Private Pilot (ASEL) Ground School Course

Lesson 03 | 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 stalls.

Lesson Completion Standards:

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

Stalls

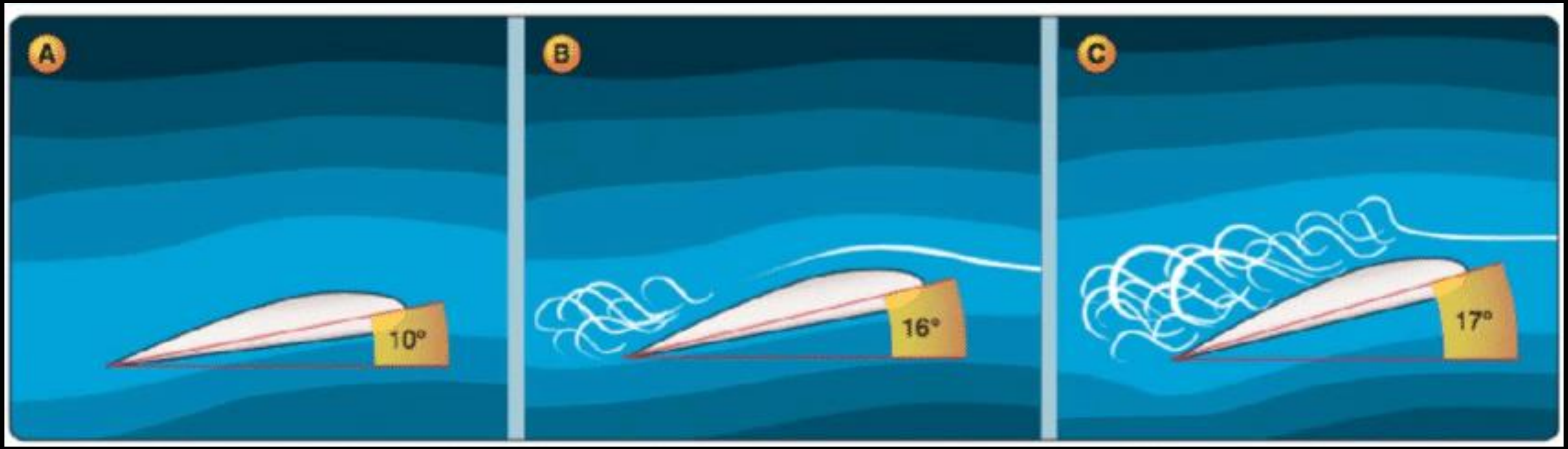
Aerodynamic Principles

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.**
- The wing never completely stops producing lift in a stalled condition. If it did, the aircraft would fall to the Earth.
- Stalls are one of the most misunderstood areas of aerodynamics because pilots often believe an airfoil stops producing lift when it stalls.

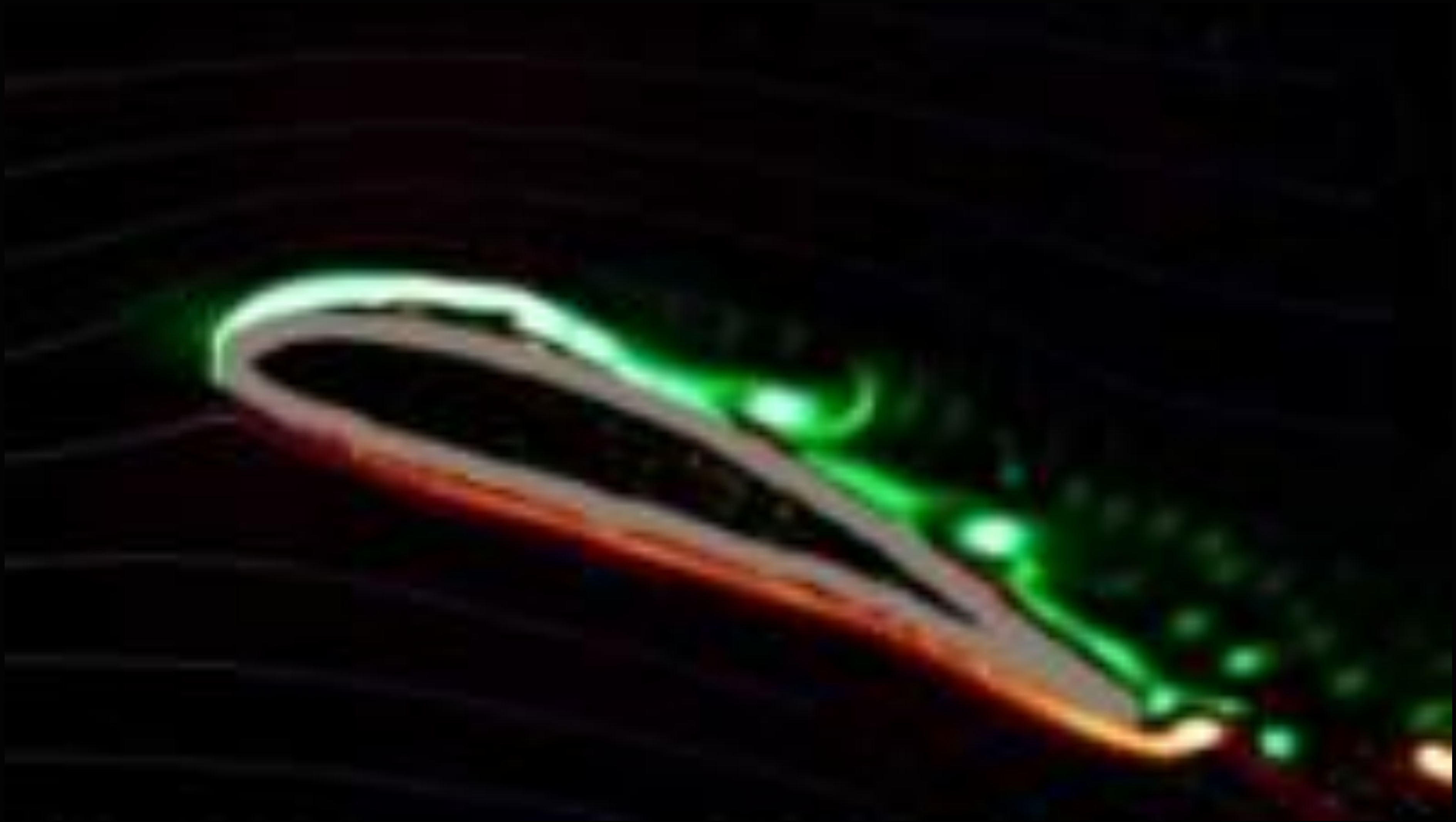
Stalls

- Why does a wing stall?
- Airflow around the wings airfoil no longer remain attached, it separates.
- Concerns?



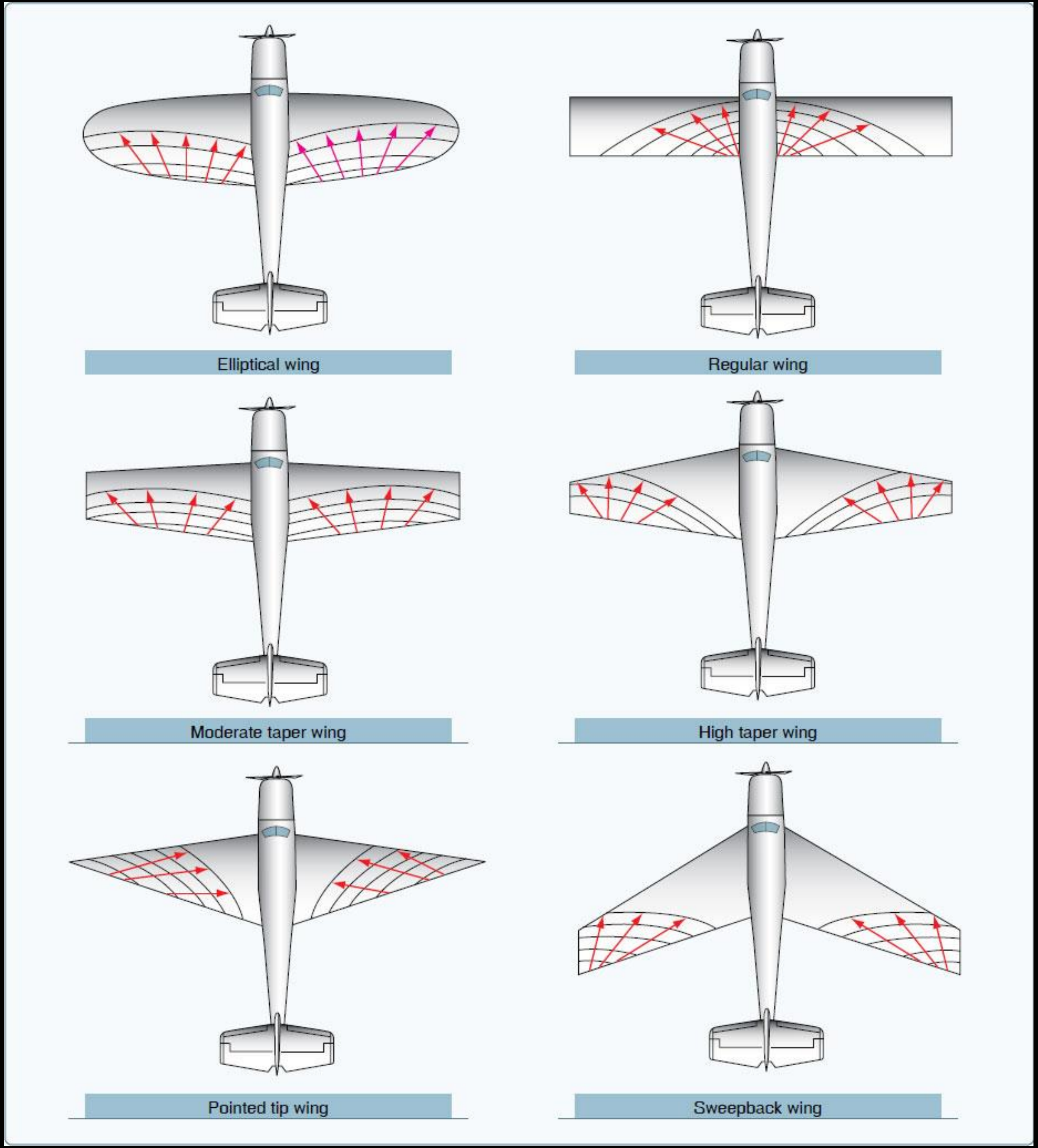
Stalls

Stalls



Stalls

- In most straight-wing aircraft, the wing is designed to stall the wing root first. The wing root reaches its critical AOA first making the stall progress outward toward the wingtip
- Improves aileron effectives into the beginning of a stall.

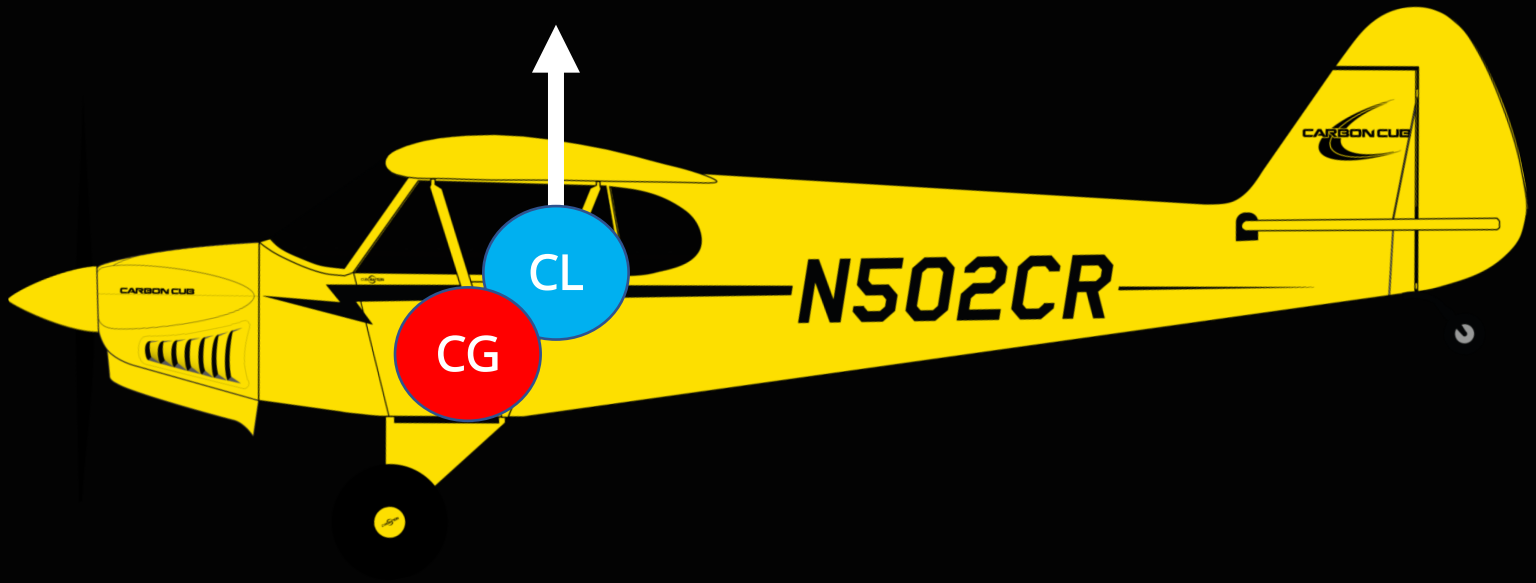


Stalls – CG. What is a moment?

