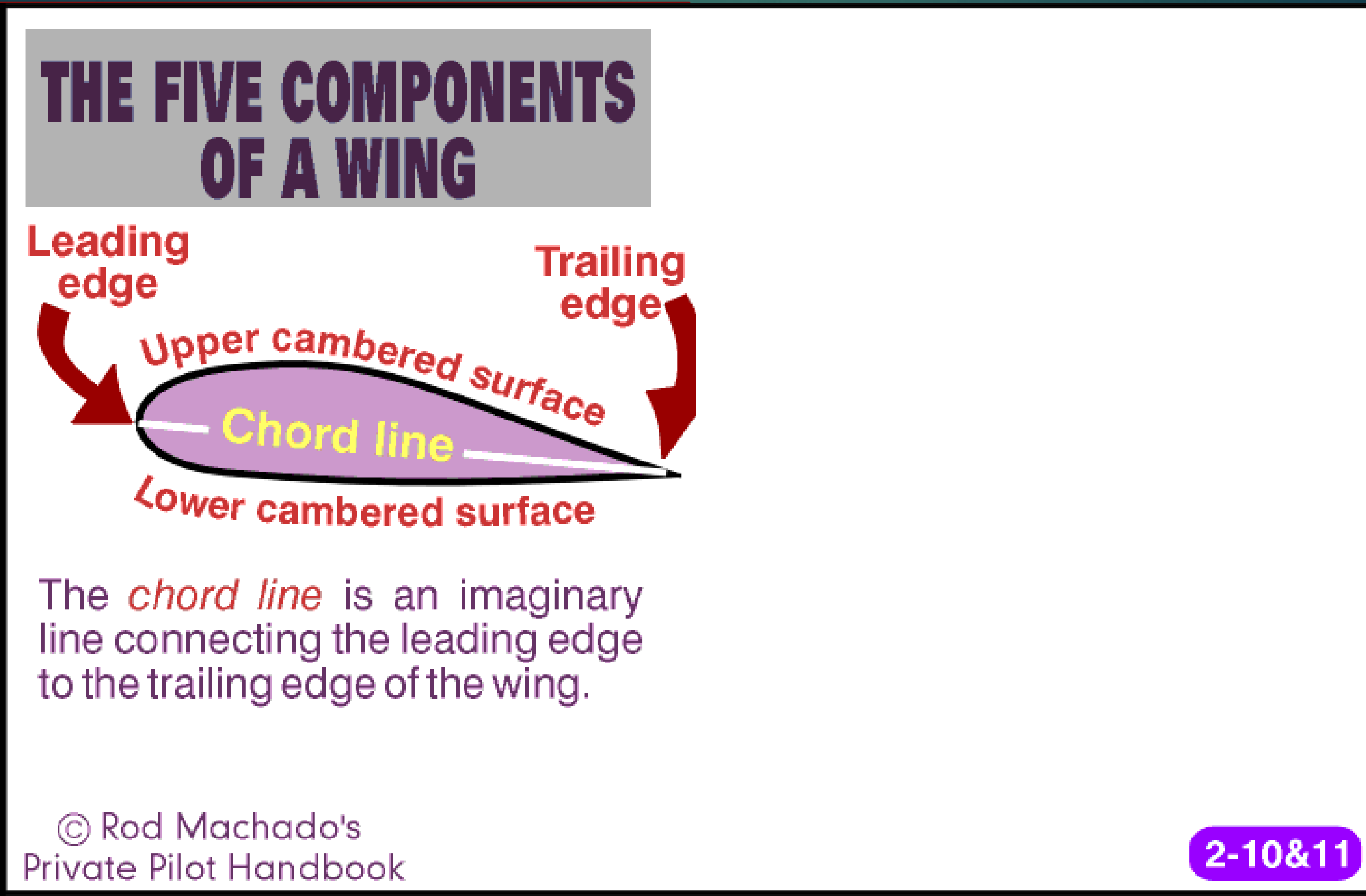
Aerodynamics of Lift

Aerodynamic Terms

Chord Line


THE FIVE COMPONENTS OF A WING
Leading edge
Trailing edge
Upper cambered surface
Chord line
Lower cambered surface
The chord line is an imaginary line connecting the leading edge to the trailing edge of the wing.
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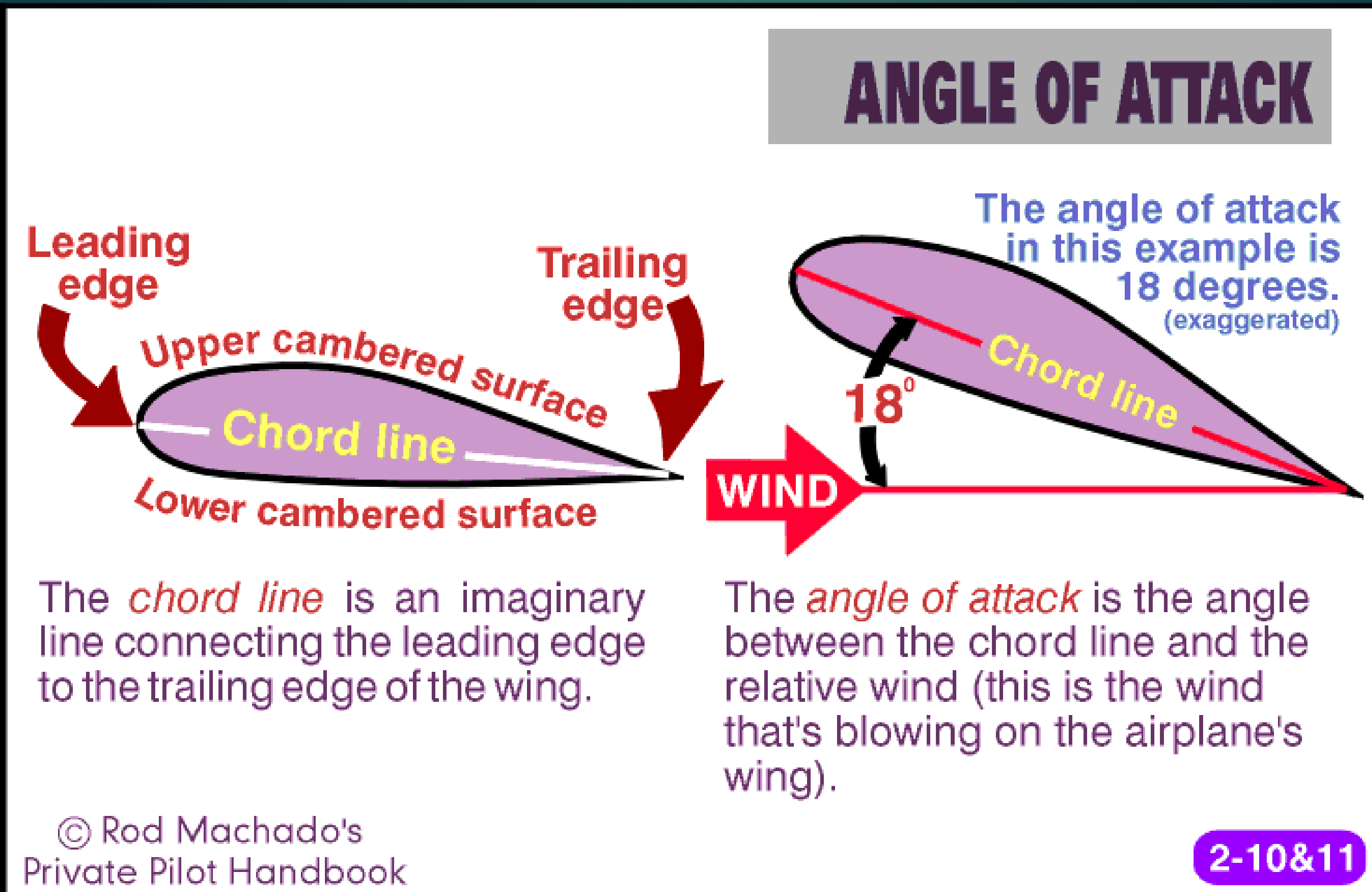
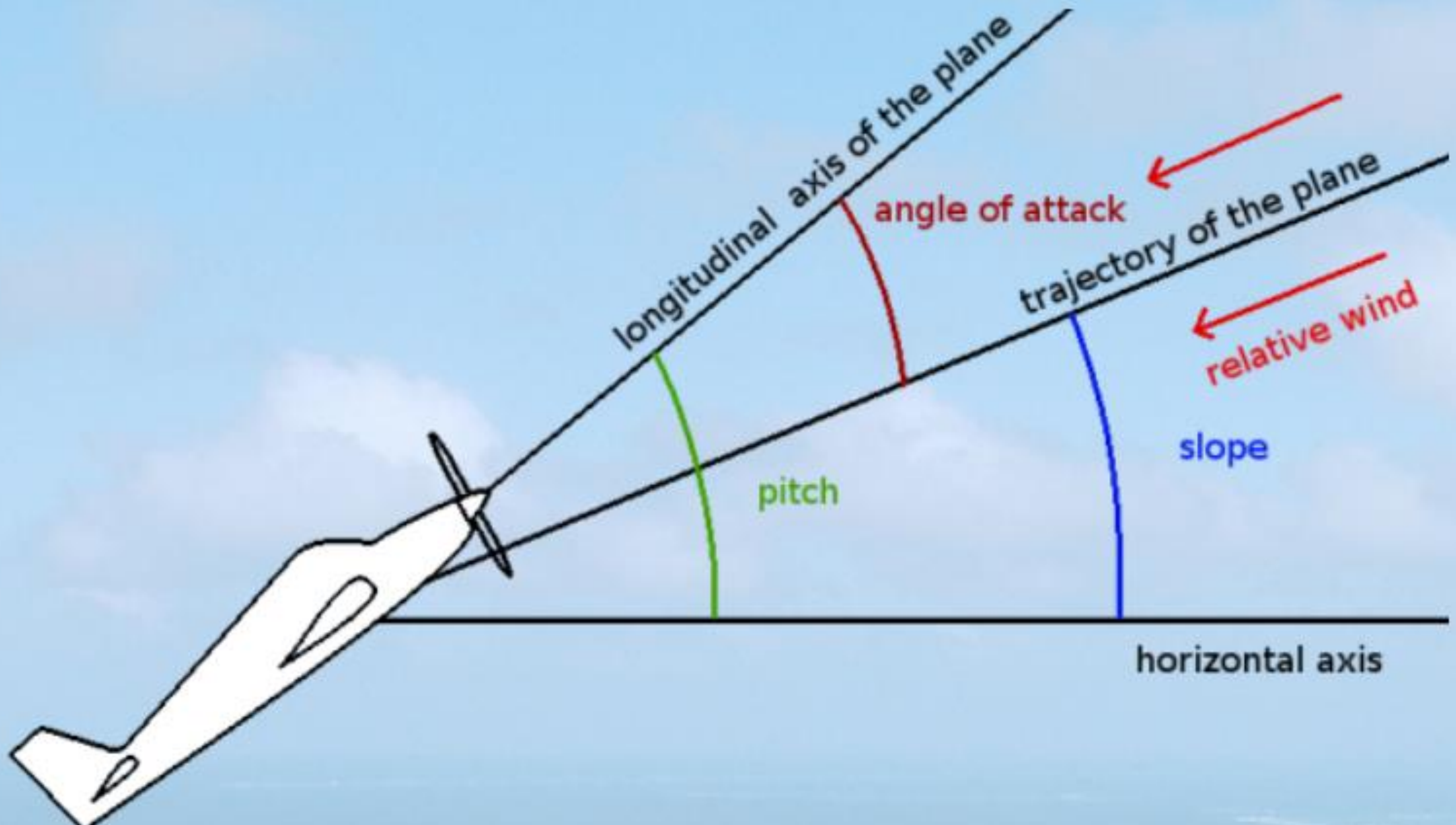
2-10&11

