Edge

The trailing edge is the **back of the airfoil**, the portion at which the airflow from the upper surface joins the airflow from the lower surface.



Trailing Edge

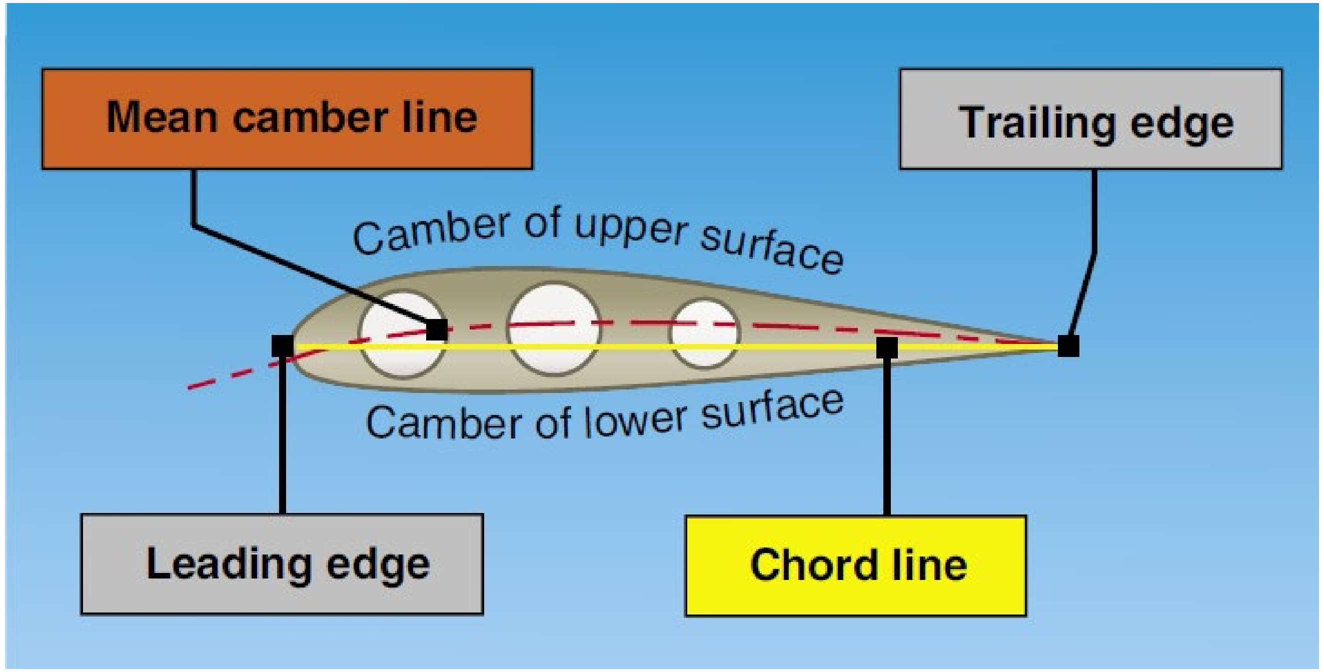
The air flowing over the upper and lower surfaces of the airfoil must meet with as little turbulence as possible, regardless of the position of the airfoil in the air.



Camber

The camber of an airfoil is the characteristic **curve of its upper or lower surface**.

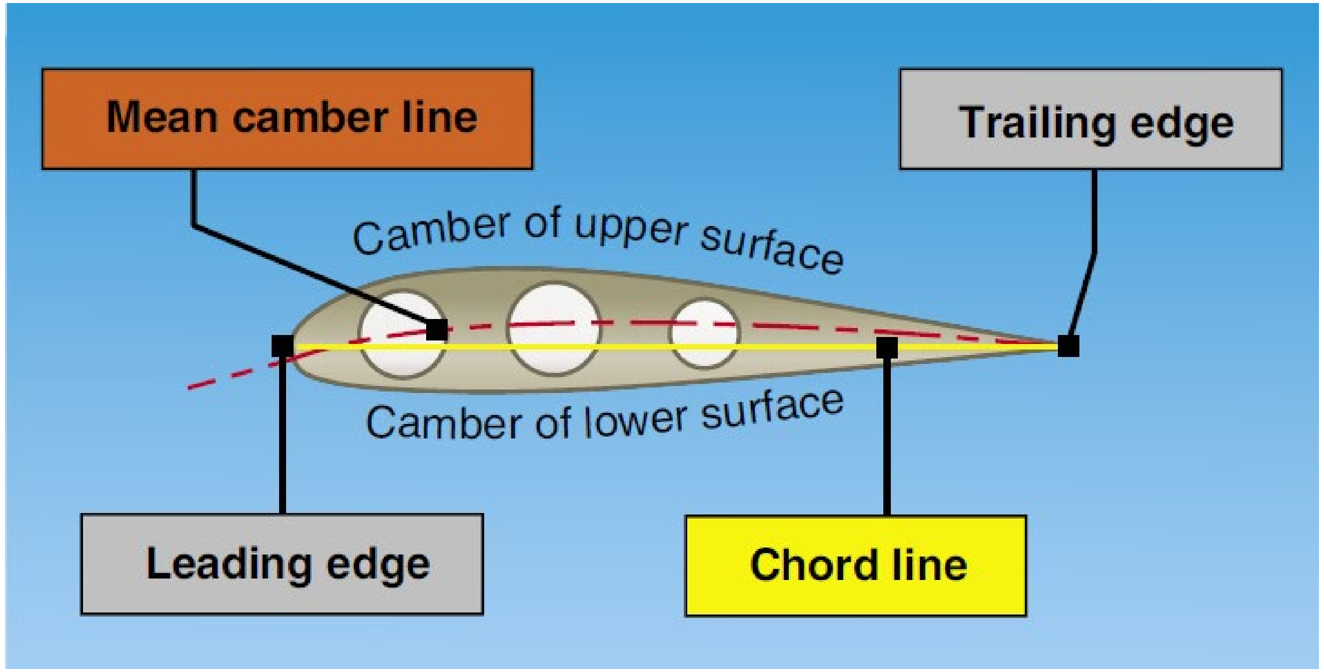
The camber determines the airfoil's thickness and subsequently the amount of lift that a wing produces as air flows around it.



Camber

A high-speed, low-lift airfoil has very little camber.

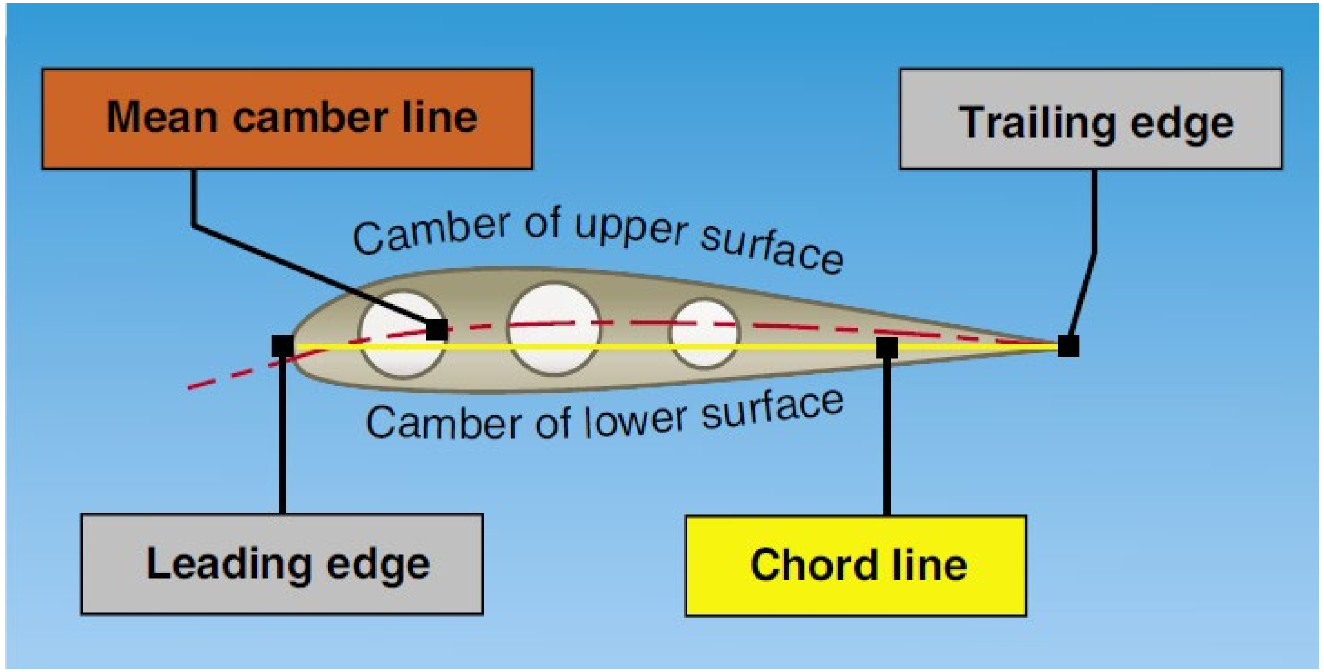
A low-speed, high-lift airfoil, like that on the Cessna 150, has a very pronounced camber.



Upper Camber and Lower Camber

Typically, upper and lower cambers differ from one another.

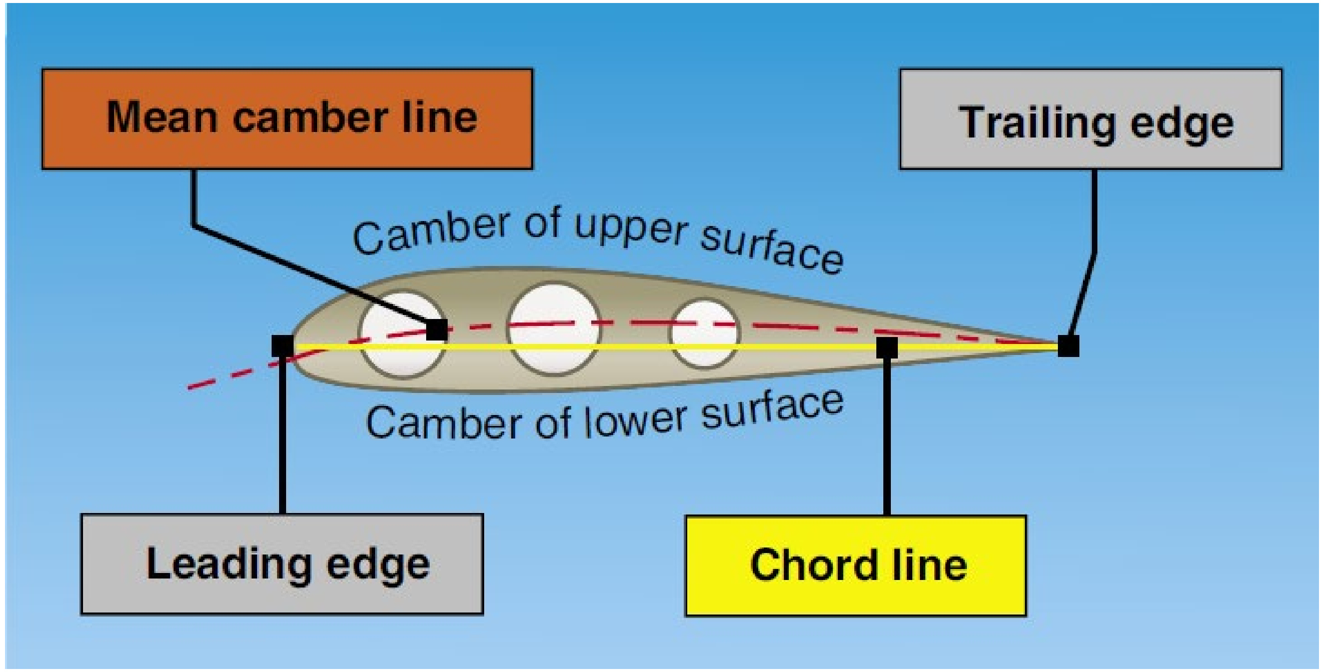
In a 172, the lower part is generally flat and the front of the upper is curved



Mean Camber

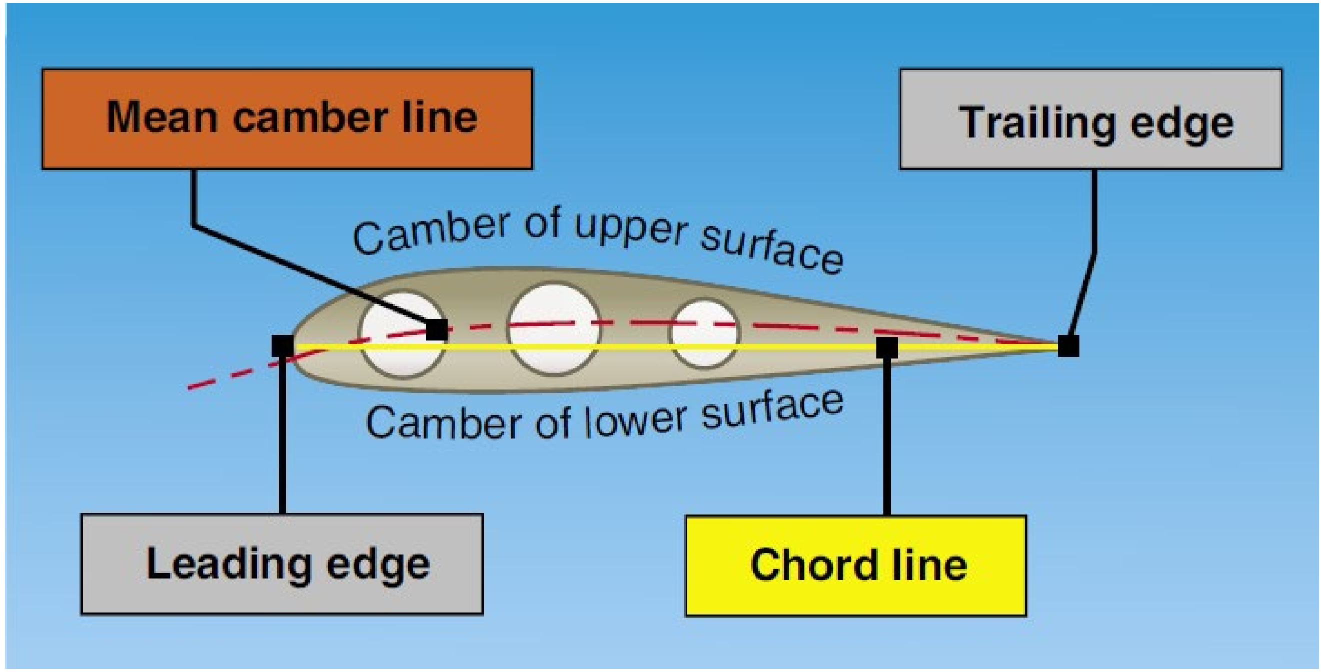
The red line in this diagram is the Mean Camber Line.

Mean Camber Line is a **line drawn halfway between the upper and lower surfaces**.



Chord

The chord of an airfoil is an imaginary **straight line drawn through the airfoil from its leading edge to its trailing edge**.



Bernoulli’s Principle

Daniel Bernoulli’s Principle states that as the velocity of a moving fluid, liquid, or gas increases, the pressure within the fluid decreases.

His basis:

Air is 'an ideal fluid'.

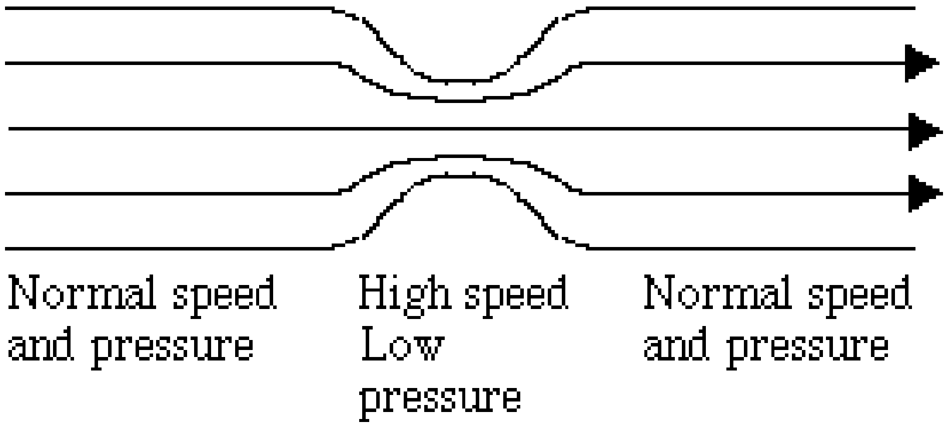
Potential energy + kinetic energy = constant total energy

A Venturi Tube

The venturi tube has an air inlet that narrows to a constricted point and an outlet section that increases in diameter toward the rear.

The diameter of the outlet is the same as that of the inlet.

The mass of air entering the tube must exactly equal the mass exiting the tube.

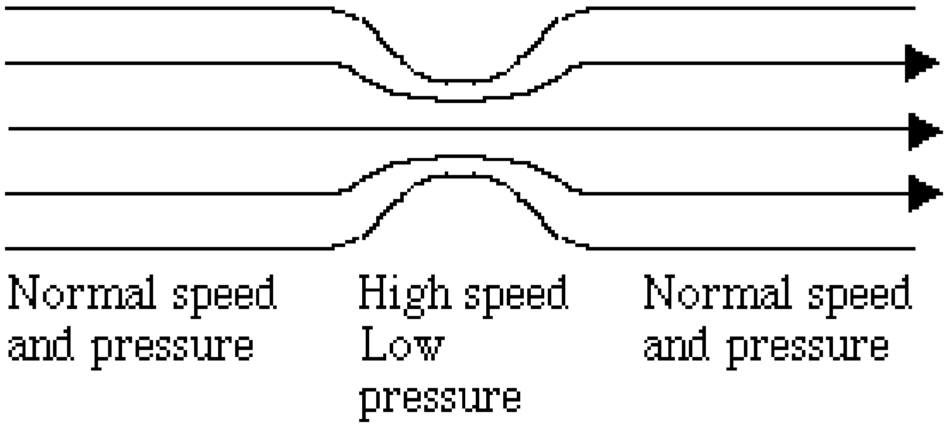


A Venturi Tube

At the constriction, the speed must increase to allow the same amount of air to pass in the same amount of time as in all other parts of the tube.

When the air speeds up, the pressure decreases.

Past the constriction, the airflow slows and the pressure increases.



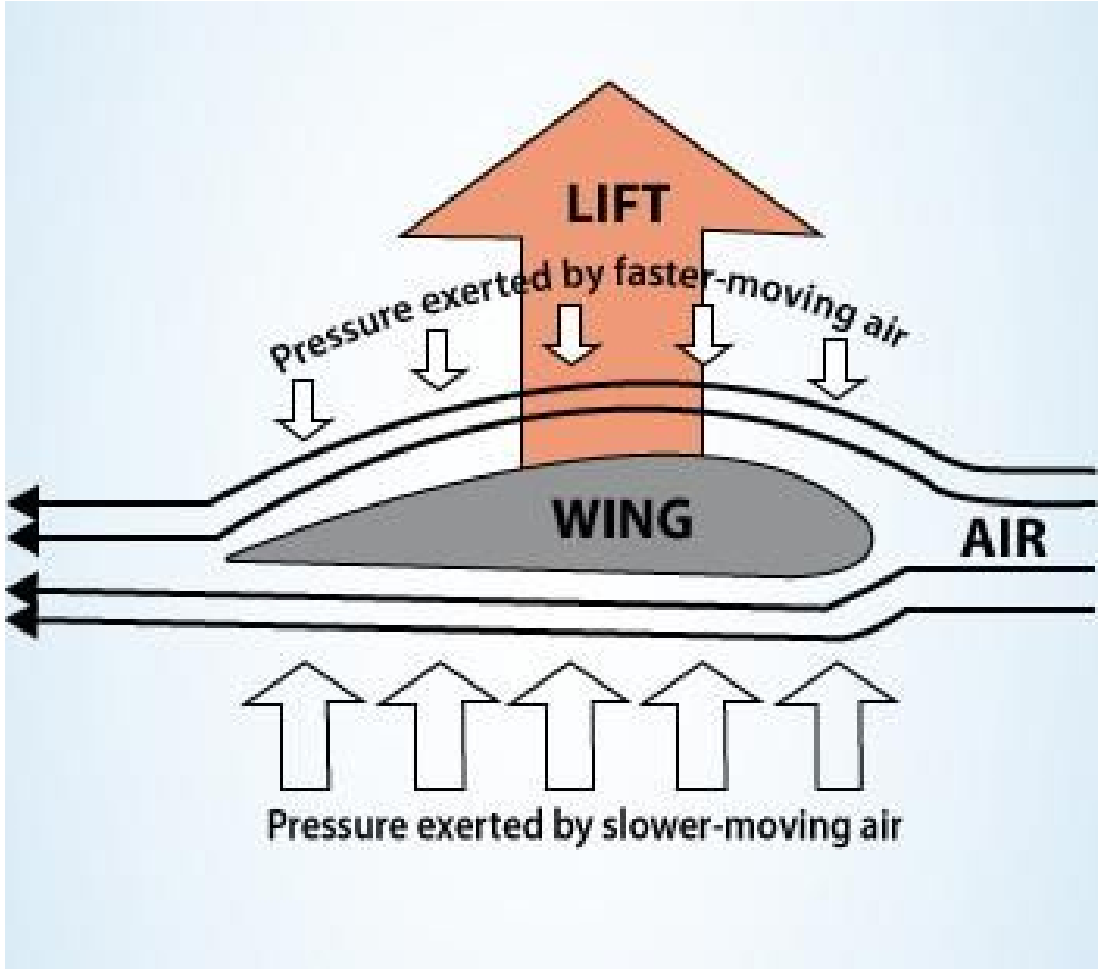
Bernoulli's Principle

Bernoulli's principle works on the outside your house

Wings and Lift

The wings of an airplane are curved on top and flat on the bottom.

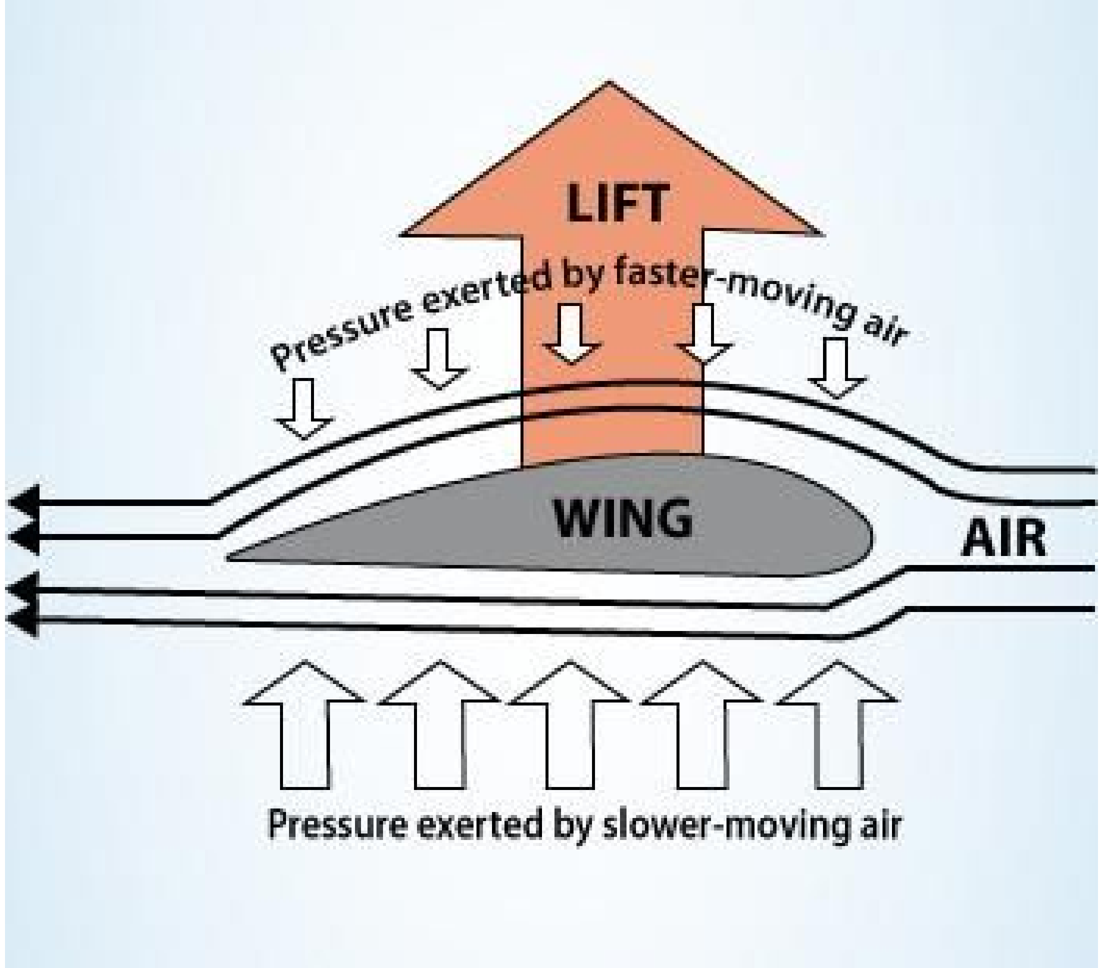
This shape causes the air to flow faster over the top of the wing than over the bottom.



Wings and Lift

According to Bernoulli's principle, the <u>faster-moving air has lower pressure</u> than the slower-moving air.

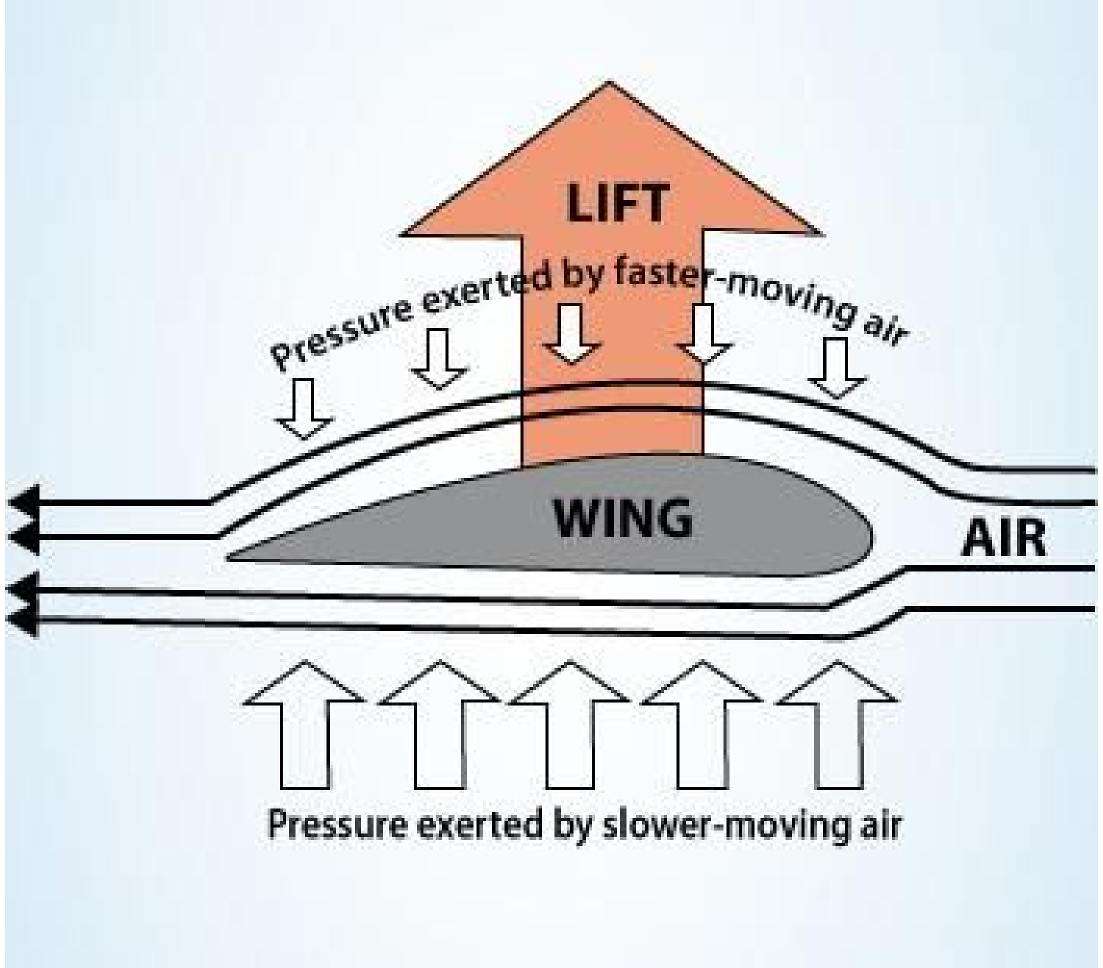
This pressure difference creates lift, which supports the weight of the airplane.



Wings and Lift

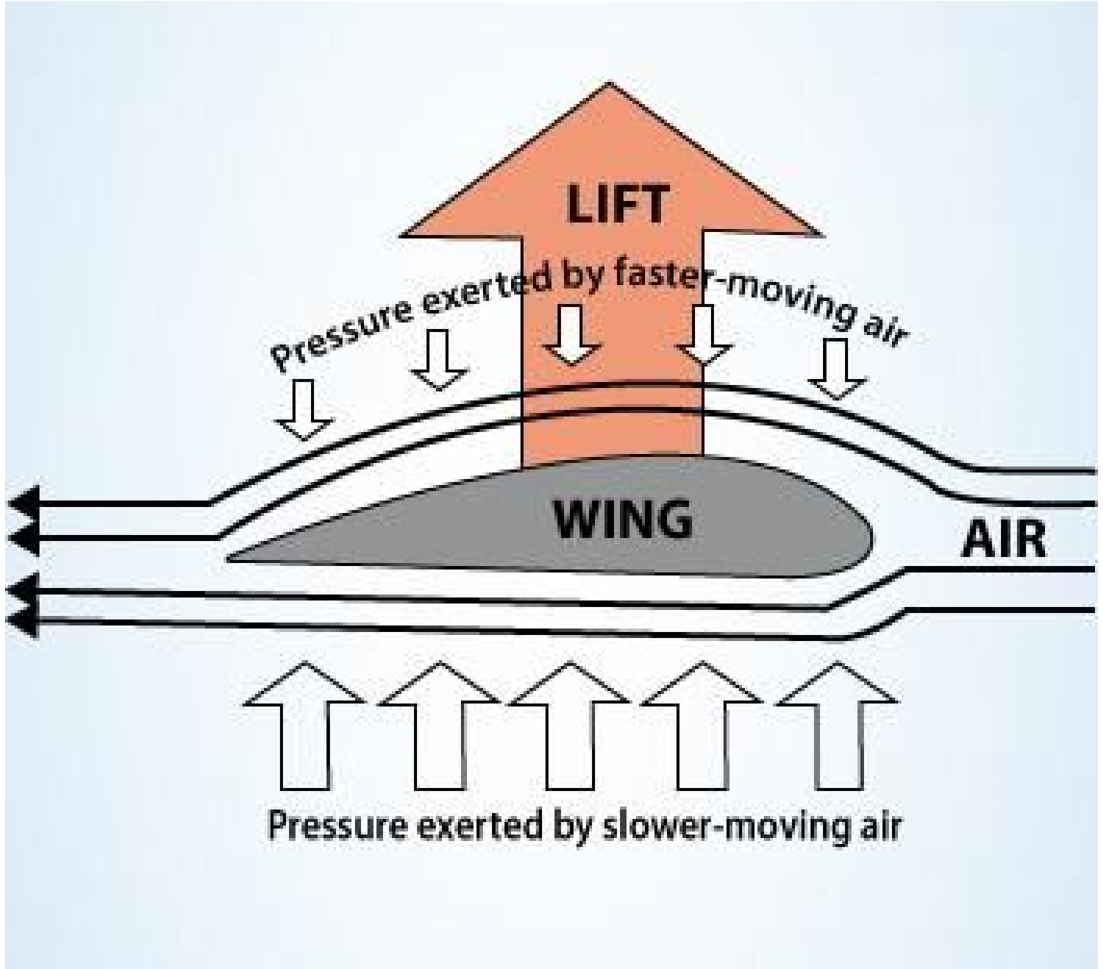
The air on the top has a longer distance to get from the front edge to the back edge

The air on the top has to ‘catch up’ to meet up with the air on the bottom



Wings and Lift

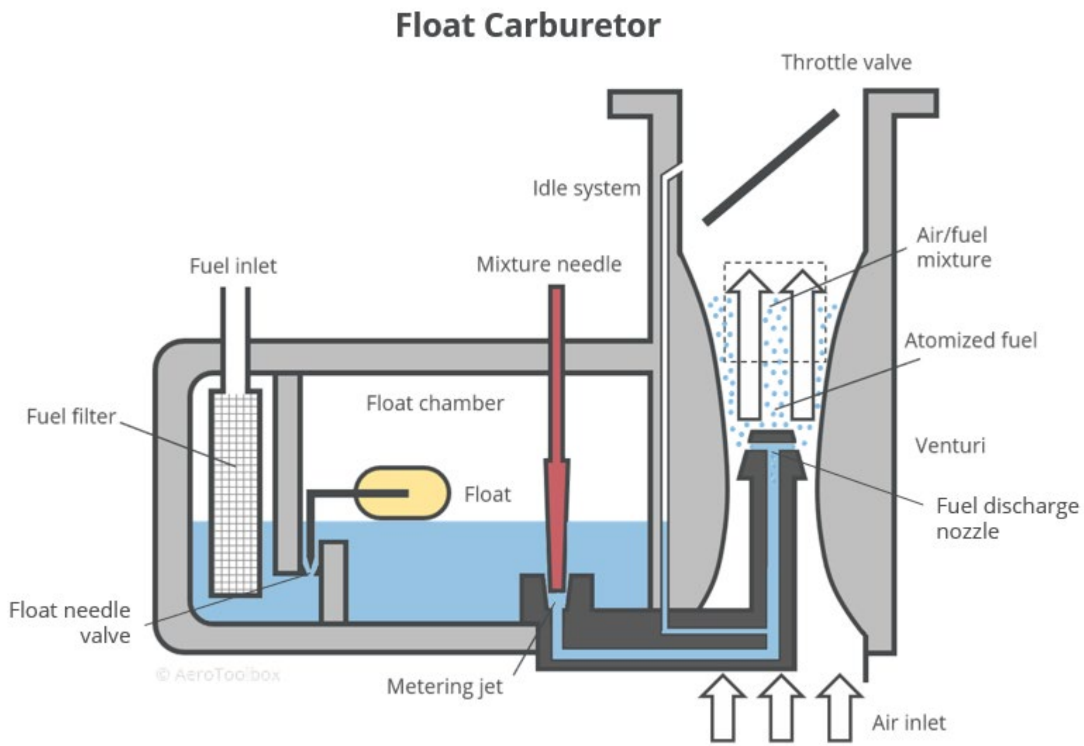
If you and a buddy leave the same location…if you take the longer path then you will need to walk faster to meet up at the meet up location



Airplane Carburetor

A carburetor is a device that mixes air and gasoline in an internal combustion engine.

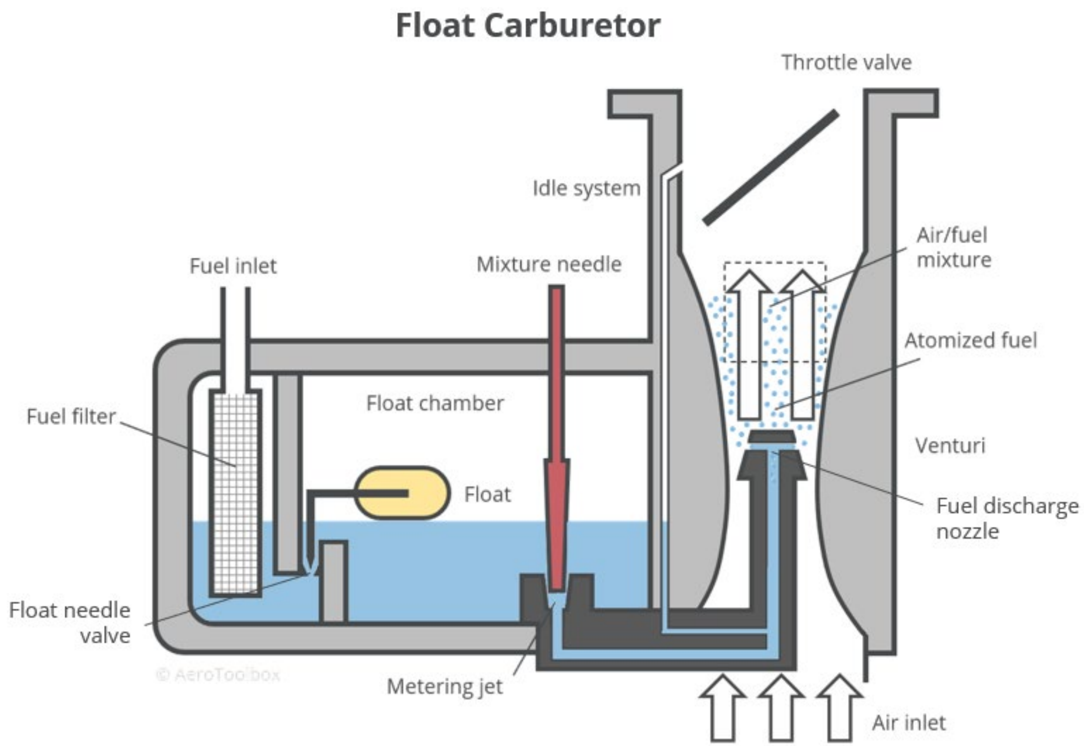
The carburetor has a narrow opening called a **venturi**.



Airplane Carburetor

When air flows through the venturi, it speeds up and creates a low-pressure area.

This low-pressure area draws gasoline from the fuel tank into the carburetor, where it is mixed with air and then ignited.



Relative Wind Definition

In aeronautics, the relative wind is the direction of movement of the atmosphere relative to an aircraft or an airfoil.

It is opposite to the direction of movement of the aircraft or airfoil relative to the atmosphere.

Relative Wind Definition

Close to any point on the surface of an aircraft or airfoil, the air is moving parallel to the surface; but at a great distance from the aircraft or airfoil, the movement of the air can be represented by a single vector.

This vector is the relative wind.

Relative Wind In a Nutshell

If you are in straight and level flight, it is horizontal/parallel to the Earth.

If you are landing, it is aligned with the glide slope.

