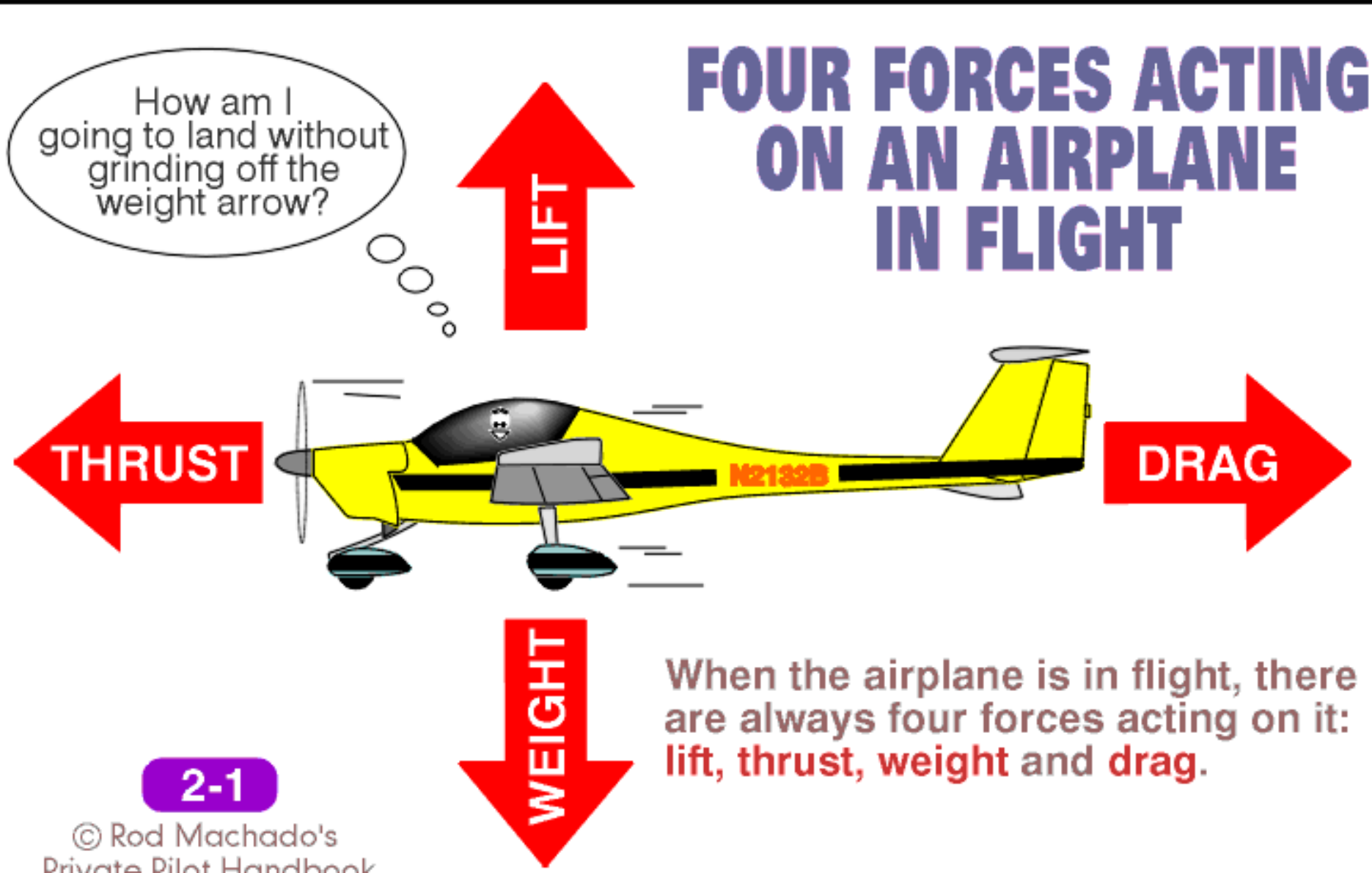
Aerodynamics of Thrust and Drag

The Four Forces Revisited



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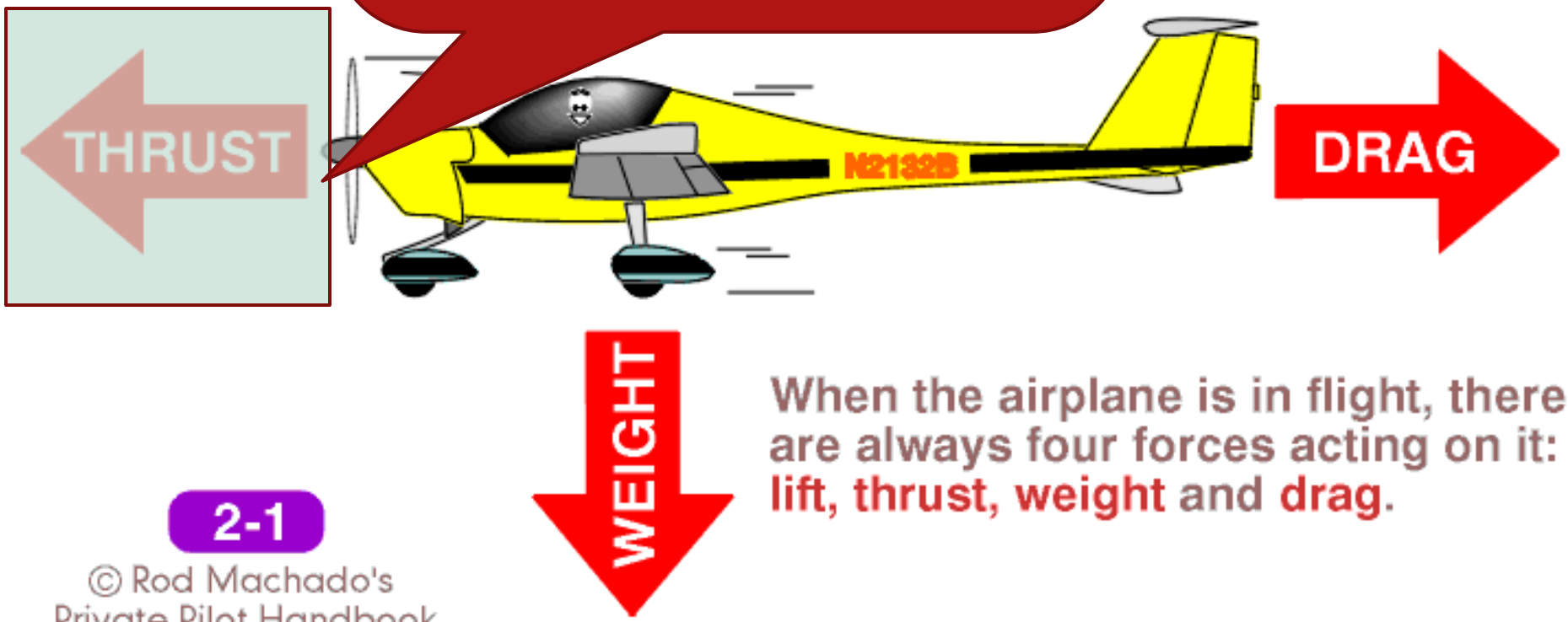
The forward force produced by the powerplant/propeller. It opposes the force of drag.

How am
going to land w
grinding off
weight arro

RCES ACTING
AIRPLANE
FLIGHT



When the airplane is in flight, there are always four forces acting on it: lift, thrust, weight and drag.