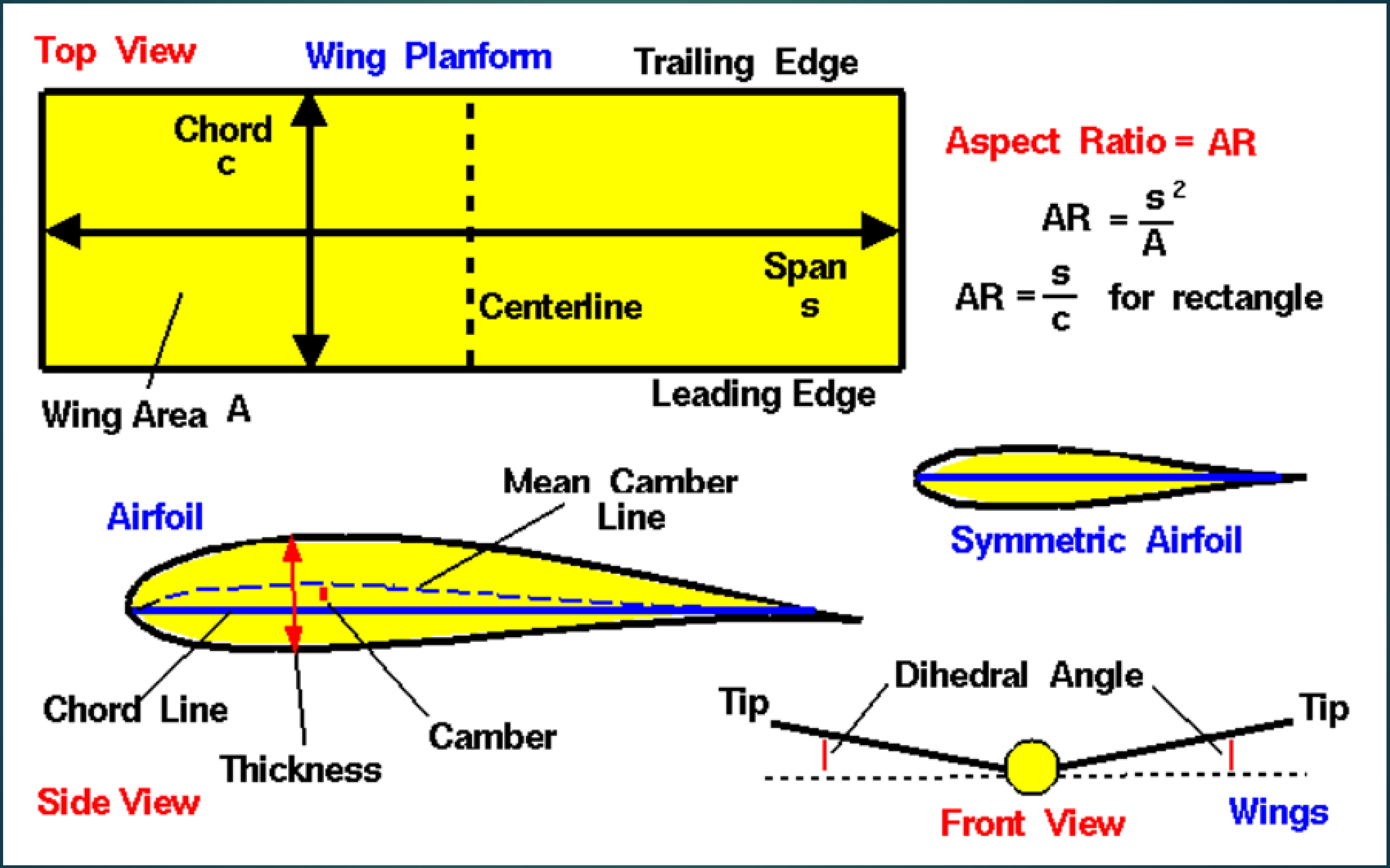
Angle of Attack



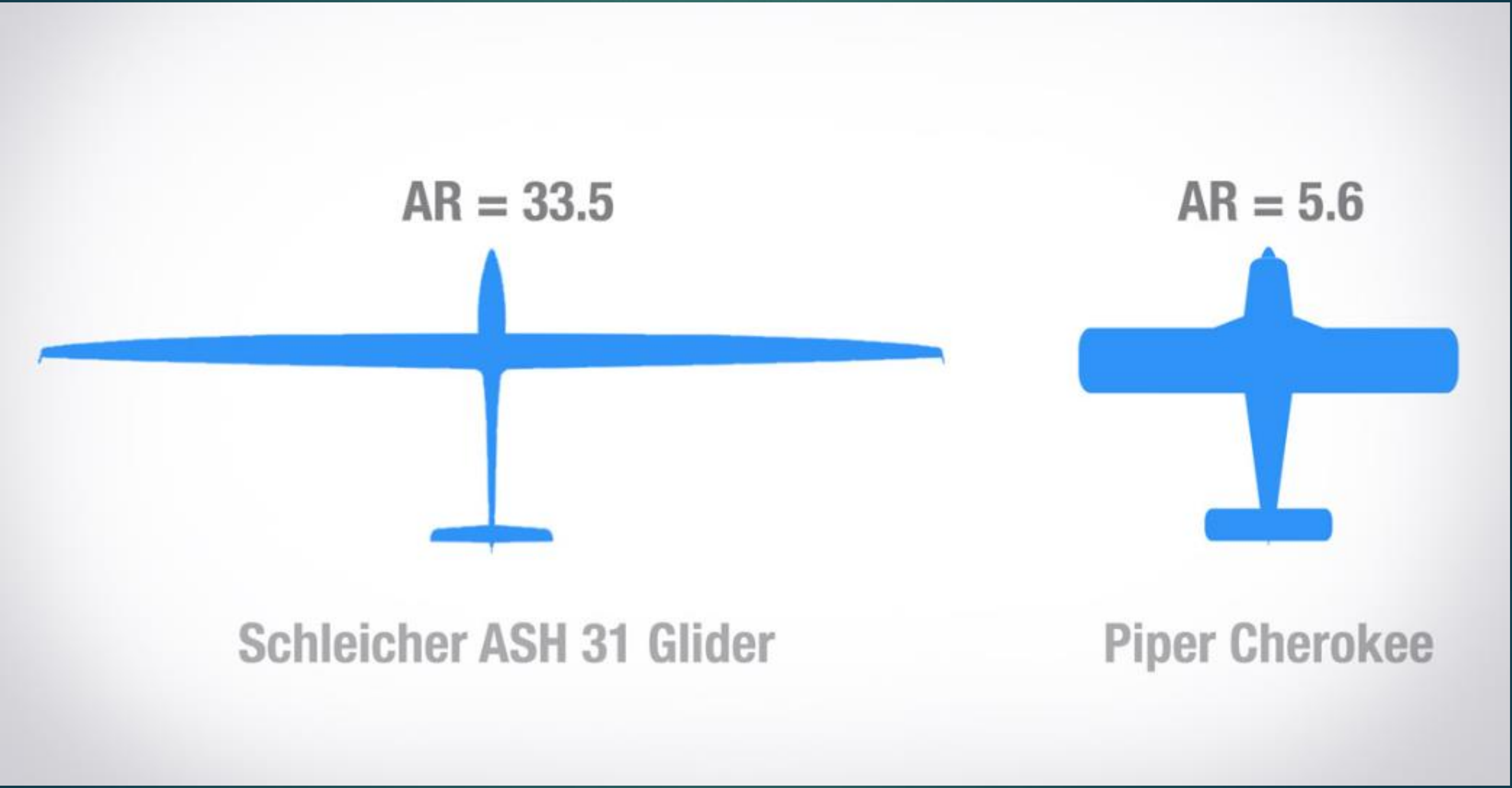
Relative Wind and AOA



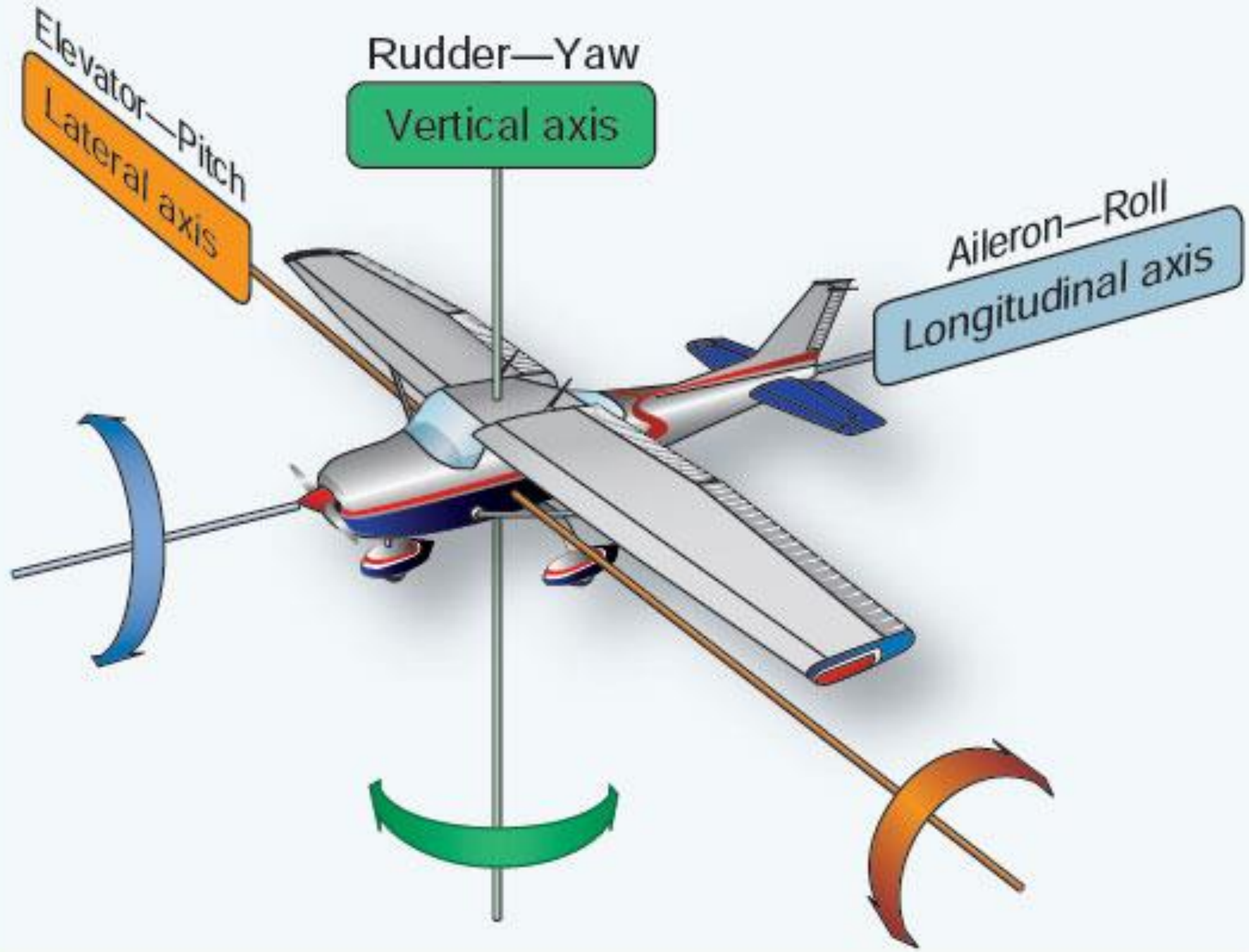
Wing Span and Aspect Ratio



Aspect Ratio



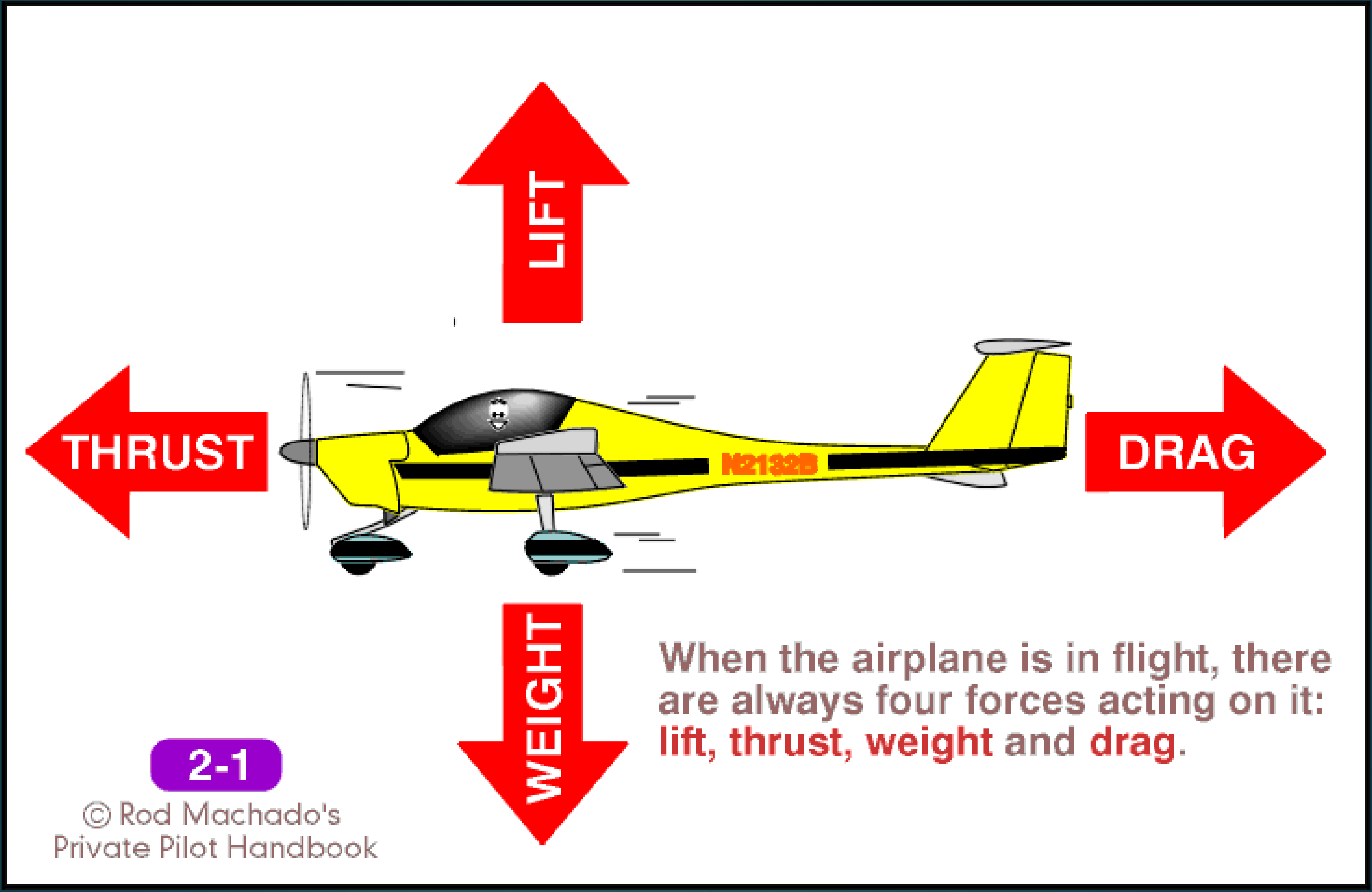
Axes of Rotation



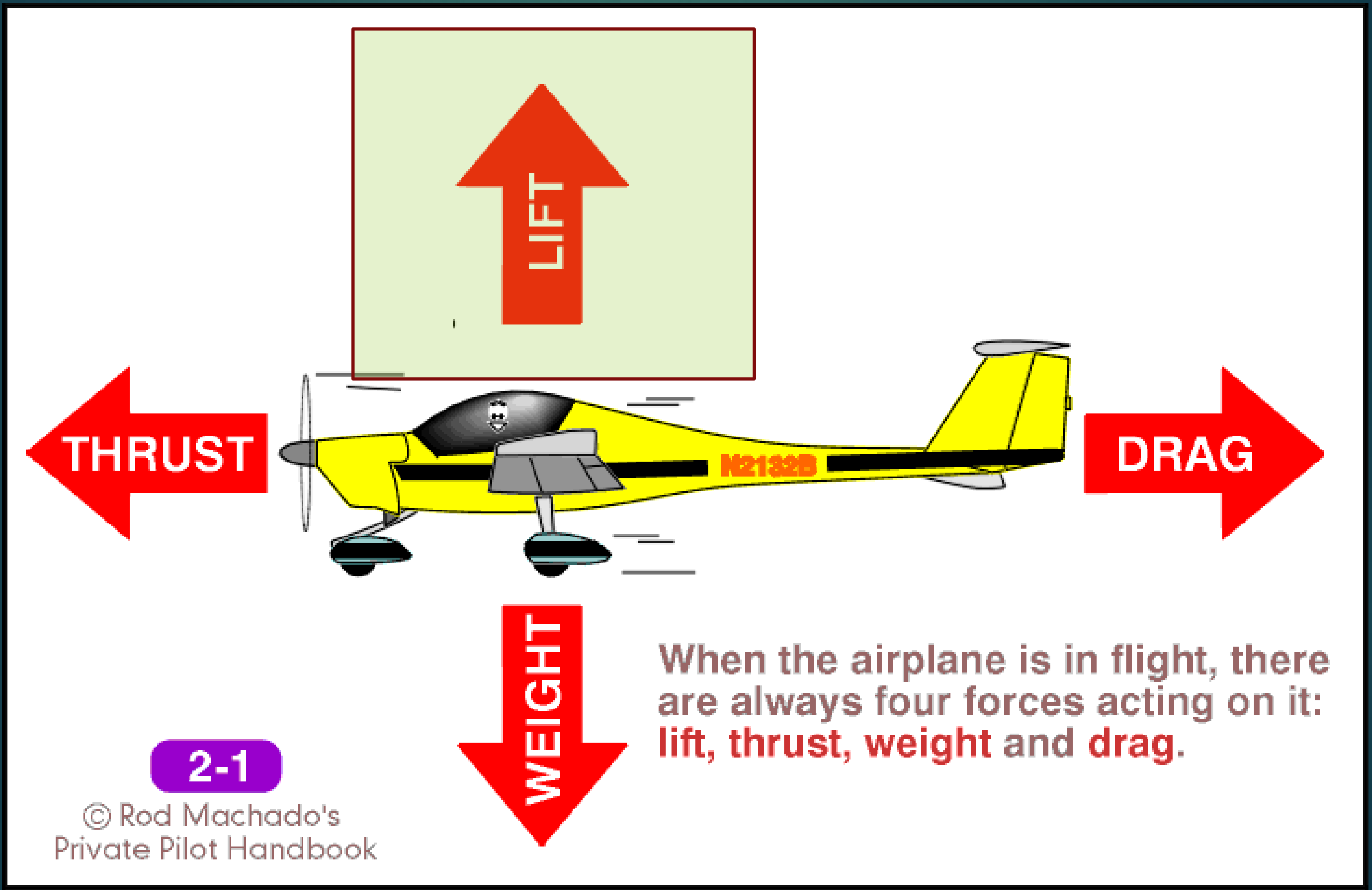
Primary control surface	Airplane movement	Axes of rotation
Aileron	Roll	Longitudinal
Elevator/stabilator	Pitch	Lateral
Rudder	Yaw	Vertical

Four Forces of Flight

The Four Forces



Lift is produced by a pressure difference between the top and bottom of the wing



Lift: Bernoulli's Principle

AIRFLOW ABOVE AND BELOW THE WING

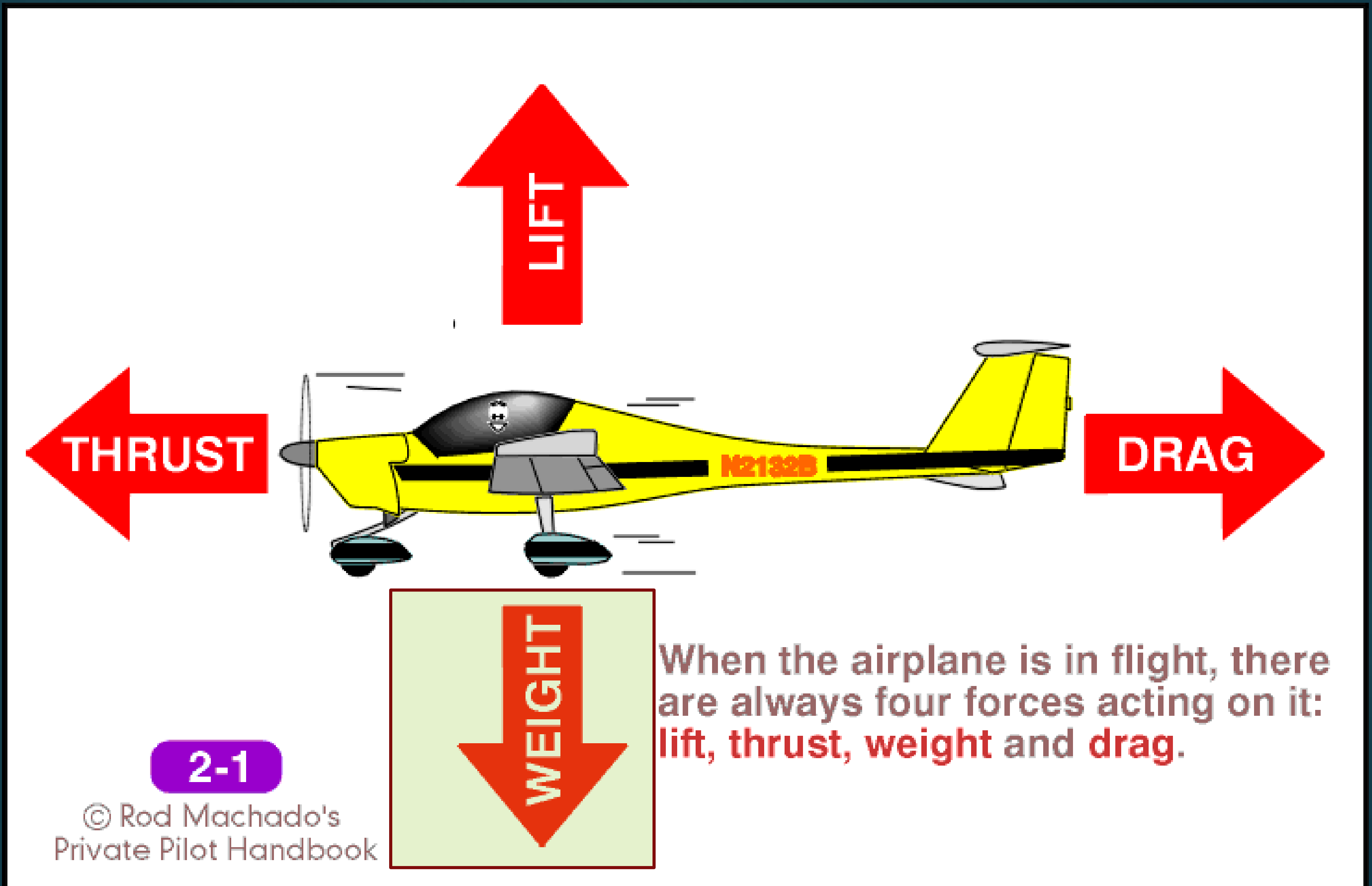
(at a small angle of attack)

At low angles of attack the air above the wing is curved while the air below the wing is relatively straight.