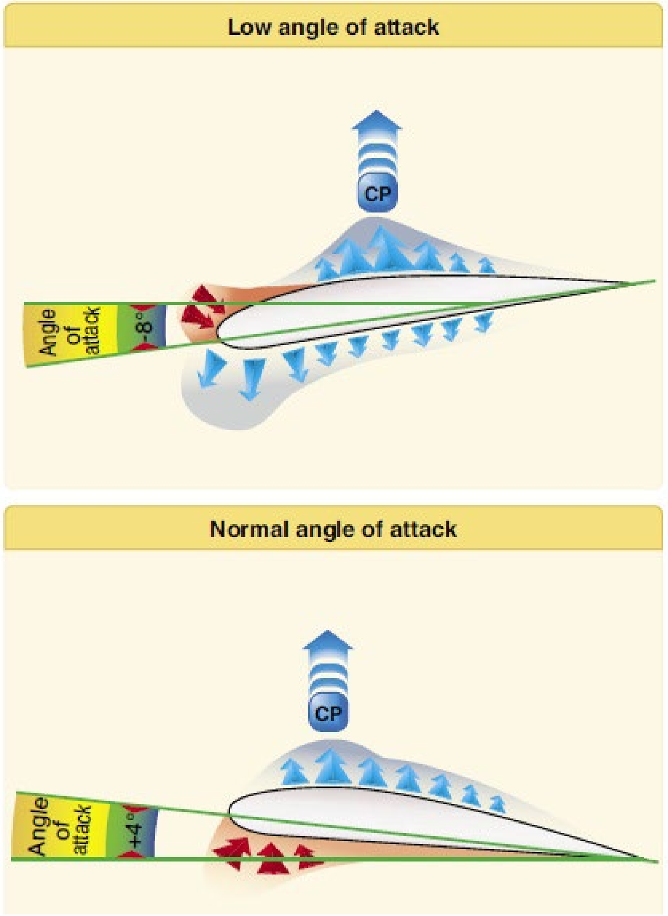
Angle of Attack (AOA)

AOA = **angle between the chord line of an airfoil and the oncoming air/relative wind**

<u>As AOA increases (+)</u>

Vertical component of velocity +

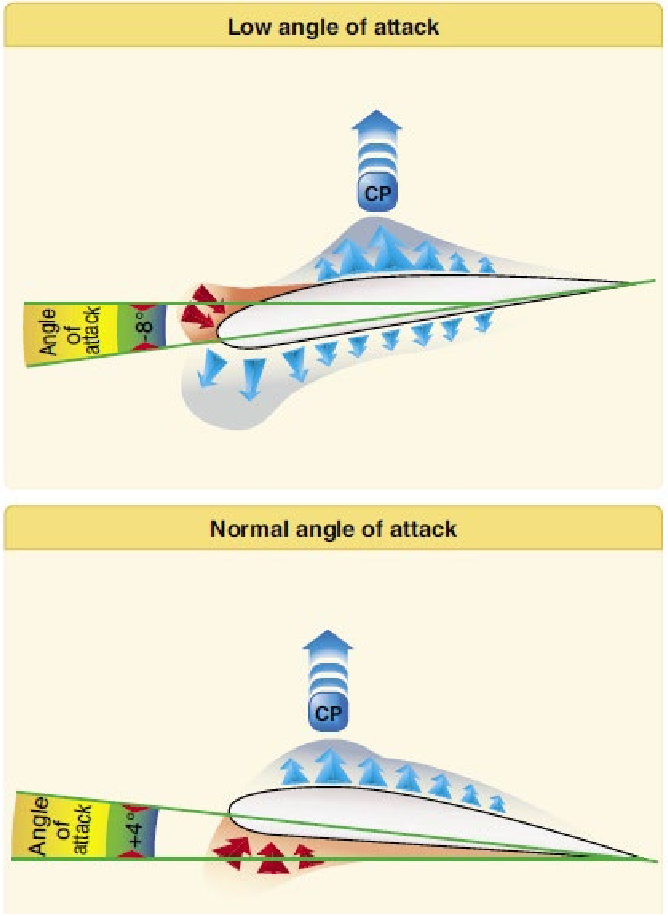
Lift +



Angle of Attack (AOA)

Increasing the AOA beyond the critical AOA causes the upper-surface flow to separate from the wing

This is what creates a stall not slow speeds



Angle of Attack

AOA = **angle between the chord line of an airfoil and the oncoming air/relative wind**

"The angle between the direction the plane is moving in and the direction the plane is pointing"

Credit to Yoel Gilman

https://youtu.be/3OEWguuPEPE&t=240

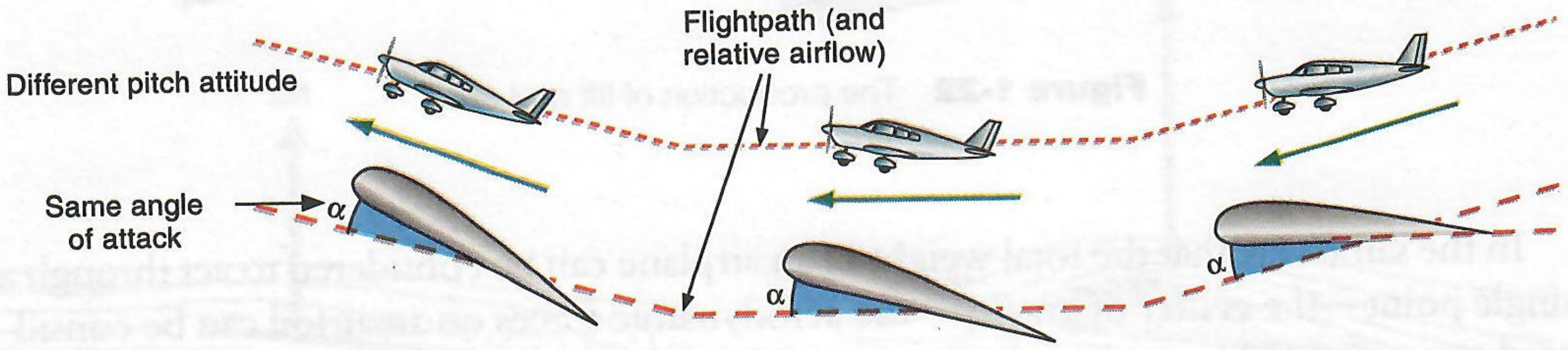


Figure 1-25 Same angle of attack, but different pitch attitudes.

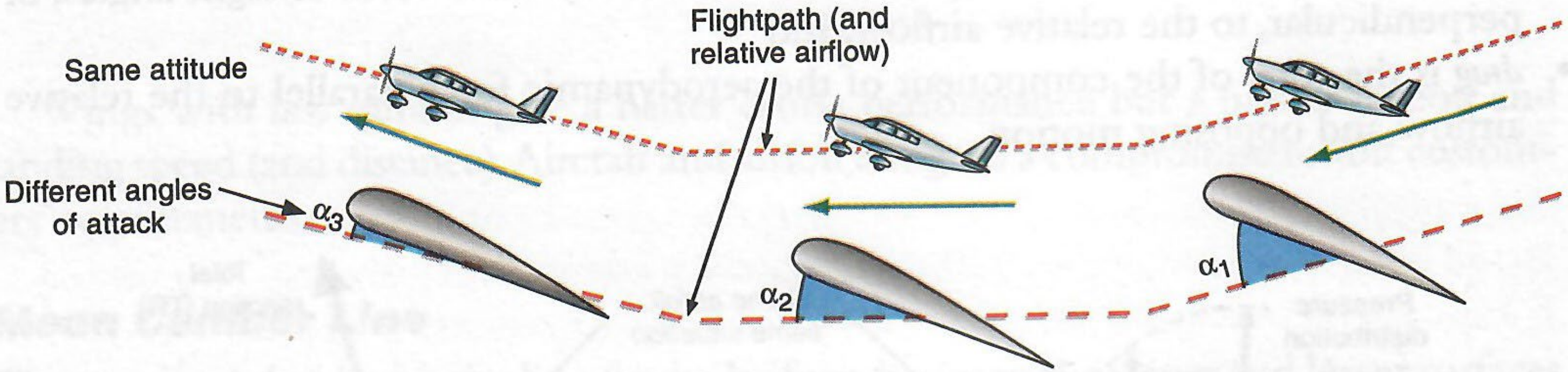


Figure 1-26 Same pitch attitude, but different angles of attack.

Stall defined in PHAK

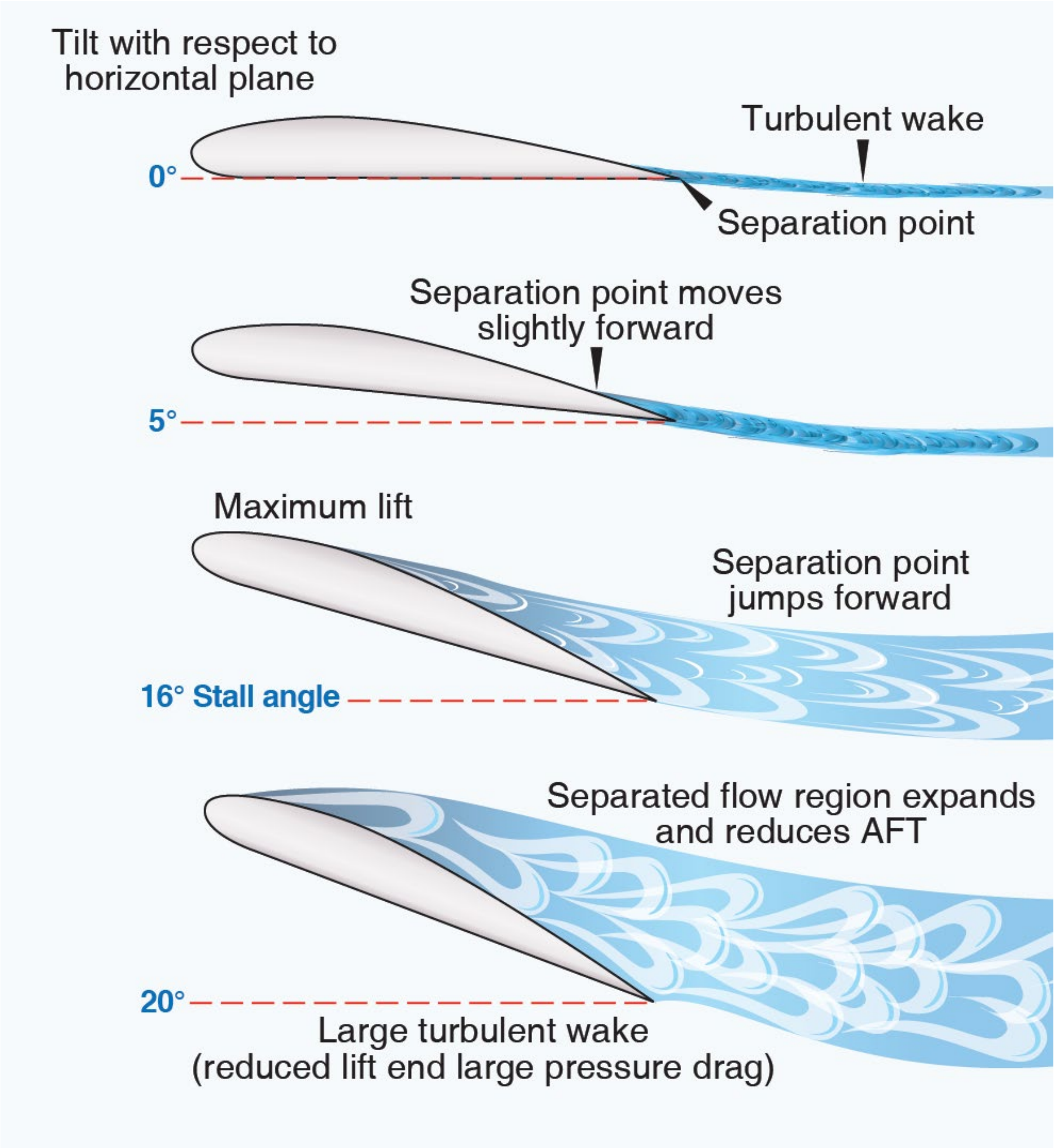
An aircraft stall results from a rapid decrease in lift caused by the separation of airflow from the wing's surface brought on by <u>exceeding the critical AOA</u>.

A stall can occur at **any pitch attitude or airspeed**.

In a stall, the wing <u>does not totally stop</u> producing lift.

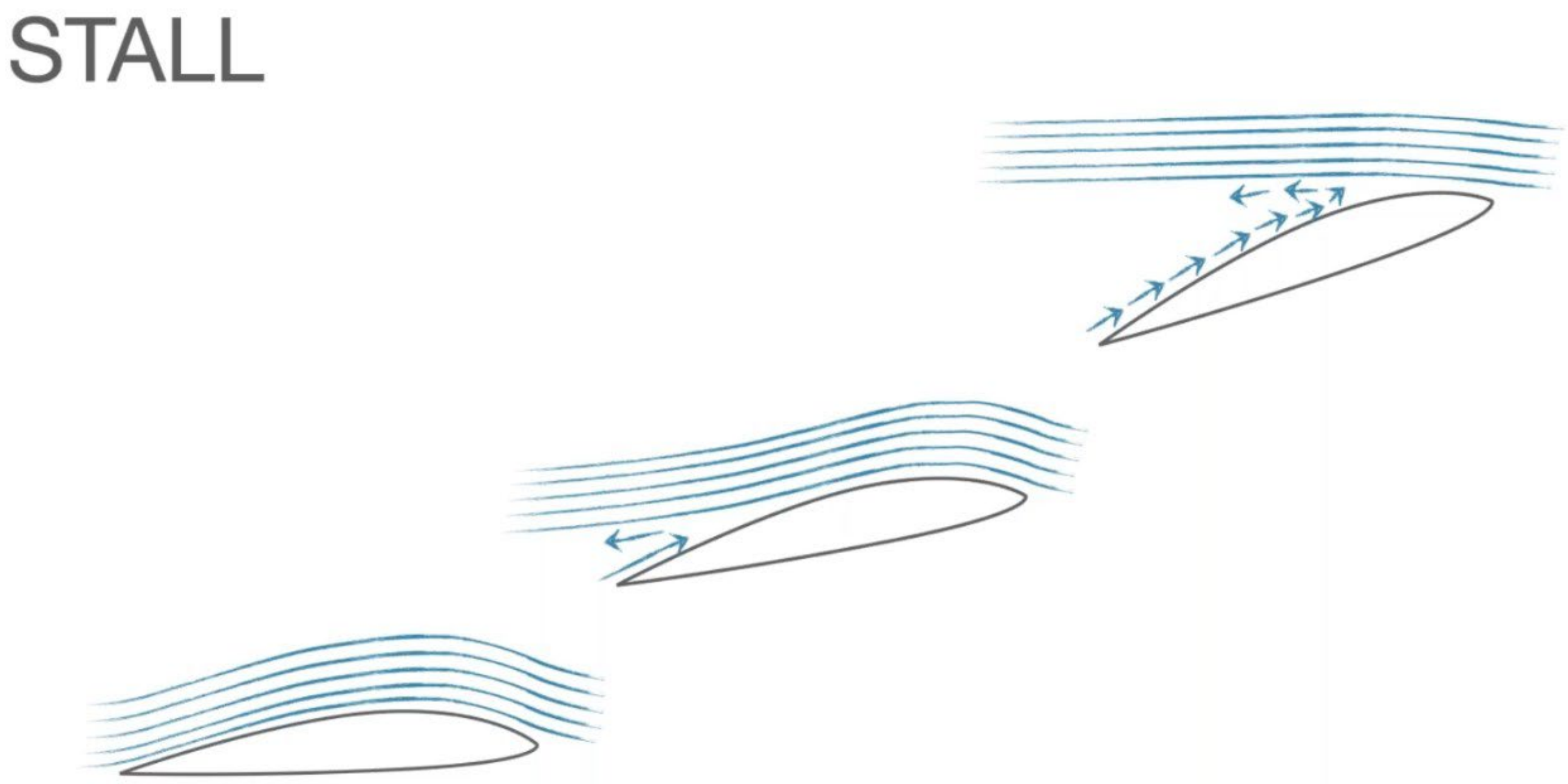
Rather, it <u>cannot generate adequate</u> lift to sustain level flight.

From AFH



Tilt with respect to horizontal plane
Turbulent wake
0°
Separation point
Separation point moves slightly forward
5°
Maximum lift
Separation point jumps forward
16° Stall angle
Separated flow region expands and reduces AFT
20°
Large turbulent wake (reduced lift end large pressure drag)

Stalls
Aerodynamics

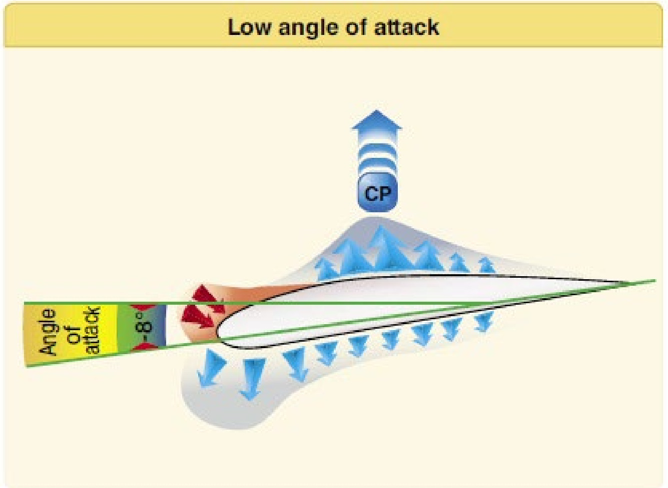


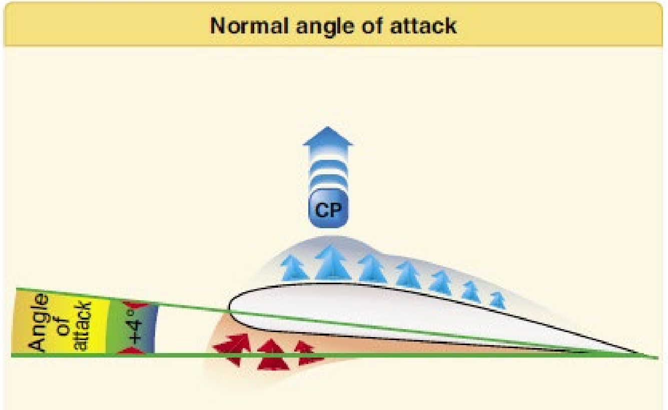
AOA and Center of Pressure (CP)

High AOA -> CP moves forward

Low AOA -> CP moves aft

The relationship of CP and CG affects the aerodynamic balance and controllability.





Newton's Third Law

Newton's third law of motion states that, for every action, there is an equal and opposite reaction.

Based on this law, wings are <u>forced upwards</u> because they are tilted, pushing air downwards so the wings get pushed upwards.

Newton’s Third Law

As air flows over the surface of a wing, it sticks slightly to the surface it is flowing past and follows the shape.

If the wing is angled correctly, the air is deflected downwards.

Newton’s Third Law

The action of the wing on the air is to force the air downwards while the reaction is the air pushing the wing upwards.

A wing’s trailing edge must be sharp, and it must be aimed diagonally downwards to create lift.

Both the upper and lower surfaces of the wing act to deflect the air.

Newton's Third Law

The amount of lift depends on the speed of the air around the wing and the density of the air.

To produce more lift, the object must speed up and/or increase the angle of attack of the wing (by pushing the aircraft's tail downwards).

Newton’s Third Law

Speeding up means the wings force more air downwards so lift is increased.

Increasing the angle of attack means the air flowing over the top is turned downwards even more and the air meeting the lower surface is also deflected downwards more, increasing lift.

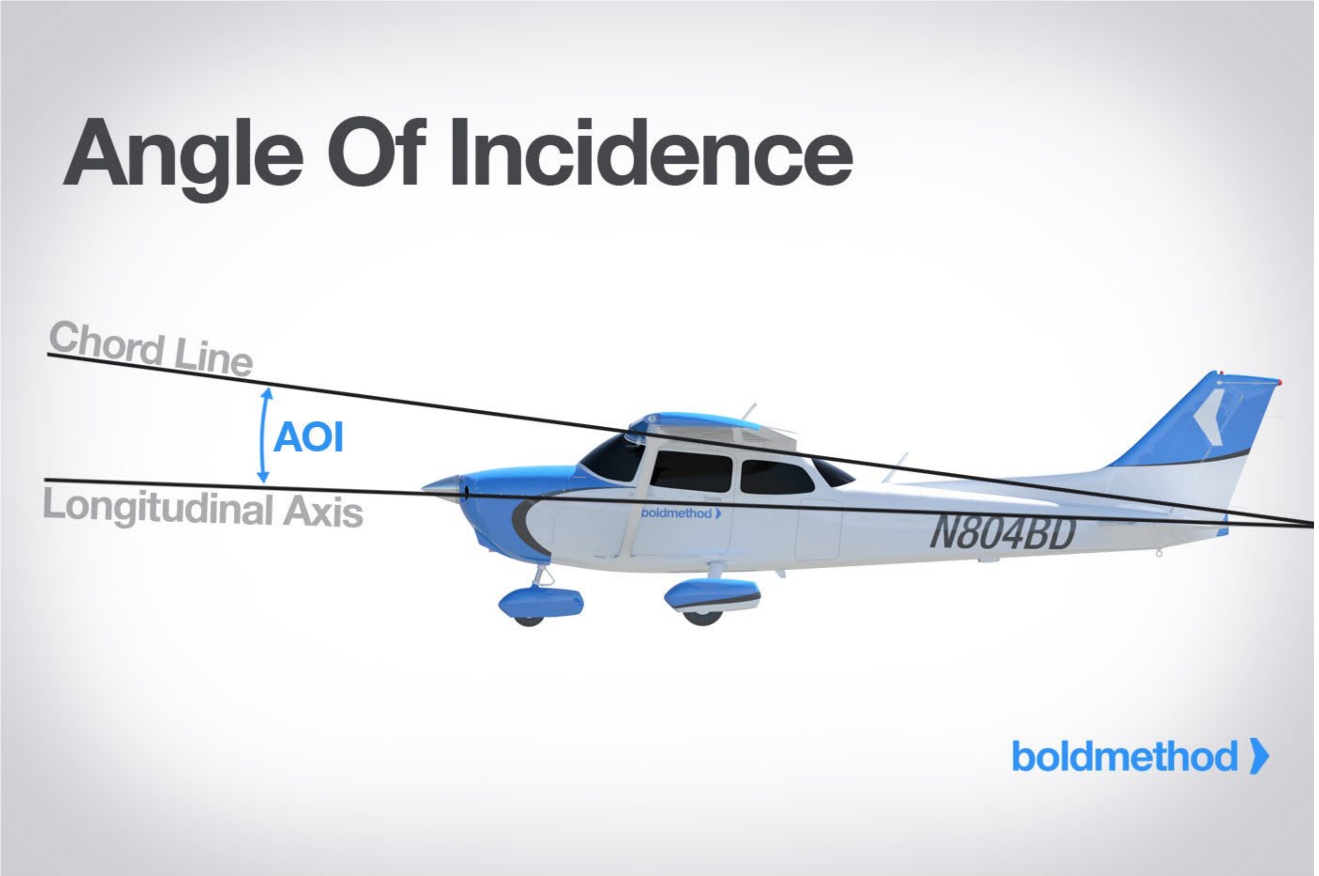
Angle of Incidence

Longitudinal axis = draw a line from the prop to the tail

Chord line = draw a line from the leading edge to the trailing edge

->

Angle of Incidence = the angle between them

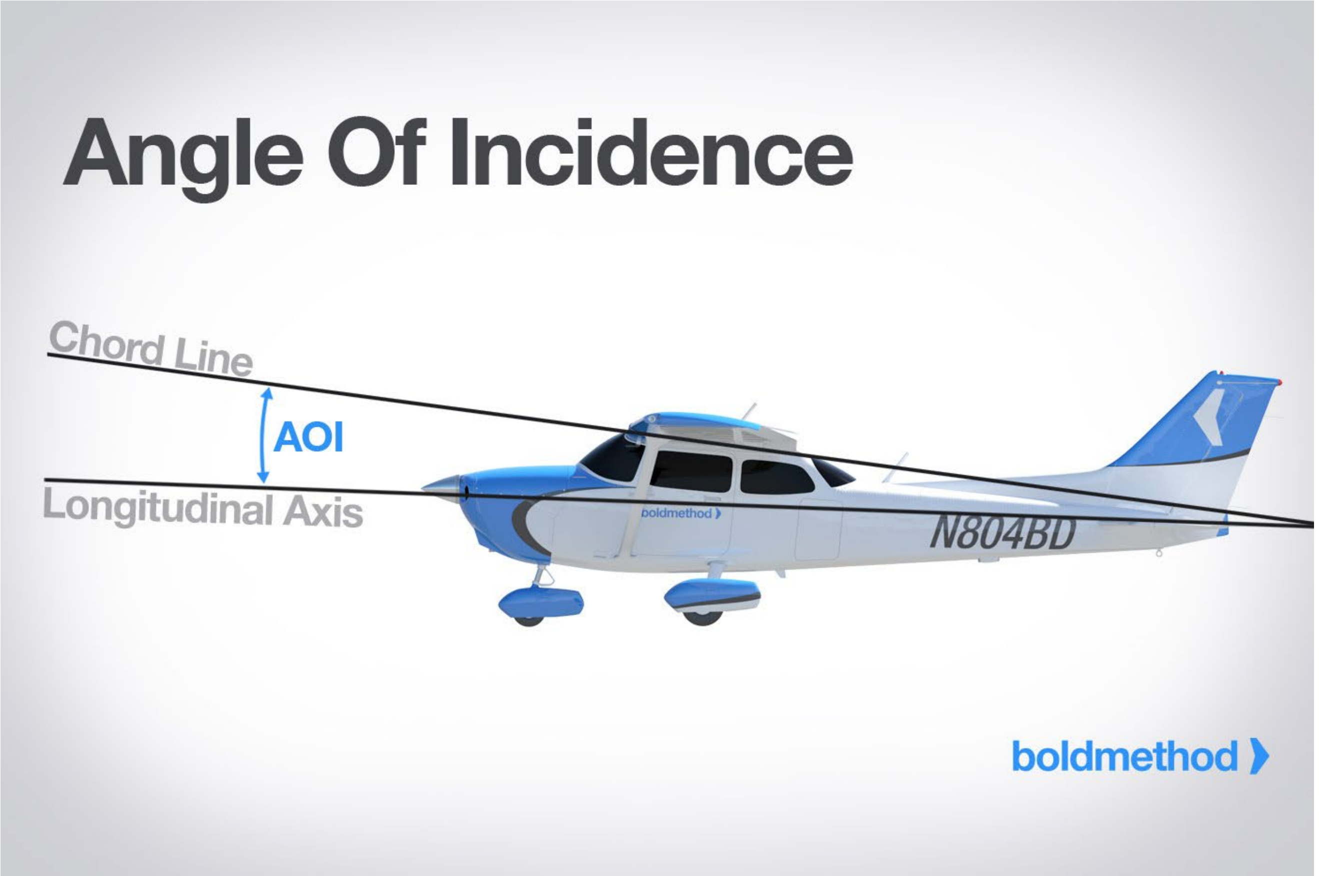


Angle of Incidence

How does the pilot change the AOI?

They can't

The engineers determined it



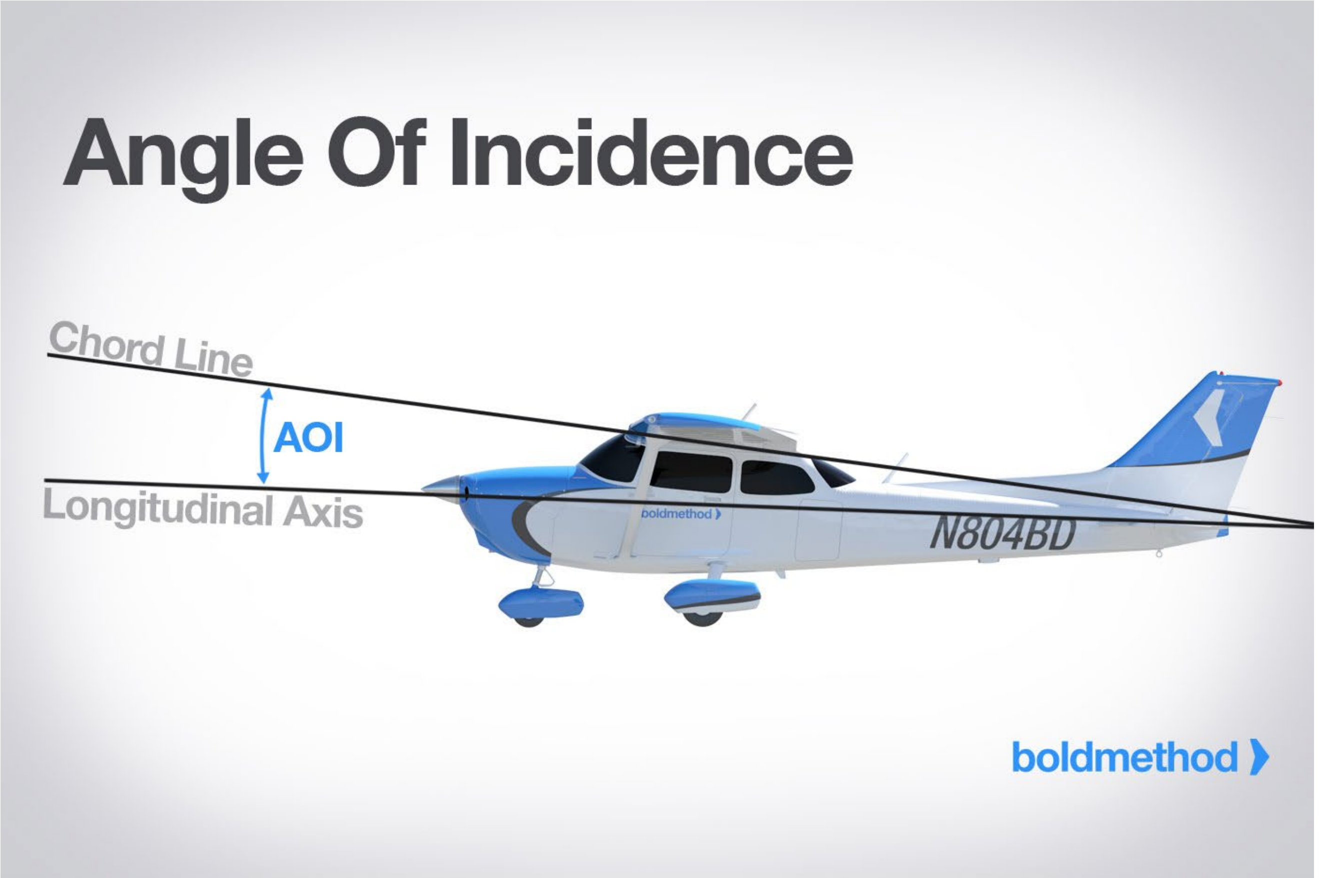
Angle of Incidence

<u>Takeoff</u>

During your takeoff roll, the relative wind is parallel to your runway.

The angle of incidence defines your angle of attack until you have enough speed (and tail down force) to lift your nose off.

The angle of incidence reduces your pitch angle, giving you better visibility during takeoff.

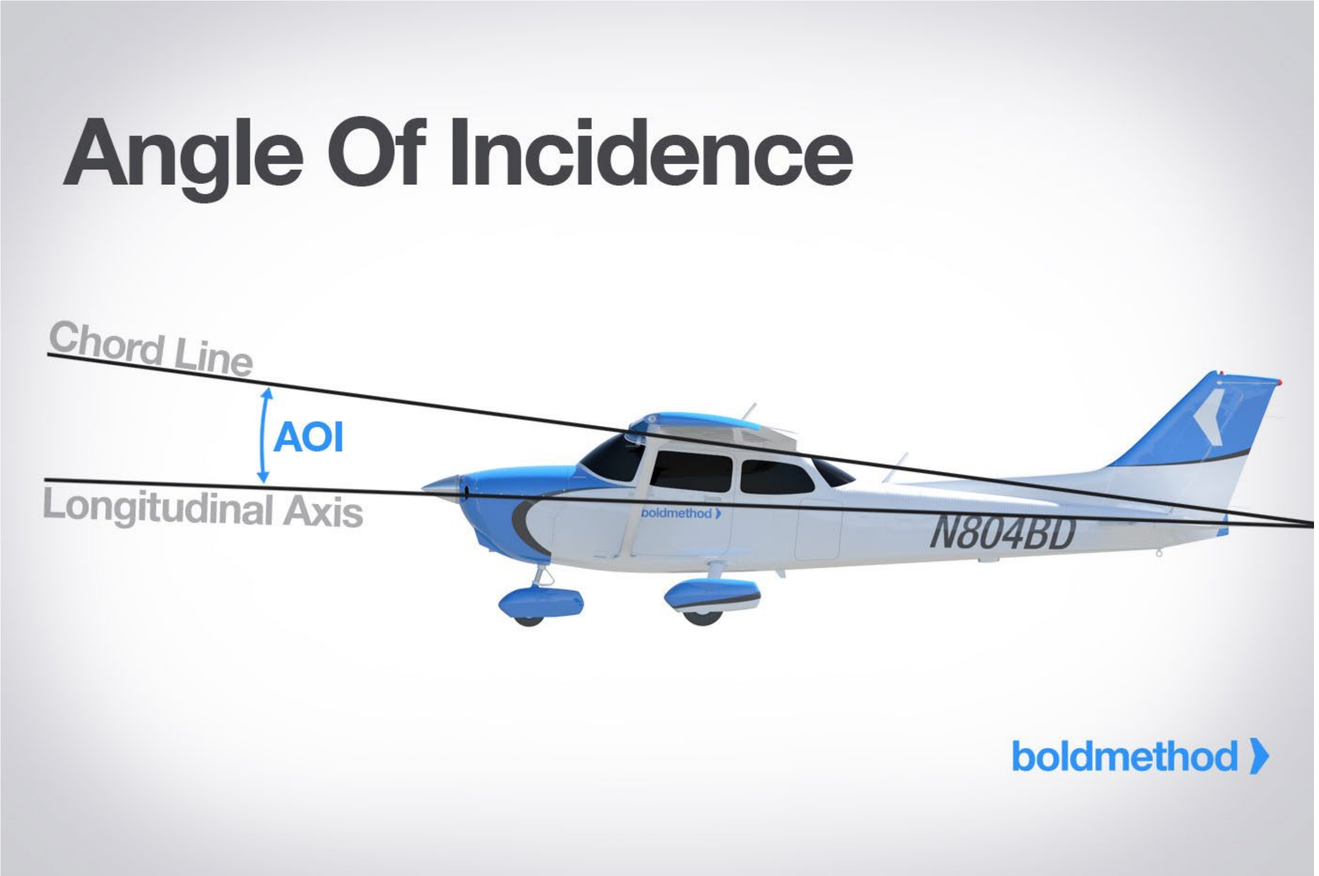


Angle of Incidence

<u>Landing</u>

During landing, the angle of incidence gives you the same advantage.

The angle of incidence reduces the pitch angle you need to achieve a high angle of attack, giving you better visibility at slower speeds.

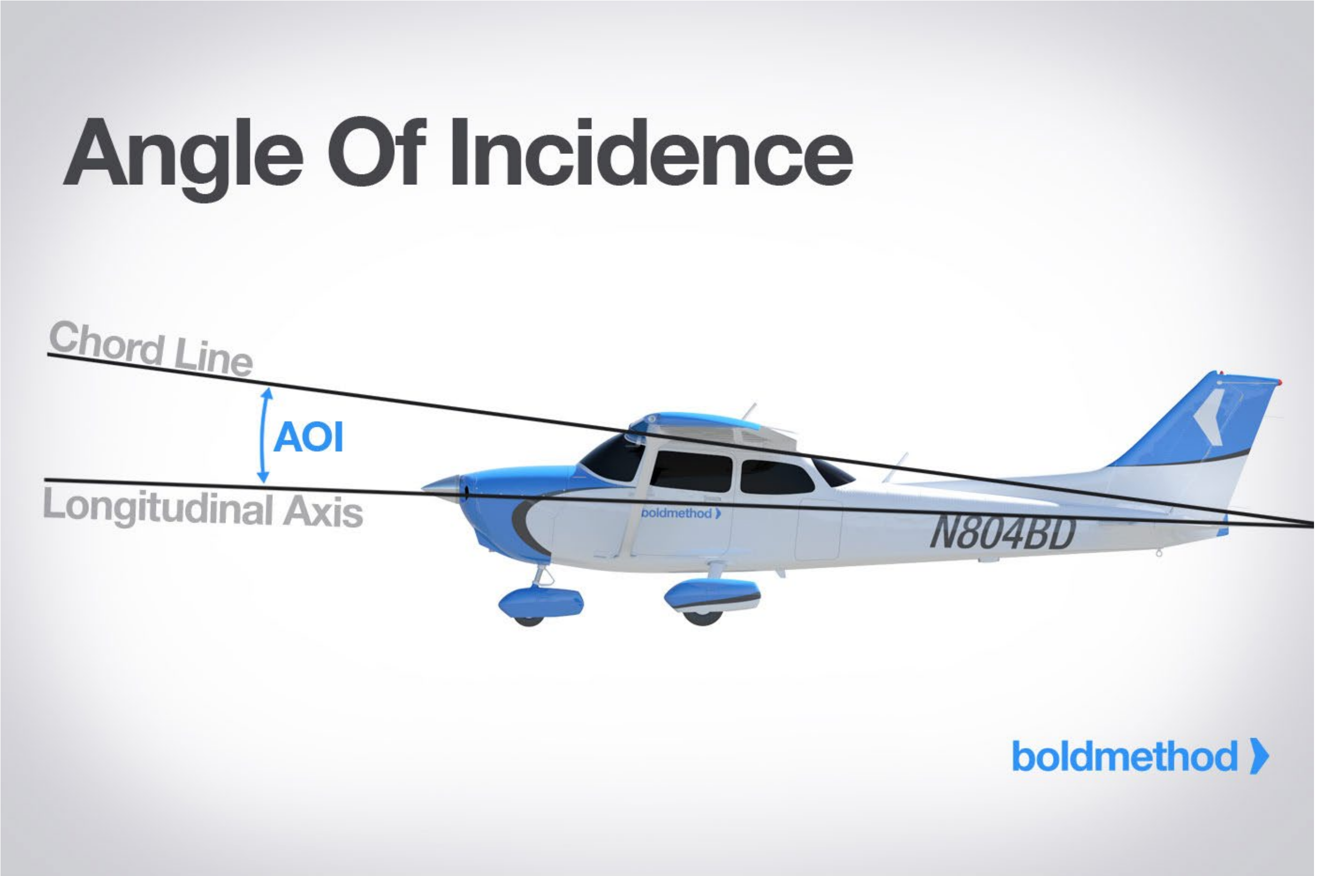


Angle of Incidence

<u>Does It Affect Lift In Flight?</u>

No.

The angle of attack and your airspeed determine how much lift your wing produces, and the angle of incidence has no effect.

