PRINCIPLES OF FLIGHT

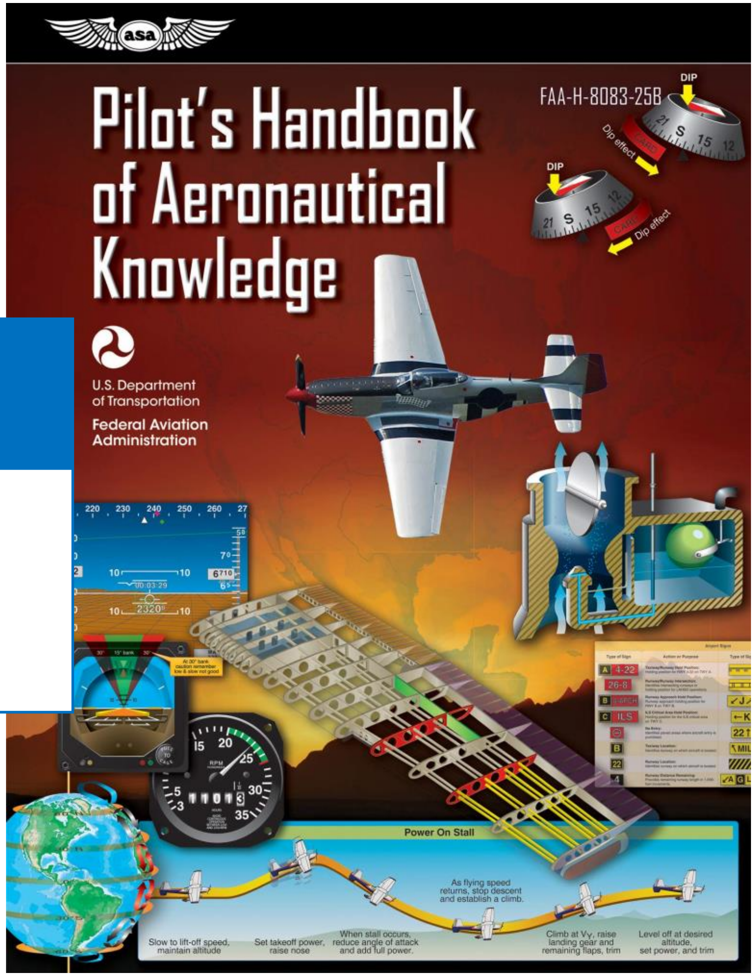
Lesson Outline

LESSON OBJECTIVE

To determine that the student exhibits acceptable knowledge of the elements related to principles of flight by describing the elements on the following slide.

LESSON SOURCE(S)

Pilot's Handbook of Aeronautical Knowledge
FAA-H-8083-25



Lesson Outline

LESSON ELEMENTS	TIMEFRAME	EQUIPMENT/TOOLS
Airfoil Design Characteristics Airplane Stability and Controllability Turning Tendencies Load Factors in Airplane Design Wingtip Vortices and Precautions To be Taken	60 Minutes *approximately* Discuss Objectives Present and Review Material Student Questions Conclusion and Quiz	Lesson Presentation Whiteboard and Markers FAA Sources and References

Lesson Outline

INSTRUCTOR ACTIONS	STUDENT ACTIONS	COMPLETION STANDARDS
Present Objectives and Standards Teach Lesson from Presentation Ask and Answer Student Questions Assign Homework Check Student's Post Lesson Quiz	Participate in Lesson Take Notes Ask and Respond to Questions Pass the Post Lesson Quiz	Student is able to understand and differentiate between the different lesson elements. Student is further able to apply this acquired knowledge in flight training/flight operation scenarios effectively and appropriately.

The Four Forces of Flight

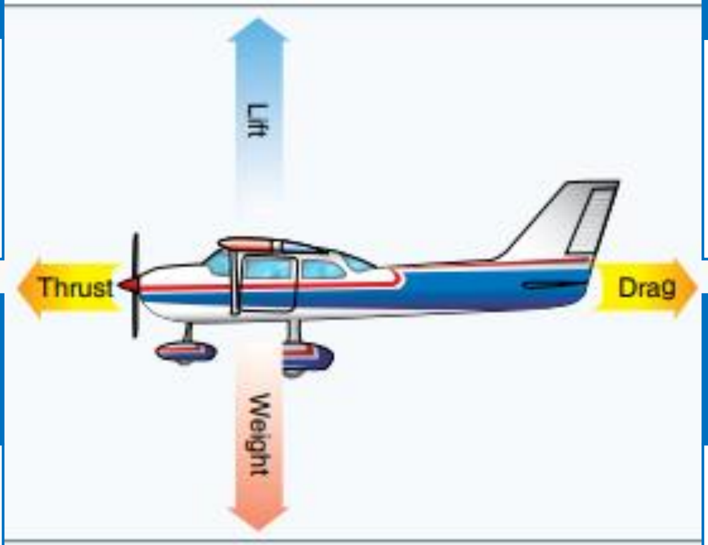
Thrust, drag, lift, and weight are forces that act upon all aircraft in flight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight.

Thrust

The forward force produced by the powerplant/propeller. It opposes or overcomes the force of drag.

Weight

The force that pulls the aircraft downward due to gravity. It opposes or overcomes the force of lift.



Lift

The force that acts perpendicular to the flight path and opposes or overcomes the force of weight.

Drag

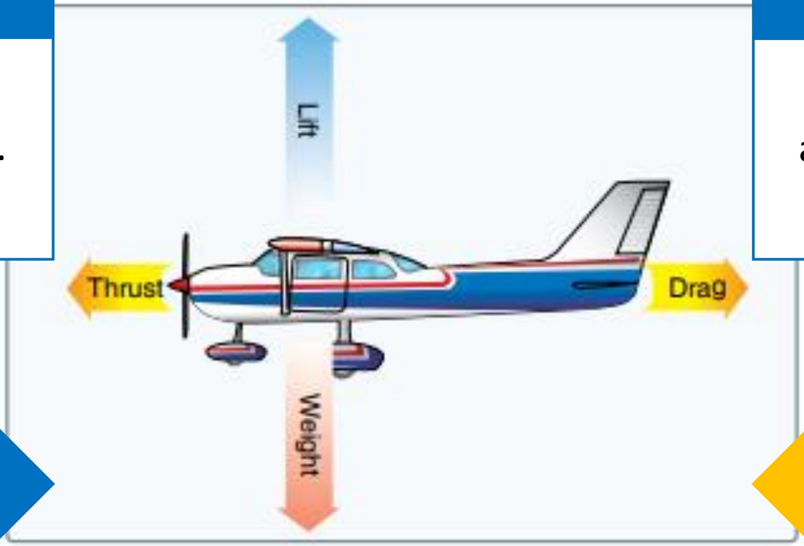
A rearward, retarding force caused by airflow disruption. It opposes or overcomes the force of thrust.

The Four Forces of Flight

Thrust, drag, lift, and weight are forces that act upon all aircraft in flight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight.

Thrust > Drag

If thrust becomes greater than drag, an aircraft will accelerate to a greater speed.



Drag > Thrust

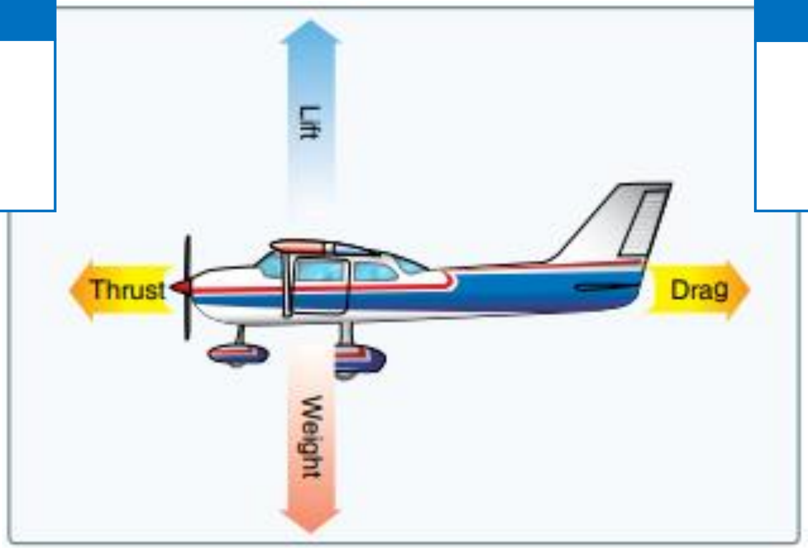
If drag becomes greater than thrust, an aircraft will decelerate to a slower speed.

The Four Forces of Flight

Thrust, drag, lift, and weight are forces that act upon all aircraft in flight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight.

Lift > Weight

If lift becomes greater than weight, an aircraft will climb to higher altitudes.



Weight > Lift

If weight becomes greater than lift, an aircraft will descend to lower altitudes.

The Four Forces of Flight

Thrust, drag, lift, and weight are forces that act upon all aircraft in flight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight.

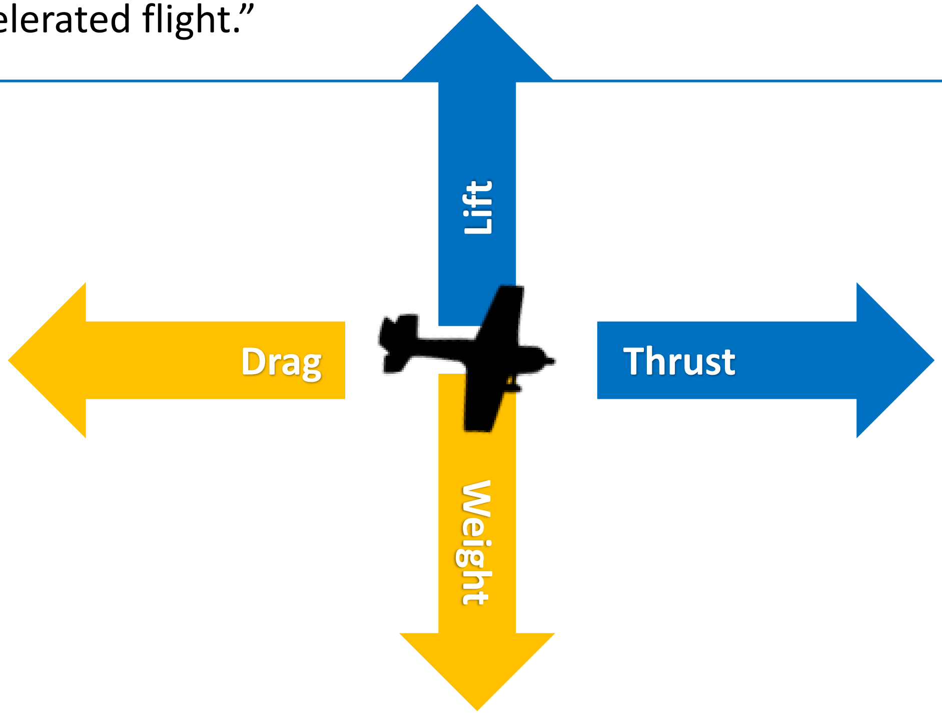
Thrust = Drag

If thrust equals drag, the aircraft will neither be accelerating or decelerating.

Lift = Weight

If lift equals weight, the aircraft will neither be climbing or descending.

In this situation, the aircraft would be in "straight and level, unaccelerated flight."

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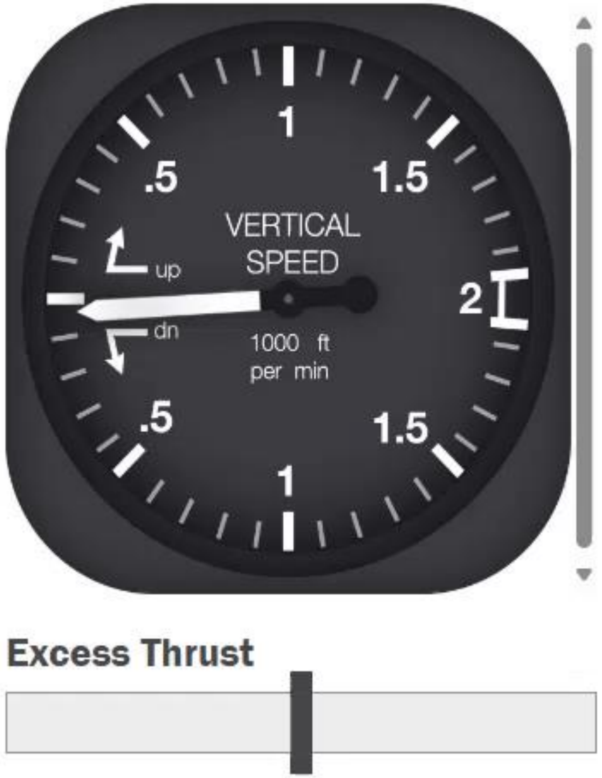
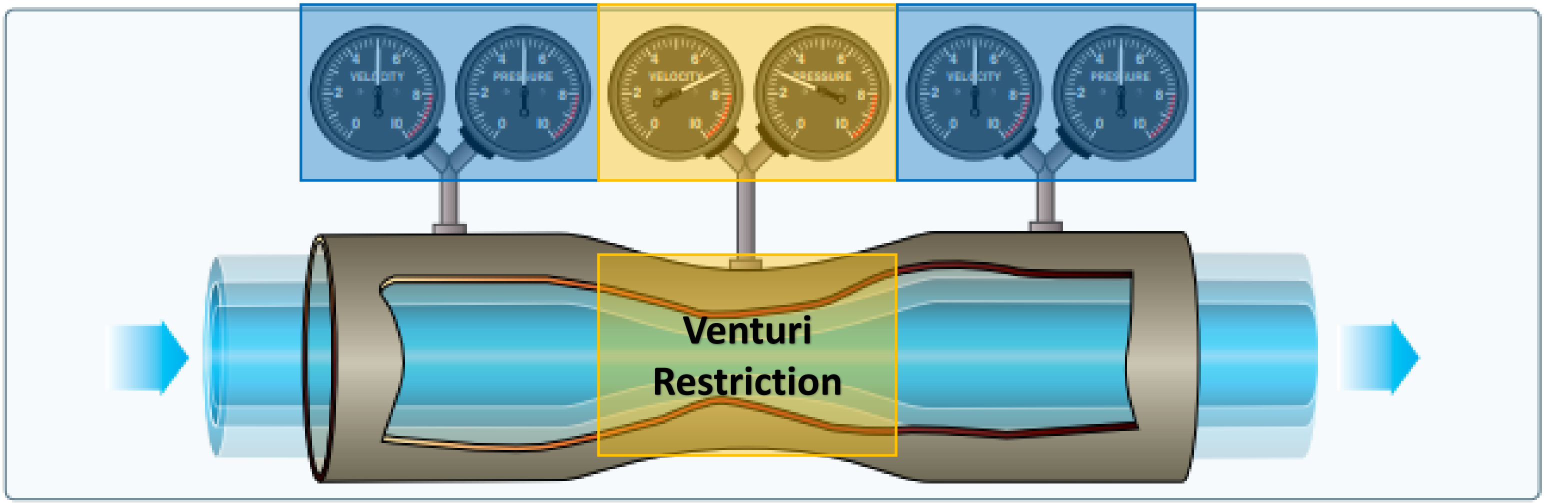

1
.5
1.5
VERTICAL
SPEED
up
2
dn
1000 ft
per min
.5
1.5
1
Excess Thrust

Airfoil Design Characteristics

An airfoil is a structure designed to obtain reaction upon its surface from the air through which it moves or that moves past such a structure. Air acts in various ways when submitted to different pressures and velocities.