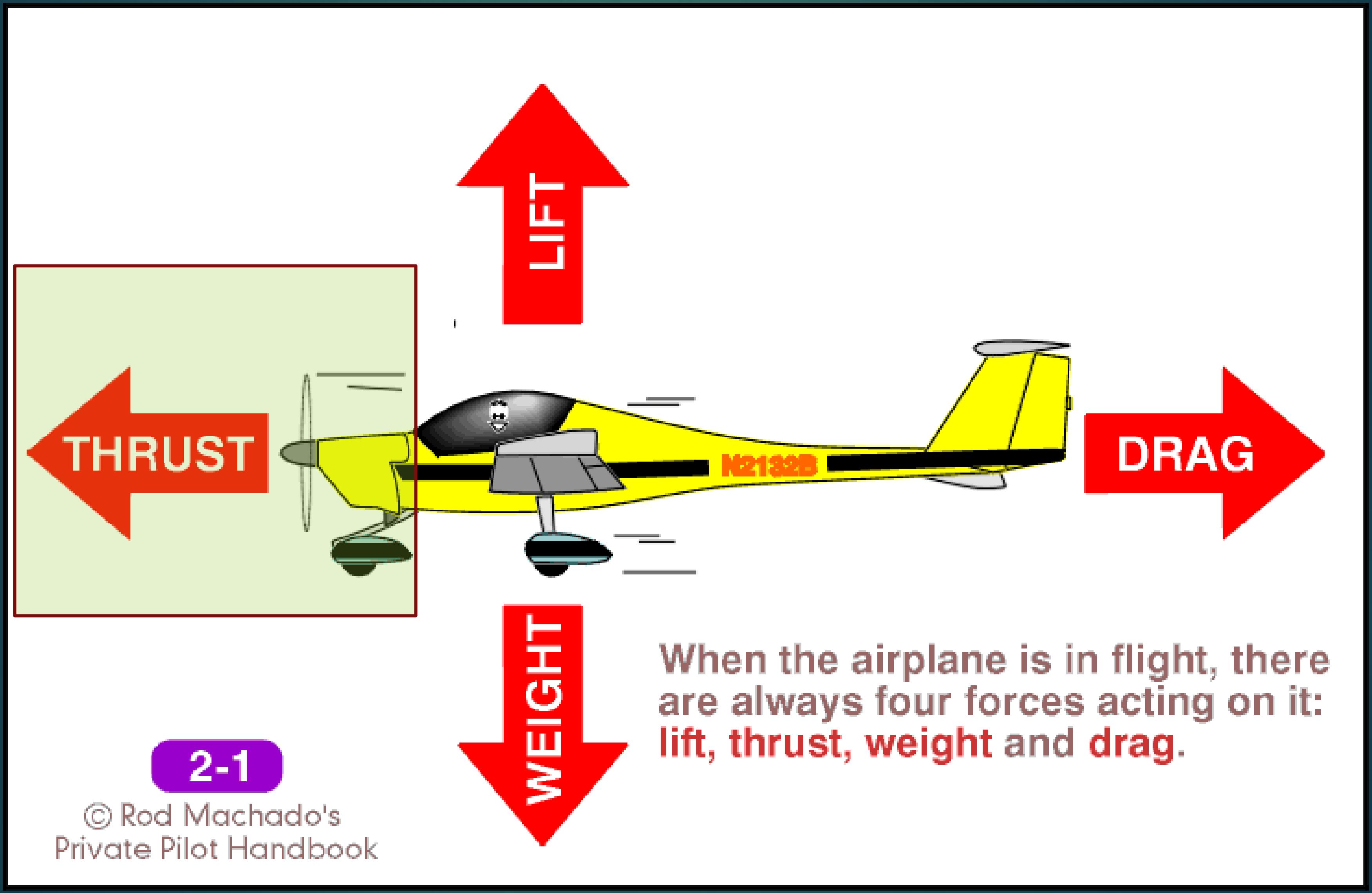
Newton vs. Bernoulli, Again

- Wing camber and angle of attack increase speed of air over top of wing
- Wing surface area also increases the downward Newtonian force
- However, increased area also increases drag
- The only two a pilot can change during flight are
  - Angle of attack
  - Chord line, to a limited extent (by deploying flaps)

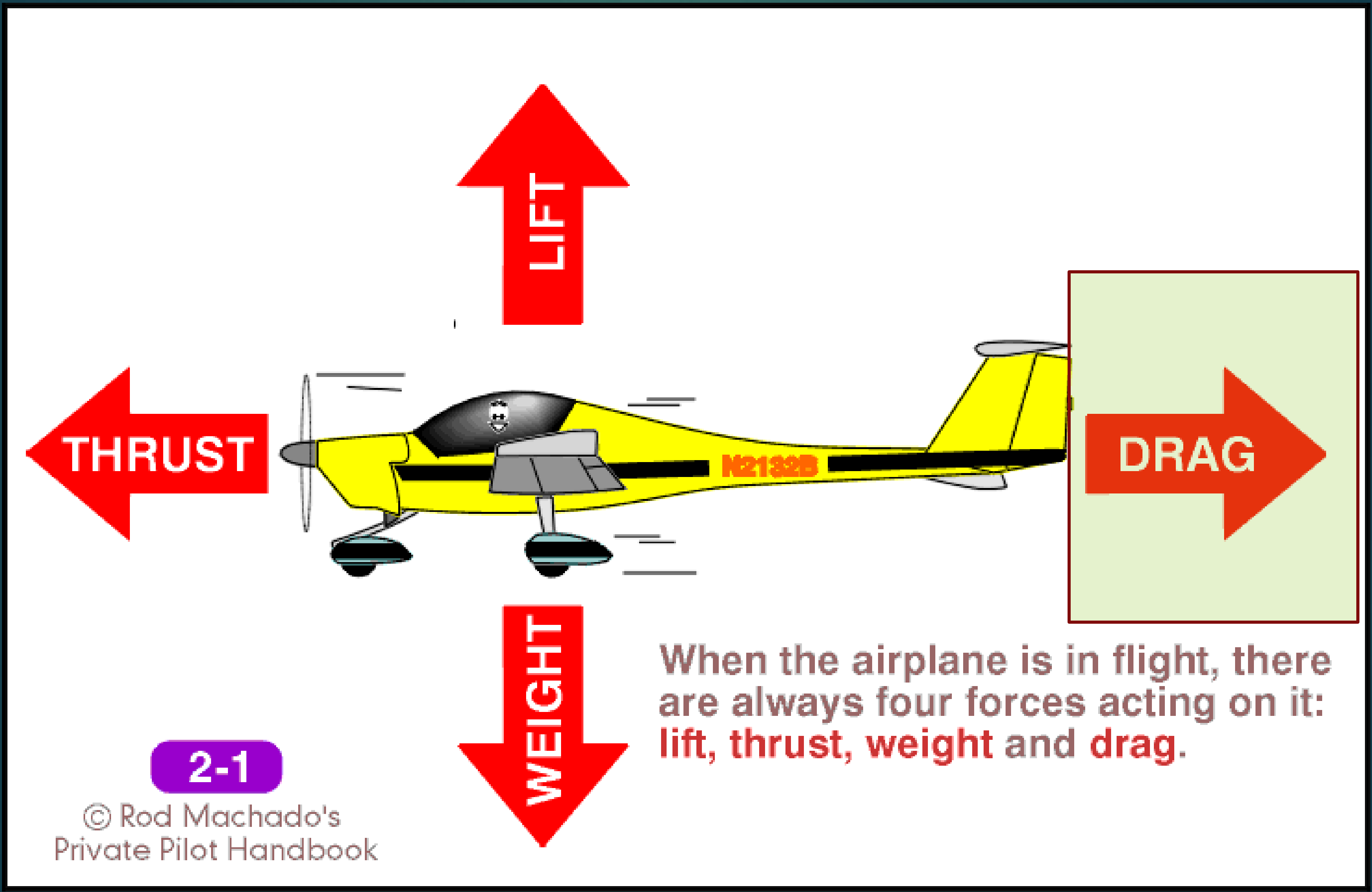
Weight: the force with which gravity attracts all bodies vertically towards the center of the earth



Thrust: forward force produced by the propeller (airfoil displaces air)

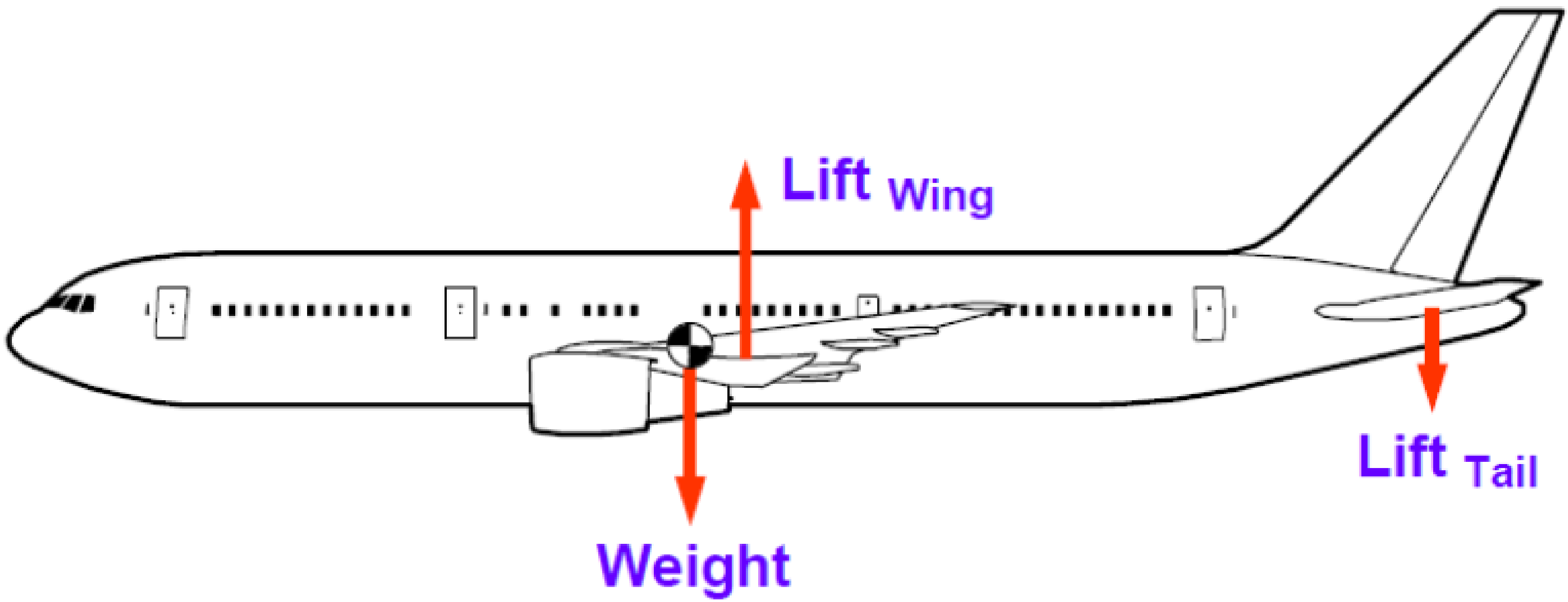


Drag resists the forward movement of an aircraft through the air



In straight and level flight, lift = weight

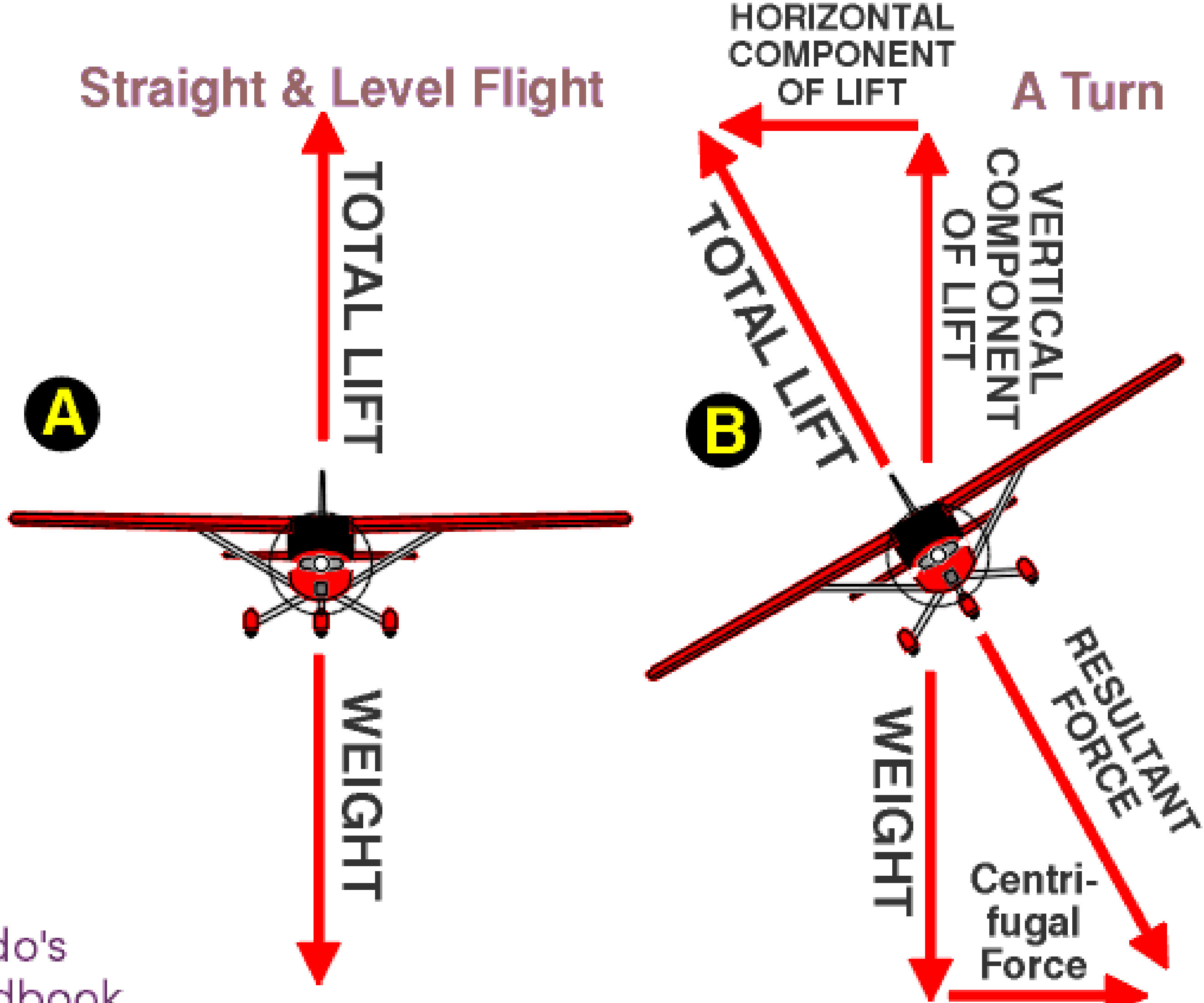
Total lift = uplift on wing + downlift on tail



Turns, Loads, and Load Factors

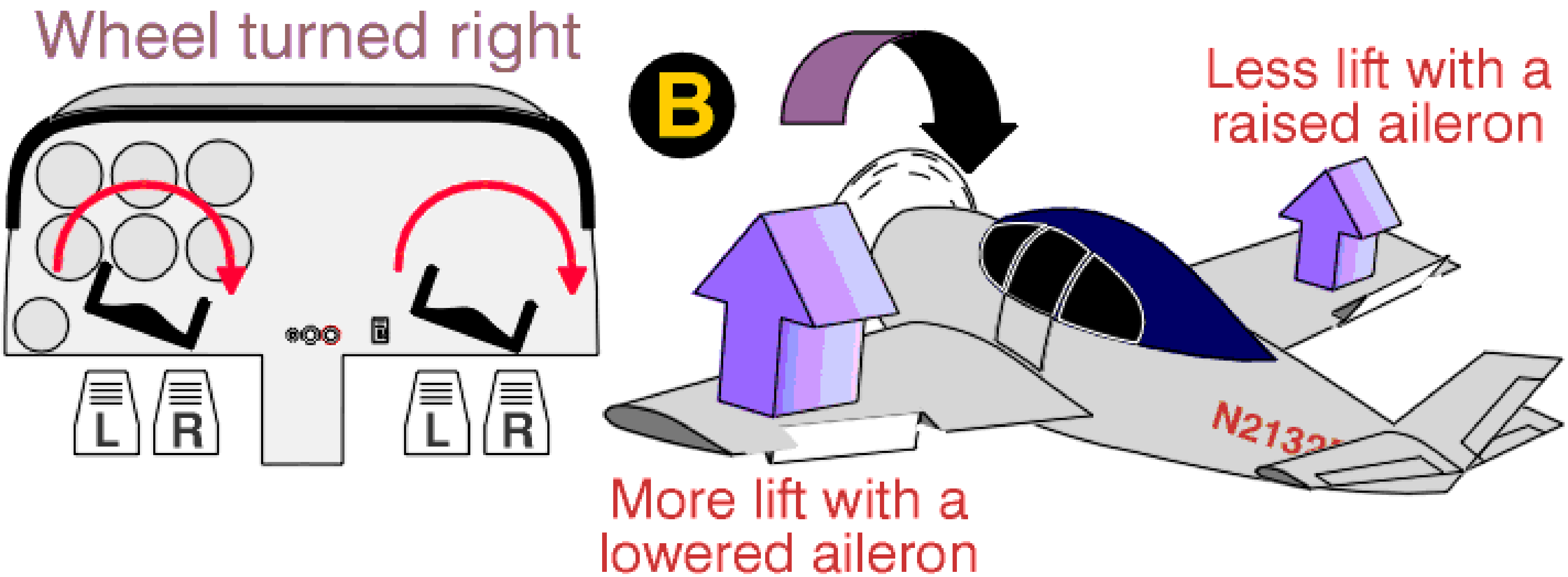
HOW AN AIRPLANE TURNS

Banking the airplane causes the lift force to tilt, which pulls the airplane in the direction of bank. Technically, it's the horizontal component of the tilted lift force that makes the airplane turn.