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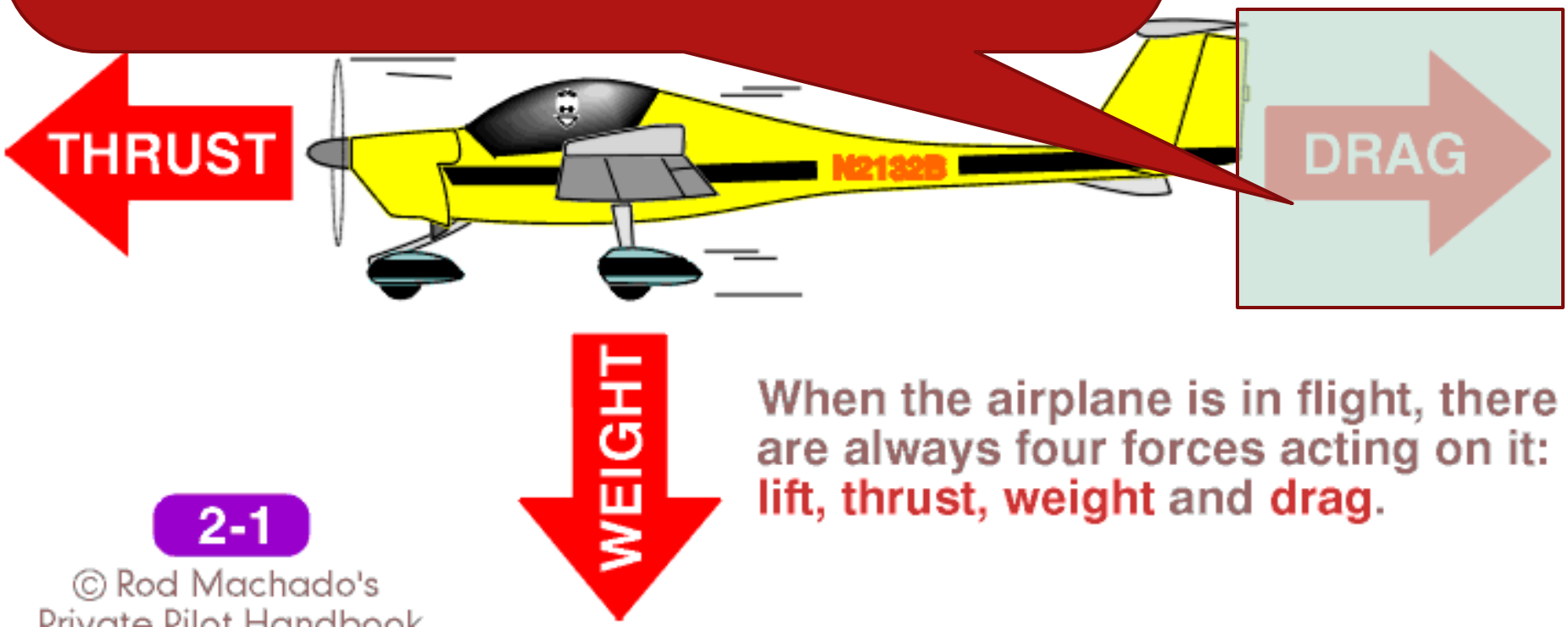
Rearward force caused by disruption of airflow by the wing, fuselage, and other protruding surfaces. Drag opposes thrust.

CES ACTING IRPLANE LIGHT



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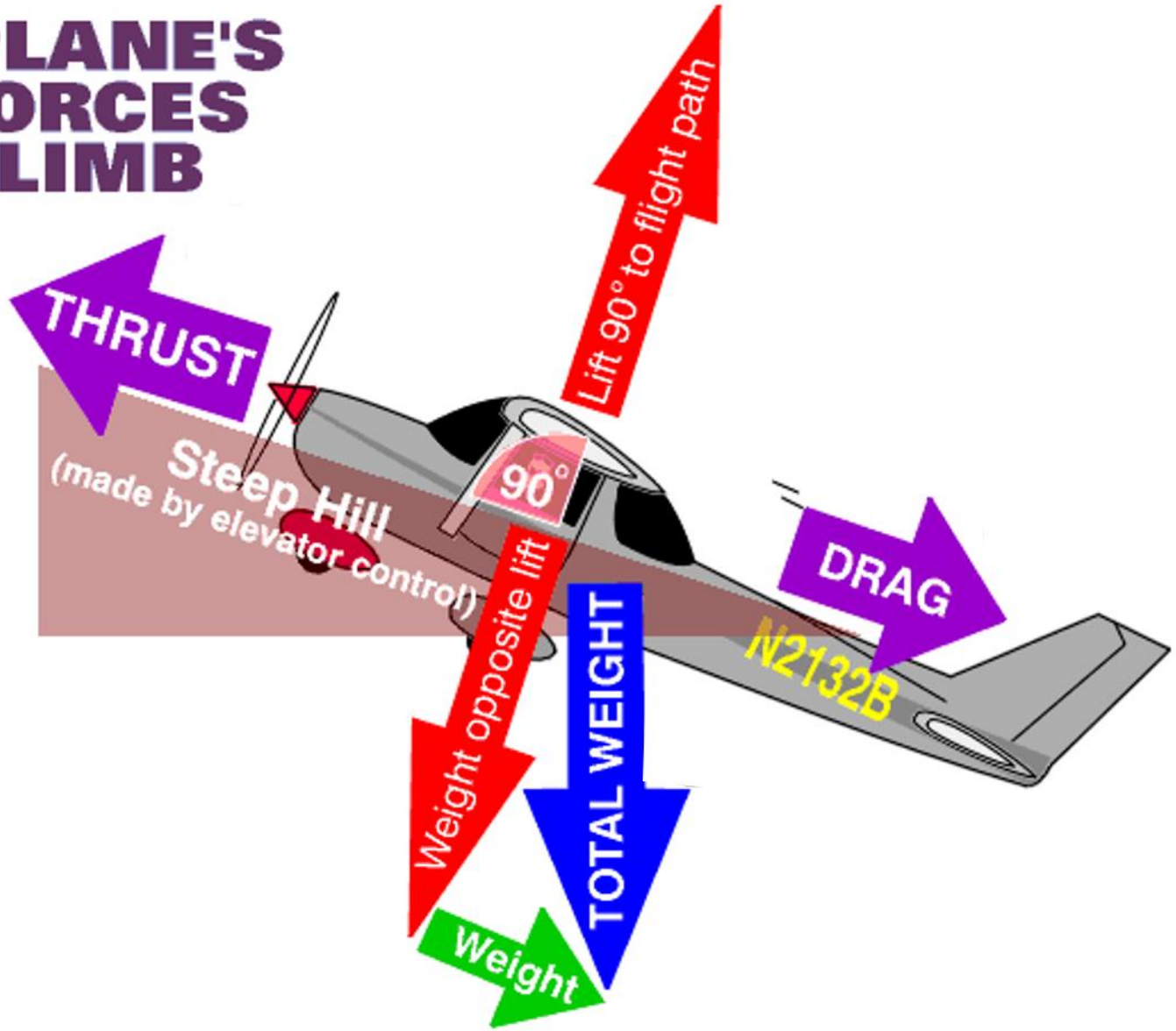
AN AIRPLANE'S FOUR FORCES IN A CLIMB



