Private Pilot (ASEL) Ground School Course

Lesson 02 | Aerodynamics of Flight

Lesson Overview

Lesson Objectives:

- Develop an understanding of the how an aircraft produces lift in many different scenarios.
- Develop an understanding of how an aircraft stability and tendencies.

Lesson Completion Standards:

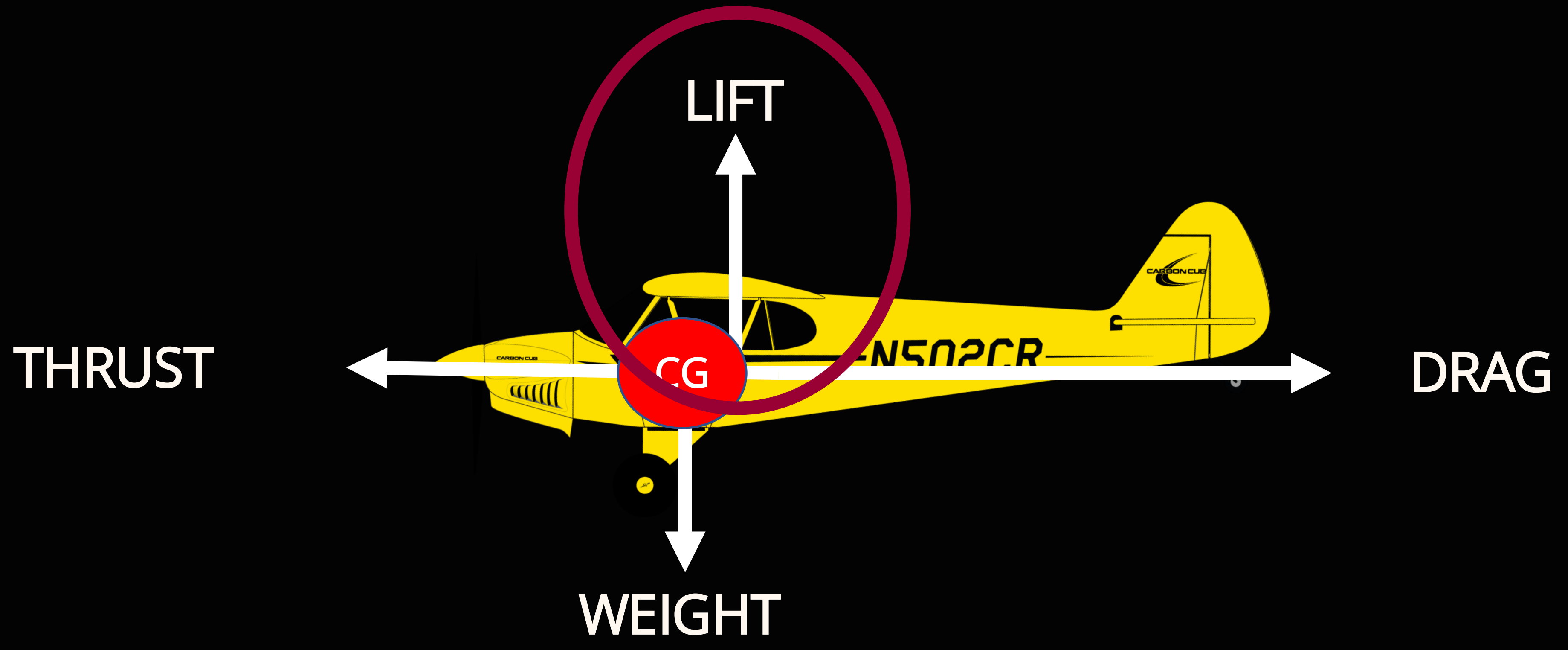
- Student demonstrates satisfactory knowledge of aerodynamic principles and stability by answering questions and actively participating in classroom discussions.

Aerodynamics of Flight

Aerodynamic Principles

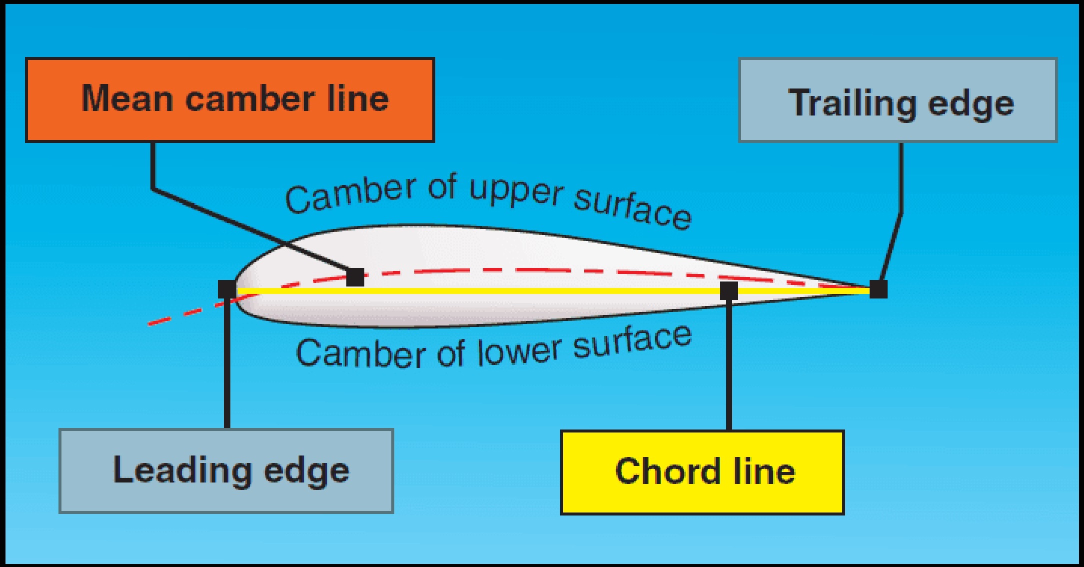
Four Forces of Flight

- Lift, Weight, Thrust, and Drag. All forces are need to make an airplane fly. Changes in each allow a change in flight path.

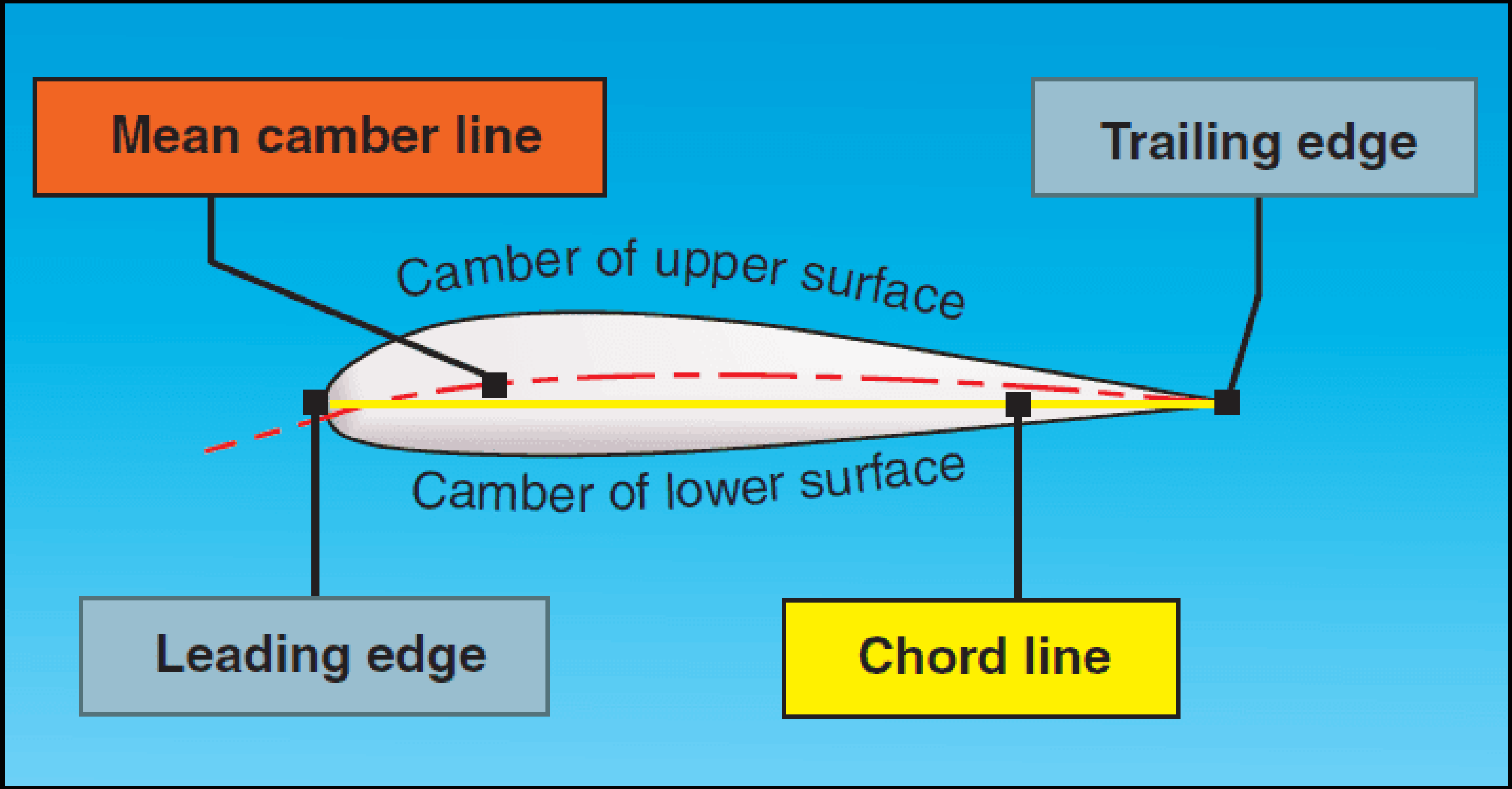


Lift Definitions

- Mean Camber: An imaginary line from the leading edge to the trailing edge, is the mean camber line.
- Trailing Edge: Back side of the wing.
- Leading Edge: Forward side of the wing.
- Chord Line: A straight line drawn through the profile connecting the extremities of the leading and trailing edges.

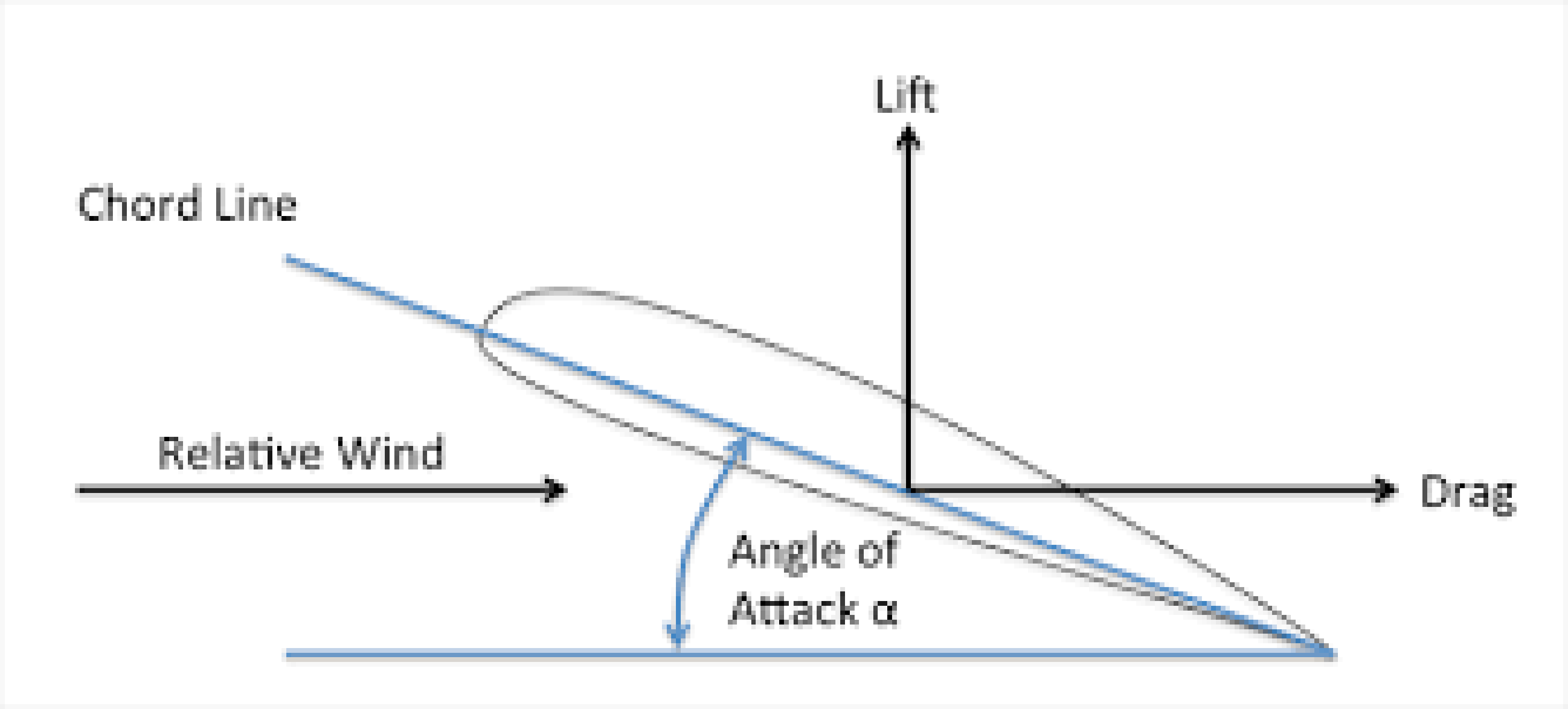


Lift Definitions



Lift Definitions – Angle of Attack

- Angle of Attack: The AOA is defined as the acute angle between the chord line of the airfoil and the direction of the relative wind.



