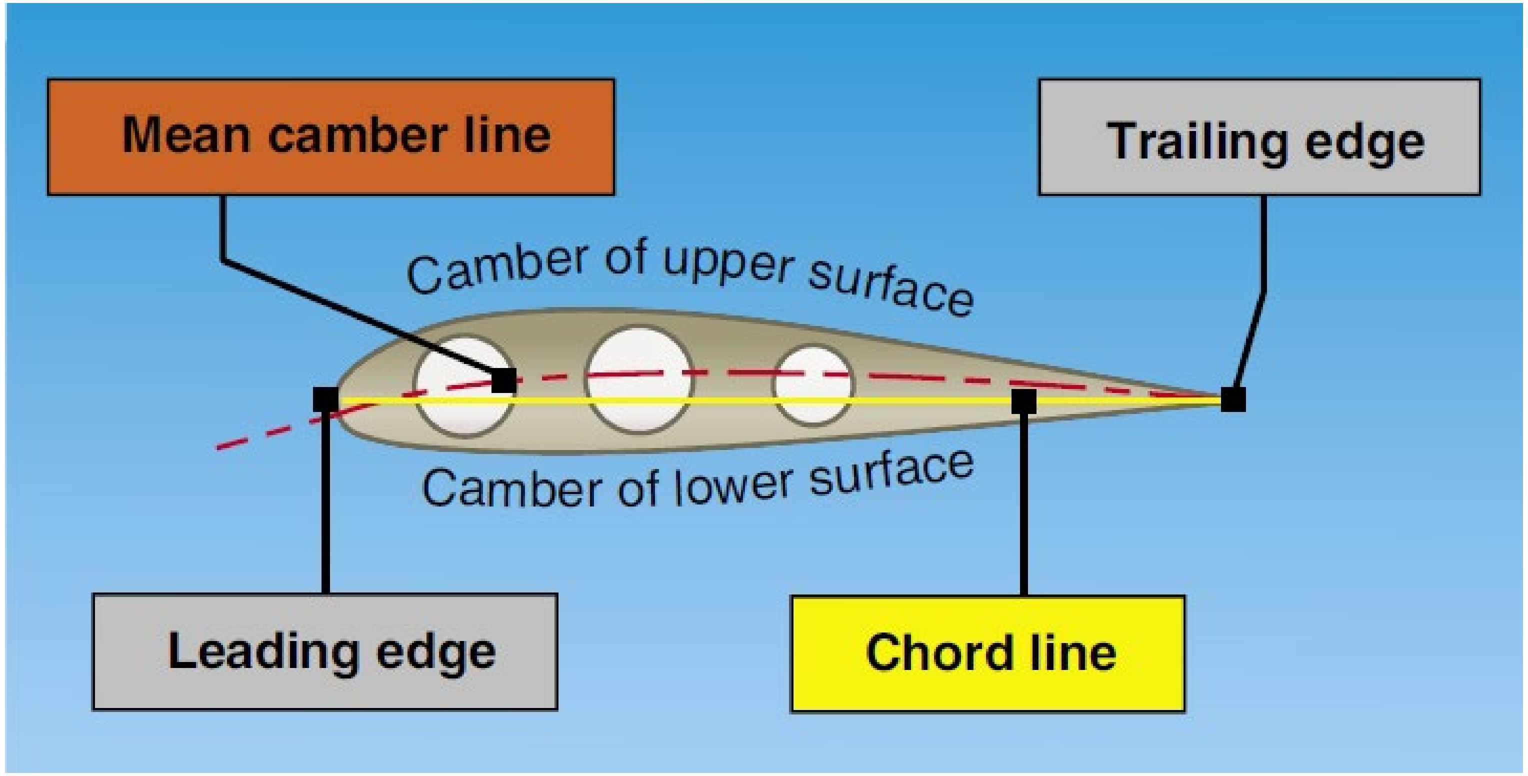
Airfoil design characteristics

Task D: Principles of Flight #1

Lesson Objective

To develop understanding why wings look the way they do

Diagram to Start With



Leading Edge

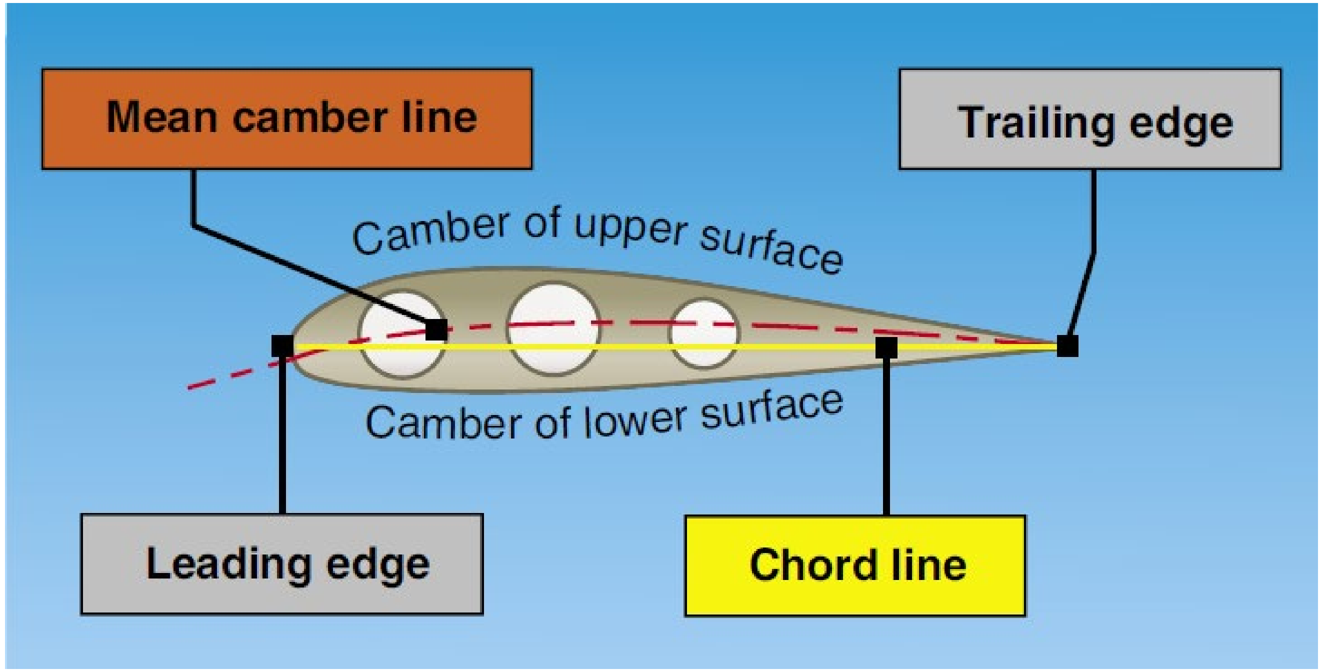
The leading edge of an airfoil is the **portion that meets the air first**.

The front of the wing.

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

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

Most aircraft lie between these two.

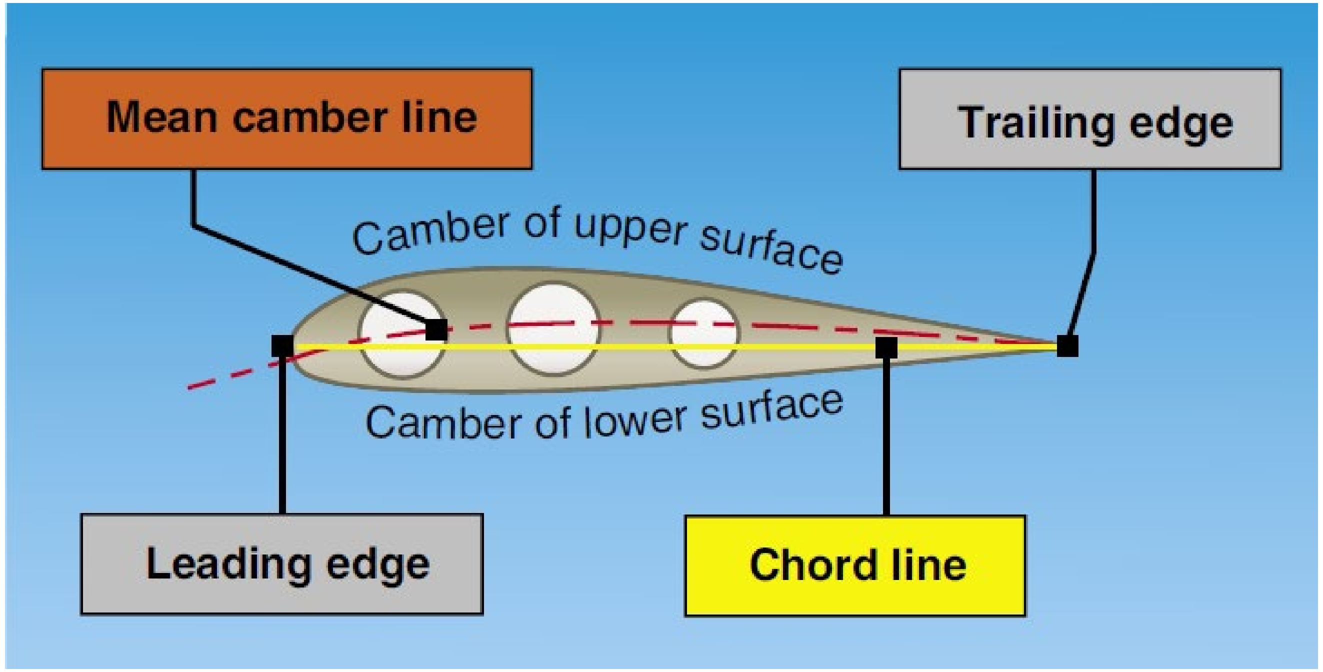


Trailing Edge

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.

The design of this portion of the airfoil is just as important as the design of the leading 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.



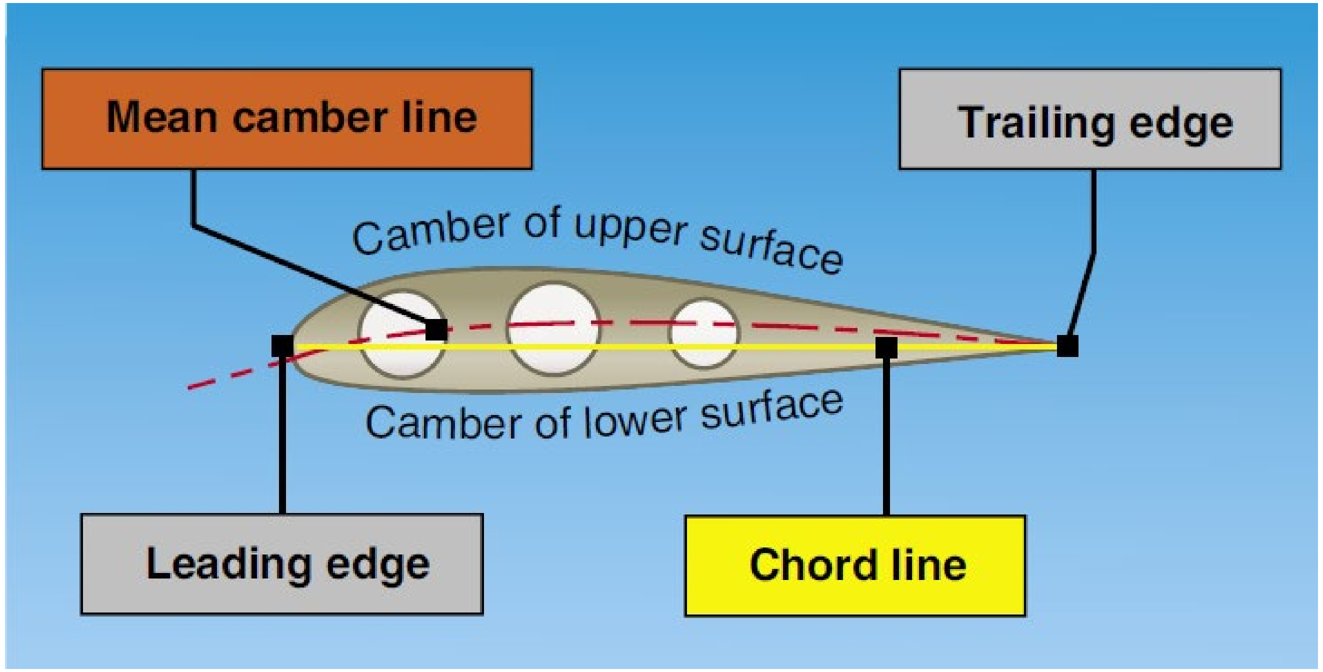
Camber

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.