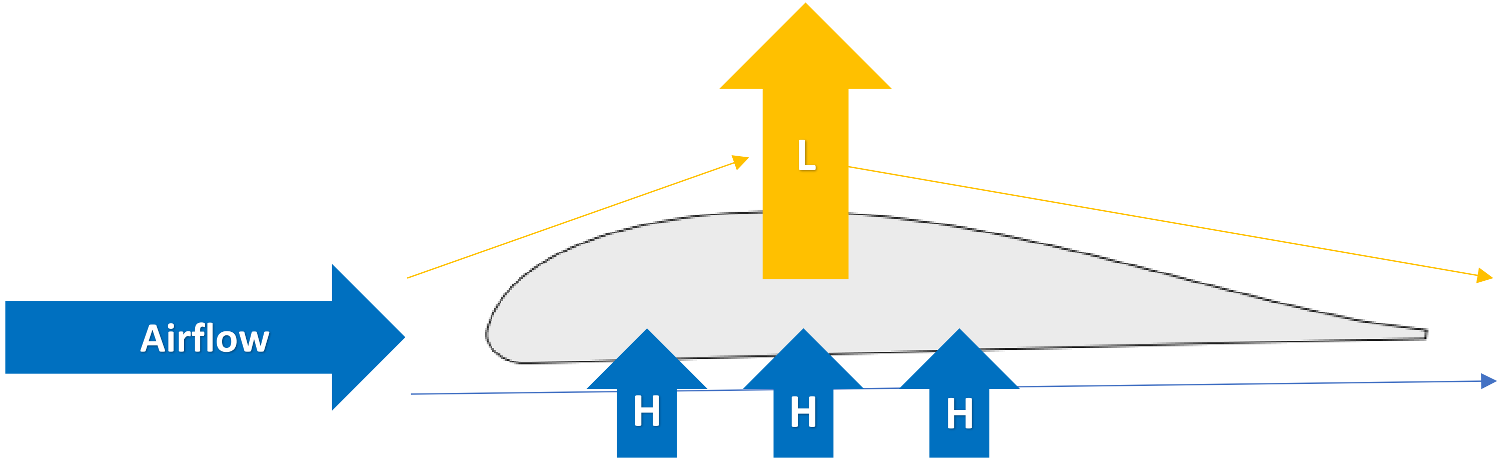
Velocity = Moderate Pressure = Moderate	Velocity = High Pressure = Low	Velocity = Moderate Pressure = Moderate



Airfoil Design Characteristics

Bernoulli’s Principle

Bernoulli’s Principle states that when air is subjected to an increase in velocity it is also accompanied by a decrease in its pressure. Vice-versa, when air decreases in velocity it is accompanied by an increase in pressure.



Airflow Over the Wing

Increased travel distance equates to an increase in velocity and decrease in pressure (hence, lower pressure).

Airflow Under the Wing

Decreased travel distance equates to a decrease in velocity and increase in pressure (hence, higher pressure).

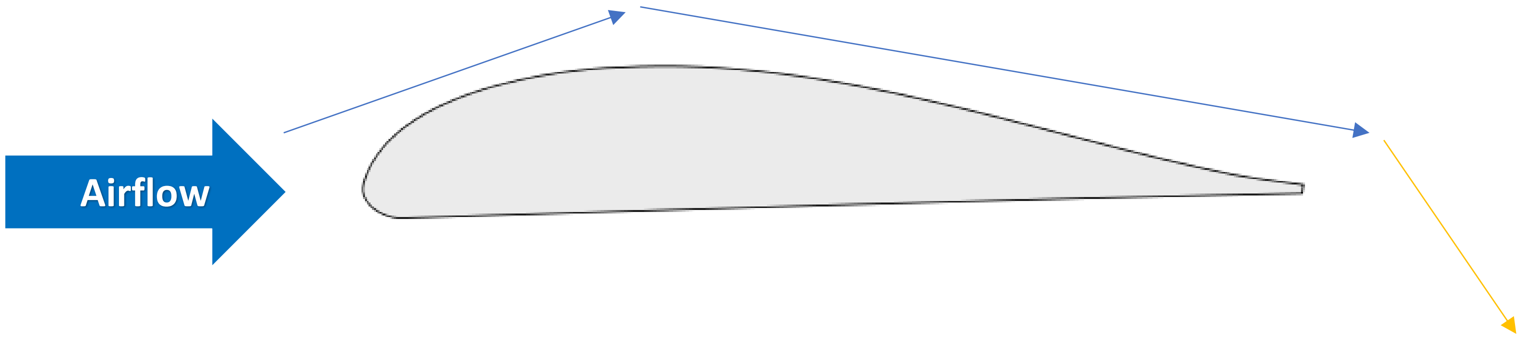
Air always wants to flow from areas of high pressure to areas of low pressure. Hence, the air under the wing tries to equalize with the air above the wing.


BERNOULLI'S PRINCIPLE
NEWTON'S THIRD LAW

Airfoil Design Characteristics

Downwash Principle

A second theory exists for how a wing produces lift, it is called the Downwash Principle and is based on Newton's Third Law of Physics that states: "For every action, there is an equal and opposite reaction."



Angular Downwash Flow

The downward flow of air off the wing's trailing edge forces the airplane to ascend into the air. "For every action…"

Airfoil Design Characteristics

Downwash Principle

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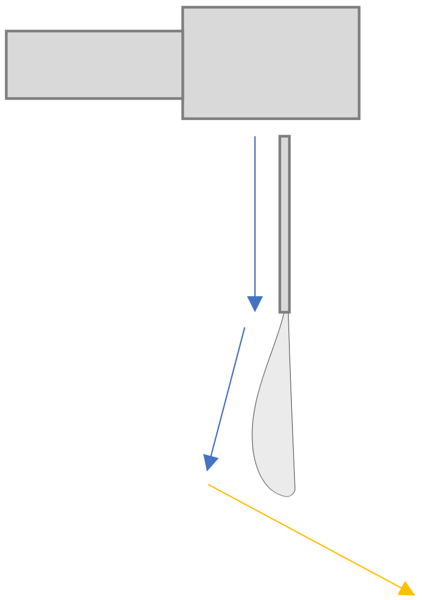
The Spoon Experiment

Downwash can be seen in action in your own home. If you take a spoon and supply a steady stream of water to the back of the spoon head, you will see the water stream exhibit angular downwash flow characteristics as seen in the depiction here.



Airfoil Design Characteristics

Terms and Definitions

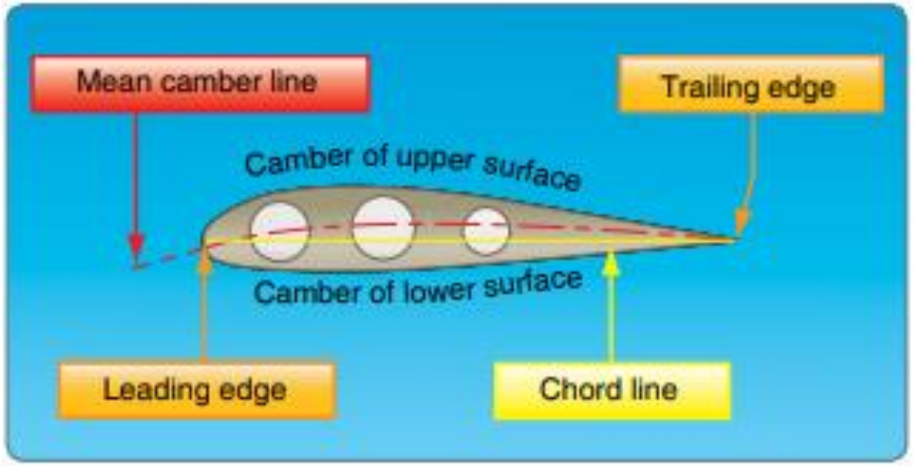
It is important that pilots understand certain terms and definitions as they apply to airfoils.

Mean Camber Line

The median camber (curvature) compared between the camber of the upper and lower surfaces of the airfoil.

Leading Edge

This is the front of the wing or airfoil. The part of the airfoil that is coming into direct contact with the airflow.



Trailing Edge

This is the back of the wing or airfoil. The part of the airfoil that is not coming into direct contact with the airflow.

Chord Line

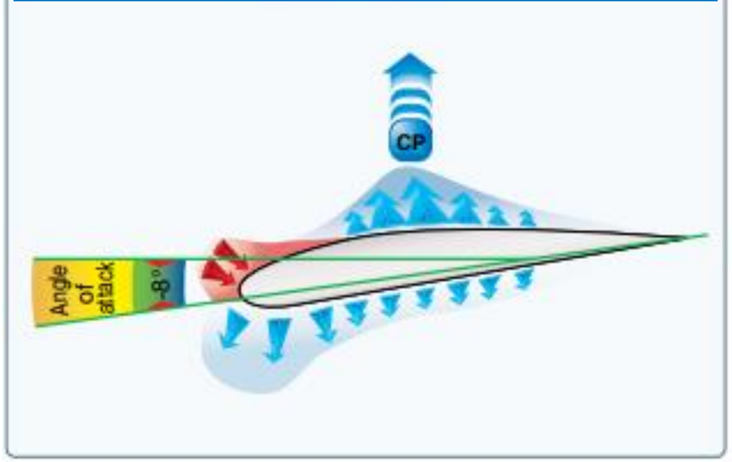
The chord line is an imaginary straight line drawn between the leading and trailing edges of a wing or airfoil.

Airfoil Design Characteristics

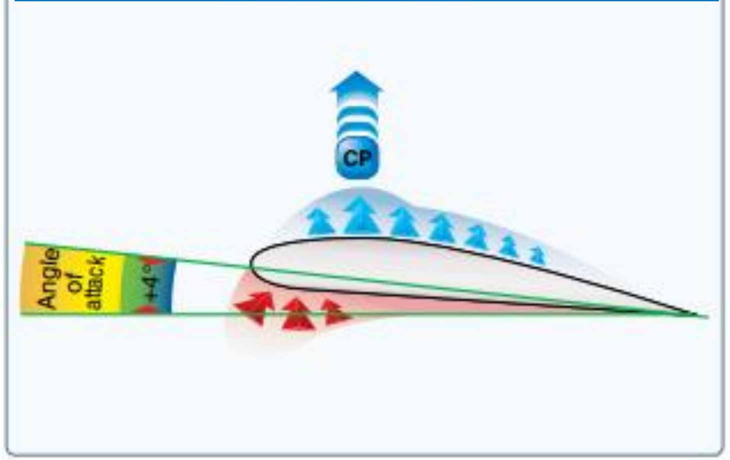
Angle Of Attack

The angle of attack of an airfoil is the angular difference between the relative airflow and the chord line.