Lift Definitions – Angle of Attack

- Any time the control yoke or stick is moved fore or aft, the AOA is changed. As the AOA increases, lift increases (all other factors being equal).
- When the aircraft reaches the maximum AOA, lift begins to diminish rapidly. The maximum is known as Critical AOA and will be discussed later in this lesson

Lift Formula

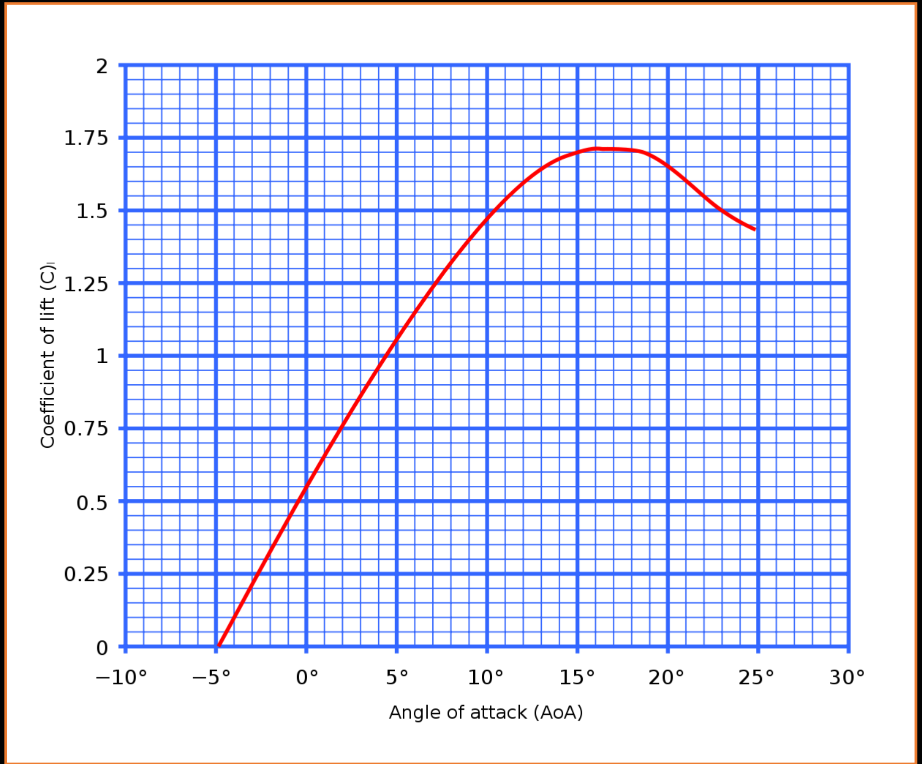
$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$

- L = Total Lift
- C_L = Lift Coefficient (AOA/Airfoil Design)
- ρ = "Rho" aka Air Density
- V^2 = Velocity (Airspeed)
- S = Surface Area of the Wing

Each one of these variables will affect lift production

Lift Formula – Coefficient of Lift

$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$



- The Coefficient of Lift is a value linked to a set AOA. This values changes based on airfoil design and current state.
- The C_L has a max value at a given AOA known as the Critical AOA.

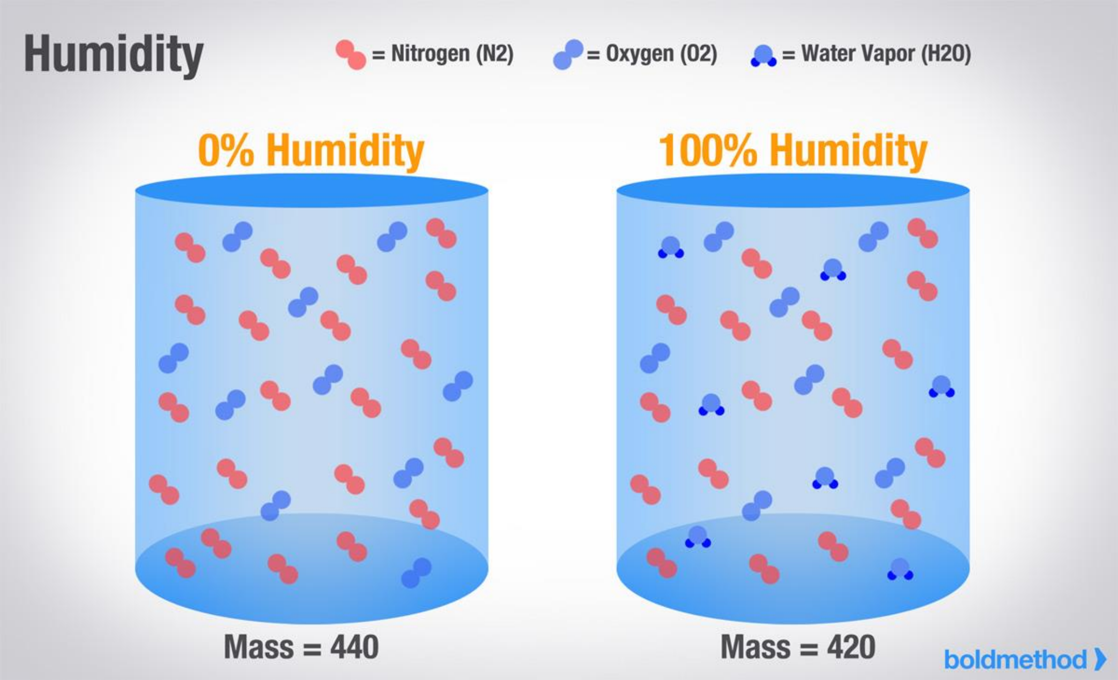
Lift Formula - Density

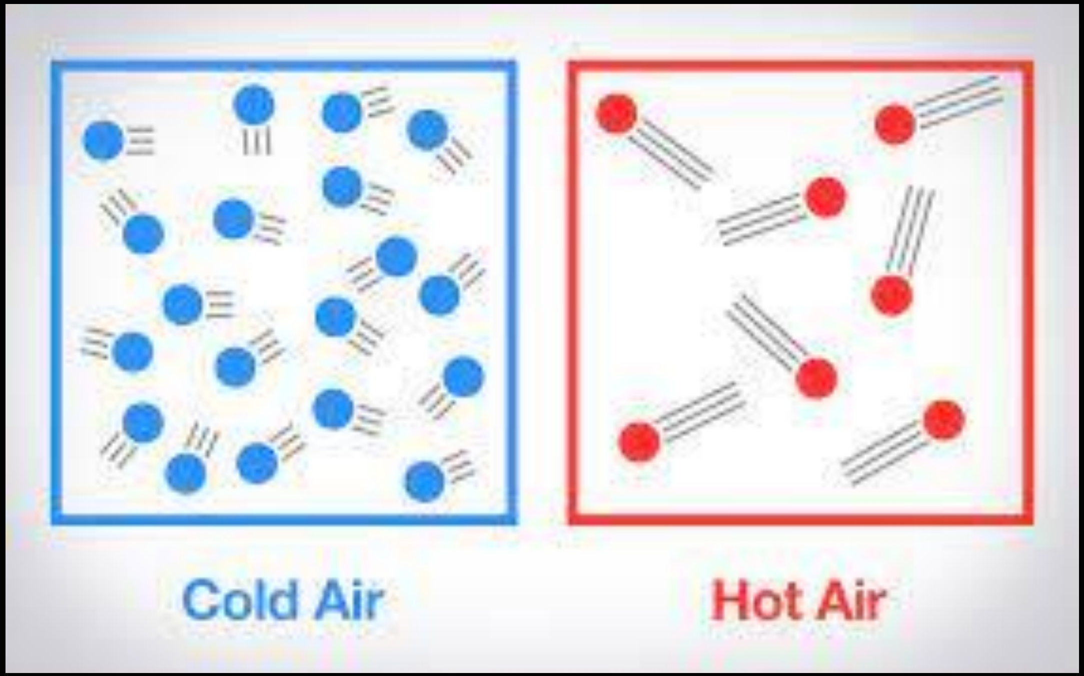
$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$

- Lift and drag also vary directly with the density of the air.
- Density is affected by several factors: pressure, temperature, and humidity.
- At an altitude of 18,000 feet, the density of the air has one-half the density of air at sea level. In order to maintain its lift at a higher altitude, an aircraft must fly at a greater airspeed for any given AOA.

Lift Formula - Density

- Warm air is less dense than cool air, and moist air is less dense than dry air. Thus, on a hot humid day, an aircraft must be flown at a greater true airspeed for any given AOA than on a cool, dry day.





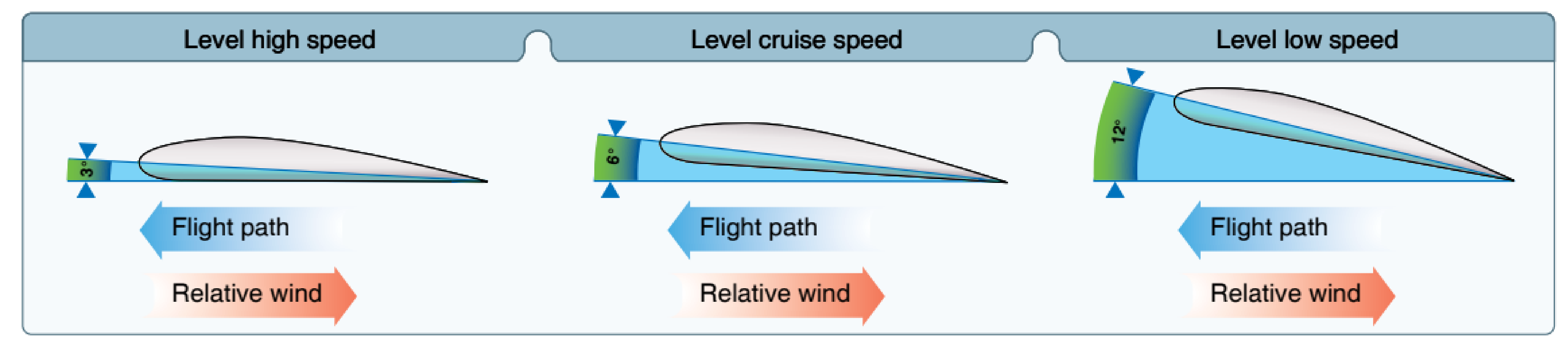
Lift Formula – Velocity

$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$

- Notice velocity is squared, therefore has a great effect on lift
- Lift is proportional to the square of the aircraft's velocity. For example, an airplane traveling at 200 knots has four times the lift as the same airplane traveling at 100 knots, if the AOA and other factors remain constant.

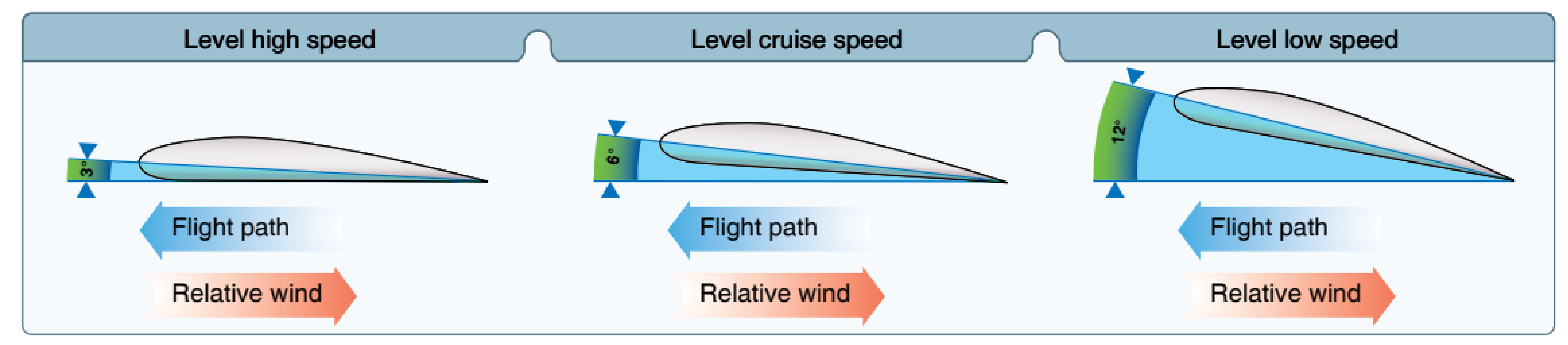
Lift Formula – Velocity

- Taking the equation further, one can see an aircraft could not continue to travel in level flight at a constant altitude and maintain the same AOA if the velocity is increased.
- Lift would increase and result in a climb or speed up.
- To maintain level flight, lift must remain equal to weight. With an increased speed, a lowered AOA must occur.



Lift Formula – Velocity

- Conversely, as the aircraft is slowed, the decreasing velocity requires increasing the AOA to maintain lift sufficient to maintain level flight.
- There is, of course, a limit to how far the AOA can be increased, if a stall is to be avoided.



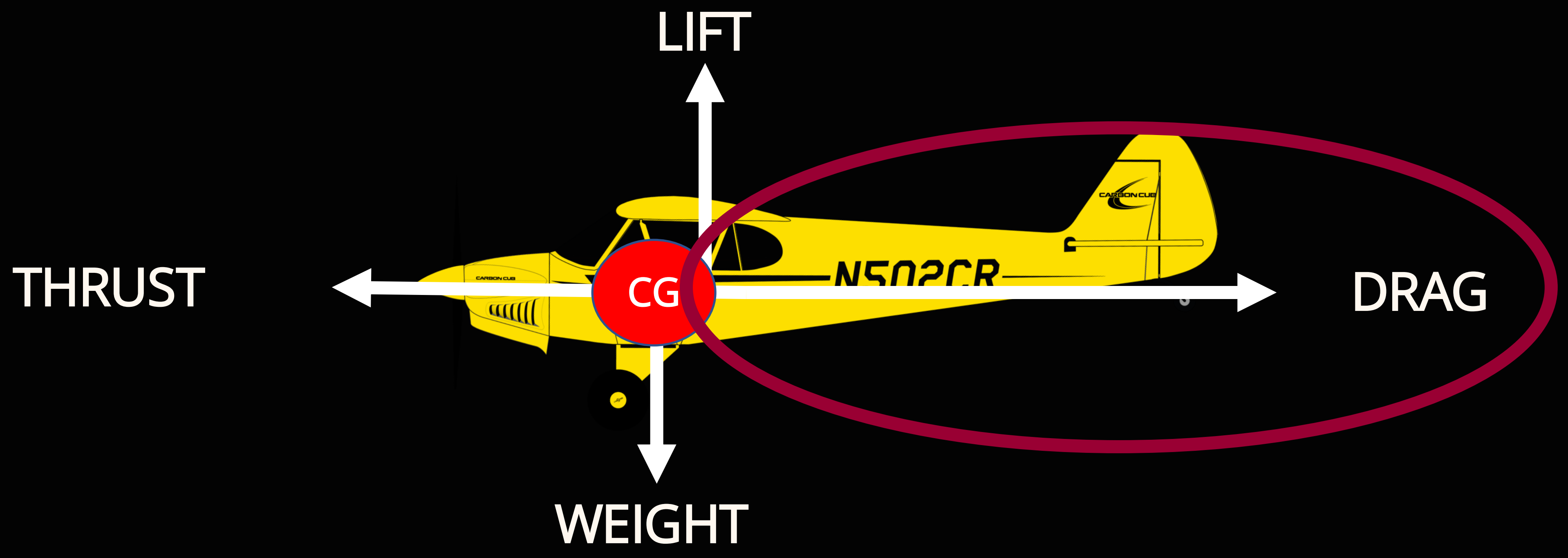
Lift Formula – Surface Area

$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$

- Lift varies directly with the wing area, provided there is no change in the wing's planform.
- If the wings have the same proportion and airfoil sections, a wing with a planform area of 200 square feet lifts twice as much at the same AOA as a wing with an area of 100 square feet.