Door example

Stalls

- Most trainer airplanes are designed for the nose to drop during a stall, naturally reducing the AOA.
- The nose-down tendency is due to the CL being aft of the CG. The CG range is very important when it comes to stall recovery characteristics**. REMAIN WITHIN CG LIMITS**



Stalls

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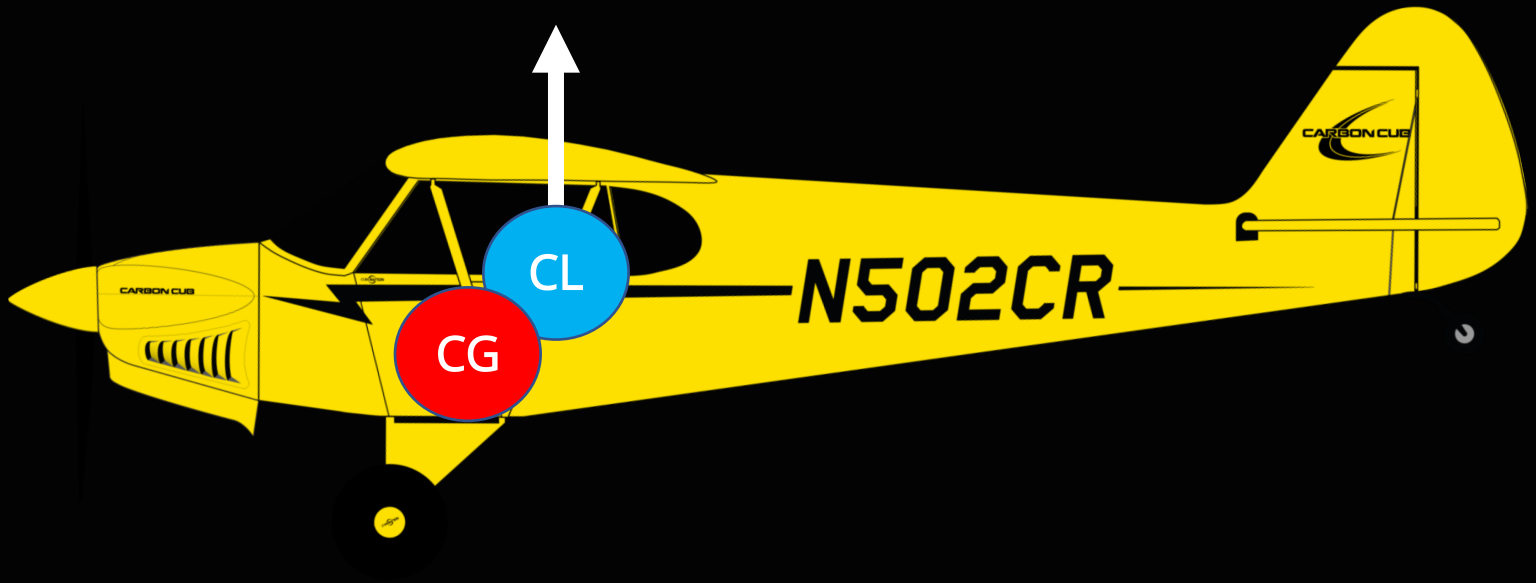
- The nose-down tendency is due to the CL being aft of the CG. The CG range is very important when it comes to stall recovery characteristics. **REMAIN WITHIN CG LIMITS**



Stalls - CG

- The most critical CG violation would occur when operating with a CG that exceeds the rear limit.
- In this situation, a pilot may not be able to generate sufficient force with the elevator to counteract the excess weight aft of the CG. Without the ability to decrease the AOA, the aircraft continues in a stalled condition until it contacts the ground.

Stalls - CG

- Forward CG increase tail down forces allowing for easier stall recover.
- Forward CG comes with other aerodynamic penalties

Stalls

- We often want to link stalls to speed. V_{SO} and V_S
- The stalling speed of a particular aircraft is not a fixed value for all flight situations, but a given aircraft always stalls at the **same AOA regardless of airspeed, weight, load factor, or density altitude.**
- This critical AOA varies from approximately 16° to 20° depending on the aircraft's design.
- Each aircraft has only one specific AOA where the stall occurs.

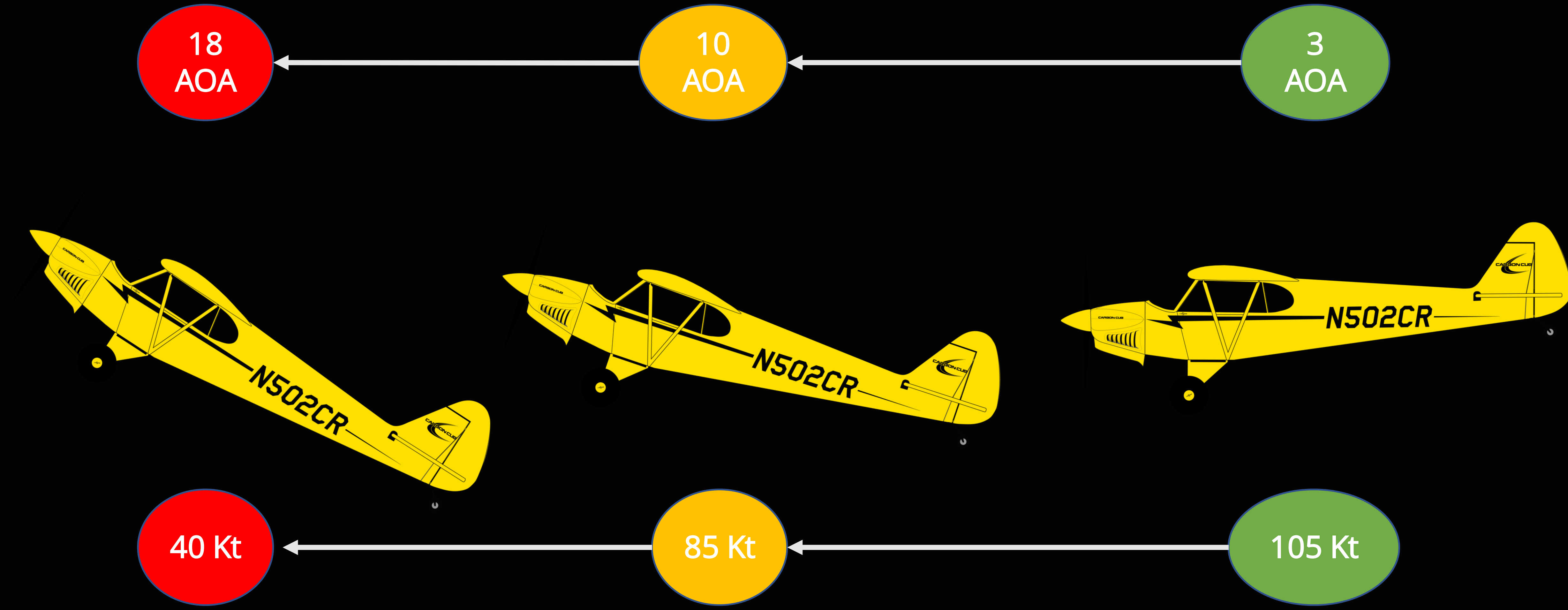
Stalls

- Three common situations the critical AOA is exceeded:
  - Low speed
  - High Speed
  - Turning

Stalls – Low Speed Scenario

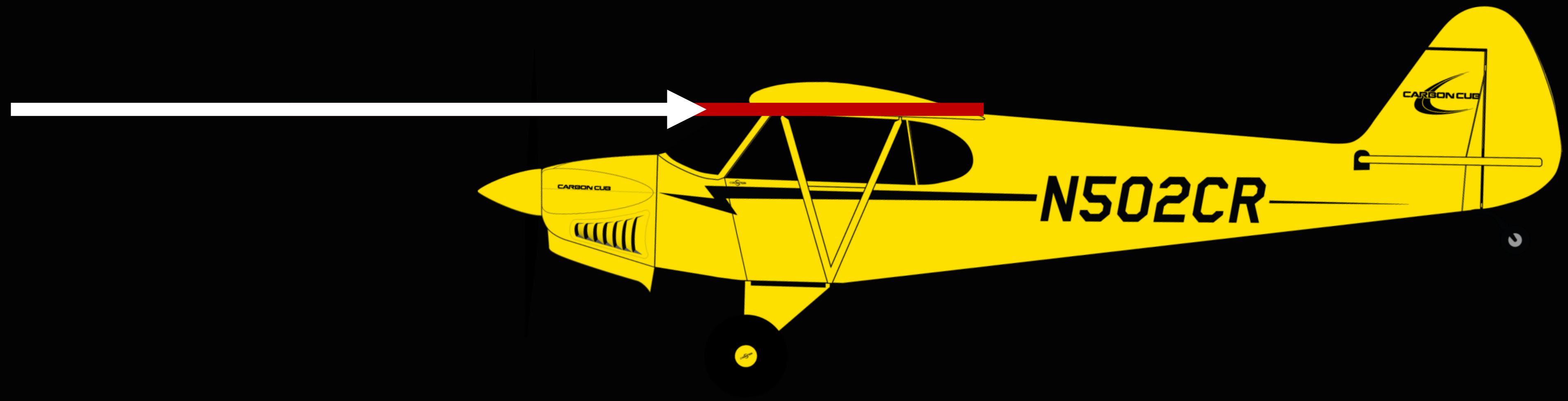
- One way the aircraft can be stalled in straight-and-level flight by flying too slowly.
- As the airspeed decreases, the AOA must be increased to retain the lift required for maintaining altitude. The lower the airspeed becomes, the more the AOA must be increased.
- Eventually, an AOA is reached that results in the wing not producing enough lift to support the aircraft, which then starts settling.
- Critical AOA is reached = Aerodynamic Wing Stall