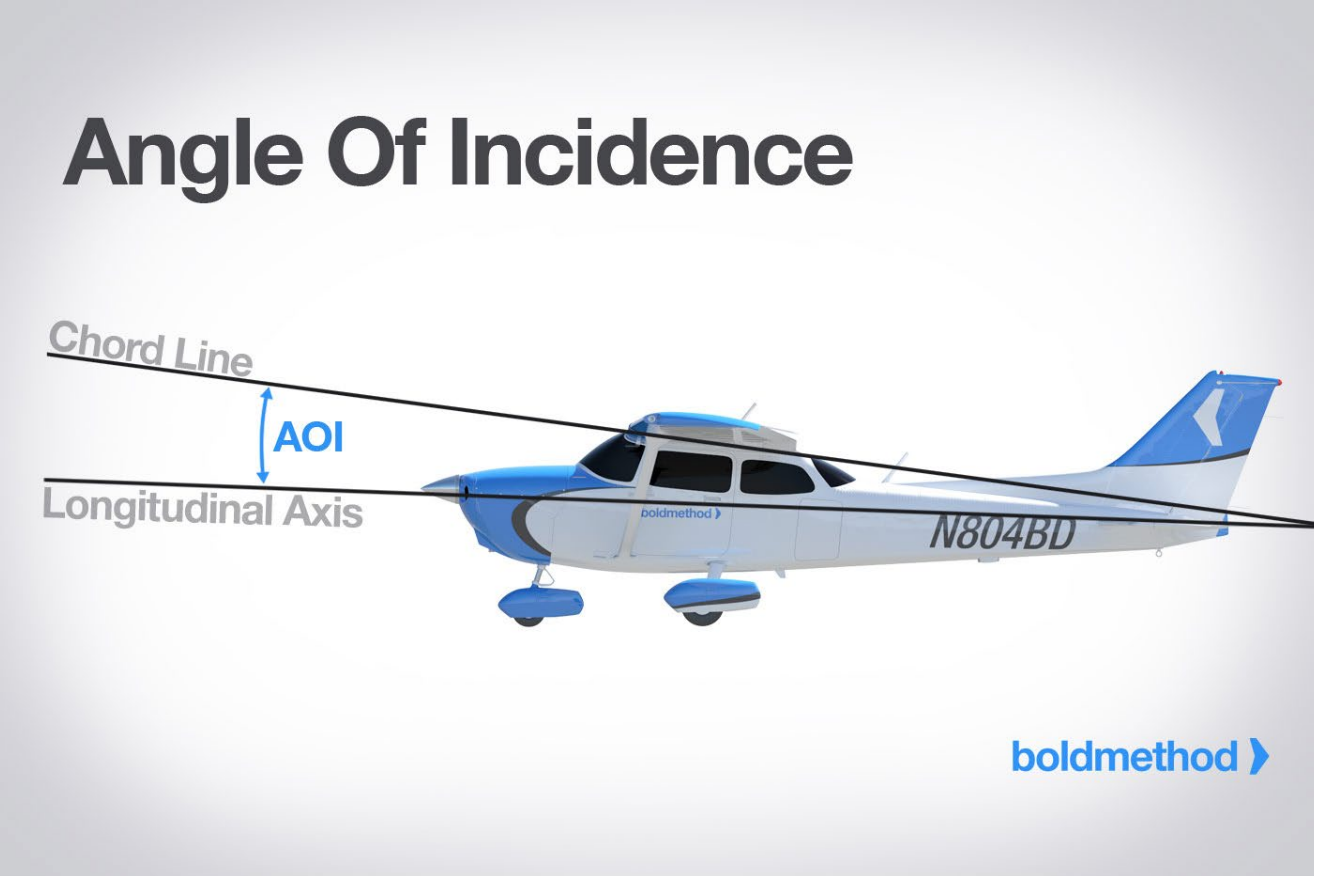


Angle of Incidence

<u>Does It Affect Lift In Flight?</u>

In flight, the angle of incidence doesn't affect the angle between the relative wind and the chord line.

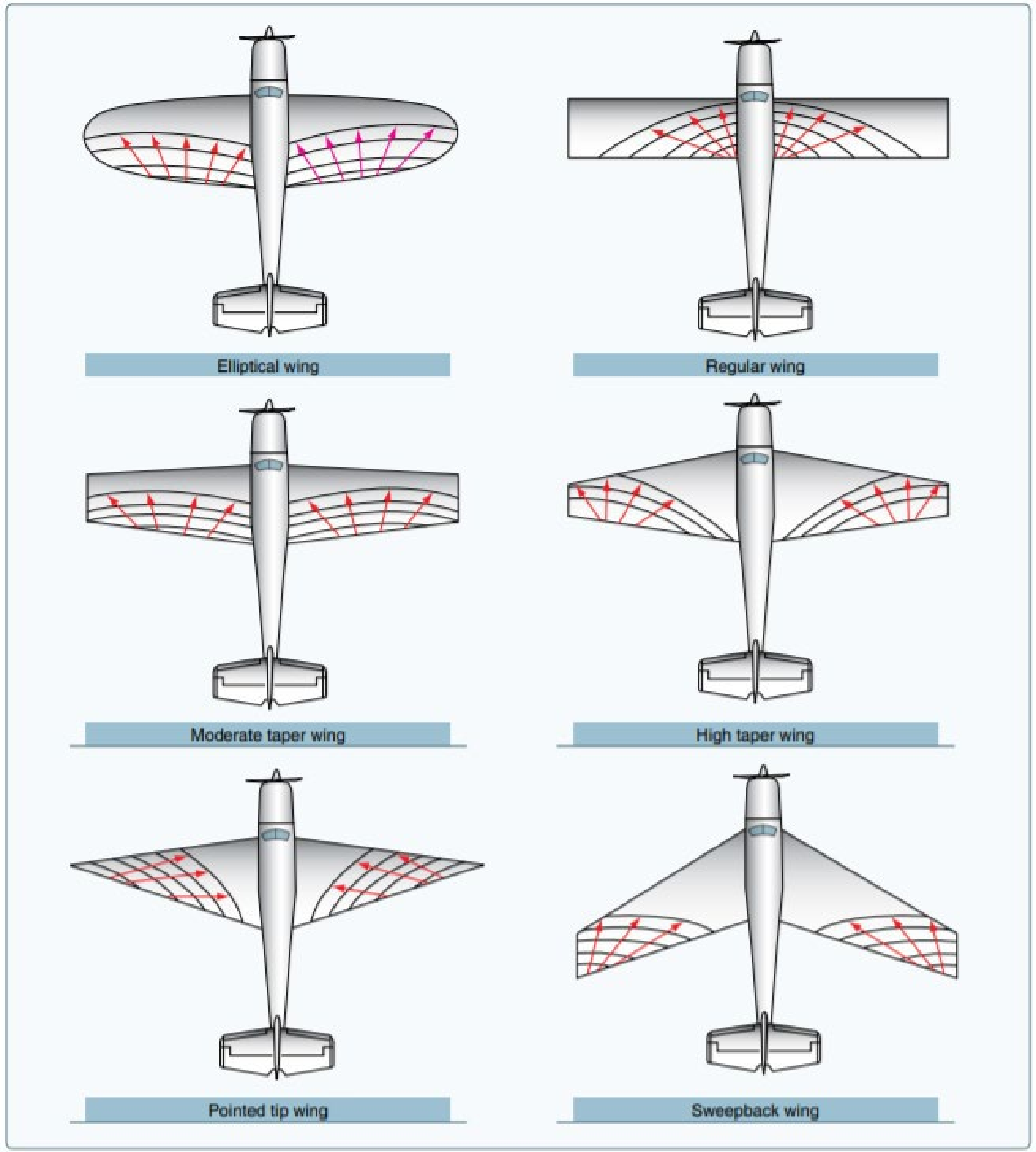
It simply changes the angle that the fuselage points - keeping the nose at a lower pitch angle.



Planform

Planform is the term that describes the wings outline as seen from above.

Many factors affect shape, including purpose, load factors, speeds, construction and maintenance costs, maneuverability/stability, stall/spin characteristics, fuel tanks, high lift devices, gear, etc.



Rectangular Wing

PROS

Tends to stall first at the wing root and provides adequate stall warning, adequate aileron effectiveness, and is very stable.

Favored in the design of low cost, low speed airplanes.

CONS

Not as efficient as elliptical wing.

Elliptical Wing

PROS

Ideal subsonic planform since it provides minimum induced drag for a given aspect ratio.

CONS

Gives little warning of a complete stall, and lateral control may be difficult because of poor aileron effectiveness.

Tapered Wing

Decrease from wing root to tip in thickness

<u>PROS</u>

Desirable weight and stiffness

<u>CONS</u>

Not as efficient aerodynamically as the elliptical wing

Sweepback Wing

A swept wing is a wing that angles either backward or occasionally forward from its root rather than in a straight sideways direction

PROS

Great for high speeds

CONS

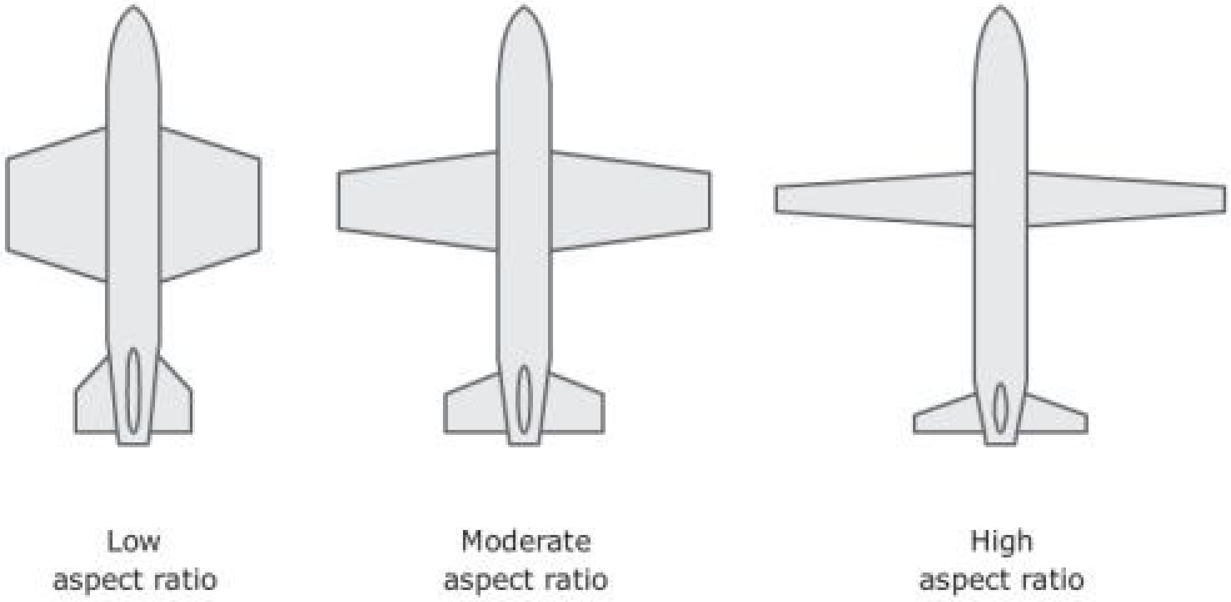
Harder to control at low speeds

Aspect Ratio

The aspect ratio of a wing is the ratio of its span to its mean chord.

Aspect ratio = wing span / mean chord

Thus, a long, narrow wing has a high aspect ratio, whereas a short, wide wing has a low aspect ratio.



High vs Low Aspect Ratio

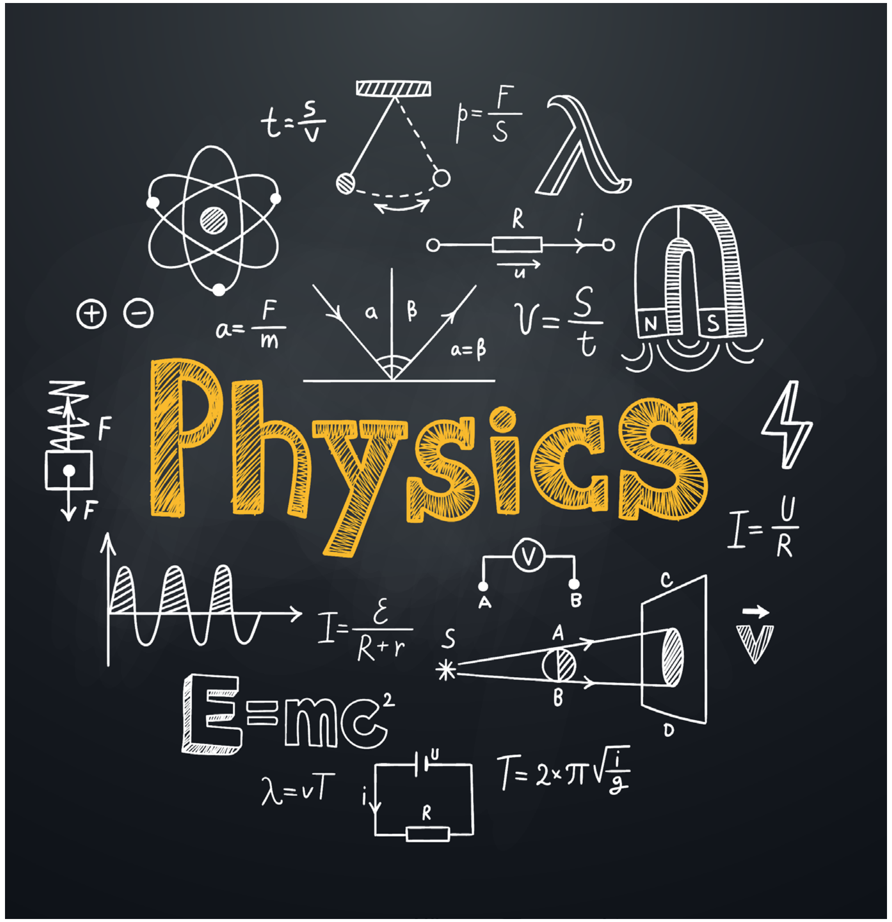
<u>Stall speed</u>

Low aspect ratio –> higher stall speed

High aspect ratio –> lower stall speed

<u>Structural</u>

A long wing has higher bending stress for a given load than a short one and therefore requires higher structural-design specifications.



High vs Low Aspect Ratio

<u>Maneuverability</u>

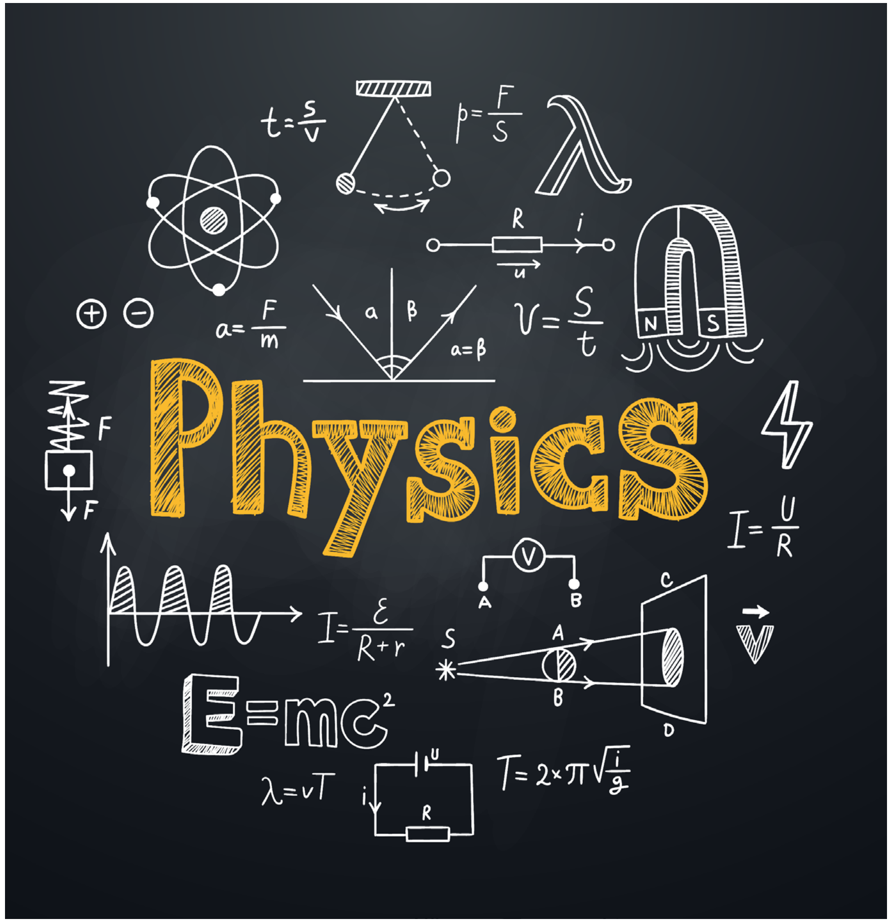
Low aspect ratio –> higher roll angular acceleration

Low aspect ratio wings are usually used on fighter aircraft

<u>Parasitic drag</u>

High aspect ratio –> create less induced drag

High aspect ratio –> greater parasitic drag



Dihedral

Dihedral is the angle at which the wings are slanted upward from the root to the tip.

Some aircraft are designed so that the outer tips of the wings are higher than the wing roots.

Dihedral

Dihedral is the upward angle of an aircraft's wings, which increases lateral stability in a bank by causing the lower wing to fly at a higher angle of attack than the higher wing.

Basically…when banking the lower wing becomes almost flat which helps it generate more lift.

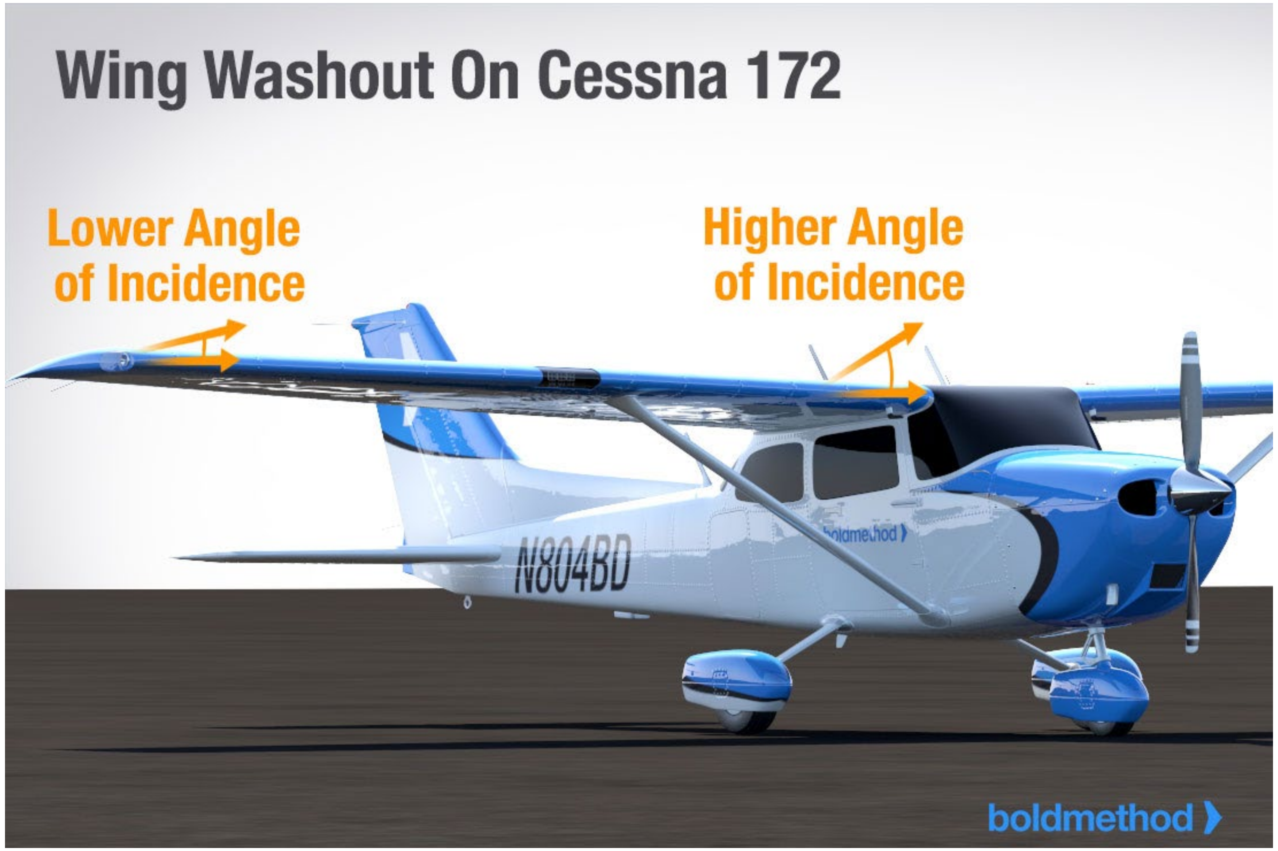
This makes it more stable to fly…

You can fly more hands off, even in turbulence.

Washout

It's a change in an airfoil's angle of incidence, measured from the root to the tip.

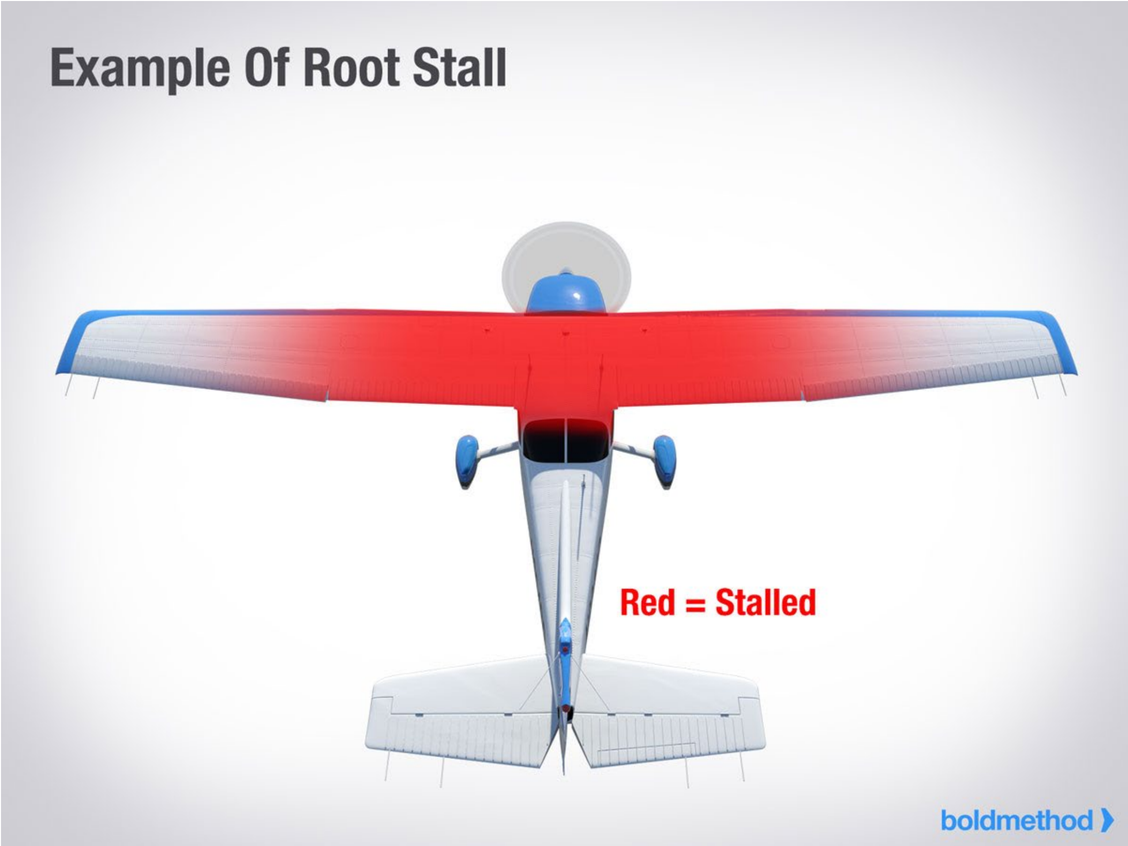
If you look closely at a wing with washout, you'll see that it twists from the root to the tip, with the root having a higher angle of incidence than the tip.



Washout

Why would engineers want to have an airplane flying around with twisted wings?

It has everything to do with a stall. When the root (inboard section) of a wing flies at a higher angle-of-attack, it also means the root will reach the critical angle-of-attack sooner than the tip, and it will stall first.



Washout

A root stall is what you want to happen in nearly all airplanes.

When an aircraft stalls at the root first, it means there's enough airflow over the tips of your wings to prevent any rapid rolling motion during a stall, which makes the airplane more stable.

It also makes your plane more resistant to entering a spin.

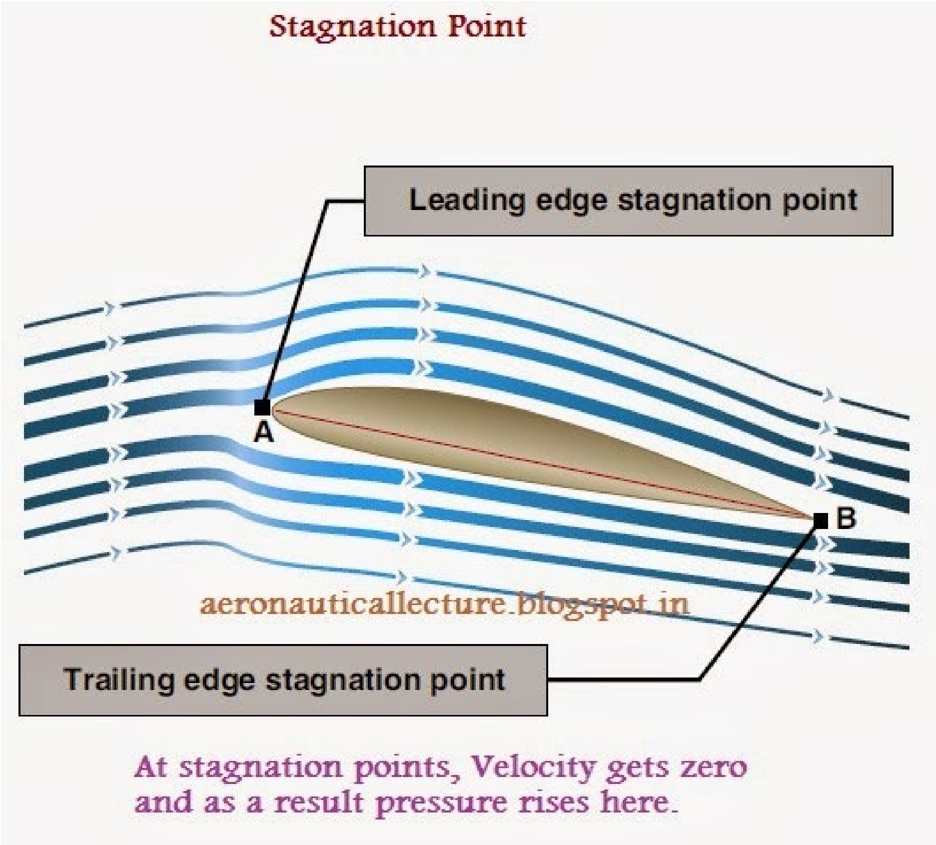
On top of that, a root stall also guarantees some aileron effectiveness during the stall, giving you greater control of your plane, especially if the stall occurs in a banked turn.

Now the Deep Dive

Stagnation Point(s)

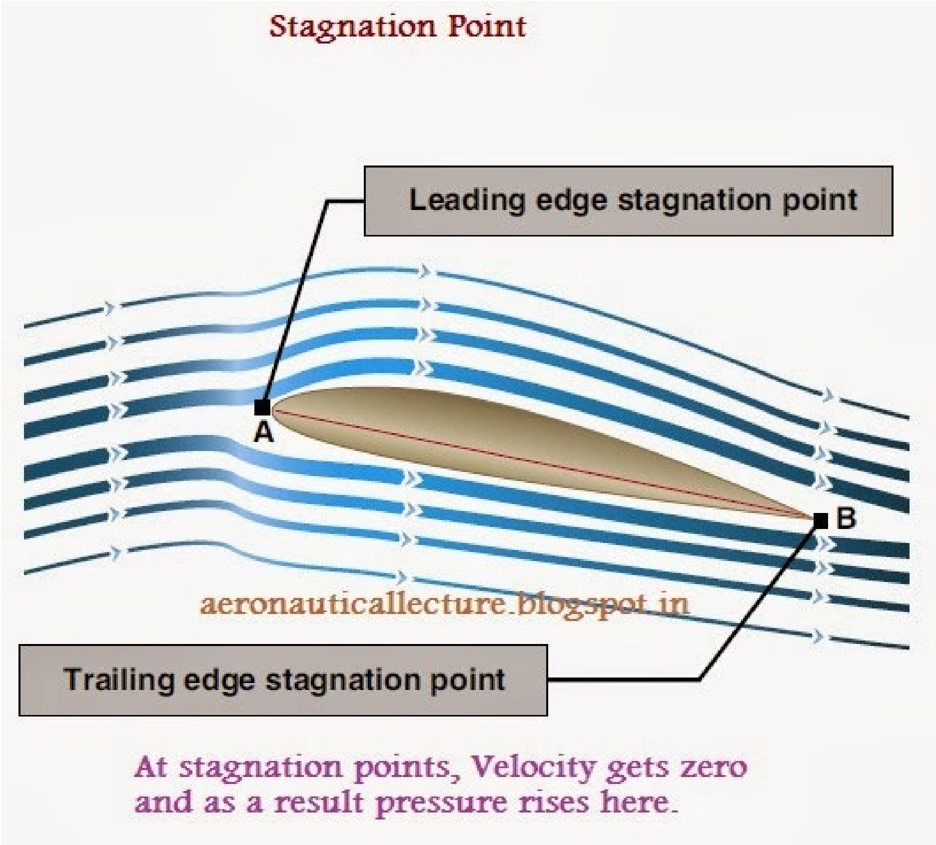
In fluid dynamics, a stagnation point is a point in a flow field where the local velocity of the fluid is zero.

As a wing is propelled through the atmosphere, the molecules of air it encounters are moved aside and forced to flow past the wing's contoured shape.



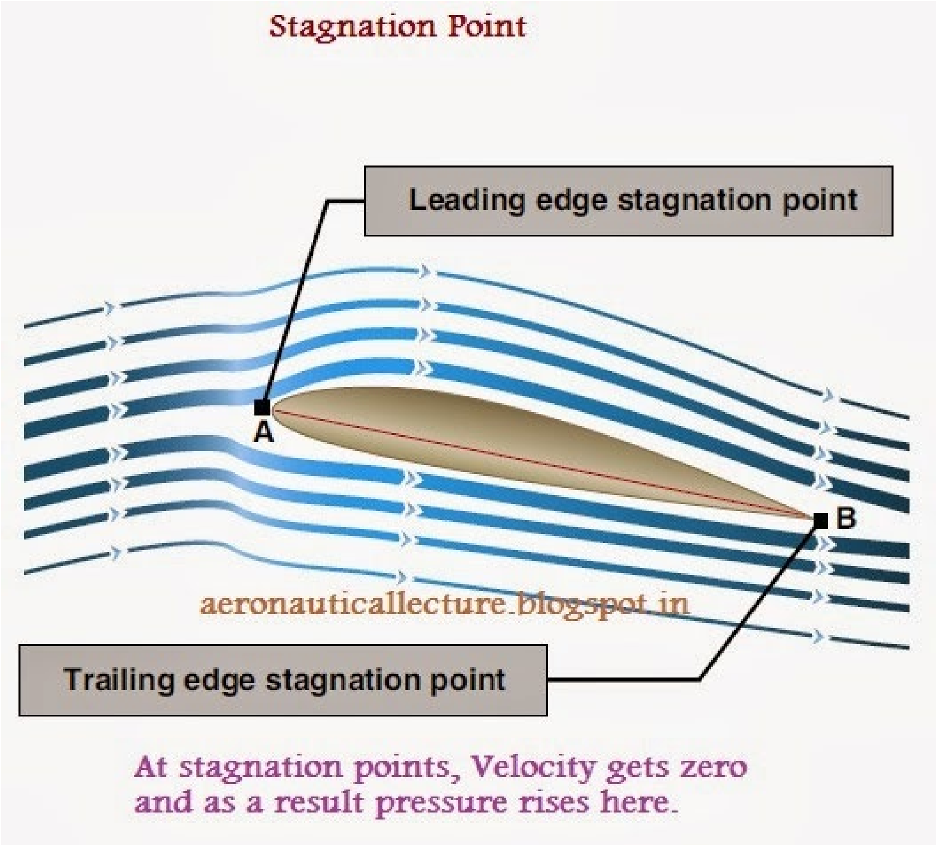
Stagnation Point(s)

Since some of the air moves under the wing and some moves over it, there is a dividing point where a molecule of air would hit the airfoil if it could not decide which way to go.

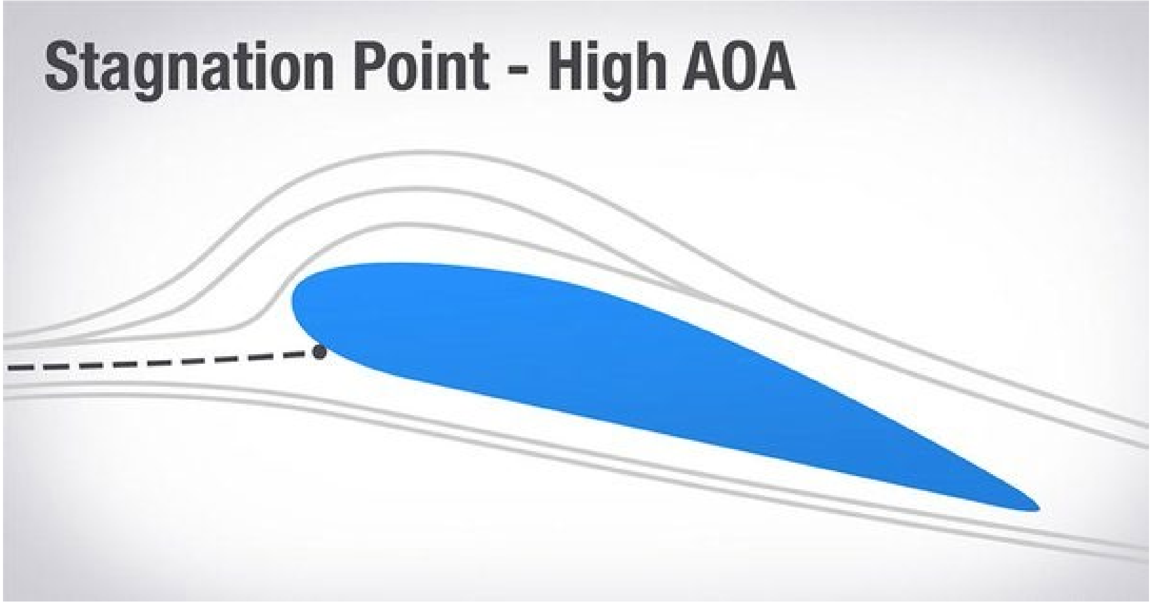


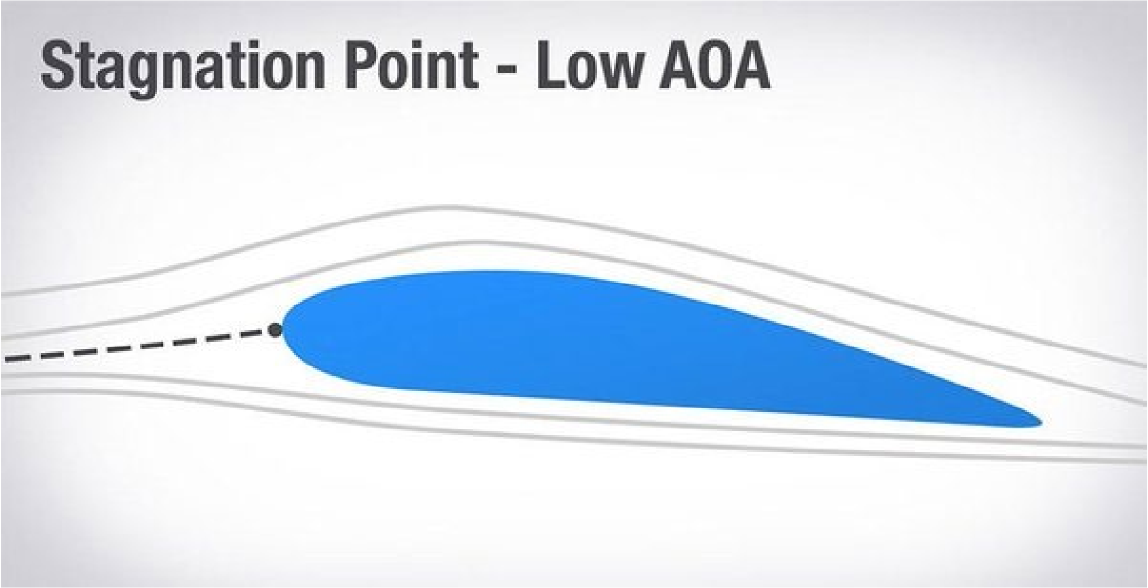
Stagnation Point(s)

The leading edge point is known as the forward stagnation point, and it is important because its location on the airfoil has much to do with how the air flows around the wing and thereby generates forces.



Stagnation Point(s)

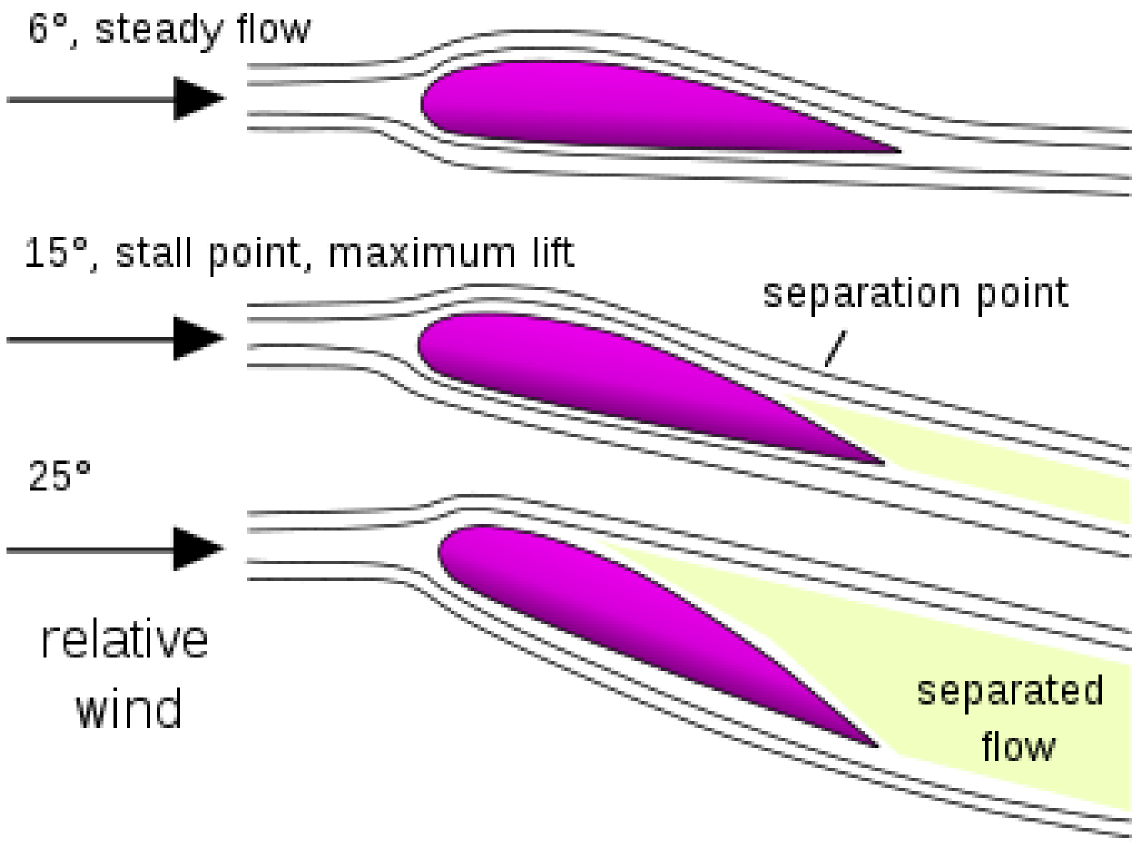




Separation Point

The separation point is the point where the air stops "sticking" to an object that is moving through the air.