Four Forces of Flight

- Lift, Weight, Thrust, and Drag. All forces are need to make an airplane fly. Changes in each allow a change in flight path.



Drag Formula

$$L = \frac{C_D \cdot \rho \cdot V^2 \cdot S}{2}$$

- L = Total Lift
- C_D = Drag Coefficient (AOA/Airfoil Design)
- ρ = "Row" aka Air Density
- V^2 = Velocity (Airspeed)
- S = Surface Area of the Wing

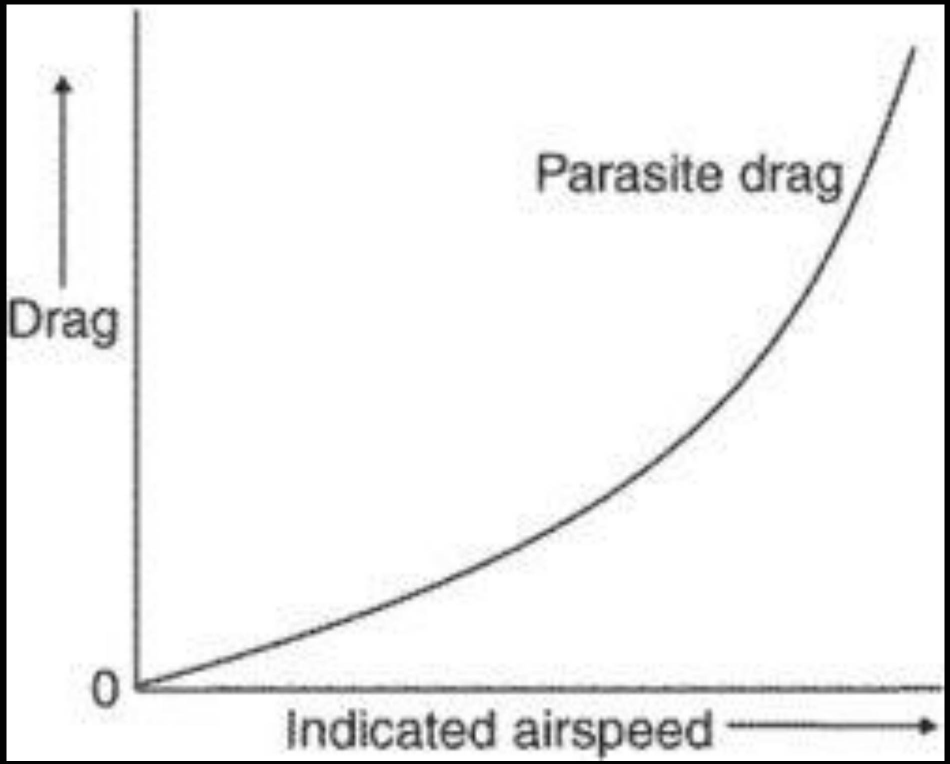
Each one of these variables will affect drag production

Types of Drag

- Parasite
  - Form
  - Interference
  - Skin Friction
- Induced
  - Wingtip Vortices

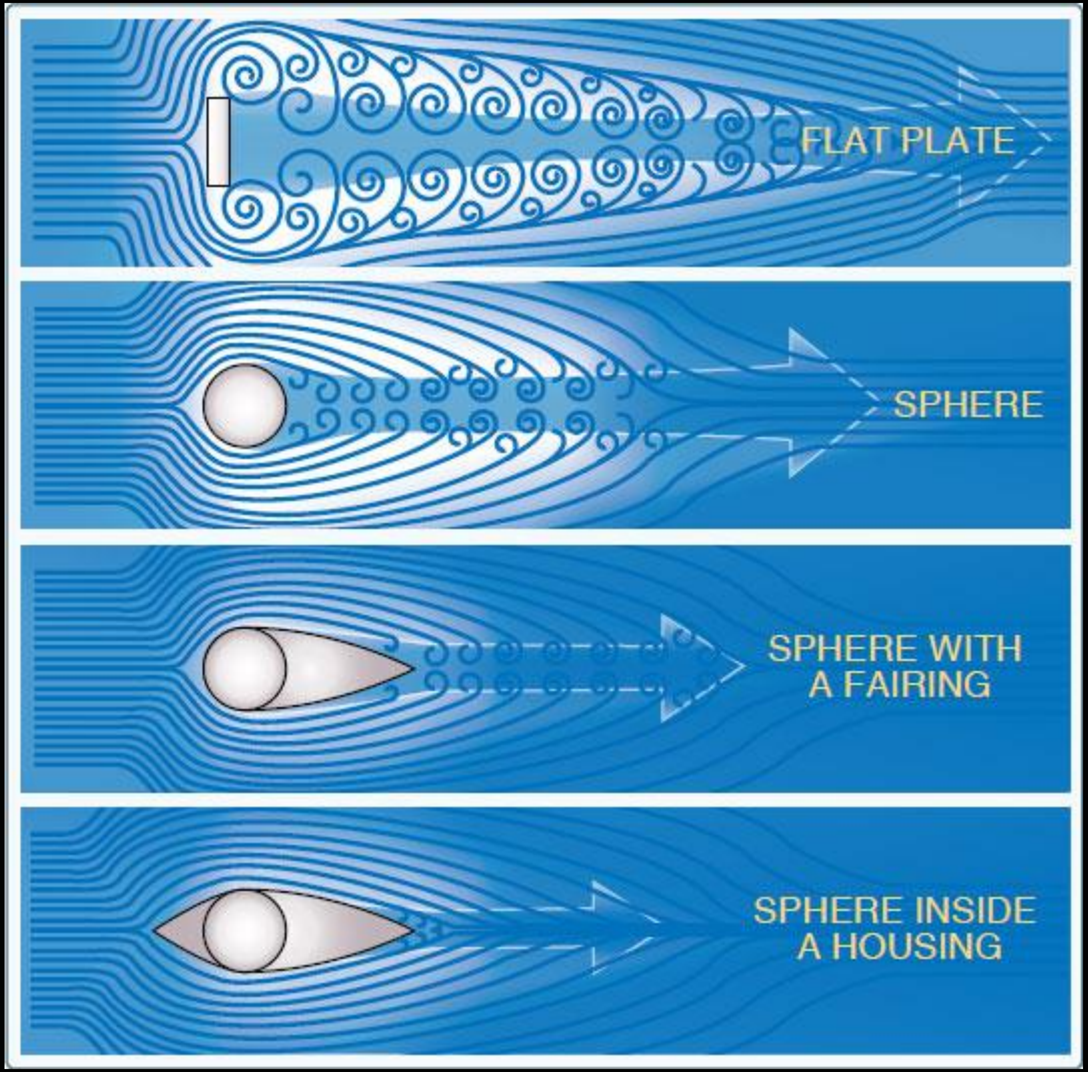
Parasite Drag

- 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 the displacement of the air by the aircraft, turbulence generated in the airstream, or a hindrance of air moving over the surface of the aircraft and airfoil.



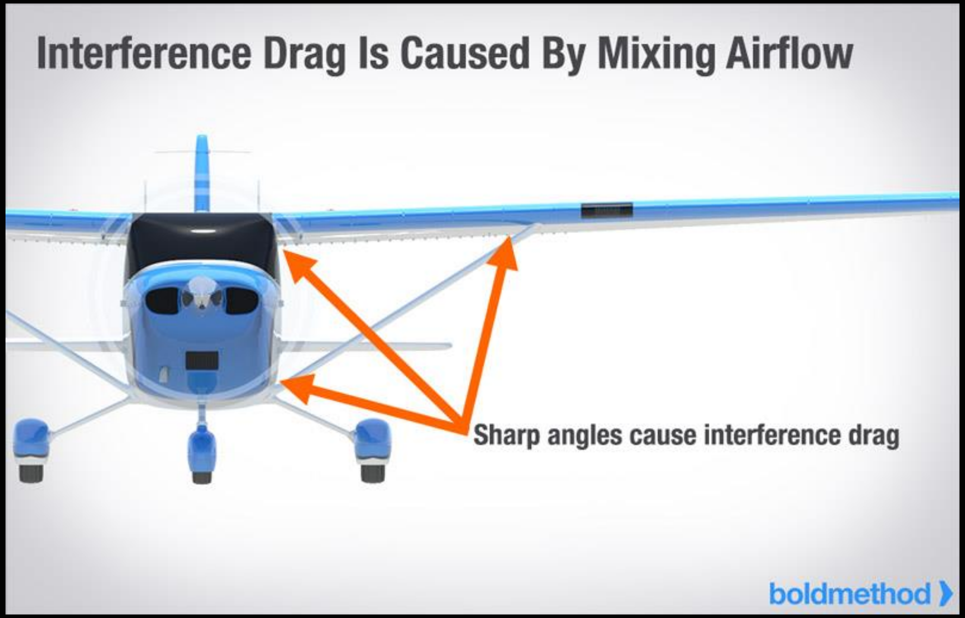
Parasite Drag – Form

- 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 the components.
- When the air has to separate to move around a moving aircraft and its components, it eventually rejoins after passing the body. How quickly and smoothly it rejoins is representative of the resistance that it creates, which requires additional force to overcome



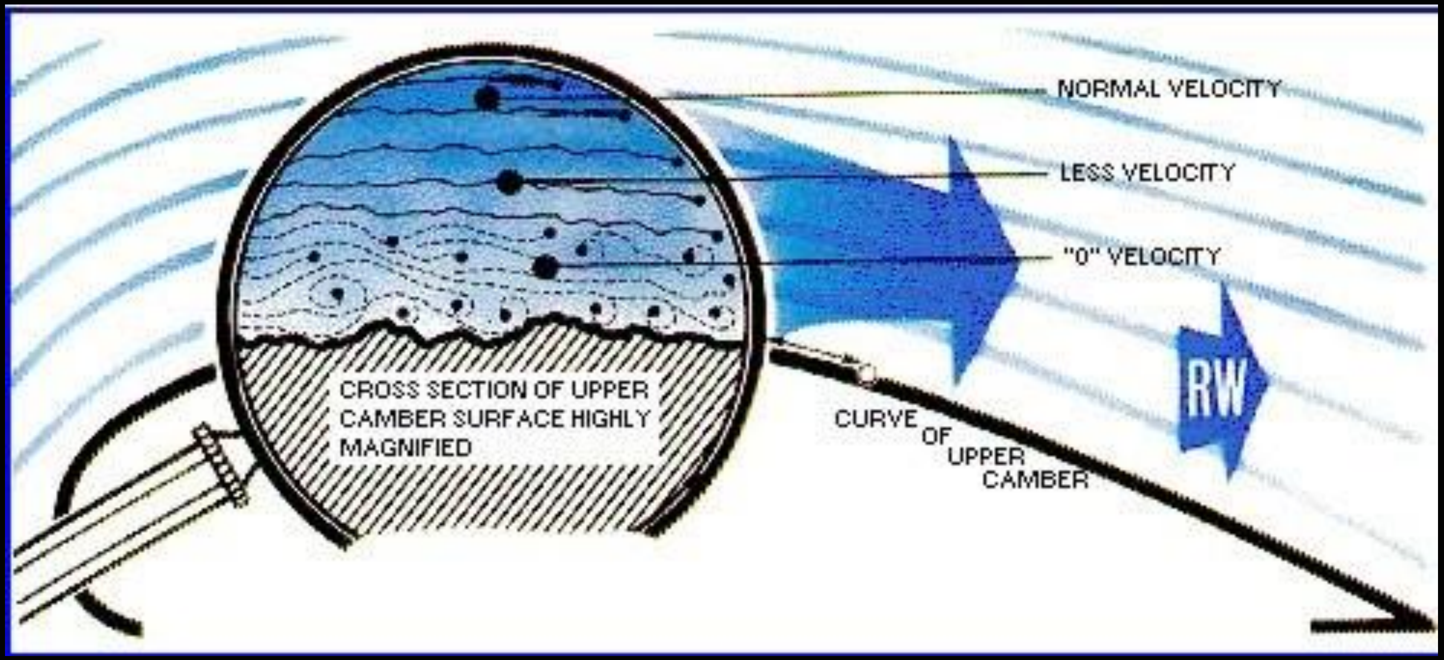
Parasite Drag – Interference

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



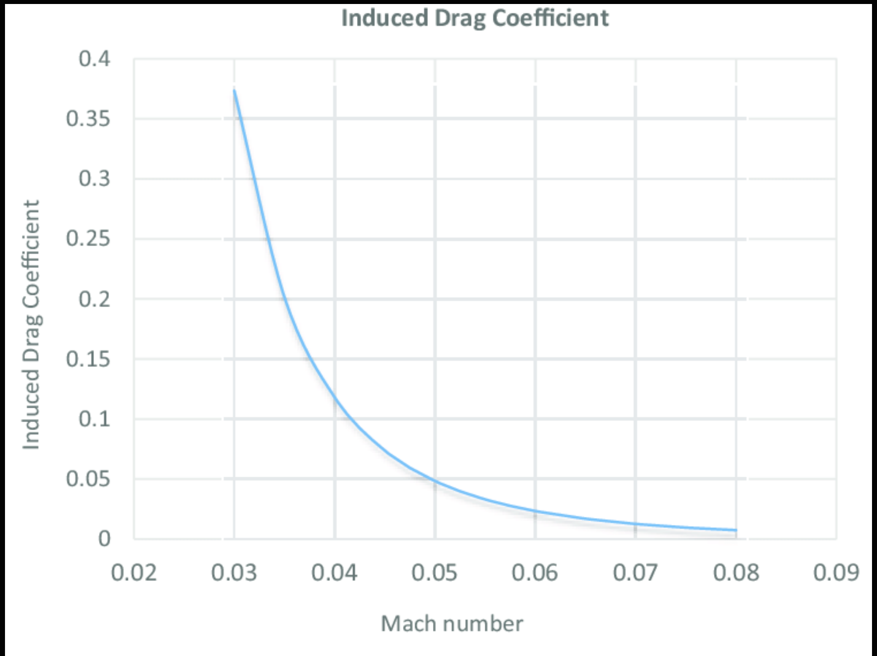
Parasite Drag – Skin Friction

- 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.