AN AIRPLANE'S FOUR FORCES IN A CLIMB

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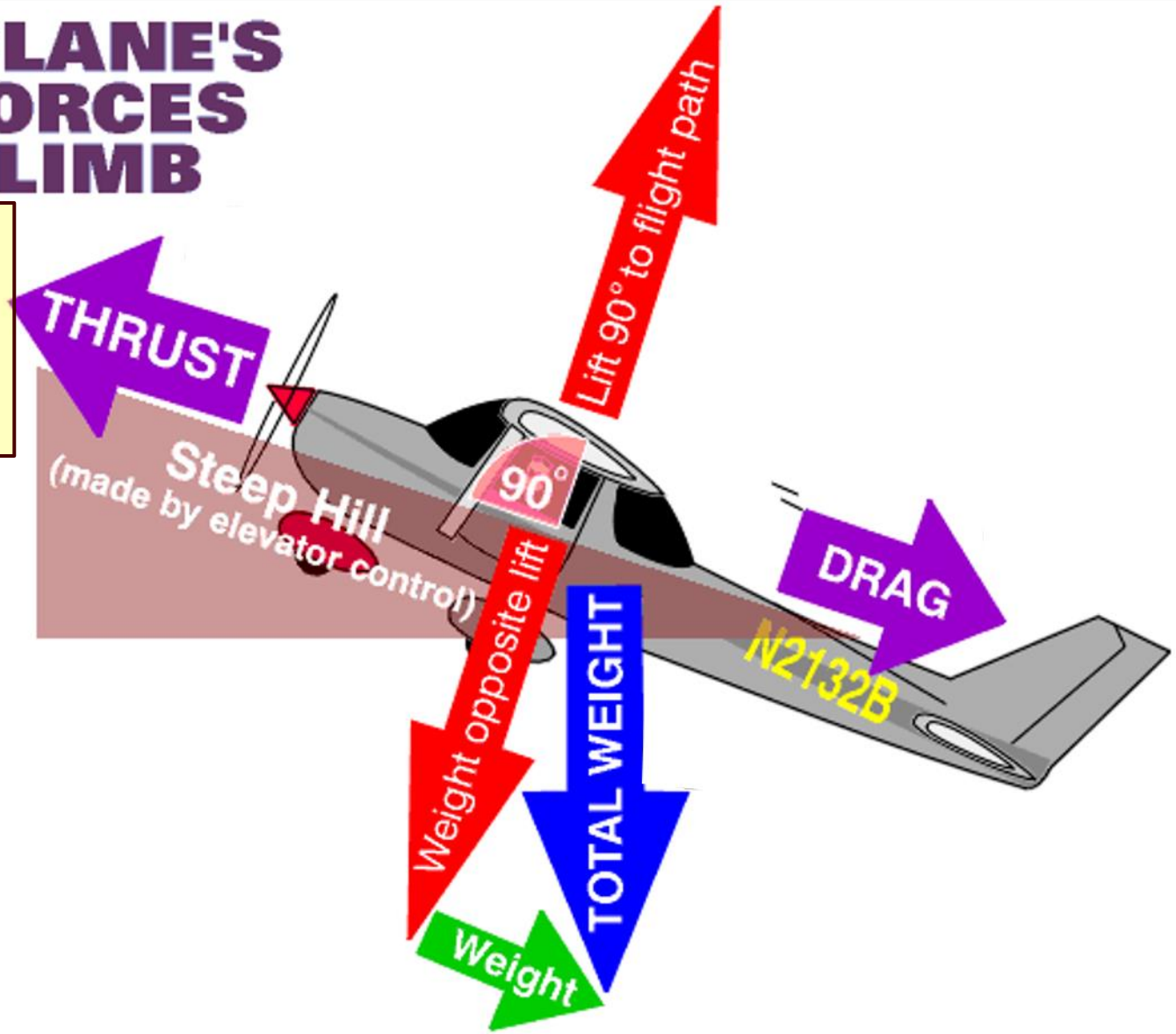
Engine power pulls the aircraft "uphill" in a climb