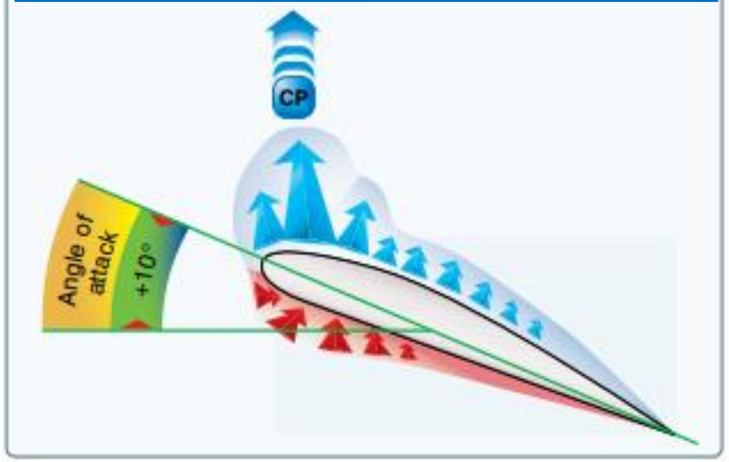
Low AOA



Normal AOA



High AOA



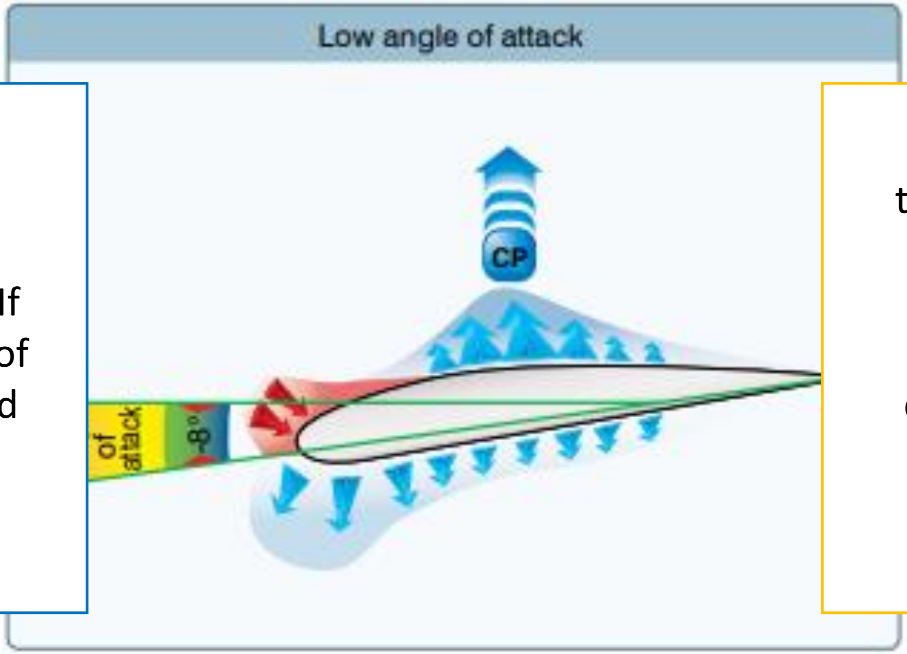
Airfoil Design Characteristics

Varying Angles of Attack

A pilot can fly an aircraft at varying angles of attack to maintain straight and level flight at various airspeeds.

High Speed Flight

If an aircraft is flying at higher speeds, and the pilot wishes to maintain straight and level flight, he/she will need to fly at a lower angle of attack. If the pilot were to fly at a higher angle of attack, the aircraft would climb instead of maintaining straight and level.



What Causes this?

The more airflow an airfoil receives, the more effective it becomes. A wing with increased airflow would generate more lift (and the aircraft would climb). The pilot must compensate for this increase in lift by decreasing the angle of attack to straight and level flight.

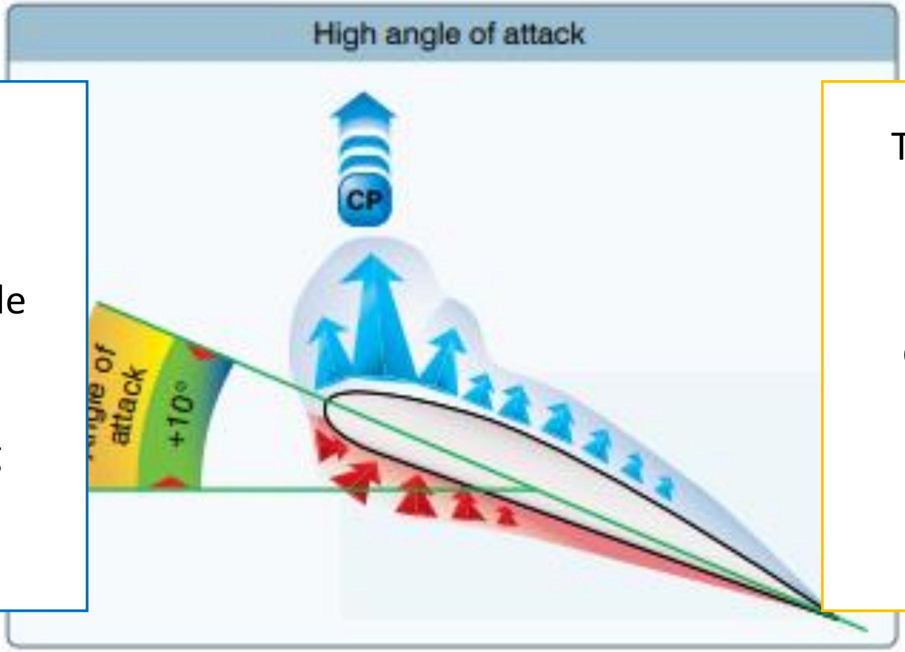
Airfoil Design Characteristics

Varying Angles of Attack

A pilot can fly an aircraft at varying angles of attack to maintain straight and level flight at various airspeeds.

Low Speed Flight

If an aircraft is flying at lower airspeeds, and the pilot wishes to maintain straight and level flight, he/she will need to fly at a higher angle of attack. If the pilot were to fly at a higher angle of attack, the aircraft would descend instead of maintaining straight and level flight.



What Causes this?

The less airflow an airfoil receives, the less effective it becomes. A wing with decreased airflow would generate less lift (and the aircraft would descend). The pilot must compensate for this decrease in lift by increasing the angle of attack to straight and level flight.

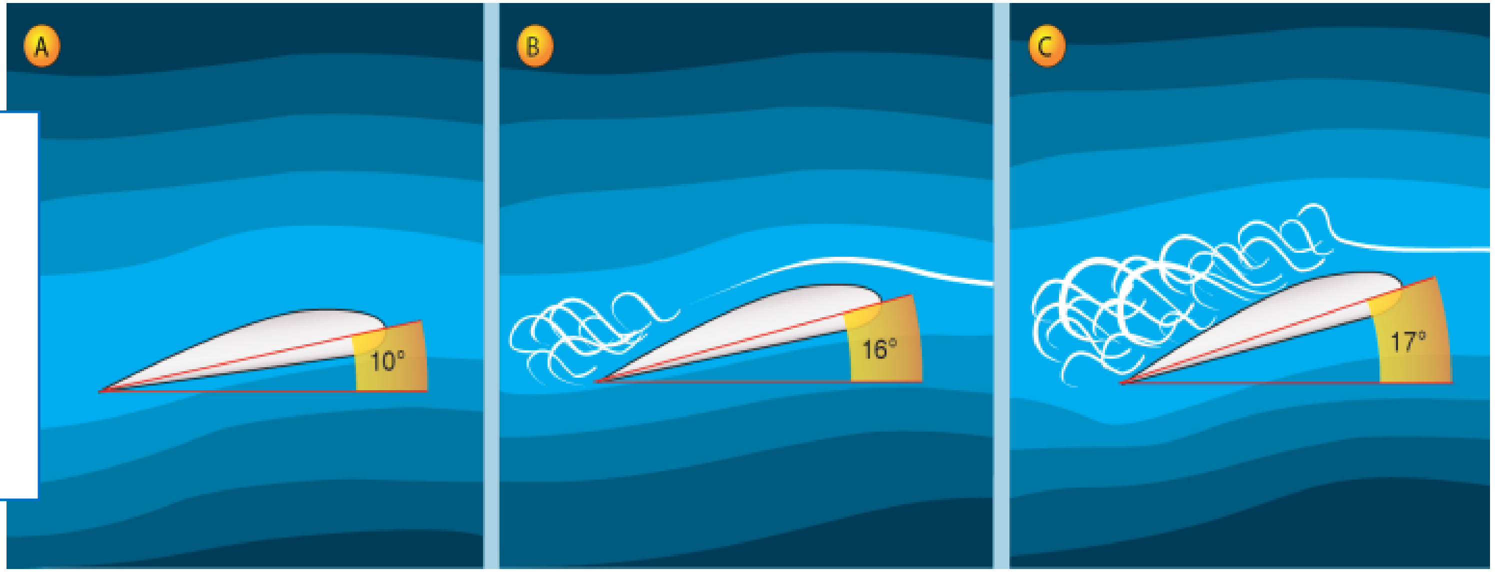
Airfoil Design Characteristics

Stalls

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.

Critical Angle of Attack

The critical angle of attack is the angle at which an aircraft will stall regardless of its airspeed. The wing never completely stops producing lift in a stalled condition (if so, it would fall to the Earth).



Airfoil Design Characteristics

Stalls

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.

Stall Recovery

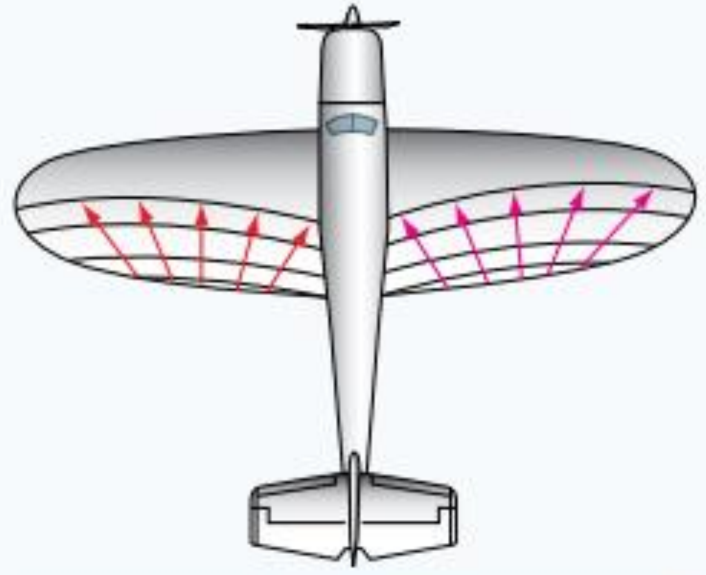
Depending on the complexity of the airplane, stall recovery could consist of as many as six steps. Even so, the pilot should remember the most important action to an impending stall or a full stall is to reduce the AOA.

Stall Recovery Template	
1. Wing leveler or autopilot	1. Disconnect
2. a) Pitch nose-down b) Trim nose-down pitch	2. a) Apply until impending stall indications are eliminated b) As needed
3. Bank	3. Wings Level
4. Thrust/Power	4. As needed
5. Speed brakes/spoilers	5. Retract
6. Return to the desired flight path	

Airfoil Design Characteristics

Effect of Wing Planforms

A planform is the shape of the wing as viewed from directly above and deals with airflow in three dimensions. Aspect ratio, taper ratio, and sweepback are factors in planform design that are very important to the overall aerodynamic characteristic of a wing.



Elliptical wing

Elliptical Wing

The elliptical wing is the ideal subsonic planform since it provides for a minimum of induced drag for a given aspect ratio. While it is true that the elliptical wing provides the best coefficients of lift before reaching an incipient stall, it gives little advance warning of a complete stall, and lateral control may be difficult because of poor aileron effectiveness.

Airfoil Design Characteristics

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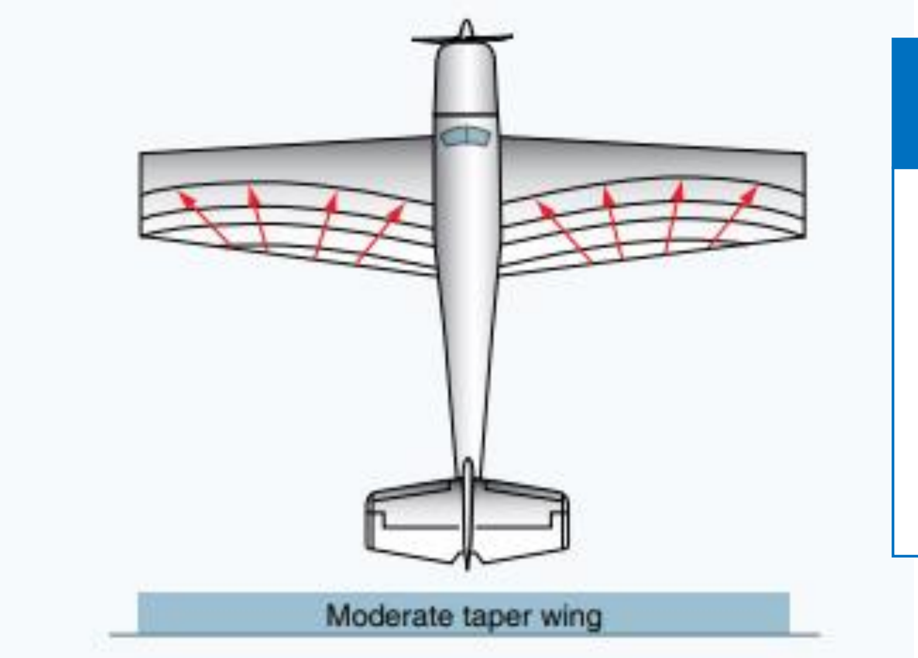

Tapered Wing

The tapered airfoil is desirable from the standpoint of weight and stiffness, but again is not as efficient aerodynamically as the elliptical wing. In order to preserve the aerodynamic efficiency of the elliptical wing, rectangular and tapered wings are sometimes tailored through use of wing twist and variation in airfoil sections.