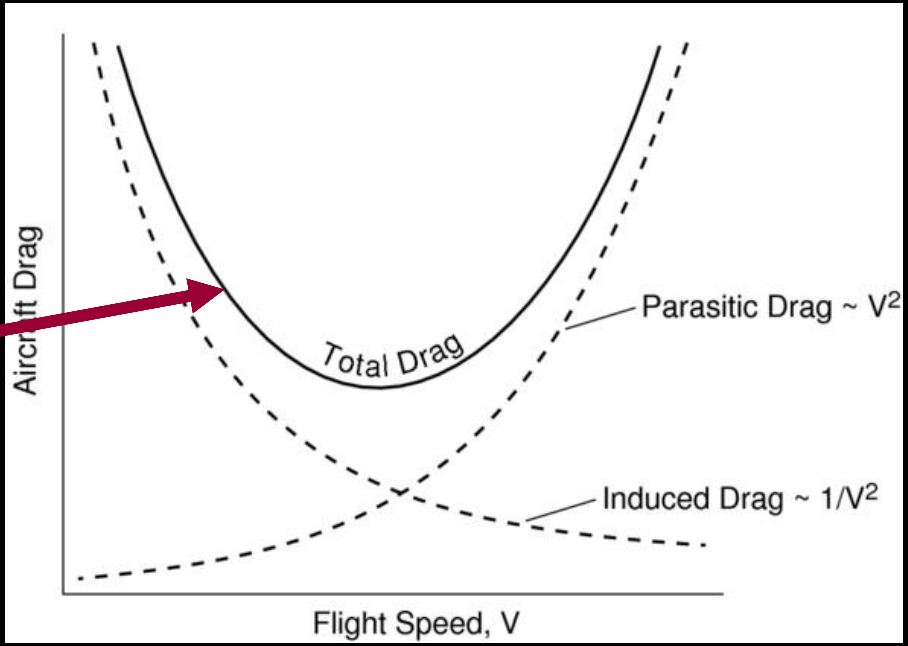
Induced Drag

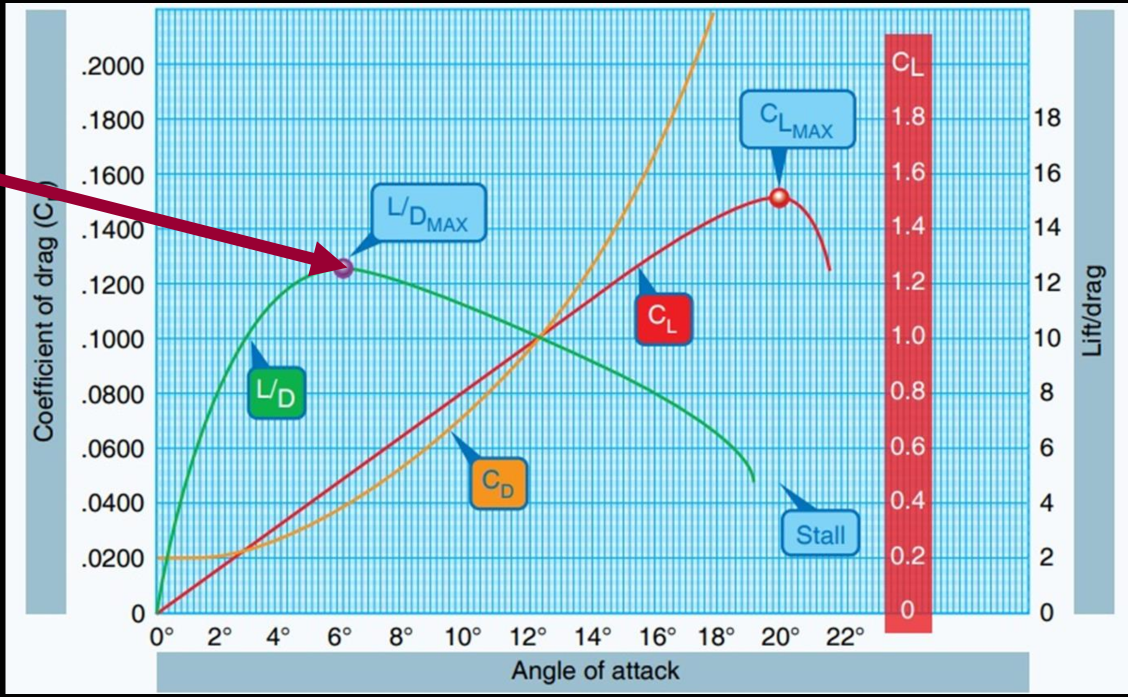
- Byproduct of lift
- Established physical fact that no system that does work in the mechanical sense can be 100 percent efficient. This means that whatever the nature of the system, the required work is obtained at the expense of certain additional work that is dissipated or lost in the system. The more efficient the system, the smaller this loss.



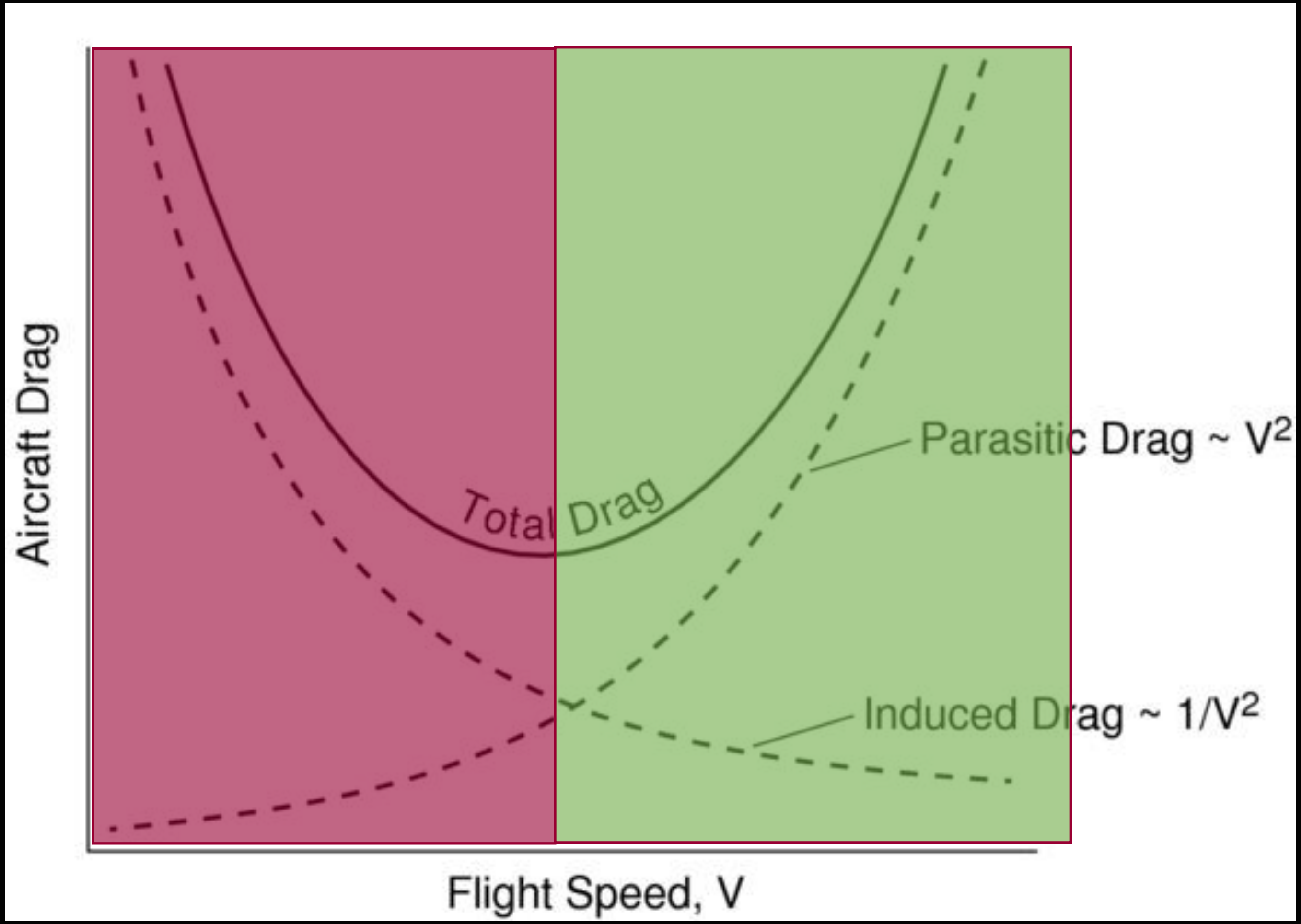
Total Drag/Lift

- When Parasite drag and induced drag are combined you get the total drag curve.
- Note that the maximum lift/drag ratio (L/D_{MAX}) occurs at one specific CL and AOA.
- L/D_{MAX} gives the least drag for maximum lift
- Drag curve may also be referred to as “Power Required.”





Power Required/Drag



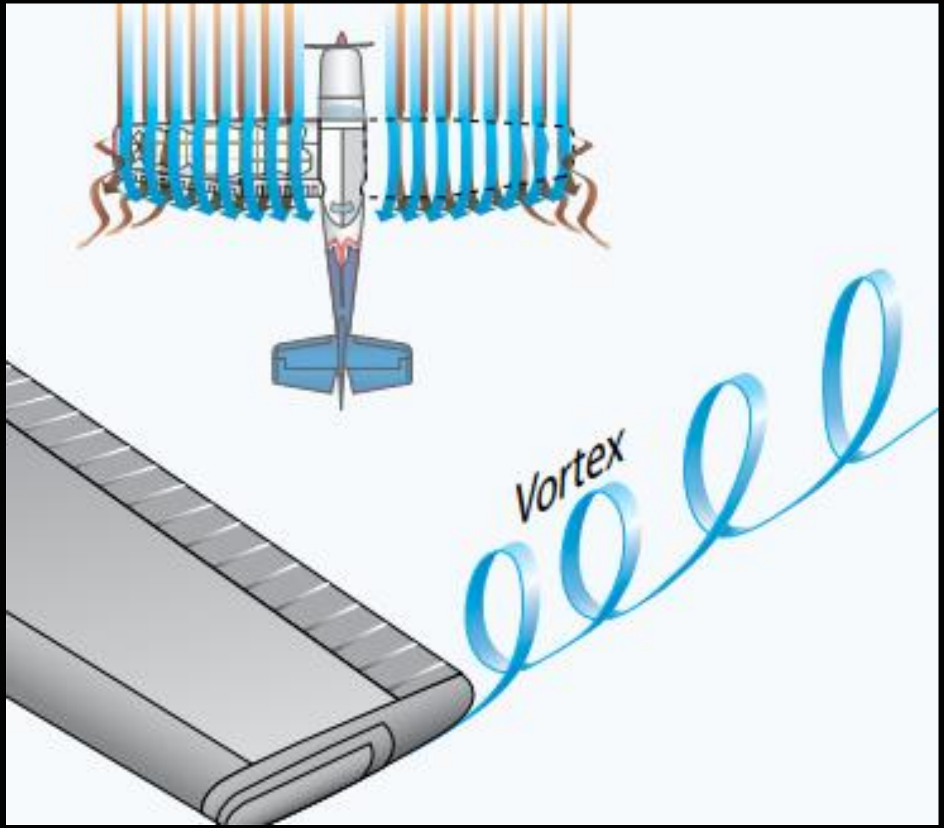
- Red: Becoming too slow
- Green: Normal Ops
- In normal cruise flight, you pitch the aircraft to maintain altitude, and power the aircraft to maintain airspeed. However, on the back side of the power curve the inputs are opposite. You pitch the aircraft to maintain airspeed and use power to maintain altitude.

Wingtip Vortices

- Whenever an airfoil is producing lift, the pressure on the lower surface of it is greater than that on the upper surface (Bernoulli's Principle). 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.
- In the vicinity of the tips, there is a tendency for these pressures to equalize, resulting in a lateral flow outward from the underside to the upper surface. This lateral flow imparts a rotational velocity to the air at the tips, creating vortices that trail behind the airfoil.

Wingtip Vortices

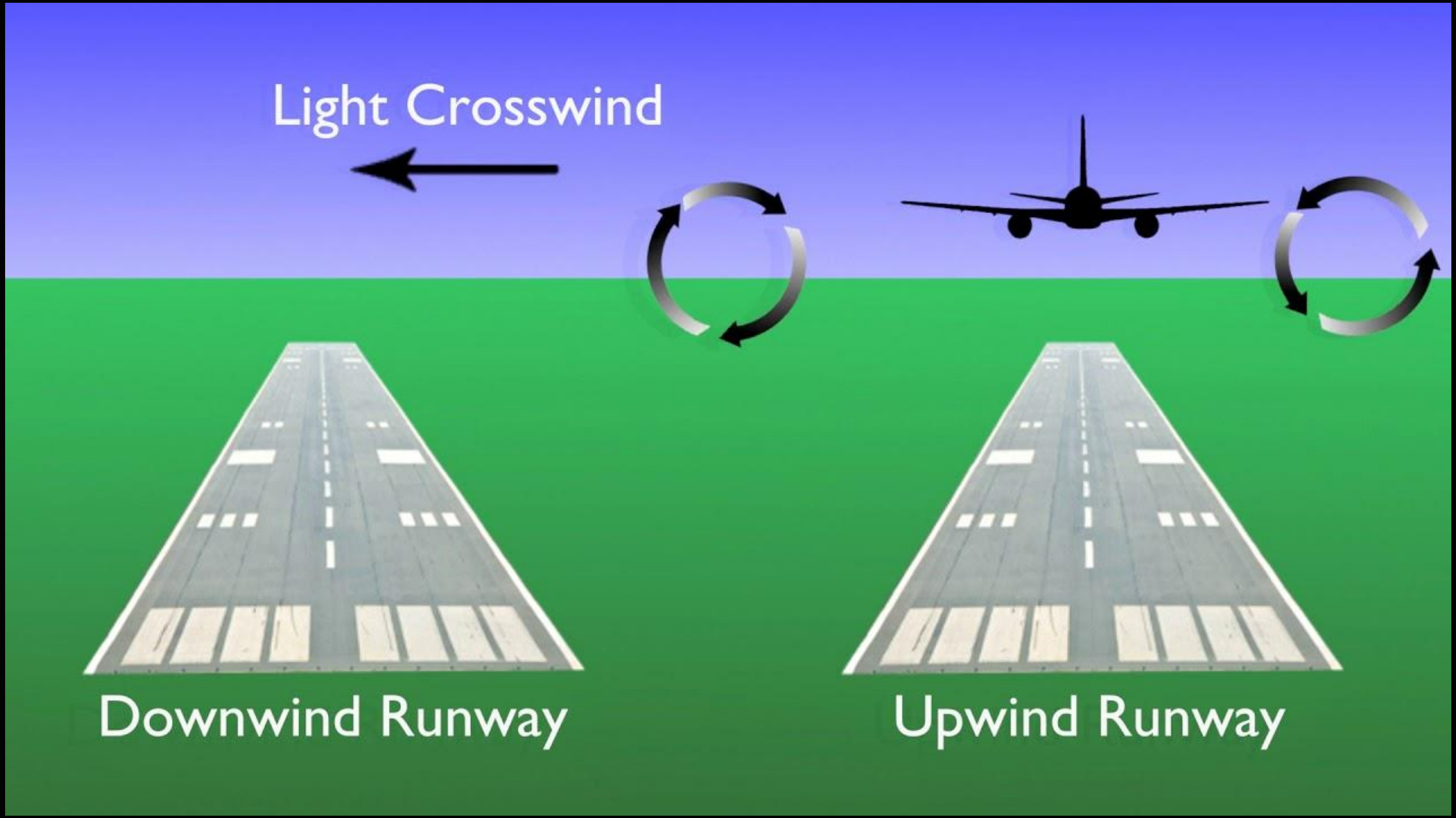
Most dangerous type of drag



Wake Turbulence

- Wingtip vortices are greatest when the generating aircraft is “heavy, clean, and slow.” This condition is most commonly encountered during approaches or departures because an aircraft’s AOA is at the highest to produce the lift necessary to land or take off.
- Avoid by:
  - Avoid flying through another aircraft’s flight path.
  - Rotate prior to the point at which the preceding aircraft rotated when taking off behind another aircraft.
  - Avoid following another aircraft on a similar flight path at an altitude within 1,000 feet.
  - Approach the runway above a preceding aircraft’s path when landing behind another aircraft and touchdown after the point at which the other aircraft wheels contacted the runway.