<u>A high-speed, low-lift airfoil has very little camber.</u>

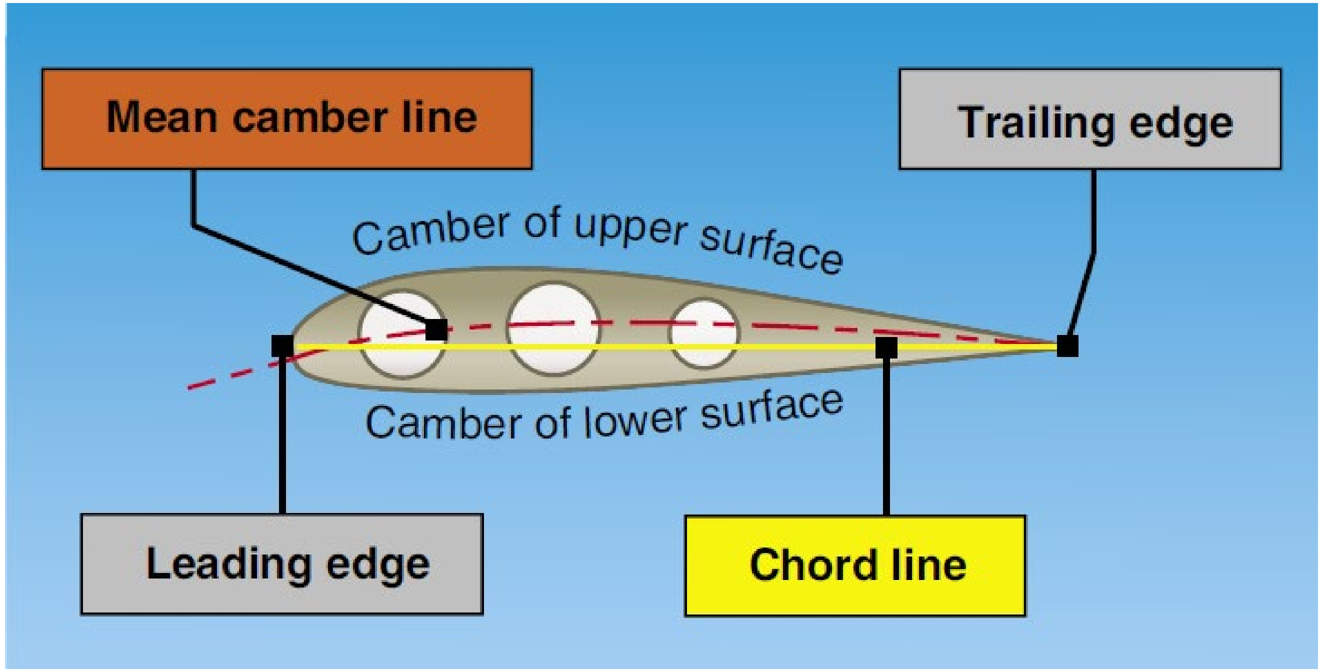
A low-speed, high-lift airfoil, like that on the Cessna 150, has a very pronounced camber.



Upper Camber and Lower Camber

Typically, upper and lower cambers differ from one another.

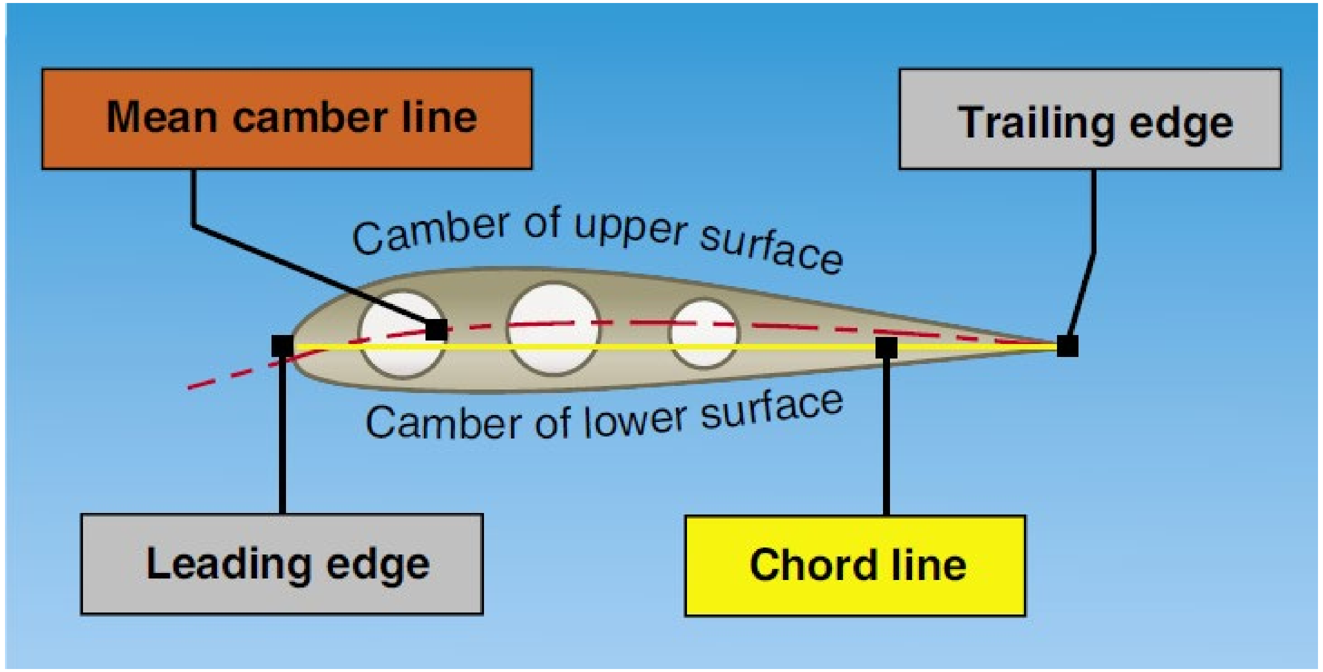
In a 172, the lower part is generally flat and the front of the upper is curved



Mean Camber

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

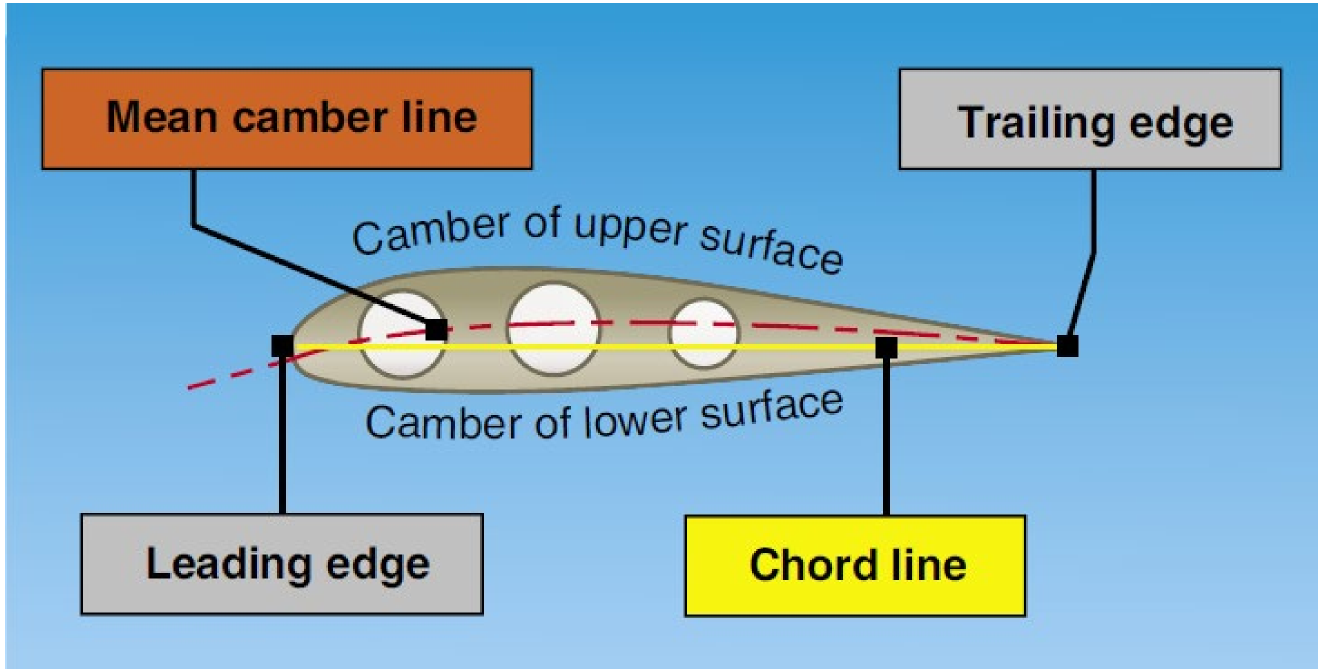
Mean Camber Line is a **line drawn halfway between the upper and lower surfaces**.



Chord

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

The chord line helps us determine how much upper or lower camber there is and how wide the wing is at any point along the wingspan.



Bernoulli's Principle

Daniel Bernoulli described the mathematics of the mechanism underlying the operation of two important technologies of the 20th century:

The carburetor

The airplane wing

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

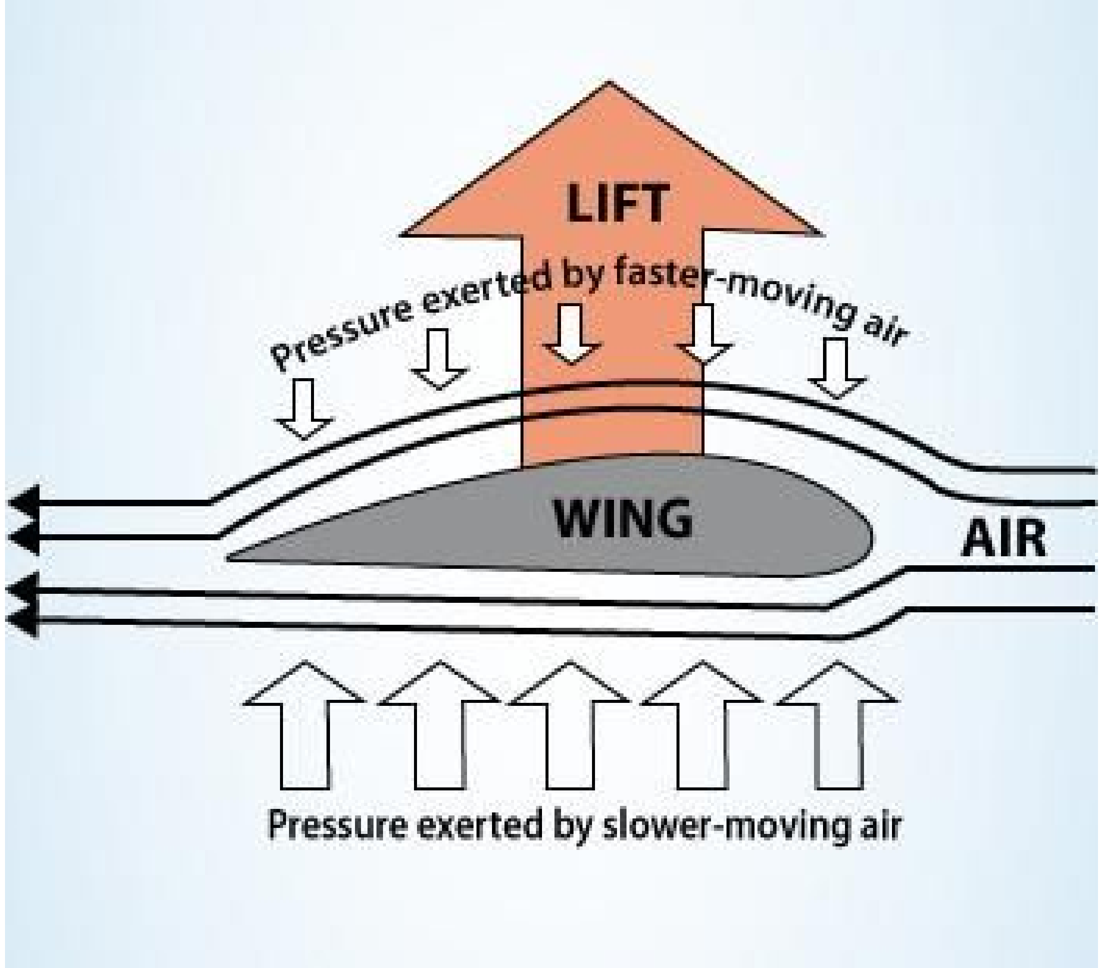
Wings and Lift

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.

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.