Stalls – Low Speed Scenario

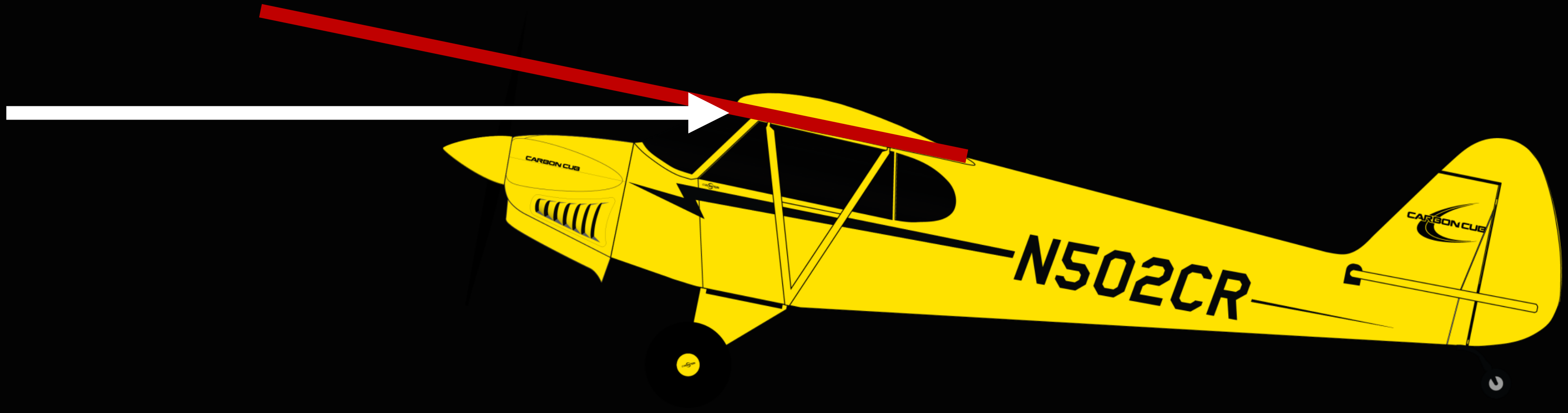


Example is in level flight – Idle engine power

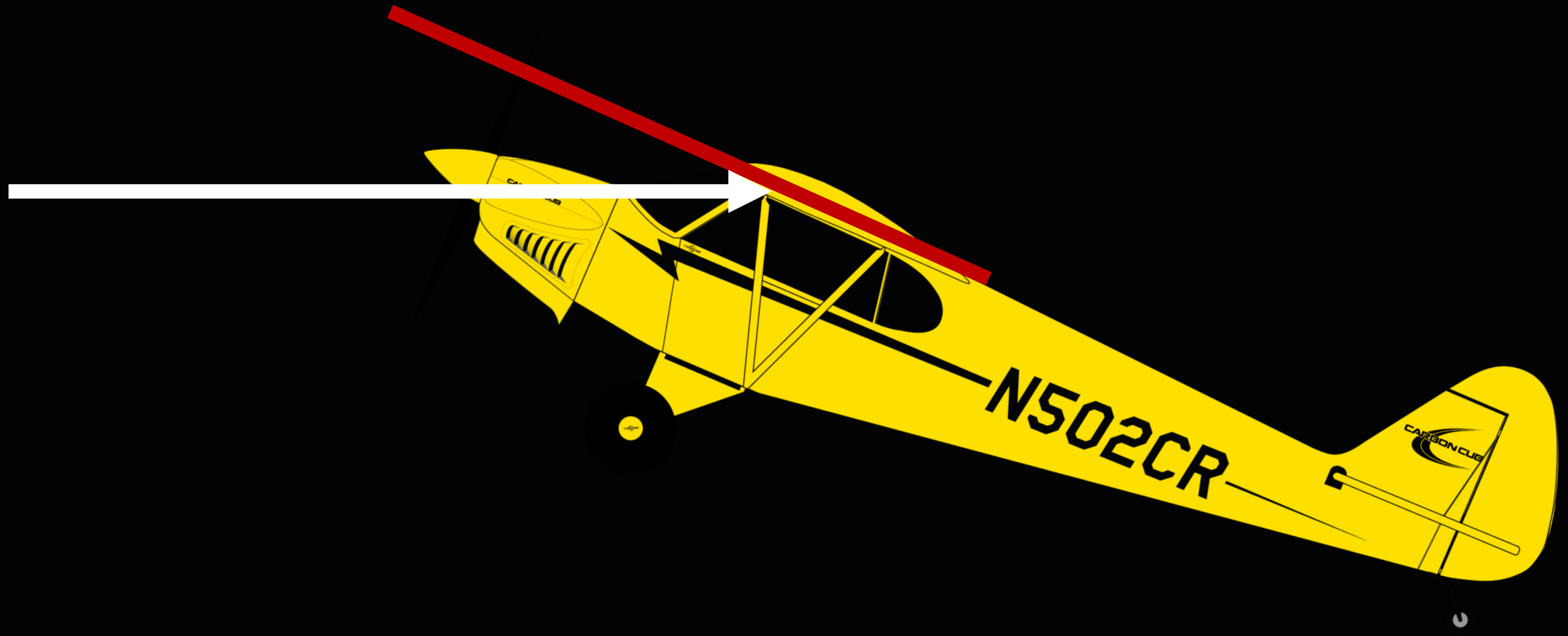
Stalls – Low Speed Scenario



Stalls – Low Speed Scenario



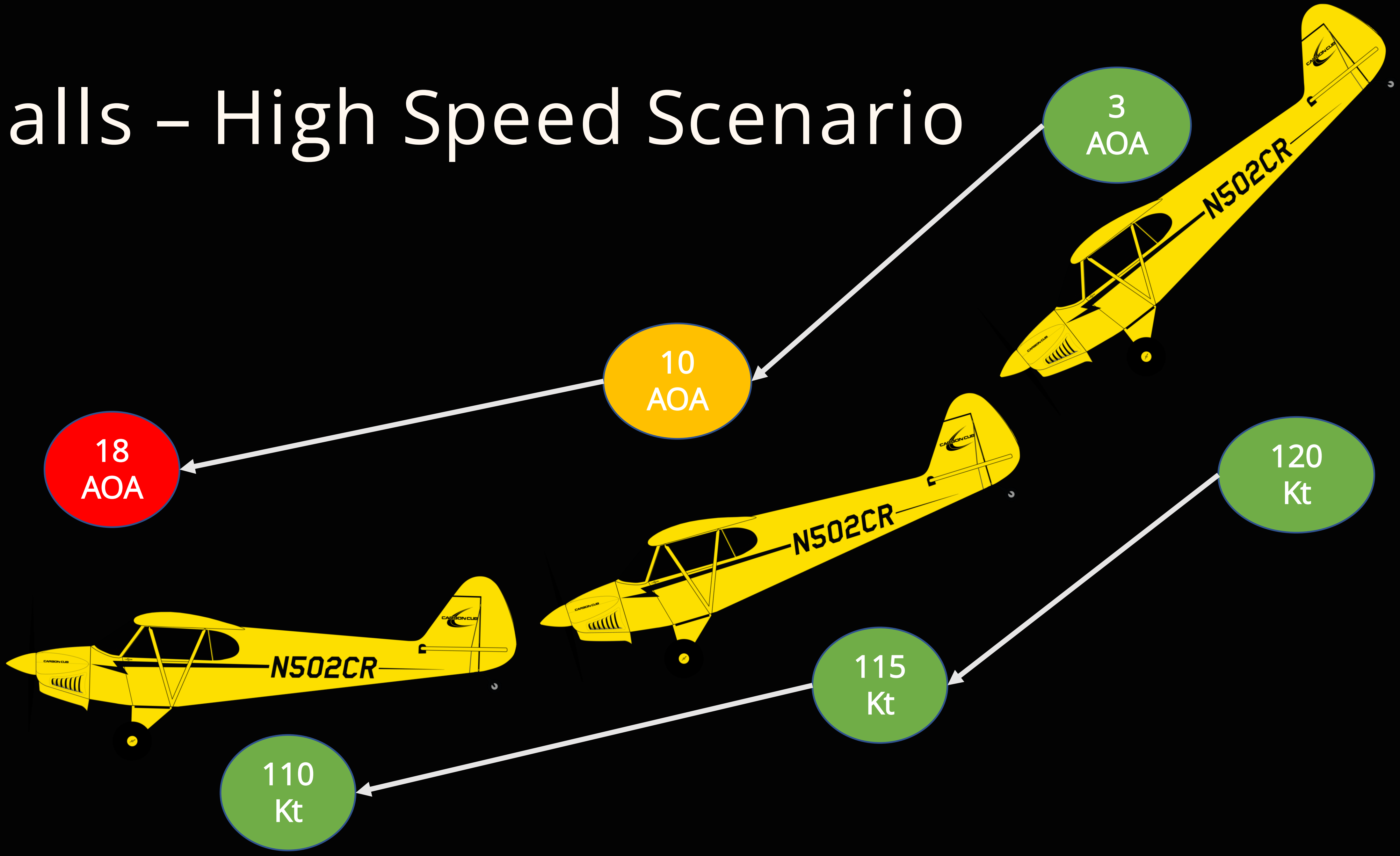
Stalls – Low Speed Scenario



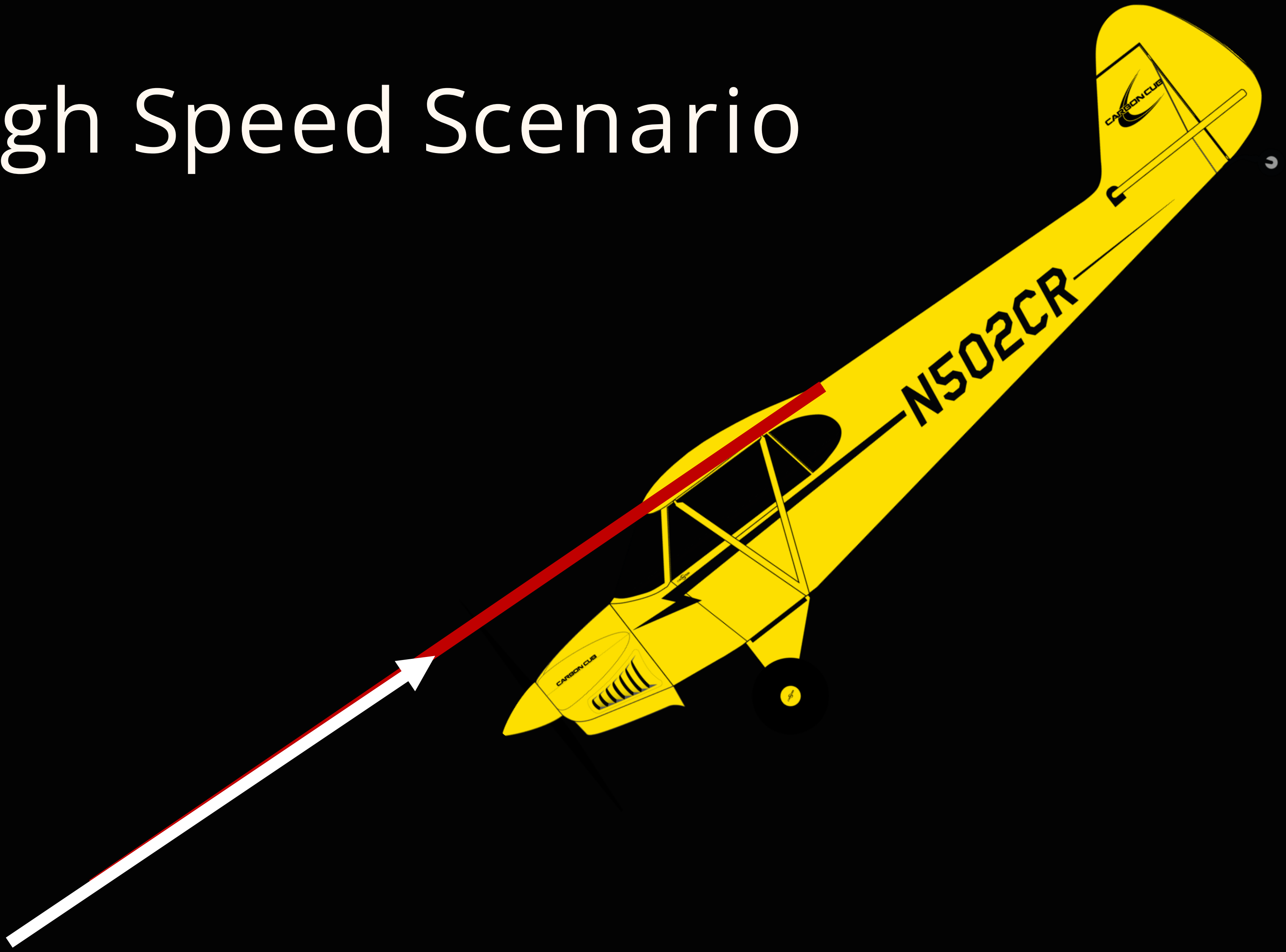
Stalls – High Speed Scenario

- An aircraft is in a dive with an airspeed of 100 knots when the pilot pulls back sharply on the elevator control. Gravity and centrifugal force prevent an immediate alteration of the flight path, but the aircraft's AOA changes abruptly from quite low to very high.
- Since the flight path of the aircraft in relation to the oncoming air determines the direction of the relative wind, the AOA is suddenly increased, and the aircraft would reach the stalling angle at a speed much greater than the normal stall speed.