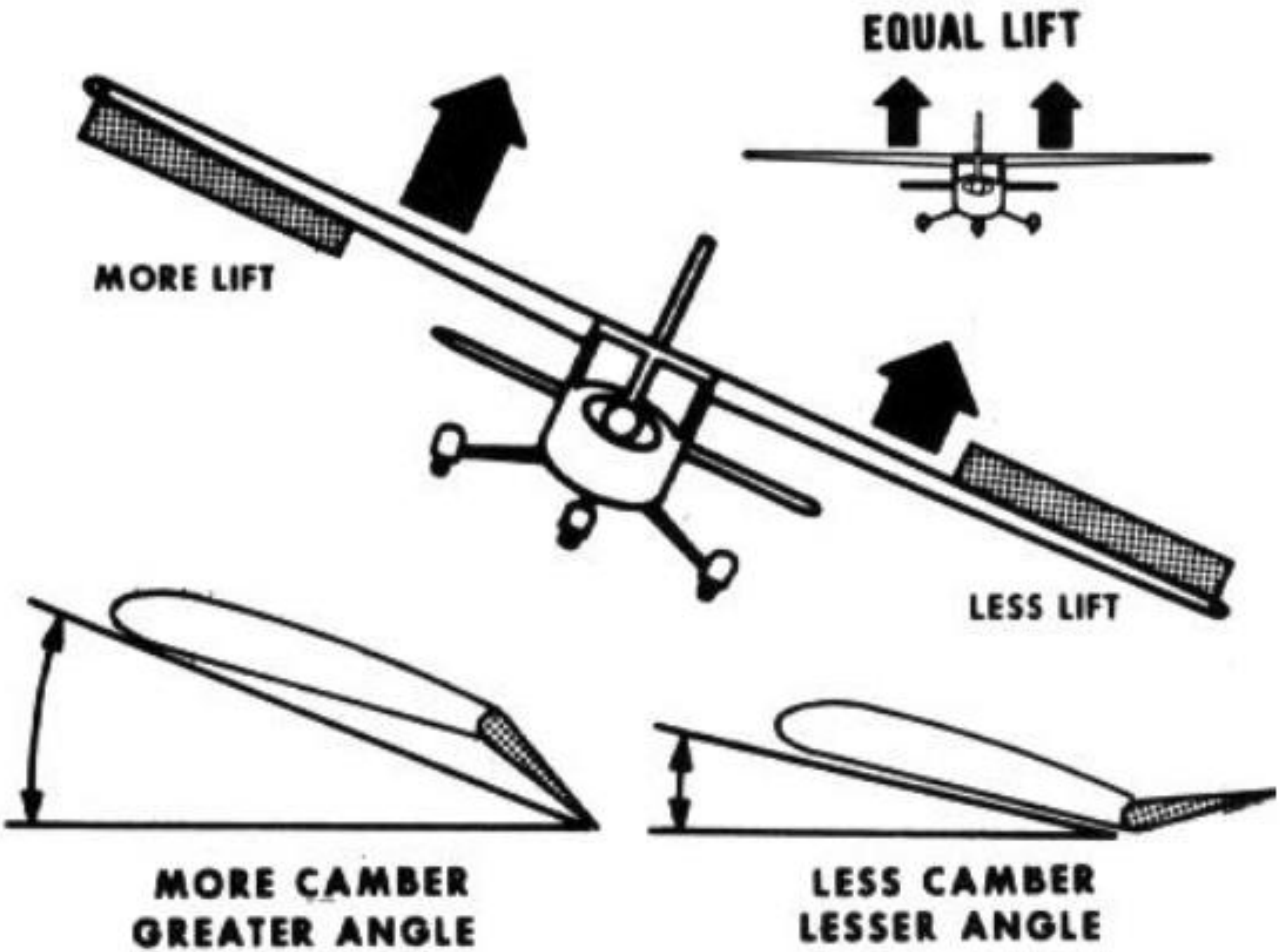


HOW AILERONS BANK THE AIRPLANE

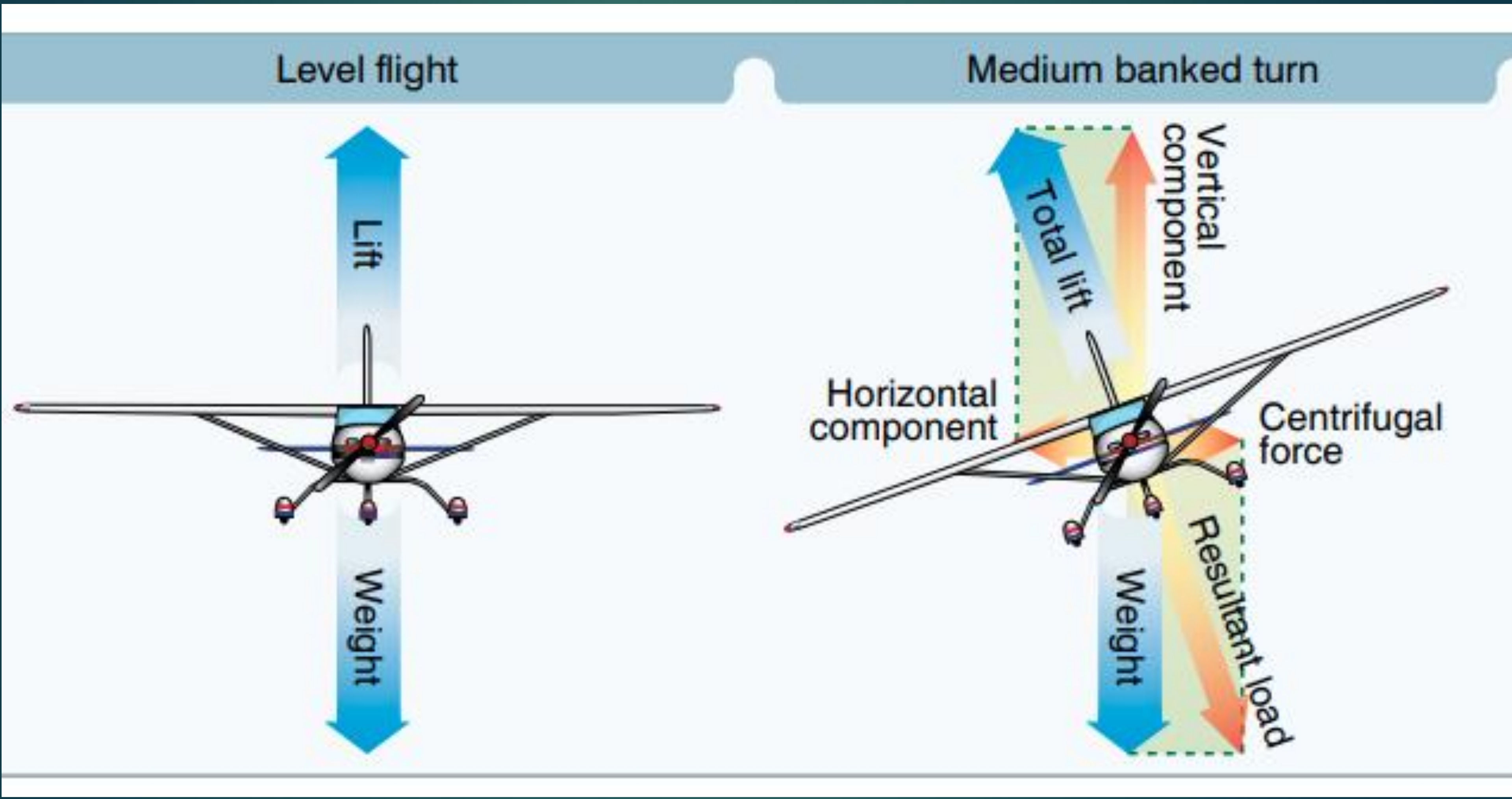
Banking to the Right



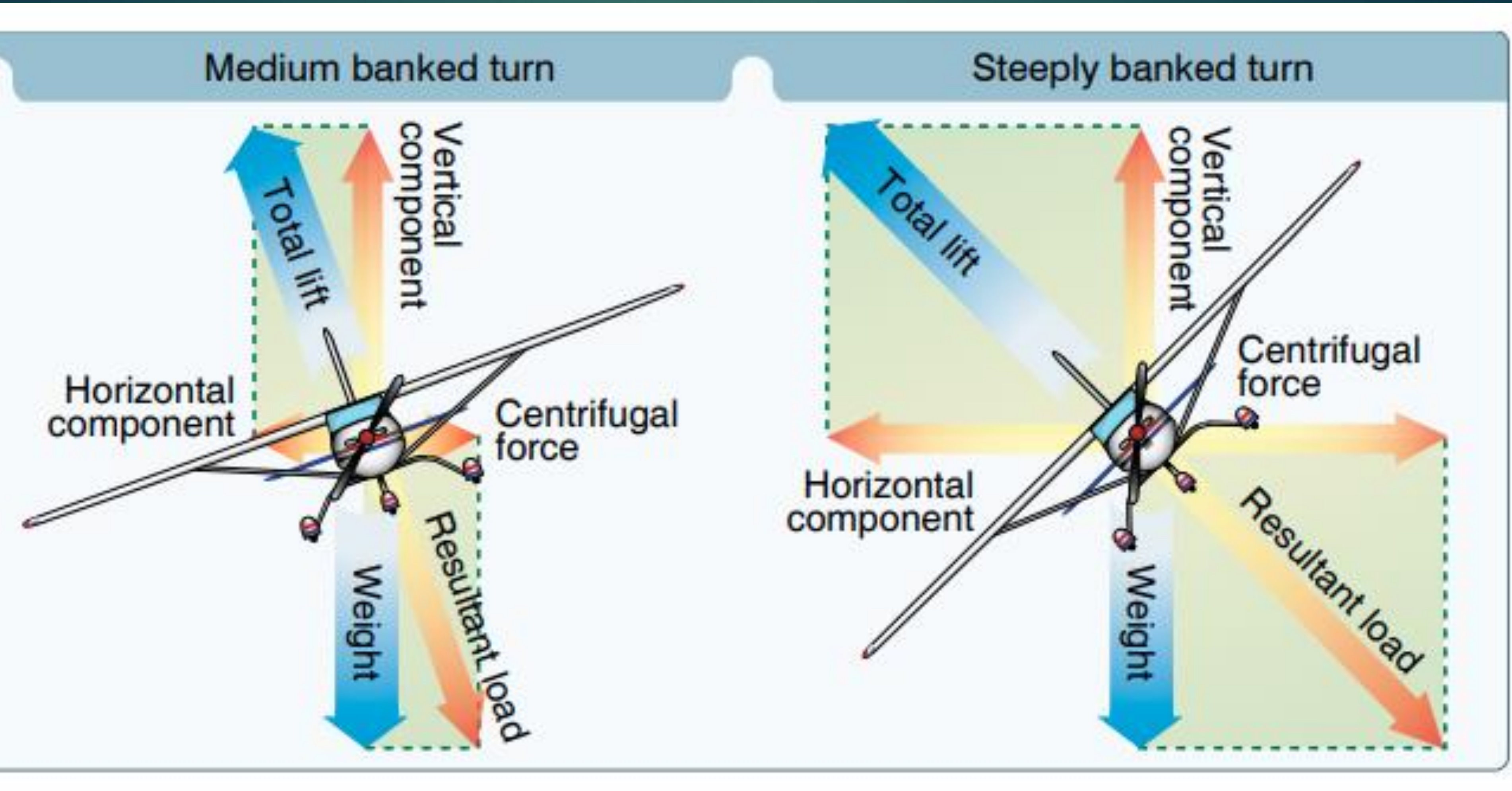
2-49B


EQUAL LIFT
MORE LIFT
LESS LIFT
MORE CAMBER
GREATER ANGLE
LESS CAMBER
LESSER ANGLE

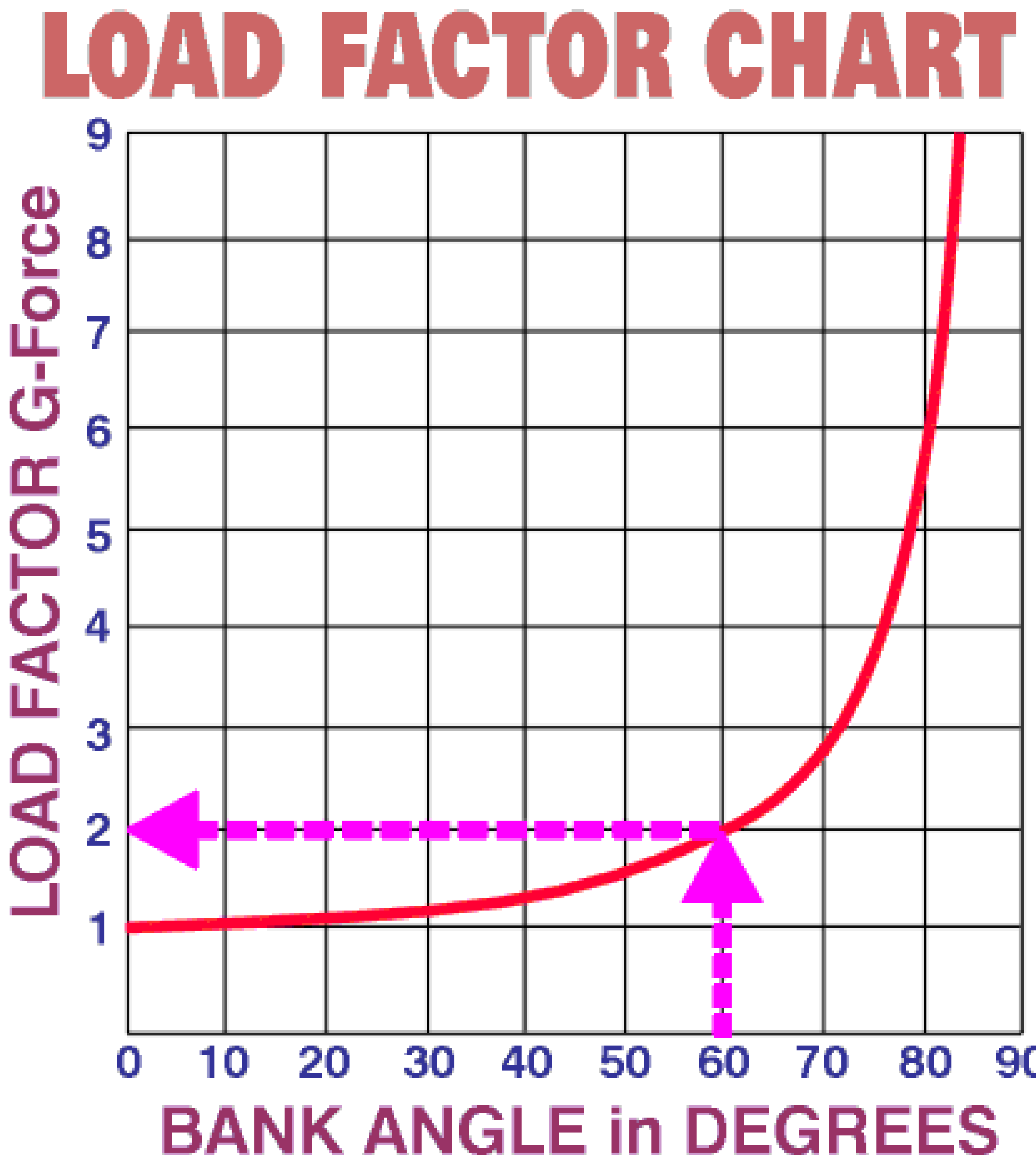
Load Factors in Flight



Load Factors in Flight



A 60° Bank Produces a Load Factor Of "2" or "2Gs."