Airfoil Design Characteristics

Effect of Wing Planforms

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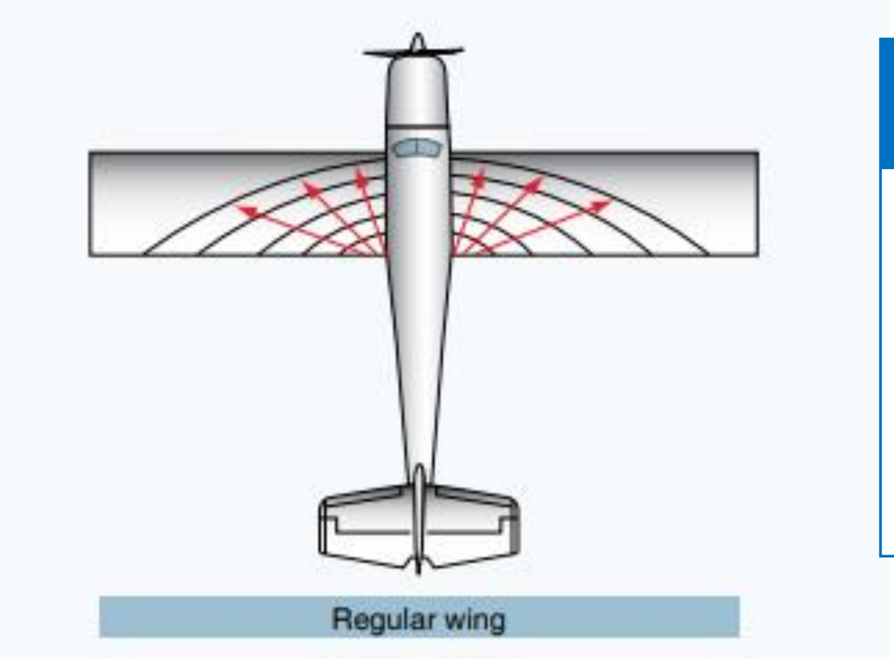


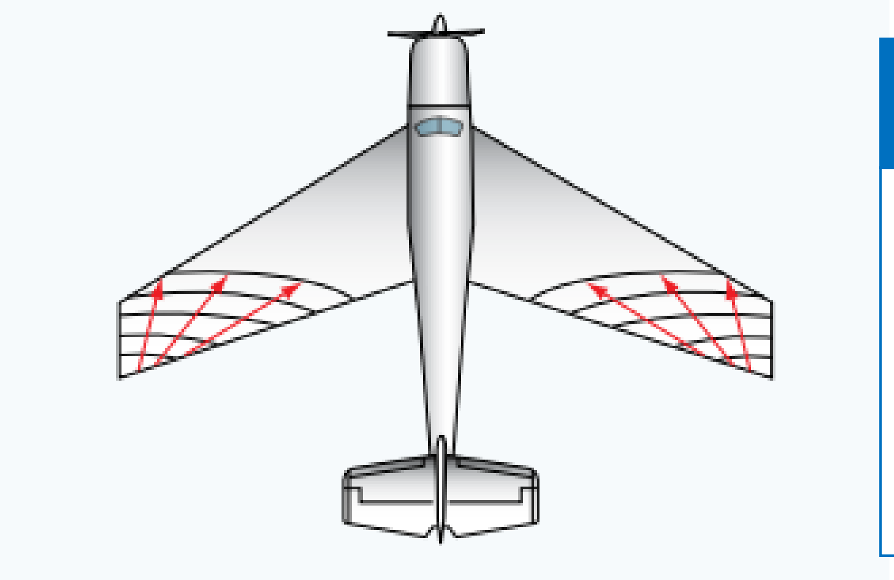
Regular Wing

The rectangular wing has a tendency to stall first at the wing root and provides adequate stall warning, adequate aileron effectiveness, and is usually quite stable. It is, therefore, favored in the design of low cost, low speed airplanes.

Airfoil Design Characteristics

Effect of Wing Planforms

A planform is the shape of the wing as viewed from directly above and deals with airflow in three dimensions. Aspect ratio, taper ratio, and sweepback are factors in planform design that are very important to the overall aerodynamic characteristic of a wing.



Sweepback wing

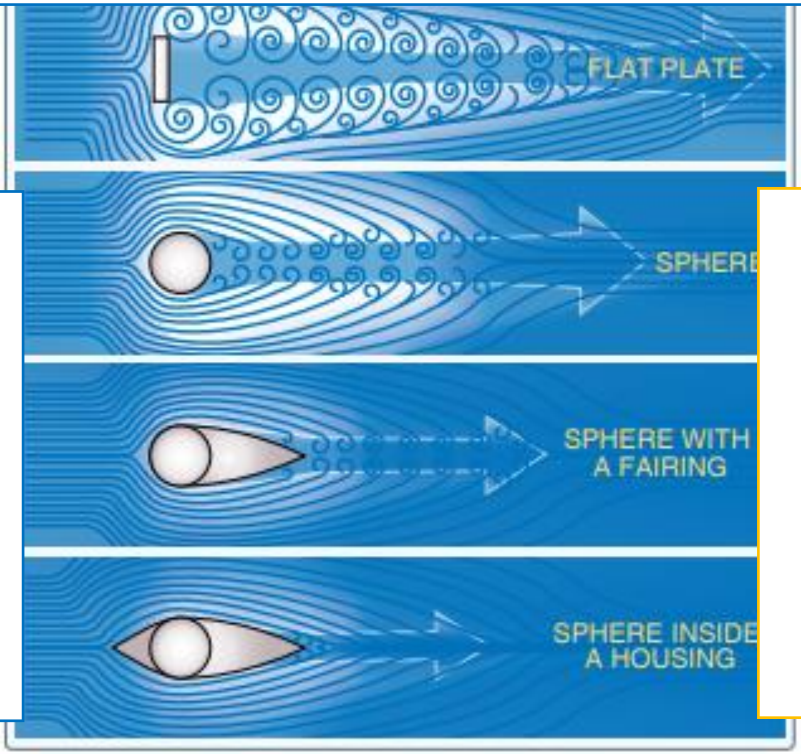
Sweepback Wing

Airplanes that are developed to operate at very high speeds demand greater aerodynamic cleanness and greater strength, which require low aspect ratios. Such airplanes require very precise and professional flying techniques, especially at slow speeds, while airplanes with a high aspect ratio are usually more forgiving of improper pilot techniques.

Airfoil Design Characteristics

Types of Drag

Drag is the force that resists movement of an aircraft through the air. There are two basic types: parasite drag and induced drag.



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. There are 3 sub-types of Parasite Drag: Form Drag, Interference Drag, and Skin Friction Drag.

Induced Drag

It is an established physical fact that no system that does work in the mechanical sense can be 100 percent efficient. This means that the required work is obtained at the expense of certain additional work that is dissipated or lost in the system. Hence, Induced Drag is a by-product of lift.

Airfoil Design Characteristics

Types of 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.

Form Drag

Form drag is the portion of parasite drag generated by the aircraft due to its shape and airflow around it. Examples include the engine cowlings, antennas, and the aerodynamic shape of other components.

Interference Drag

Interference drag comes from the intersection of airstreams that creates eddy currents, turbulence, or restricts smooth airflow. For example, the intersection of the wing and the fuselage at the wing root has significant interference drag.

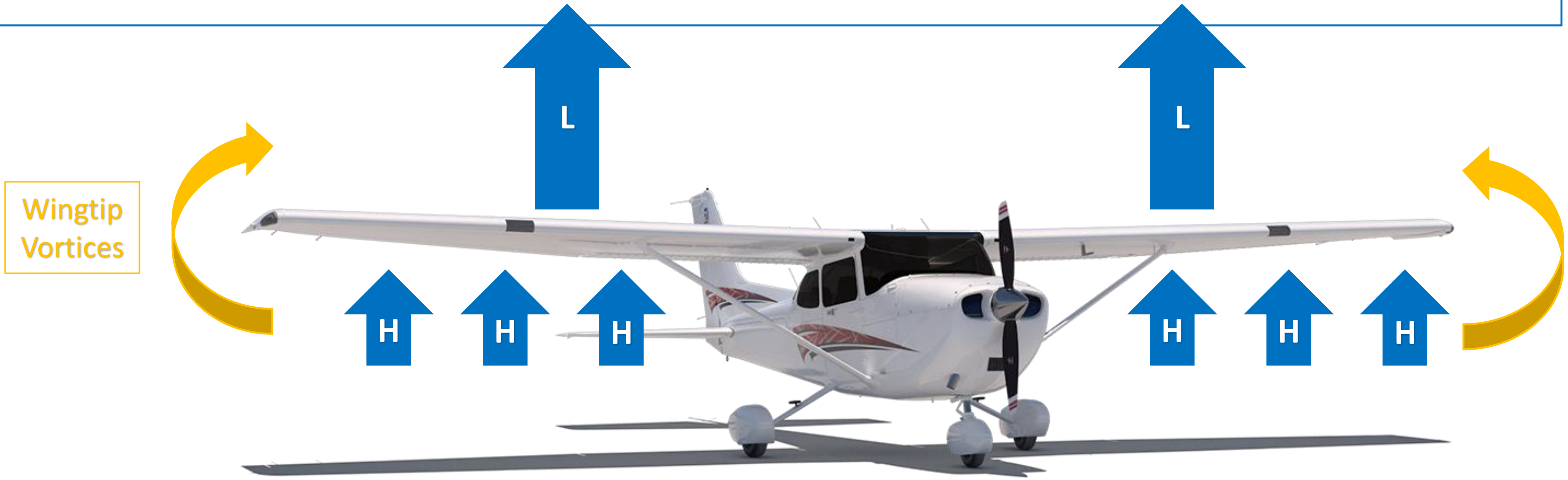
Skin Friction Drag

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.

Airfoil Design Characteristics

Induced Drag

An airfoil produces lift by making use of the energy of the free airstream. Whenever an airfoil is producing lift, the pressure on the lower surface of it is greater than that on the upper surface. As a result, the air tends to flow from the high pressure area below the tip upward to the low pressure area on the upper surface.



Airfoil Design Characteristics

Lift/Drag Ratio

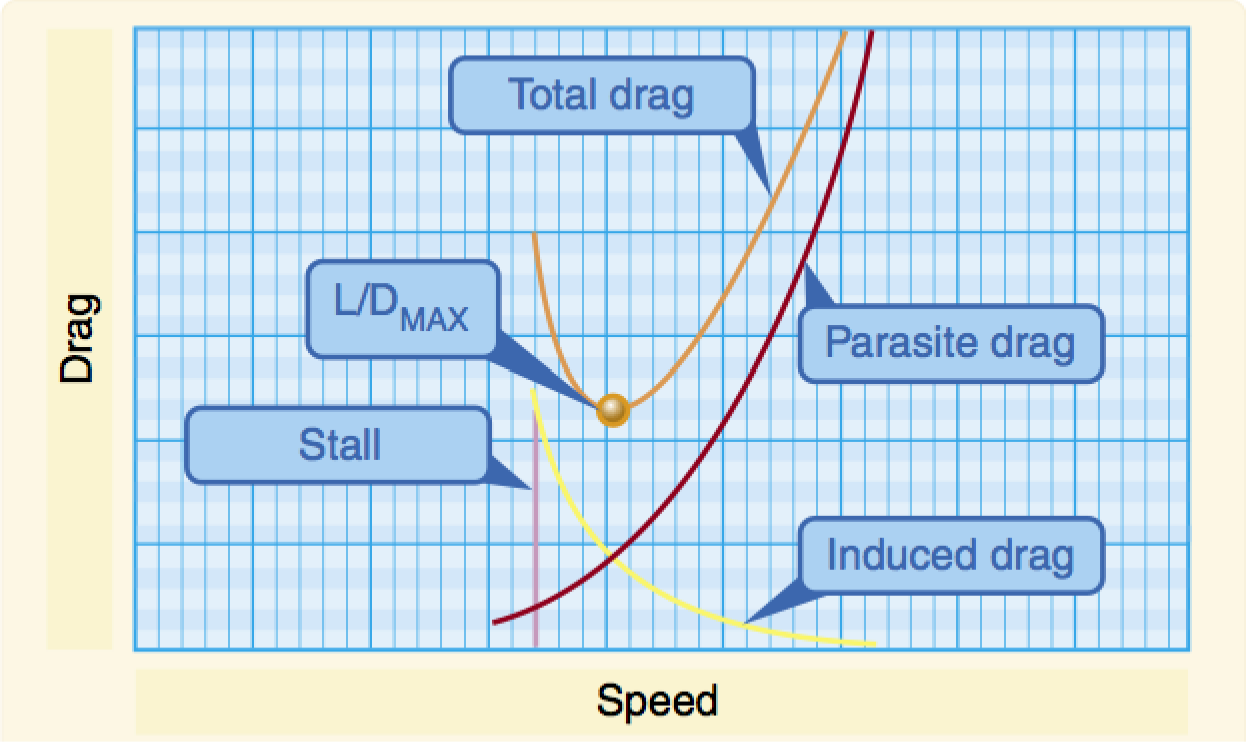
Parasite and Induced Drag will vary depending upon the speed of the aircraft.

Parasite Drag

Parasite drag increases as airspeed increases.

Induced Drag

Induced drag decreases as airspeed increases.