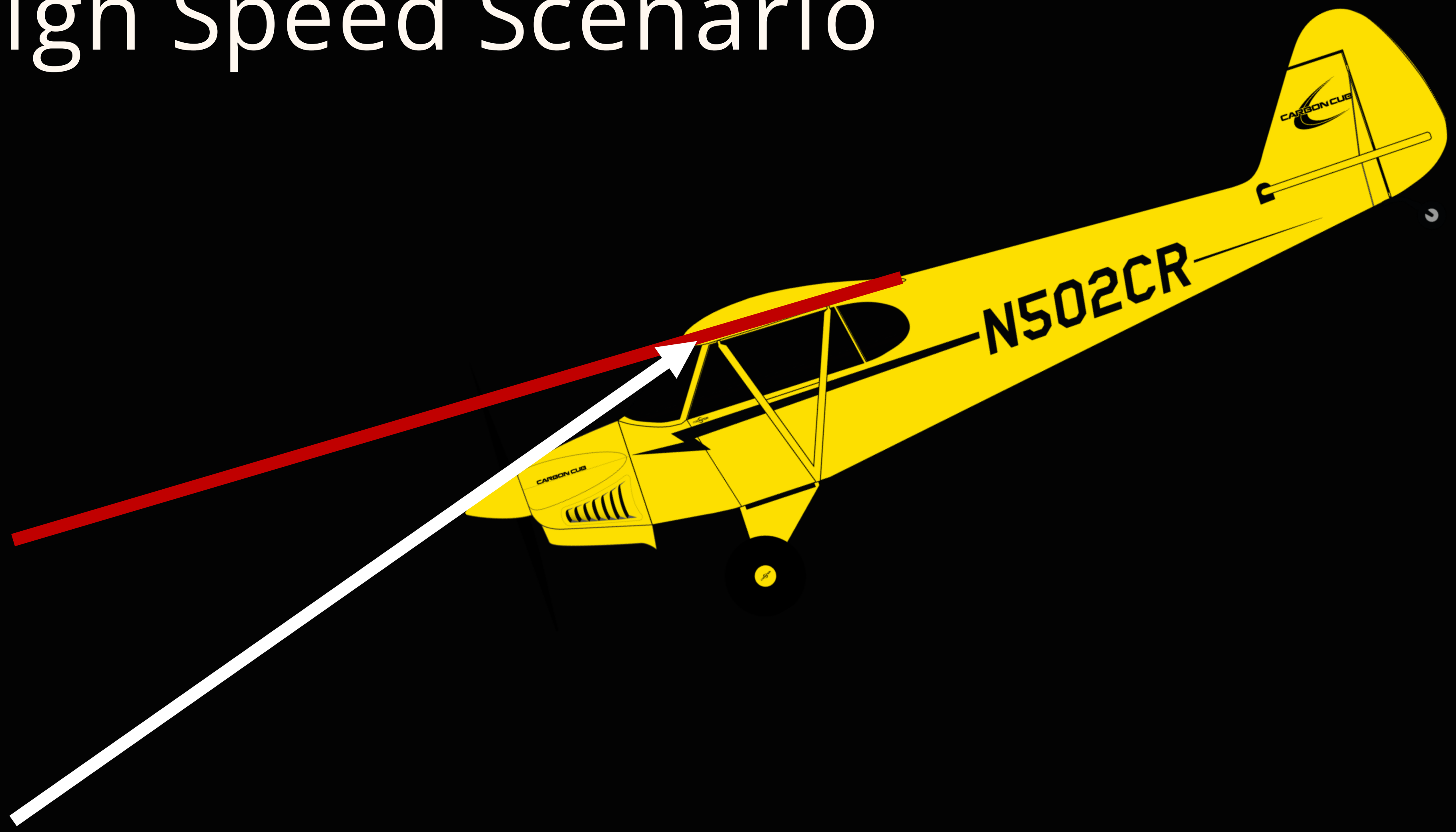
Stalls – High Speed Scenario



Stalls – High Speed Scenario



Stalls – High Speed Scenario

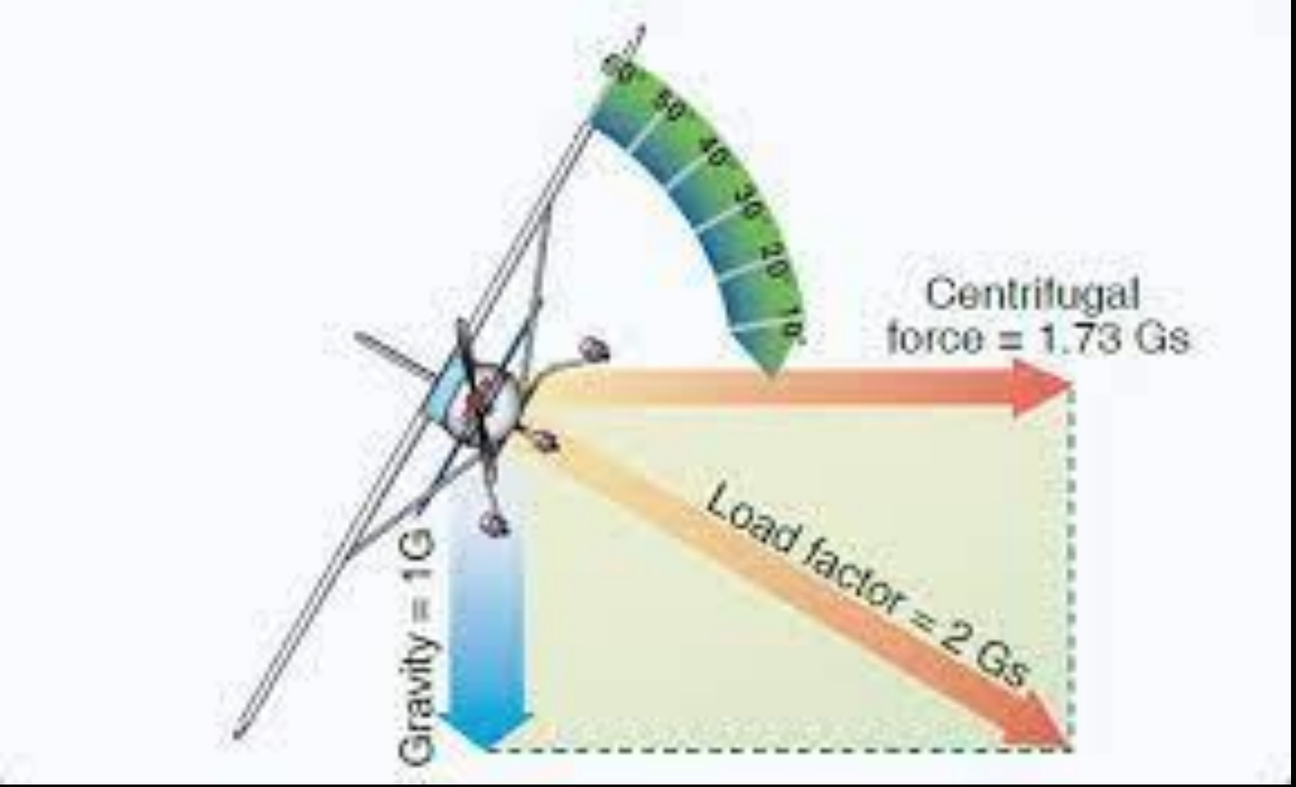


Stalls – High Speed Scenario

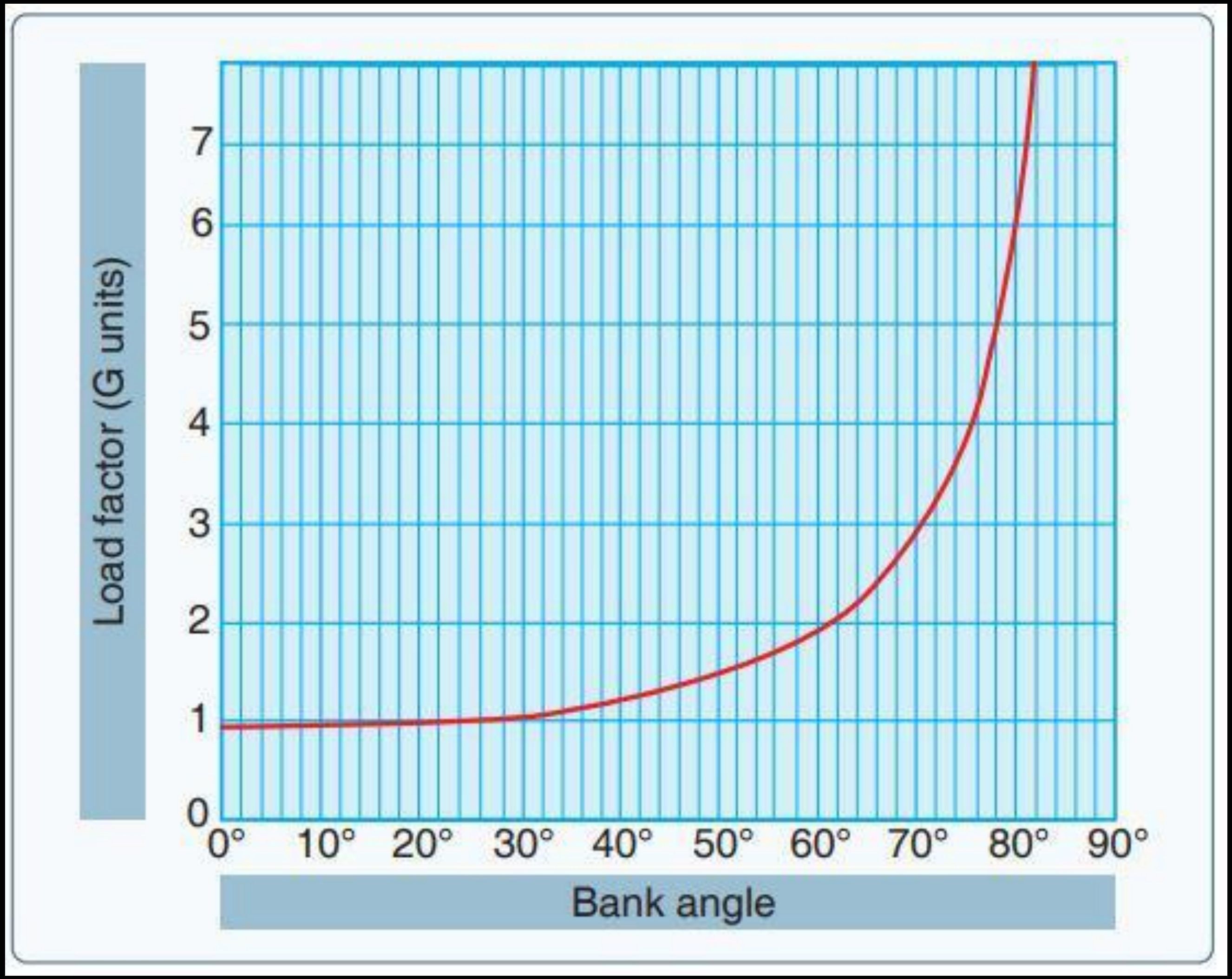
Stalls – Turning

- The stalling speed of an aircraft is also higher in a level turn than in straight-and-level flight
- Centrifugal force is added to the aircraft's weight and the wing must produce sufficient additional lift to counterbalance the load imposed by the combination of centrifugal force and weight.
- In a turn, the necessary additional lift is acquired by applying back pressure to the elevator control.
- This will increase the AOA. If the AOA increase becomes too great, a stall may occur.
- Pitching up to maintain altitude increase AOA and load factor.

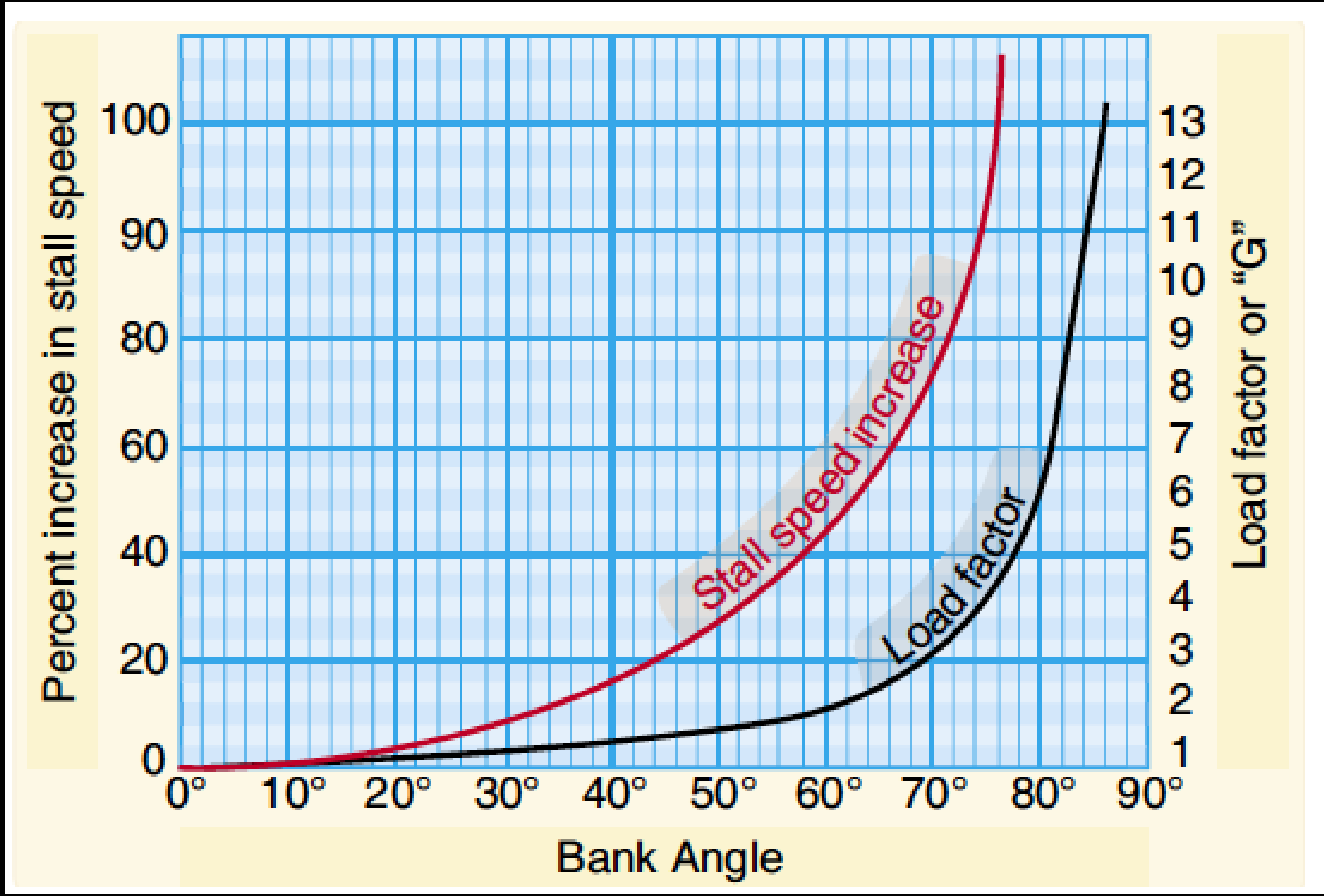
Stalls – Turning (Load Factor)



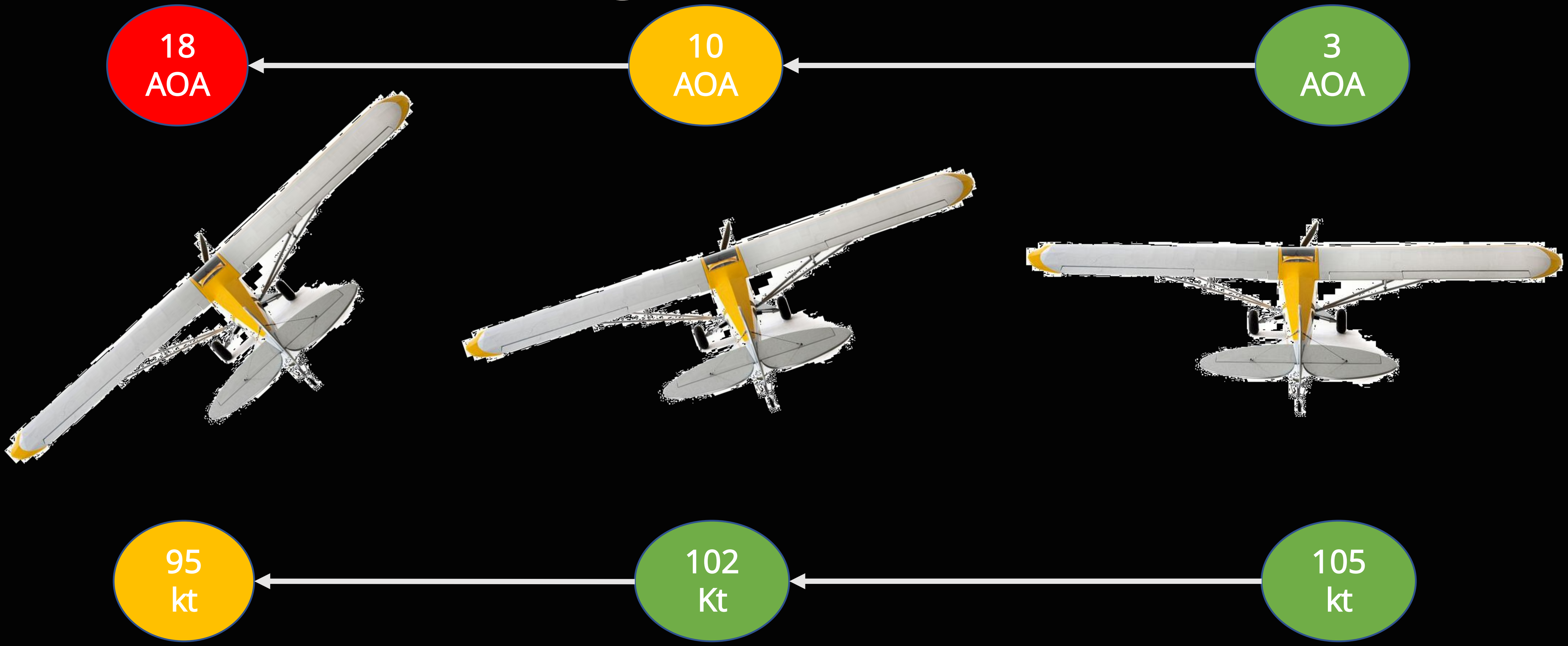
Stalls – Turning (Load Factor)