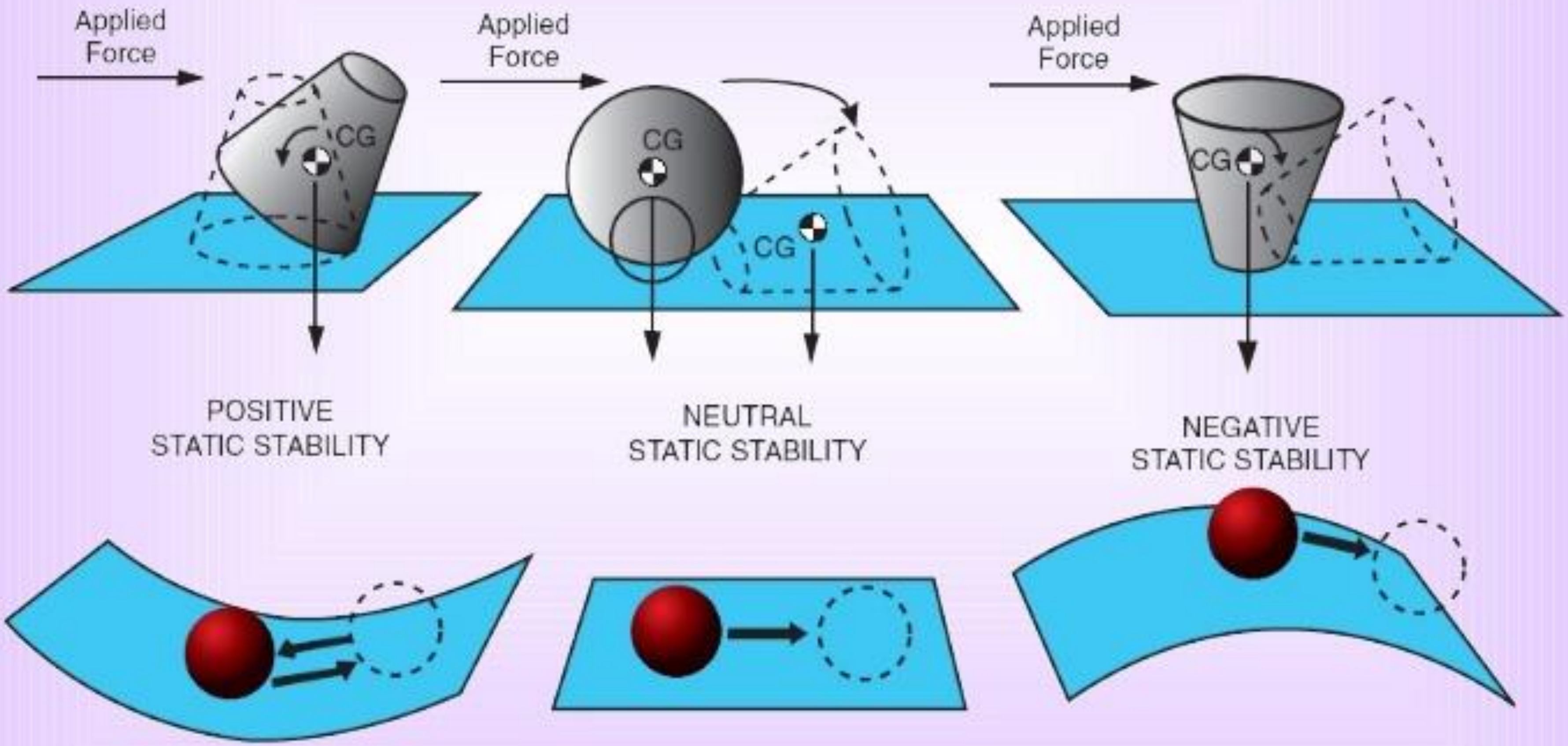


2-30

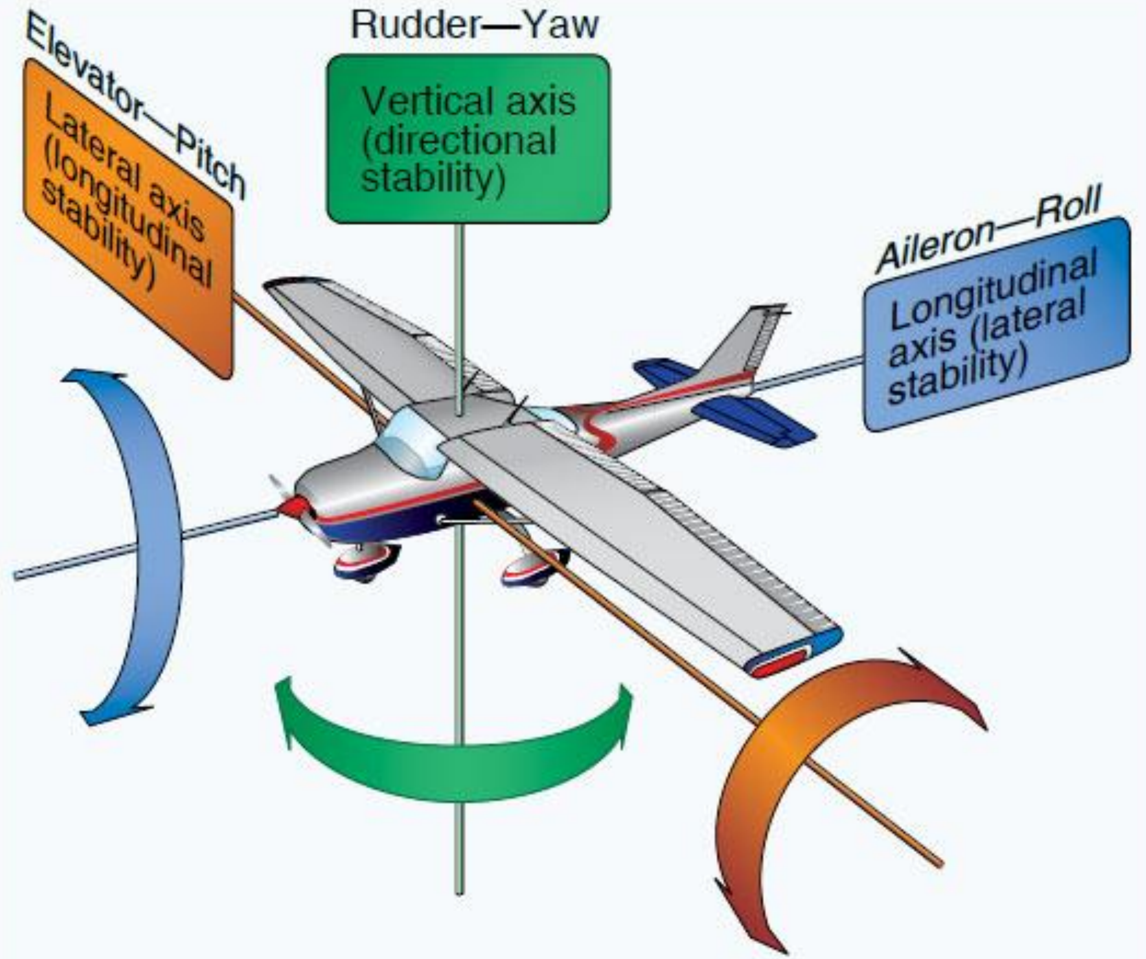
Stability

Static Stability

Positive-Neutral-Negative



Axes of Stability



Primary Control Surface	Airplane Movement	Axes of Rotation	Type of Stability
Aileron	Roll	Longitudinal	Lateral
Elevator/ Stabilator	Pitch	Lateral	Longitudinal
Rudder	Yaw	Vertical	Directional

Uncoordinated Flight

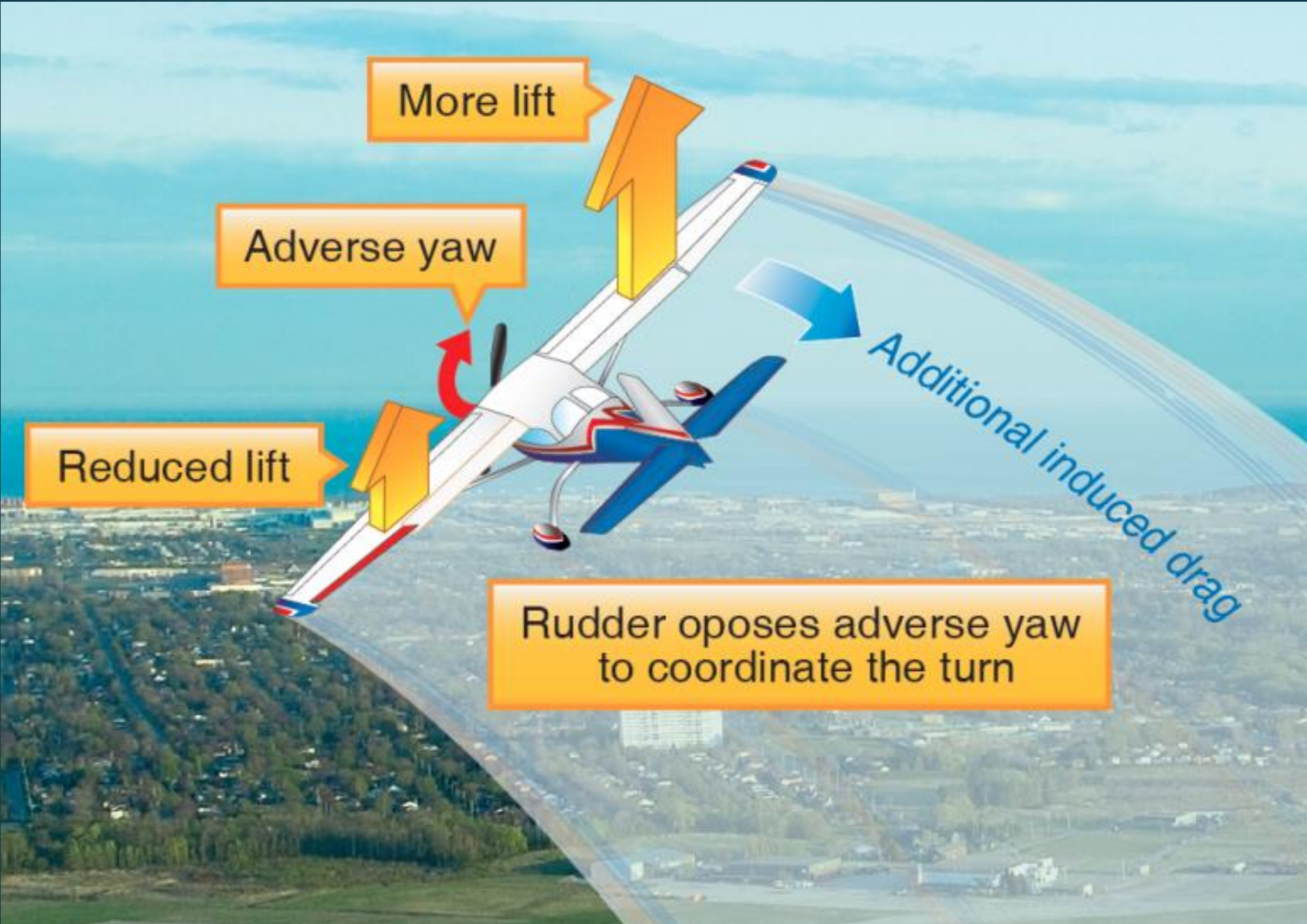
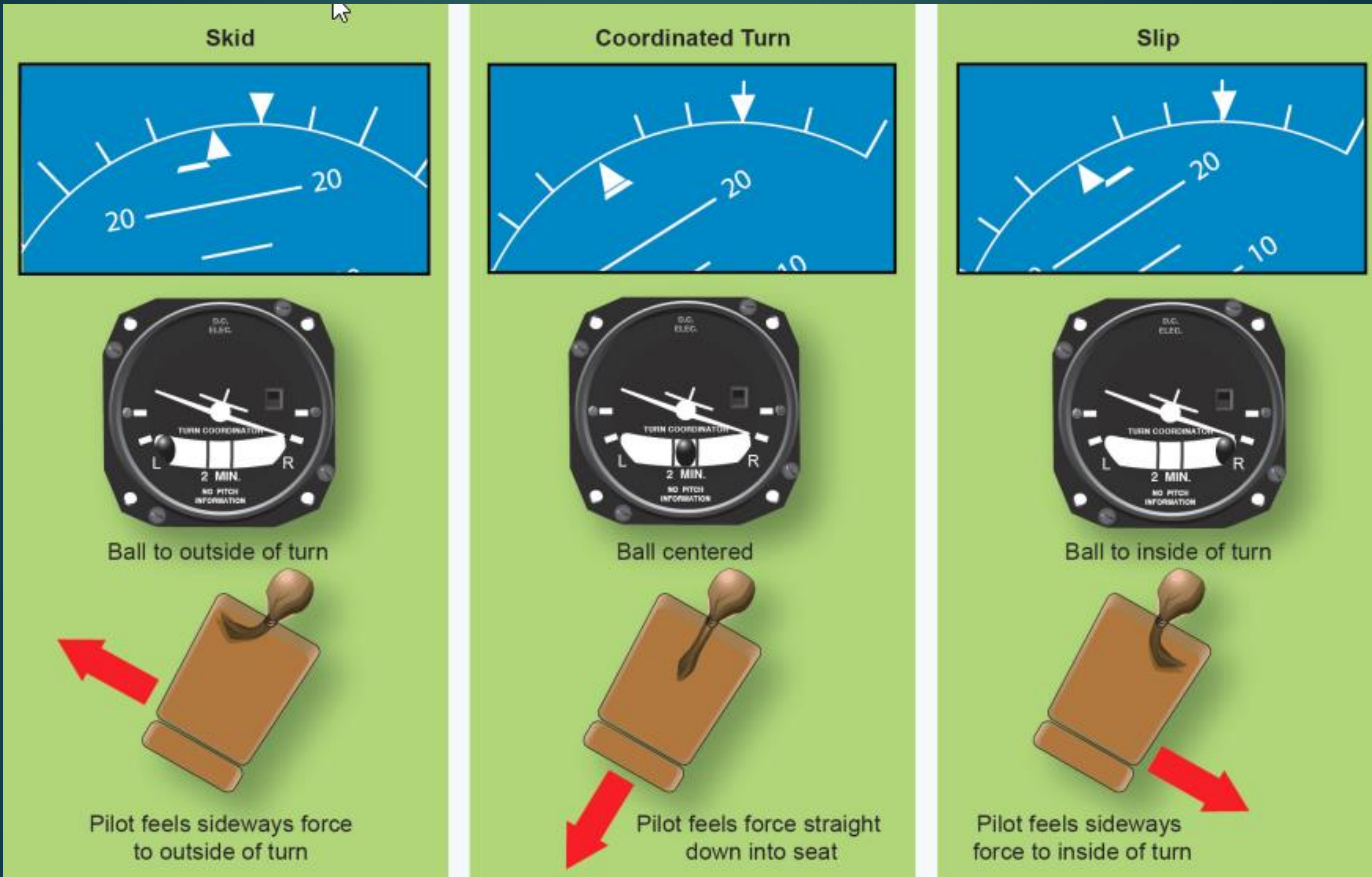
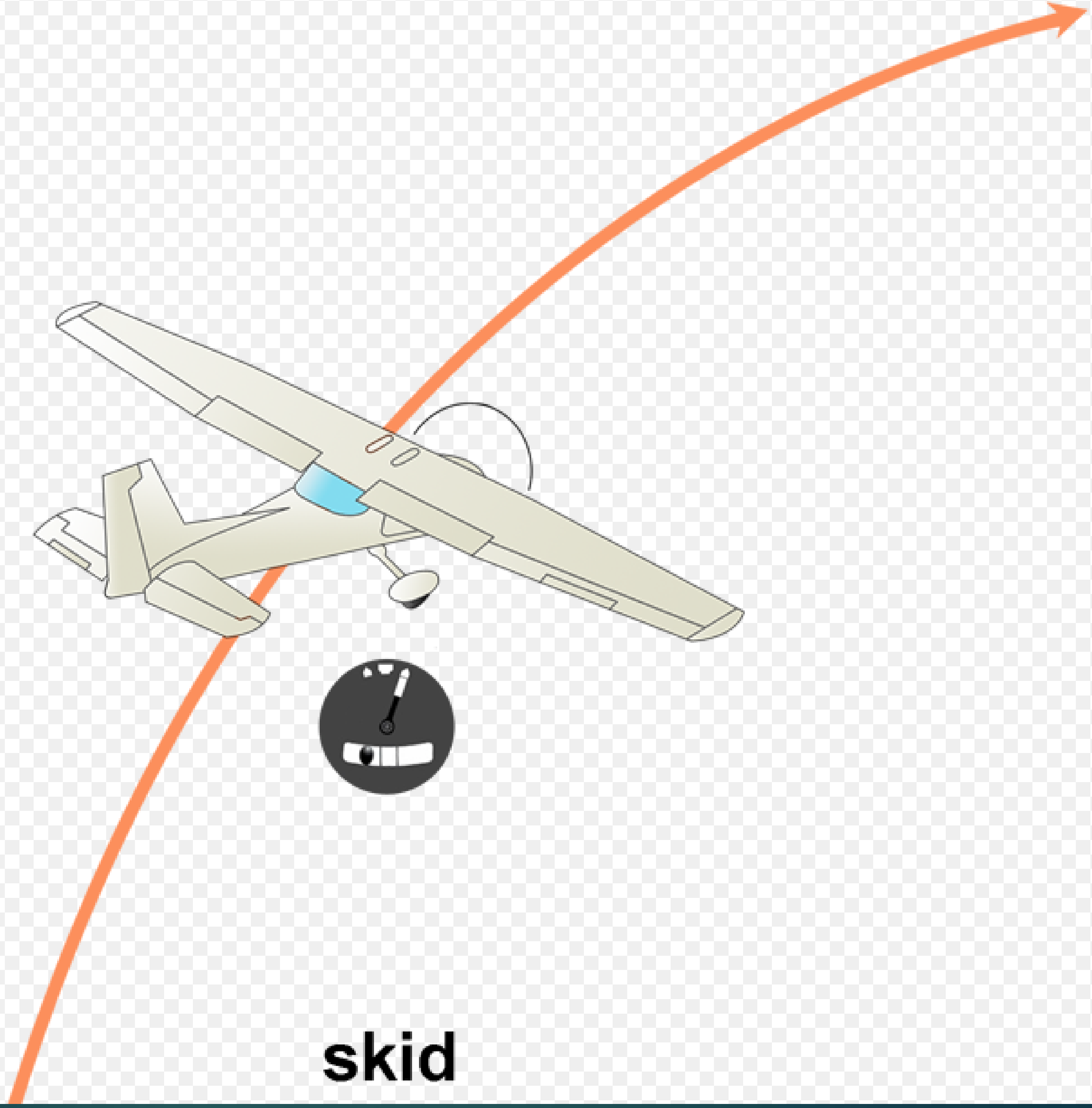

More lift
Adverse yaw
Reduced lift
Additional induced drag
Rudder oposes adverse yaw to coordinate the turn