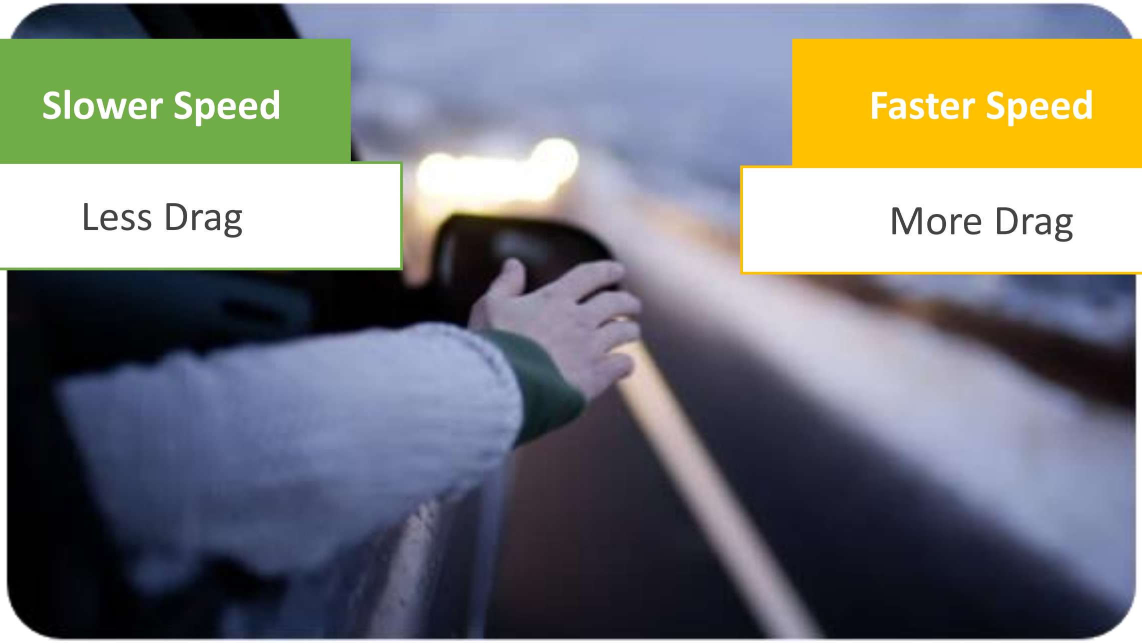
Airfoil Design Characteristics

Lift/Drag Ratio

Parasite and Induced Drag will vary depending upon the speed of the aircraft.

Parasite Drag

Parasite drag increases as airspeed increases. Imagine putting your hand outside of your car window while driving. The faster the speed of the vehicle, the more drag you will feel with your hand. This is how Parasite Drag works with an aircraft.



Slower Speed

Less Drag

Faster Speed

More Drag

Airfoil Design Characteristics

Lift/Drag Ratio

Parasite and Induced Drag will vary depending upon the speed of the aircraft.

Induced Drag

Induced drag decreases as airspeed increases. Imagine 2 identical airplanes flying at 7,000’ MSL. One is travelling at 120 KIAS and the other at 70 KIAS. The one travelling at 120 KIAS will have a lower angle of attack, be more streamlined with the relative airflow, and will be producing less induced drag.

Faster Speed

Lower AOA
Less Drag

120 KIAS
AOA = 3

Slower Speed

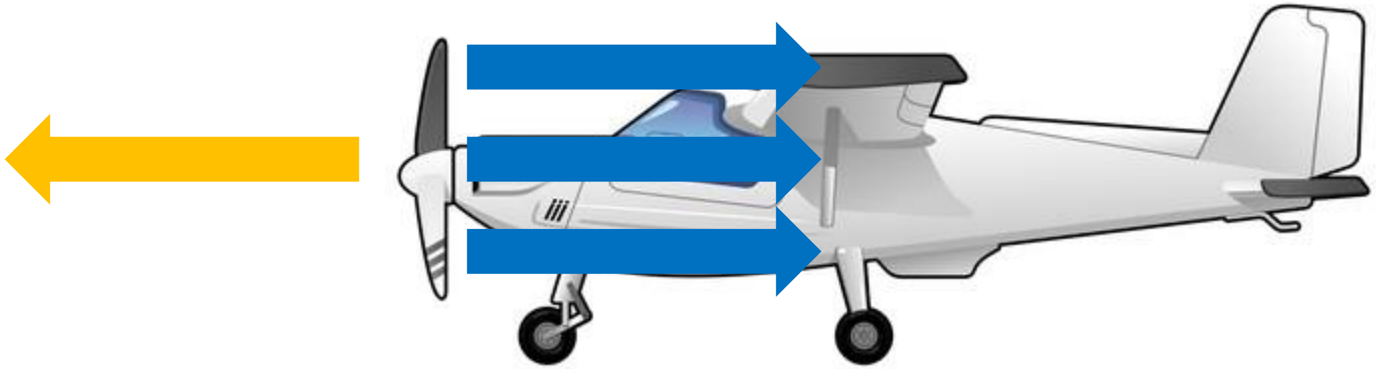
Higher AOA
More Drag

70 KIAS
AOA = 7

Airfoil Design Characteristics

The Propeller

The propeller is also considered an airfoil because it interacts with airflow to produce a desired effect. While wings produce lift, a propeller produces “horizontal lift” or thrust to propel an airplane forward.



Airfoil Design Characteristics

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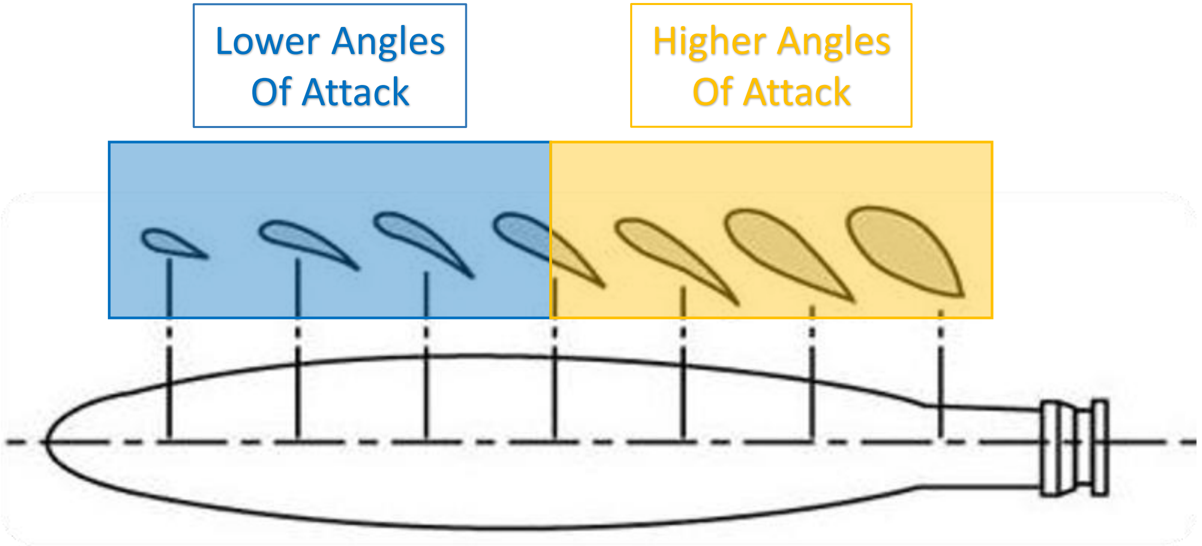
Propeller Twist

In order for a propeller to produce uniform thrust along the entire length of its blades, it is twisted as seen in the depiction on this slide.



Airfoil Design Characteristics

The Propeller

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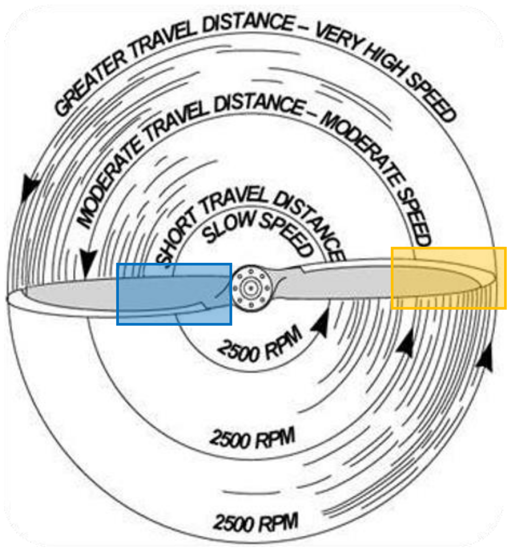
Why is Propeller Twist Necessary?

This is because the propeller blades are spinning faster at the tips and slower towards the hub. Hence, the tips will need a lower angle of attack and the sections near the hub will need a greater angle of attack to produce the desired uniform amounts of thrust.

Slower Speeds
Higher AOA

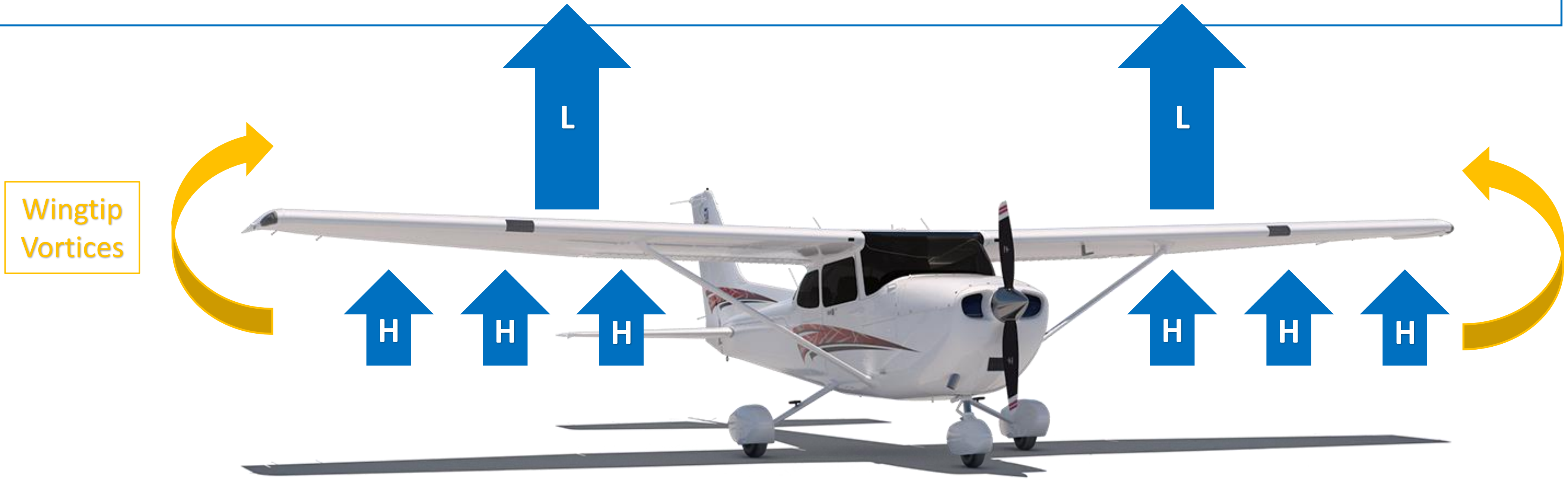


Higher Speeds
Lower AOA

Wingtip Vortices

Wingtip Vortices

To this point, the discussion has centered on the flow across the upper and lower surfaces of an airfoil. While most of the lift is produced by these two dimensions, a third dimension, the tip of the airfoil also has an aerodynamic effect.



Wingtip Vortices

Wingtip Vortices

In flight, as these wingtip vortices make their way around the wingtips of the airplane, they make contact with the top of the wing. This causes an increase in drag and a decrease in airspeed.

Wingtip Vortices

Ground Effect

However, when the aircraft is within about a wings distance from the ground, the surface of the Earth deflects the wingtip vortices. Hence, they do not make contact with the top of the wing. This results in an decrease in drag and a sudden increase in lift. Most pilots have felt this effect during takeoffs and landings.


12:05:14
Aviation Safety Network

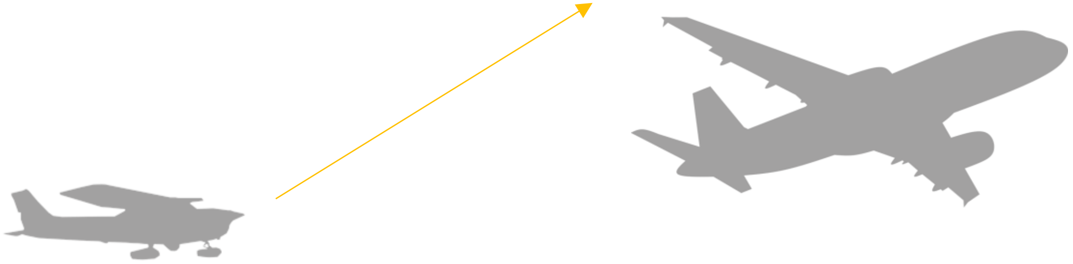
Wingtip Vortices

Wake Turbulence Avoidance

When an airplane is producing wingtip vortices, those vortices will begin at the wingtip and then move out, down, and away from the aircraft producing them. This means, there are certain measures pilots can take to avoid the turbulence associated with another aircraft's wingtip vortices.

Avoidance During Takeoff

First, a pilot can delay his or her takeoff for a time to allow the preceding aircraft's wingtip vortices to dissipate. Secondly, a pilot should attempt to takeoff prior to the preceding aircrafts takeoff point and remain above their flightpath. If it is not possible to outclimb the preceding aircraft, the pilot can sidestep into the wind (if there is a crosswind component).



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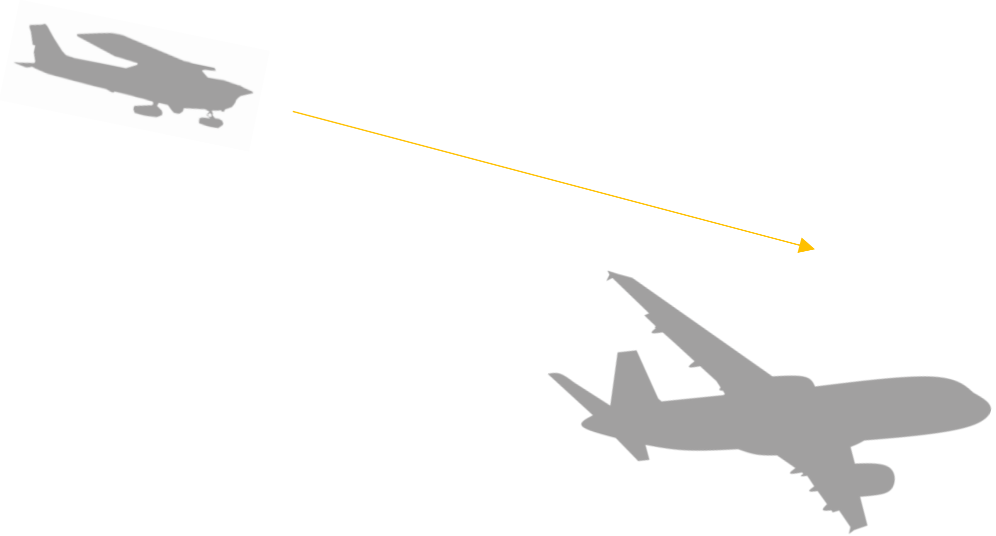
Avoidance During Landing

First, a pilot should not follow another aircraft on final descent closely enough to be disturbed by its wake turbulence. Secondly, a pilot should maintain a higher approach path than the preceding aircraft and attempt to land further down the runway, if safe and practical.