Stalls – Turning



Stalls – Turning



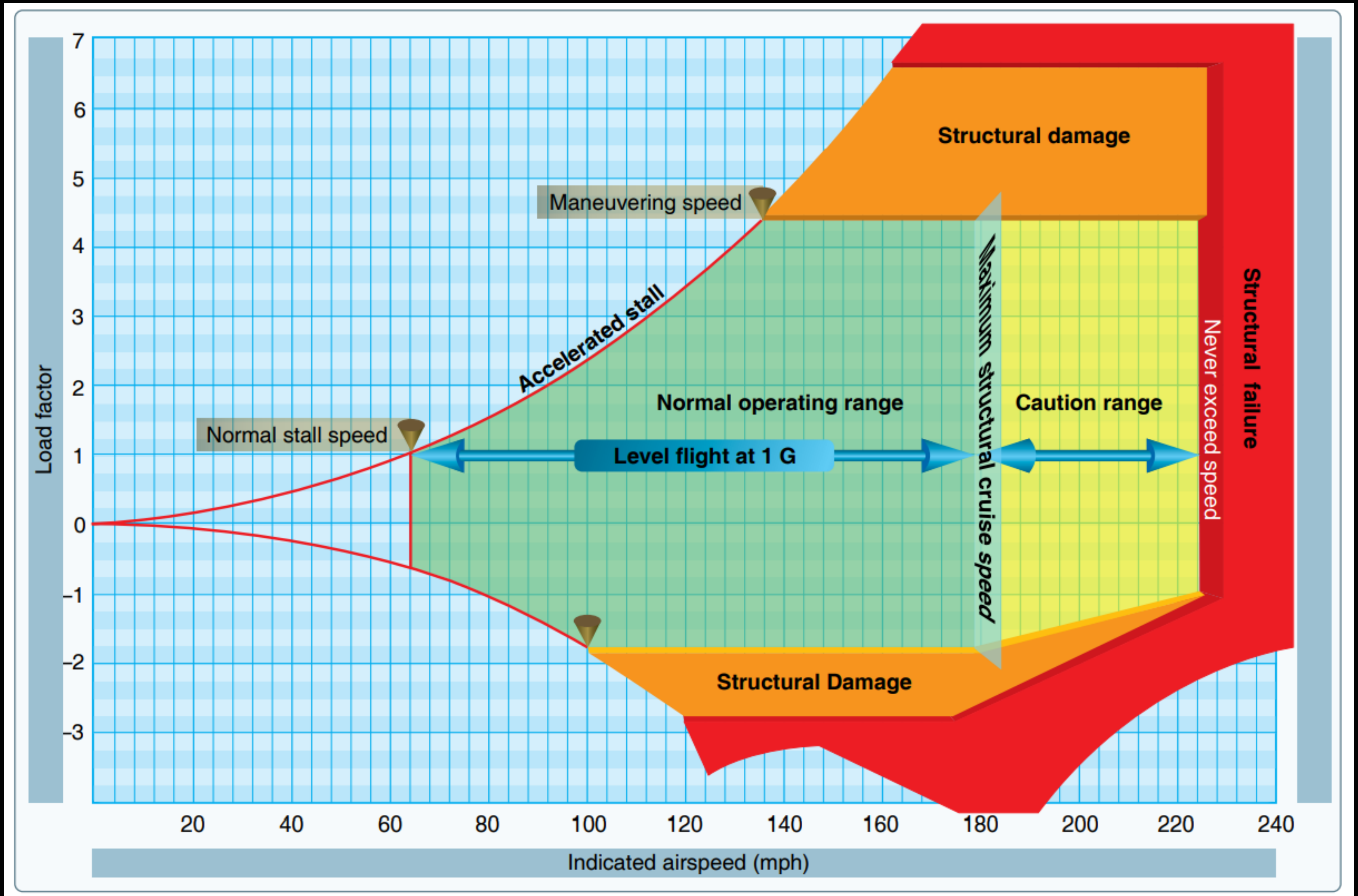
Stalls – Turning

Stalls – Turning

Stalls – V_G Diagram

- The flight operating strength of an aircraft is presented on a graph whose vertical scale is based on load factor.
- Graph is aircraft specific.

Stalls – V_G Diagram

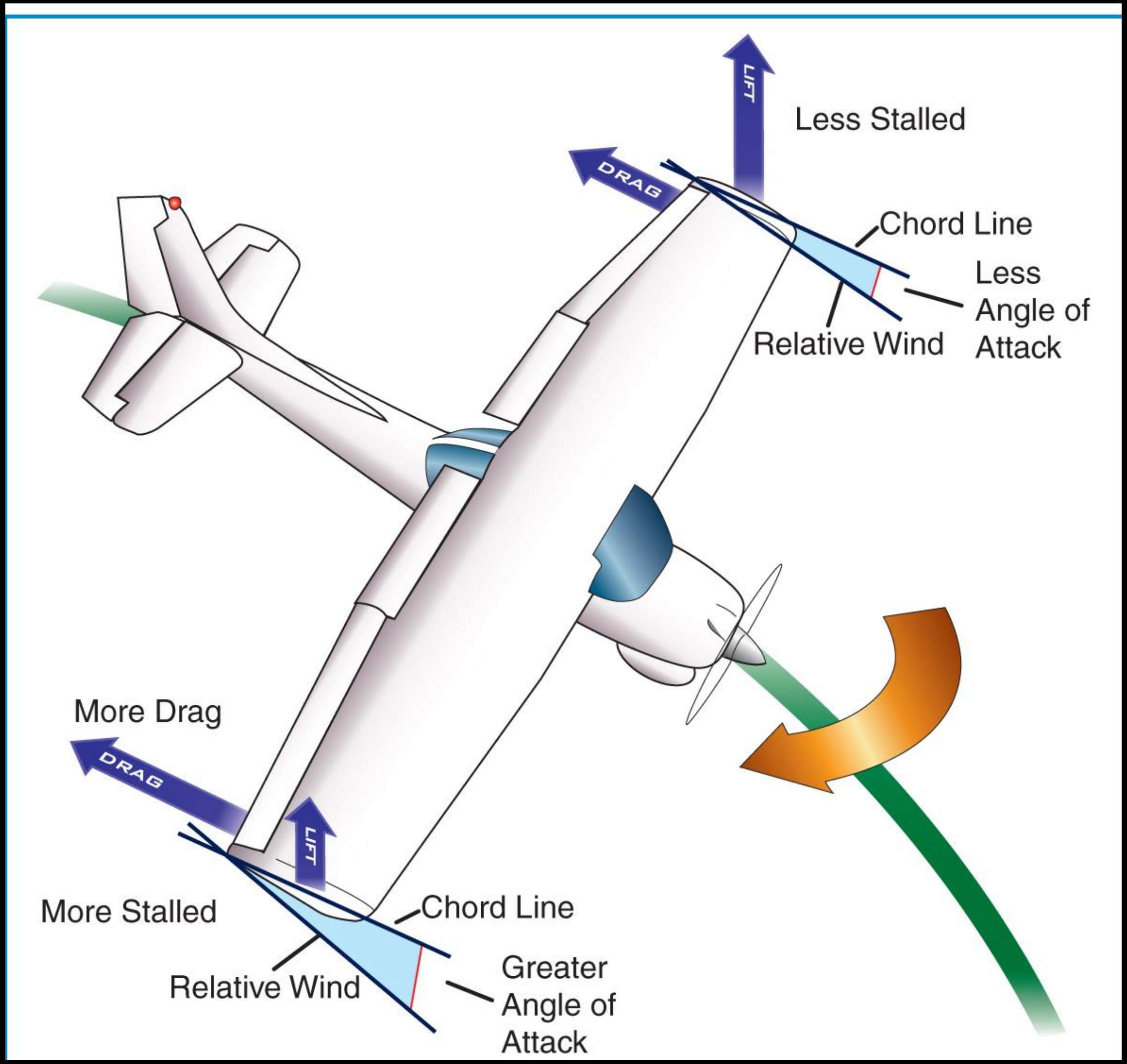


Stalls – Spins

- What happens when we stall the airplane uncoordinated. (Yaw moment induced)?
- Spin
- What is a spin?
- An aggravated stall that results in an airplane descending in a helical, or corkscrew path
- Both wings are stalled in a spin, but one is more deeply stalled than the other. The "more stalled" wing is on the inside of the spin, it flies at a higher angle-of-attack, and it generates less lift than the outside wing.

Stalls – Spins

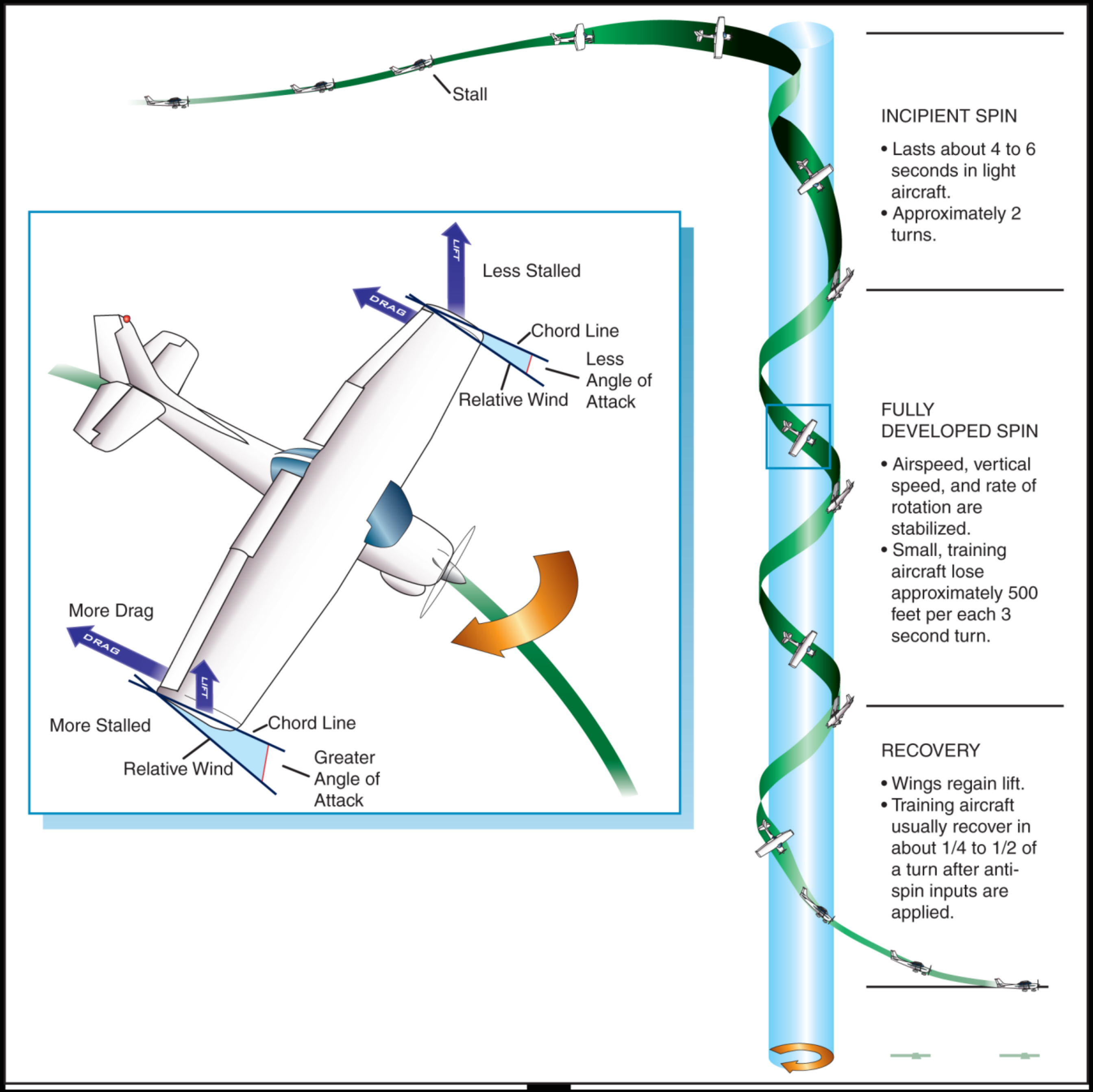
- Stall causes initial issue
- Inside wing is “more stalled,” and produces more drag. This causes the yaw
- Outside wing is “less stalled,” still producing lift causing the rolling moment.