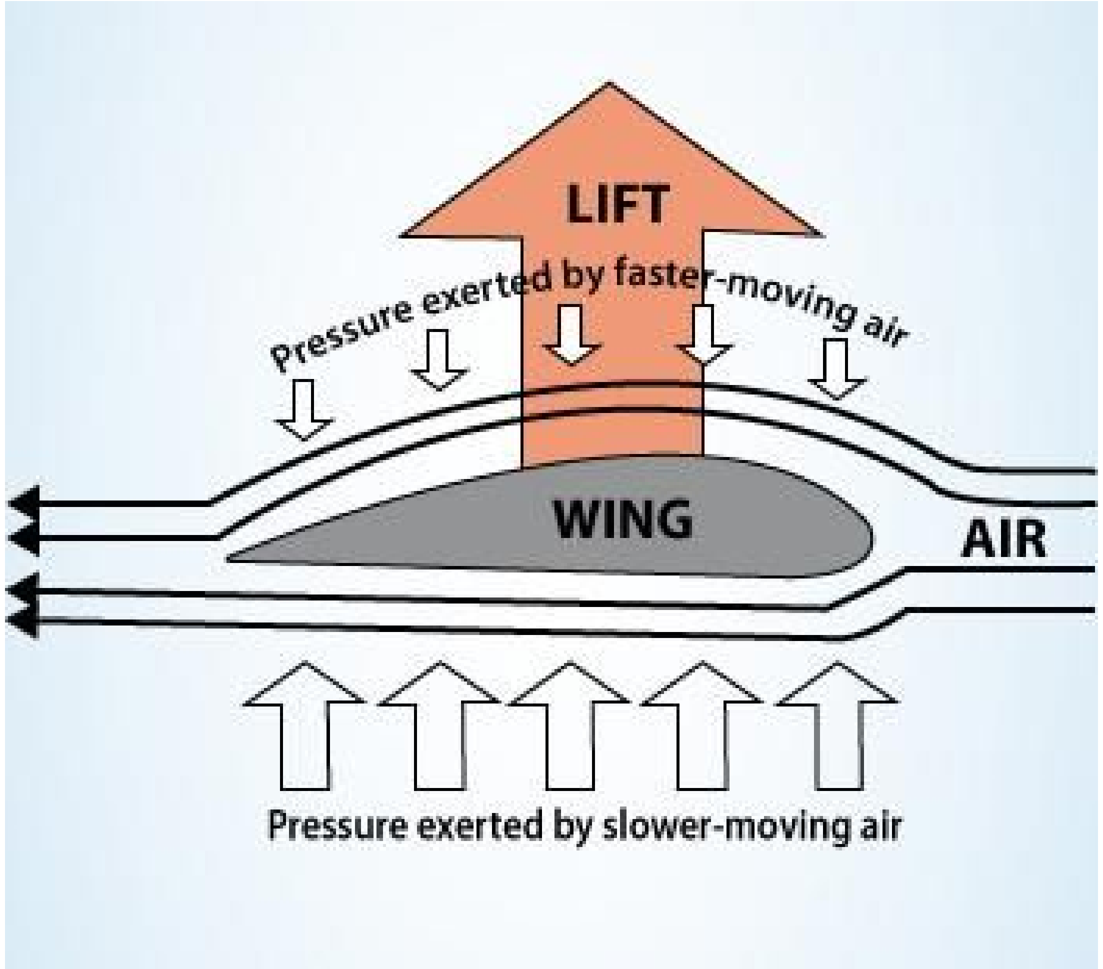
Wings and Lift

In a nutshell…

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

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



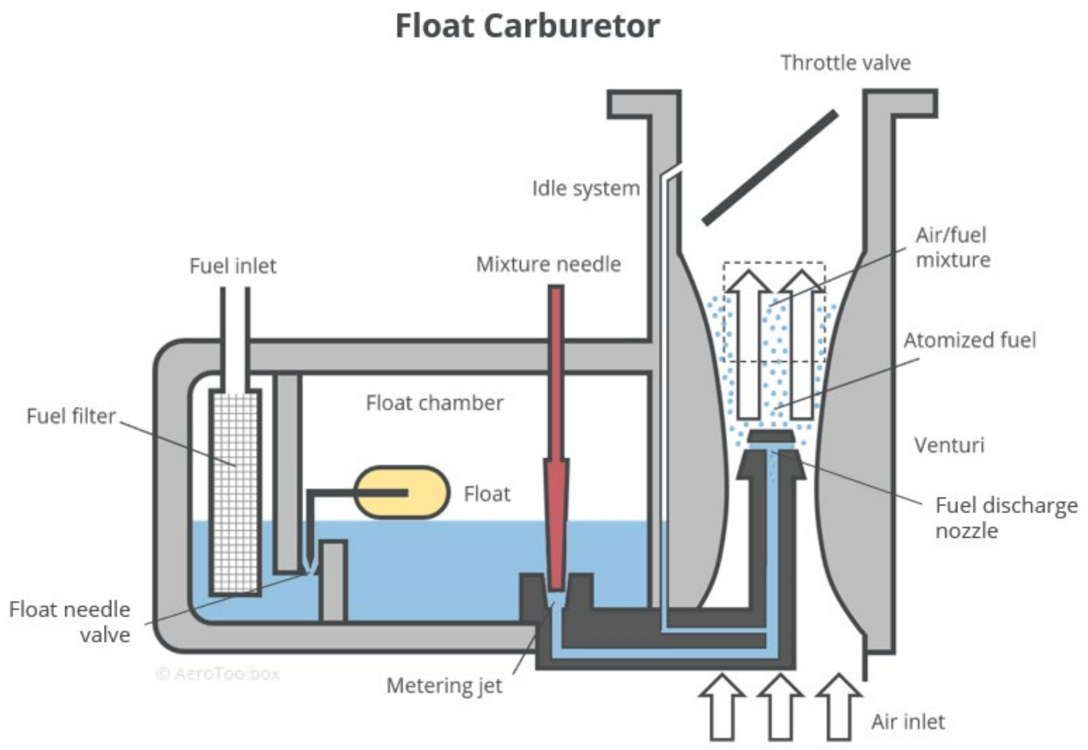
Airplane Carburetor

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

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

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

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



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.

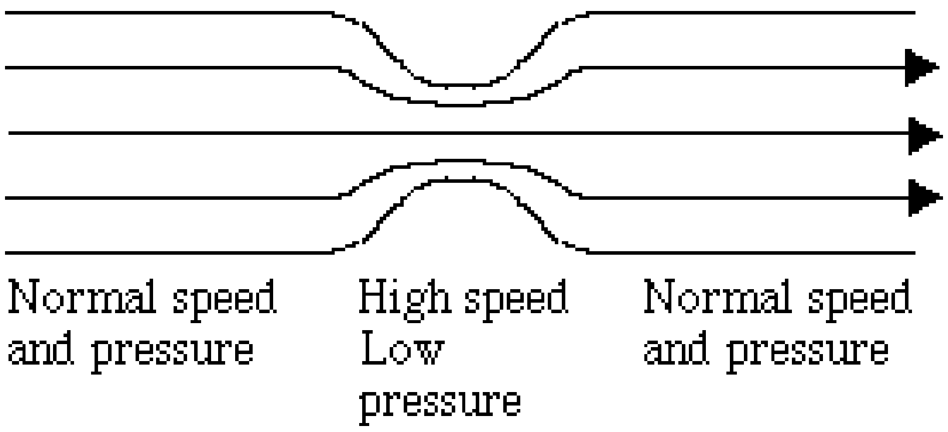
The diameter of the outlet is the same as that of the inlet.

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

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.

<u>When the air speeds up, the pressure decreases.</u>

<u>Past the constriction, the airflow slows and the pressure increases.</u>



Bernoulli's Principle

Bernoulli's principle also works on the ground…outside your house

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.

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**

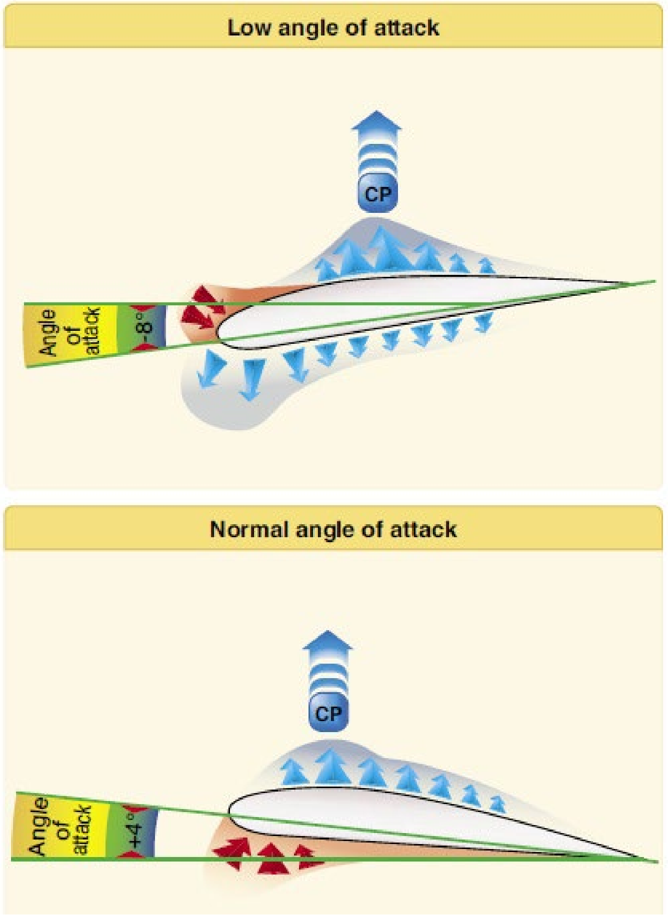
<u>As AOA increases (+)</u>

Vertical component of velocity +

Lift +

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

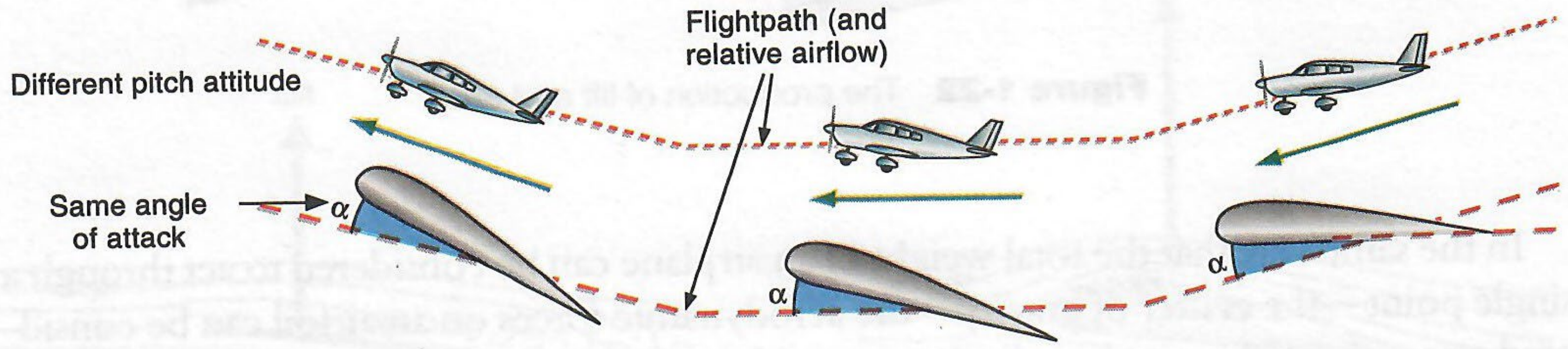


Figure 1-25 Same angle of attack, but different pitch attitudes.

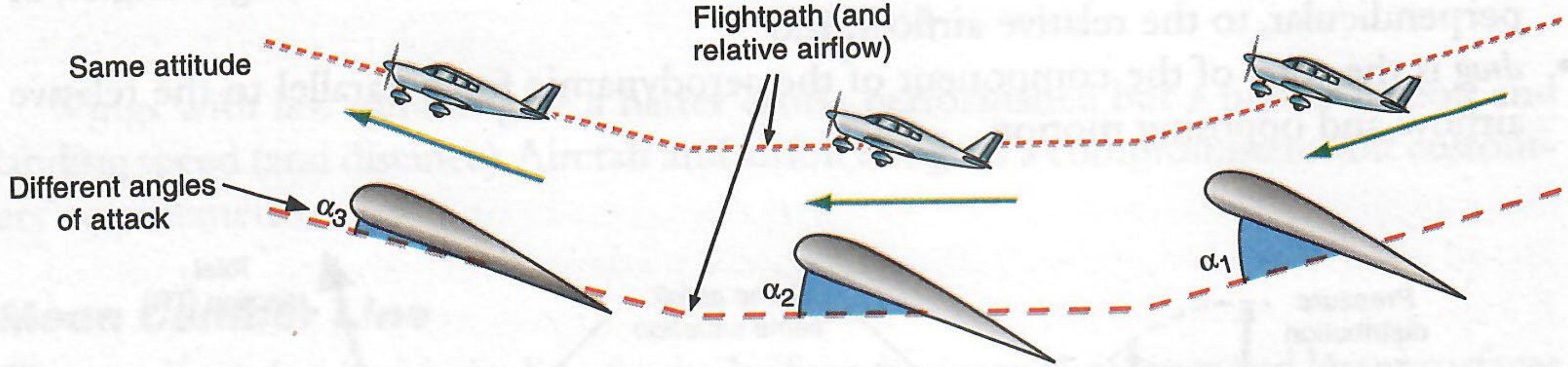


Figure 1-26 Same pitch attitude, but different angles of attack.