Wingtip Vortices

Wake Turbulence Avoidance

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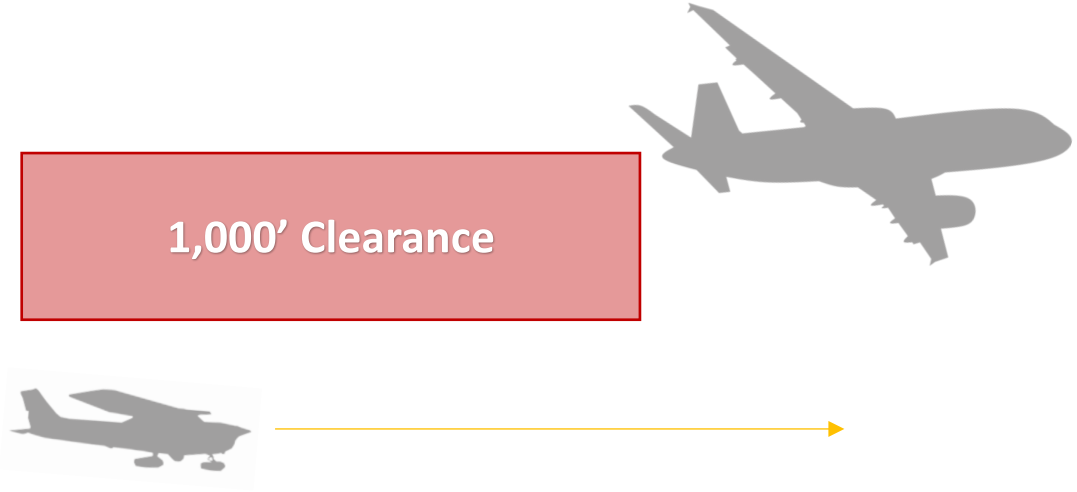
Avoidance During Cruise Flight

In cruise flight, a pilot should avoid flying through another aircraft's flight path. Additionally, the pilot should avoid following another aircraft on a similar flight path at an altitude within 1,000 of the preceding aircraft.



Turning Tendencies

Left Turning Tendencies

Because the propeller rotates clockwise (as seen from the cockpit) there are 4 inherent tendencies that will cause the airplane to want to turn to the left.

They are:

1. P-Factor
2. Torque
3. Gyroscopic Precession
4. Spiraling Slipstream

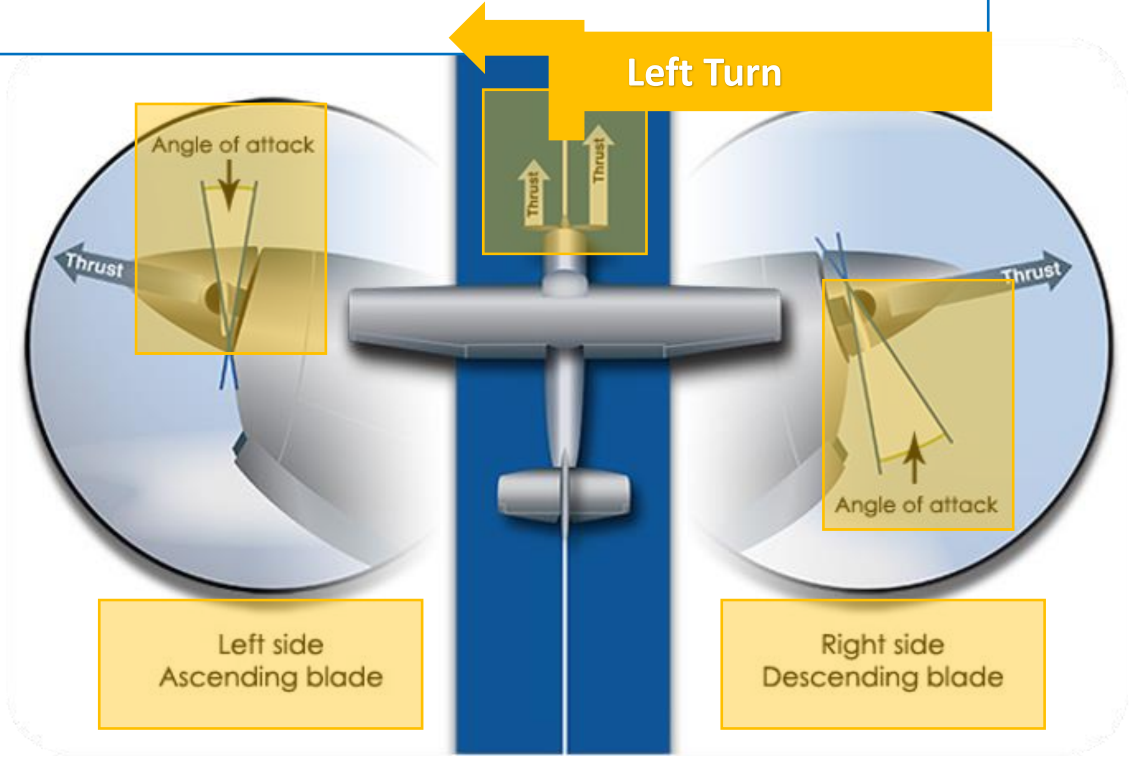
Turning Tendencies

Left Turning Tendencies

Because the propeller rotates clockwise (as seen from the cockpit) there are 4 inherent tendencies that will cause the airplane to want to turn to the left.

P-Factor

When an airplane is flying at a positive (or increased) angle of attack, the “bite” of the downward moving blade is greater than the “bite” of the upward moving blade. Since the downward moving blade is on the right side (as seen from the cockpit) this moves the center of thrust to the right of the propeller hub. Thus, creating a left turning tendency. This is corrected by proper use of the right rudder by the pilot.



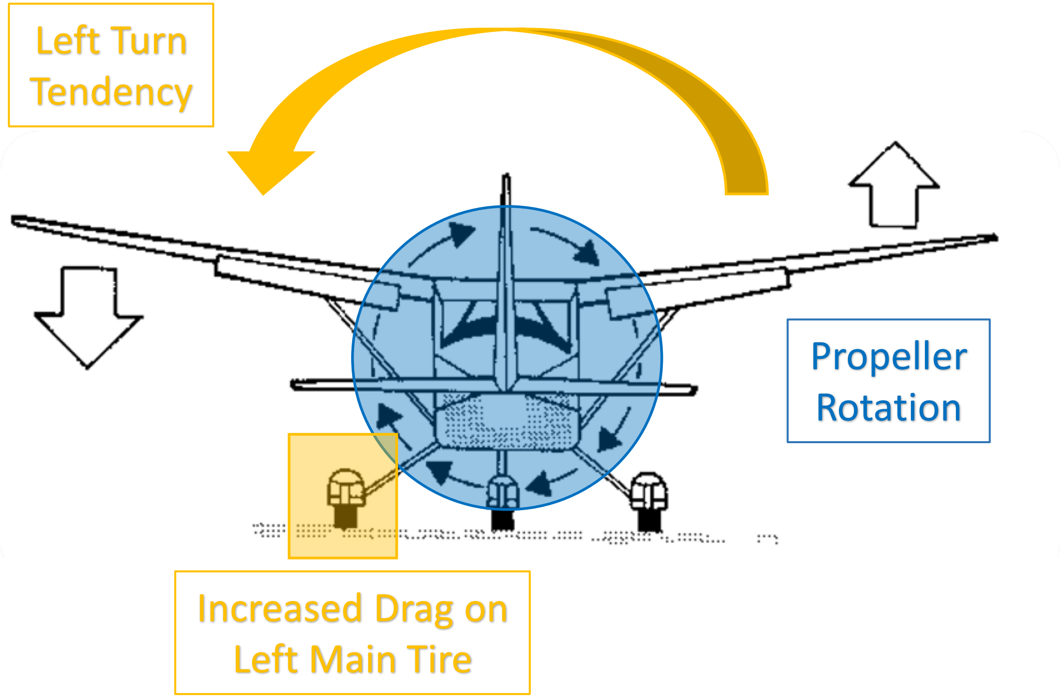
Turning Tendencies

Left Turning Tendencies

Because the propeller rotates clockwise (as seen from the cockpit) there are 4 inherent tendencies that will cause the airplane to want to turn to the left.

Torque

Newton's Third Law of Physics states: "For every action there is an equal and opposite reaction." Because the propeller blades are rotating clockwise (as seen from the cockpit) the airplane will have a natural tendency to want to rotate in the opposite direction (counter-clockwise) creating a left turning tendency. This will be most pronounced during the takeoff roll with high power settings.



Turning Tendencies

Left Turning Tendencies

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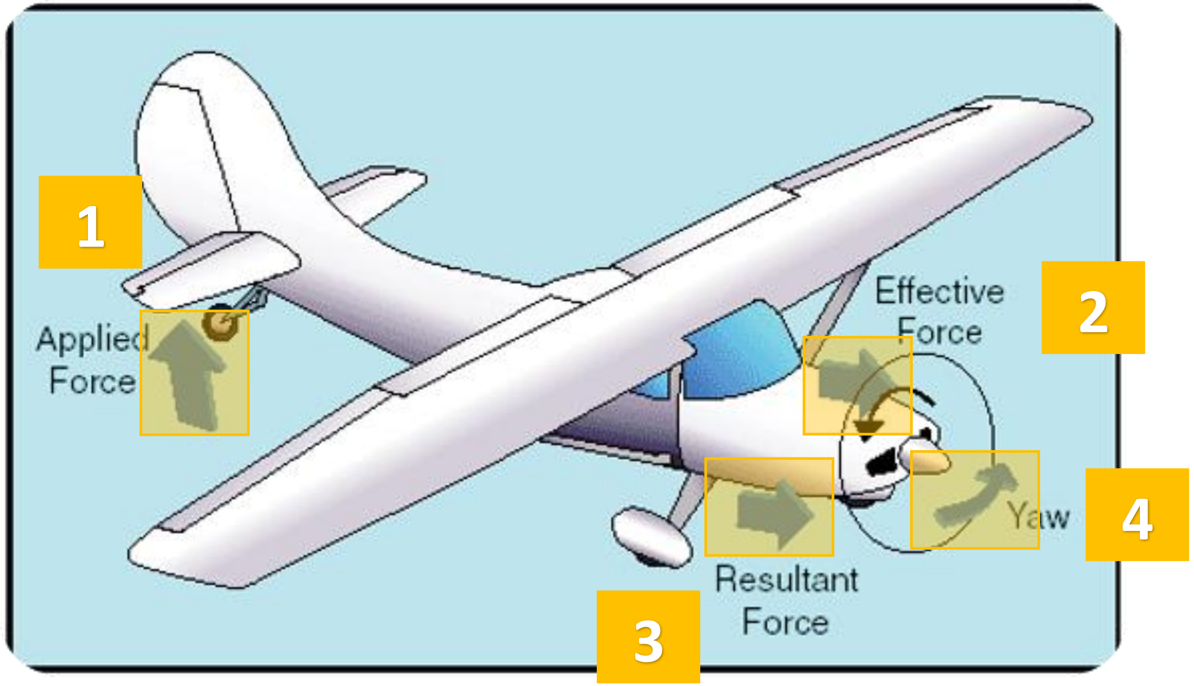
Gyroscopic Precession

Gyroscopic Precession means that a spinning object will have a resultant force that is experience 90 degrees after (in the direction of rotation) of an effective or applied force. This turning tendency is most common on tailwheel aircraft during the takeoff roll and can be better understood with the visual depicted on this slide.



Turning Tendencies

Left Turning Tendencies

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Spiraling Slipstream

The high-speed rotation of an aircraft propeller gives a corkscrew or spiraling rotation to its slipstream. At high propeller speeds and low forward (aircraft) speed, this spiraling rotation is very compact and exerts a strong sideward force on the aircraft's vertical stabilizer. This force pushes the nose of the aircraft to the left and results in a left turning and left yawing tendency as can be seen in the depiction.

Stability and Controllability

Airplane Axes

An airplane rotates around 3 different axes. They are the: lateral axis, longitudinal axis, and vertical axis.