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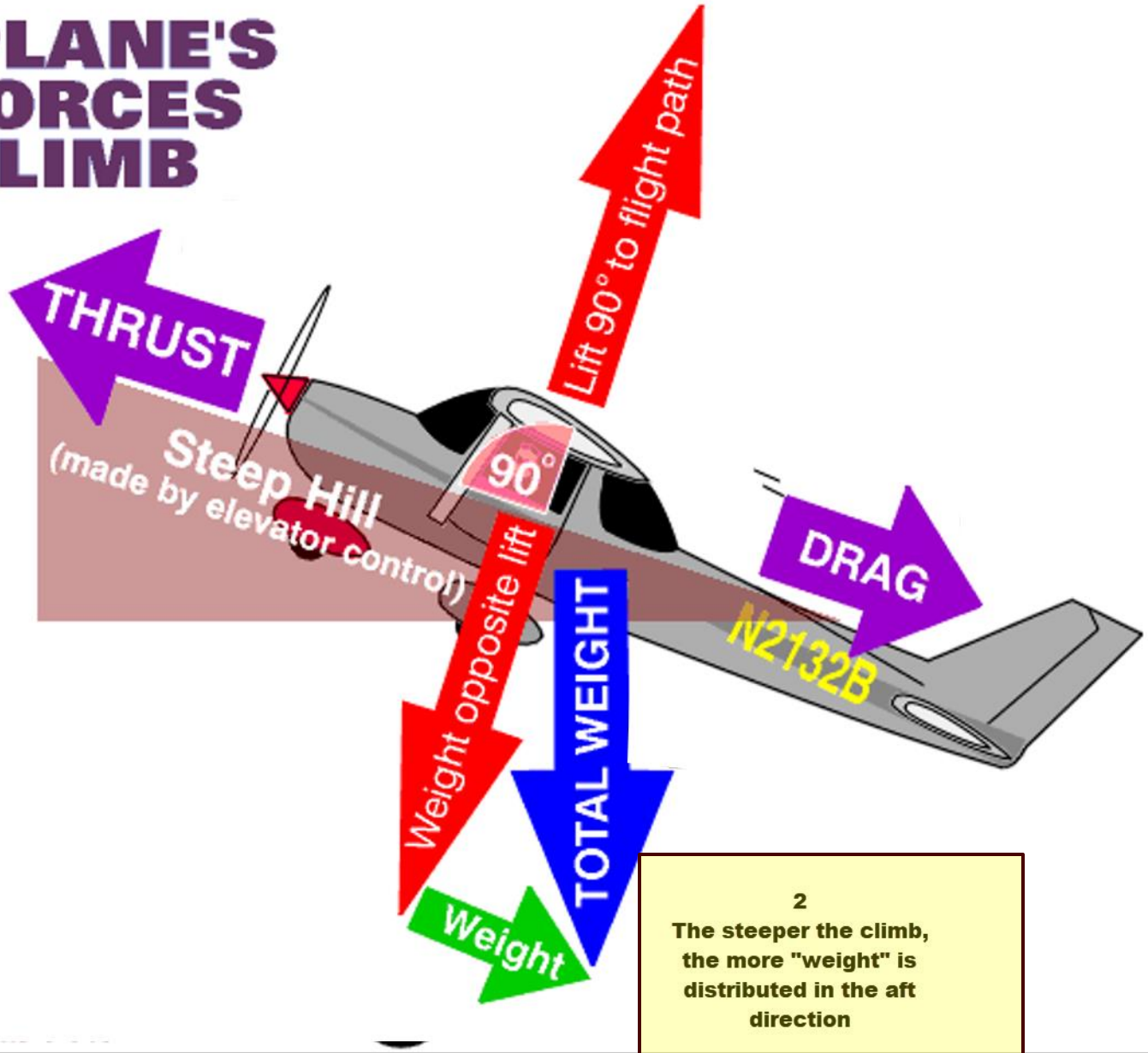