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 exceeding the critical AOA.

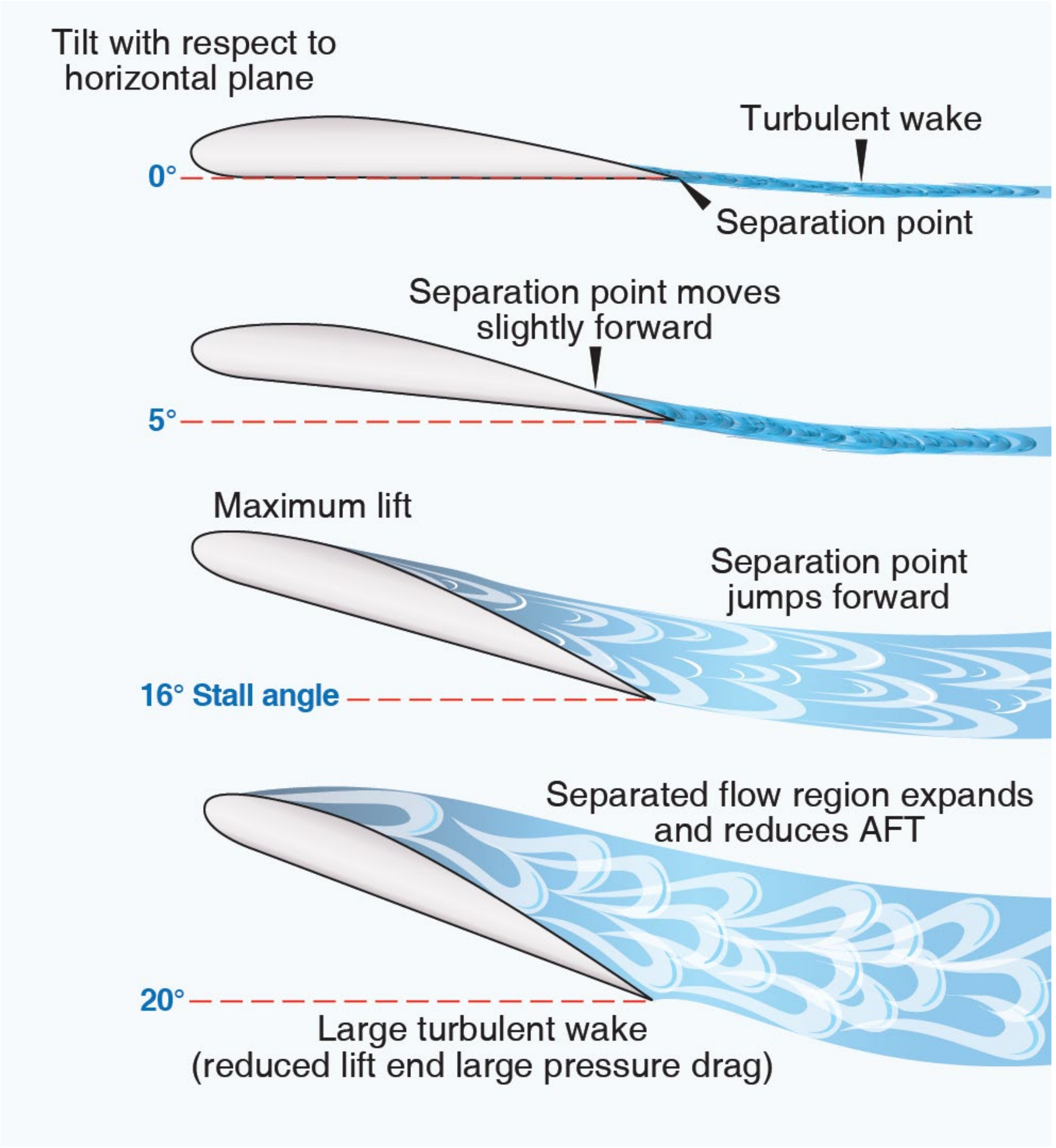
A stall can occur at **any pitch attitude or airspeed**.

Stalls are one of the most misunderstood areas of aerodynamics because pilots often believe an airfoil stops producing lift when it stalls.

In a stall, the wing does not totally stop producing lift.

Rather, it cannot generate adequate 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)

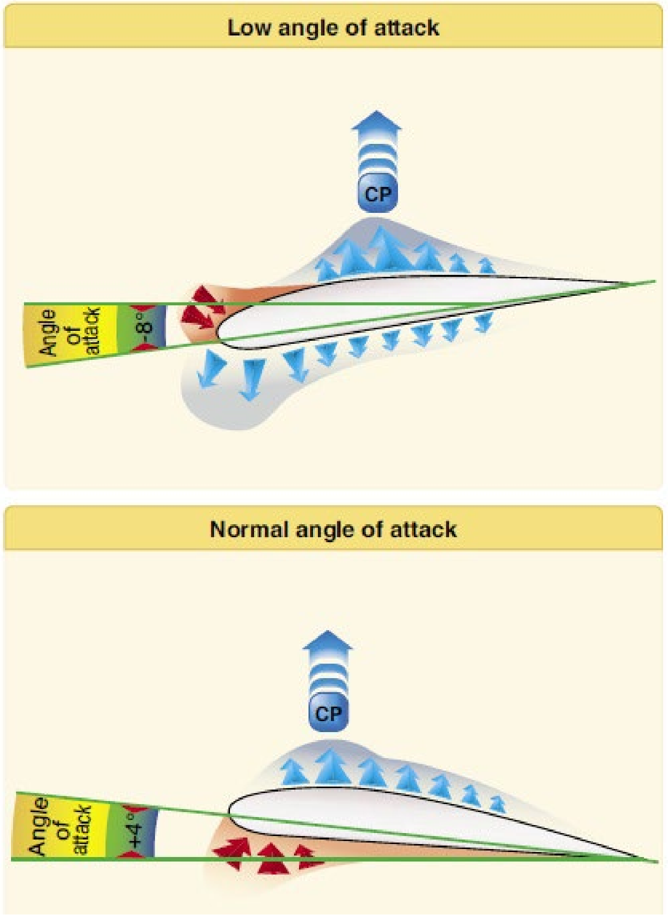
AOA and Center of Pressure (CP)

In general…

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 forced upwards because they are tilted, pushing air downwards so the wings get pushed upwards.

This is the angle of attack or the angle at which the wing meets the airflow.

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).

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

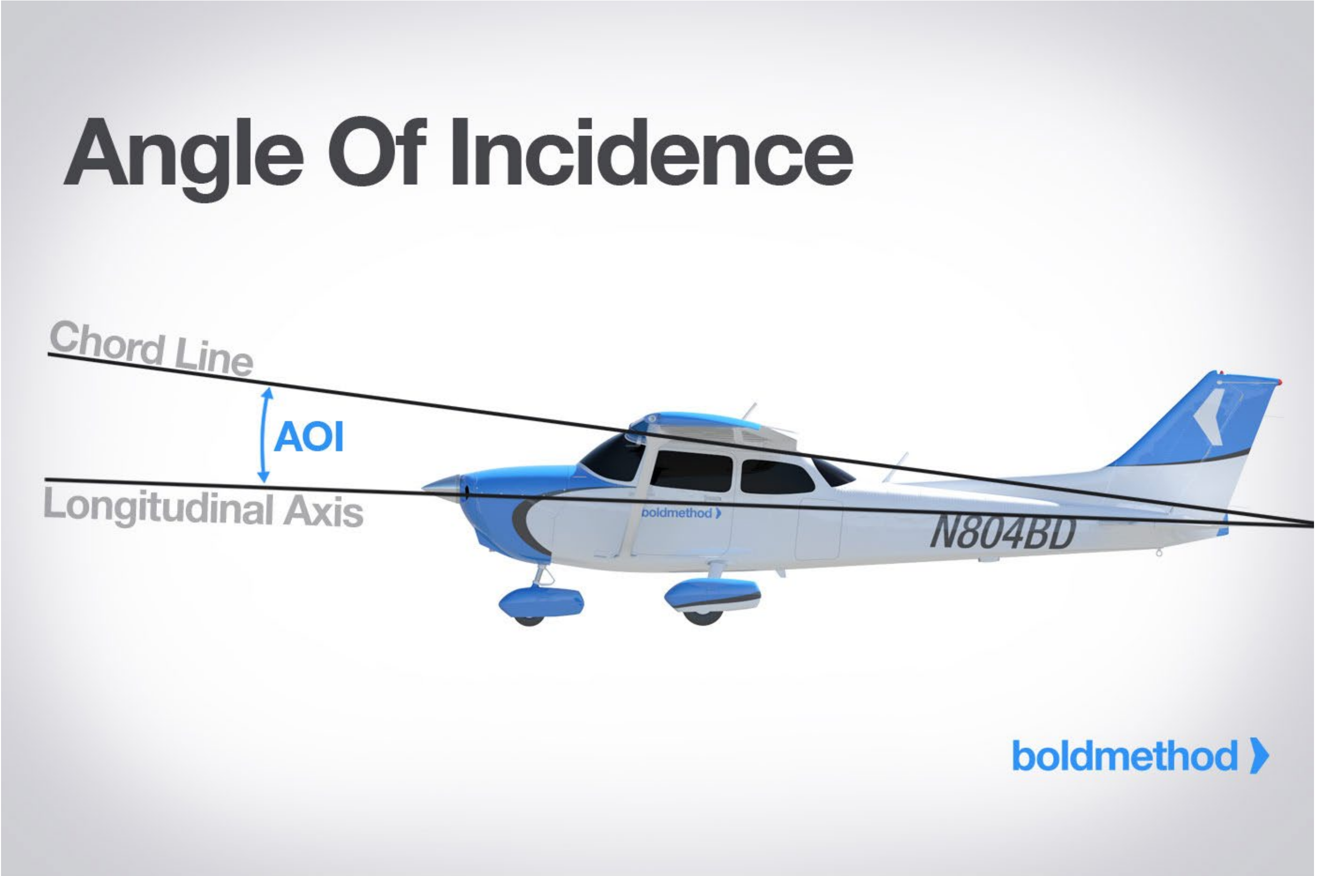
Increasing the angle of attack means the air flowing over the top is turned downwards even more and the air meeting the lower surface is also deflected downwards more, increasing lift.