Lateral Axis

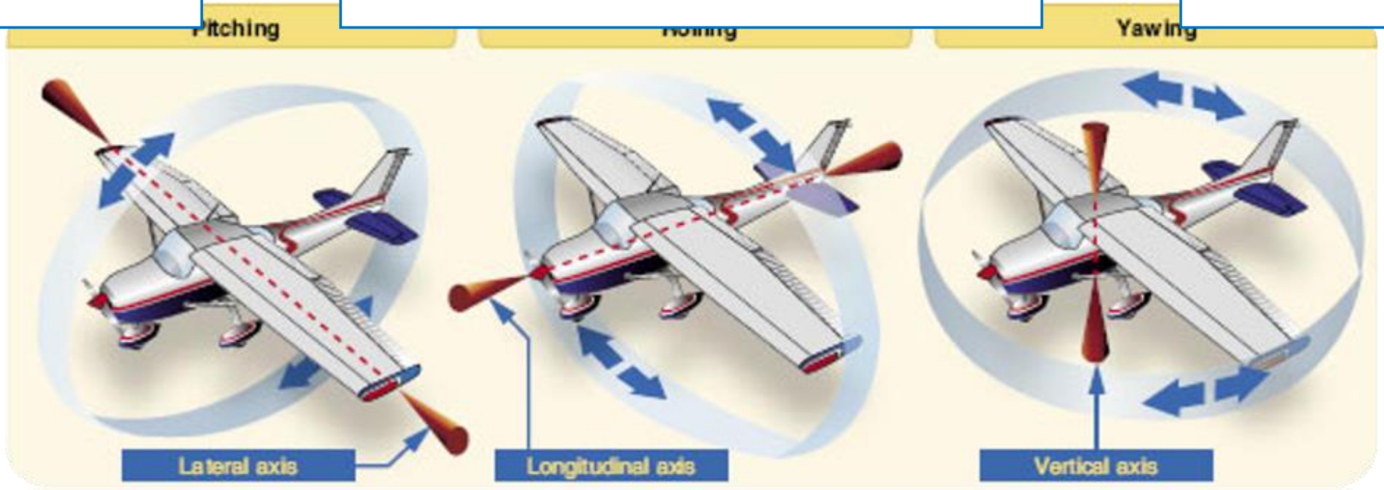
The aircraft pitches about the lateral axis.

Longitudinal Axis

The aircraft rolls about the longitudinal axis.

Vertical Axis

The aircraft yaws about the vertical axis.



Stability and Controllability

Airplane Stability

Stability is the inherent quality of an aircraft to correct for conditions that may disturb its equilibrium and to return to or to continue on the original flight path. It is primarily an aircraft design characteristic.

Static Stability

Static stability refers to the initial tendency, or direction of movement, back to equilibrium.

Sub-Types

There are 3 sub-types of both static and dynamic stability, they are: positive, negative, and neutral.

Dynamic Stability

Dynamic stability refers to how the aircraft will respond to a disturbance over time.

Stability and Controllability

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flight club

Stability and Controllability

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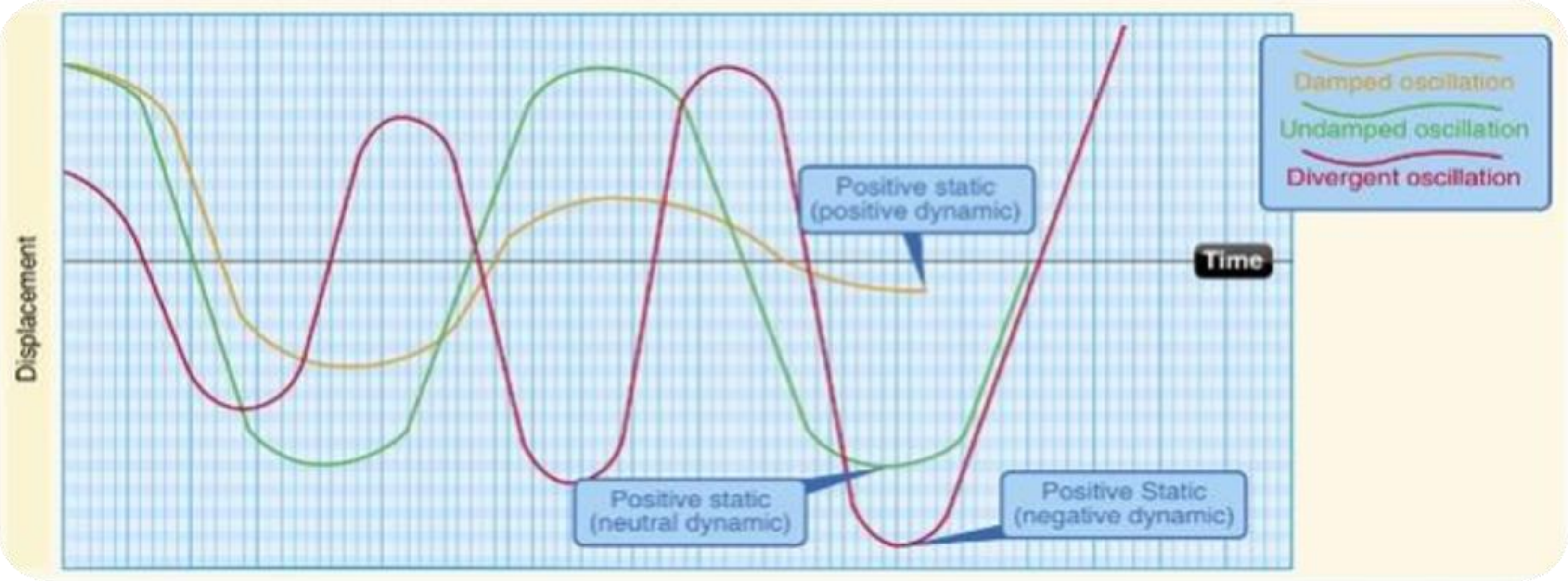


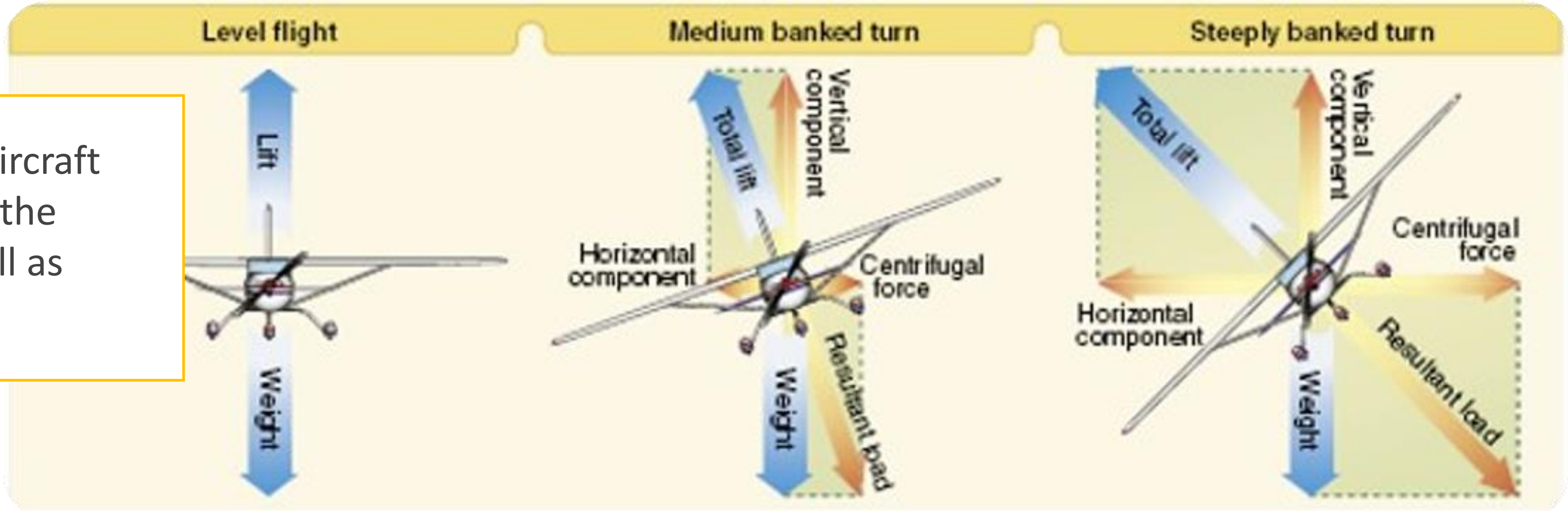
Stability and Controllability

Forces in Turns

If an aircraft were viewed in straight-and-level flight from the front, and if the forces acting on the aircraft could be seen, lift and weight would be apparent: two forces. If the aircraft were in a bank it would be apparent that lift did not act directly opposite to the weight, rather it now acts in the direction of the bank.

A Basic Truth

A basic truth about turns is that when the aircraft banks, lift acts inward toward the center of the turn, perpendicular to the lateral axis as well as upward.



Stability and Controllability

Forces in Turns

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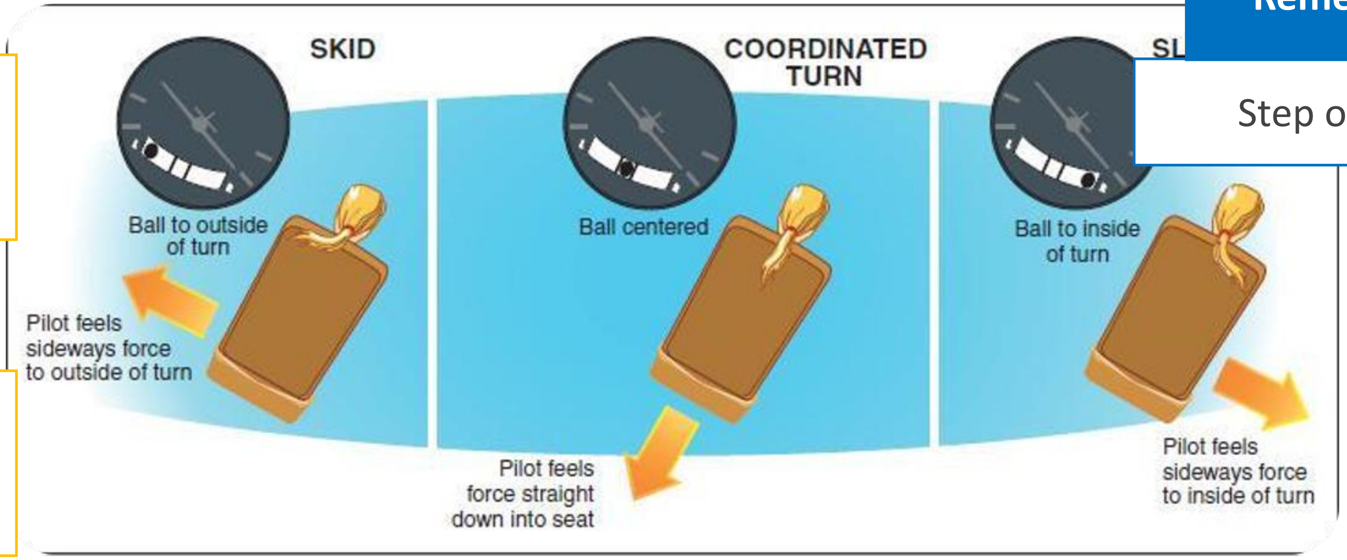
Slipping Turns

The aircraft is banked too much for the Rate of Turn.

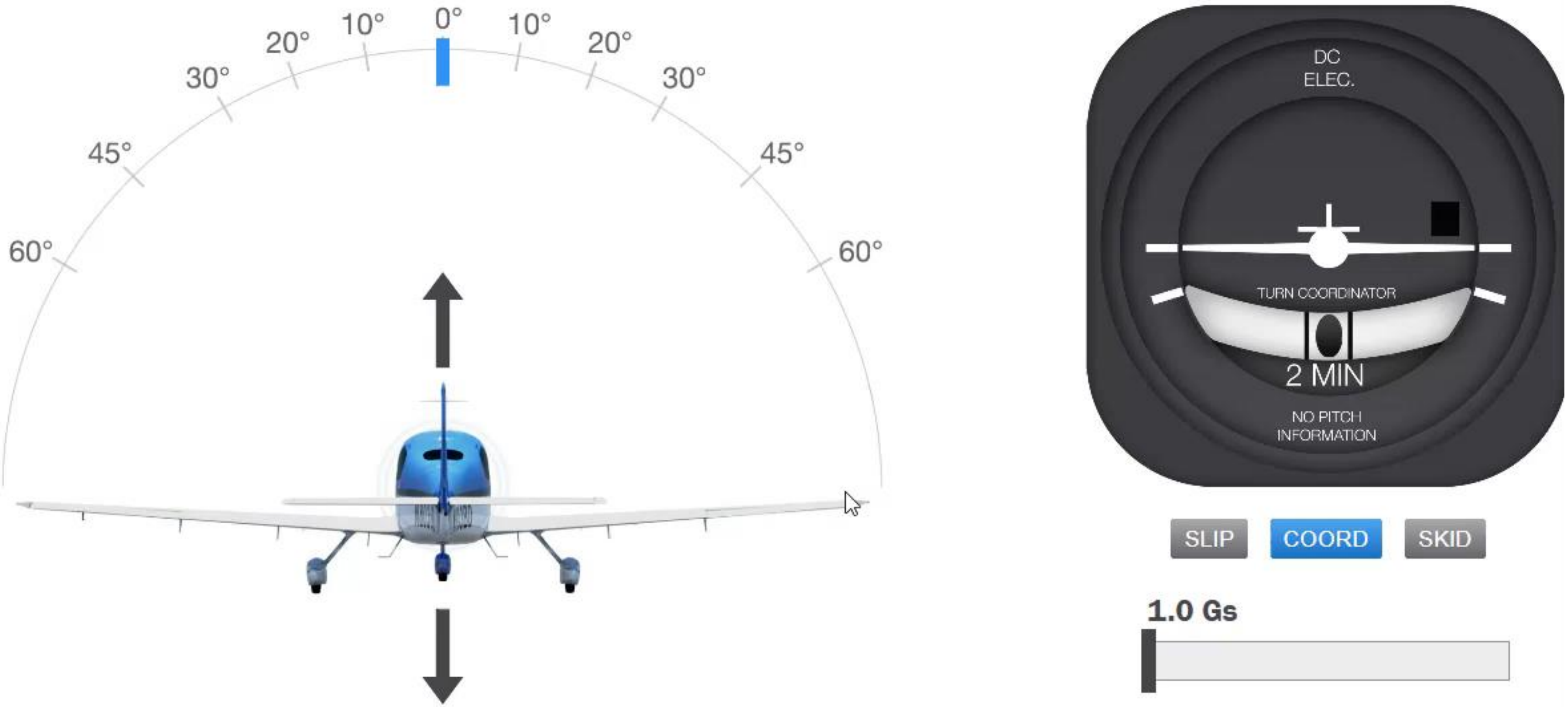
Skidding Turns

The rate of turn is too great for the angle of bank.