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The steeper the climb, the more "weight" is distributed in the aft direction

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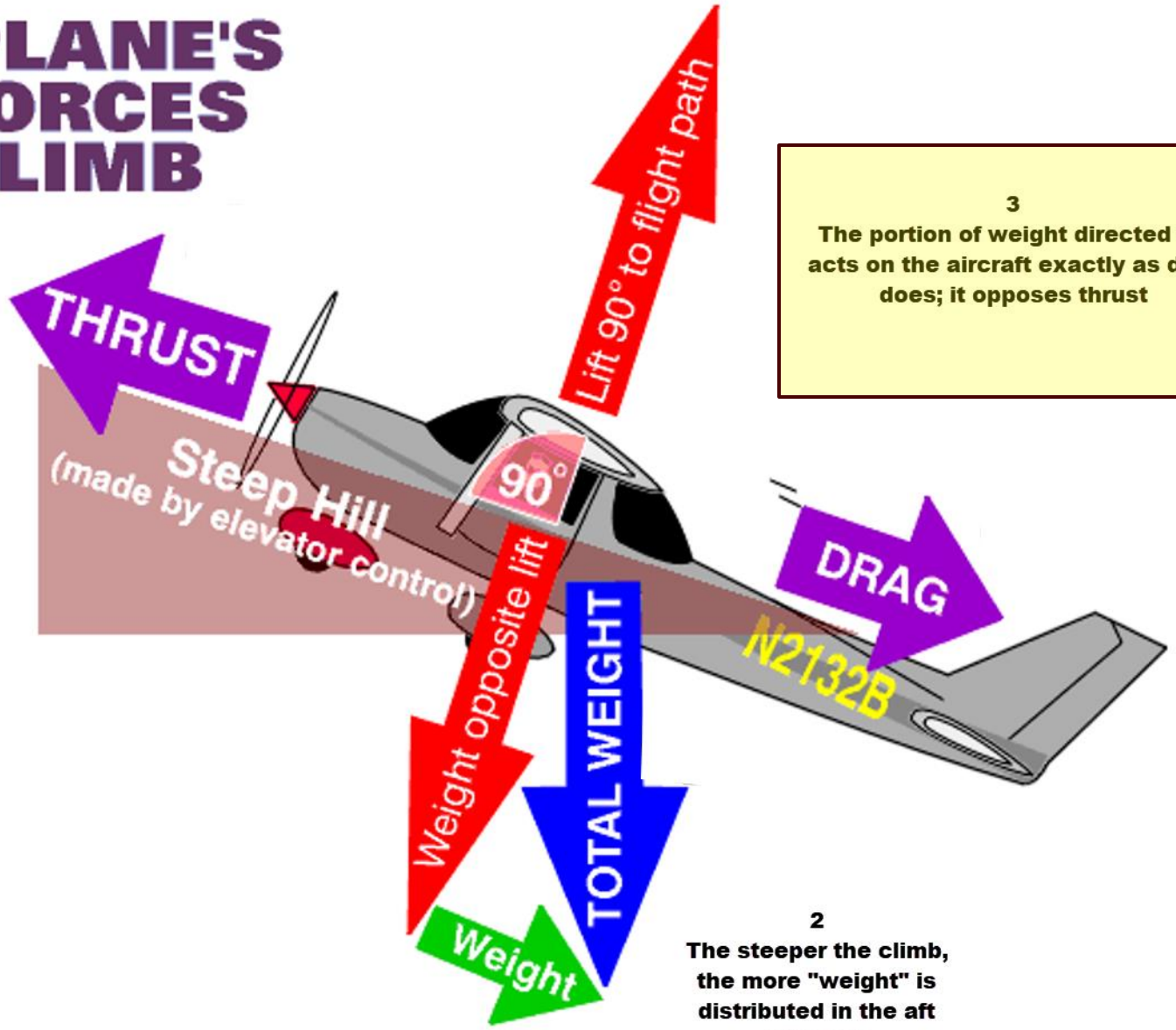