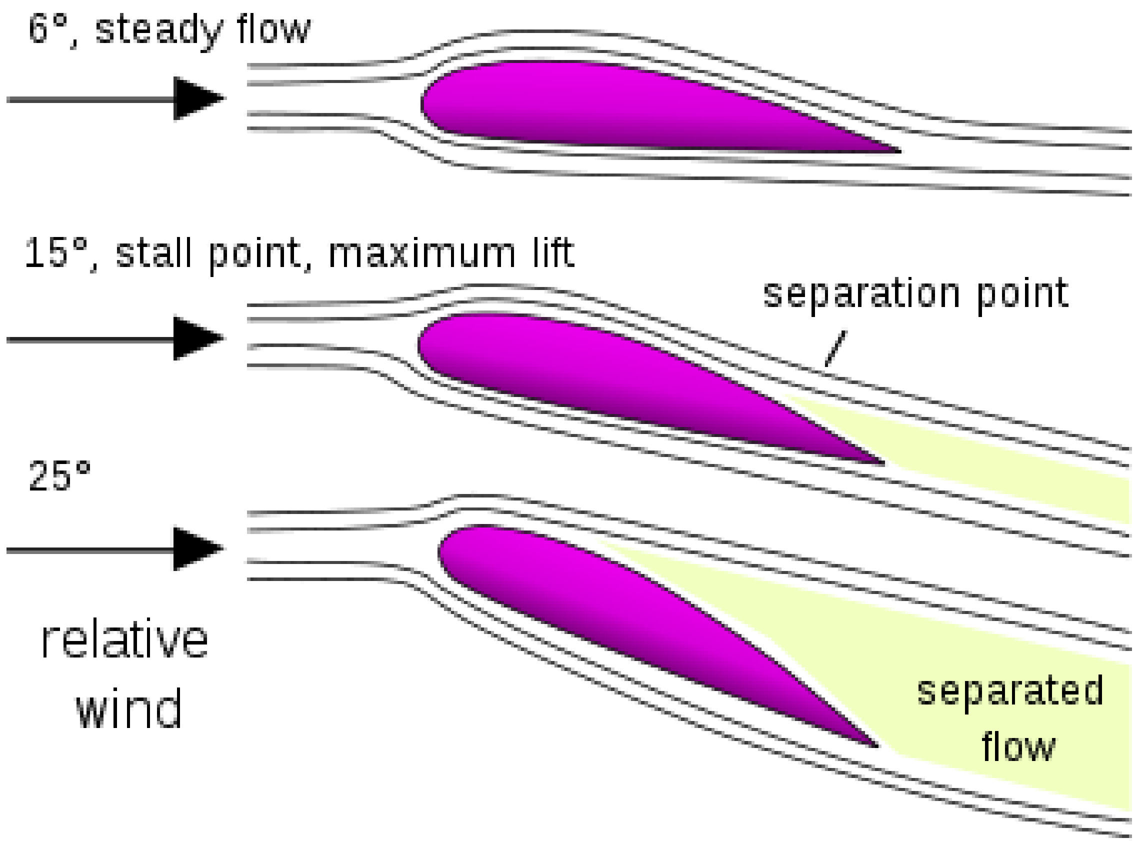
When an object is moving through the air, the air molecules push back on it and resist the object's movement - this resistance is called pressure drag.



Separation Point

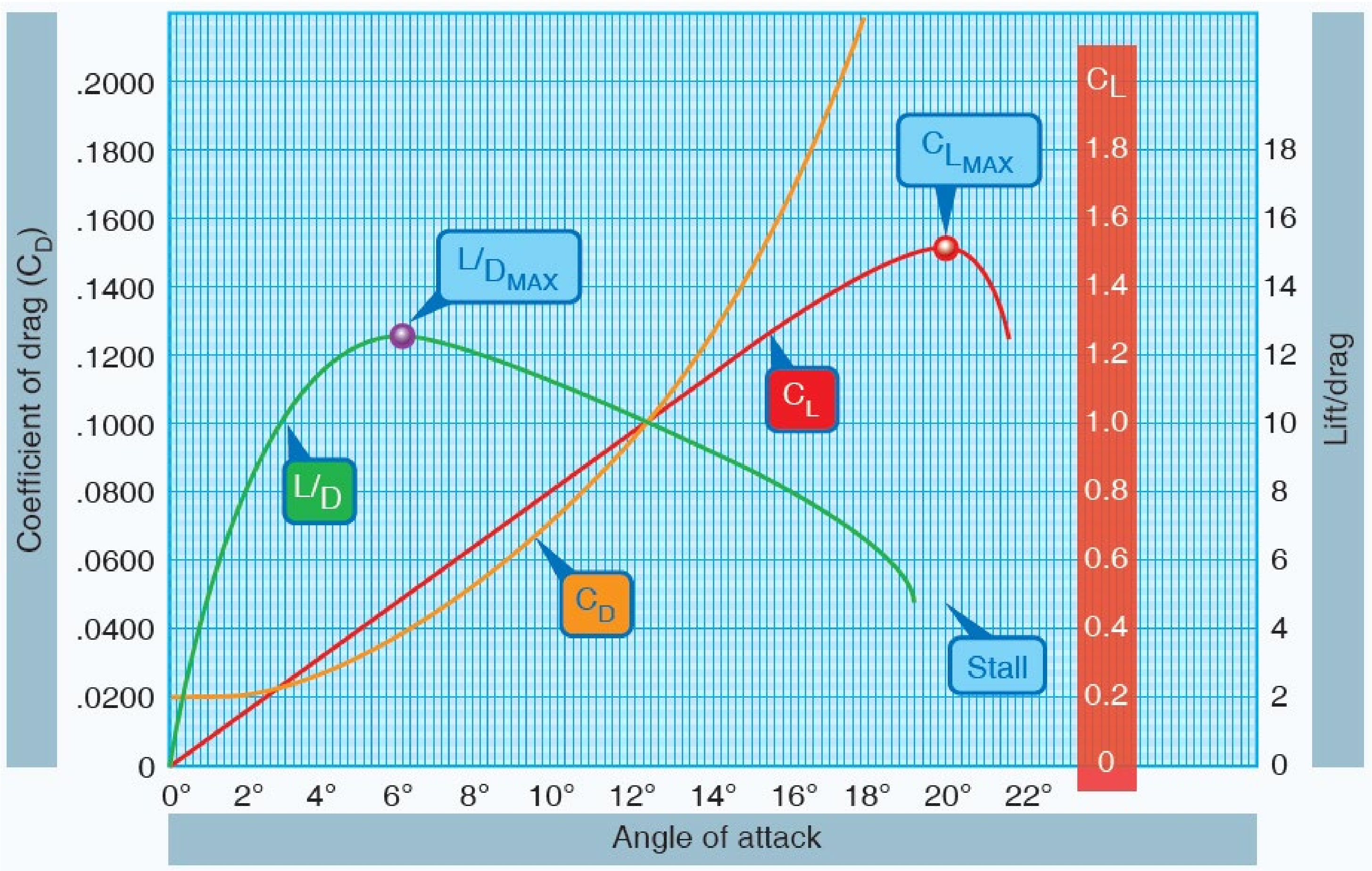
On an aircraft wing, the flow separation occurs when the boundary-layer travels far enough against an adverse pressure gradient.

The velocity of the particles nearest to the surface falls almost to zero.



Advanced Wing Physics Chart

CL = Coefficient of Lift, CD = Coefficient of Drag

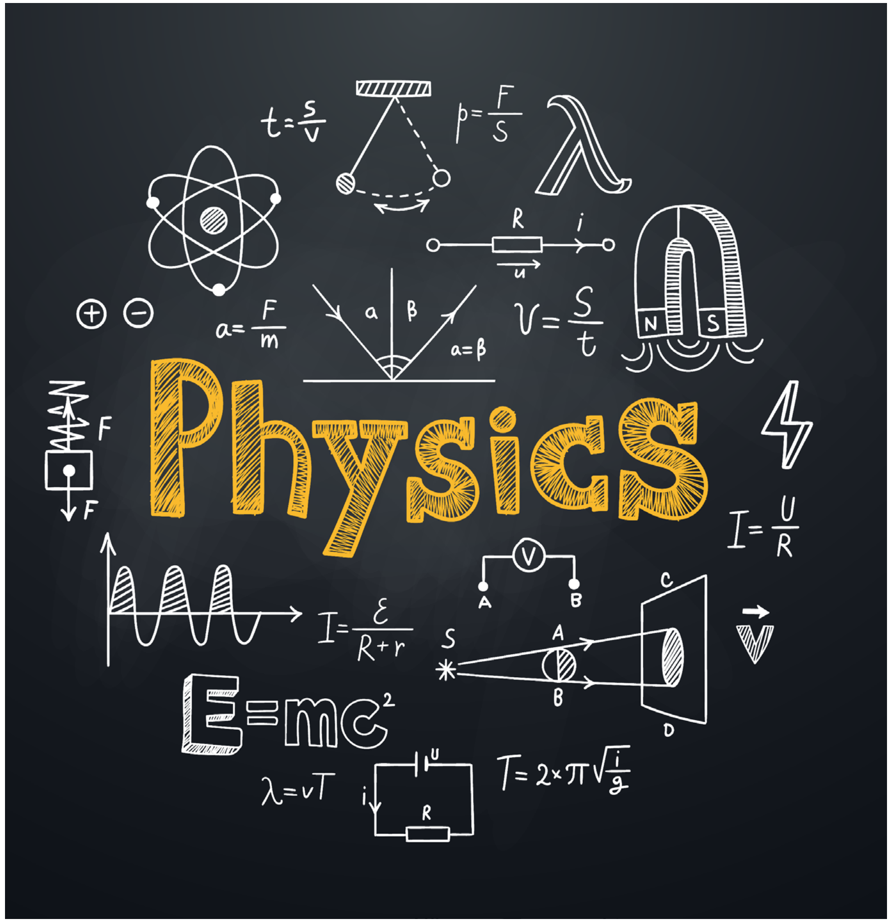


Coefficient of Lift

Lift = CL x Dynamic Pressure x Area of wing

CL depends on geometry, angle of attack, and some constant

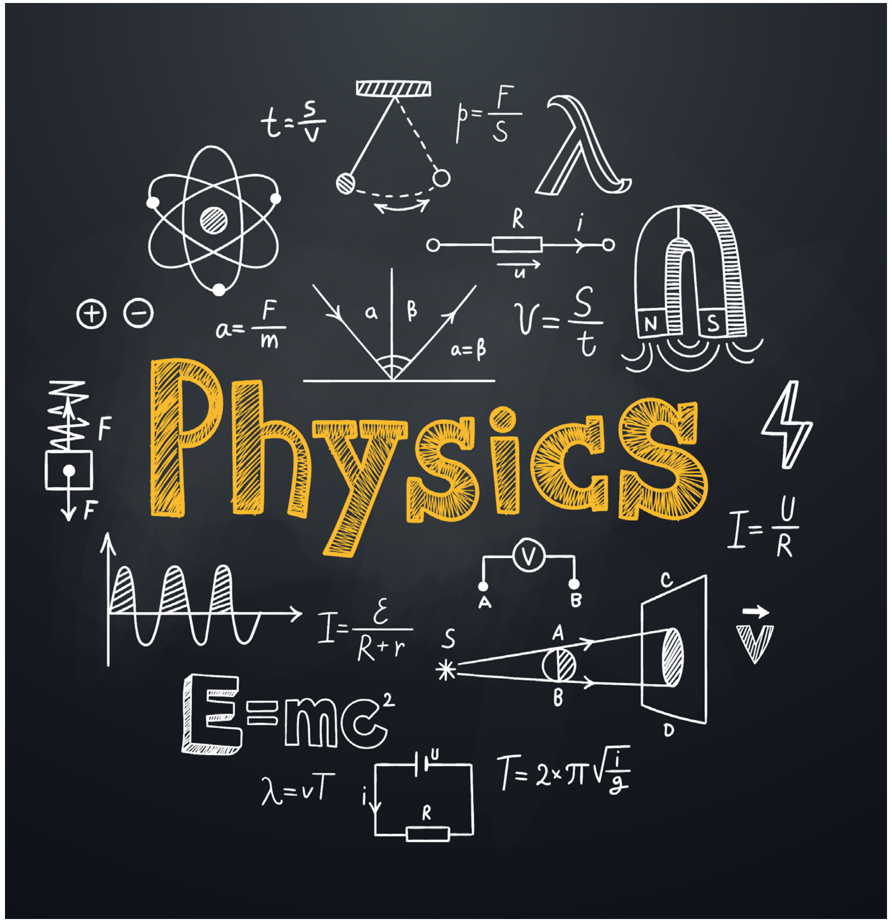
Dynamic Pressure = 0.5 x Density x Velocity squared



Coefficient of Lift

If we know the Cl for an airfoil and we know the flight conditions (dynamic pressure) and the area, we can determine the lift of the wing. (Designs the weight of an aircraft)

Weight = Lift = CL x Dynamic Pressure x Area



Coefficient of Lift

Let's set the Angle to 5 degrees, Thickness = 0.5, Camber = 0.2.

Now let's say we have a large airliner flying at 250 mph, at 25,000 ft, with a wing area of 1000 sq ft.

Lift = about 88,250 pounds.

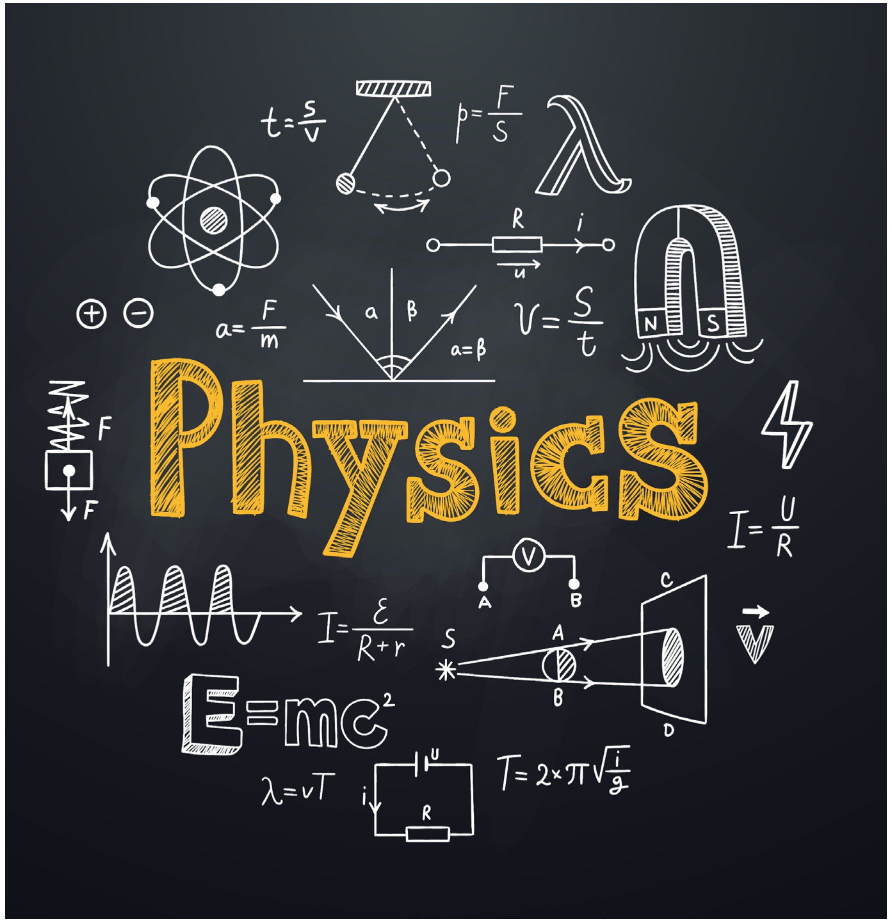
CL = Lift / Dynamic pressure / Area

Dynamic Pressure = 0.5 x Density x Velocity squared

Get the density from the simulator (Density = 0.00107)

Dynamic pressure = 0.5 (0.00107) (250) (250) = 33.43

CL = 88250 / 33.43 / 1000 = 2.64



Mean Aerodynamic Chord (MAC)

On small airplanes and on all helicopters, the center of gravity location is identified as being a specific number of inches from the datum. The center of gravity range is identified the same way. On larger airplanes, from private business jets to large jumbo jets, the center of gravity and its range are typically identified in relation to the width of the wing.

Mean Aerodynamic Chord (MAC)

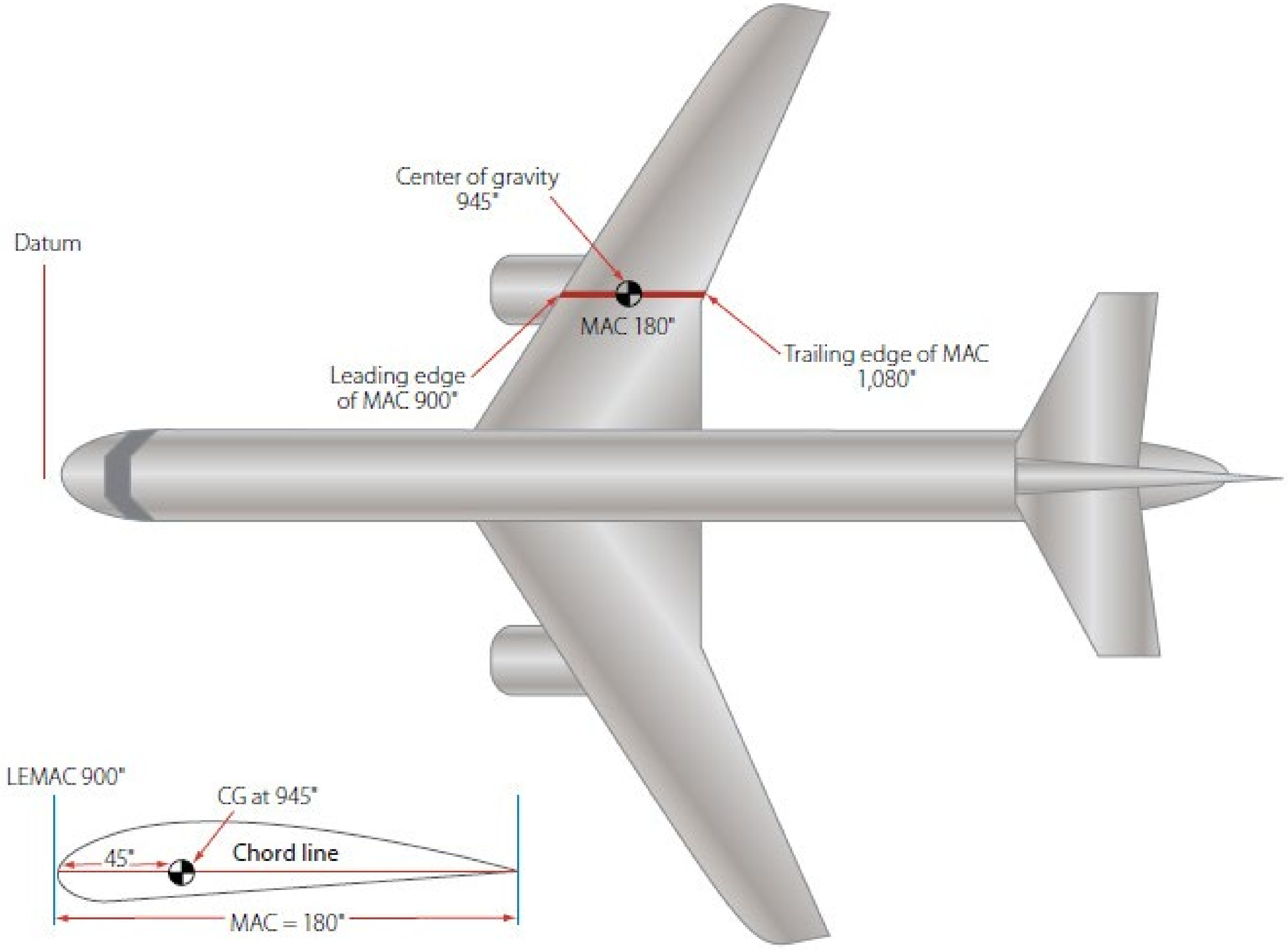
The width of the wing on an airplane is known as the chord. If the leading edge and trailing edge of a wing are parallel to each other, the chord of the wing is the same along the wing's length. Business jets and commercial transport airplanes have wings that are tapered and that are swept back, so the width of their wings is different along their entire length. The width is greatest where the wing meets the fuselage and progressively decreases toward the tip. In relation to the aerodynamics of the wing, the average length of the chord on these tapered swept-back wings is known as the mean aerodynamic chord (MAC).

Mean Aerodynamic Chord (MAC)

On these larger airplanes, the CG is identified as being at a location that is a specific percent of the mean aerodynamic chord (% MAC). For example, imagine that the MAC on a particular airplane is 100", and the CG falls 20" behind the leading edge of the MAC. That means it falls one-fifth of the way back, or at 20% of the MAC.

Mean Aerodynamic Chord (MAC)

The figure shows a large twin-engine commercial transport airplane. The datum is forward of the nose of the airplane, and all the arms shown in the figure are being measured from that point. The center of gravity for the airplane is shown as an arm measured in inches. In the lower left corner of the figure, a cross section of the wing is shown, with the same center of gravity information being presented.


Center of gravity
945"
Datum
MAC 180"
Leading edge
of MAC 900"
Trailing edge of MAC
1,080"
LEMAC 900"
CG at 945"
45"
Chord line
MAC = 180"

Mean Aerodynamic Chord (MAC)

1. Identify the center of gravity location, in inches from the datum.

2. Identify the leading edge of the MAC (LEMAC), in inches from the datum.

3. Subtract LEMAC from the CG location.

4. Divide the difference by the length of the MAC.

5. Convert the result in decimals to a percentage by multiplying by 100.

Locating Percent MAC

$$\text{CG Percent MAC} = \frac{(\text{CG Arm of Airplane}) - 25.90}{0.5880}$$

Any questions I can answer or follow up later on?

Turns

Lesson Objective

To develop understanding of all the forces in turns and the factors of uncoordinated turns.

Diagrams

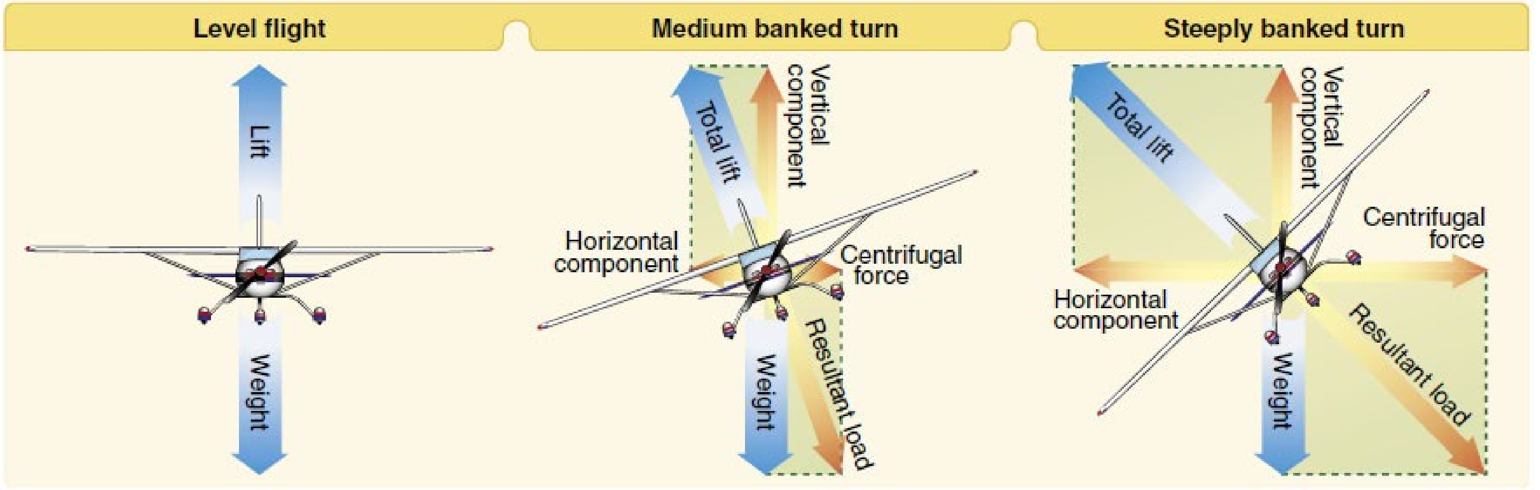


Figure 4-28. *Forces during normal coordinated turn.*

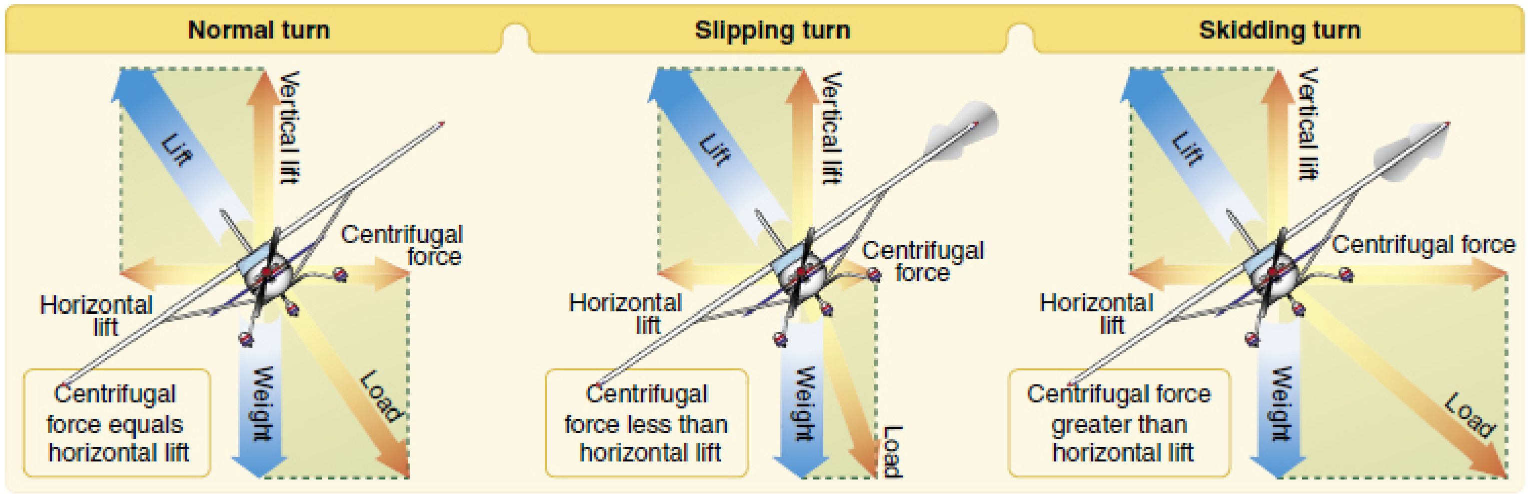


Figure 4-29. *Normal, slipping, and skidding turns.*

If you turn without using rudders

If you turn right...

Plane goes right, Ball goes left

If you turn left…

Plane goes left, Ball goes right

Figure from Knowledge Tests

1 = Skid

2 = Slip

3 = Coordinated

Imagine the ball as to where the tail currently is in relation to where it should be.

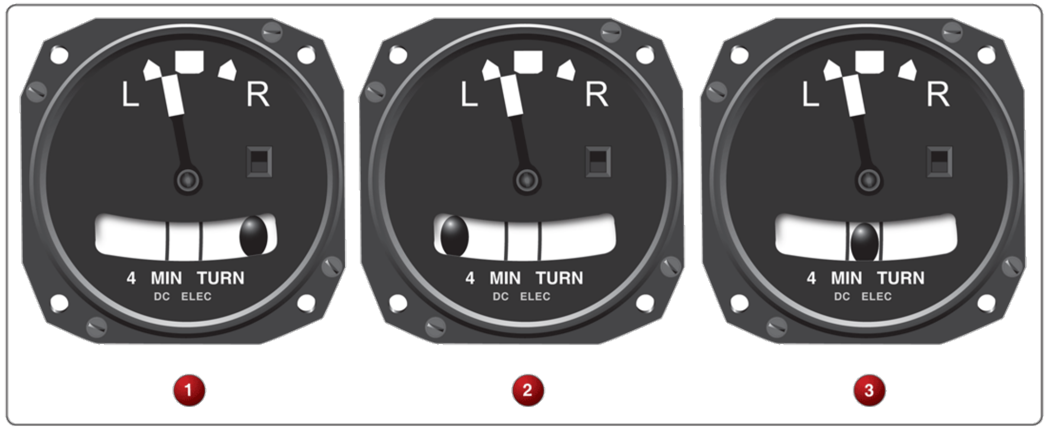


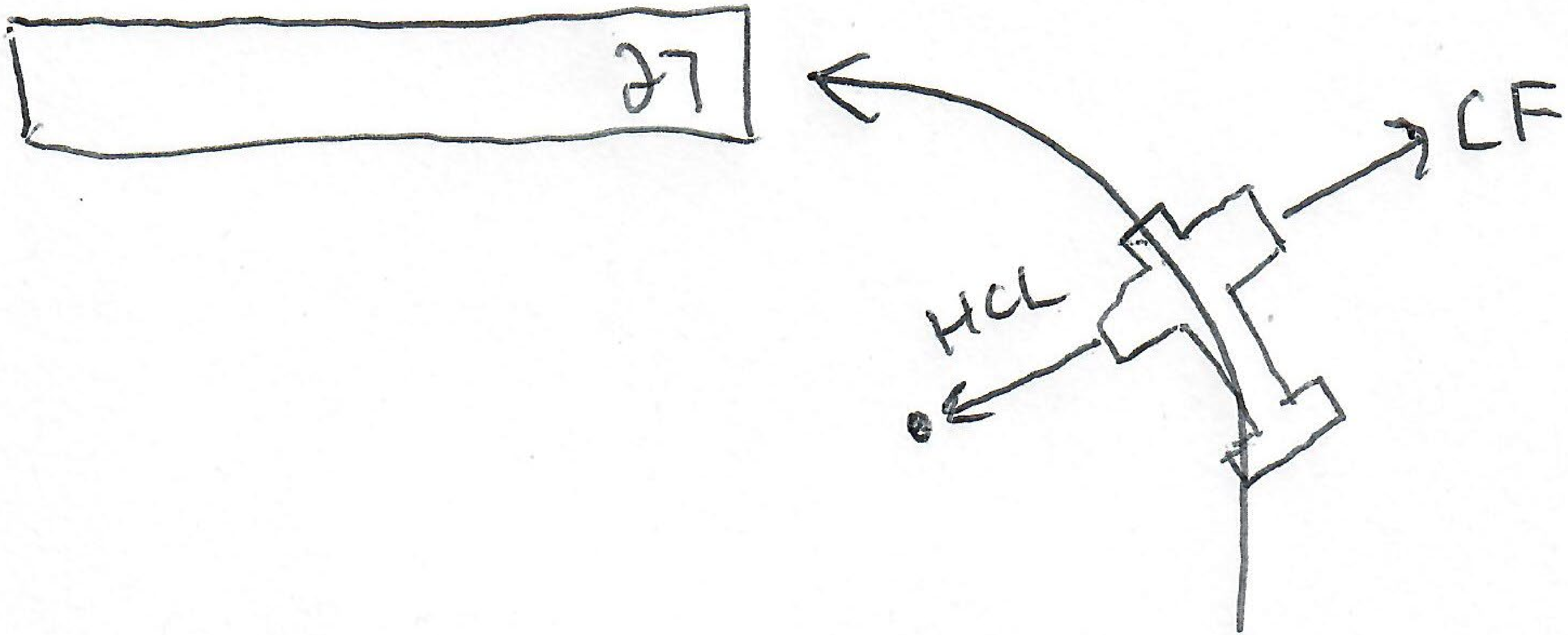
Figure 144. Turn-and-Slip Indicator. ©ASA

HCL & CF

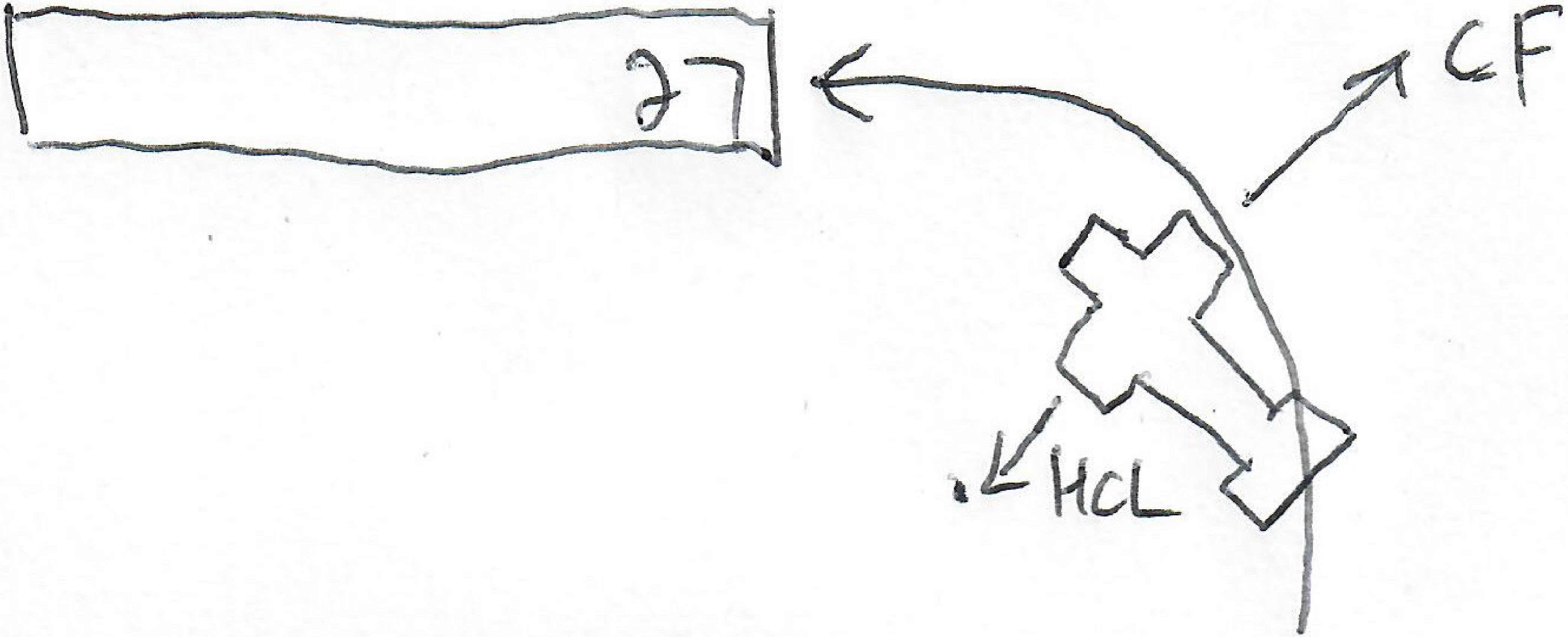
The horizontal component of lift (HCL) is the force that pulls the aircraft from a straight flight path to make it turn.

Centrifugal force (CF) is the “equal and opposite reaction” of the aircraft to the change in direction and acts equal and opposite to the horizontal component of lift.

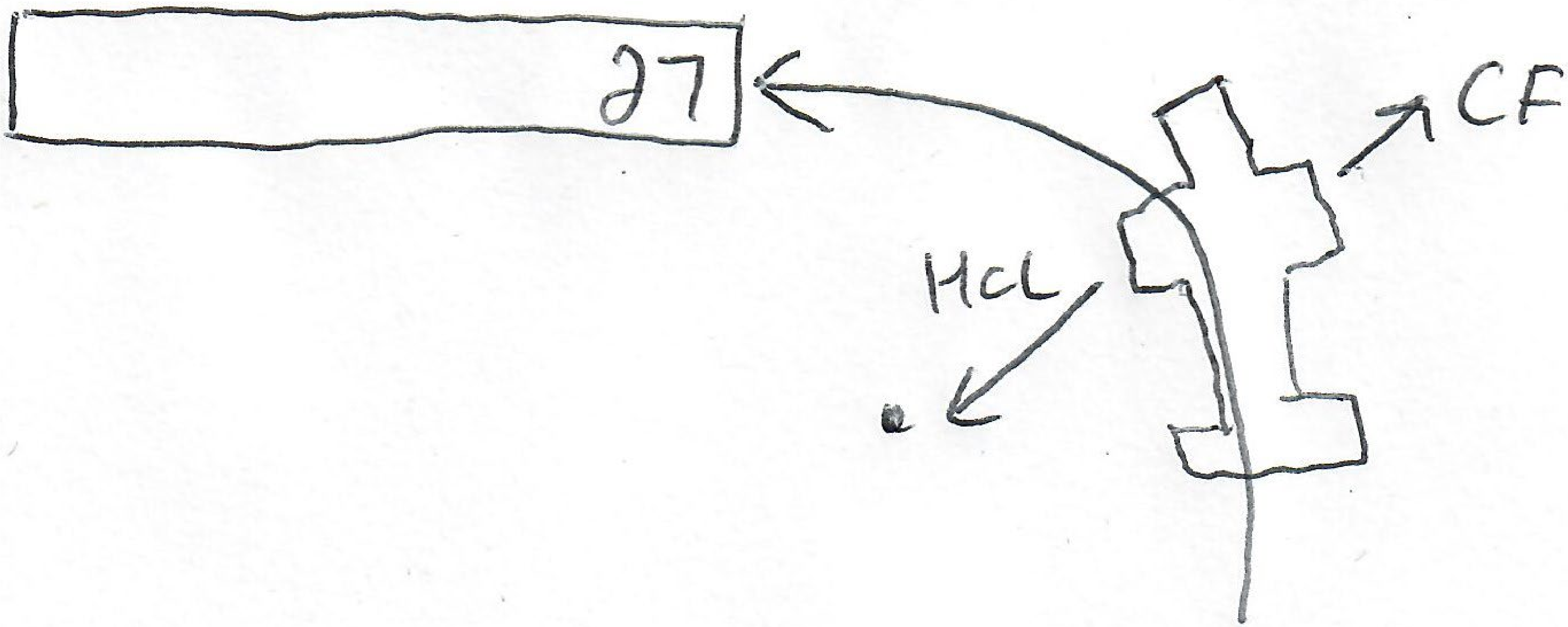
HCL & CF – Good Turn

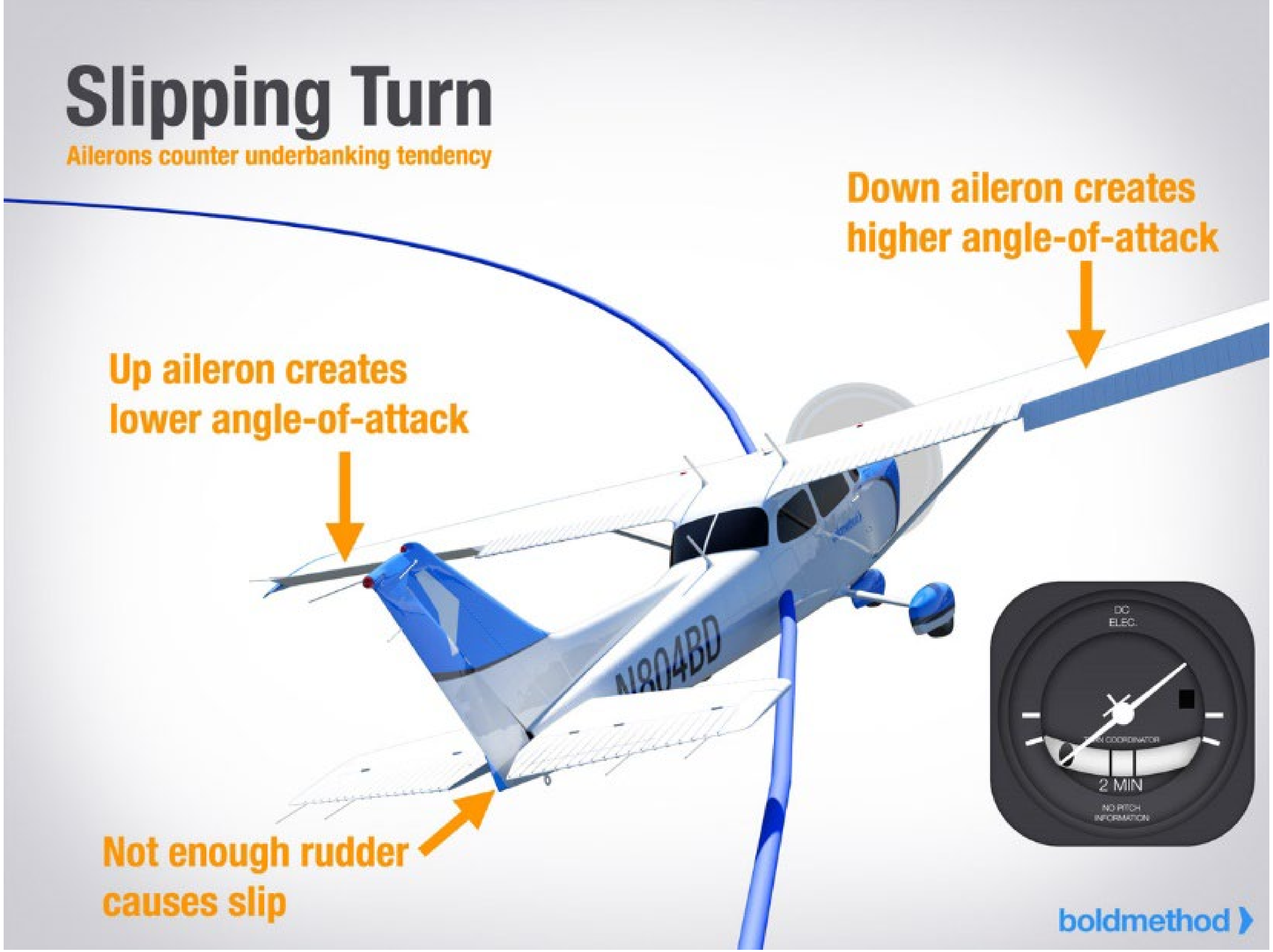


HCL & CF – Skid



HCL & CF – Slip



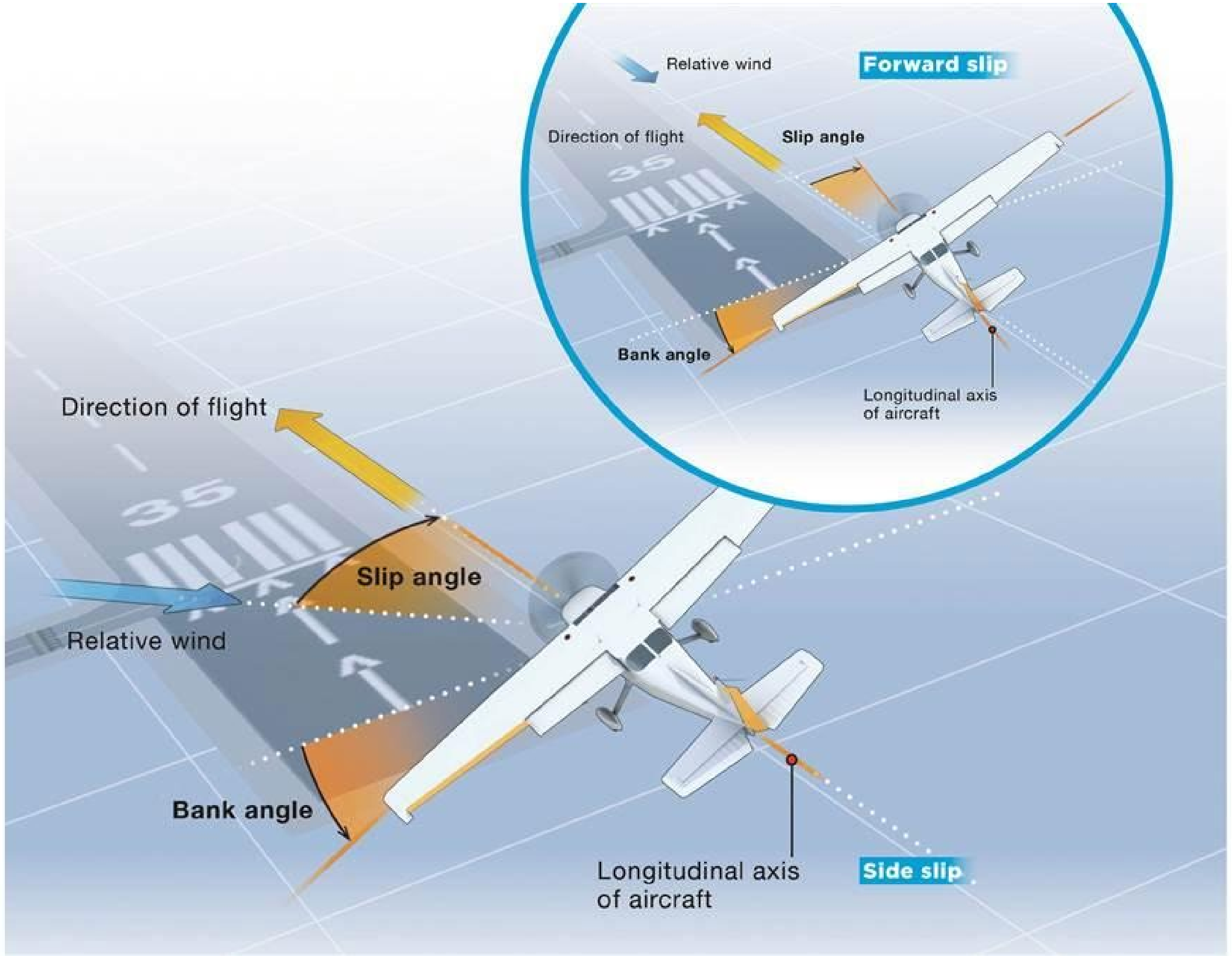


Slip

A slip does not have enough rudder or using rudder opposite to the direction of the bank.