Wake Turbulence

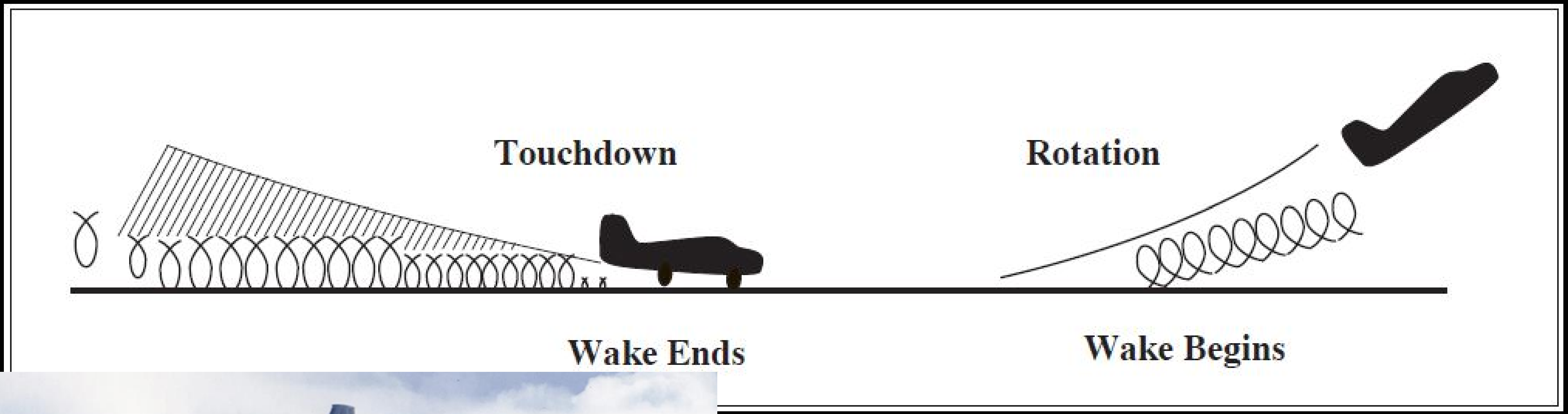


Wake Turbulence

Wake Turbulence – Accident

Wake Turbulence – Accident

Wake Turbulence



“Produces wake when generating lift” “Lift generated is a function of weight”

Wake Turbulence - RECAT

Wake Turbulence Class	Identifier	MTOW (lb)	Wingspan (b)
Super Heavy	CAT-A	MTOW>300,000	b>245 ft
Upper Heavy	CAT-B	MTOW>300,000	245 ft > b > 175 ft
Lower Heavy	CAT-C	MTOW> 300,000	175 ft > b > 125 ft
Upper Medium	CAT-D	MTOW< 300,000	175 ft > b > 125 ft
		MTOW> 41,000	125 ft > b > 90 ft
Lower Medium	CAT-E	MTOW> 41,000	90 ft > b > 65 ft
Light	CAT-F	MTOW< 41,000	125 ft > b
		MTOW<15,500	-

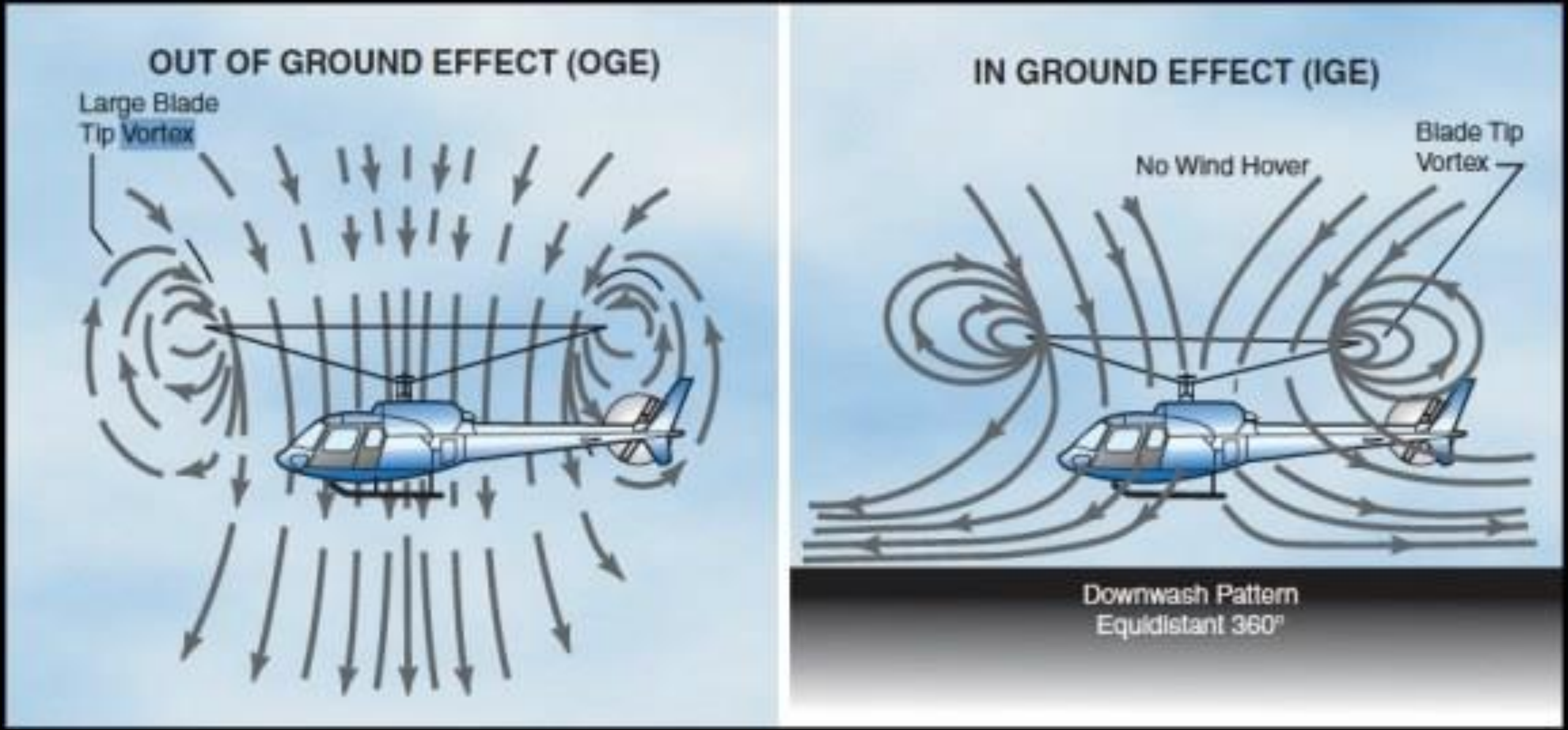
Wake Turbulence Separation for On Approach

		Follower					
		A	**B**	**C**	**D**	**E**	**F**
Leader	**A**		5NM	6NM	7NM	7NM	8NM
	B		3NM	4NM	5NM	5NM	7NM
	C				3.5NM	3.5NM	6NM
	D						4NM
	E						
	F						

Wake Turbulence

- A hovering helicopter generates a down wash from its main rotor(s) similar to the vortices of an airplane. Pilots of small aircraft should avoid a hovering helicopter by at least three rotor disc diameters to avoid the effects of this down wash.
- In forward flight, this energy is transformed into a pair of strong, high-speed trailing vortices similar to wing-tip vortices of larger fixed-wing aircraft. Helicopter vortices should be avoided because helicopter forward flight airspeeds are often very slow and can generate exceptionally strong wake turbulence.
- Rule of Thumb: Wake drift 1,000 feet for every 10 knots of wind

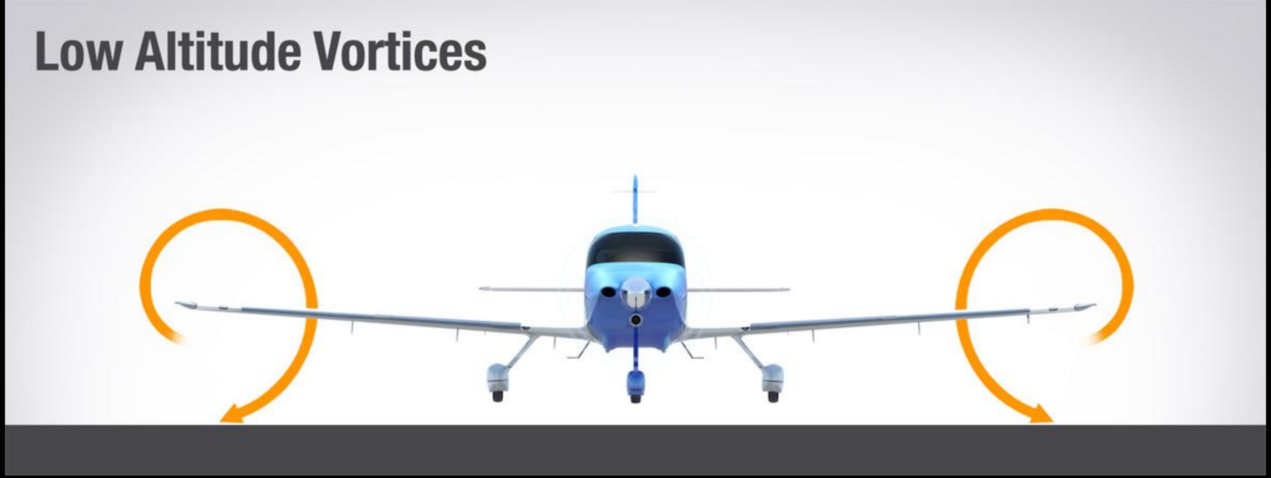
Wake Turbulence



Ground Effect

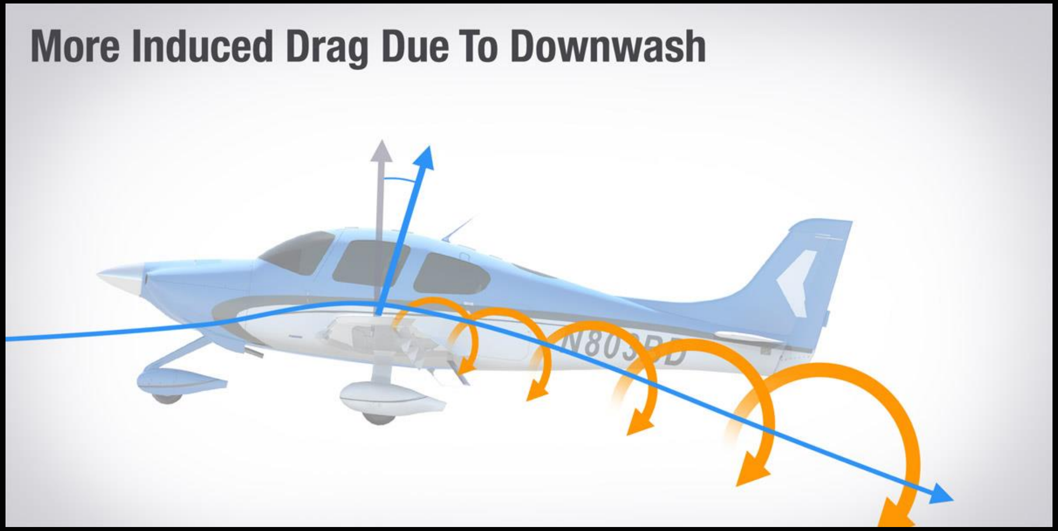
- When an aircraft in flight comes within several feet of the surface, ground or water, a change occurs in the three-dimensional flow pattern around the aircraft because the vertical component of the airflow around the wing is restricted by the surface.
- This alter airflow around the wing.

Ground Effect



- The ground limits wing tip vortices therefore reducing drag.
- This cause the airplane to have additional lift during ground effect.
- Occurs within about one wingspan of the ground.