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



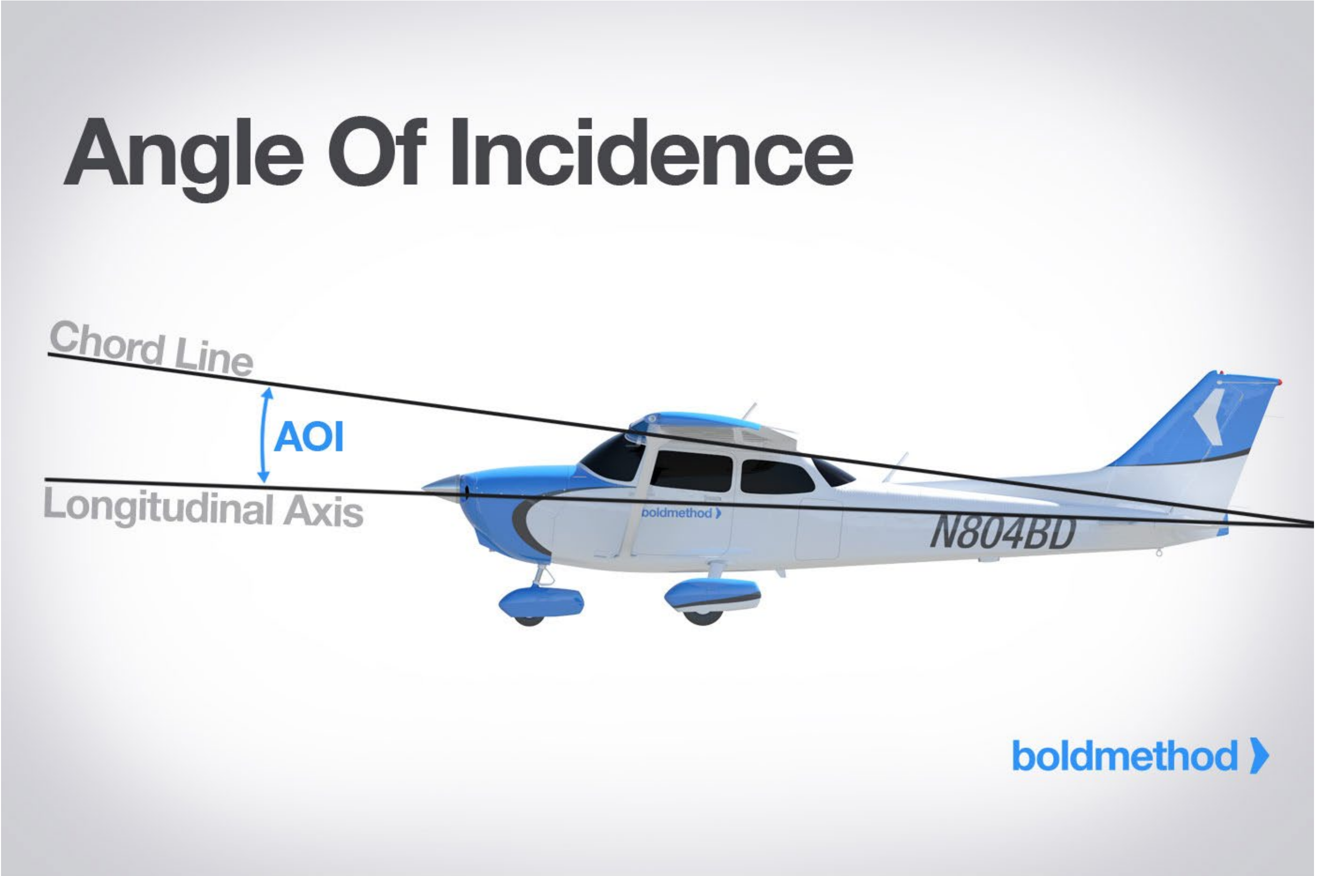
Angle of Incidence

Takeoff

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.

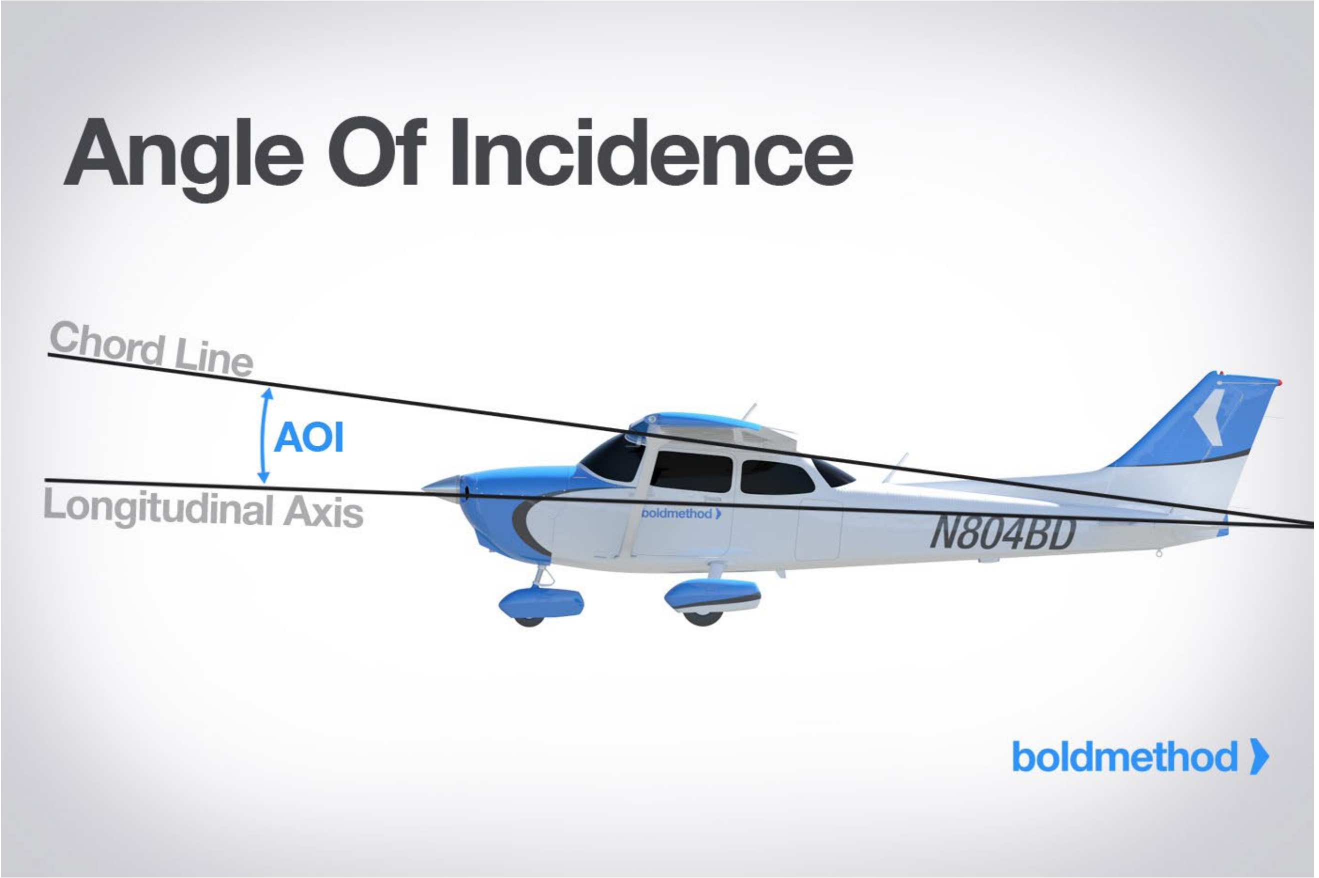


Angle of Incidence

<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

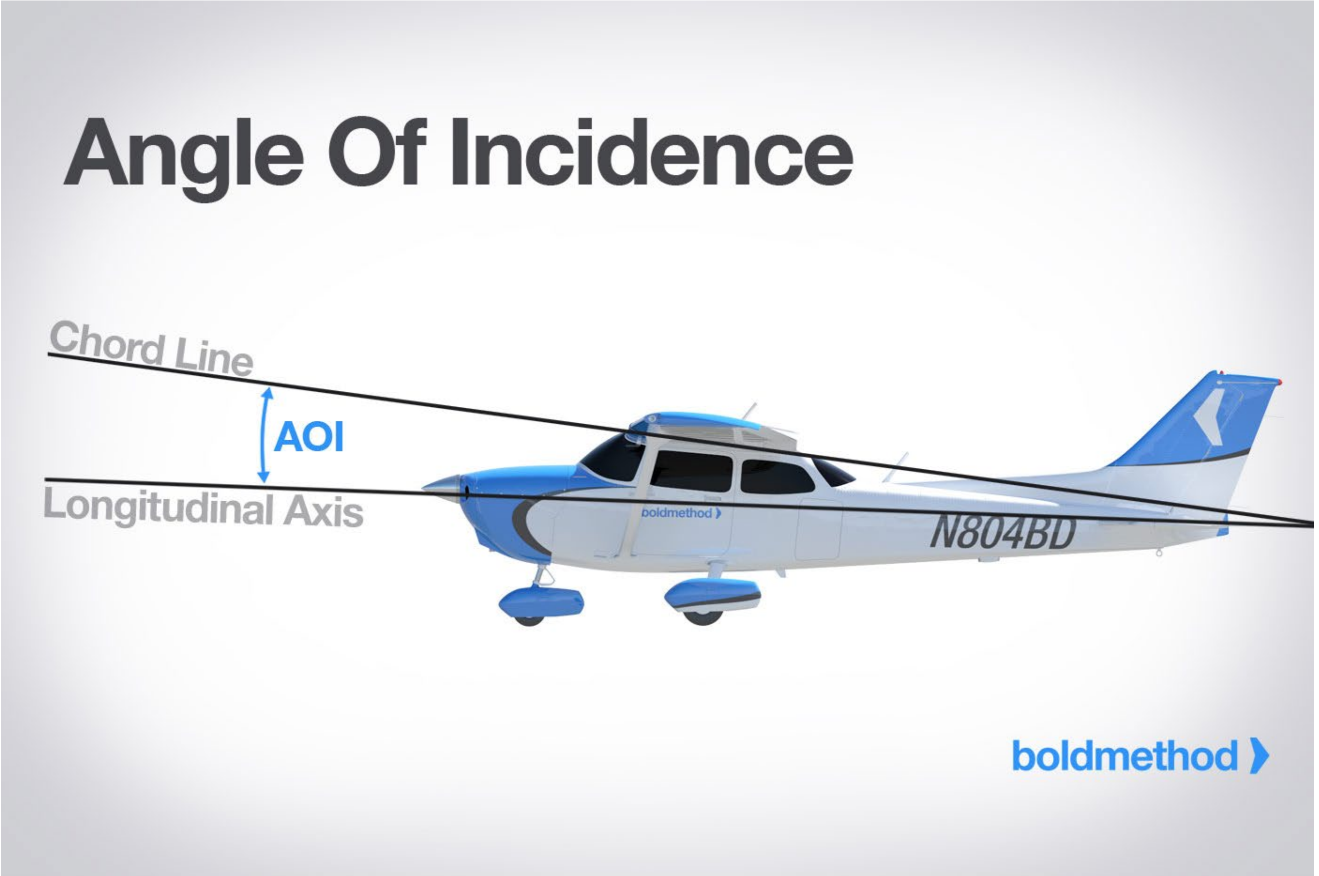
<u>Does It Affect Lift In Flight?</u>

No.

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

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

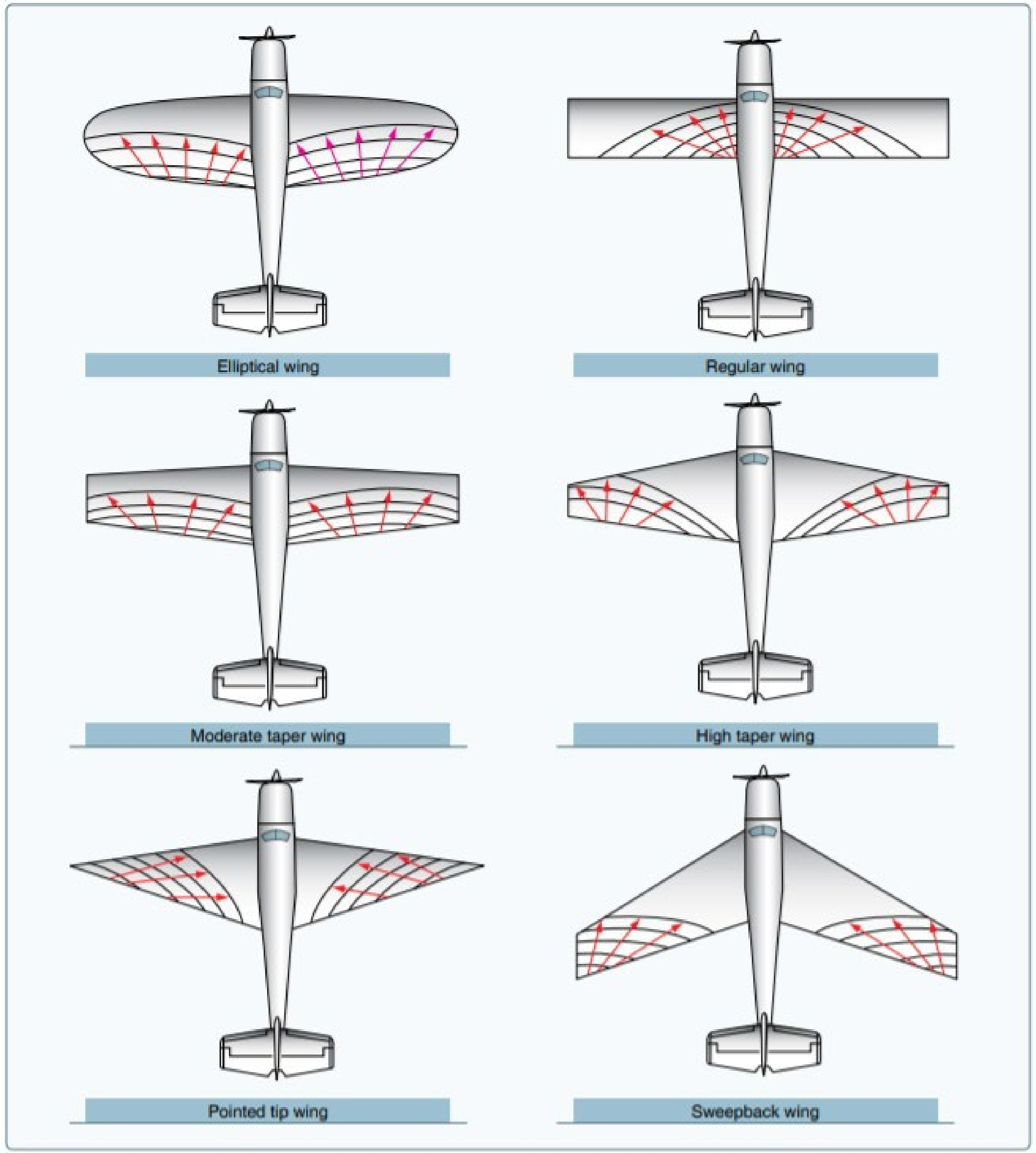
It simply changes the angle that the fuselage points - keeping the nose at a lower pitch angle.