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The portion of weight directed aft acts on the aircraft exactly as drag does; it opposes thrust

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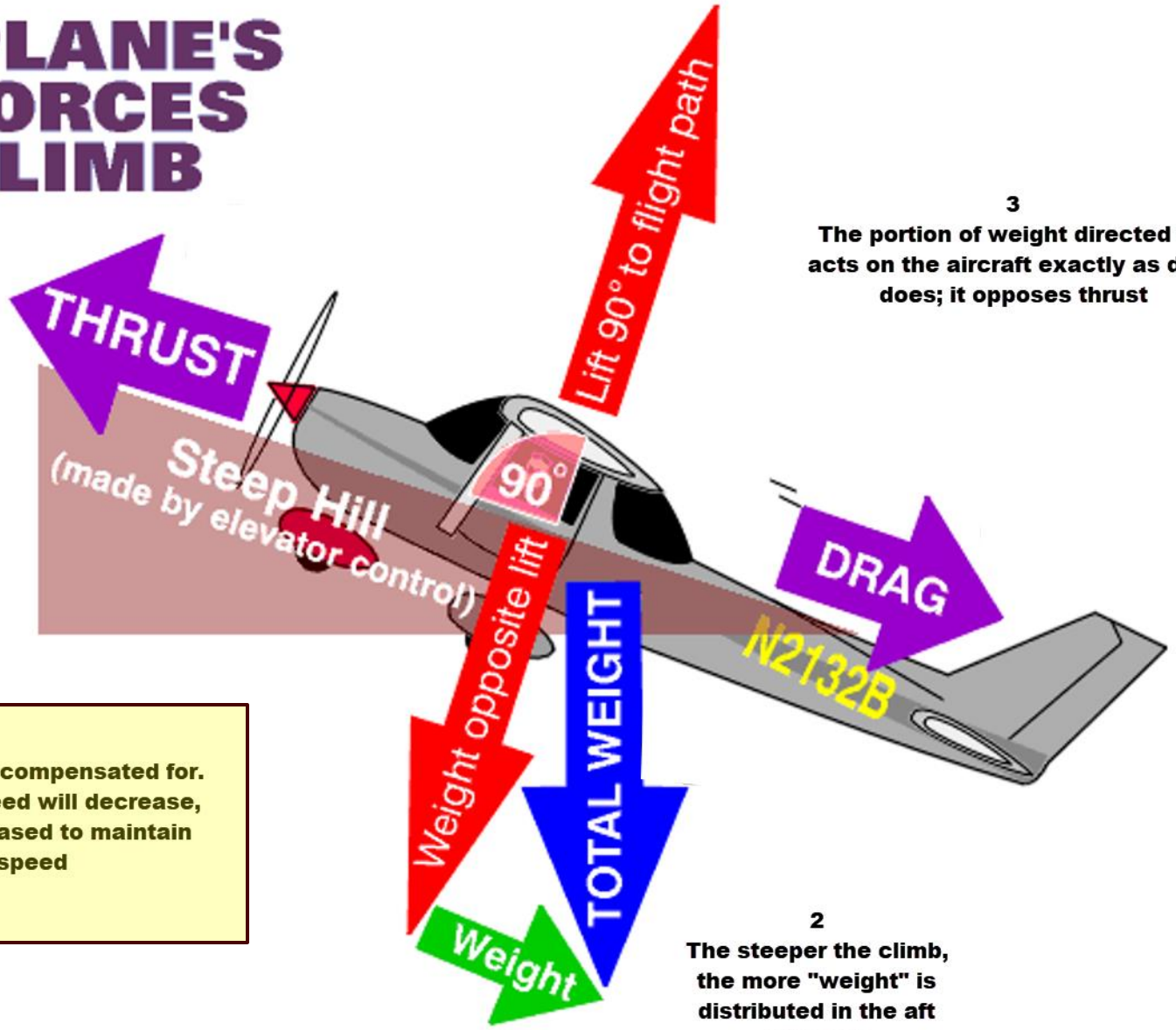