Remember to

Step on the Ball


0°
10°
10°
20°
20°
30°
30°
45°
45°
60°
60°
DC
ELEC.
TURN COORDINATOR
2 MIN
NO PITCH
INFORMATION
SLIP
COORD
SKID
1.0 Gs

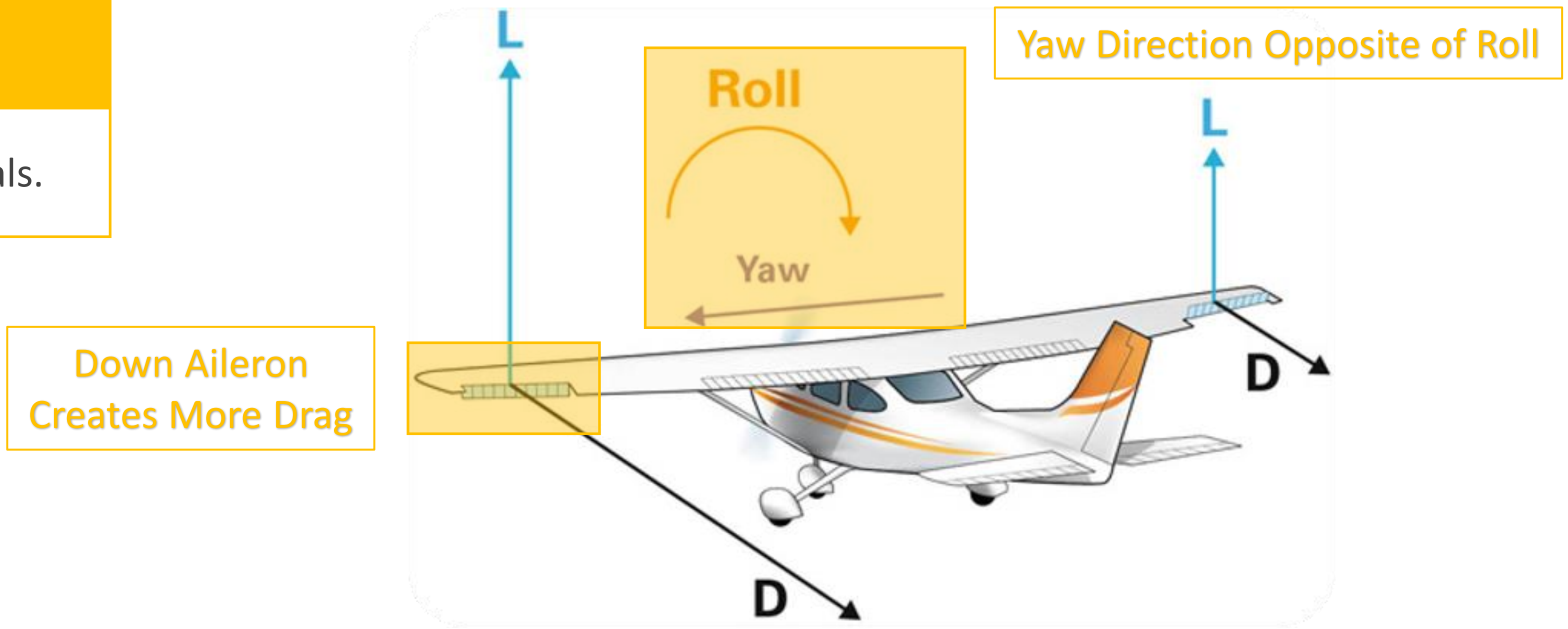
Stability and Controllability

Adverse Yaw

Adverse yaw is the natural and undesirable tendency for an aircraft to yaw in the opposite direction of a roll. This is due to the drag created by the deflection of the ailerons.

How to Correct It

Proper use of the Rudder Pedals.



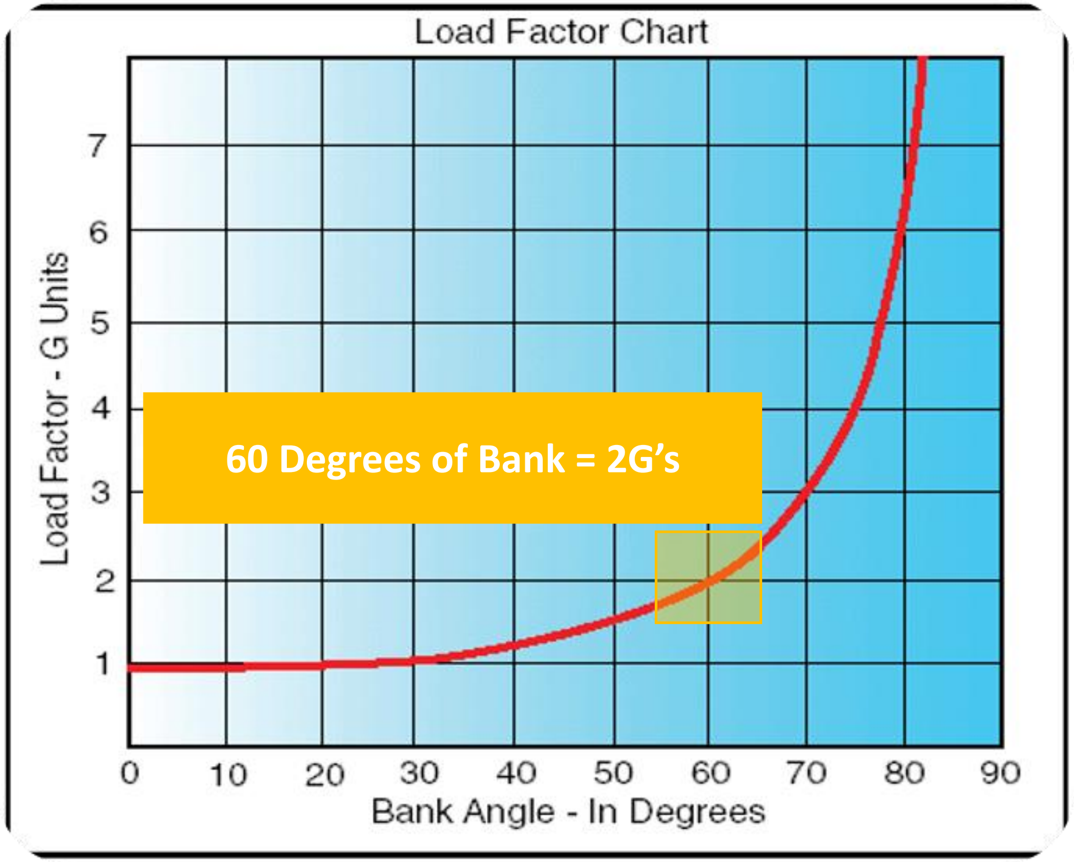
Load Factor

Definition

In aerodynamics, the maximum load factor (at a given bank angle while maintaining altitude) is a proportion between lift and weight and has a trigonometric relationship. The load factor is measured in “Gs” (acceleration of gravity), a unit of force equal to the force exerted by gravity on a body at rest and indicates the force to which a body is subjected when accelerated.

Make it Simple

An object subjected to 2G’s will weight double what it weighs at 1G (and so on and so forth).



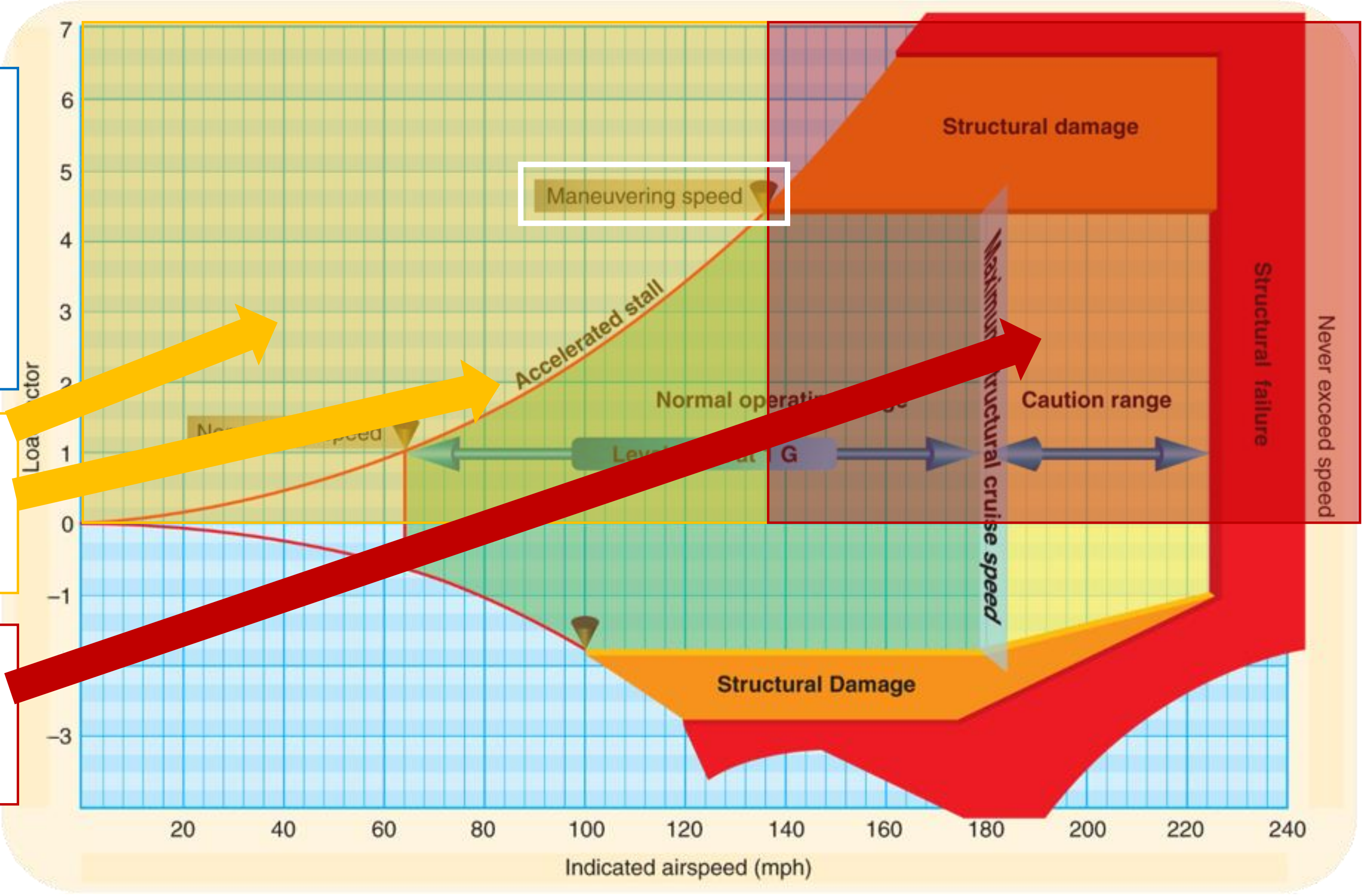
Load Factor

The Vg Diagram

The flight operating strength of an aircraft is presented on a graph whose vertical scale is based on load factor. This called the “Velocity versus G Load” (or Vg) Diagram and varies for each different type of aircraft.

Increasing load factor below Maneuvering Speed (Va) will cause the airplane to stall.

Increasing load factor above Maneuvering Speed (Va) may cause structural damage.



Load Factor

Maneuvering Speed (Va)

Maneuvering Speed (Va) is basically the boundary between when an airplane will stall versus when it can experience structural damage when subjected to increased load factors.

Why Does Va Change with Weight?

It all has to do with the airplane's Critical Angle of Attack. This is the Angle of Attack that the airplane will stall at regardless of its weight. Heavier airplanes must fly at an increased Angle of Attack to maintain altitude in straight and level flight. Whereas, lighter airplanes can fly at a decreased Angle of Attack to maintain straight and level flight.

This Means Heavier Airplanes

Are awarded a Higher Va Speed.

This Means Lighter Airplanes

Are restricted to a Lower Va Speed.

Load Factor

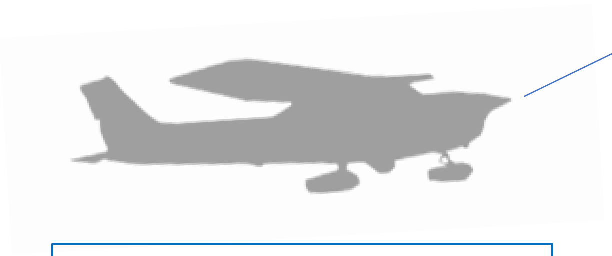
Maneuvering Speed (Va) Example

Let’s assume we have 2 identical Cessna 172’s. The only difference between them is that one airplane weighs 2500 lbs while the other weighs 1800 lbs. They both have a Critical Angle of Attack of 17 degrees.

AWARDED A HIGHER VA

2500

17



Travel to Stall = 14

Straight and Level AOA = 3

Less Travel to Stall

RESTRICTED TO LOWER VA

1800

17

Travel to Stall = 17

Straight and Level AOA = 0

More Travel to Stall

Lesson Summary

In this lesson we discussed various airfoil design characteristics, airplane stability and controllability, the 4 left turning tendencies, wingtip vortices and wake turbulence avoidance, and load factor with the Vg diagram.