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.

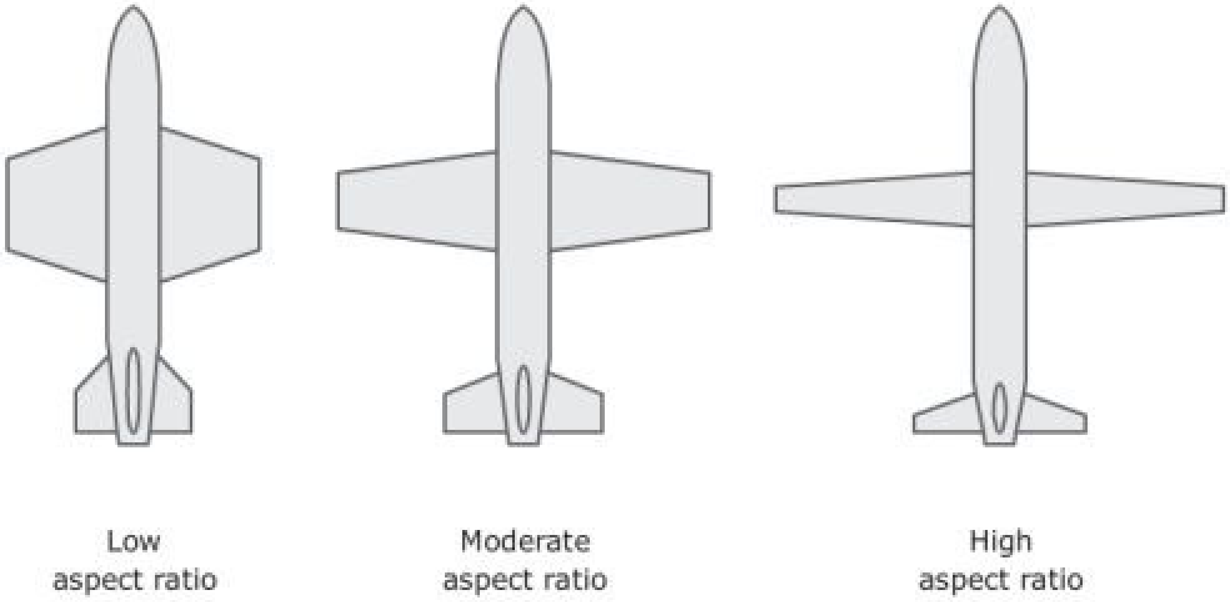


Aspect Ratio

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

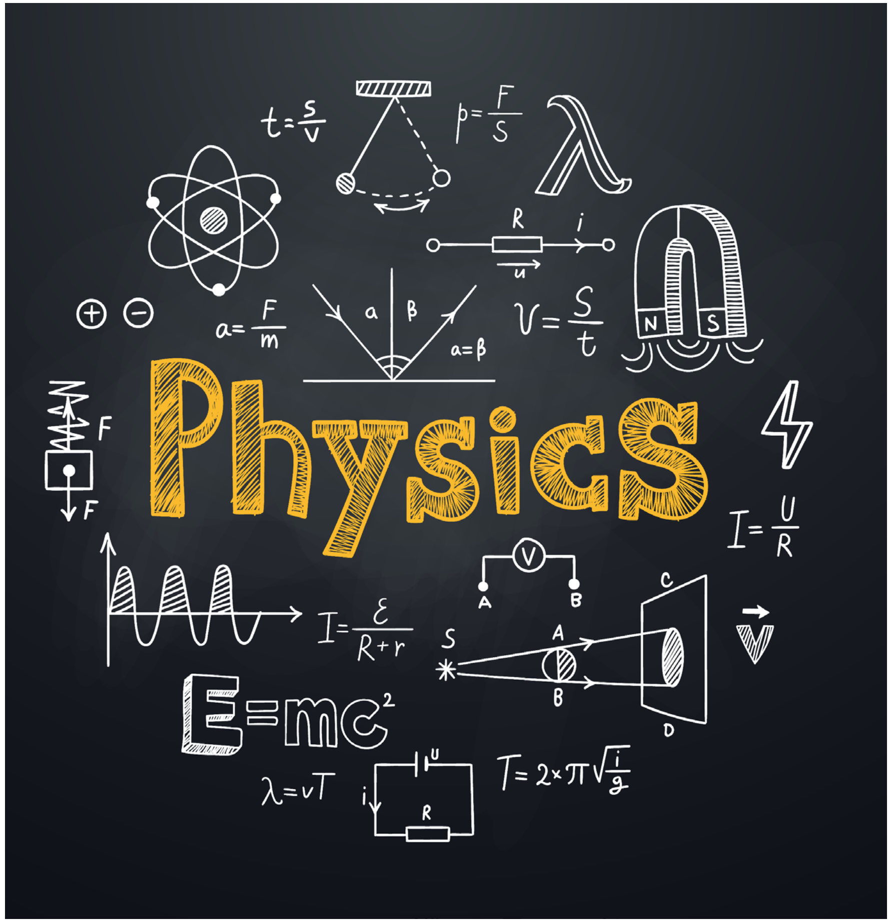
<u>Stall speed</u>

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>

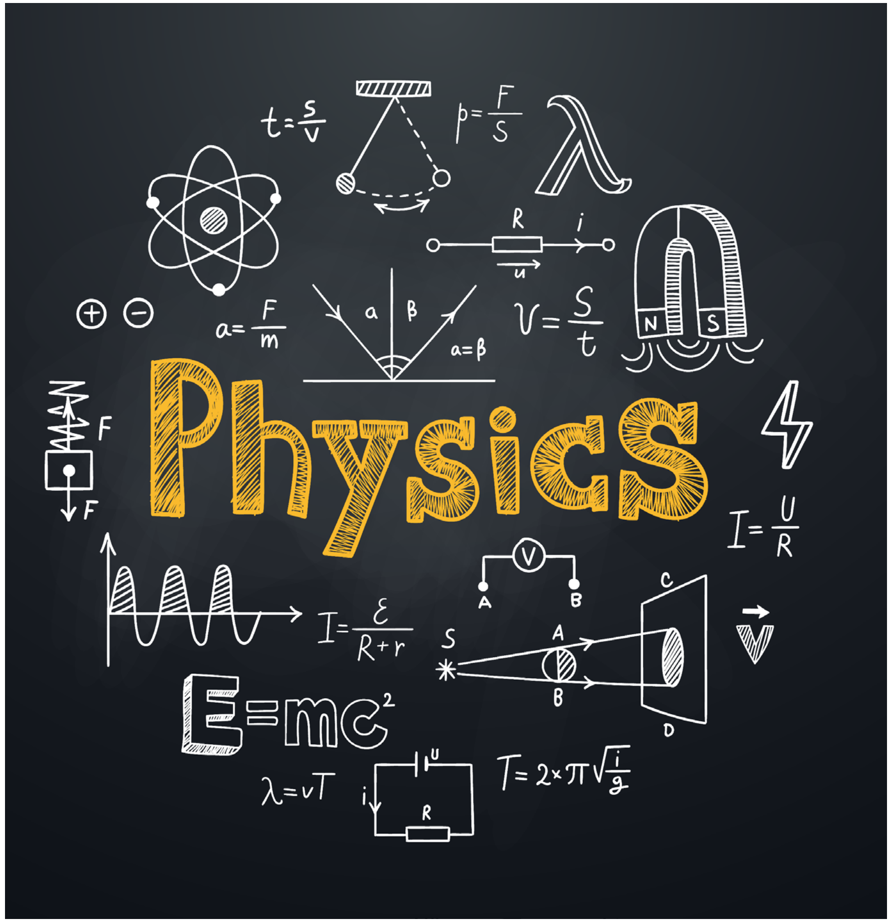
Low aspect ratio –> higher roll angular acceleration

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



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

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 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.

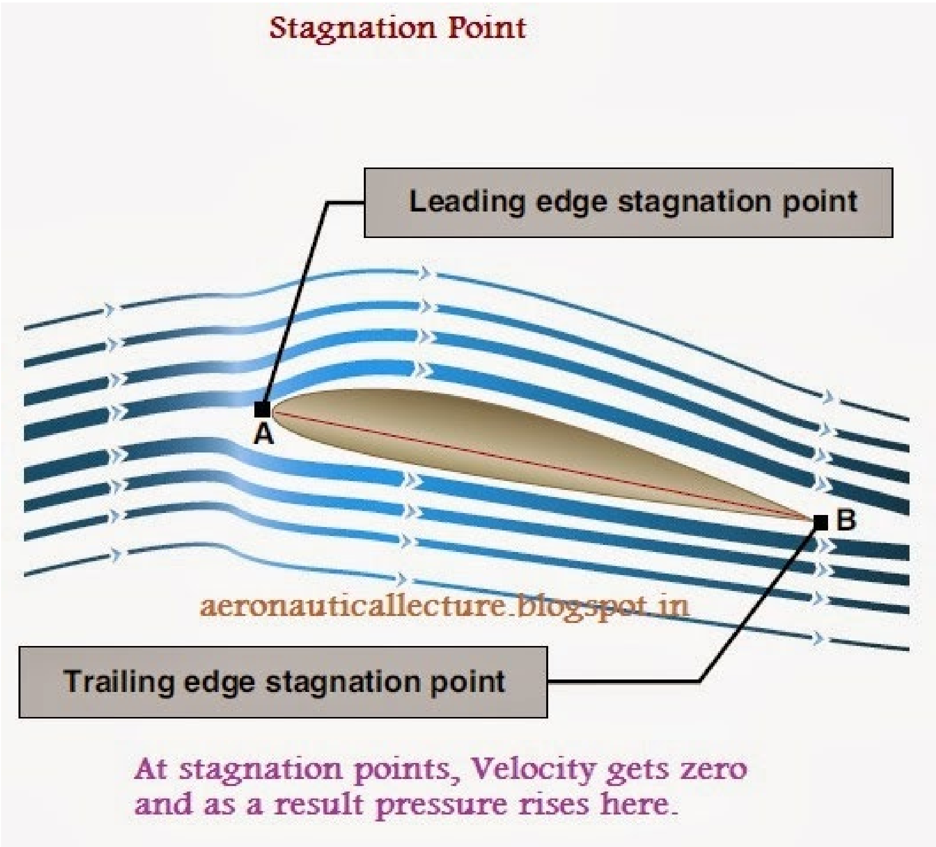
What it really means is that you can fly more hands off, even in turbulence.

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.

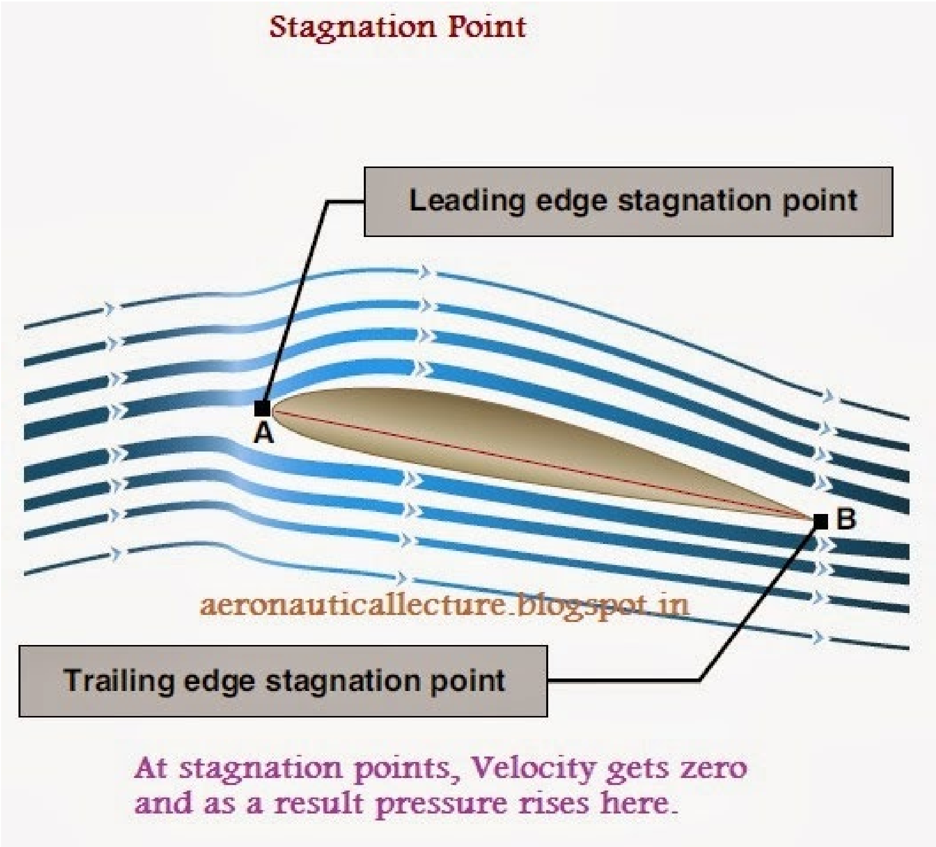
As a wing is propelled through the atmosphere, the molecules of air it encounters are moved aside and forced to flow past the wing's contoured shape.