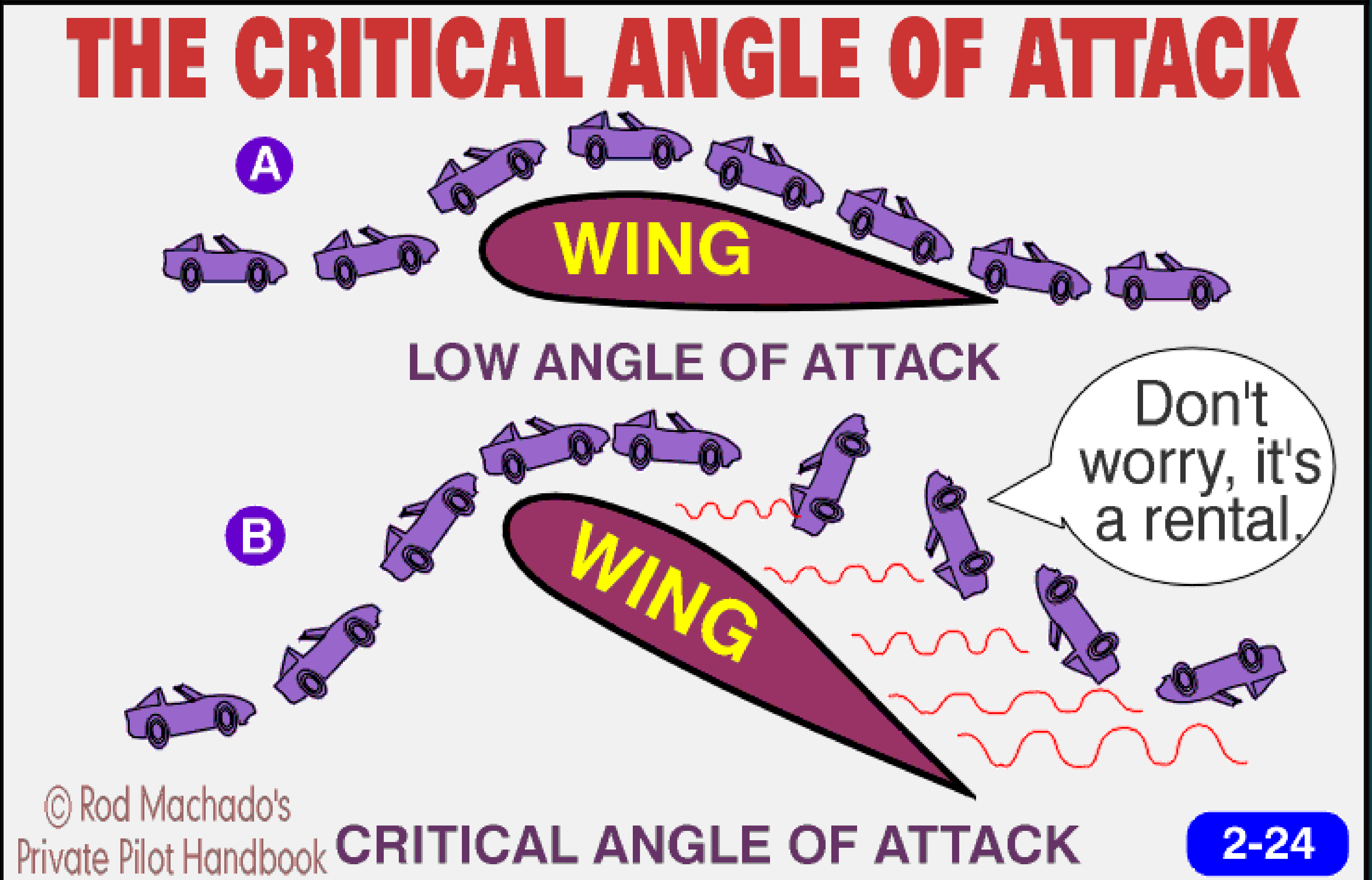
Figure 1: Turn Coordinator


Skid
20
20
Ball to outside of turn
Pilot feels sideways force to outside of turn
Coordinated Turn
20
Ball centered
Pilot feels force straight down into seat
Slip
20
10
Ball to inside of turn
Pilot feels sideways force to inside of turn
TURN COORDINATOR
L
R
2 MIN.
NO PITCH INFORMATION
D.C. ELEC.



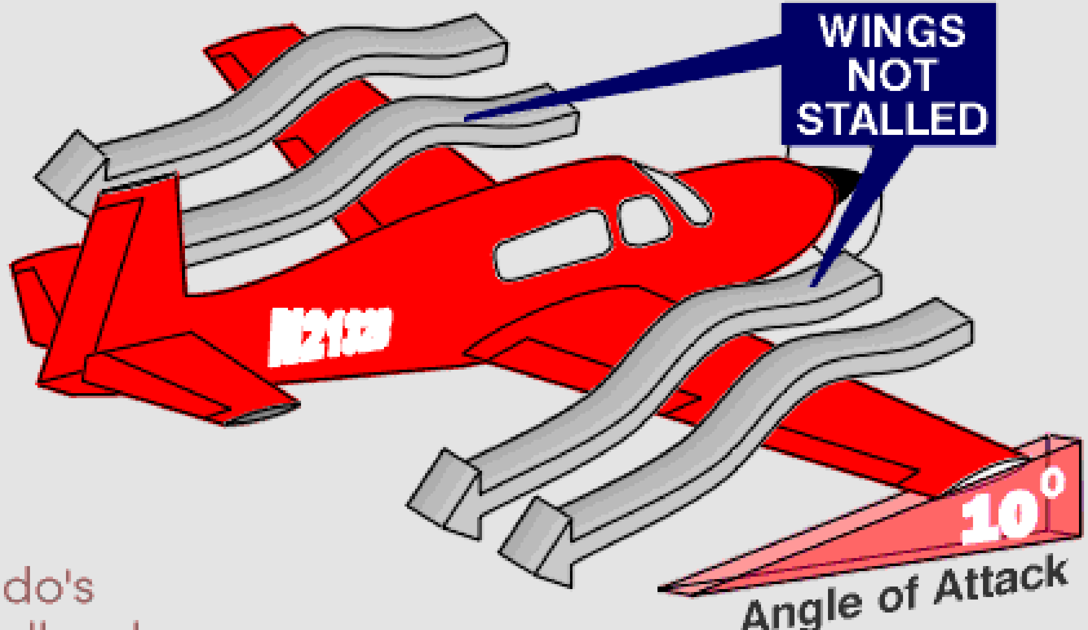
skid

Stalls
And
Spins


THE CRITICAL ANGLE OF ATTACK
A
WING
LOW ANGLE OF ATTACK
B
WING
Don't worry, it's a rental.
© Rod Machado's Private Pilot Handbook
CRITICAL ANGLE OF ATTACK
2-24

STALLED VS. UNSTALLED WINGS

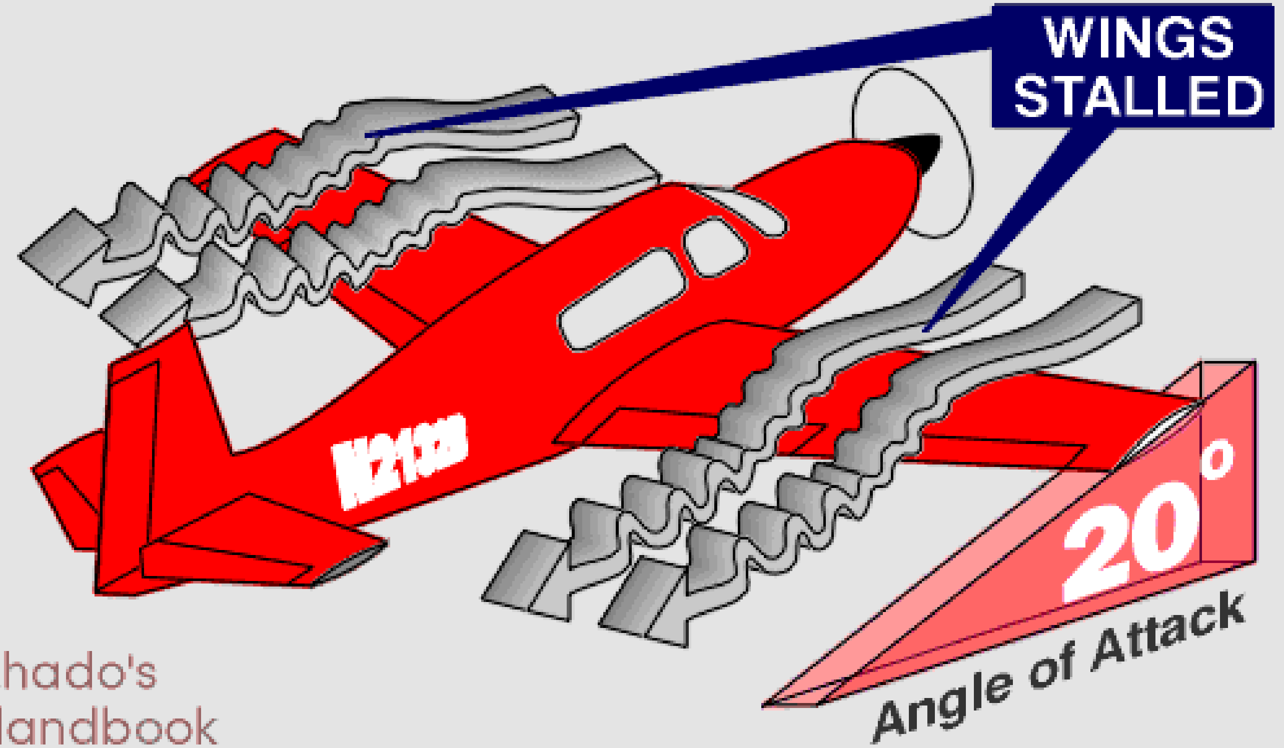
Wings operating below their critical angle of attack allow smooth, high velocity airflow to move over their upper surface. This keeps the pressure on the wing's upper surface low and maintains the required lift.



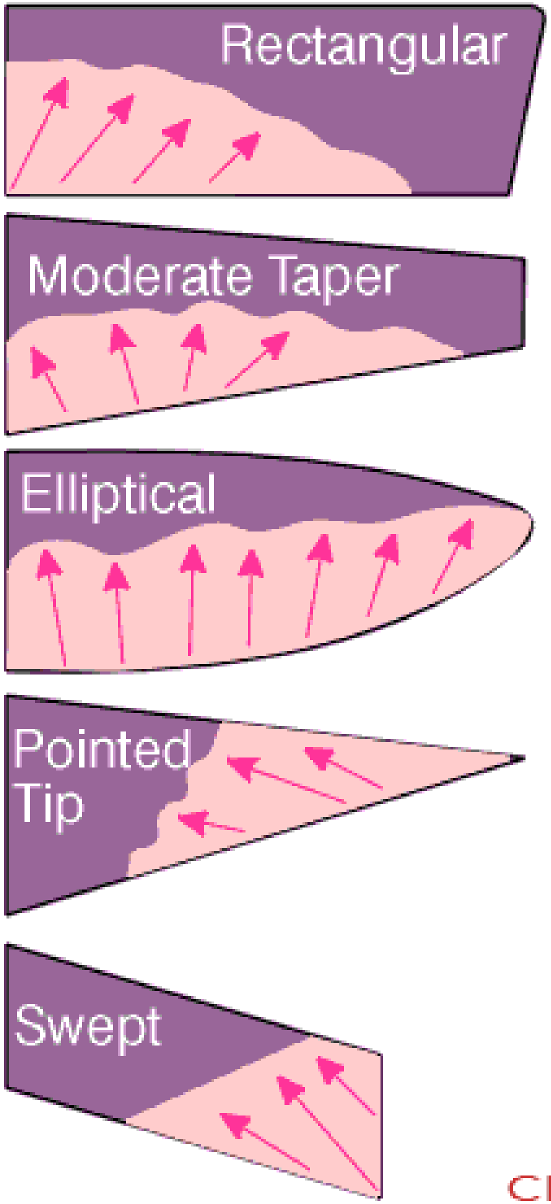
2-25B

STALLED VS. UNSTALLED WINGS

When the wings exceed their critical angle of attack, airflow over their upper surface, becomes chaotic and starts to burble. It is no longer smooth, high velocity airflow. Consequently, lift decreases.

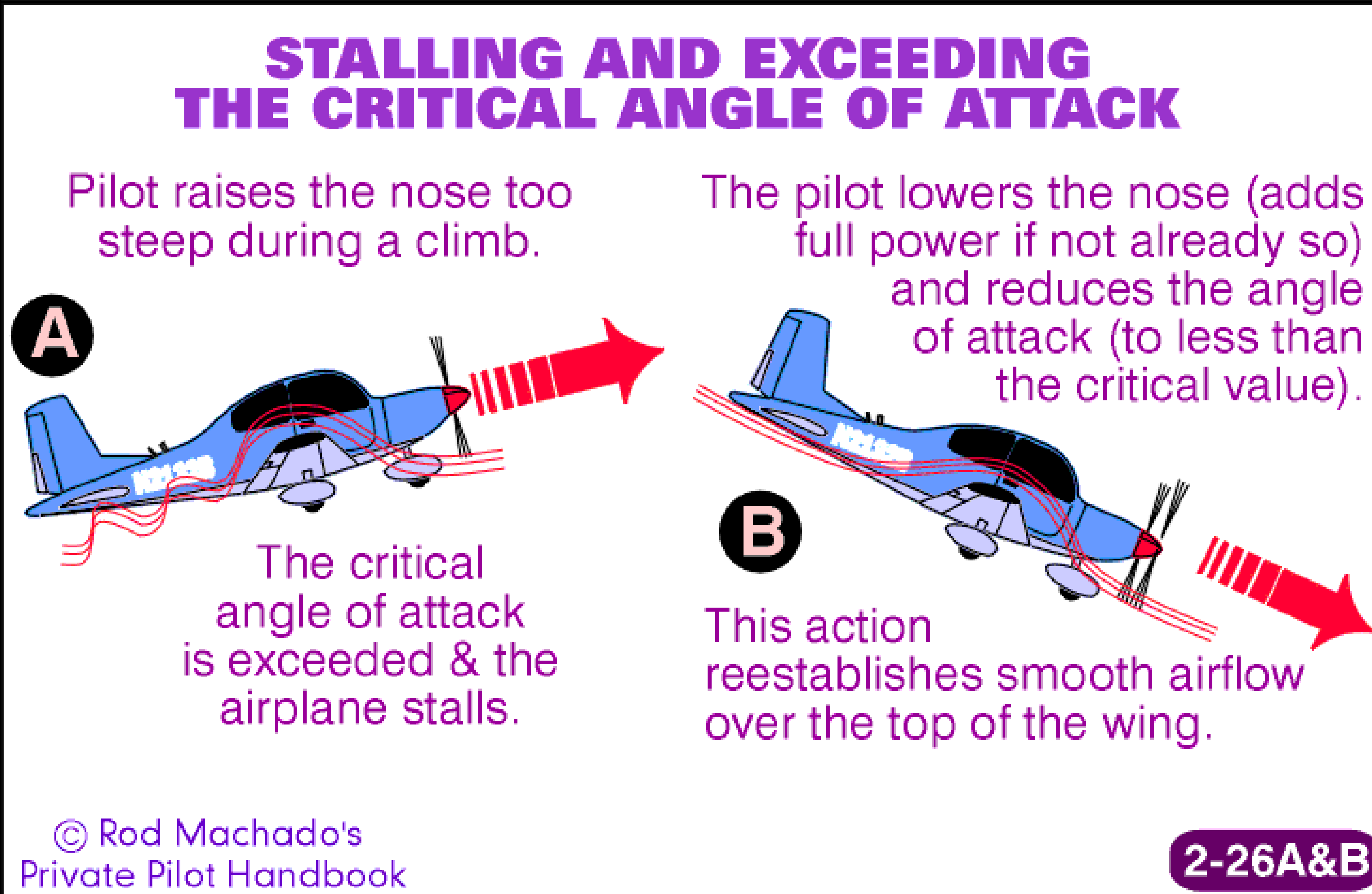


2-25A



STALL PATTERN PROGRESSION

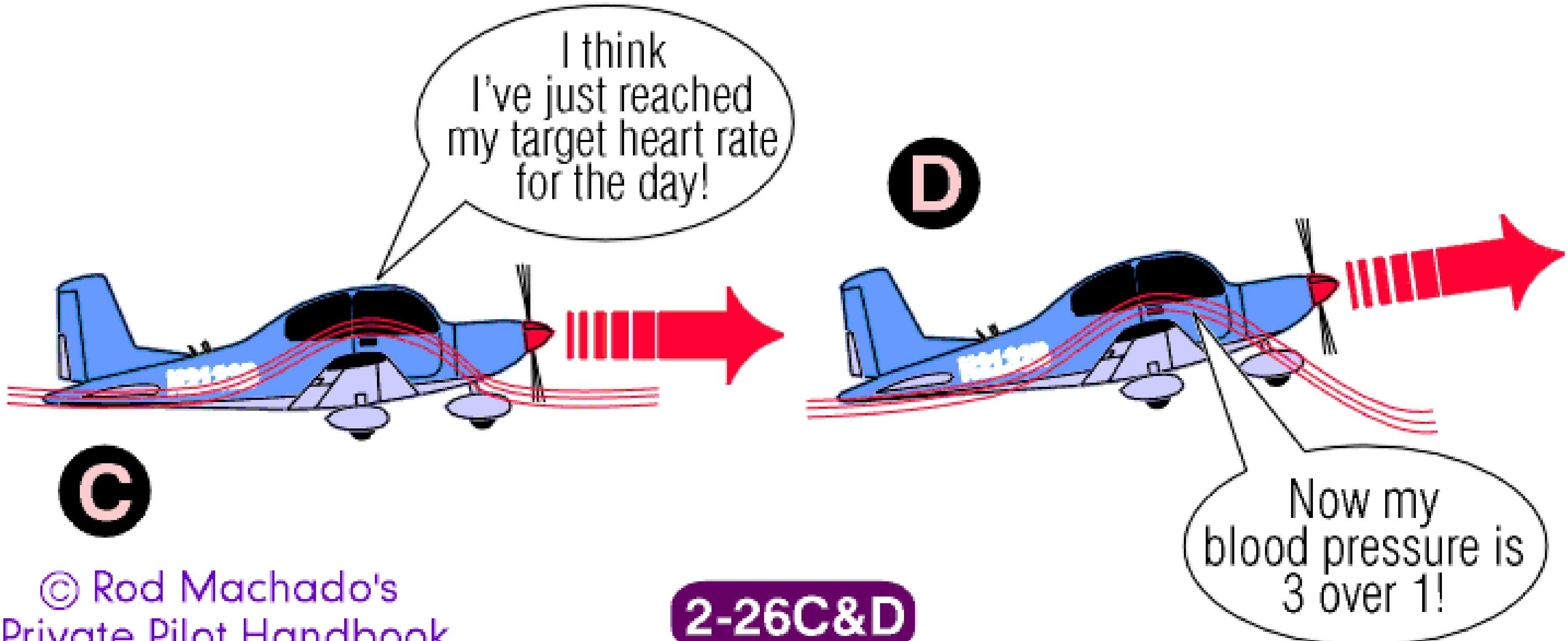
Wing design has an effect on how the airflow separates from the wing during a stall. The rectangular wing has the advantage of stalling at the root first. This keeps the ailerons effective at high angles of attack and provides you with a good stall warning buffet. A moderate taper on the wing allows more of the wing to reach a stall at the same time. This tends to reduce aileron effectiveness during a stall. All sections of the elliptical wing reach the stall at the same time. Ailerons may lack effectiveness during the stall on this wing. Pointed and swept wings stall at the tips first, then progress inward rendering the ailerons ineffective during the stall.