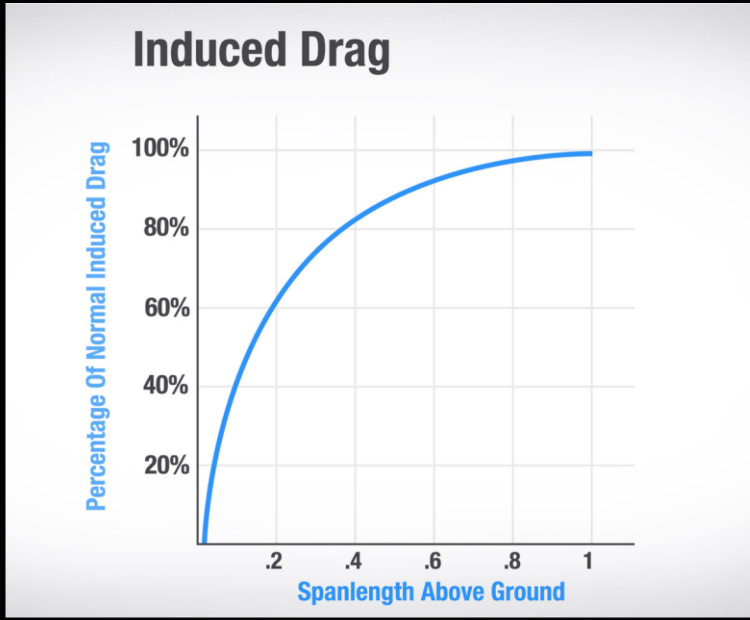
Ground Effect



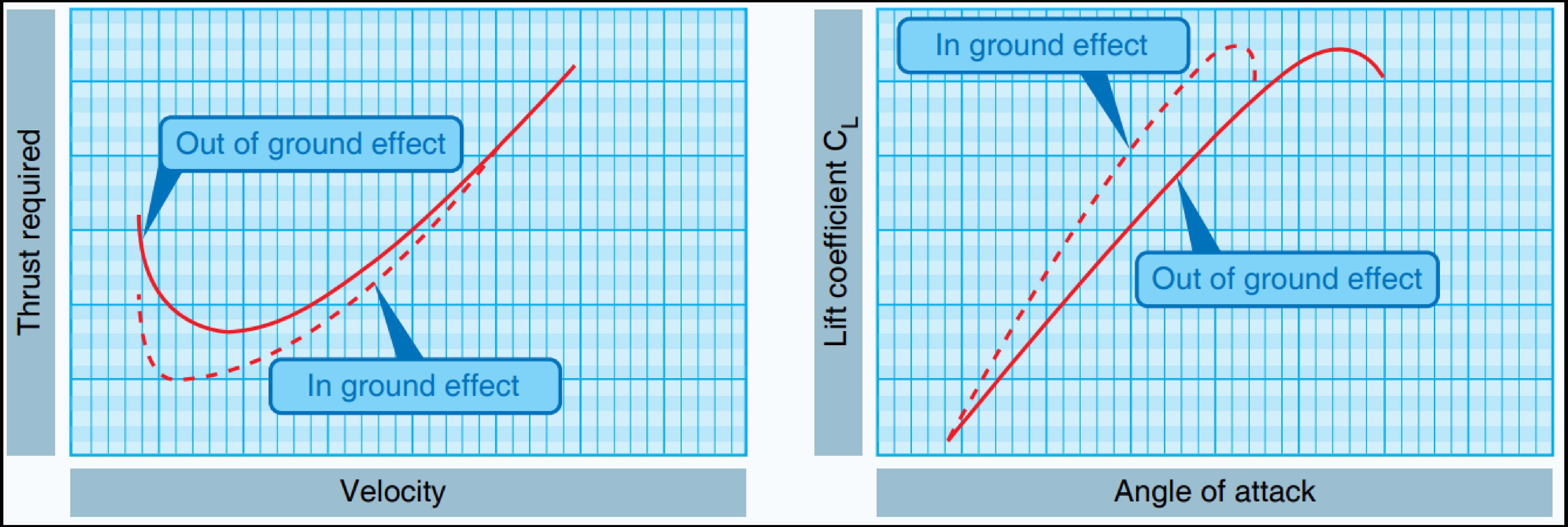
- Downwash from the wing (accelerating air around the airfoil) contribute to lift greatly. Not the only factor.
- Less downwash = greater lift
  - Less work
- Also, more lift due to more vertical lift at a given AoA.
- Aka… Less induced drag

Ground Effect

- During ground effect you have
  - More vertical lift, which opposes weight
  - Less rearward lift, which reduces drag
  - Smaller vortices and less downwash, which reduces drag



Ground Effect



Ground Effect

- Leaving ground effect you:
  - 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

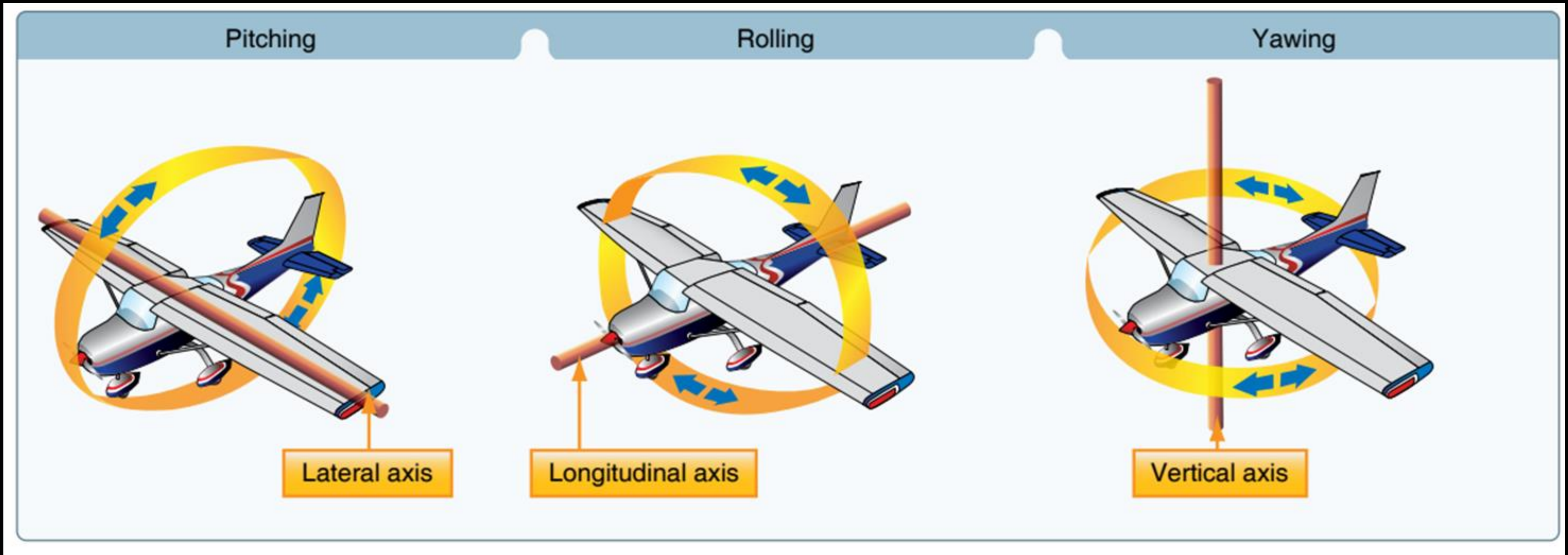
Stability of Aircraft

Aerodynamic Principles

Three Axis of an Aircraft

- Stability requires good understanding of aircraft motions and axis of movement.
- The aircraft's motion about its longitudinal axis resembles the roll of a ship from side to side. In fact, the names used to describe the motion about an aircraft's three axes were originally nautical terms.
- The motion about the aircraft's longitudinal axis is "Roll."
- The motion about its lateral axis is "Pitch."
- The motion about its vertical axis is "Yaw."
- Roll is controlled by the ailerons; pitch is controlled by the elevators; yaw is controlled by the rudder. Will discuss in detail in next lesson.

Three Axis of an Aircraft

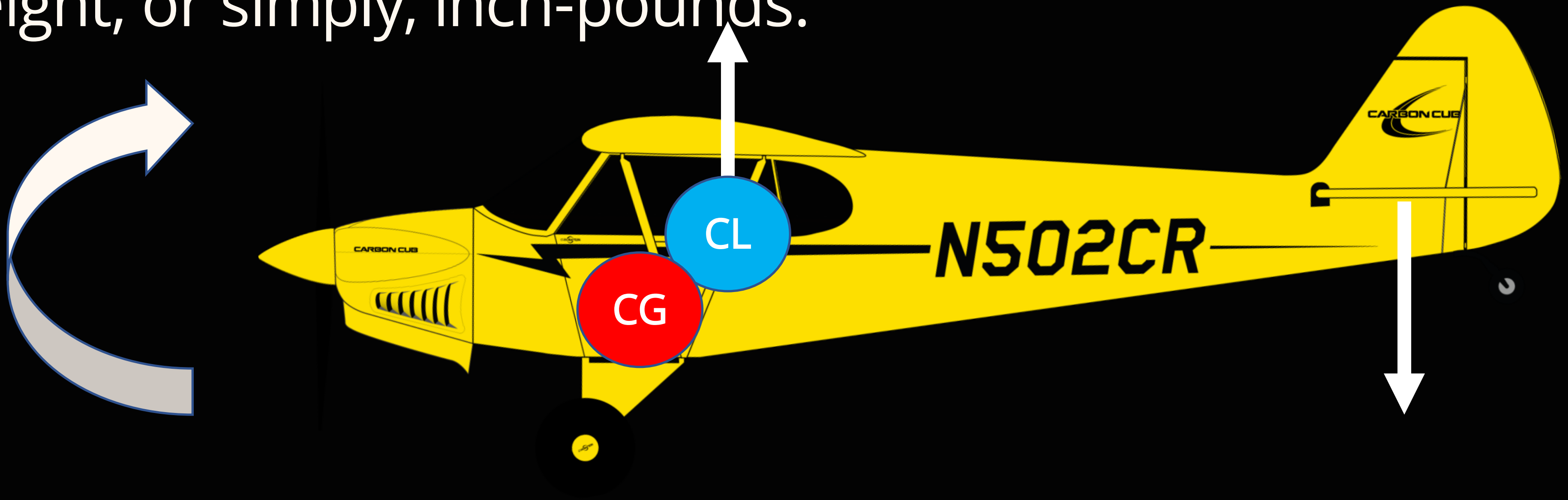


Three Axis of an Aircraft

- Other types of axis designs exist:
- For example, weight-shift control aircraft control two axes (roll and pitch) using an "A" frame suspended from the flexible wing attached to a three-wheeled carriage
- A powered parachute wing is a parachute that has a cambered upper surface and a flatter under surface. The two surfaces are separated by ribs that act as cells, which open to the airflow at the leading edge and have internal ports to allow lateral airflow.

Moment

- A study of physics shows that a body that is free to rotate will always turn about its CG. In aerodynamic terms, the mathematical measure of an aircraft's tendency to rotate about its CG is called a "moment."
- For aircraft weight and balance computations, "moments" are expressed in terms of the distance of the arm times the aircraft's weight, or simply, inch-pounds.



Stability

- Since you have no direct control of those forces (Indirect by moving flight control surfaces) it is important to undertint their design limitations.
- Each aircraft handles somewhat differently because each resists or responds to control pressures in its own way. For example, a training aircraft is quick to respond to control applications, while a transport aircraft feels heavy on the controls and responds to control pressures more slowly.
- Stability will also affect maneuverability and controllability qualities.

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.

Static Stability

- Initial tendency, or direction of movement, back to equilibrium

Dynamic Stability

- Dynamic stability refers to the aircraft response over time after being displaced from, equilibrium.