Stalls – Spins

- Four Phases
  - Stall
  - Incipient
  - Fully Developed
  - Recover

- DO NOT STALL
- NEVER BE UNCOORDINATED



Stalls – Spins

- Recovery – PARE
  - Power – Idle
  - Ailerons – Neutral
  - Rudder – Opposite to direction of spin
  - Elevator – Forward

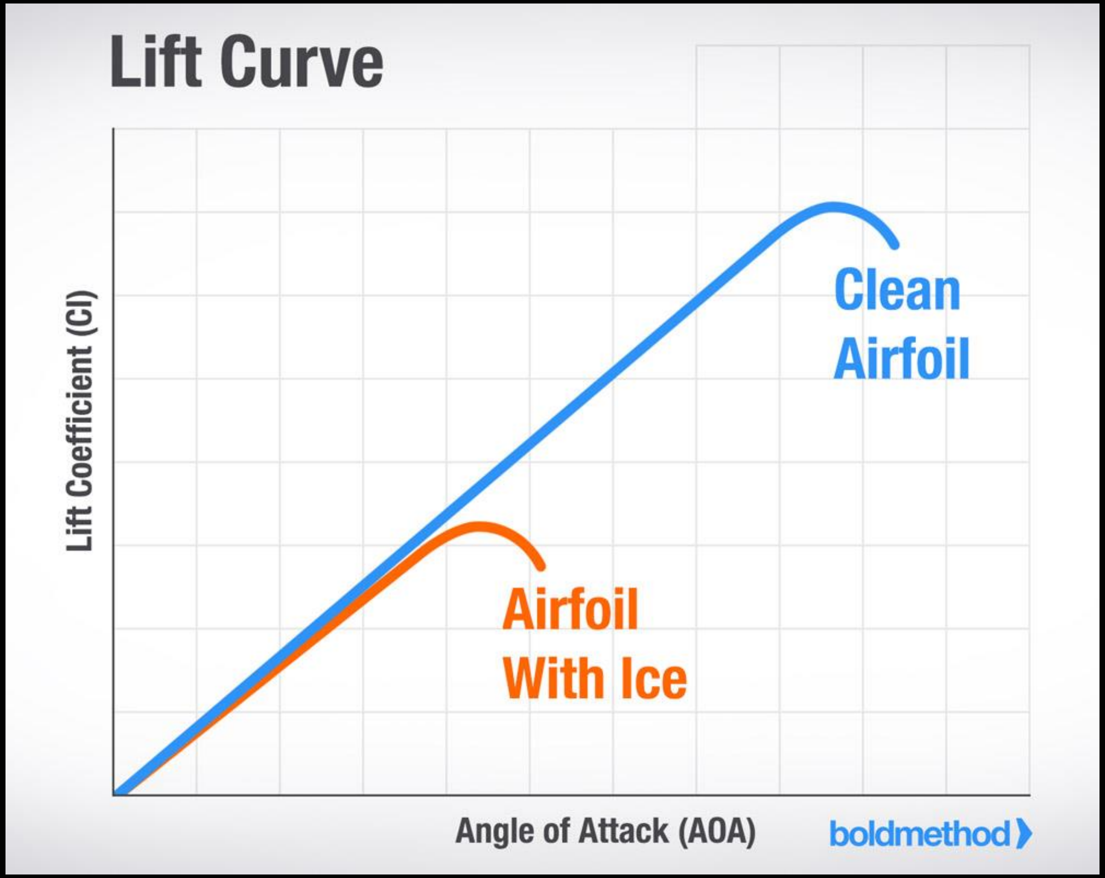
- Spins will be discussed further in flight training

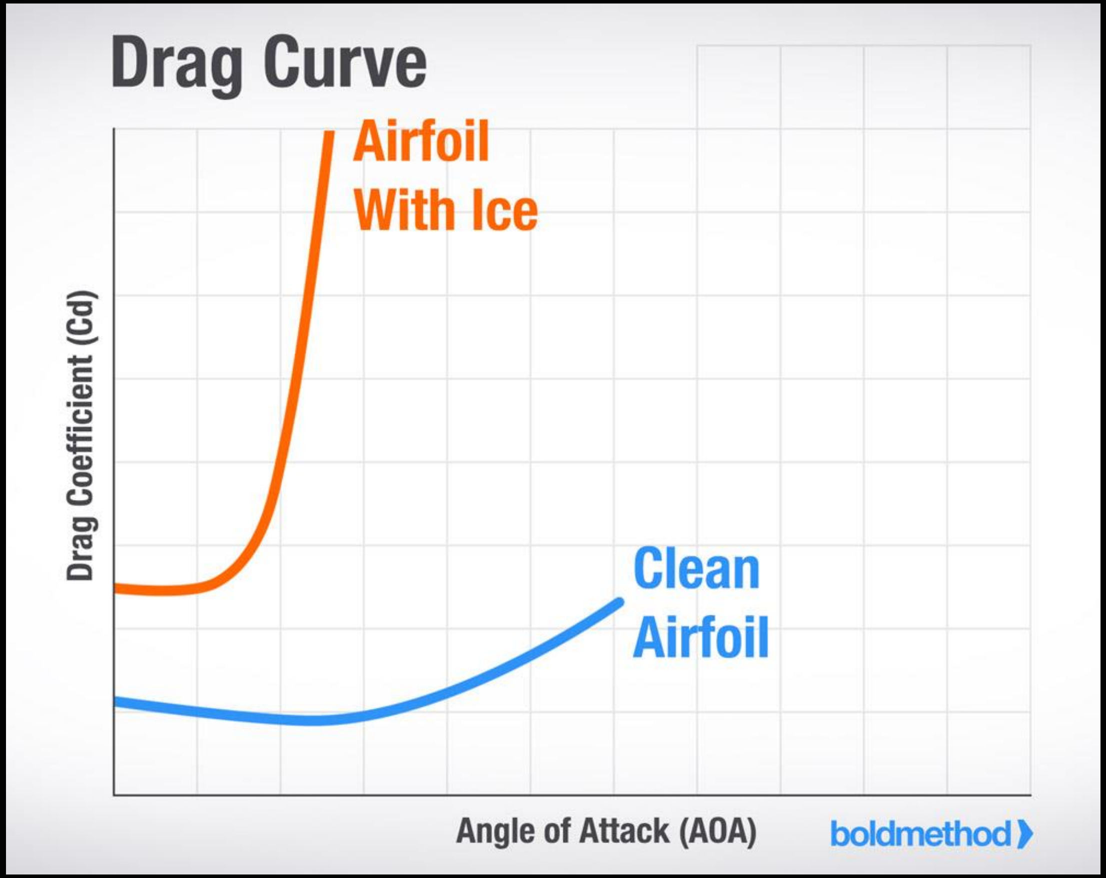
Stalls

- Airfoil shape and degradation of that shape must also be considered in a discussion of stalls.
- For example, if ice, snow, and frost are allowed to accumulate on the surface of an aircraft, the smooth airflow over the wing is disrupted.
- This causes the boundary layer to separate at an AOA lower than that of the critical angle

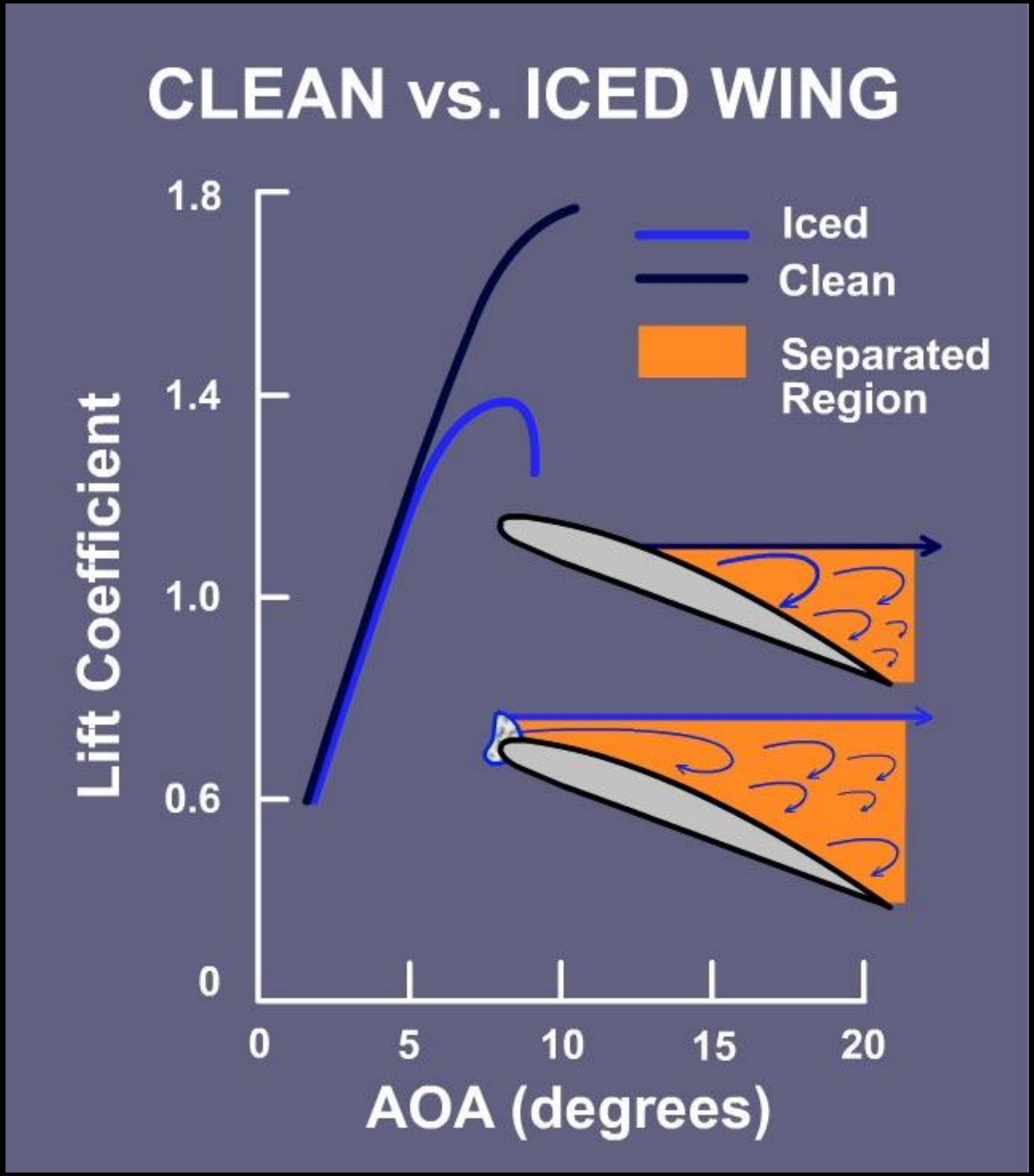
Stalls

Stalls

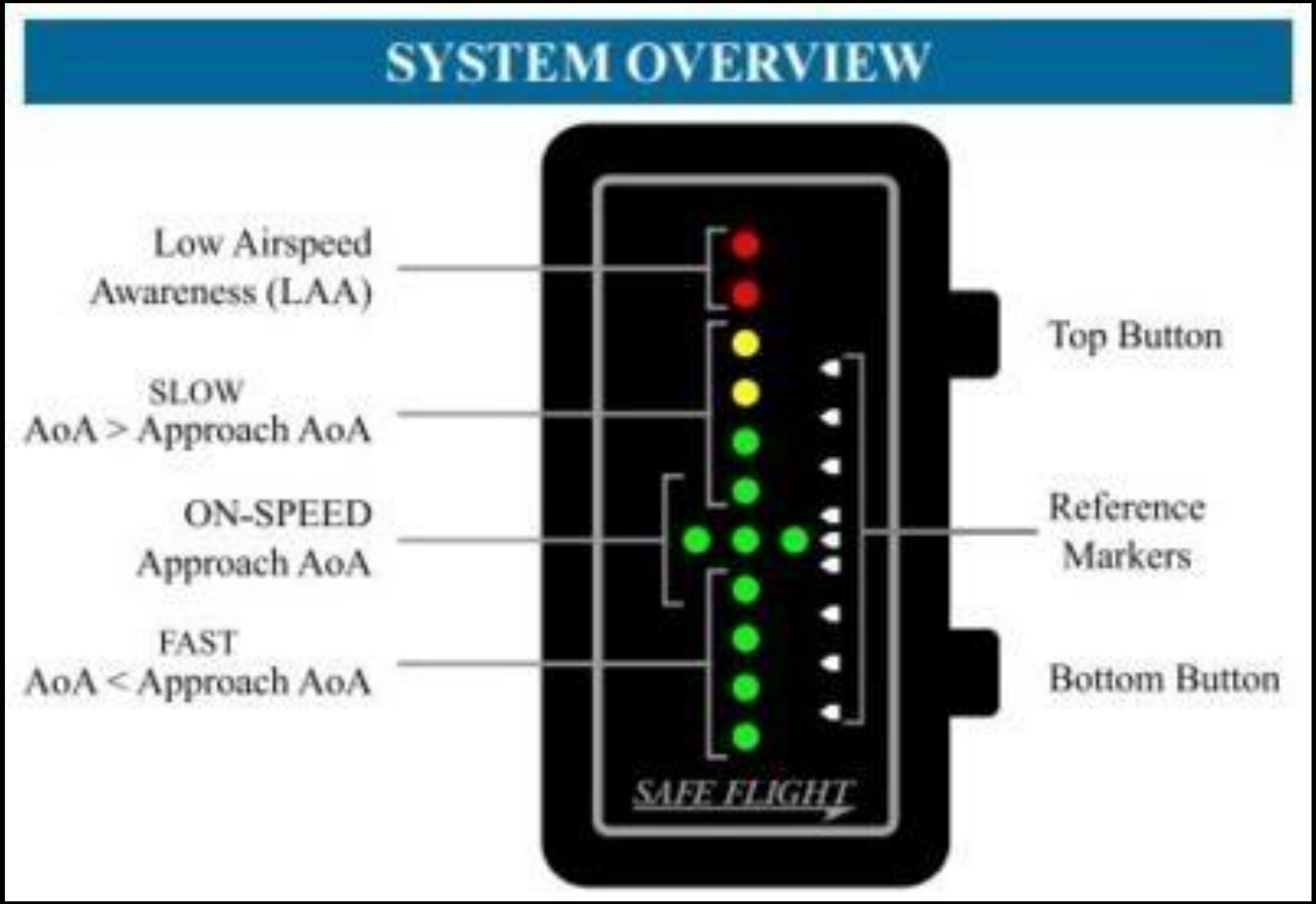

Lift Curve
Clean
Airfoil
Airfoil
With Ice
Lift Coefficient (Cl)
Angle of Attack (AOA)
boldmethod


Drag Curve
Airfoil
With Ice
Clean
Airfoil
Drag Coefficient (Cd)
Angle of Attack (AOA)
boldmethod

Stalls


CLEAN vs. ICED WING
1.8
1.4
1.0
0.6
0
Lift Coefficient
Iced
Clean
Separated Region
0
5
10
15
20
AOA (degrees)