STALLING AND EXCEEDING
THE CRITICAL ANGLE OF ATTACK
Pilot raises the nose too steep during a climb.
A
The critical angle of attack is exceeded & the airplane stalls.
The pilot lowers the nose (adds full power if not already so) and reduces the angle of attack (to less than the critical value).
B
This action reestablishes smooth airflow over the top of the wing.
© Rod Machado's Private Pilot Handbook
2-26A&B

STALLING AND EXCEEDING THE CRITICAL ANGLE OF ATTACK

Once the airplane is no longer stalled, the pilot raises the nose slowly.

Pilot now resumes climb without exceeding the critical angle of attack.



2-26C&D

Flow over aerofoils

H Babinsky

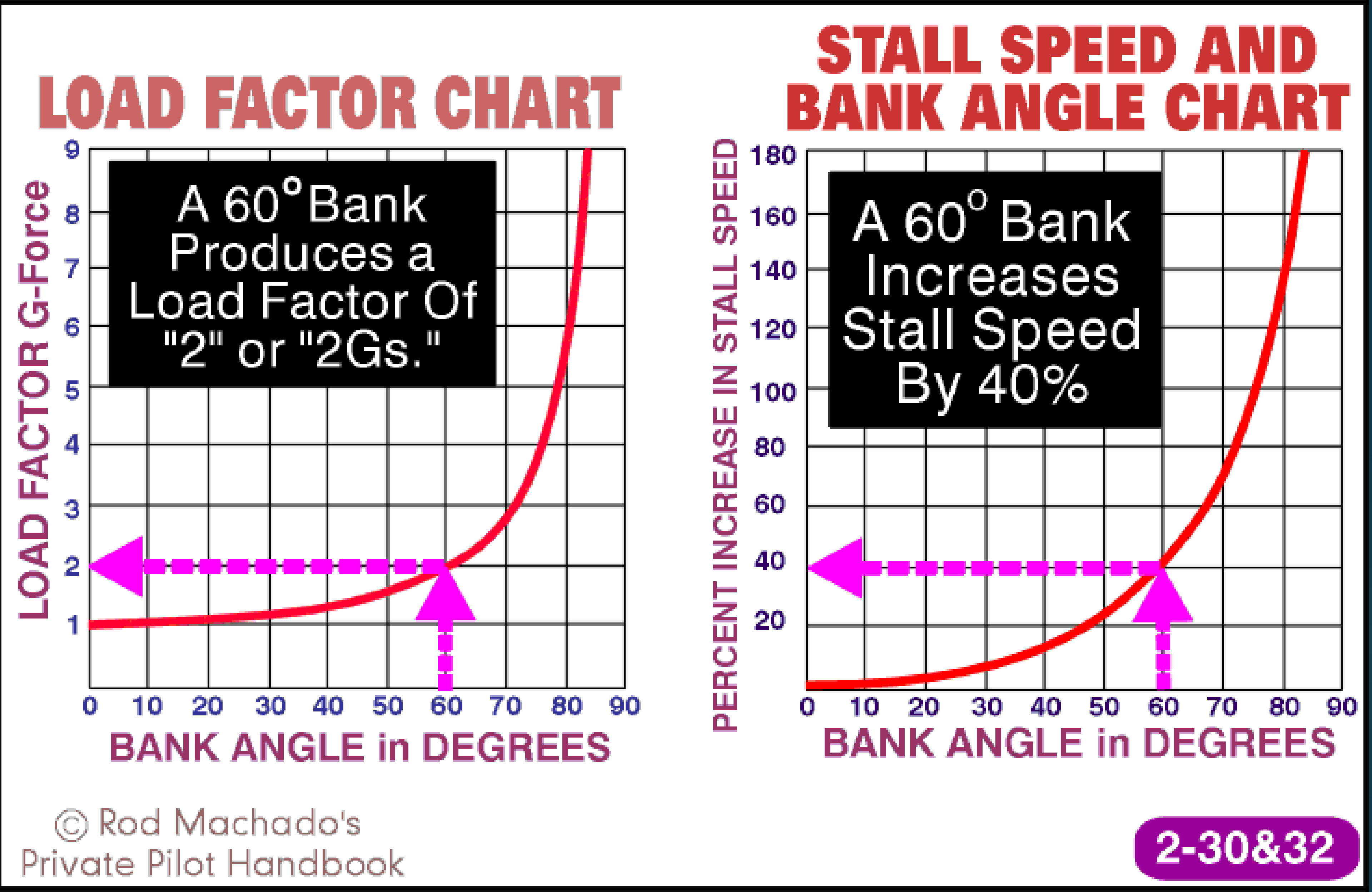
Cambridge University
Department of Engineering

STALL SPEED CHART

Power Off **Stalling Speeds** Knots =IAS

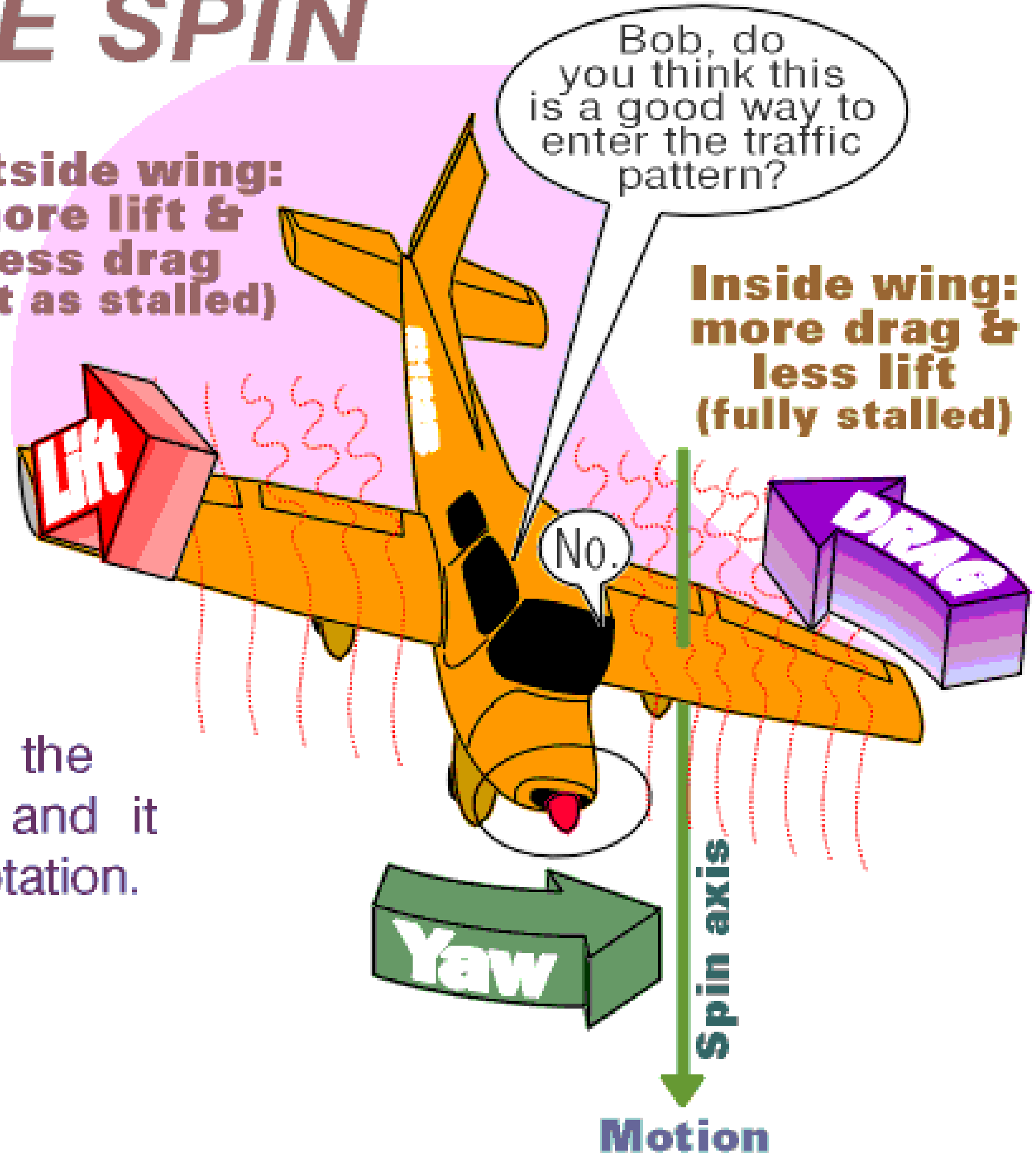
Gross Weight 2,550 lbs.

Condition	Angle Of Bank 0°	30°	45°	60°
Flaps Up	50	54	59	71
Flaps 10°	42	45	50	59
Flaps 30°	40	43	48	57


LOAD FACTOR CHART
A 60° Bank Produces a Load Factor Of "2" or "2Gs."
LOAD FACTOR G-Force
1 2 3 4 5 6 7 8 9
0 10 20 30 40 50 60 70 80 90
BANK ANGLE in DEGREES
STALL SPEED AND BANK ANGLE CHART
A 60° Bank Increases Stall Speed By 40%
PERCENT INCREASE IN STALL SPEED
20 40 60 80 100 120 140 160 180
0 10 20 30 40 50 60 70 80 90
BANK ANGLE in DEGREES
© Rod Machado's Private Pilot Handbook
2-30&32

THE SPIN

For an airplane to spin, it must first be stalled. When the stall occurs, rudder is applied in the direction you desire to spin. The elevator is held back and the airplane commences to autorotate. The out- side wing is not as stalled as the inside wing, caus- ing the airplane to rotate about the spin axis. After the first two turns the airplane's inertial forces balance and it settles into a predictable pattern of rotation.



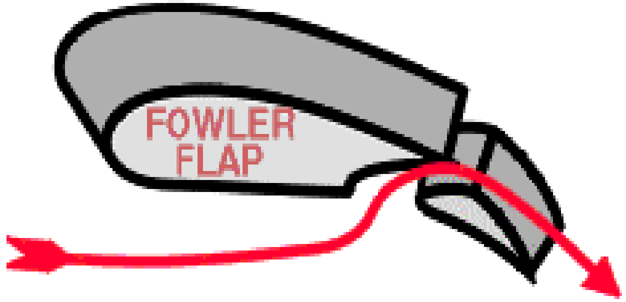
Pg-B20

Flaps

TYPES OF FLAPS

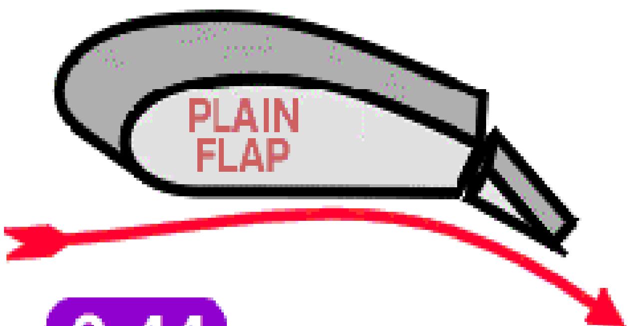
Fowler flaps move rearward and downward thereby increasing wing area and wing curvature. High velocity airflow from underneath the wing, flowing up and over the flap, helps delay the onset of a stall.

A



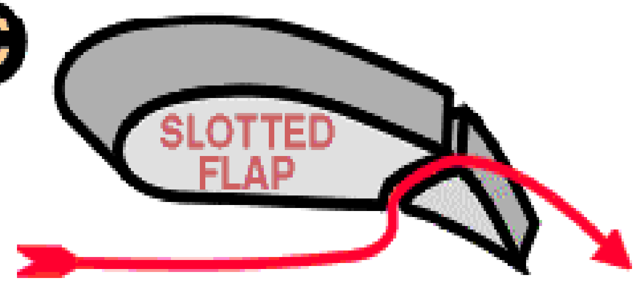
Plain flaps lower the trailing edge of the wing, increasing its curvature. This acts to increase the wing's lift.

B



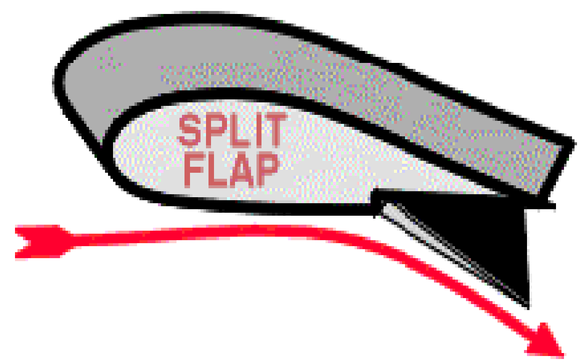
Slotted flaps allow high velocity airflow from underneath the wing to flow up and over the flap. This helps prevent airflow separation and delays

C



Split flaps generate some lift and a lot of drag since they disrupt airflow on the underside of the wing.