Tail on inside

Centrifugal force < Horizontal lift

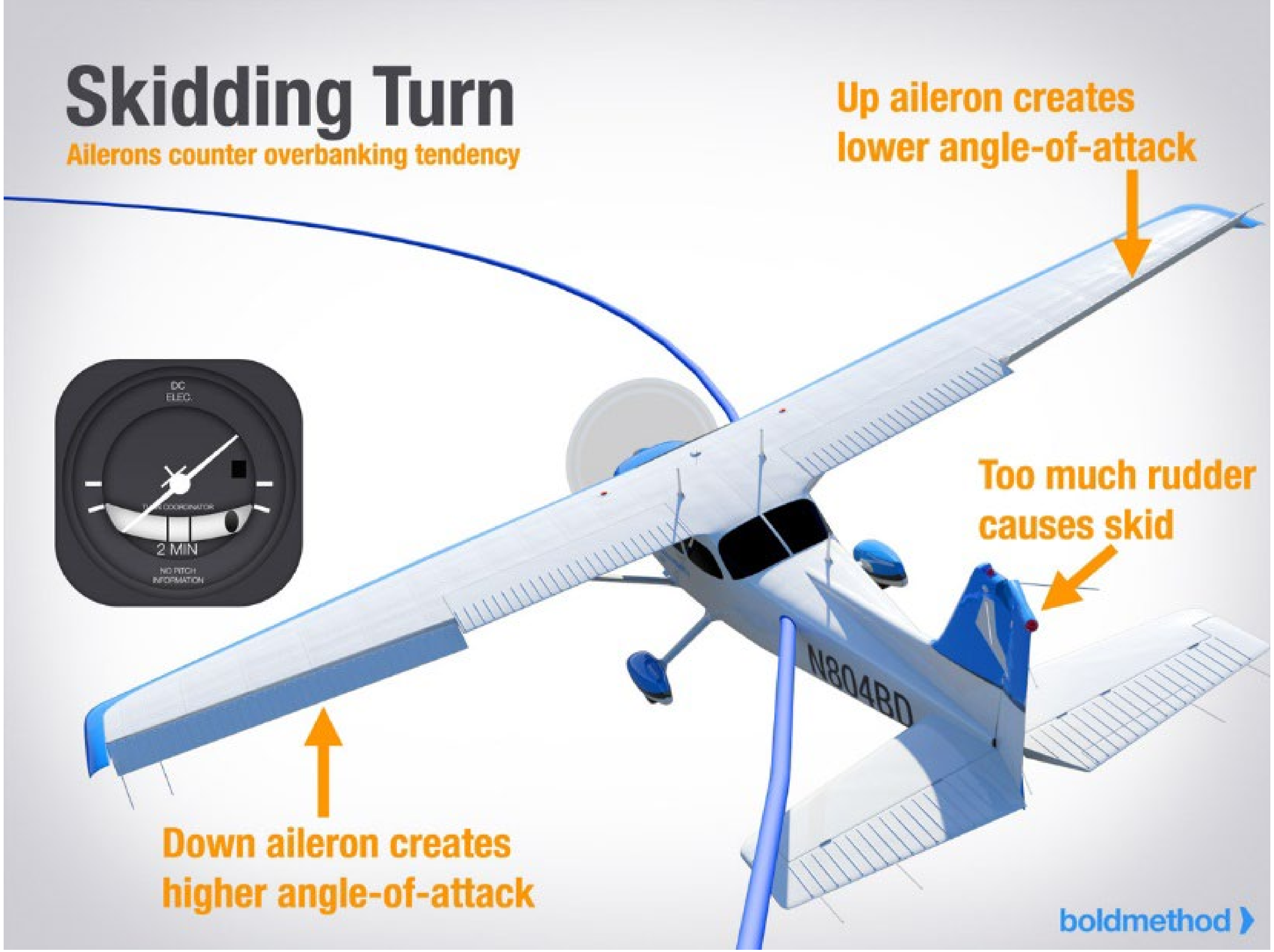


Slip

The inside wing gets most of the relative wind.

The higher AOA causes the outside wing to stall first so worse case you end up back in a level attitude.

It is much harder to end up in a spin to the death.

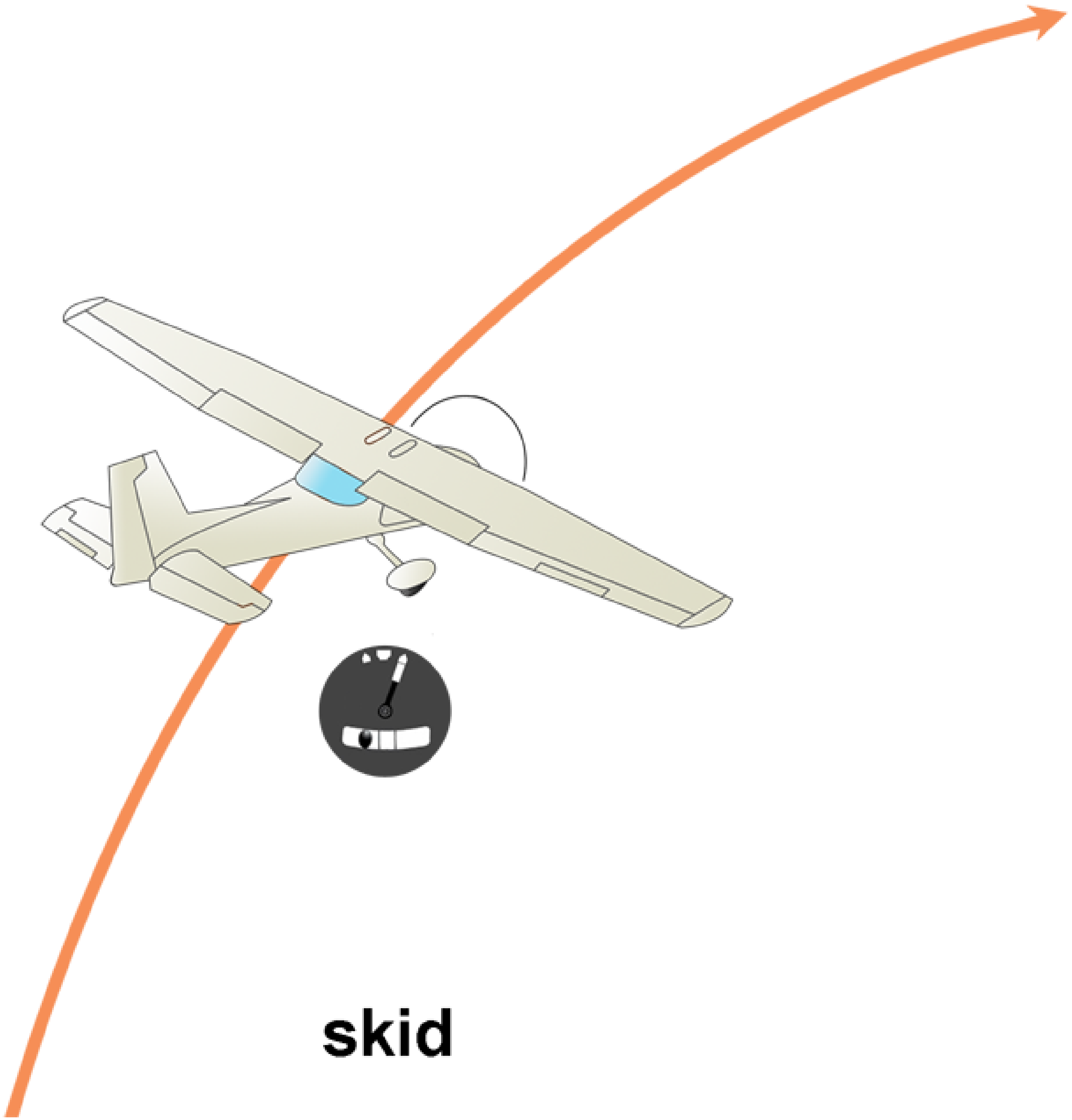


Skid

A skid has too much rudder used in the direction of bank.

Tail on outside

Centrifugal force > Horizontal lift

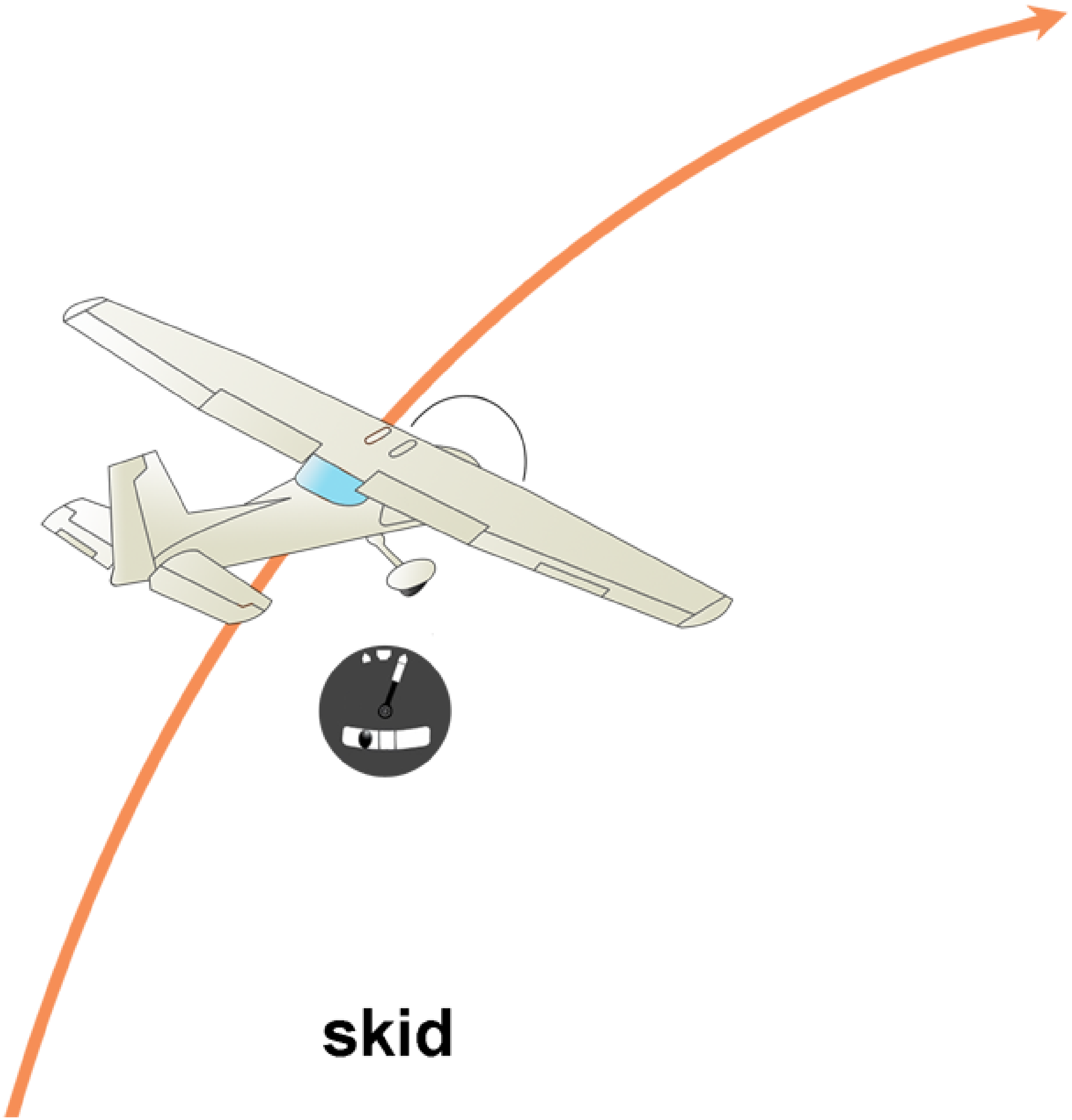


Skid

Almost the entire inside wing will be blocked from the relative wind.

This will greatly reduce the lift produced by the inside/lower wing.

The inside/lower wing will stall first.



Skid

The outside/higher wing will then have an increase in the Angle of Attack.

The outside/higher wing will have more lift.

Why Skids Are More Dangerous Than Slips

Most of us are simply taught to keep an aircraft coordinated when stalling.

Most stall-spin accidents happen down low likely when you're turning base to final.

Here's a common scenario:

You're turning left base to final, but you're going to overshoot the runway.

You add left rudder to tighten the turn, but you don't keep the bank and rudder coordinated - putting the airplane into a skid.

Why Skids Are More Dangerous Than Slips

The skid causes an over banking tendency, which you counter by adding opposite aileron (often subconsciously).

That also pulls the nose down, which you oppose with elevator…pitching up too much.

Suddenly the aircraft stalls and snaps to the left in an incipient spin.

At 700' AGL, you will never be able to recover.

Why Skids Are More Dangerous Than Slips

The answer is really simple - don't use rudder to tighten a turn.

Simply go-around if you can't make that turn from base to final.

A go-around gives you the chance to set up again, and line up the landing like a pro.

Why Skids Are More Dangerous Than Slips

Catherine Cavagnaro owns Ace Aerobatic School in Sewanee, Tennessee

"When I teach spins and aerobatics, we stall the airplane in both slipping and skidding configurations. The first time, we let the airplane turn upside down and witness the full effect. Next up is a powerful and encouraging demonstration. We set up a slipping (or skidding) stall once more and as soon as the airplane is departing into the spin, apply a quick burst of forward yoke and note that the spin stops immediately. You can be on your way into the spin and it is never too late to stop it. Pushing forward on the yoke is key."

https://www.aopa.org/news-and-media/all-news/2019/april/pilot/technique-taming-the-stall https://youtu.be/RKfG3lWCZ80

https://youtu.be/WoSXiNpZC_w

Airspeed and Bank

When airspeed is decreased in a turn, what must be done to maintain level flight?

When airspeed is reduced, the vertical component of lift is reduced. To keep level flight you must either increase the angle of attack or reduce the angle of bank.

Airspeed –

=> bank angle – or AOA +

Airspeed +

=> bank angle + or AOA –

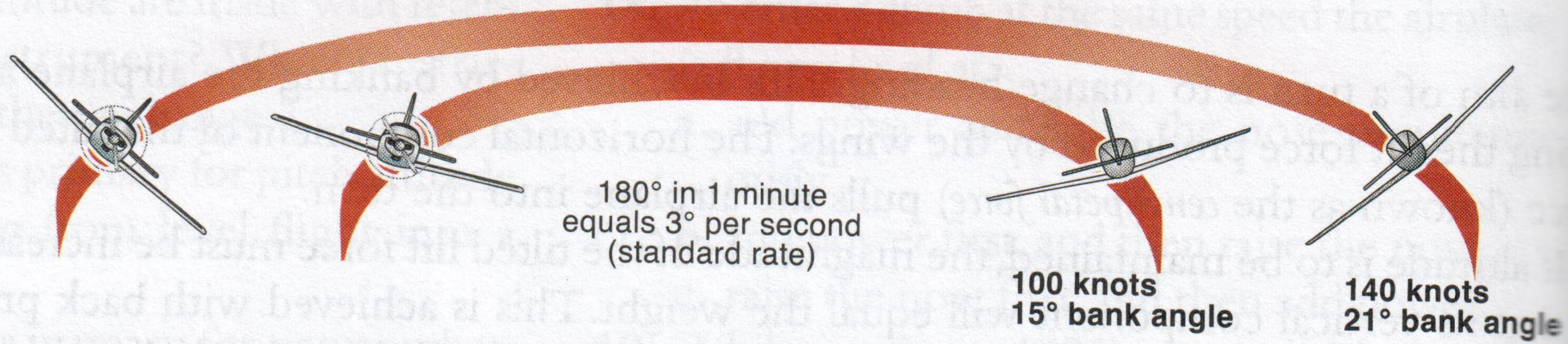
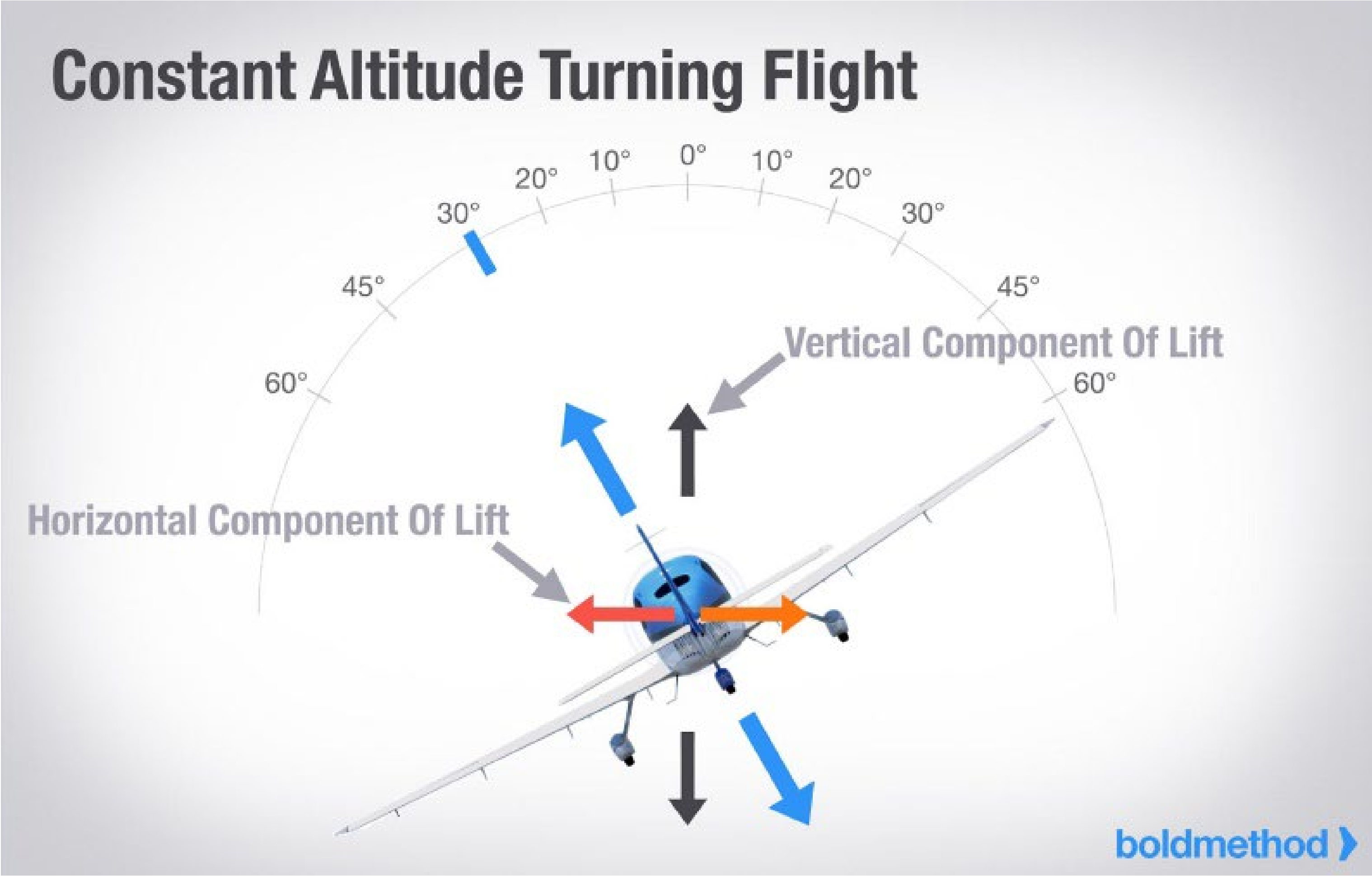
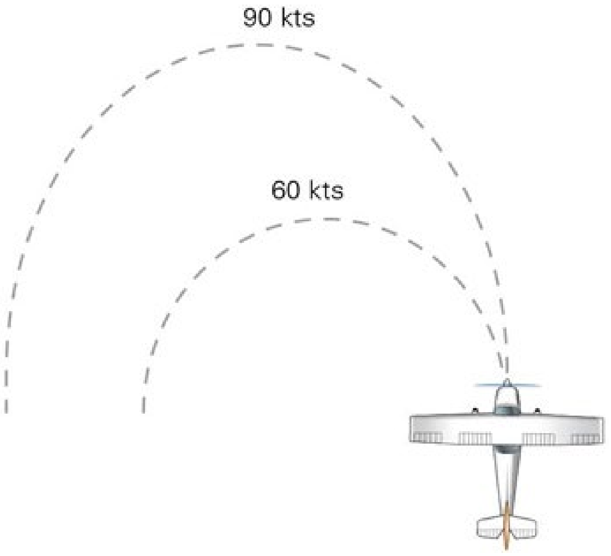


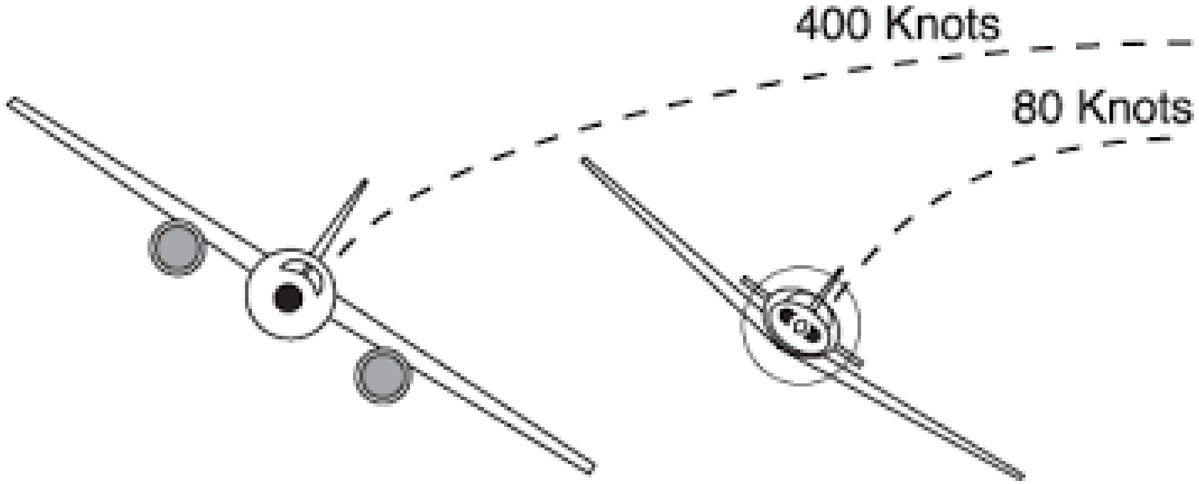
Figure 6-2 A standard-rate turn requires a steeper bank at a higher airspeed (same rate of turn).

Maintaining Constant Altitude



Radius of turn is based on airspeed





Increased Loading

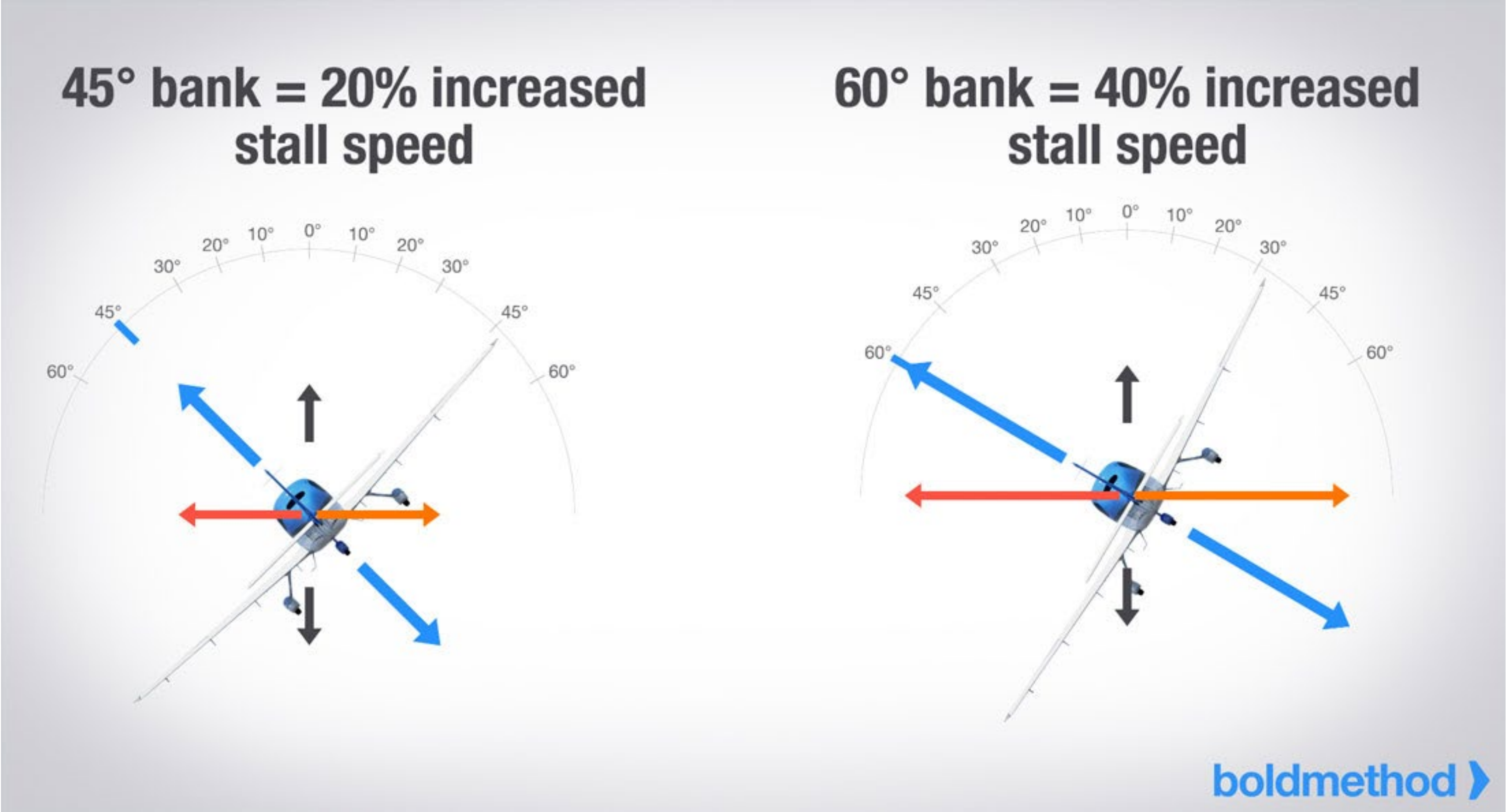
You're "loading the wing" as you increase back pressure to compensate for reduced vertical lift.

There is a downside to increased loading though: your stall speed increases.

As you increase your wing's angle-of-attack with back pressure, you start approaching your airplane's critical angle-of-attack and risk entering an accelerated stall.

This is exactly why you were taught that your stall speed increases during a steep turn, for instance.

Stall Speed Effect



Any questions I can answer or follow up later on?

Load Factor

Lesson Objective

To develop understanding of load factor

Summary

The force that must be supported by the wings and structure.

From PHAK

Any force applied to an aircraft to deflect its flight from a straight line produces a stress on its structure.

The amount of this force is the load factor.

In aerodynamics, the maximum load factor at given bank angle is a proportion between lift and weight.

The load factor is measured in Gs (acceleration of gravity).

In a nutshell…

Think of Load Factor as Lift Factor

Load Factor = **Lift / Weight** (expressed in number of "Gs")

Lift Needed = Load Factor * Weight

A load factor of 3 means the total load on an aircraft's structure is 3X its weight.

Since load factors are expressed in terms of Gs, a load factor of 3 may be spoken of as 3 Gs.

From PHAK

The problem of load factors in aircraft design becomes how to determine the highest load factors that can be expected in normal operation under various operational situations.

These load factors are called “limit load factors.”

For reasons of safety, it is required that the aircraft be designed to withstand these load factors without any structural damage.

Although the Code of Federal Regulations (CFR) requires the aircraft structure be capable of supporting one and one-half times these limit load factors without failure, it is accepted that parts of the aircraft may bend or twist under these loads and that some structural damage may occur.

From PHAK

This 1.5 load limit factor is called the “factor of safety” and provides, to some extent, for loads higher than those expected under normal and reasonable operation.

This strength reserve is not something that pilots should willfully abuse; rather, it is there for protection when encountering unexpected conditions.

From PHAK

The above considerations apply to all loading conditions, whether they be due to gusts, maneuvers, or landings.

The gust load factor requirements now in effect are substantially the same as those that have been in existence for years.

Hundreds of thousands of operational hours have proven them adequate for safety.

From PHAK

Since the pilot has little control over gust load factors (except to reduce the aircraft’s speed when rough air is encountered), the gust loading requirements are substantially the same for most general aviation type aircraft regardless of their operational use.

Generally, the gust load factors control the design of aircraft which are intended for strictly non-acrobatic usage.

+ or -

Gs can be positive or negative

• positive Gs: A sharp pull up and the resulting force pushing the pilot into the seat

• negative Gs: A sharp push down and the resulting force lifting the pilot off the seat

Limits

Aircraft designed under the category system are readily identified by a placard in the flight deck, which states the

operational category (or categories) in which the aircraft is certificated.

The maximum safe load factors (limit load factors) specified for aircraft in the various categories are:

<u>Normal</u>

3.8 to –1.52

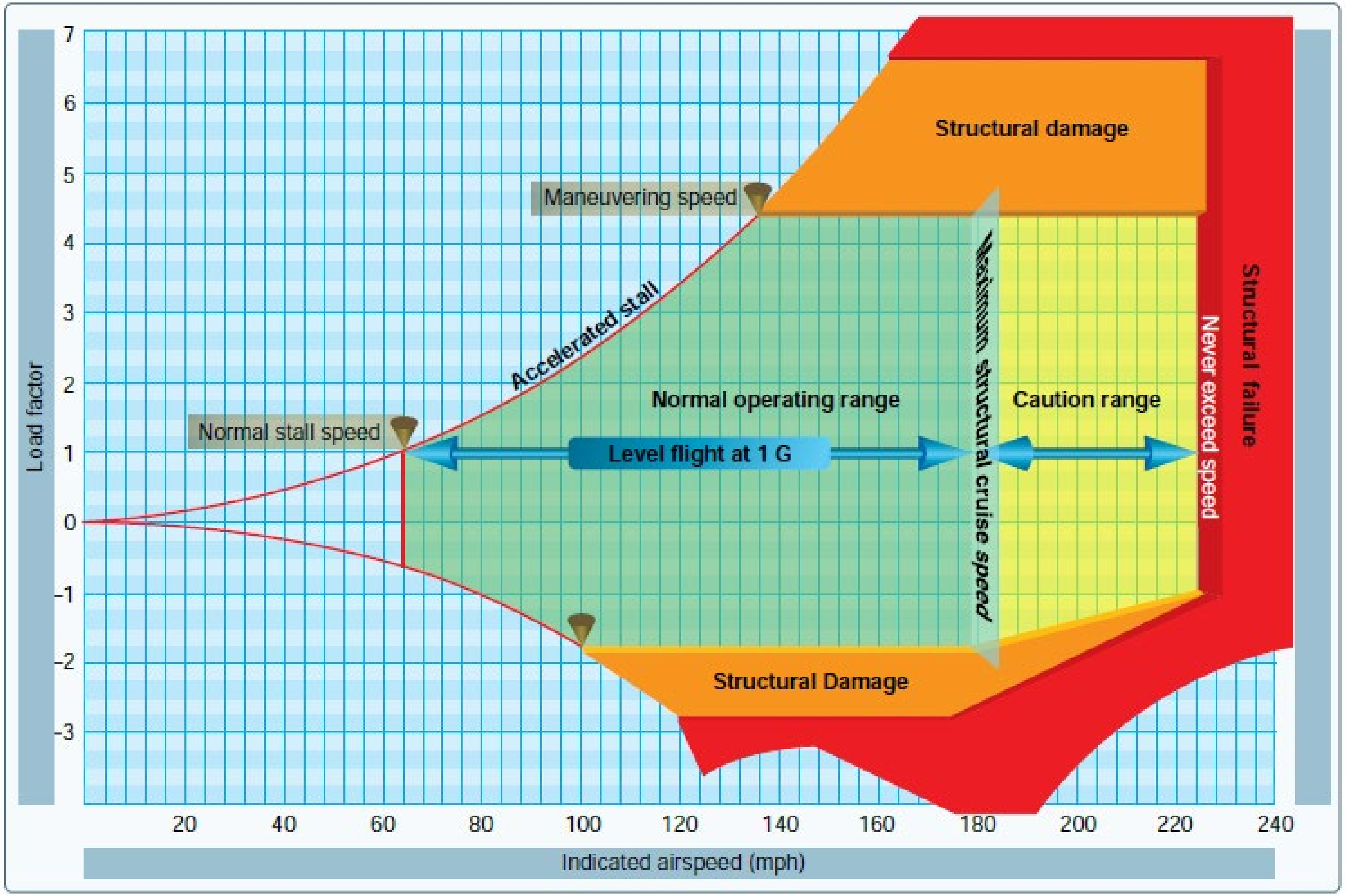
<u>Utility (mild acrobatics, including spins)</u>

4.4 to –1.76

<u>Acrobatic</u>

6.0 to –3.00

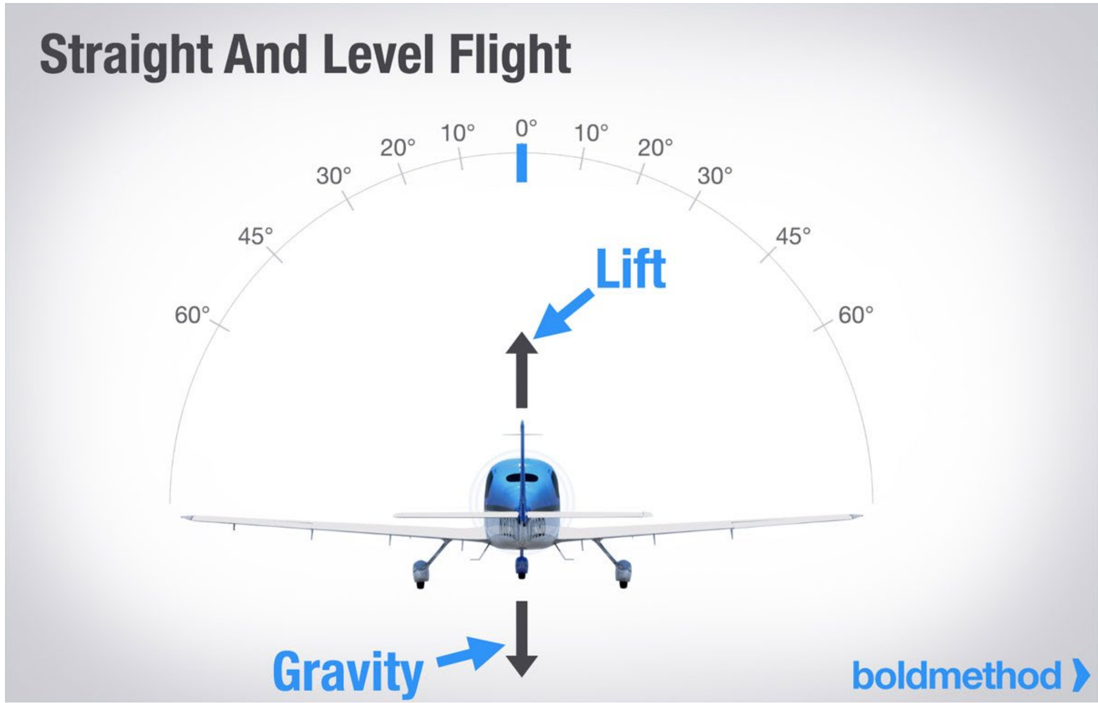
Limits



Structural damage
Maneuvering speed
Accelerated stall
Normal operating range
Maximum structural cruise speed
Caution range
Never exceed speed
Structural failure
Normal stall speed
Level flight at 1 G
Structural Damage
Load factor
7
6
5
4
3
2
1
0
-1
-2
-3
20
40
60
80
100
120
140
160
180
200
220
240
Indicated airspeed (mph)

Load Factors in Turns

When you start to bank, the lift vector starts moving.