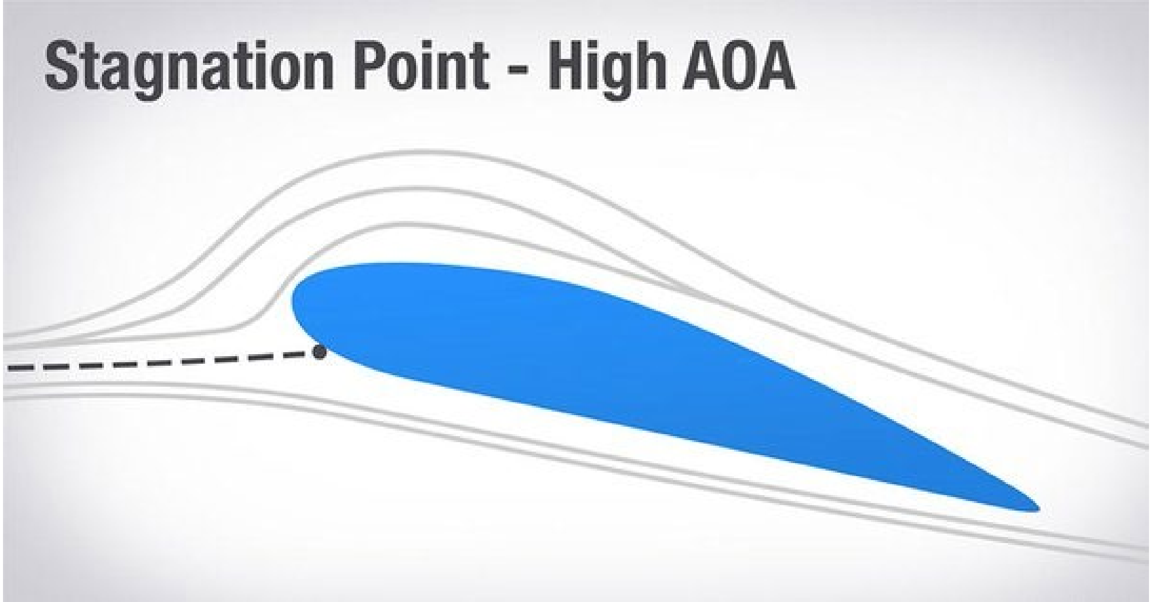
Stagnation Point(s)

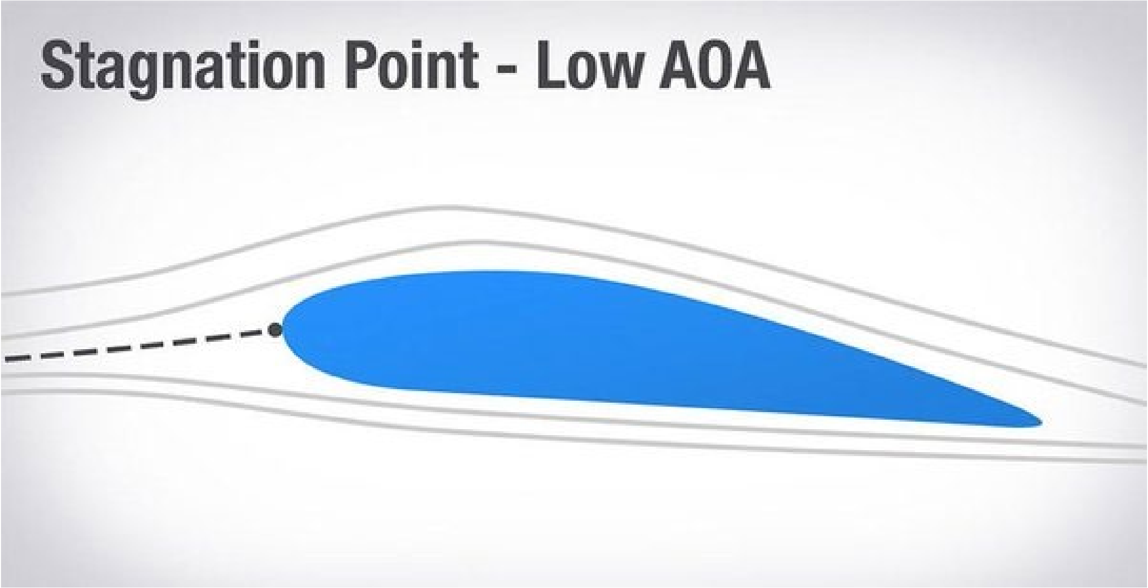
Since some of the air moves under the wing and some moves over it, there is a dividing point where a molecule of air would hit the airfoil if it could not decide which way to go.

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)

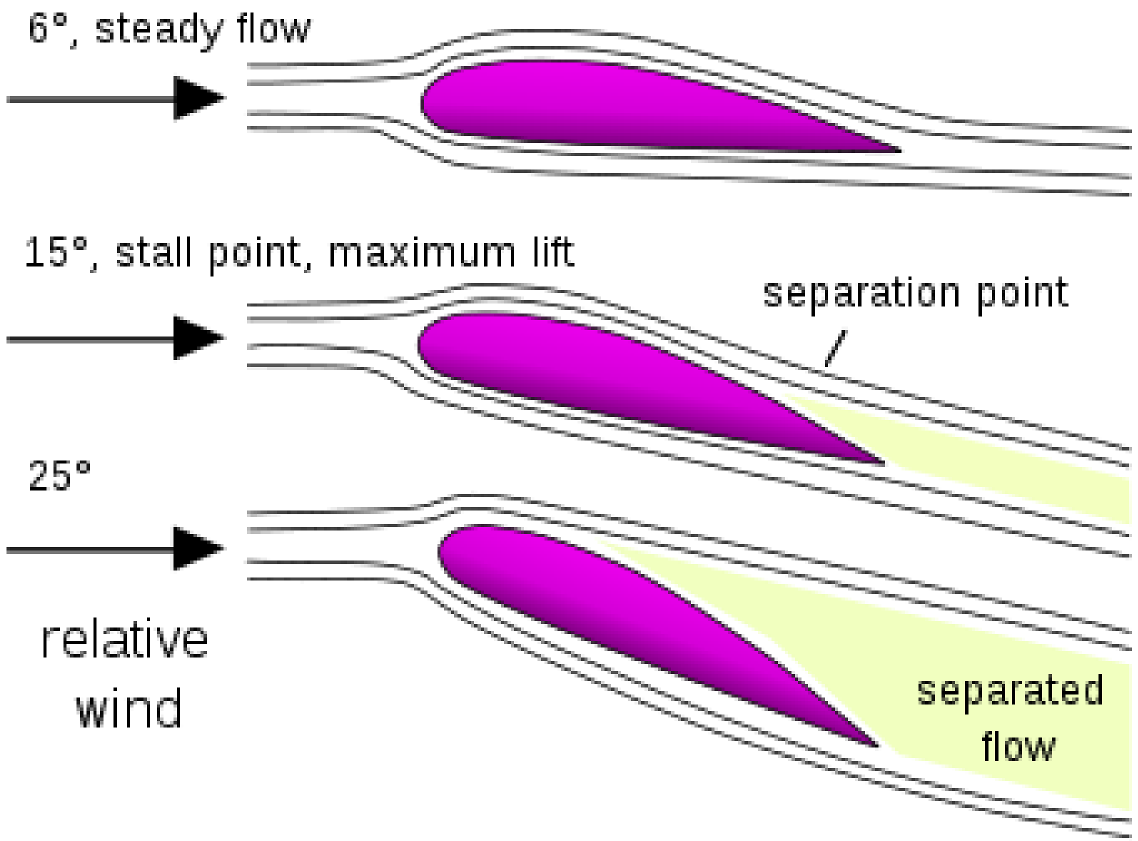




Separation Point

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

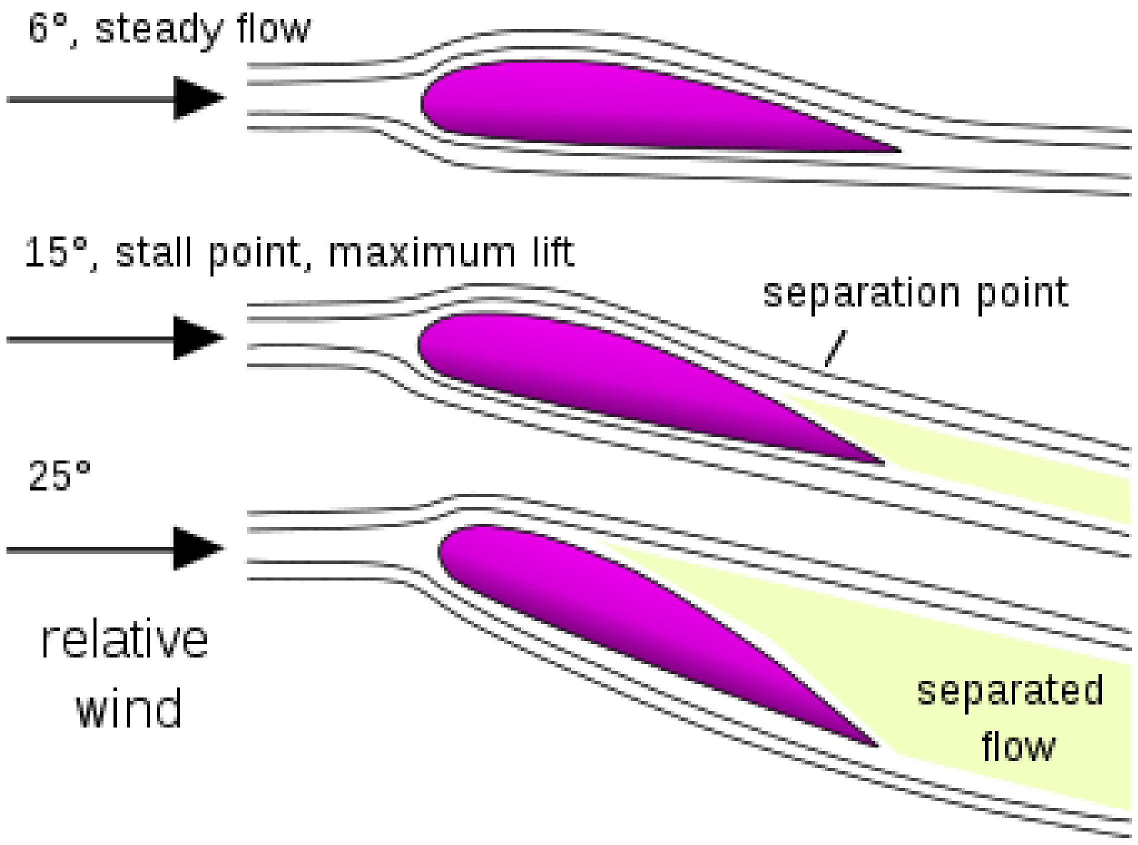
When an object is moving through the air, the air molecules push back on it and resist the object's movement - this resistance is called pressure drag.