Stalls – AOA Indicators



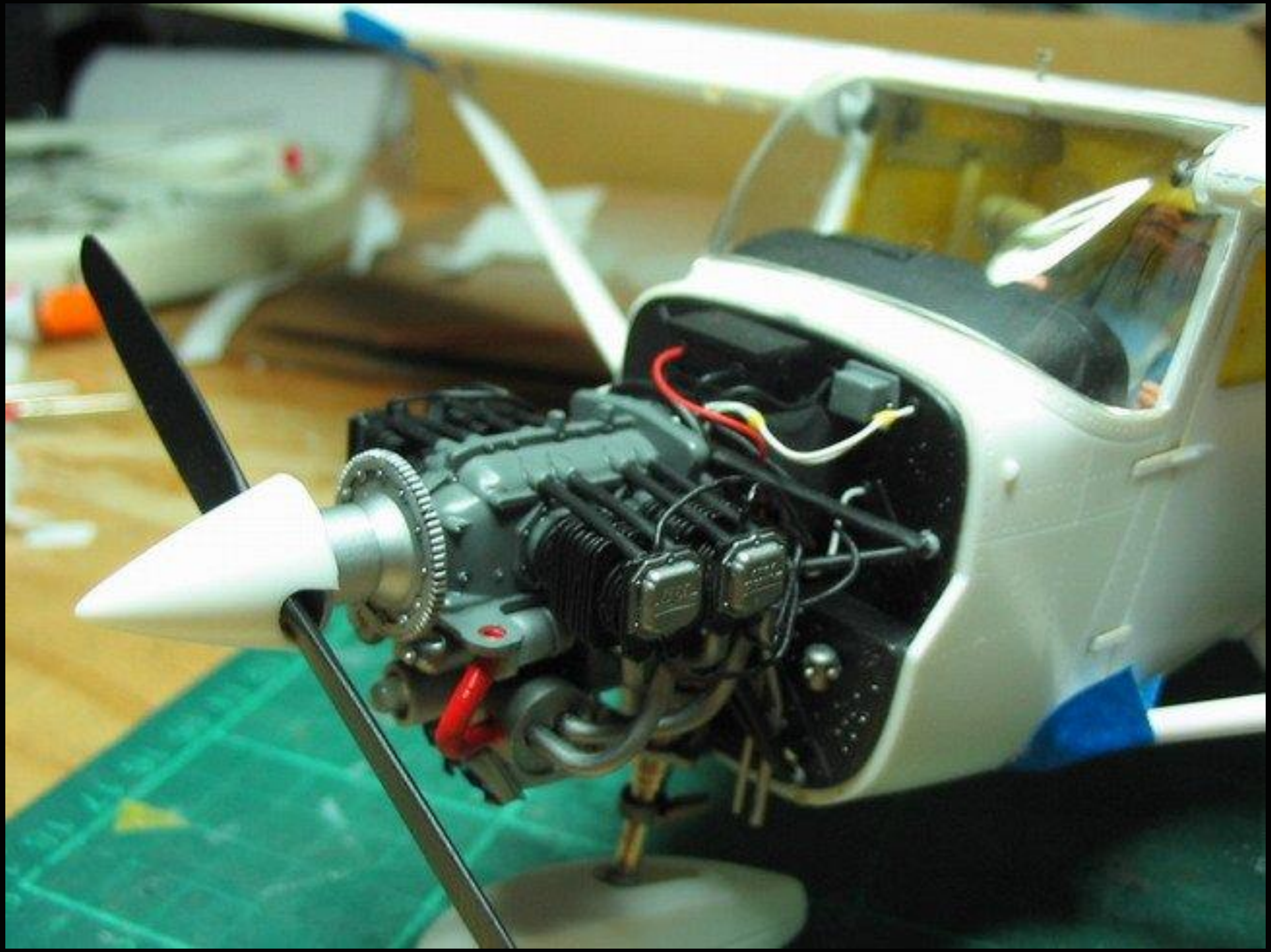
Effects of the Propeller

Aerodynamic Principles

Propeller Design

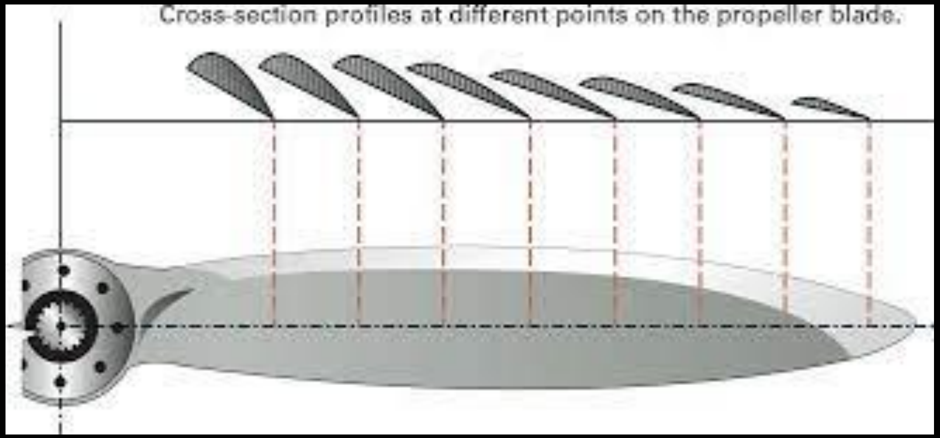
- The aircraft propeller consists of two or more blades and a central hub to which the blades are attached. (Rotating wing)
- The engine furnishes the power needed to rotate the propeller blades through the air at high speeds, and the propeller transforms the rotary power of the engine into forward thrust.
- When the aircraft is at rest on the ground with the engine operating, or moving slowly at the beginning of takeoff, the propeller efficiency is very low because the propeller is restrained from advancing with sufficient speed to permit its fixed-pitch blades to reach their full efficiency. (WANTS TO FLY)

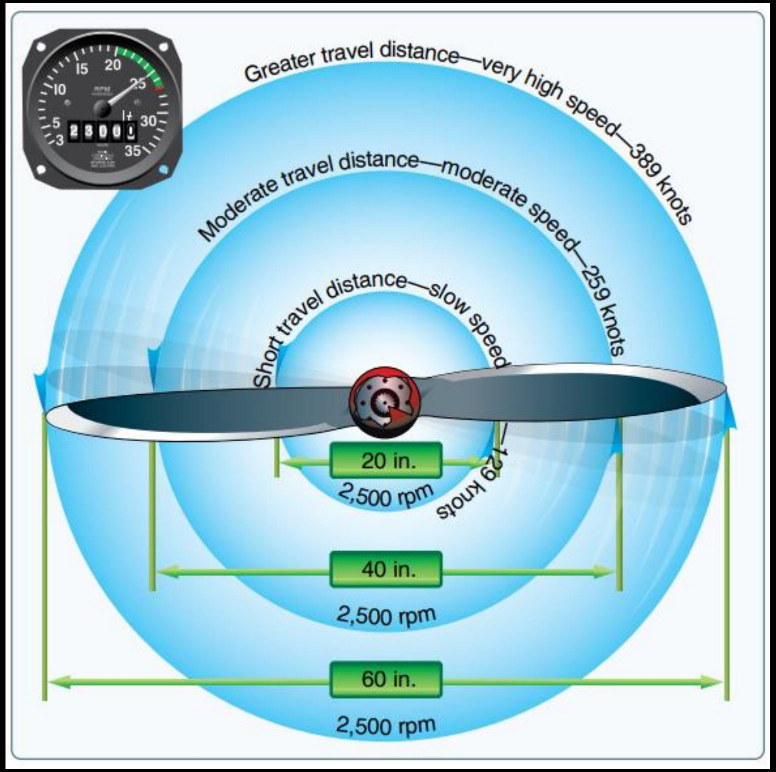
Propeller Design



Propeller Design

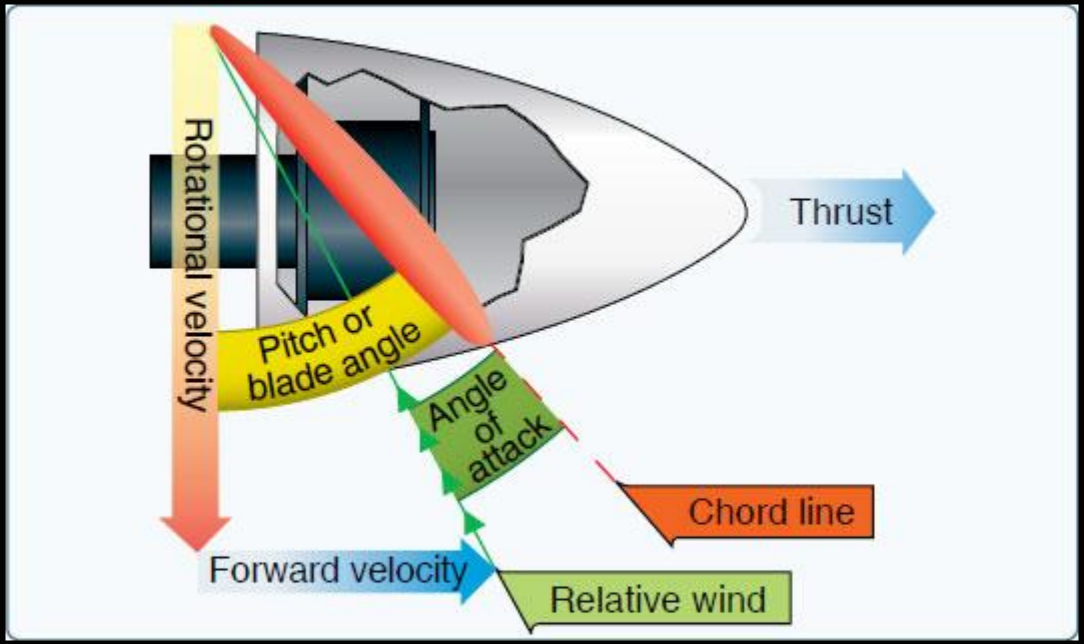
- Propellers must have a changing AOA along the length to accommodate a continuous lift force
- If this did not happen the propeller would begin to bend.
- This back to the lift equation (V^2)
- Natural twist



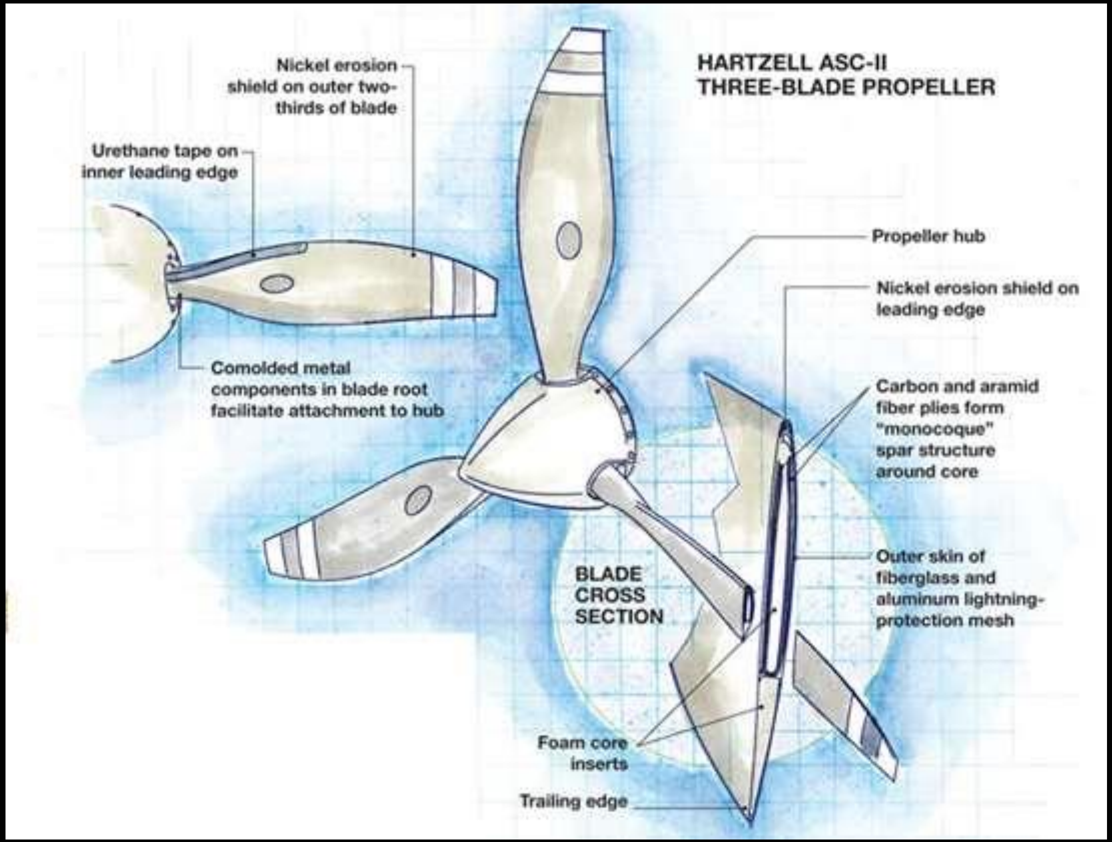


Propeller Design

- Fixed Pitch Propellers do not change the AOA in flight.
- Some propellers can adjust the AOA along the entire propeller (Variable-Pitch Propellers)



Propeller Design



- Different aircraft maty have more than one propeller.
- More propeller increase thrust output but also increases drag