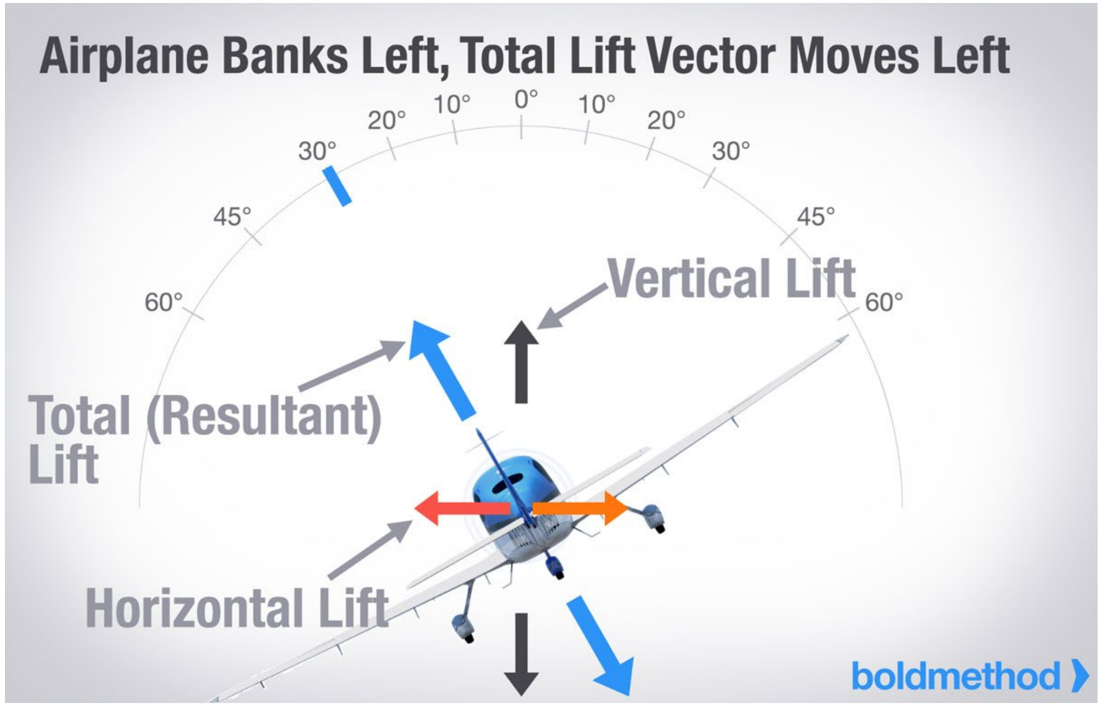


Load Factors in Turns

And as you can see in the diagram above, you now have two components of lift: a vertical component, and a horizontal component.

When you combine the two, you get a total lift vector.

The horizontal component of lift is what makes your airplane turn, and the vertical component is what makes your airplane maintain altitude.



Now Pitch Up

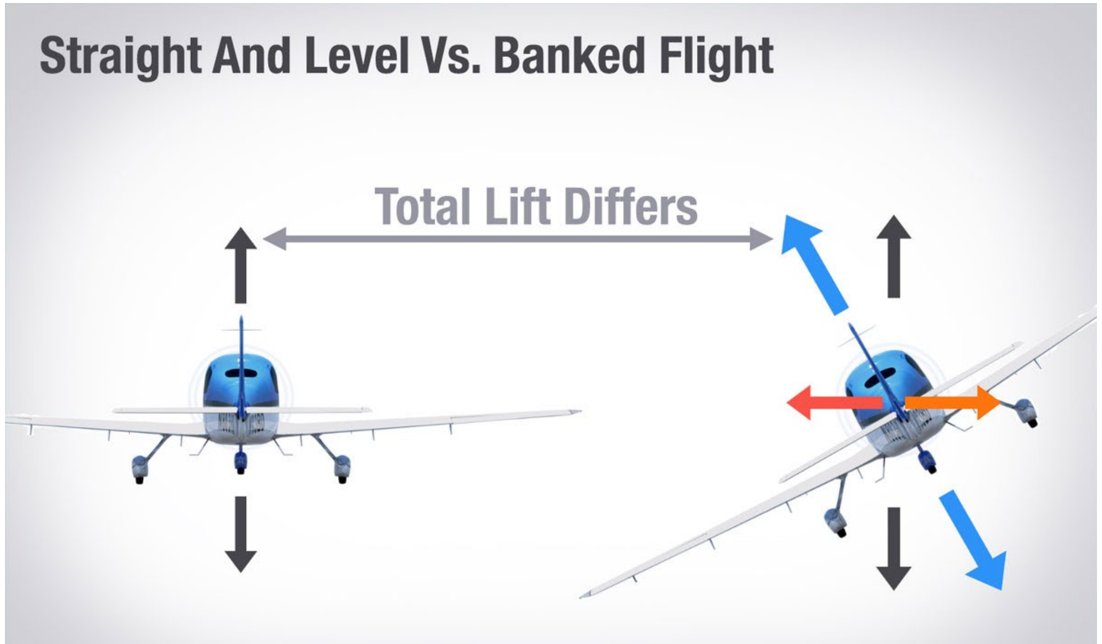
So how do you turn and maintain altitude?

You need to increase the total amount of lift your wing is producing.

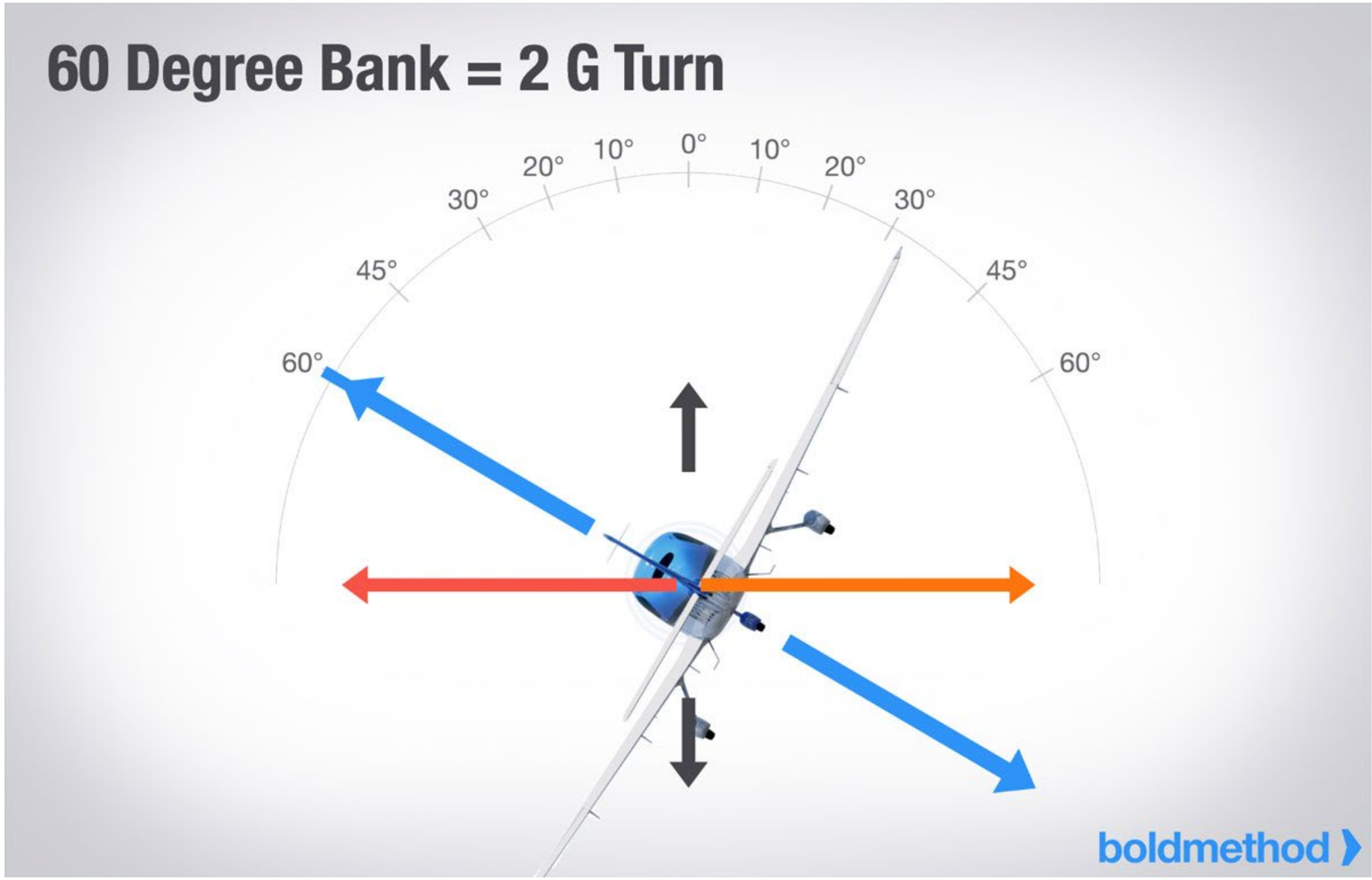
And to do that, you need to pull back on the yoke, which increases the angle-of-attack that your wing is flying at.

When you increase your angle-of-attack, you get closer to the critical angle of attack, which is the point when your wing stalls.

See the lesson on Accelerated Stalls.

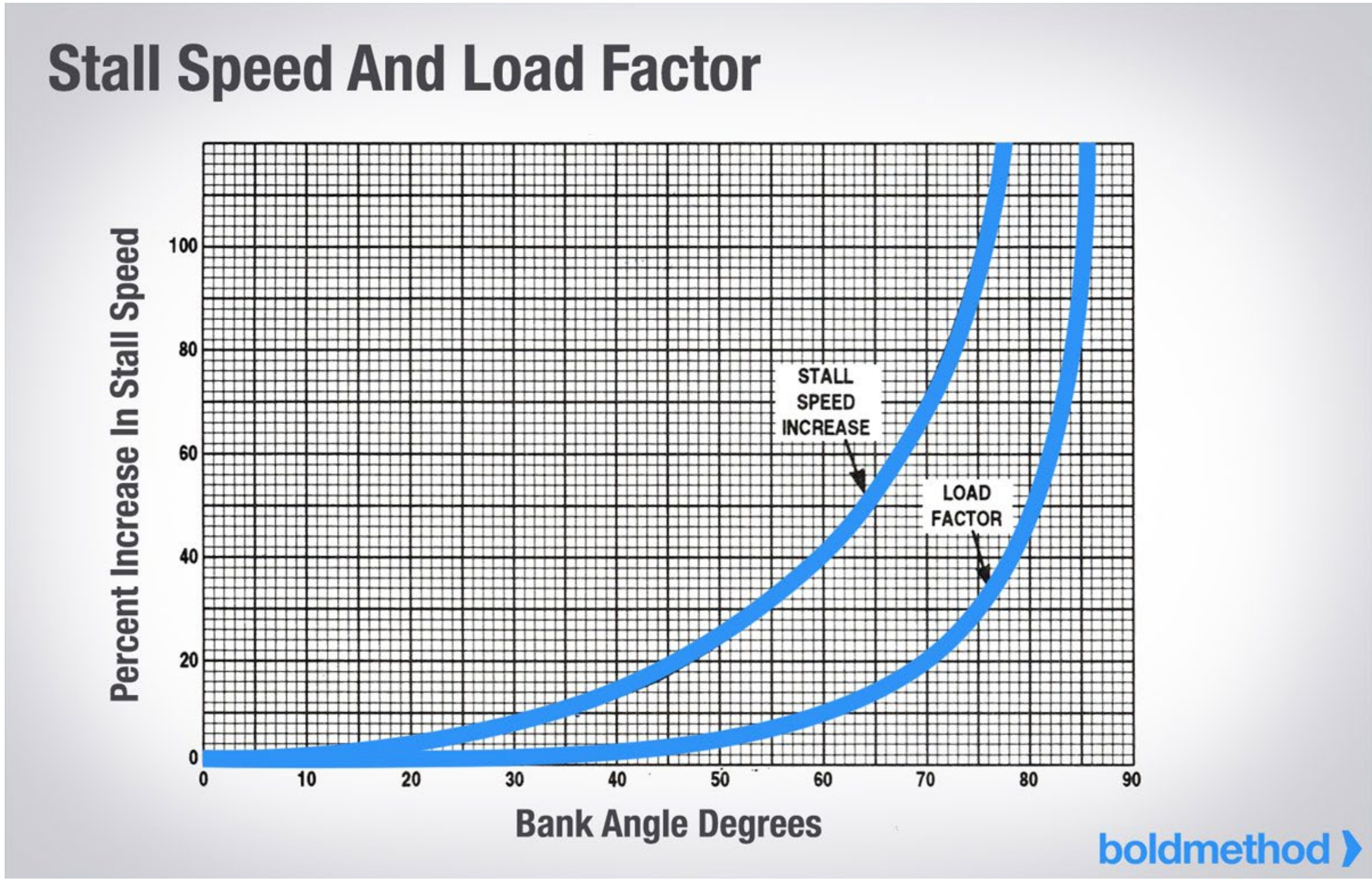


2Gs



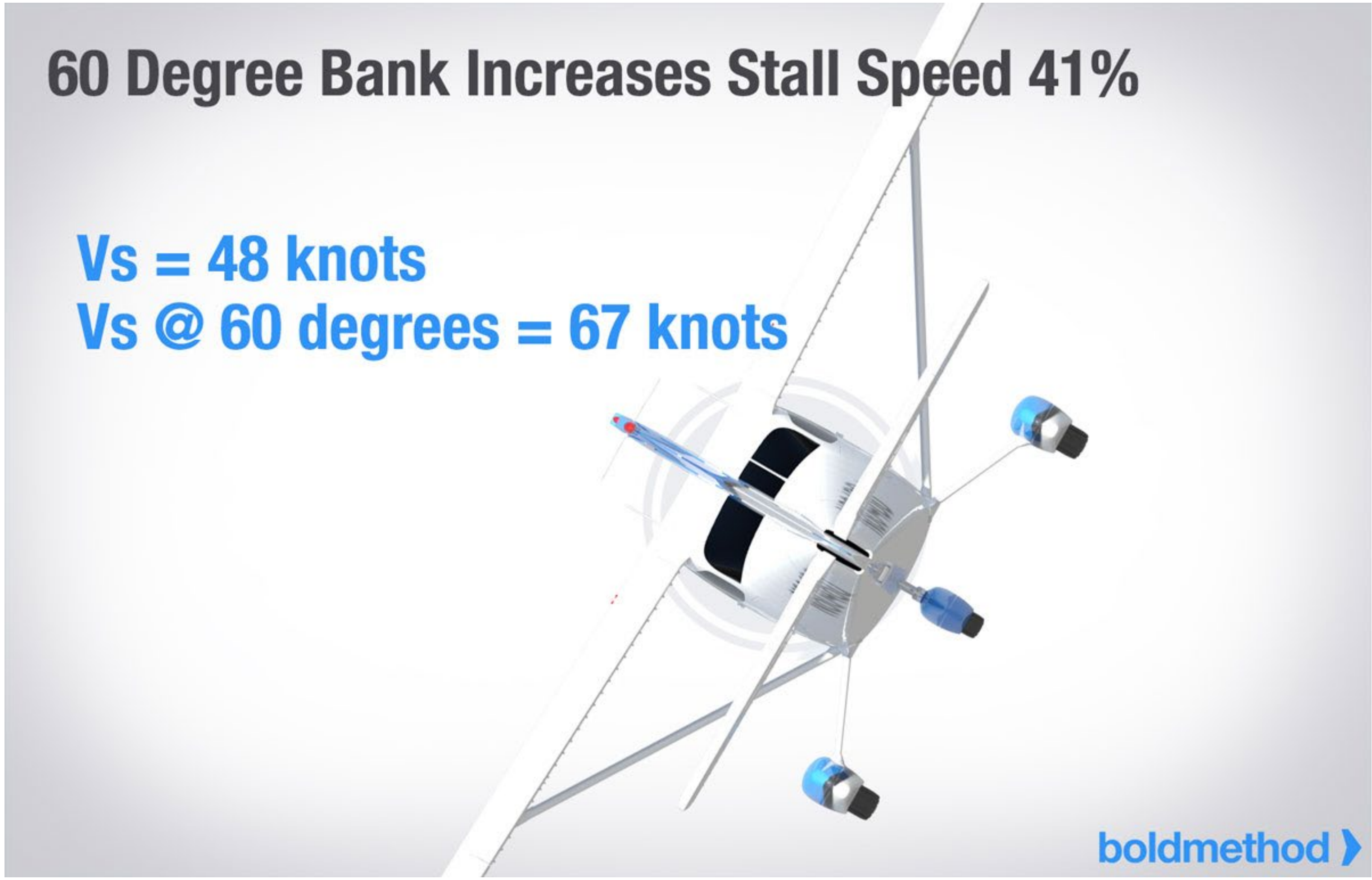
Stall Speed is Related

Stall speed increases in proportion to the square root of load factor.



Stall speed increases in proportion to the square root of load factor.

Stall Speed is Related



https://youtu.be/QB9Tuwq424M

Any questions I can answer or follow up later on?

Adverse Yaw

Cleared For the Option!

Lesson Objective

To develop understanding of what we mean when we say adverse yaw

Ailerons Cause Adverse Yaw

A tendency for the plane to want to yaw in the opposite direction of the turn

Caused by having more induced drag on the upward wing

Induced drag is a product of lift

Ailerons Cause Adverse Yaw

When you roll your airplane to the right, your right aileron goes up, and your left aileron goes down.

The aileron in the upward position (the right aileron in this example) creates less lift and less drag than the aileron that is lowered.

The aileron angled downward (the left aileron in this example) produces more drag and more lift, initially yawing the airplane in the opposite direction of your roll.

Adverse Yaw Summary

Adverse yaw during a turn entry is caused by:

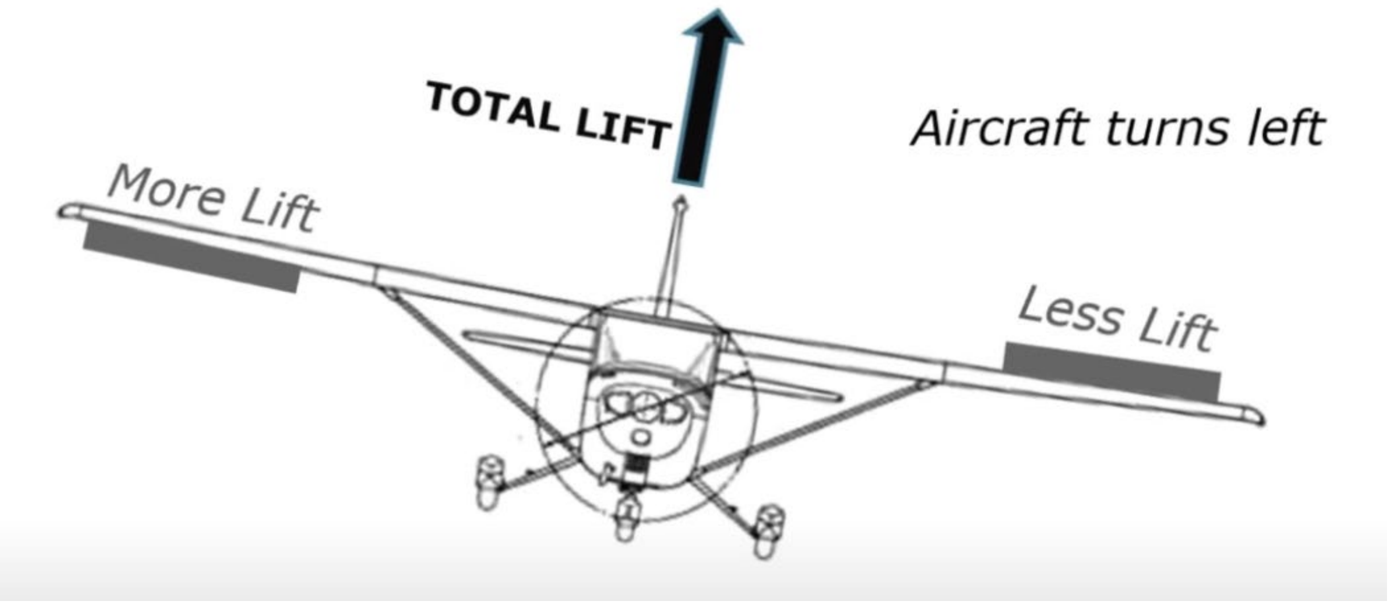
- decreased induced drag on the lowered wing
- increased induced drag on the raised wing

Adverse Yaw Summary

Adverse yaw during a turn entry is caused by:

• decreased induced drag on the lowered wing

• increased induced drag on the raised wing



Differential Ailerons

Differential ailerons counter adverse yaw.

One aileron is raised a greater distance than the other aileron is lowered.

The extra upward aileron movement produces more drag change than an increase in AOA on the downward aileron.

This produces an increase in drag on the descending wing, which reduces adverse yaw.

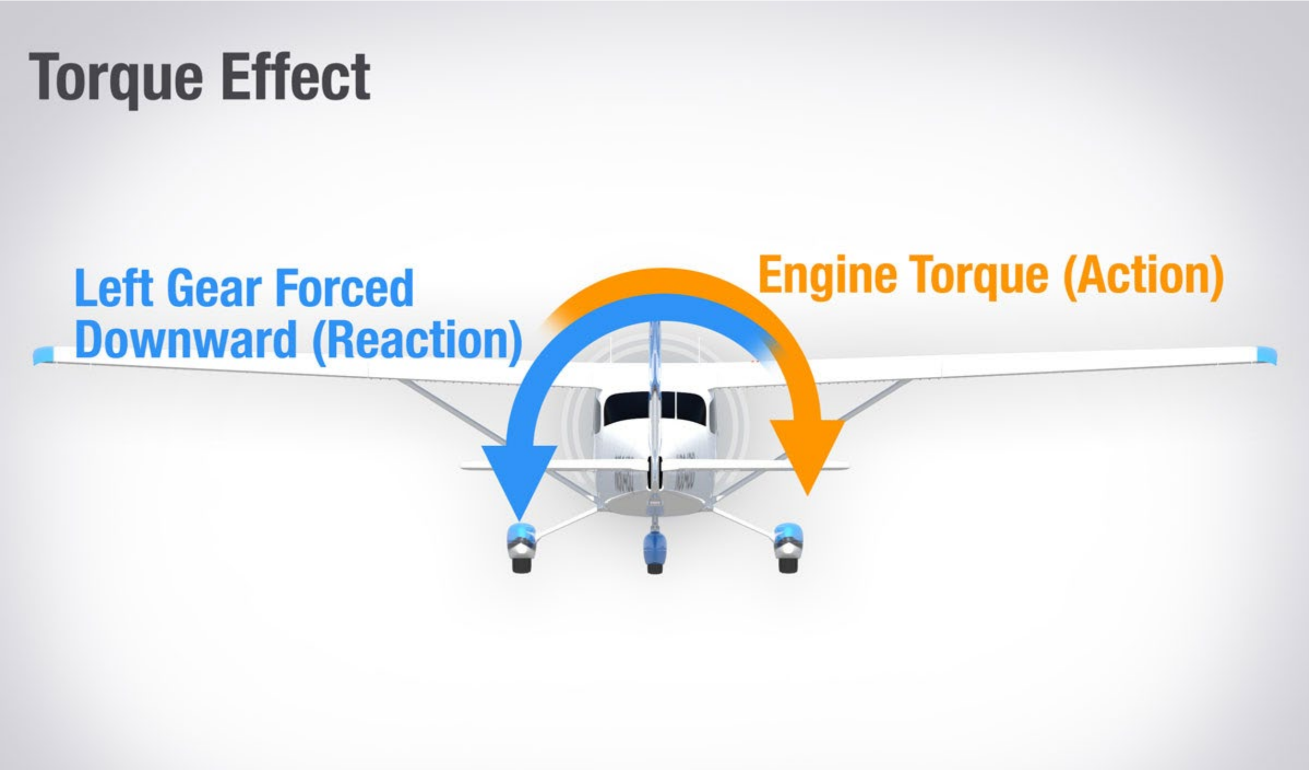
Any questions I can answer or follow up later on?

Turning tendency (torque effect)

Lesson Objective

To develop understanding of all these left turning tendencies

Torque

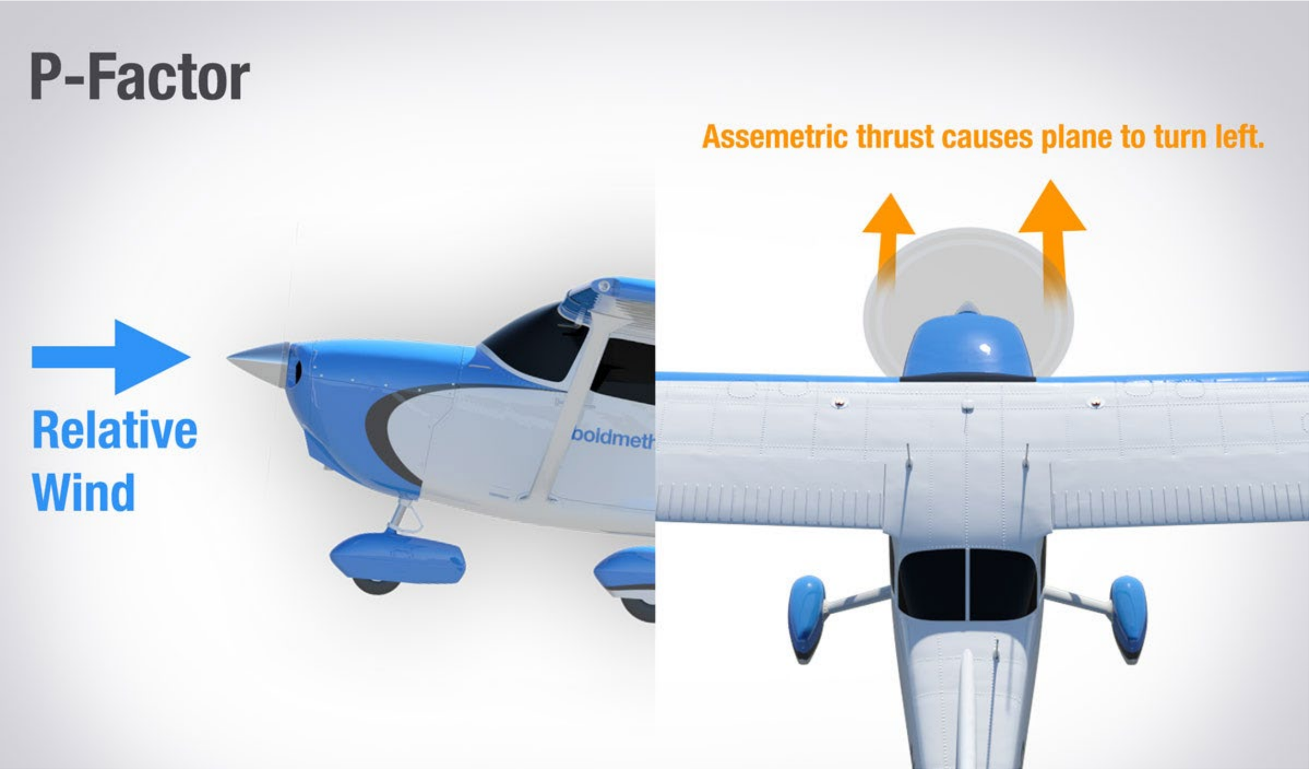


Newton's third law states that "for every action, there is an equal and opposite reaction.

As you throttle up your engine for takeoff, the **right-turning direction of your engine and propeller forces the left side of your airplane down toward the runway**.

When the left side of the airplane is forced down onto the runway, the left tire has more friction with the ground than the right tire, making your aircraft want to turn left.

P-Factor

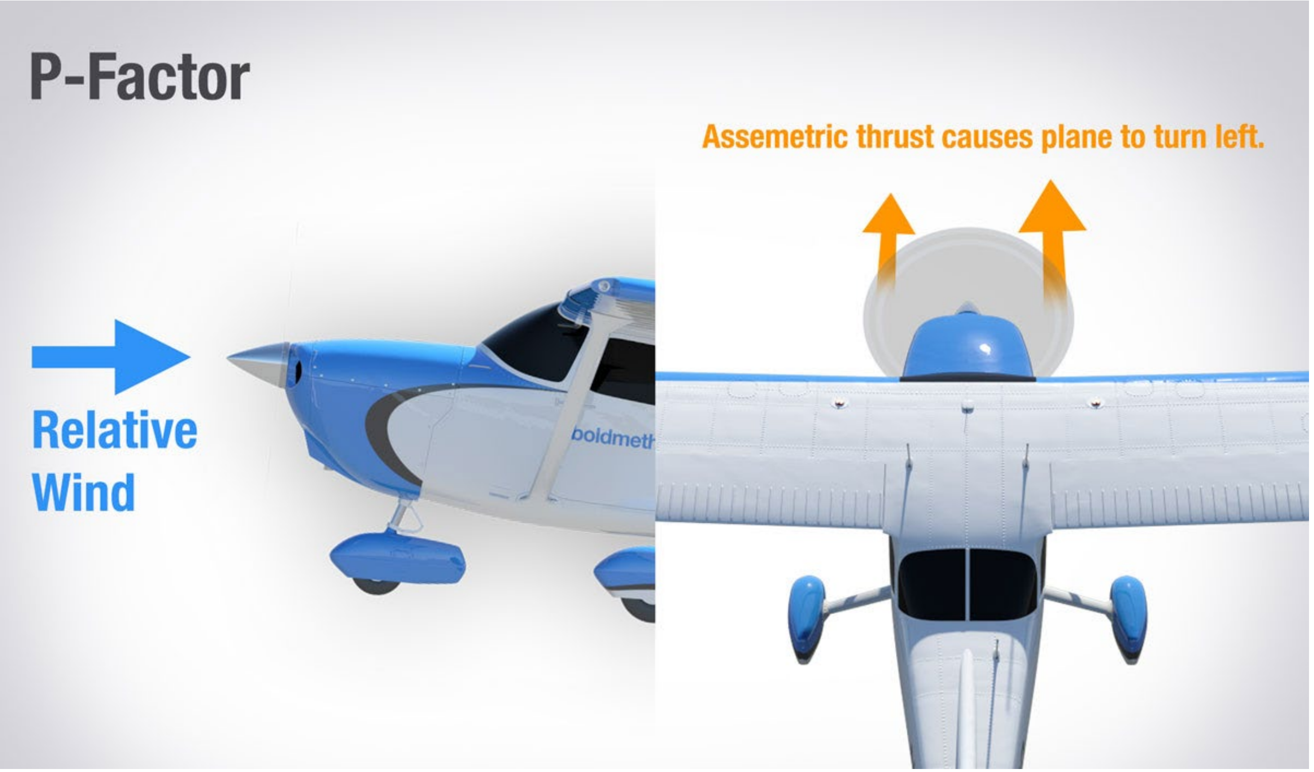


When the plane is going down the runway, the prop has relatively symmetric loading.

When the plane pitches up, the prop has relatively asymmetric loading.

The downward moving propeller blade (right side) takes a **bigger "bite"** of air than the upward moving blade.

P-Factor



This happens in two scenarios:

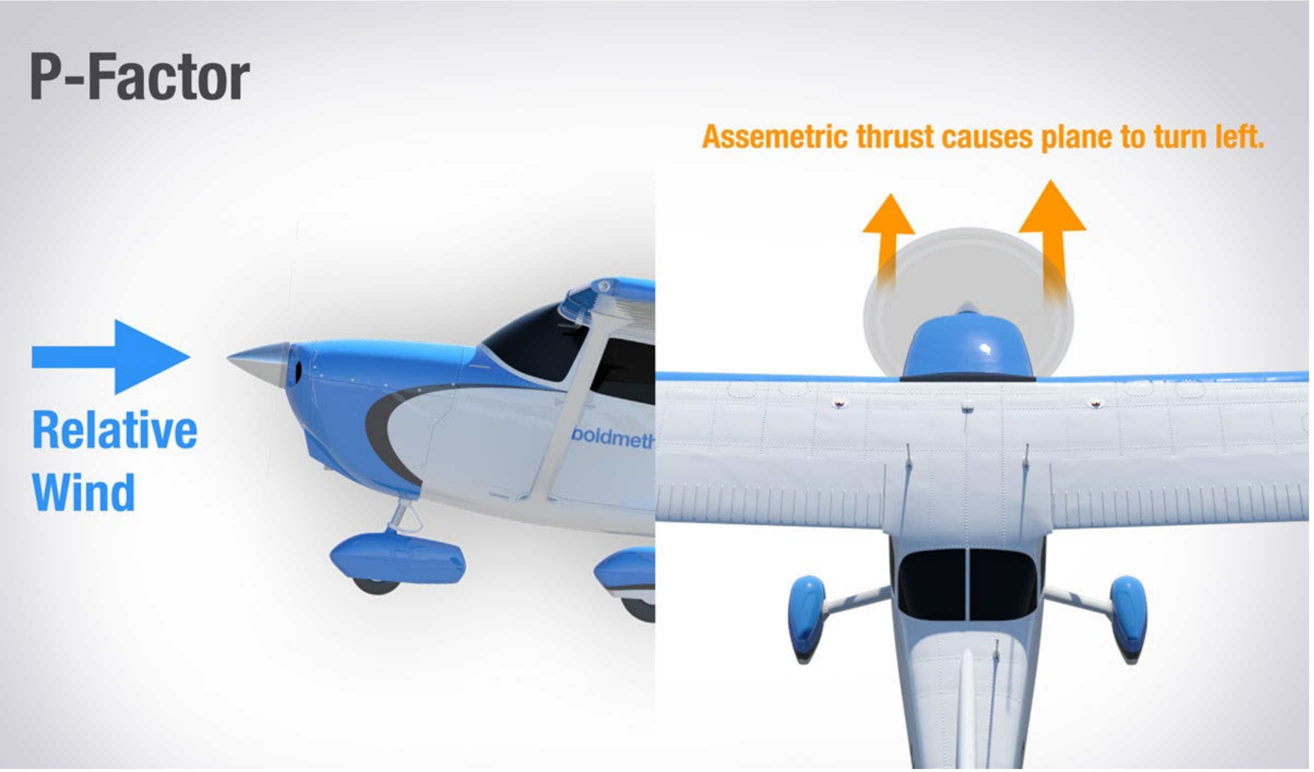
1) Your plane is flying at a high angle-of-attack like takeoff
2) You're taking off in a tailwheel airplane.

Your downward sweeping blade is at a much higher angle-of-attack than your upward sweeping blade.

With a higher AOA, the downward sweeping blade creates much more thrust (or lift), making your airplane want to yaw to the left.

Expect it when you have **Power + Pitch**

P-Factor

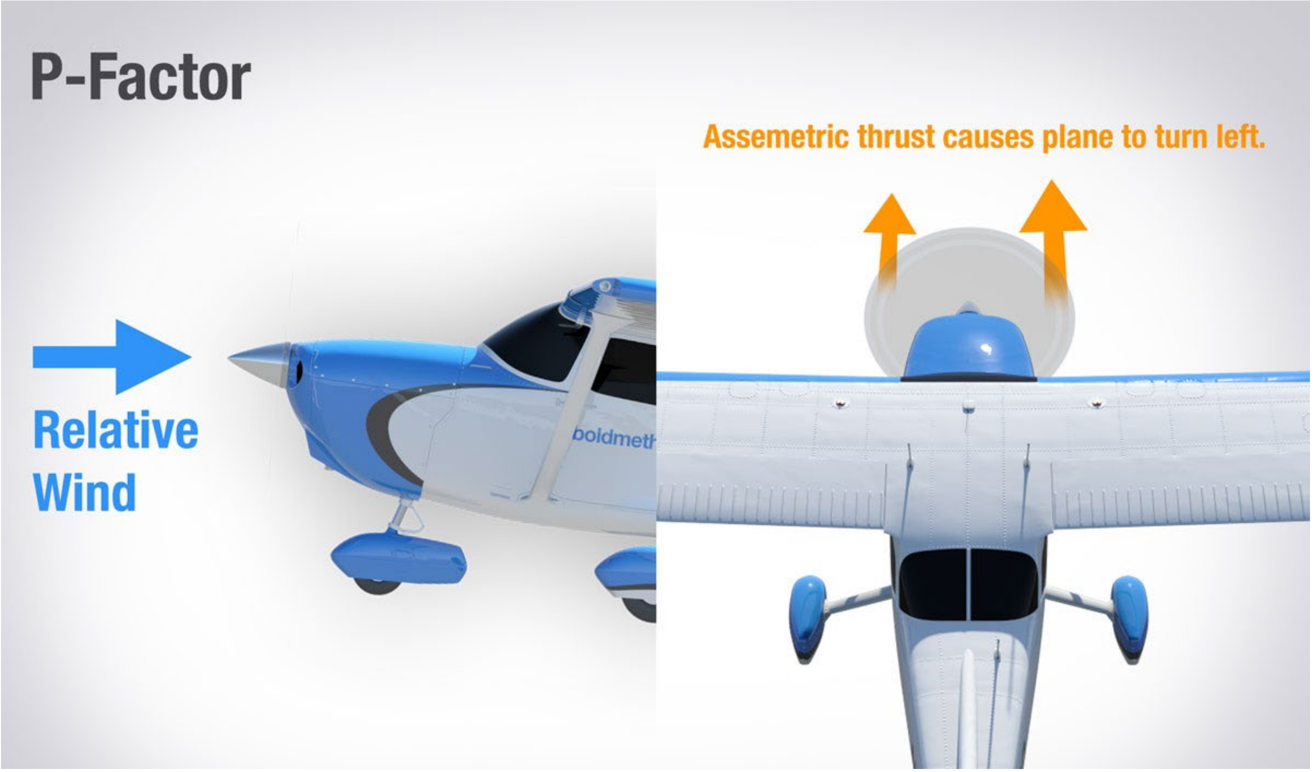


Have you been in a canoe before?

What happens if you use the oars too much on the right side?