Static Stability

Positive Static Stability

- Initial tendency to return equilibrium

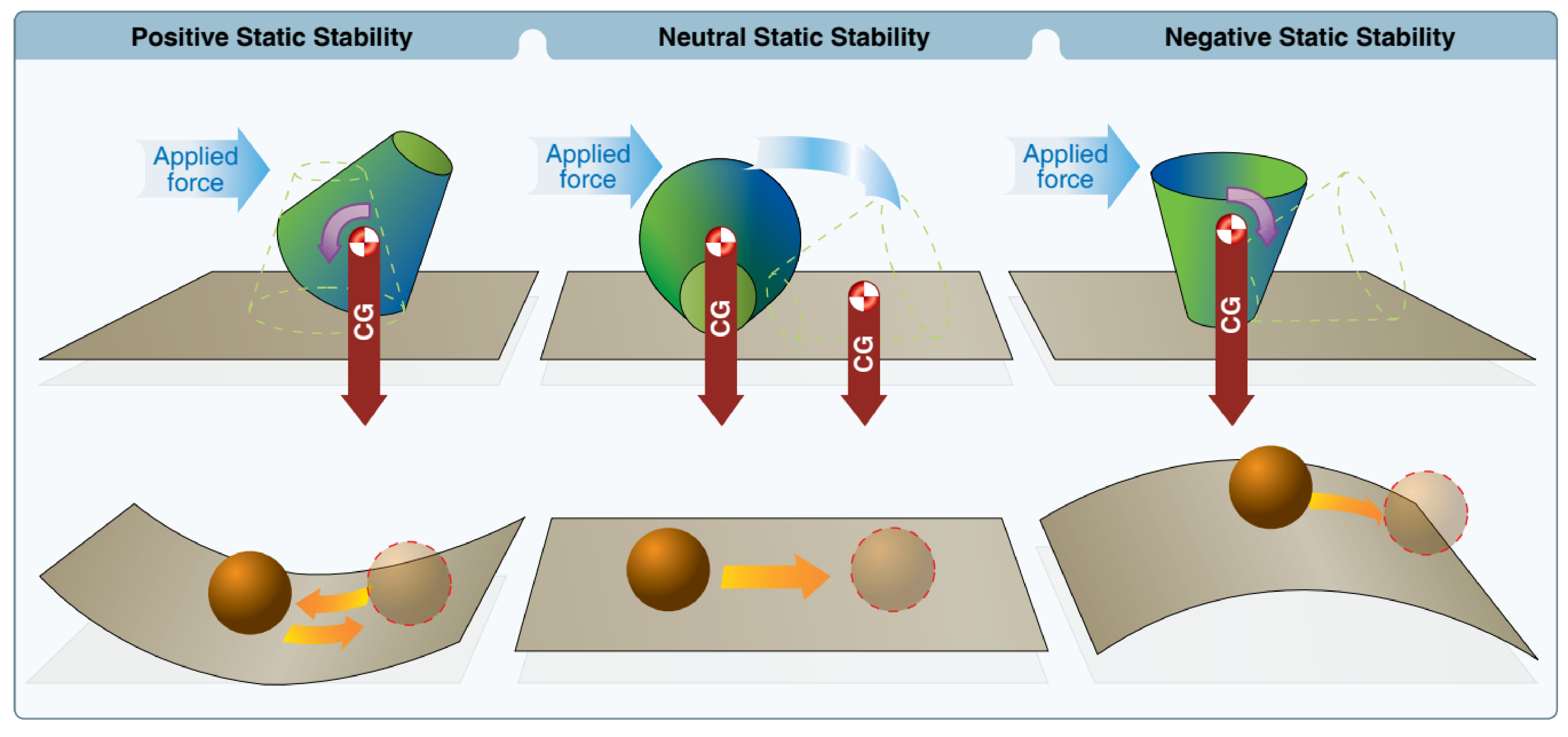
Neutral Static Stability

- Initial tendency to remain in the displaced condition

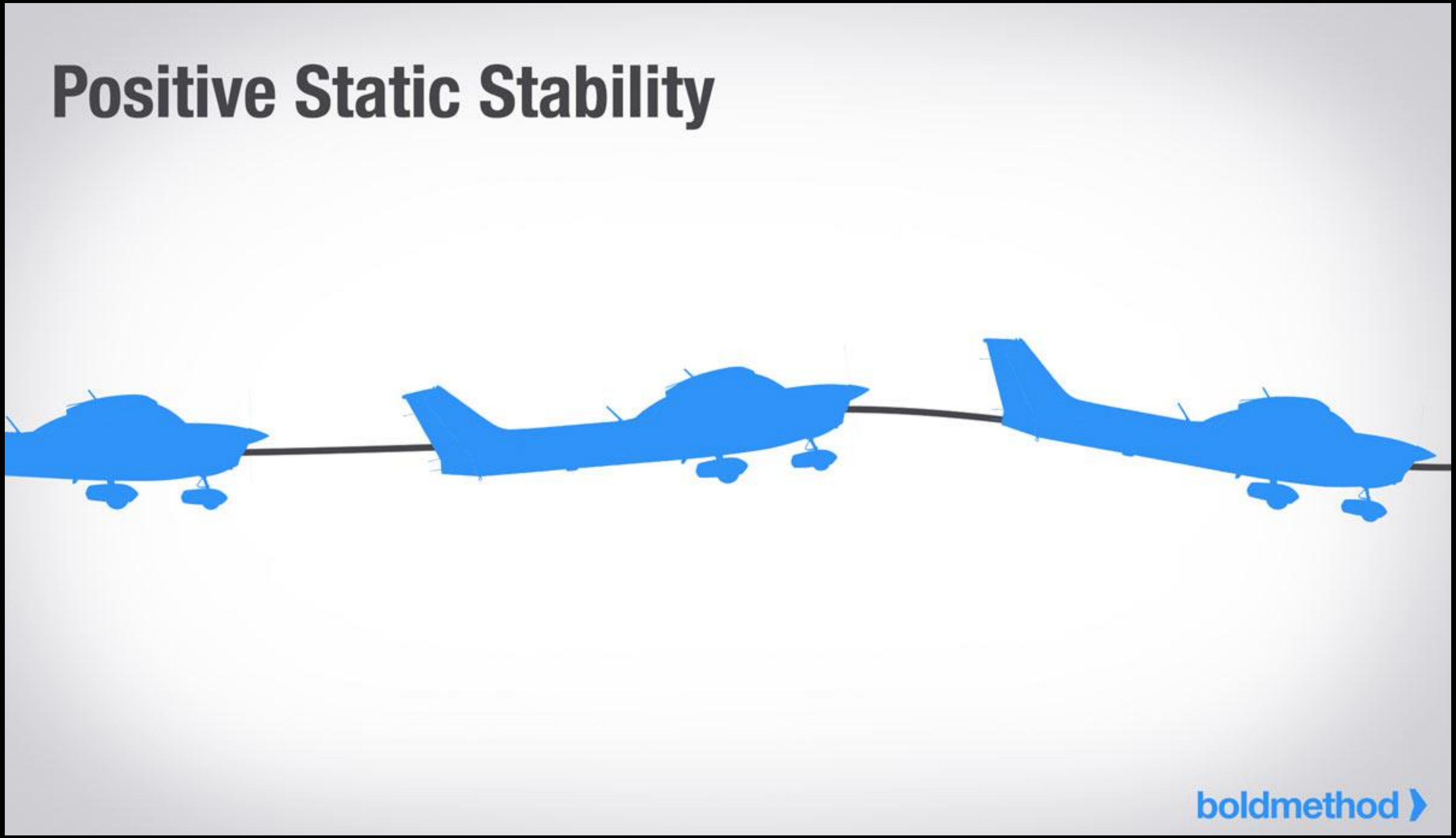
Negative Static Stability

- Initial tendency to move away from equilibrium

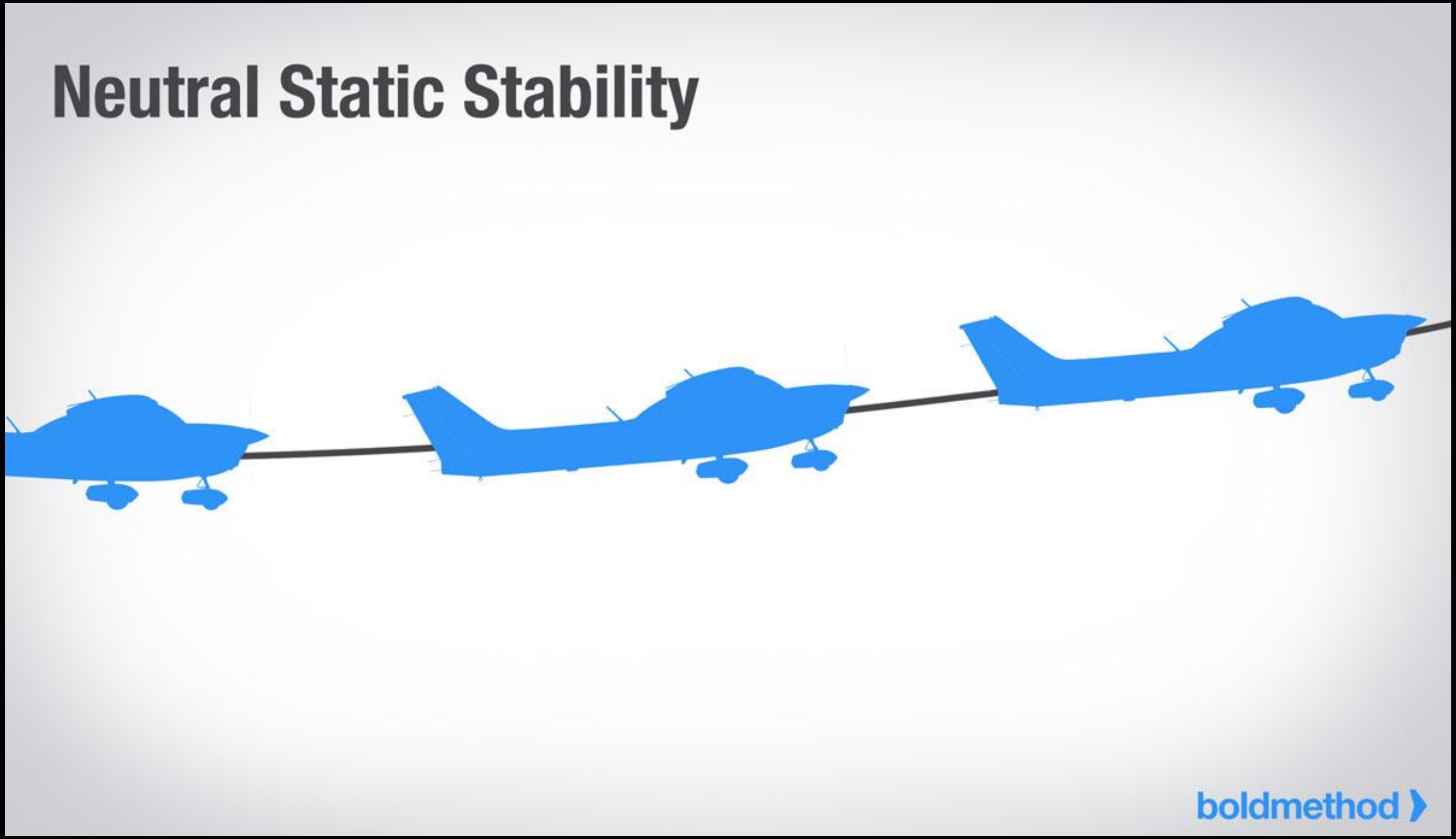
Static Stability



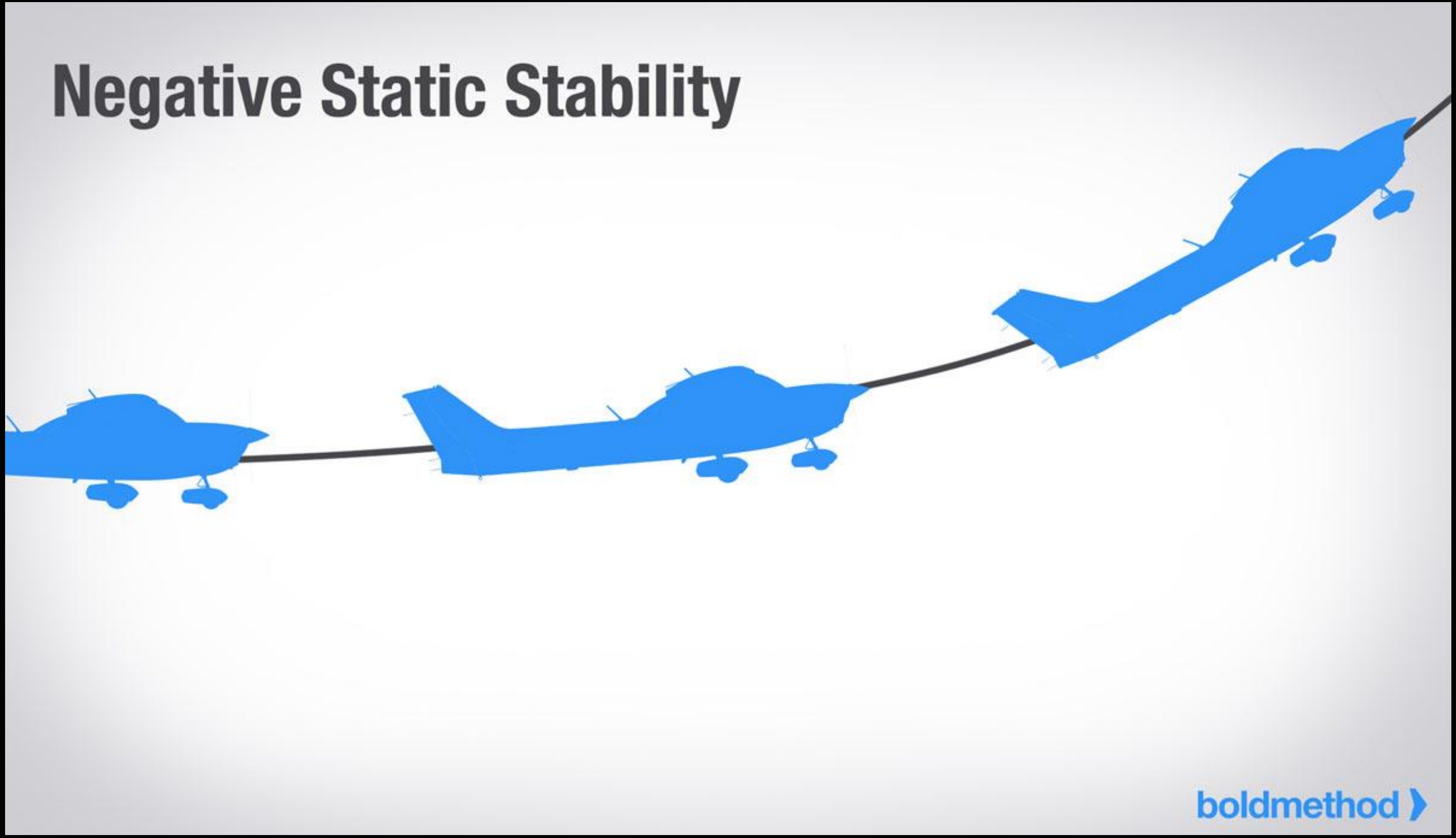
Static Stability



Static Stability



Static Stability



Dynamic Stability

Positive Dynamic Stability

- Tendency over time to dampen oscillation and return to equilibrium

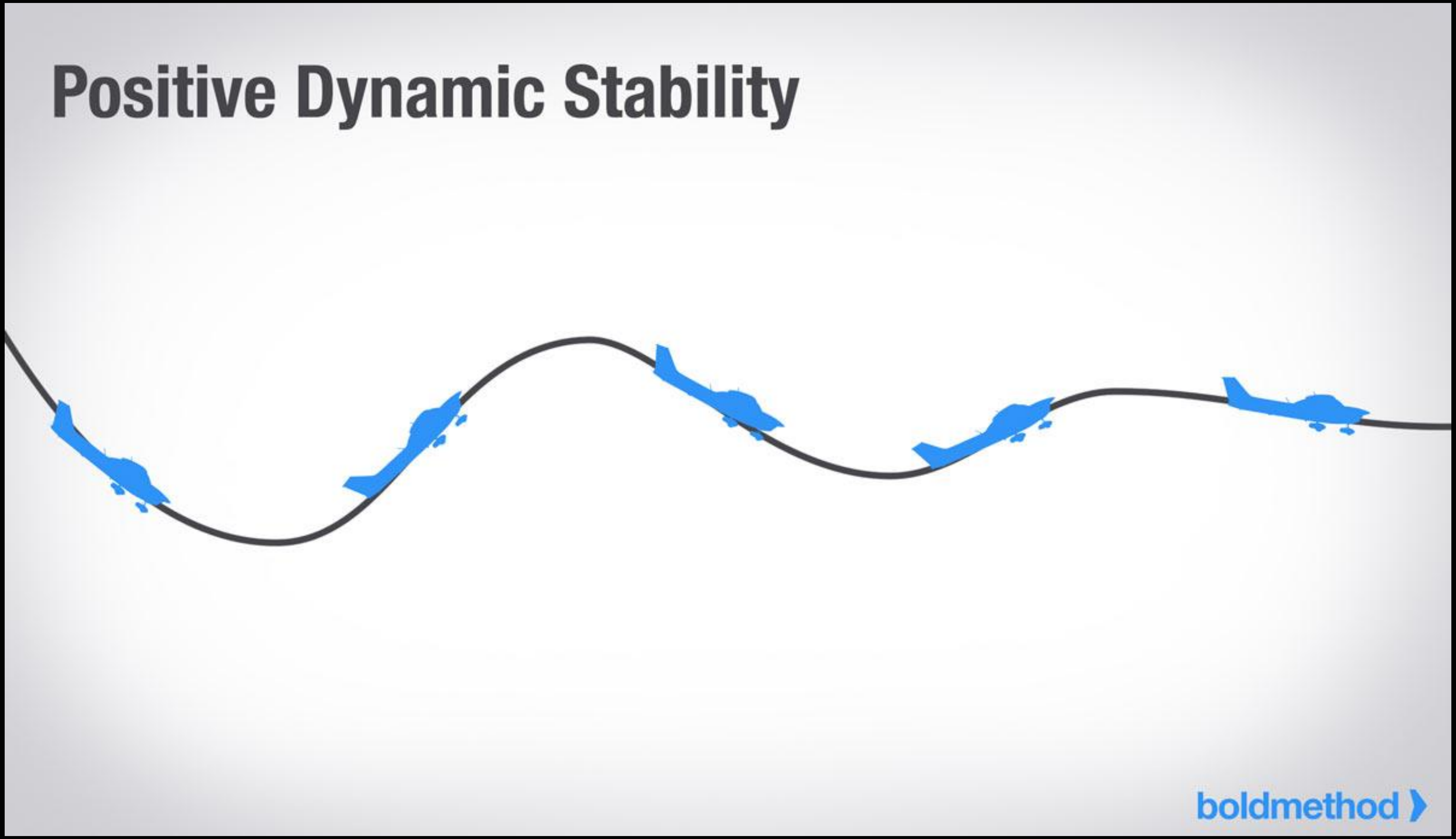
Neutral Dynamic Stability

- Tendency over time to not dampen oscillation

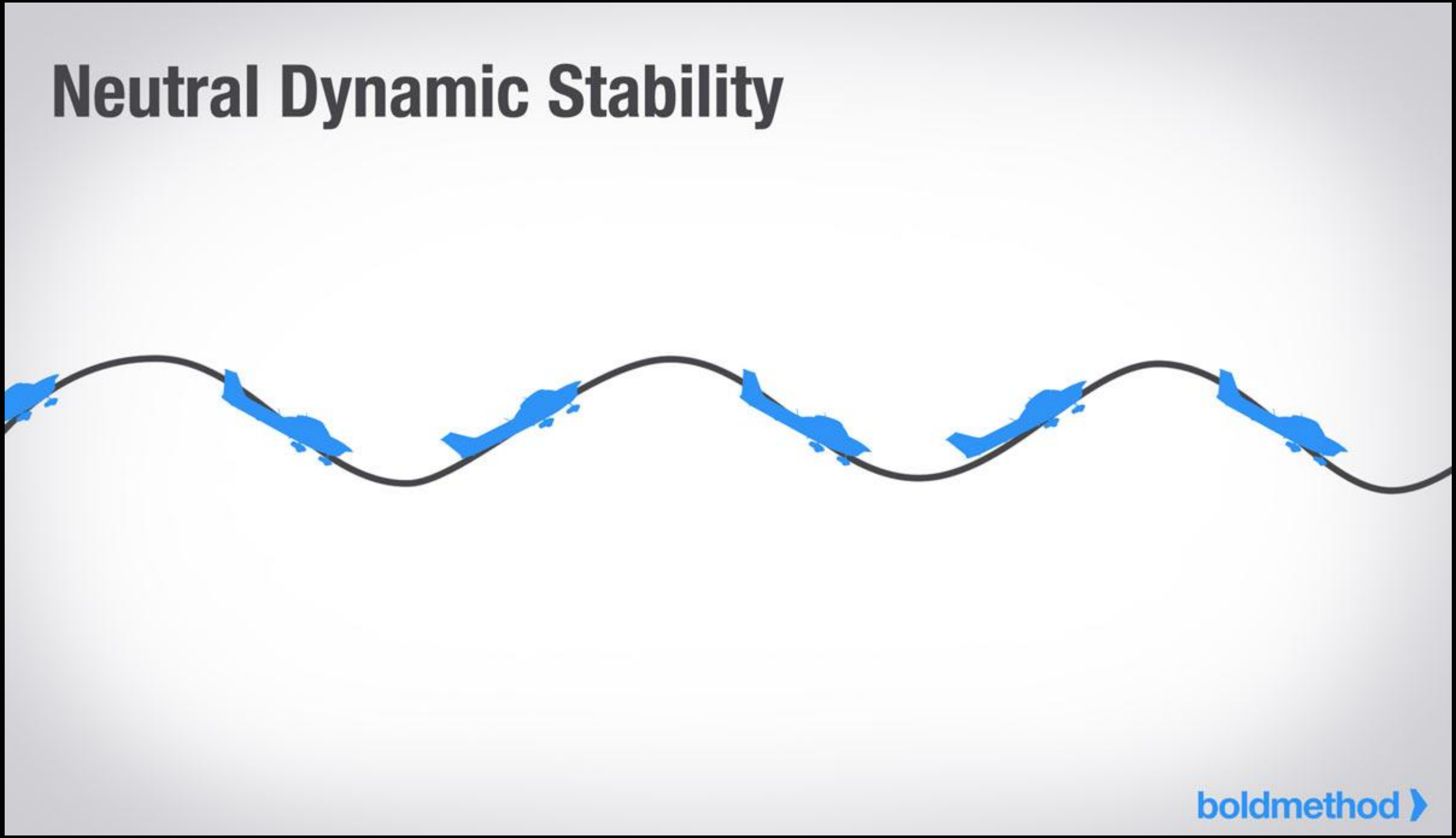
Negative Dynamic Stability

- Tendency over time to increase oscillation over time

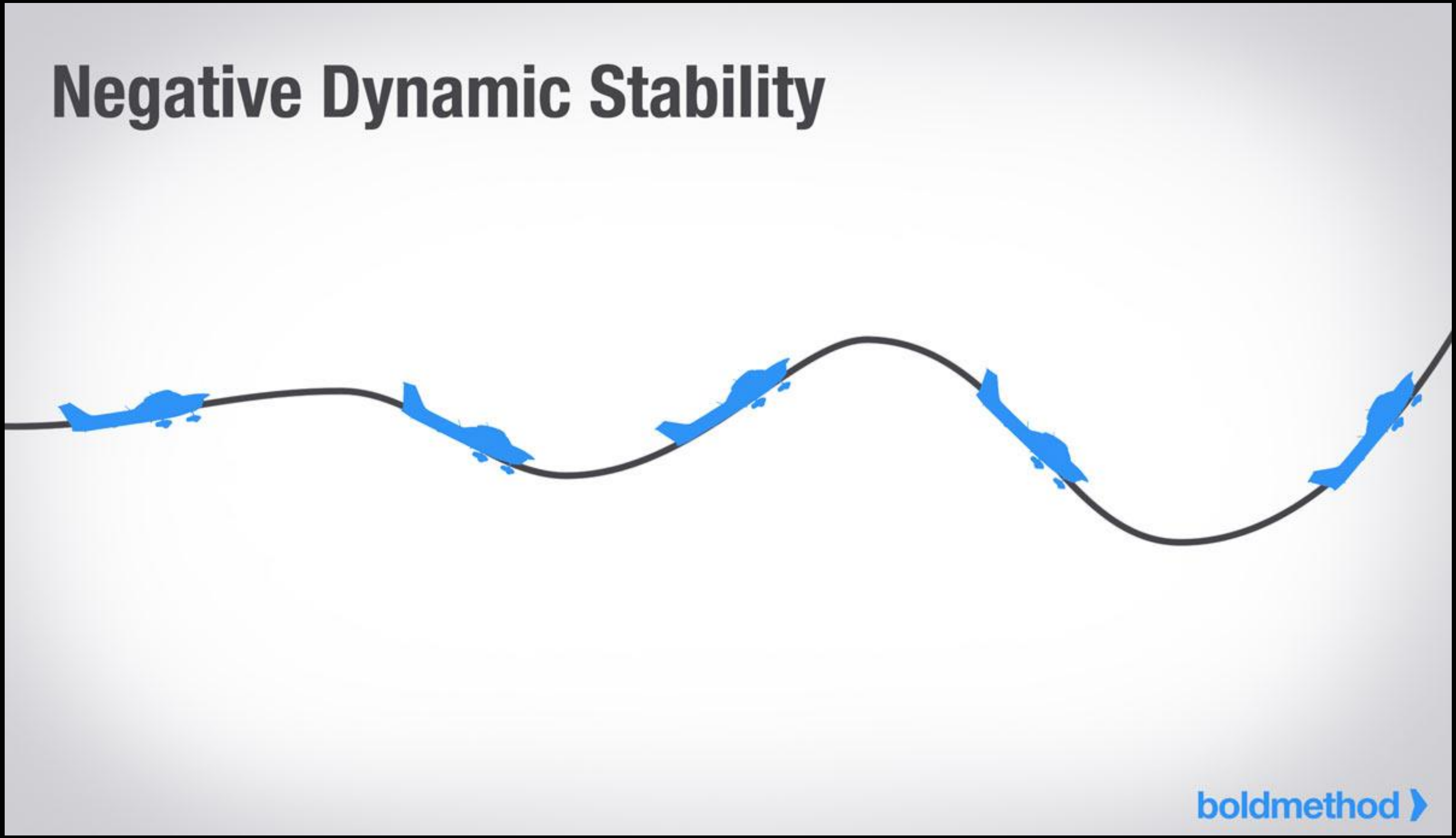
Static Stability



Static Stability



Static Stability



Stability

- These stability concepts apply in each axis of motion.
- What type of flying characteristics would each stability type create?
- Roll
- Yaw
- Pitch

Stability – Design Factors

- Dihedral in wings is key to stability design
- Dihedral is the angle of the wing flexing up (Stable) counteracts roll
  - Anhedral is the angle of the wing flexing down (Unstable)

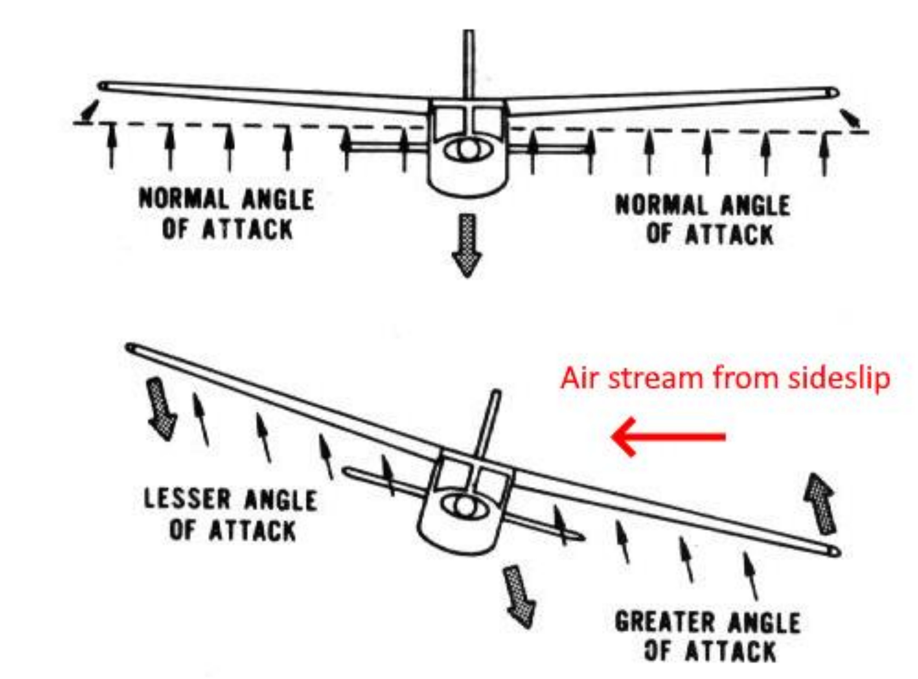
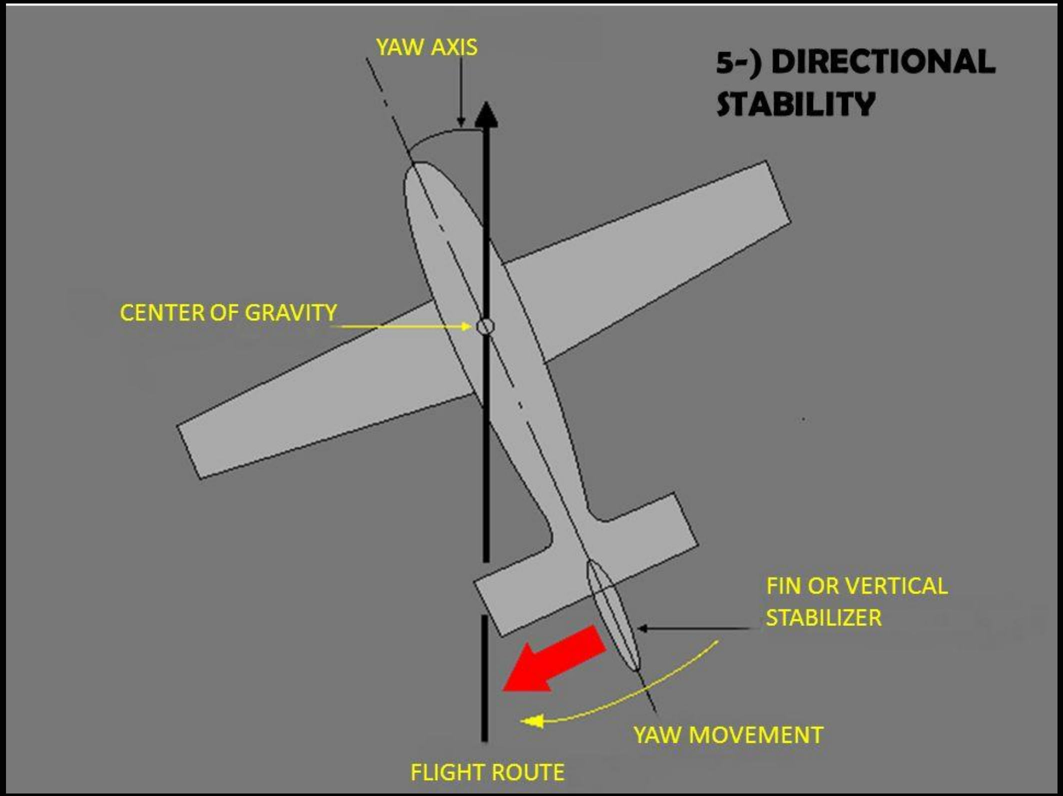


Figure 17–29 Dihedral for Lateral Stability

Stability – Design Factors

Stability – Design Factors

- Vertical stability is a function of surface area aft of the CG.
- Force counteracts turn to return aircraft to original position (Stability)



Stability – Design Factors