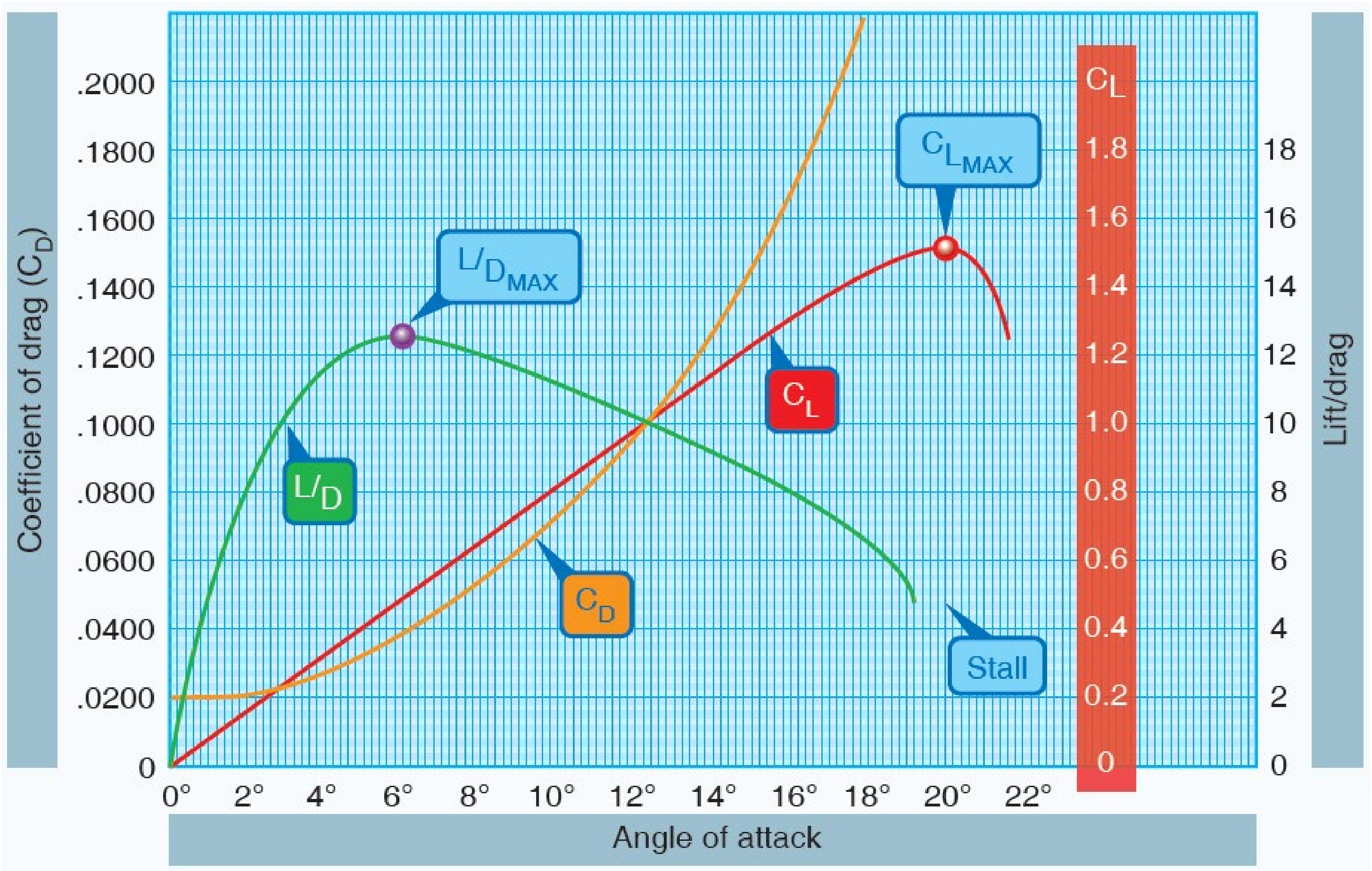
Separation Point

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

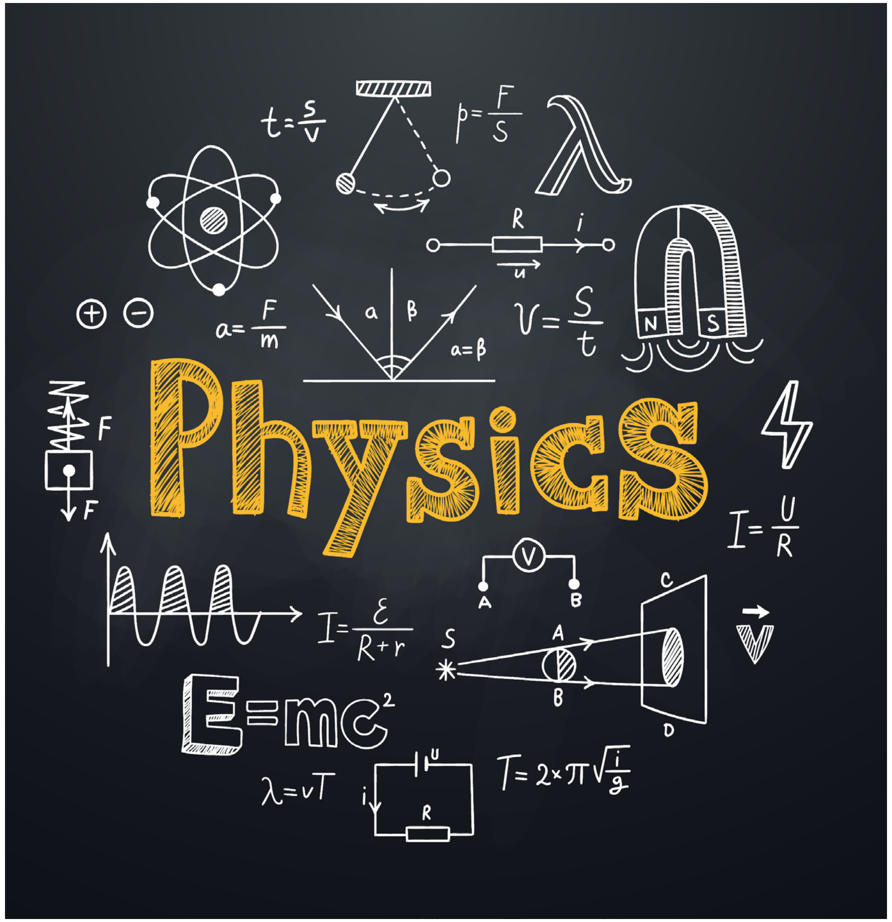
Lift = CL x Dynamic Pressure x Area of wing

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

Dynamic Pressure = 0.5 x Density x Velocity squared

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.

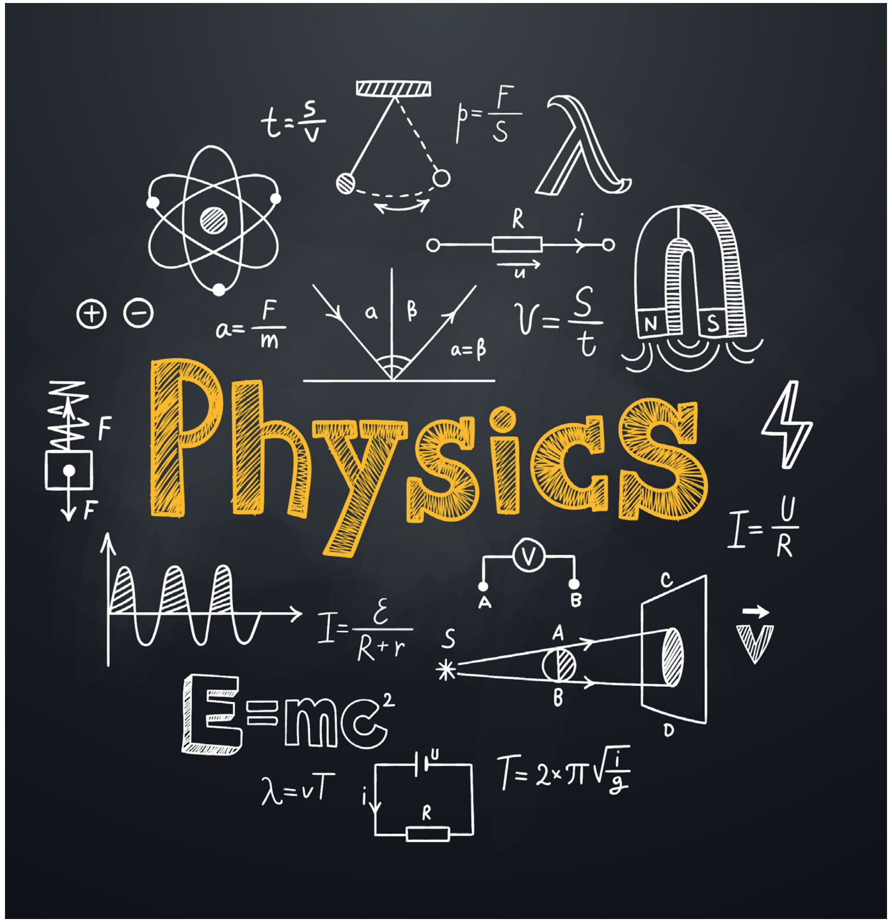
CL = Lift / Dynamic pressure / Area

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)

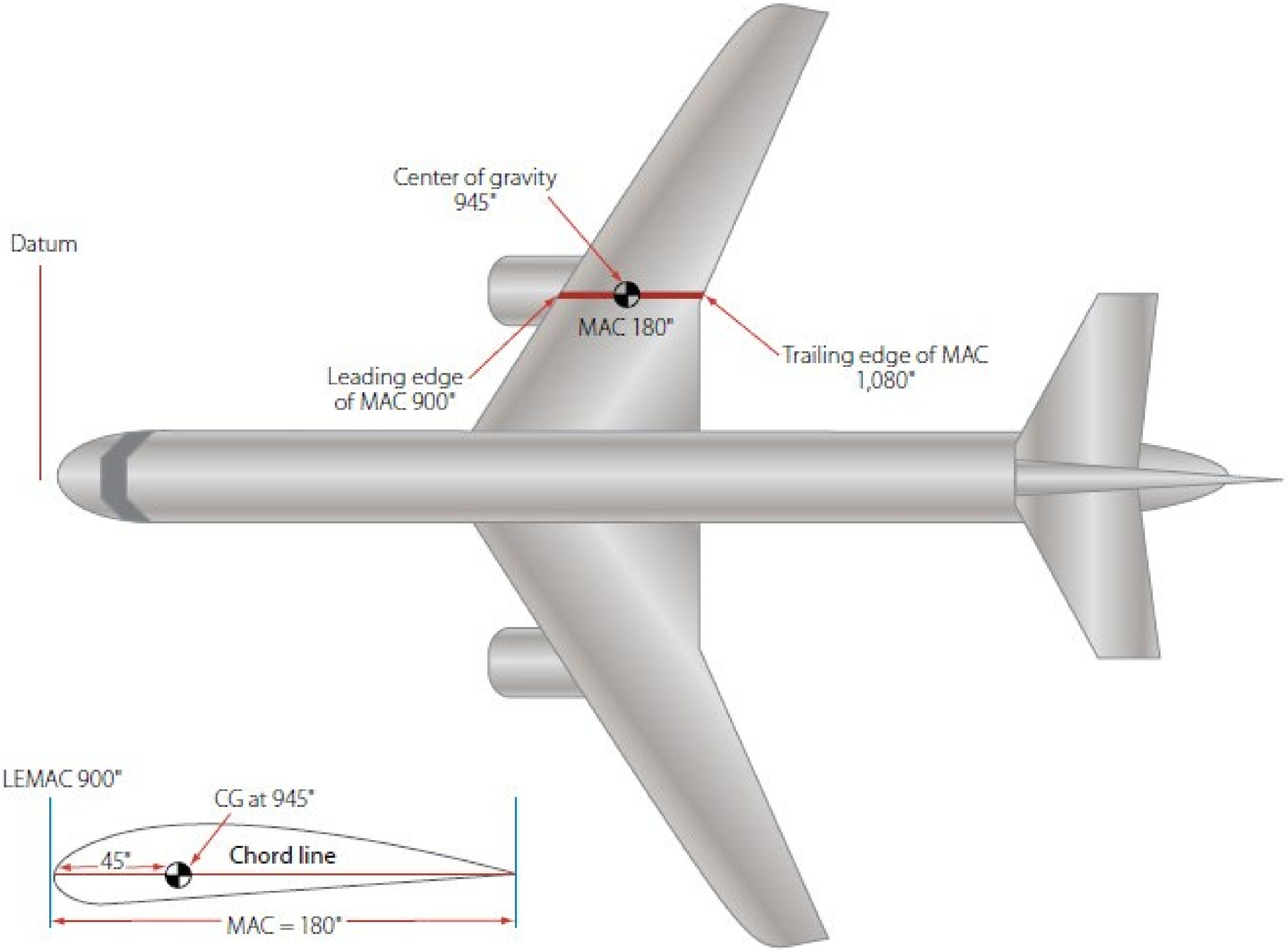
On small airplanes and on all helicopters, the center of gravity location is identified as being a specific number of inches from the datum. The center of gravity range is identified the same way. On larger airplanes, from private business jets to large jumbo jets, the center of gravity and its range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

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.

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"
Trailing edge of MAC
1,080"
Leading edge
of MAC 900"
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

(INOS

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

Any questions I can answer or follow up later on?