It goes left too much

P-Factor

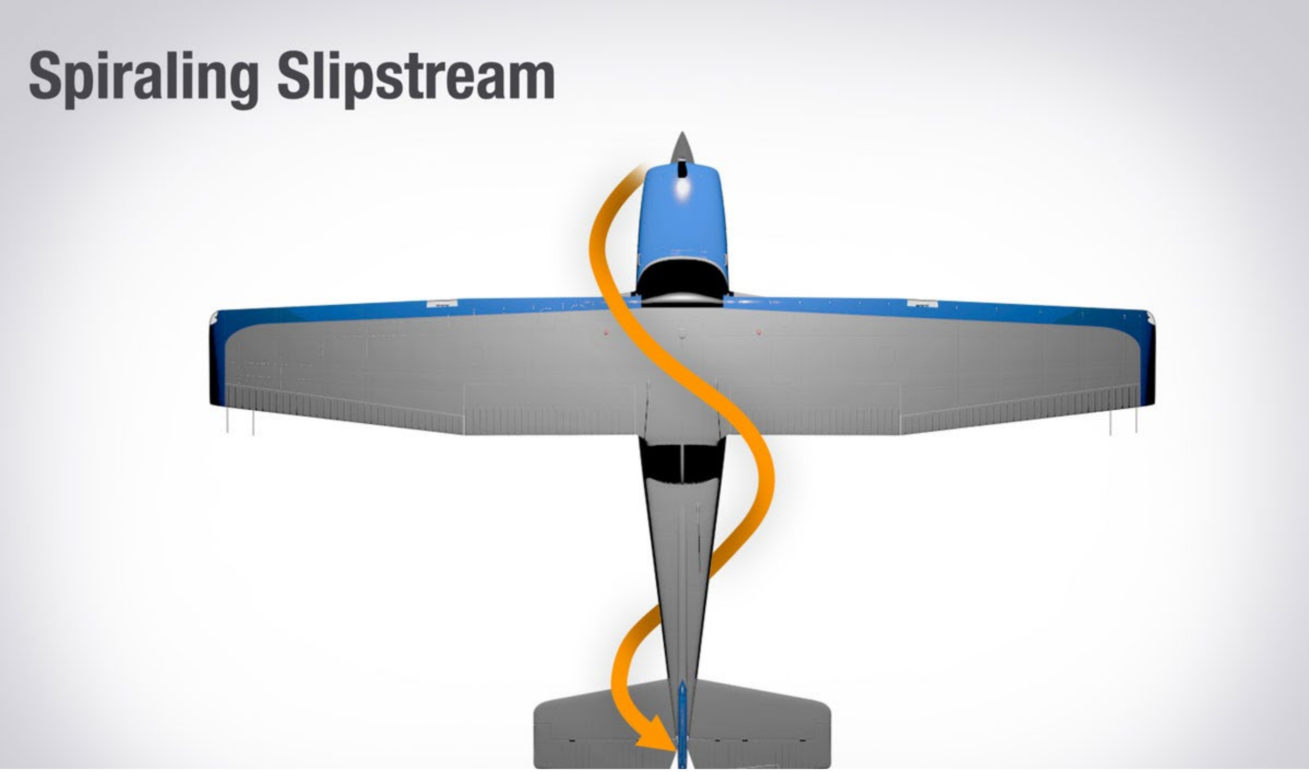


Pitch and Power

=>

More right rudder

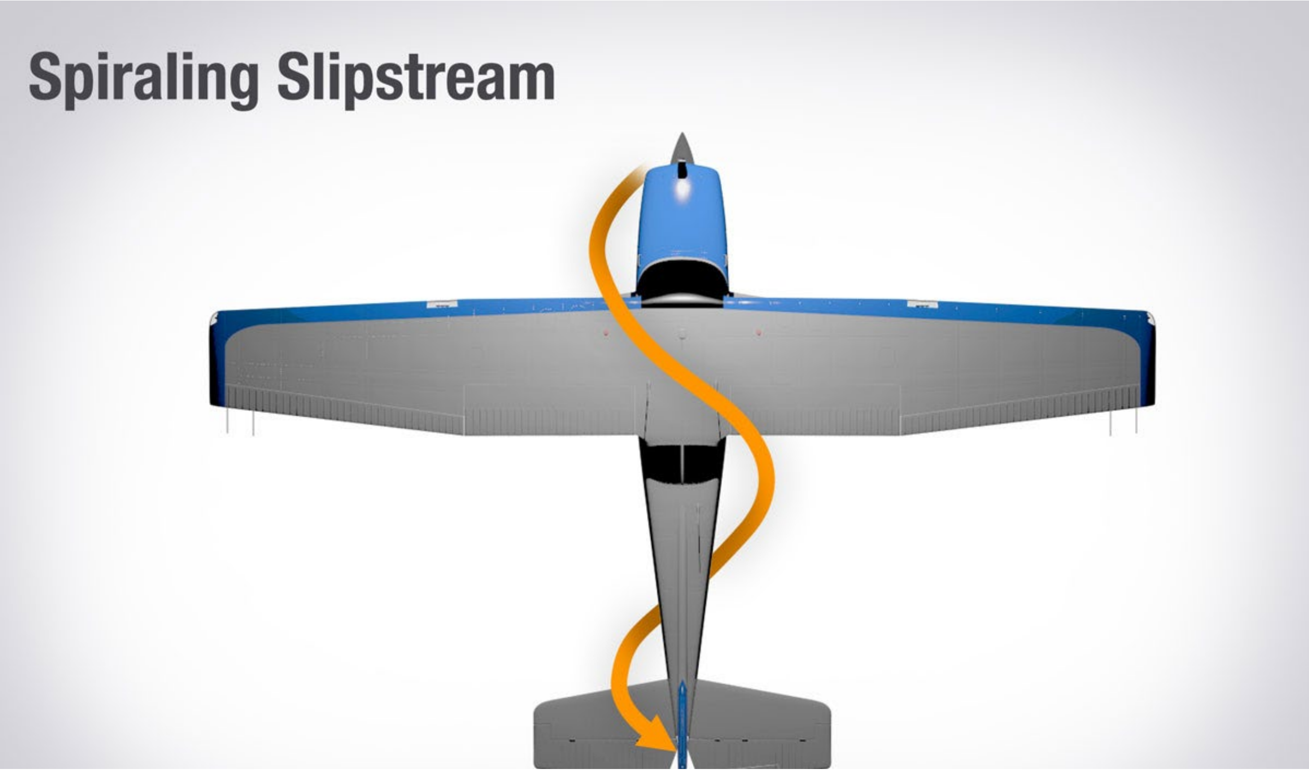
Spiraling Slipstream



Spiraling slipstream is the fourth and final left-turning tendency.

It happens when your prop is moving fast and your plane is moving slow.

Spiraling Slipstream



During takeoff, air accelerated behind the prop (known as the slipstream) follows a corkscrew pattern.

As it wraps itself around the fuselage of your plane, it **hits the left side of your aircraft's tail, creating a yawing motion, and making the aircraft yaw left**.

Gyroscopic Precession

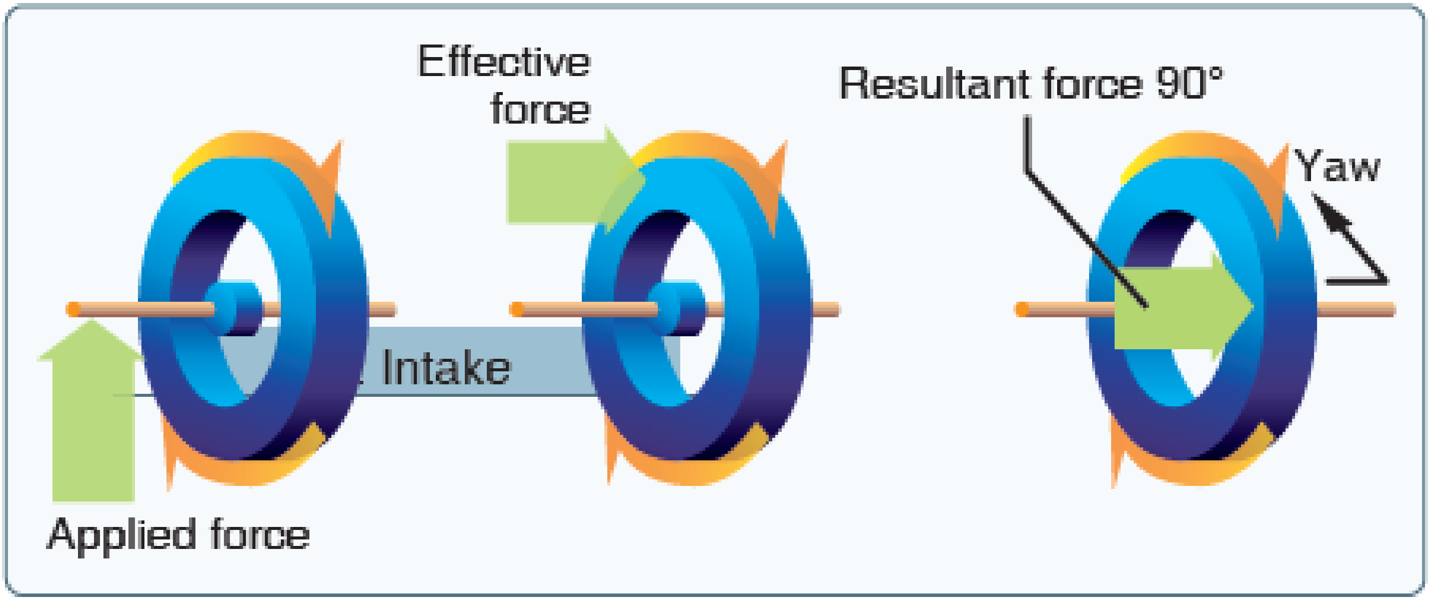


Figure 5-49. *Gyroscopic precession.*

<u>Properties of a gyroscope</u>

Rigidity in space

Precession

Precession happens when you apply force to a spinning disc.

Gyroscopic Precession

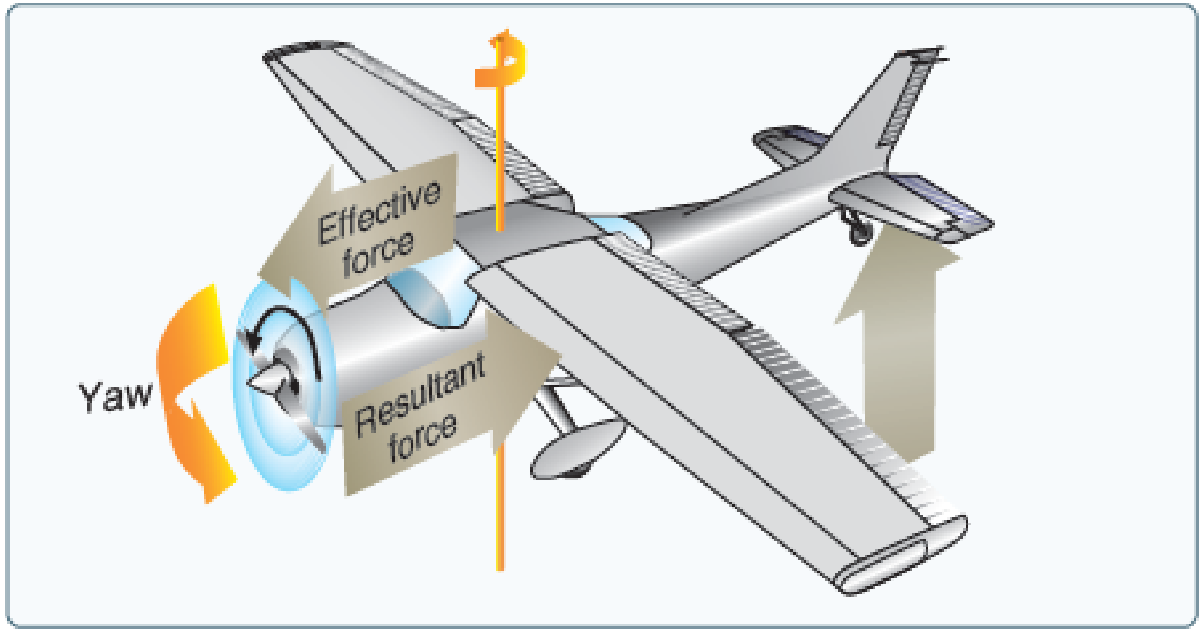


Figure 5-50. *Raising tail produces gyroscopic precession.*

A spinning propeller is essentially a gyroscope, which is a spinning disc.

As such it will be affected by precession.

Precession happens when you apply force to a spinning disc.

When you pitch down some…

Yaws left

https://youtu.be/VJOYERf6380

Gyroscope Demo https://youtu.be/P3smLuTr0Fk

https://youtu.be/-f9akJLd--c

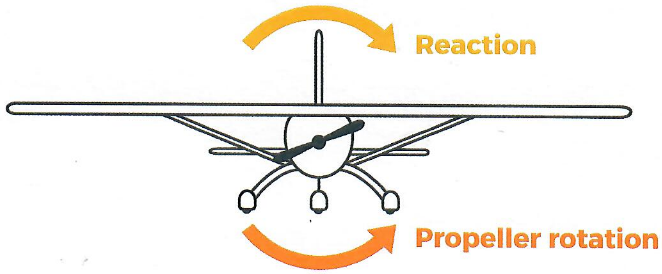
https://youtu.be/zsITk3SifE0&t=30s

https://youtu.be/-f9akJLd--c

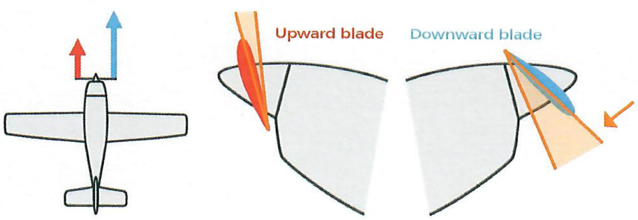
https://youtu.be/5k1VtNZIA9A

Any questions I can answer or follow up later on?

Newton's Third Law of Motion states that for every action there is an equal and opposite reaction. Typically aircraft engines rotate the propeller in a clockwise motion (from the pilot's perspective), creating **torque**, and an equal force is trying to rotate the aircraft in the opposite direction.

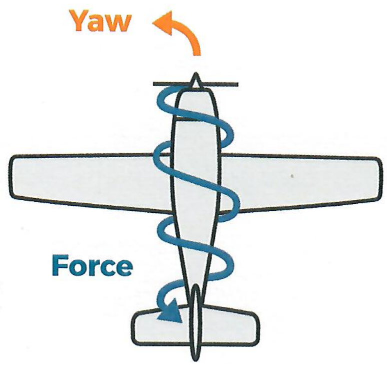


P-Factor: At positive aircraft angles of attack, the downward moving blade of a propeller on the right side of the aircraft is at a higher angle of attack than the upward moving blade on the left side of the aircraft. The downward (right side) blade produces more thrust and creates a leftward yawing force. (Illustrations not to scale.)



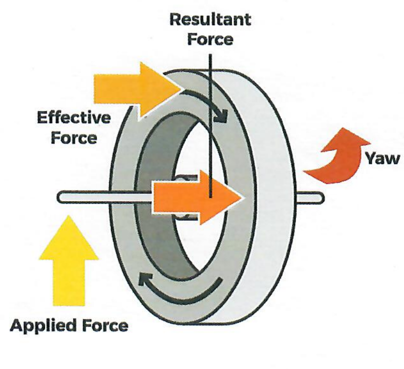
The angle of attack of the propeller blade is based on the chord line of the propeller and the relative wind.

Spiral Slipstream: The propeller creates a "corkscrew" spiraling slipstream of air around the aircraft fuselage in a clockwise motion (looking forward from the pilot's perspective) and strikes the tail on the left side of the aircraft, producing a leftward yawing force.



Gyroscopic Precession: A force applied to a gyroscope will be expressed 90 degrees later in the direction of its rotation.

Example: In tailwheel aircraft, when the tail is raised during takeoff, it is like applying a forward force to the top of the propeller, which expresses that force 90 degrees later in the propeller's clockwise rotation (from the pilot's perspective), creating a leftward yawing force.



Airplane Stability and Controllability

Lesson Objective

To develop understanding of why some aircraft are designed the way they are…the pros and cons

Info

Maneuverability = The quality of an aircraft that permits it to be operated easily and to withstand the stresses imposed

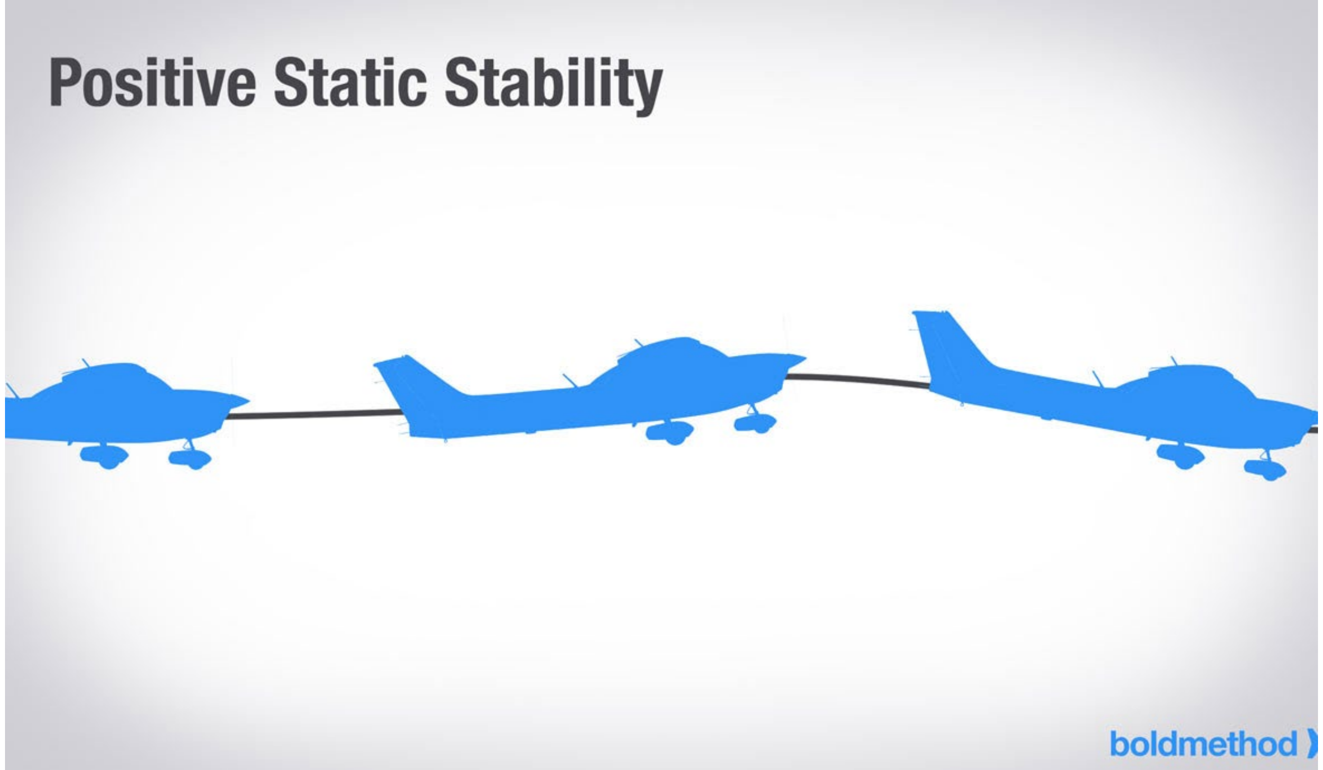
Controllability = The capability of an aircraft to respond to a pilot's inputs, especially with regard to flightpath and attitude

Stability = The tendency of an aircraft to develop forces which restore it to its original condition, when disturbed from a condition of steady flight

Positive Static Stability

An aircraft that has positive static stability tends to return to its original attitude when it's disturbed.

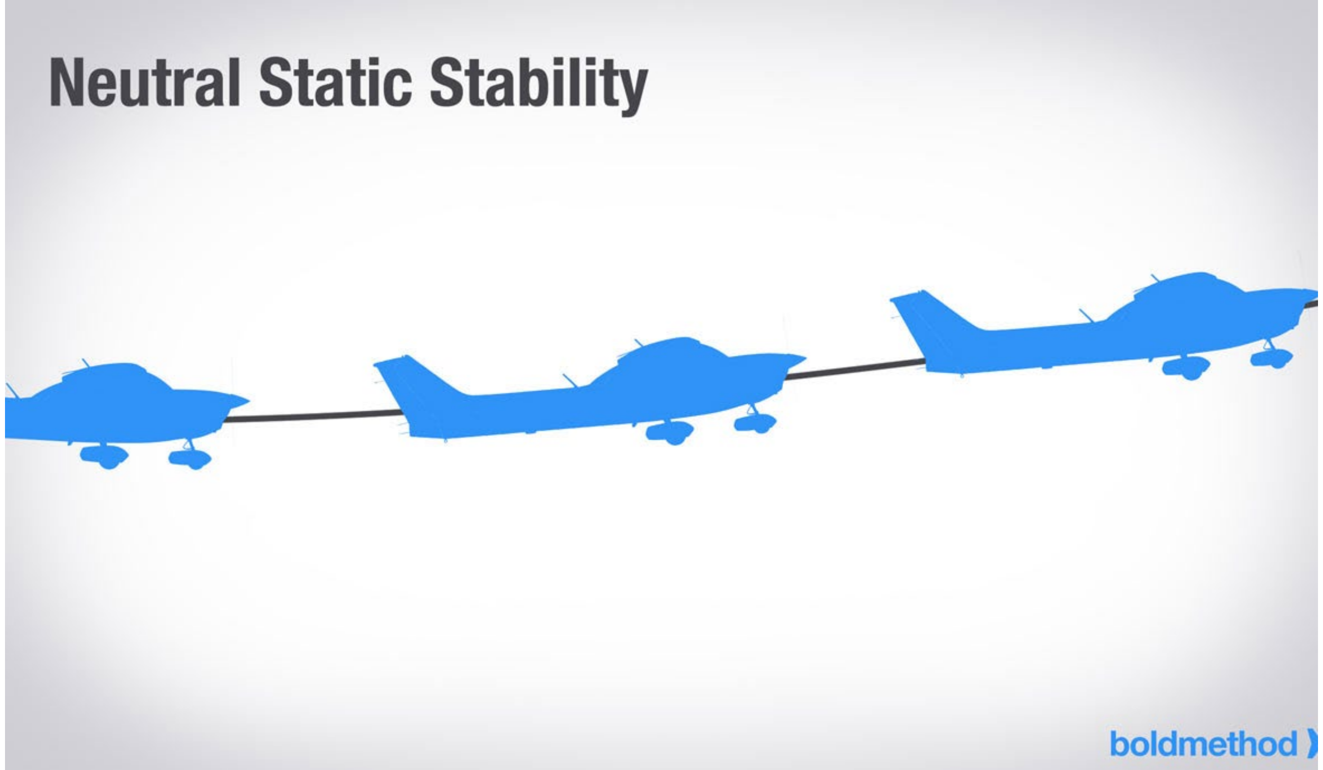
That's an example positive static stability, and it's something you'd see flying an airplane like a Cessna 172.



Neutral Static Stability

An aircraft that has neutral static stability tends to stay in its new attitude when it's disturbed.

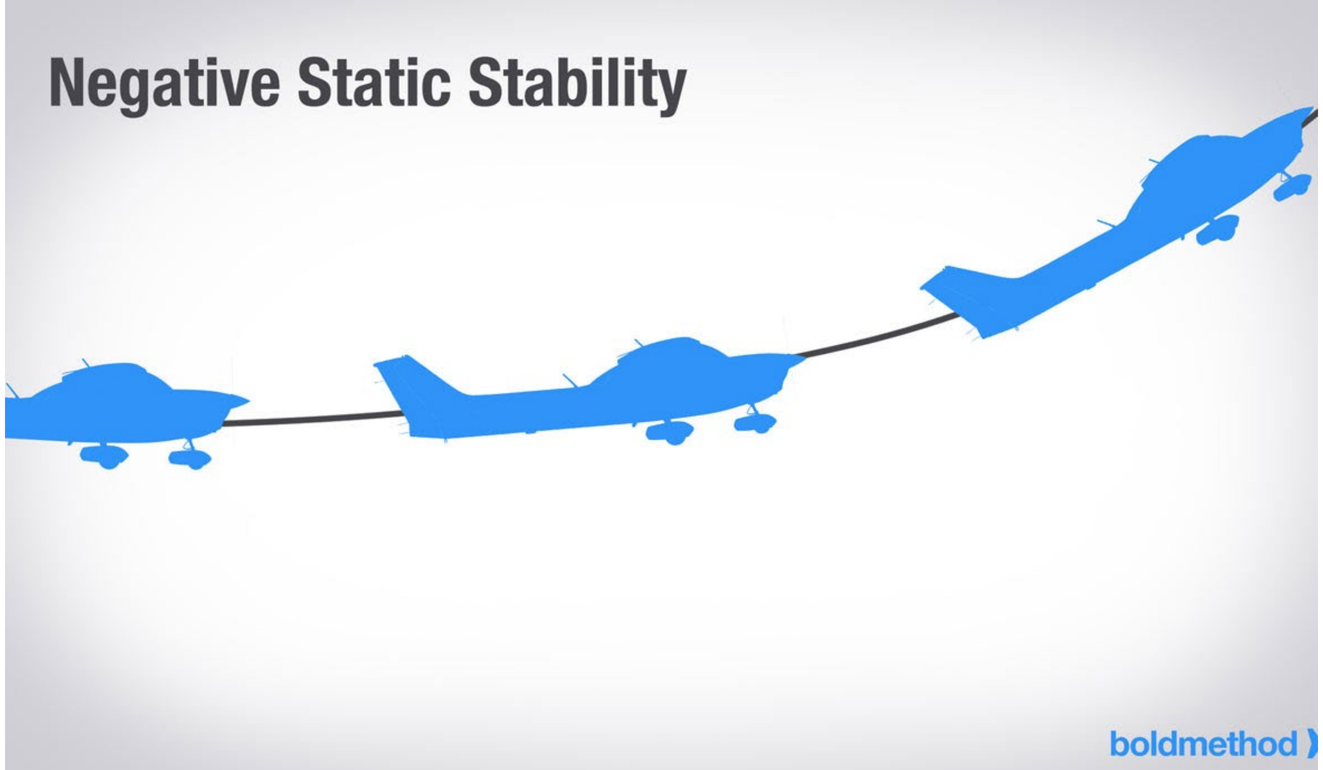
For example, if you hit turbulence and your nose pitches up 5 degrees, and then immediately after that it stays at 5 degrees nose up, your airplane has neutral static stability.



Negative Static Stability

An aircraft that has negative static stability tends to continue moving away from its original attitude when it's disturbed.

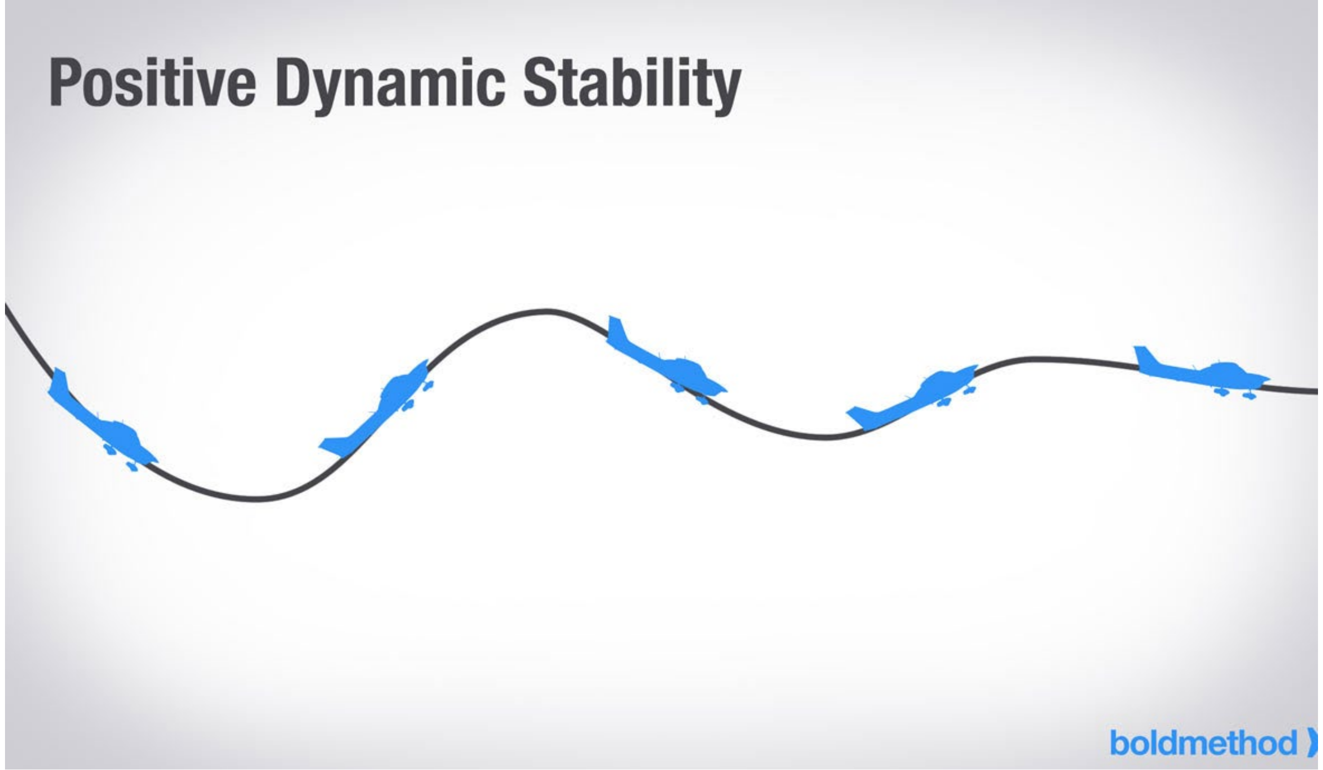
For example, if you hit turbulence and your nose pitches up, and then immediately continues pitching up, you're airplane has negative static stability.



Positive Dynamic Stability

Aircraft with positive dynamic stability have oscillations that dampen out over time.

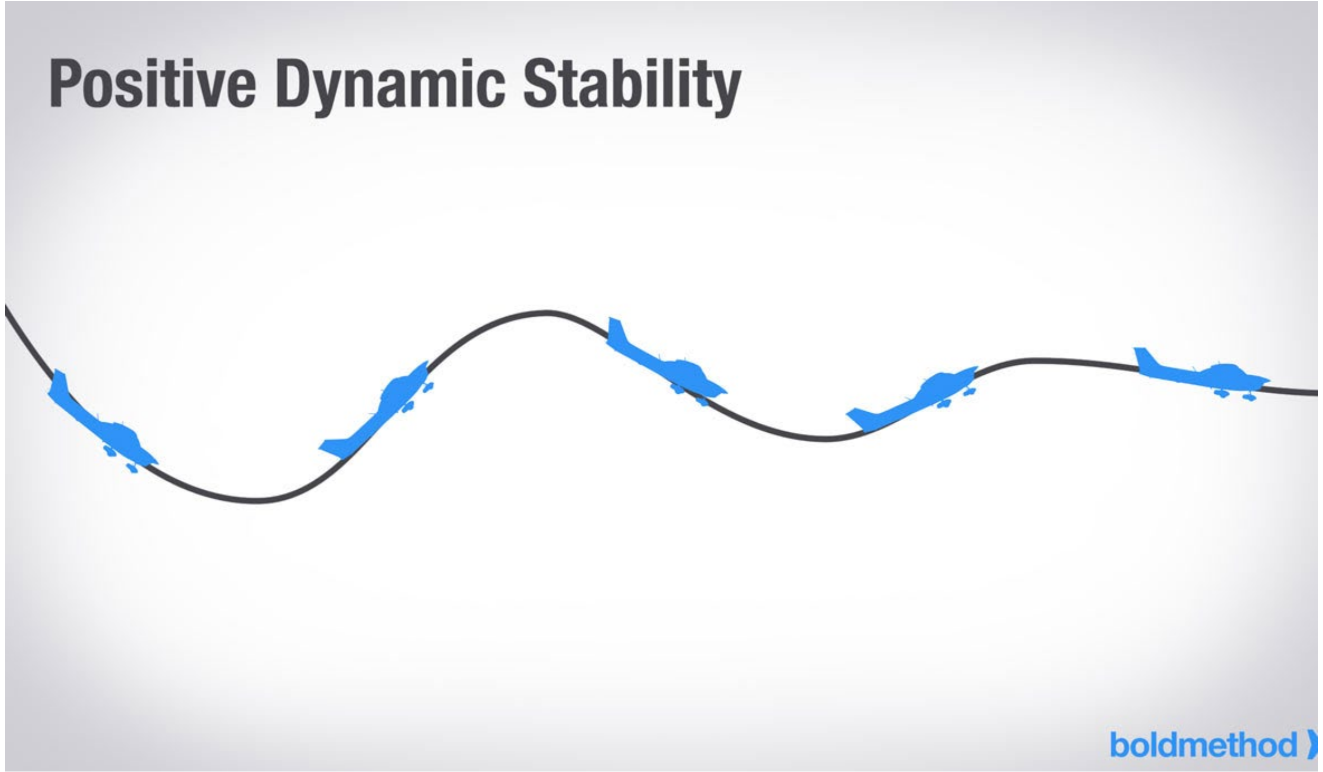
If your 172 is trimmed for level flight, and you pull back on the yoke and then let go, the nose will immediately start pitching down.



Positive Dynamic Stability

Depending on how much you pitched up initially, the nose will pitch down slightly nose low, and then, over time, pitch nose up again, but less than your initial control input.

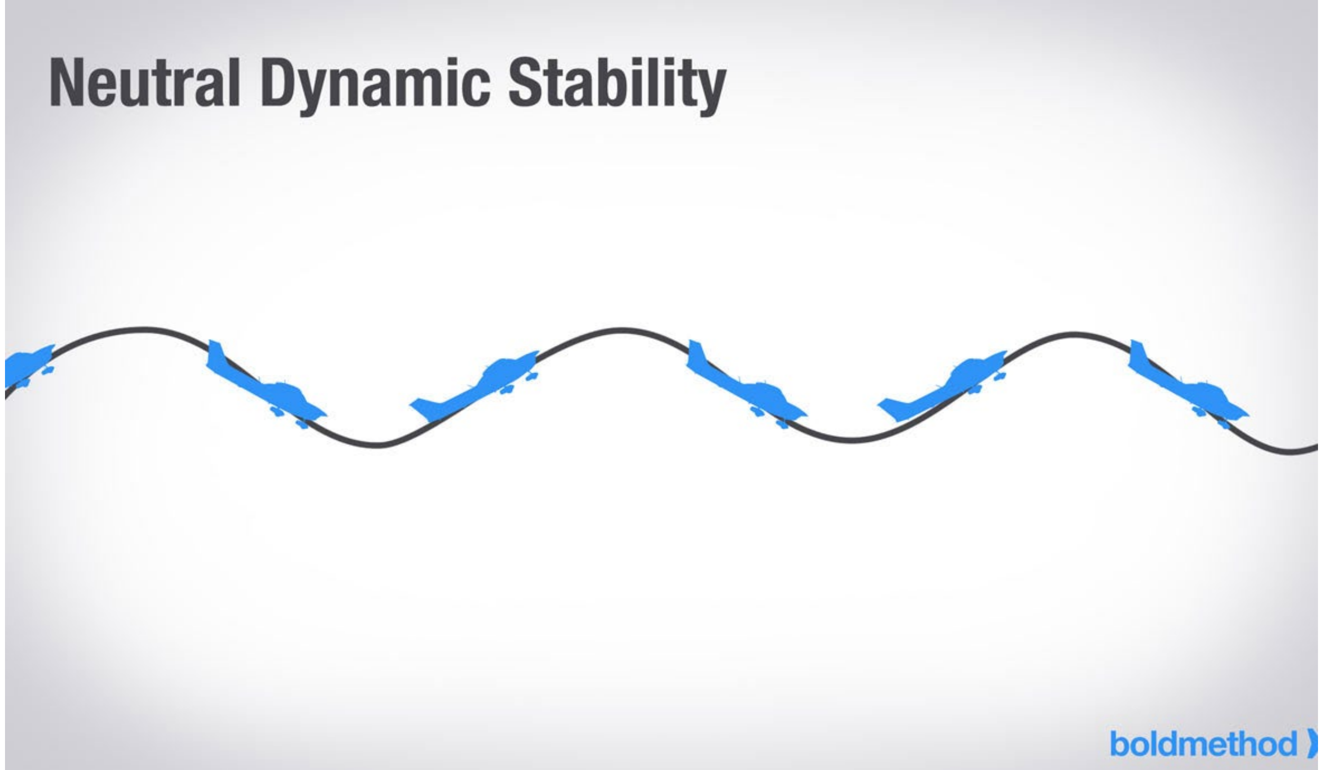
Over time, the pitching will stop, and your 172 will be back to its original attitude.



Neutral Dynamic Stability

Aircraft with neutral dynamic stability have oscillations that never dampen out.

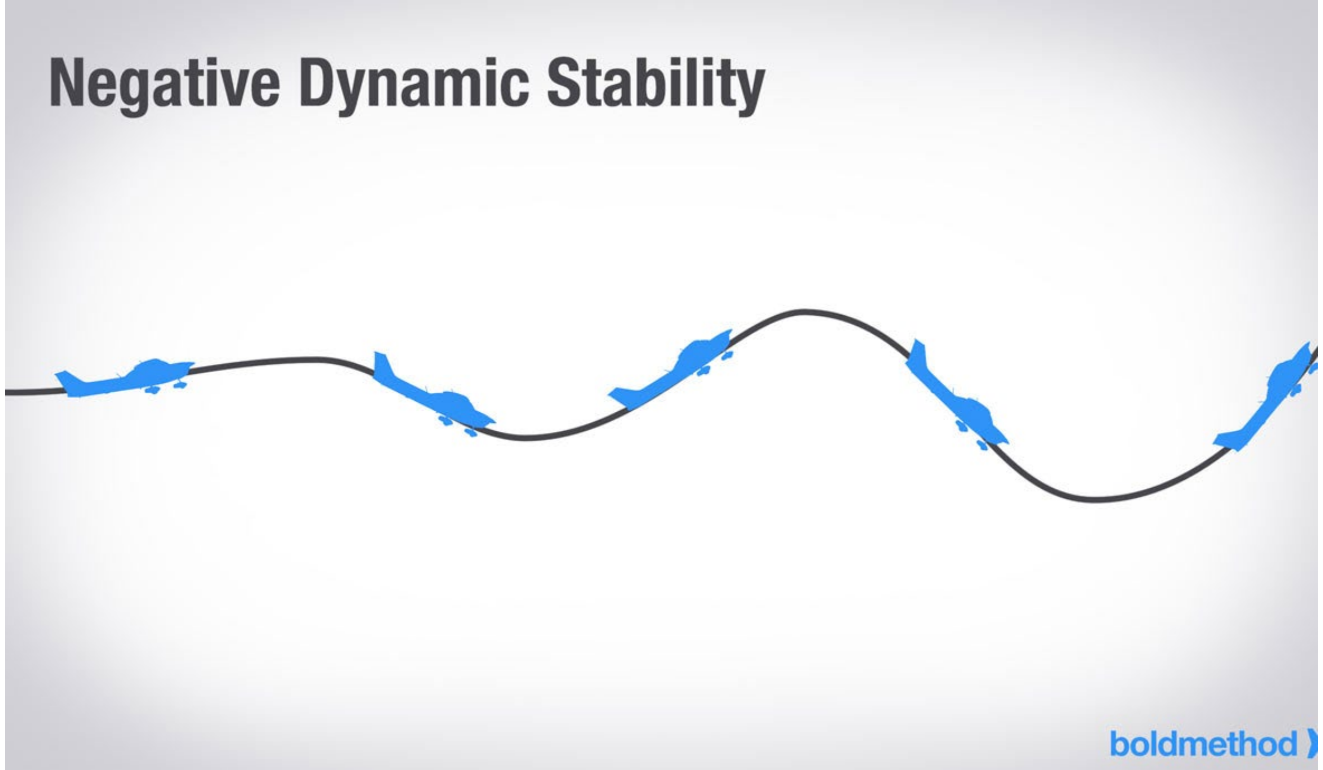
If you pitch up a trimmed, neutrally dynamic stable aircraft, it will pitch nose low, then nose high again, and the oscillations will continue, in theory, forever.