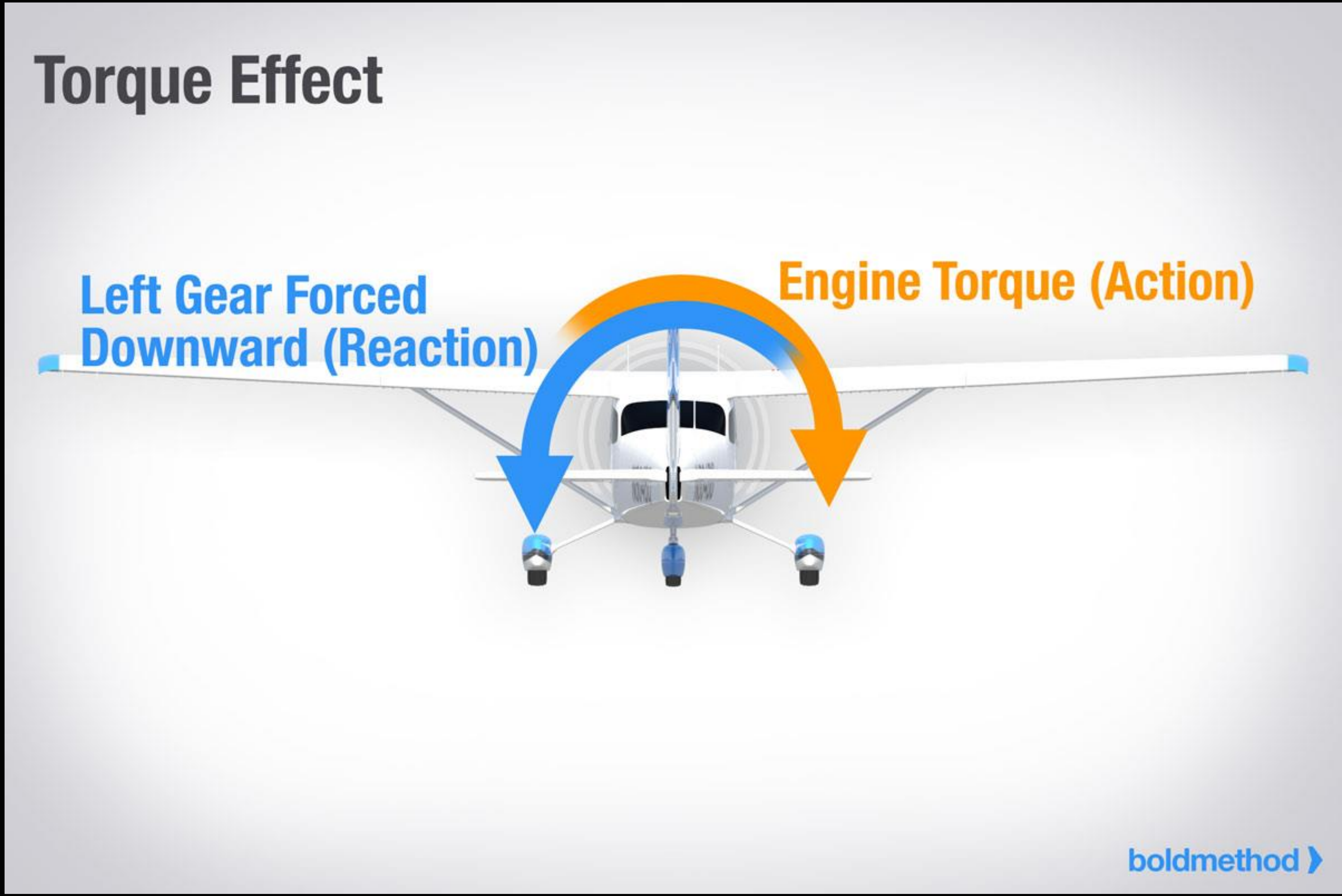
Propeller Limitations

- Torque
- Asymmetric loading (P-Factor)
- Gyroscopic Precession
- Spiraling Slipstream

Propeller Limitations - Torque

- Torque reaction involves Newton's Third Law of Physics—for every action, there is an equal and opposite reaction.
- Engine parts and propeller are revolving in one direction, an equal force is trying to rotate the aircraft in the opposite direction.
- This creates a left turning tendency
- Force is linked to power output. Greater at higher power settings. Lower at lower power settings.

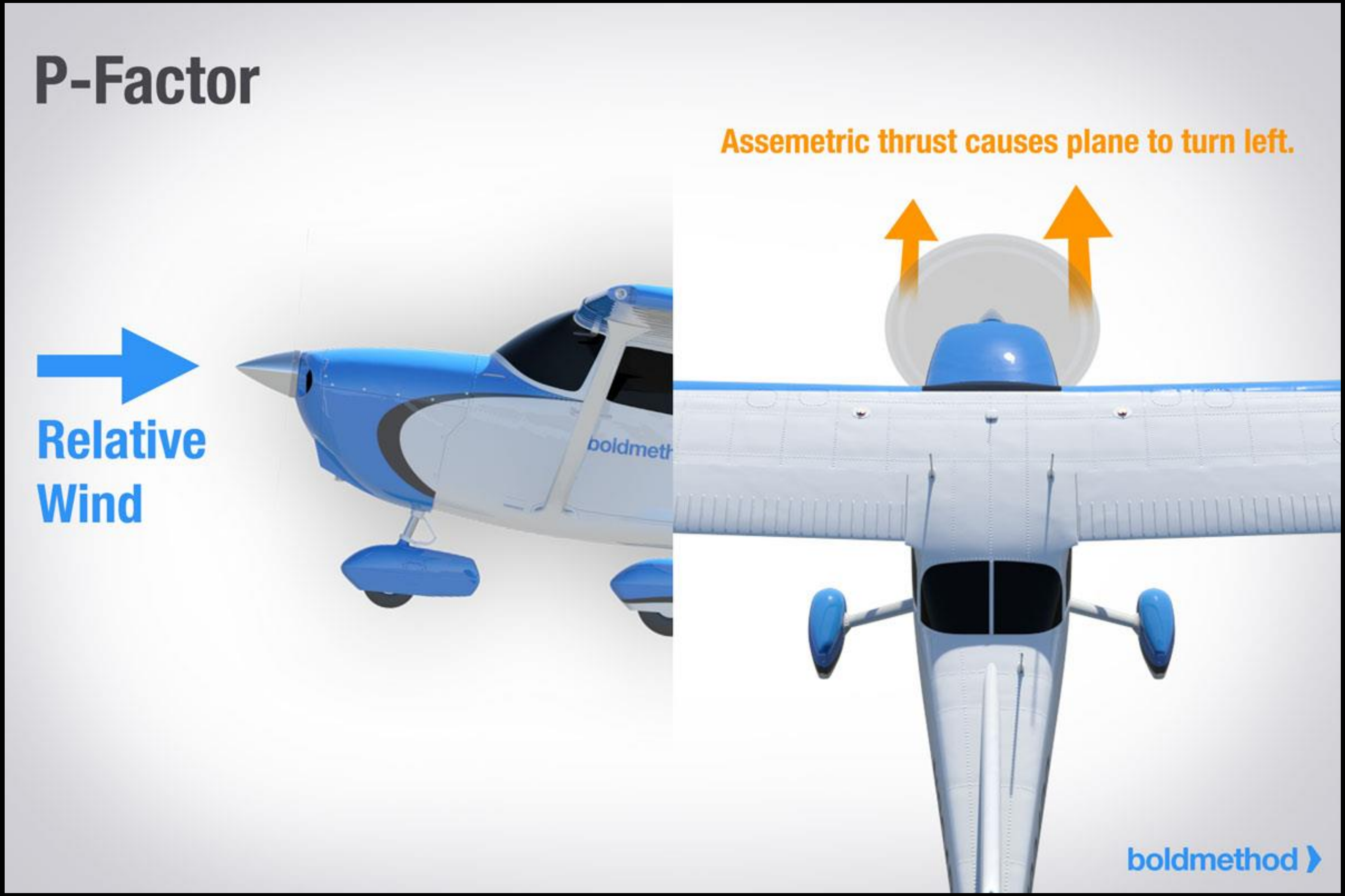
Propeller Limitations - Torque



Propeller Limitations – P-Factor

- When an aircraft is flying with a high AOA, the "bite" of the downward moving blade is greater than the "bite" of the upward moving blade.
- This moves the center of thrust to the right of the prop disc area, causing a yawing moment toward the left around the vertical axis.
- This creates a left-turning tendency

Propeller Limitations – P-Factor



Propeller Limitations - Gyroscopic Precession

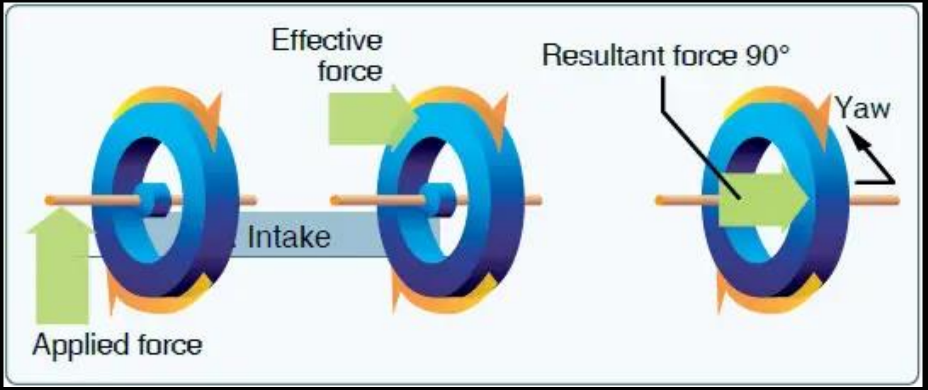
- Before the gyroscopic effects of the propeller can be understood, it is necessary to understand the basic principle of a gyroscope.

Rigidity in Space

- Tendency for a rotating gyroscope to remain in a fixed position around its axis of rotation.

Precession

- Precession is the resultant action, or deflection, of a spinning rotor when a deflecting force is applied to its rim.
- Force is felt 90° ahead in the direction of rotation



Propeller Limitations - Gyroscopic Precession

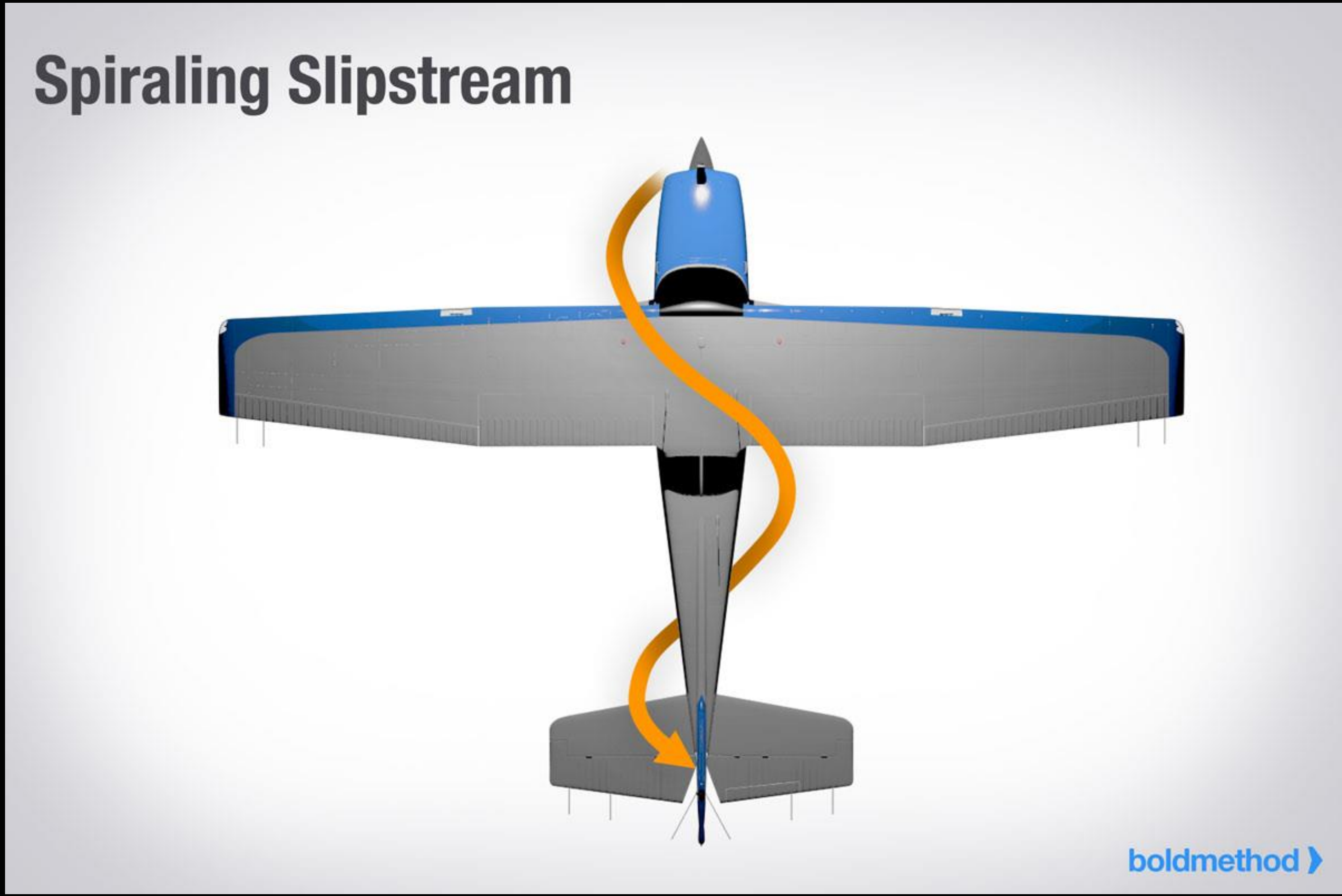
Propeller Limitations - Gyroscopic Precession

- Raising the nose can be thought of as applying a force to the bottom of the propeller.
  - This causes a left turning force
- Lowering the nose can be thought of a applying a force to the top of the propeller.
  - This causes a right turning force.
- Conventional gear V. Traditional Gear
- Climb V. Descent

Propeller Limitations – Spiraling Slipstream

- The high-speed rotation of an aircraft propeller gives a corkscrew or spiraling rotation to the slipstream.
- At high propeller speeds and low forward speed (as in the takeoffs and approaches to power-on stalls), this spiraling rotation is very compact and exerts a strong sideward force on the aircraft's vertical tail surface.
- This force against the tail causes a yawing moment to the left.

Propeller Limitations – Spiraling Slipstream



Propeller Limitations

- Left turning tendencies are most noticeable in these conditions:
  - High power setting
  - High AOA
  - Low airspeed

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

Will an airplane will always stall at the same AOA?

A. True
B. False

Knowledge Check

Will an airplane will always stall at the same AOA?

A. True
B. ~~False~~

Knowledge Check

Which turning tendency can have both left and right forces?

A. Torque
B. P-Factor
C. Spiraling Slipstream
D. Gyroscopic Precession

Knowledge Check

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B. ~~P-Factor~~
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