Knowledge Check

What is the definition of the chord line?

A. Line drawn from the leading edge to trailing edge
B. Line from trailing edge to leading edge the consider chamber
C. Line from the wing CG to the trailing edge
D. Line from leading edge to the wing CG

Knowledge Check

What is the definition of the chord line?

A. Line drawn from the leading edge to trailing edge

B. ~~Line from trailing edge to leading edge the consider chamber~~

C. ~~Line from the wing CG to the trailing edge~~

D. ~~Line from leading edge to the wing CG~~

Knowledge Check

What is the definition of AOA?

A. Angle between relative wind and mean chamber
B. Angle between chamber and chord line
C. Angle between relative wind and chord line
D. Angle between flight path and relative wind

Knowledge Check

What is the definition of AOA?

A. ~~Angle between relative wind and mean chamber~~
B. ~~Angle between chamber and chord line~~
C. Angle between relative wind and chord line
D. ~~Angle between flight path and relative wind~~

Knowledge Check

When does an aircraft produce wake turbulence?

A. When turning
B. With flaps down only
C. In a climb only
D. When producing lift

Knowledge Check

When does an aircraft produce wake turbulence?

A. ~~When turning~~
B. ~~With flaps down only~~
C. ~~In a climb only~~
D. When producing lift

Knowledge Check

In pitch, most GA airplanes have what type of stability?

A. Positive dynamic
B. Neutral dynamic
C. Negative dynamic
D. Negative static

Knowledge Check

In pitch, most GA airplanes have what type of stability?

A. Positive dynamic (Positive Static)
B. ~~Neutral dynamic~~
C. ~~Negative dynamic~~
D. ~~Negative static~~