Negative Dynamic Stability

Aircraft with negative dynamic stability have oscillations that get worse over time.

Over time, the pitch oscillations get more and more amplified.



Dutch Roll

Dutch roll is a series of out-of-phase turns, when the aircraft rolls in one direction and yaws in the other. Its name comes from the motion of a classic Dutch skating technique.

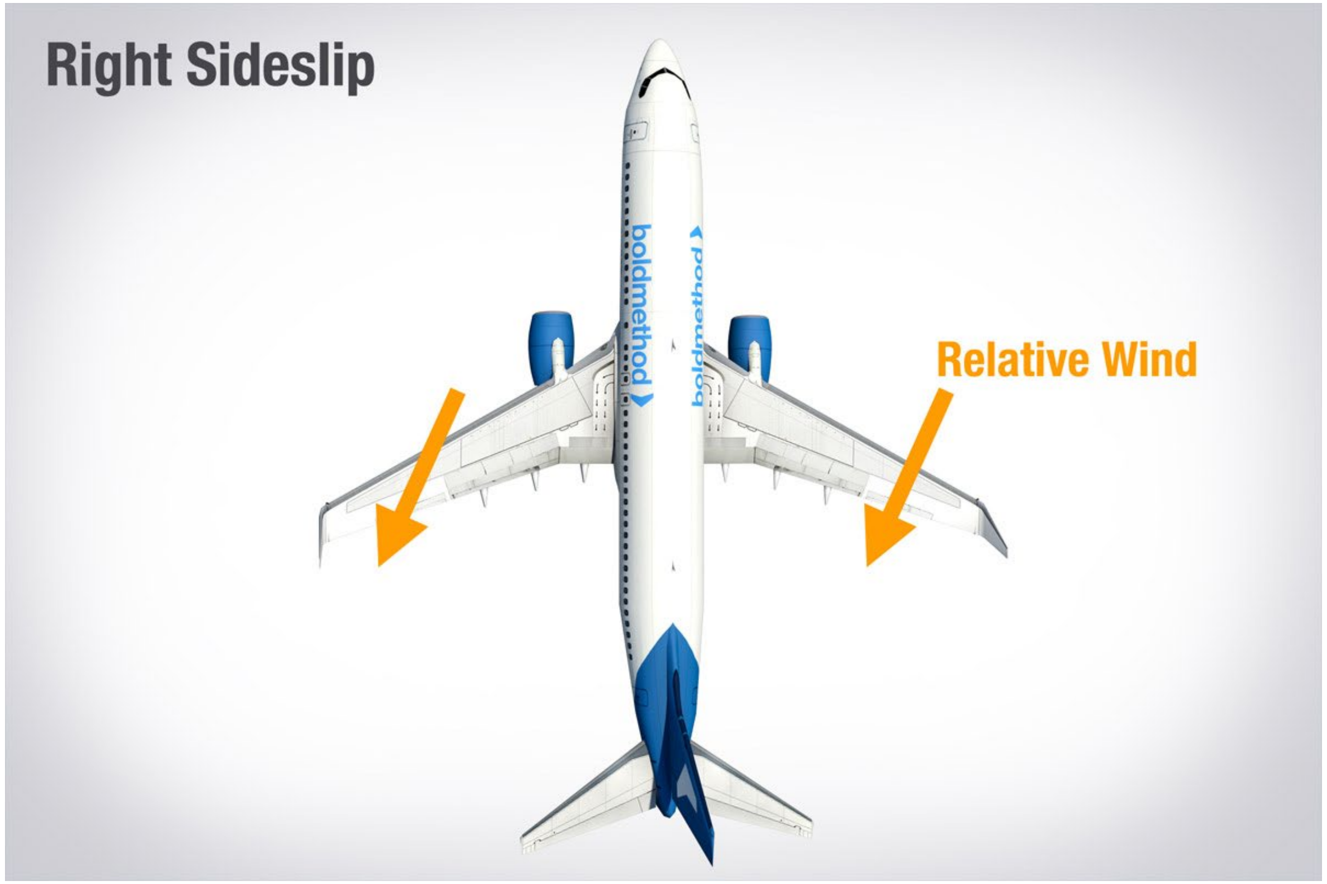
Dutch roll happens naturally in many aircraft. Sometimes it's performed intentionally as an aerobatic maneuver, and other times it happens accidentally and makes everyone feel like an out of control aerobatic passenger.

Strong Roll Stability

Let's look at a 737 example: you've started an uncoordinated roll to the right.

That tilts the lift vector to the right, causing a sideslip motion. Instead of the airflow blowing straight down your nose, it's now coming from the right.

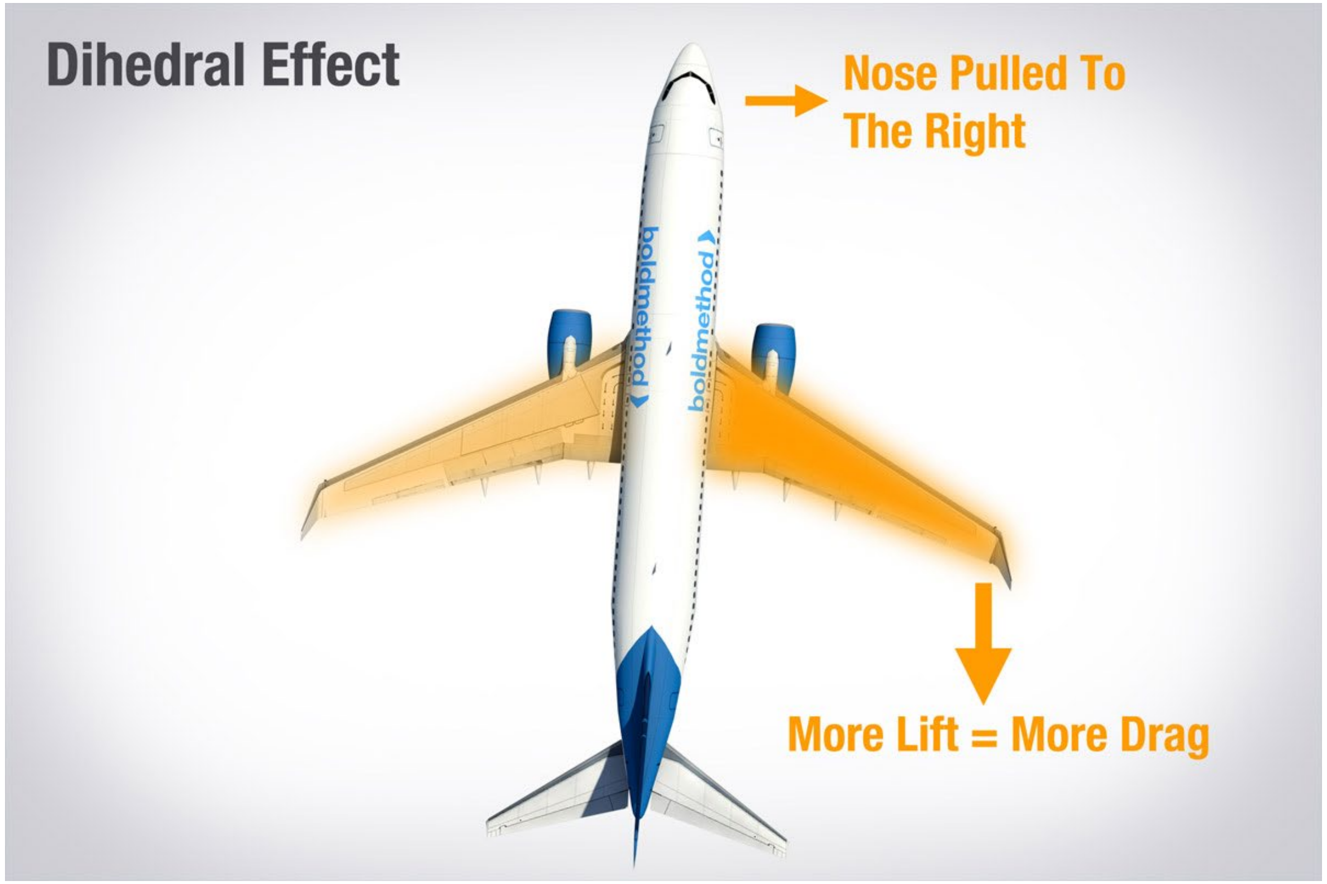
Take a look at the example below - see how the air is hitting the right wing's leading edge straight on, and the left wing's leading edge at an angle?



Strong Roll Stability

Only the air flowing parallel to the chord line creates lift. In the example above, the right wing has more air flowing parallel to the chord line than the left wing, meaning the right wing generates more lift.

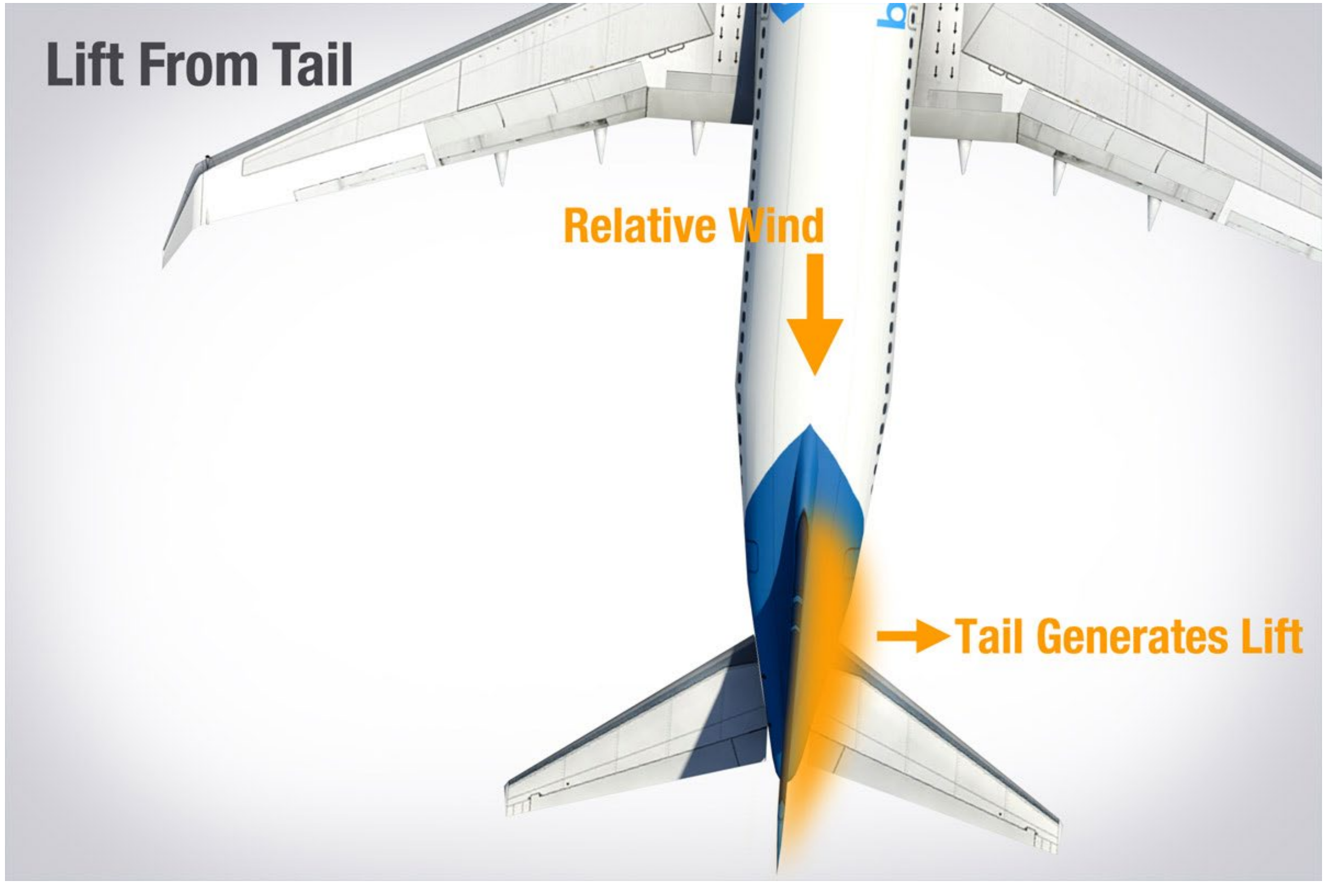
This effect is known as dihedral effect because it simulates the stabilizing effect of dihedral. It results in positive roll stability; the extra lift rolls the aircraft back towards level. However, this extra lift also generates drag that pulls your nose to the right.



Weaker Roll Stability

Your vertical stabilizer helps stop the yaw motion caused by the right wing's drag. With your nose yawed to the right, the relative airflow approaches the vertical stabilizer from the left. Your vertical stabilizer generates lift towards the right, yawing the nose back to the left. The vertical stabilizer actually generates lift - it's not just air "pushing" the tail back into position.

With a typical swept wing aircraft, this yaw stability isn't as strong as the roll stability caused by the sweepback.



For more info

See PHAK FAA-H-8083-25B 5-14 to 5-20

See ASA Pilot’s Manual Ground School Chapter 2

Any questions I can answer or follow up later on?

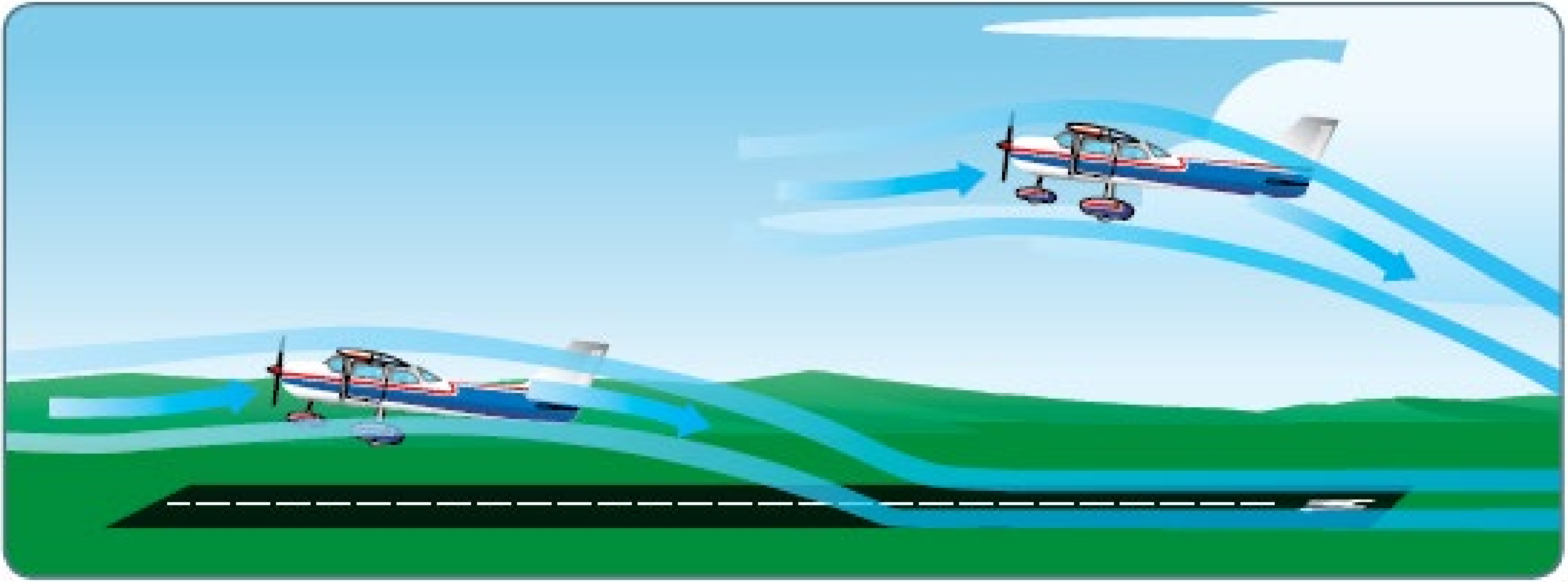
Ground Effect

Ground Effect (from PHAK)

Ever since the beginning of manned flight, pilots realized that just before touchdown it would suddenly feel like the aircraft did not want to go lower, and it would just want to go on and on. This is due to the air that is trapped between the wing and the landing surface, as if there were an air cushion. This phenomenon is called ground effect.

When an aircraft in flight comes within several feet of the surface, ground or water, a change occurs in the three dimensional flow pattern around the aircraft because the vertical component of the airflow around the wing is restricted by the surface. This alters the wing's upwash, downwash, and wingtip vortices. Ground effect, then, is due to the interference of the ground (or water) surface with the airflow patterns about the aircraft in flight..

Ground Effect (from PHAK)



Ground Effect (from PHAK)

Ground effect is the reduced aerodynamic drag that an aircraft's wings generate when they are close to a fixed surface.

When the wing is at a height equal to its span, the reduction in induced drag is only 1.4 percent. However, when the wing is at a height equal to one-fourth its span, the reduction in induced drag is 23.5 percent and, when the wing is at a height equal to one-tenth its span, the reduction in induced drag is 47.6 percent. Thus, a large reduction in induced drag takes place only when the wing is very close to the ground.

Ground Effect (from PHAK)

An aircraft leaving ground effect after takeoff encounters just the reverse of an aircraft entering ground effect during landing. The aircraft leaving ground effect will:

- Require an increase in AOA to maintain the same CL
- Experience an increase in induced drag and thrust required
- Experience a decrease in stability and a nose-up change in moment
- Experience a reduction in static source pressure and increase in indicated airspeed

Ground Effect (from PHAK)

Ground effect must be considered during takeoffs and landings.

For example, if a pilot fails to understand the relationship between the aircraft and ground effect during takeoff, a hazardous situation is possible because the recommended takeoff speed may not be achieved.

Due to the reduced drag in ground effect, the aircraft may seem capable of takeoff well below the recommended speed.

As the aircraft rises out of ground effect with a deficiency of speed, the greater induced drag may result in marginal initial climb performance.

In extreme conditions, such as high gross weight, high density altitude, and high temperature, a deficiency of airspeed during takeoff may permit the aircraft to become airborne but be incapable of sustaining flight out of ground effect.

In this case, the aircraft may become airborne initially with a deficiency of speed and then settle back to the runway.

Ground Effect (from PHAK)

A pilot should not attempt to force an aircraft to become airborne with a deficiency of speed.

The manufacturer’s recommended takeoff speed is necessary to provide adequate initial climb performance.

It is also important that a definite climb be established before a pilot retracts the landing gear or flaps.

Never retract the landing gear or flaps prior to establishing a positive rate of climb and only after achieving a safe altitude.

Ground Effect (from PHAK)

If, during the landing phase of flight, the aircraft is brought into ground effect with a constant AOA, the aircraft experiences an increase in CL and a reduction in the thrust required, and a “floating” effect may occur.

Because of the reduced drag and lack of power-off deceleration in ground effect, any excess speed at the point of flare may incur a considerable “float” distance.

As the aircraft nears the point of touchdown, ground effect is most realized at altitudes less than the wingspan.

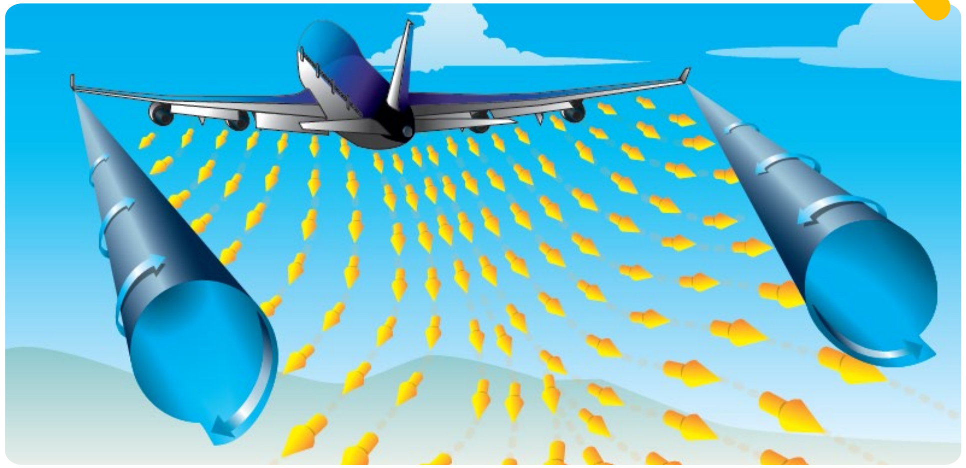
During the final phases of the approach as the aircraft nears the ground, a reduction of power is necessary to offset the increase in lift caused from ground effect otherwise the aircraft will have a tendency to climb above the desired glidepath (GP).

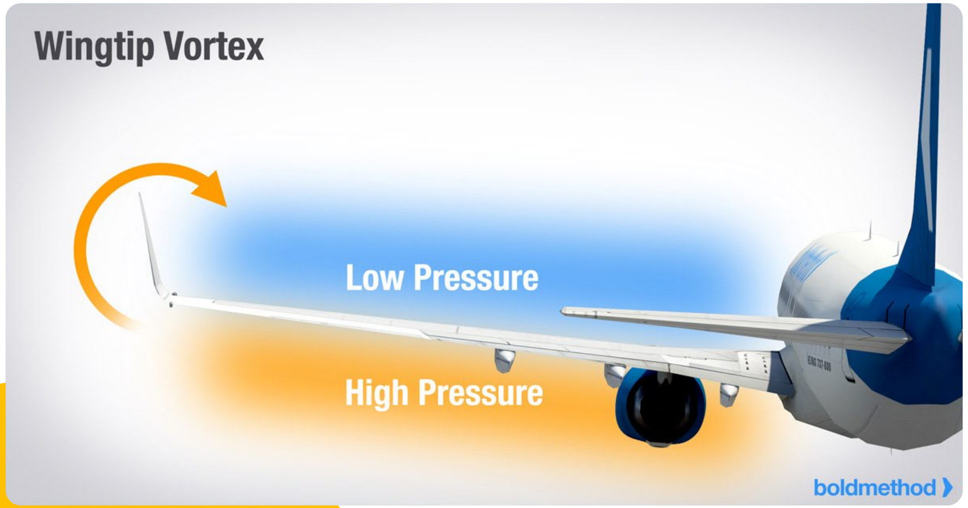
Any questions I can answer or follow up later on?

Wingtip vortices and precautions to be taken

Lesson Objective

To develop understanding of wingtip vortices and precautions to be taken



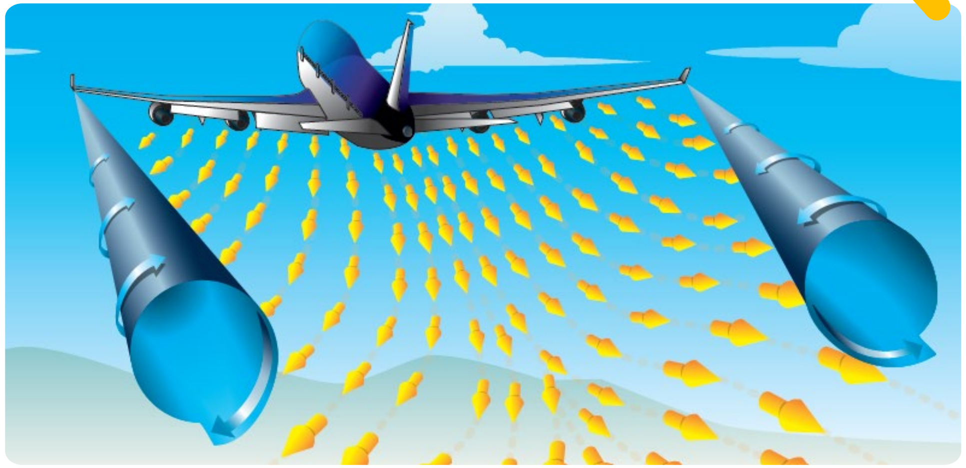


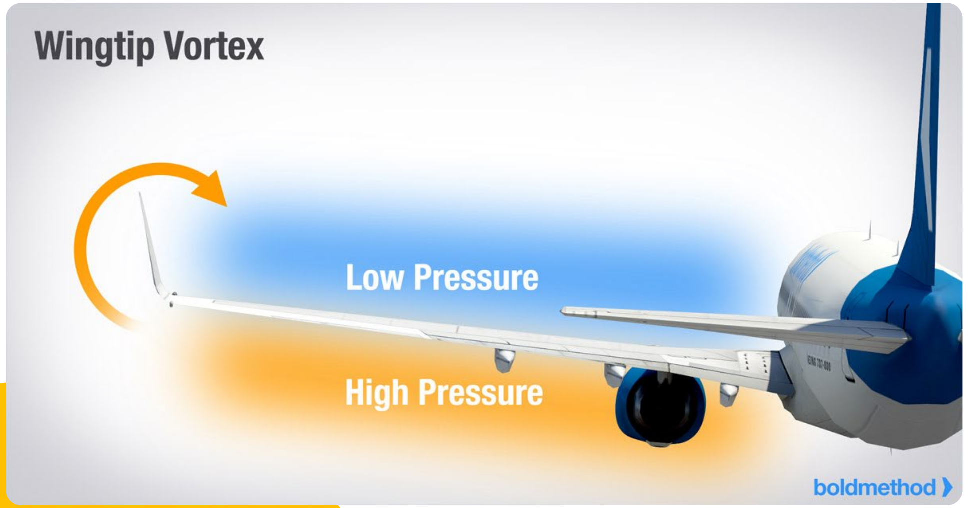
Info

Wingtip vortices are swirling tunnels of air that form on your wingtips.

High pressure air from the bottom of your wing escapes around the wingtip, moving up towards the lower pressure area on the top of the wing.

This movement creates a vortex or tunnel of air, rotating inwards behind the wing.





Info

They're strongest when the air pressure difference between the top and the bottom of the wing is the greatest - which happens when you're generating the most induced lift.

Thus, the strongest vortices occur during takeoff, climb and landing.

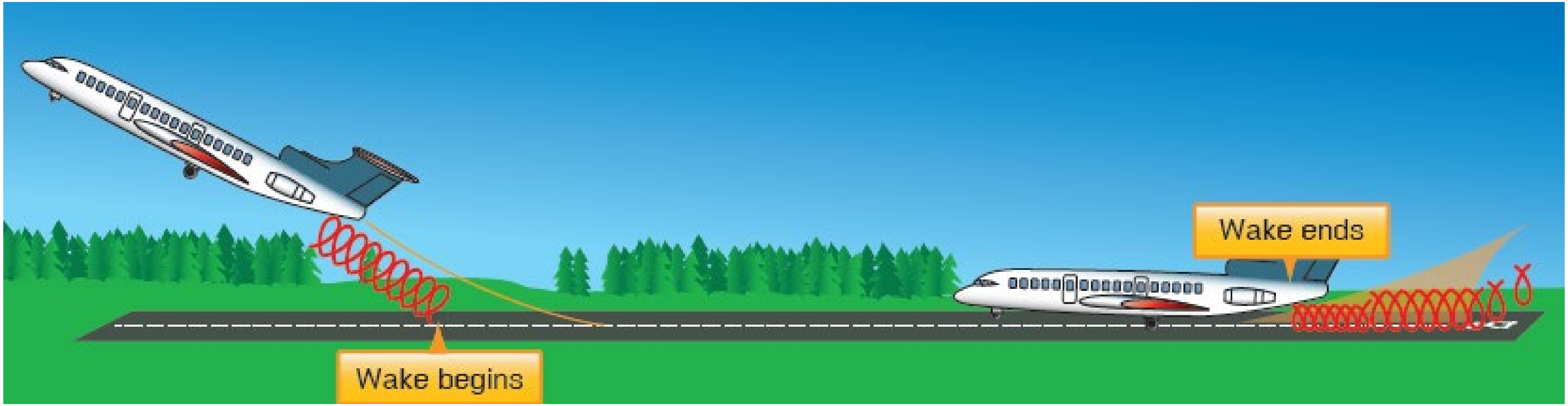
This occurs when you're at high angles of attack.

The strong vortices occur when the aircraft is heavy, clean and slow.

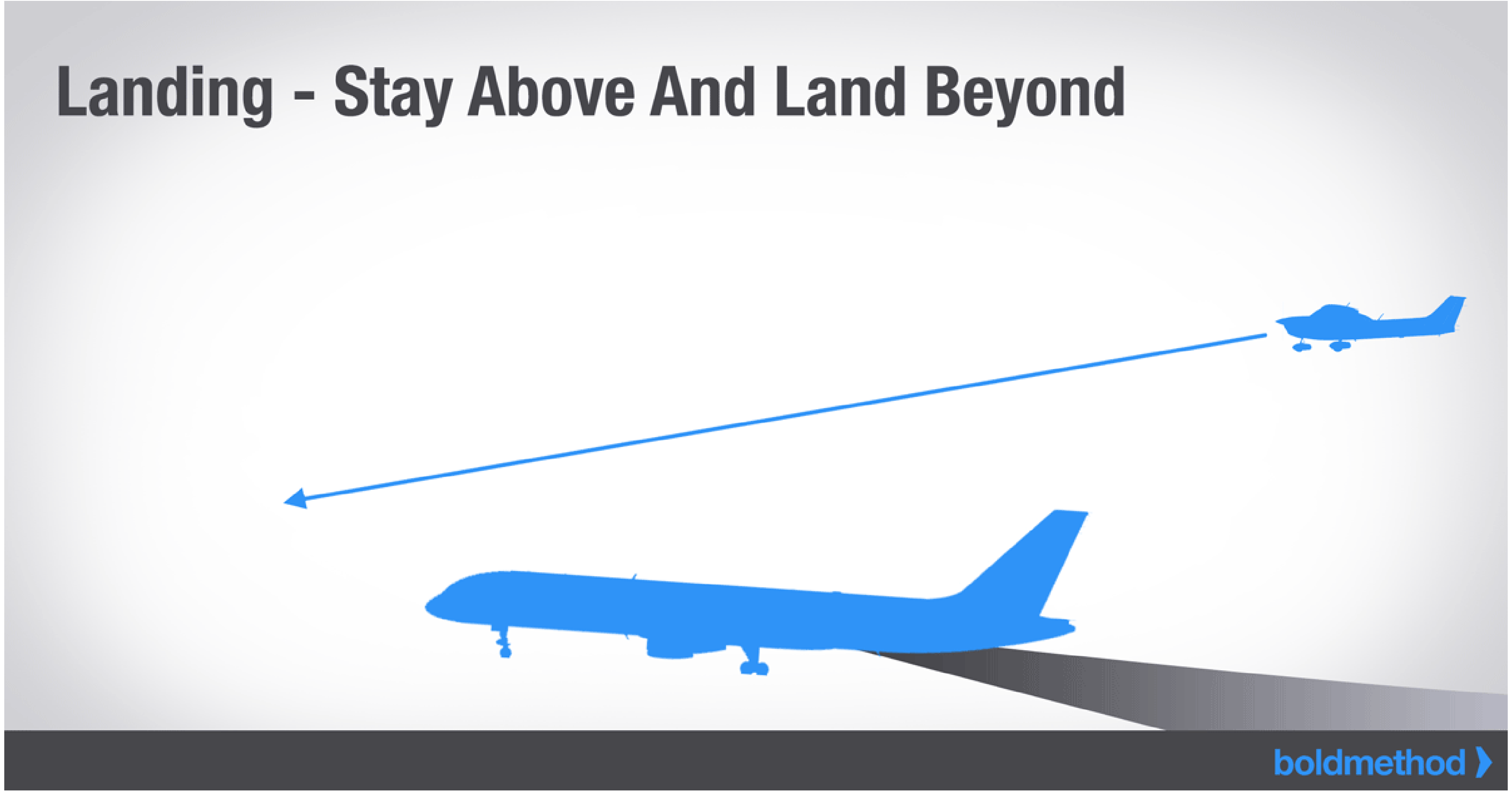
Danger

The vortices from larger aircraft pose problems to encountering aircraft. The wake of these aircraft can impose rolling moments exceeding the roll control authority of the encountering aircraft. Also, the turbulence generated within the vortices can damage aircraft components and equipment if encountered at close range. For this reason, a pilot must envision the location of the vortex wake and adjust the flight path accordingly.

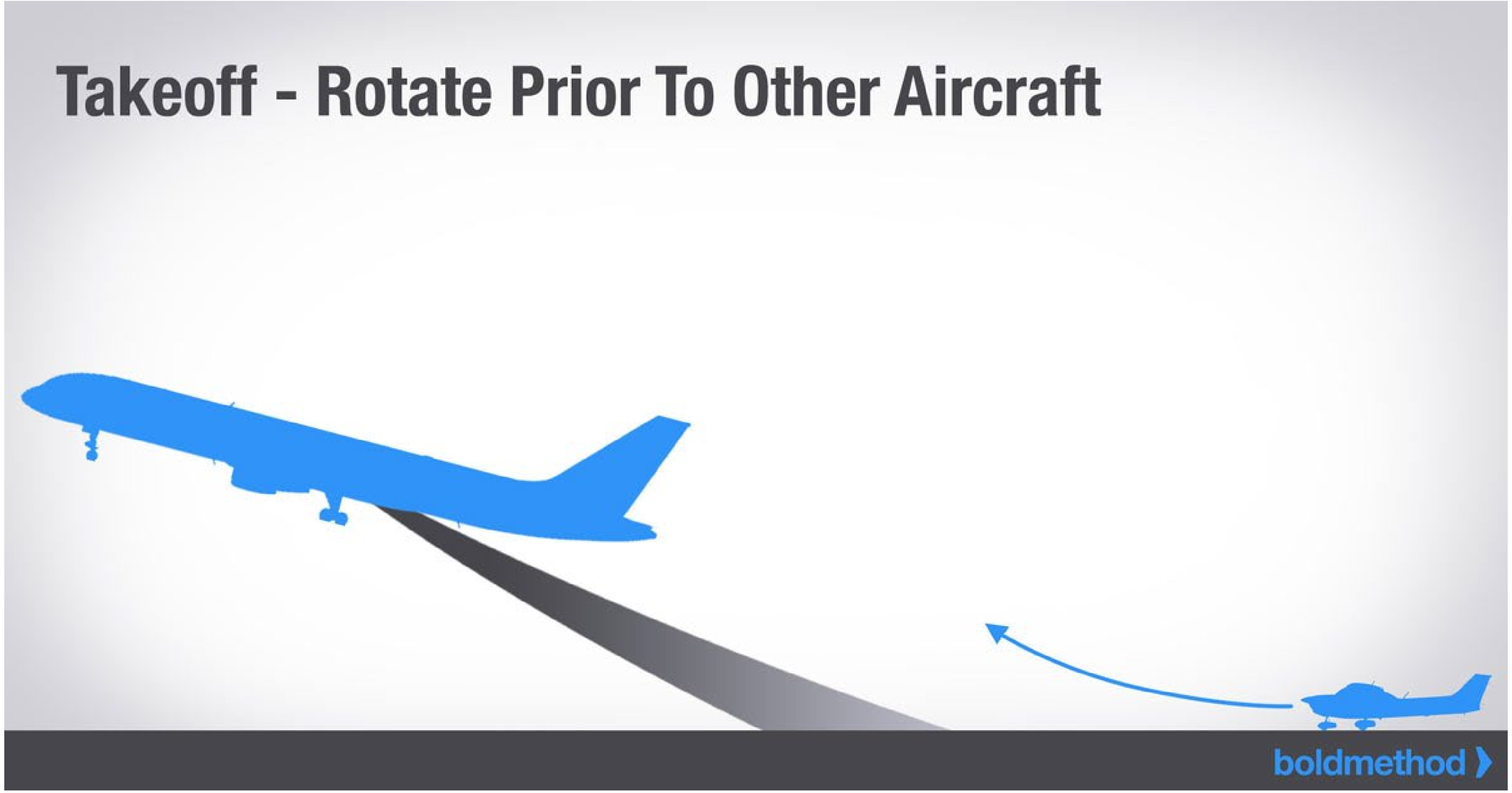
The Wake Created by Jets



The Wake Created by Jets



The Wake Created by Jets



How to Avoid

- Landing behind a larger aircraft on the same runway— stay at or above the larger aircraft's approach flight path and land beyond its touchdown point.
- Landing behind a larger aircraft on a parallel runway closer than 2,500 feet—consider the possibility of drift and stay at or above the larger aircraft's final approach flight path and note its touchdown point.
- Landing behind a larger aircraft on crossing runway— cross above the larger aircraft's flight path.
- Landing behind a departing aircraft on the same runway—land prior to the departing aircraft's rotating point.

How to Avoid

• Landing behind a larger aircraft on a crossing runway—note the aircraft's rotation point and, if that point is past the intersection, continue and land prior to the intersection. If the larger aircraft rotates prior to the intersection, avoid flight below its flight path. Abandon the approach unless a landing is ensured well before reaching the intersection.

• Departing behind a large aircraft—<u>rotate prior to the large aircraft's rotation point and climb above its climb path until turning clear of the wake</u>.

• For intersection takeoffs on the same runway— be alert to adjacent larger aircraft operations, particularly upwind of the runway of intended use. If an intersection takeoff clearance is received, avoid headings that cross below the larger aircraft's path.

How to Avoid

- If departing or landing after a large aircraft executing a low approach, missed approach, or touch-and-go landing (since vortices settle and move laterally near the ground, the vortex hazard may exist along the runway and in the flight path, particularly in a quartering tailwind), it is prudent to wait at least 2 minutes prior to a takeoff or landing.
- En route, it is advisable to <u>avoid a path below and behind a large aircraft</u>, and if a large aircraft is observed above on the same track, change the aircraft position laterally and preferably upwind.

Any questions I can answer or follow up later on?

Understanding the effect of true airspeed on propeller efficiency and engine performance involves several interconnected factors.

Propeller Efficiency

Advance Ratio

• A key concept is the "advance ratio," which is essentially the ratio of the aircraft's forward speed to the propeller's rotational speed. It plays a significant role in propeller efficiency.
• At different true airspeeds, the advance ratio changes, affecting the angle of attack of the propeller blades.
• For a fixed-pitch propeller, there's a specific airspeed where efficiency is optimal. As airspeed deviates from this point, efficiency decreases.
• Constant-speed propellers, which can adjust blade pitch, maintain a more consistent and optimal advance ratio across a wider range of airspeeds, thus improving efficiency.

Angle of Attack

• The angle at which the propeller blade meets the oncoming airflow directly impacts efficiency.
• Changes in true airspeed alter this angle, and if it's not within the optimal range, efficiency suffers.

Tip Speed

• As true airspeed increases, the relative speed of the propeller tips also increases.
• If the tip speed approaches the speed of sound, it can cause a significant loss of efficiency due to compressibility effects.

Engine Performance

Engine Power and Drag

• Increased true airspeed generally leads to increased drag on the aircraft. To maintain this higher speed, the engine must produce more power.
• The efficiency of the engine in converting fuel into power also plays a role.

Air Density

• True airspeed is closely related to altitude and air density. Higher altitudes generally mean lower air density, which affects both engine and propeller performance.
• Less dense air reduces the engine's power output and the propeller's ability to generate thrust.

Relationship Between Engine and Propeller

• The engine provides the power that the propeller converts into thrust. Therefore, the efficiency of both is intertwined.
• If the propeller's efficiency is low, it requires more engine power to achieve a given thrust, impacting fuel consumption.

In summary

• True airspeed significantly influences propeller efficiency through its effect on advance ratio and blade angle of attack.
• Higher true airspeeds typically require more engine power due to increased drag.
• Air density, which is often related to changes in true airspeed (due to altitude changes) also heavily impacts both engine and propeller performance.

- Modern constant speed props greatly aid in optimizing propeller efficiency across varied airspeeds.