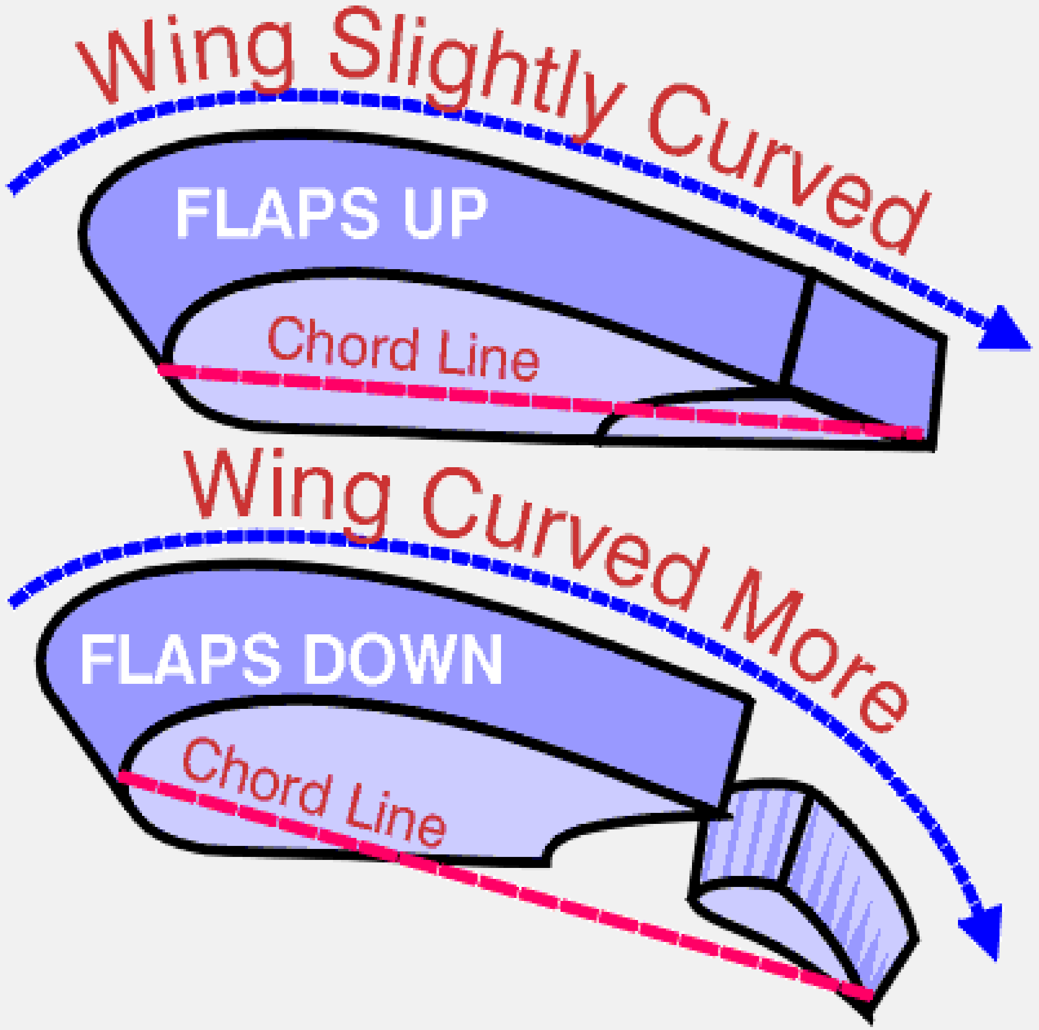
D



2-44

HOW FLAPS CHANGE THE WING'S CURVATURE

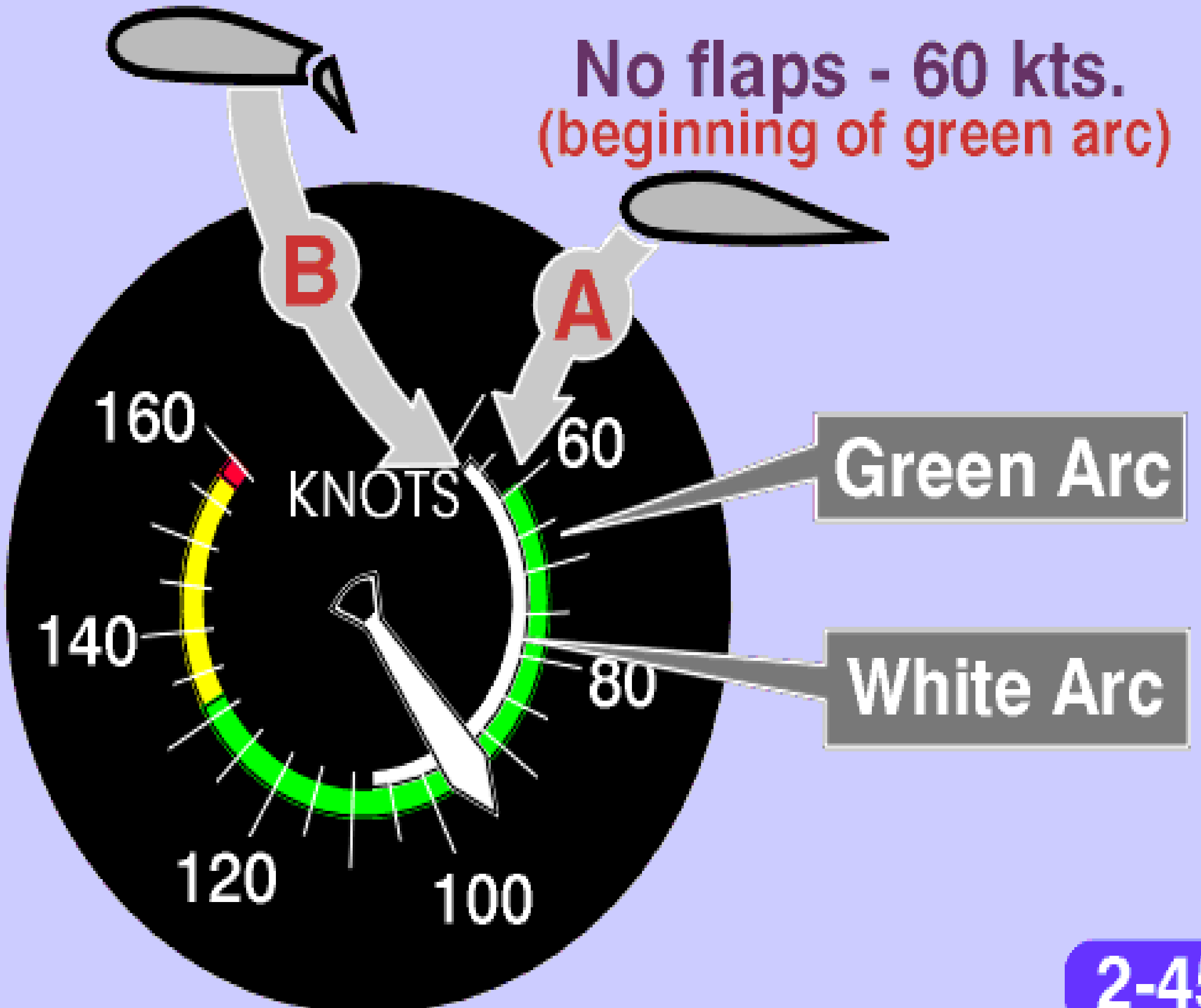
When flaps are lowered, the wing's curvature increases (surface area can increase too) and the chord line moves to increase the wing's angle of attack. This allows the wing to produce more lift for a given airspeed.



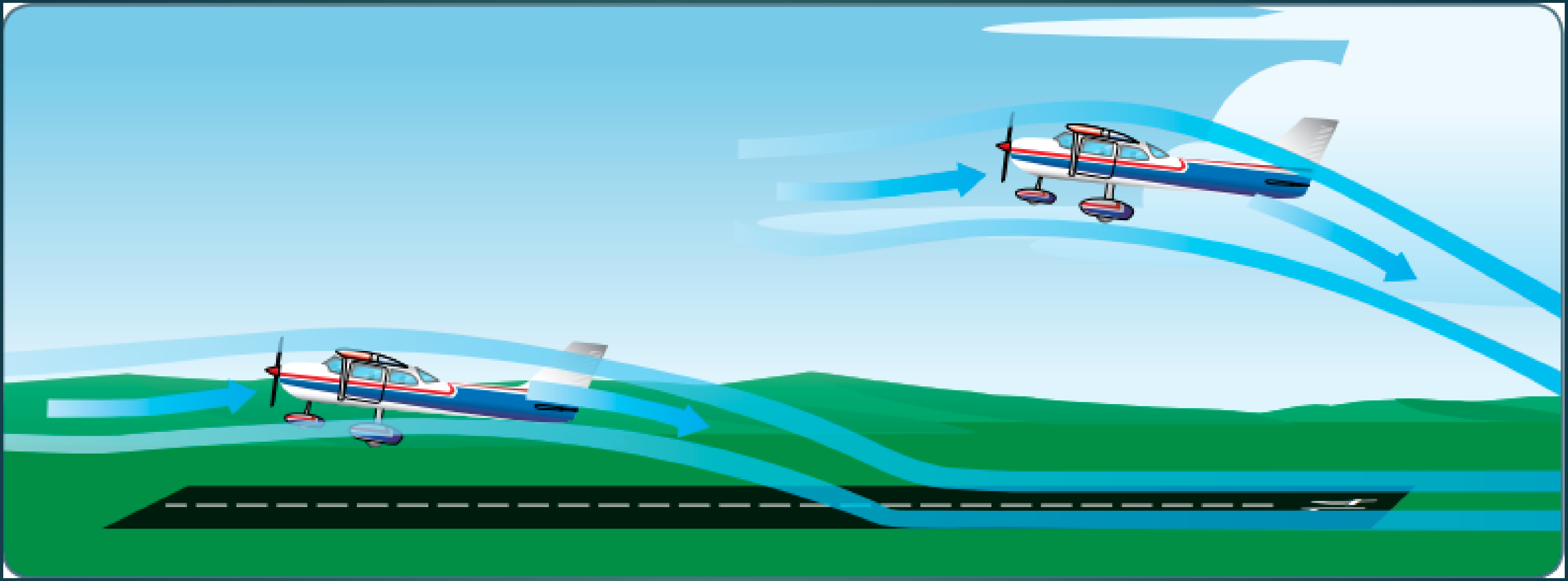
FLAP SPEED RANGE

Flaps extended - 53 kts.
(beginning of white arc)

No flaps - 60 kts.
(beginning of green arc)



Ground Effect



- Direct increase in lift generated by the wing due to compression of downward forced air by proximity to ground
- Indirect increase in lift produced by reduction of drag at the wing tip. (Caused by change in the shape of wing tip vortices, effectively increasing the chord of the wing.)
- Overall effect is that a greater amount of lift will be produced for a given angle of attack than would be required in free air.

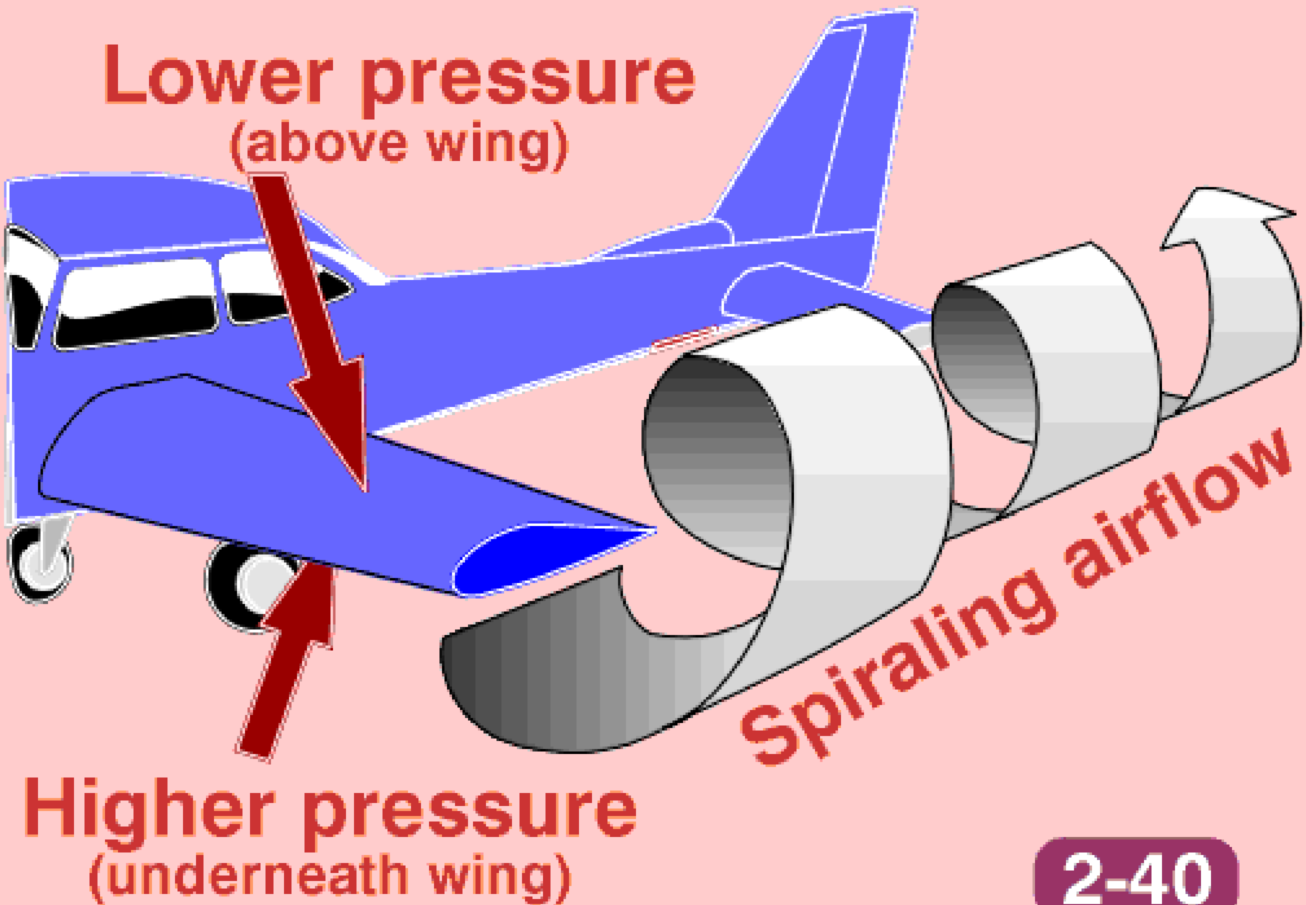
Wingtip Vortices And Wake Turbulence

How Vortices are Created

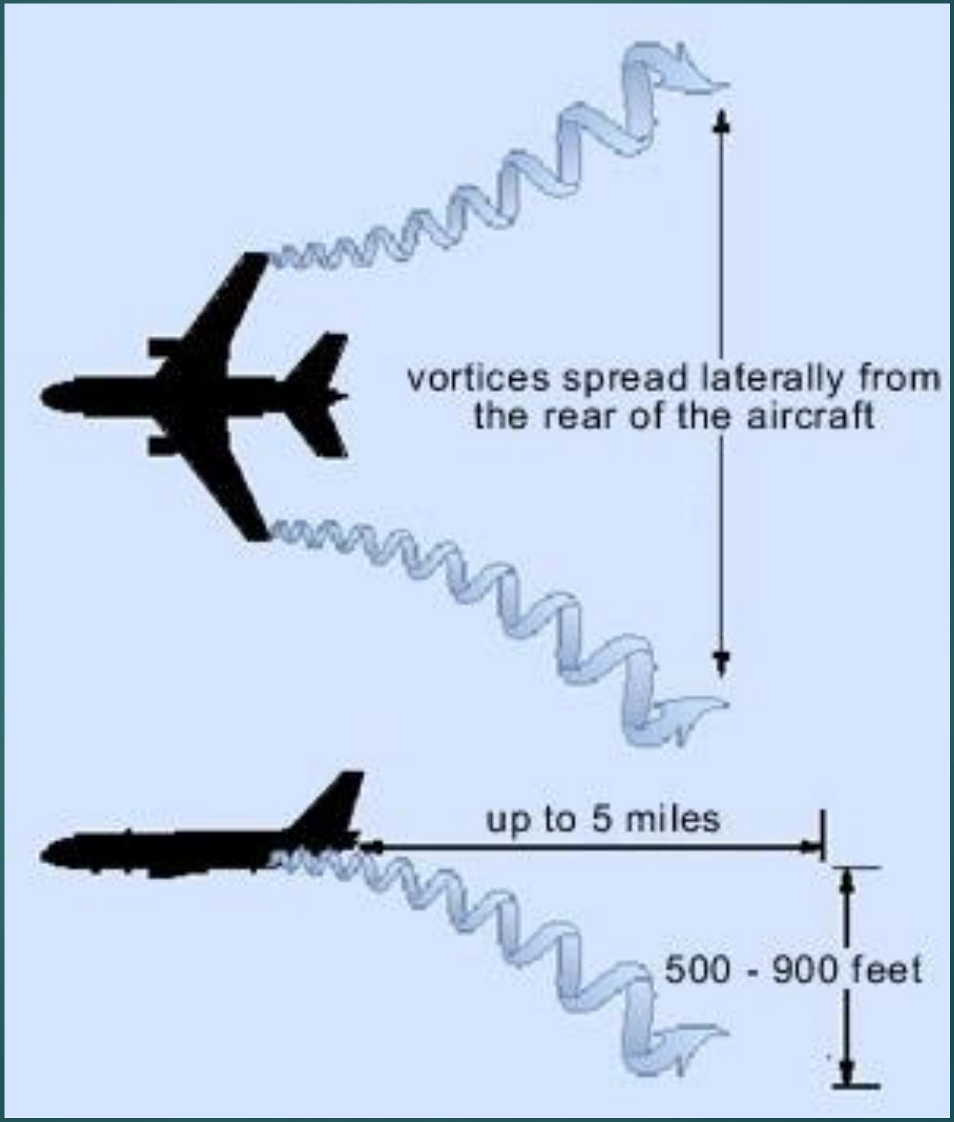
- Effect of the creation of lift and the pressure differential between the air above and below the wing
- In air's endless effort to equalize pressure, the air from top and bottom of the wing flows outward towards the wingtip, then upward and around, creating vortices
- Vortex strength is dependent on the weight, speed, and shape of the airfoil of the aircraft – larger aircraft such as airliners produce strong enough wake turbulence to seriously affect light aircraft

WINGTIP VORTEX

Air sneaks from underneath the wing where the pressure is high, to the top of the wing, where the pressure is lower. As the wing moves forward, it creates a spiral of air trailing off the wingtips. This spiral moves outward, upward, & inward, trailing behind the wing.



How Do Vortices (Wake Turbulence) Act?



- Wake turbulence is worst when the aircraft is heavy, clean (flaps & gear up), and slow.
- Vortices descend, and move laterally with the wind.
- Behind large aircraft, wake turbulence can cause uncommanded roll / loss of control.

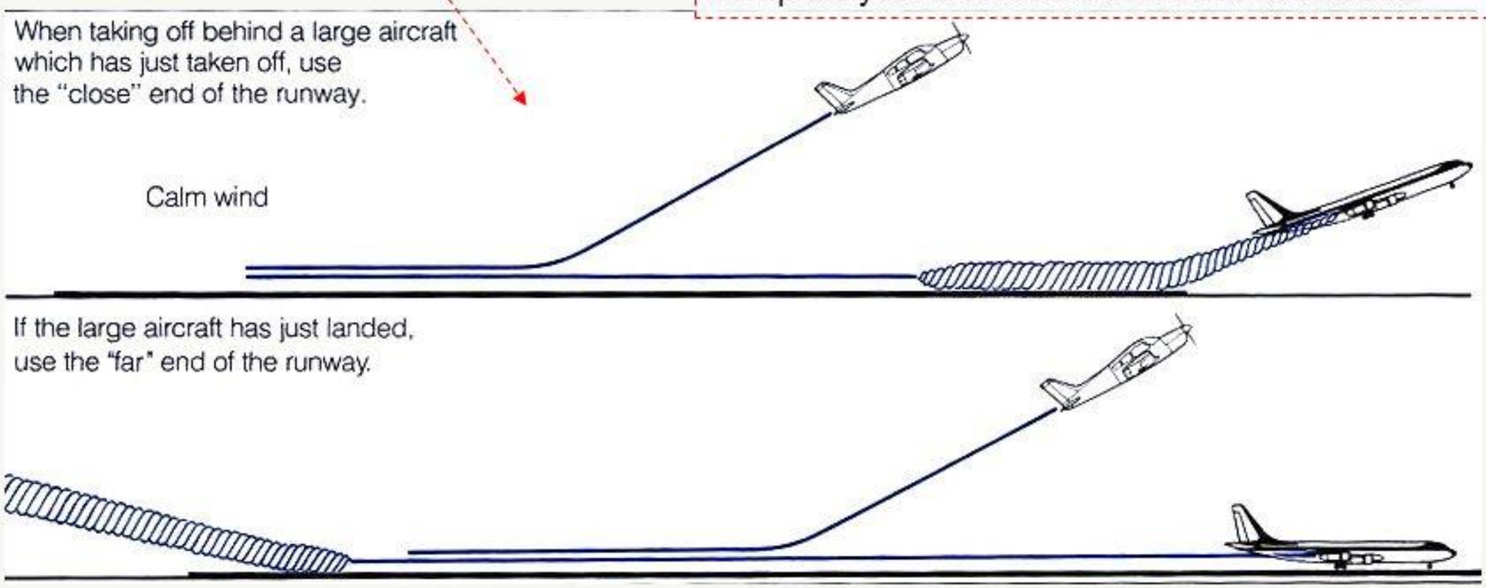
Wake Turbulence

What other options do you have for avoiding wake turbulence?

When taking off after a heavy plane that just took off before you, in which portion of the runway must you complete your take-off to avoid wake turbulence?

Are these realistic climb profiles?

When taking off after a heavy plane that just landed before you, in which portion of the runway must you complete your take-off to avoid wake turbulence?



Next Session: Feb 5

- Quiz: Aerodynamics of Lift
- Presentation: Aerodynamics of Thrust and Drag
- Reading:
  - Machado Chapter 2
  - Pilot's Handbook Chapter 5