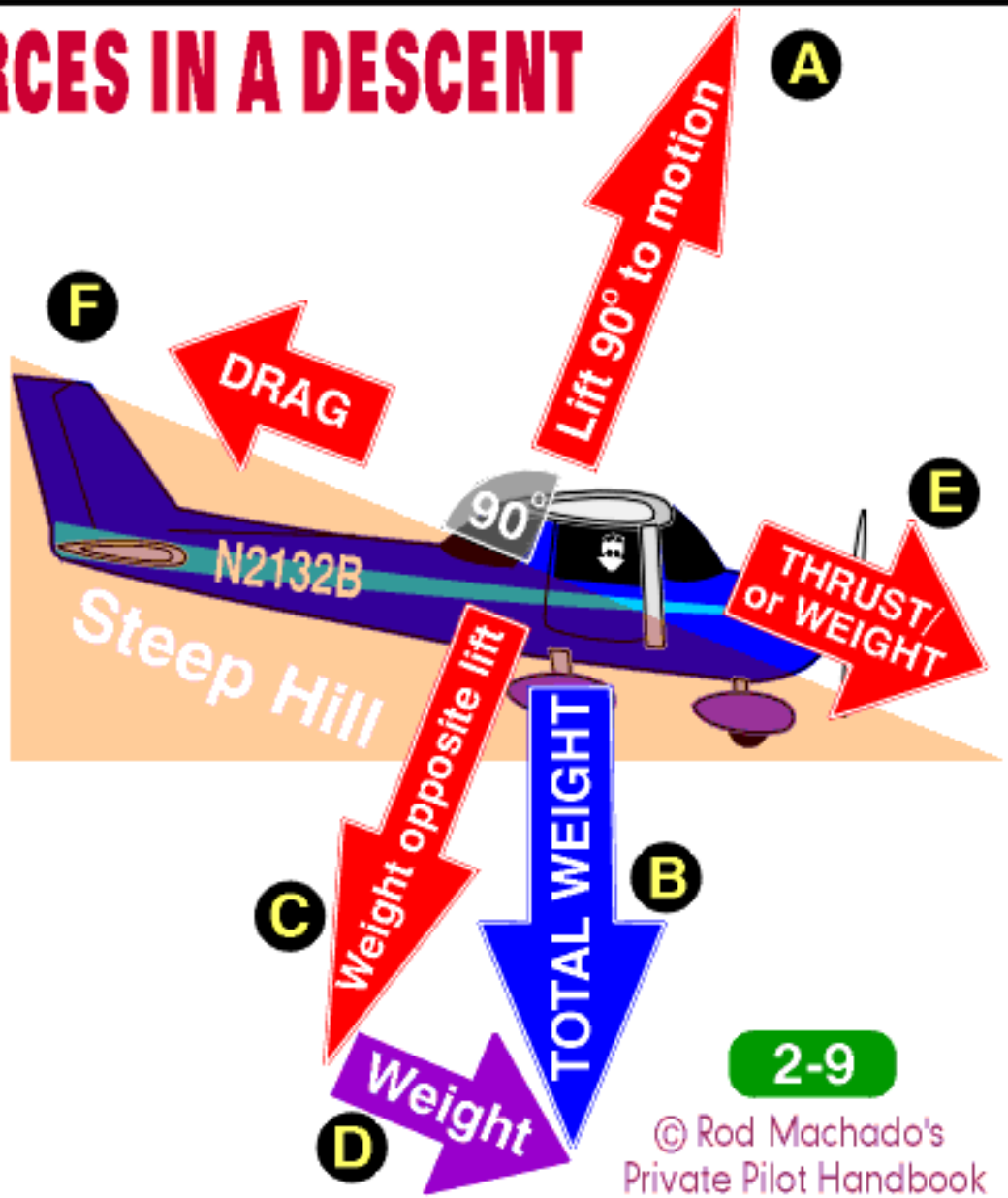
3
The portion of weight directed aft acts on the aircraft exactly as drag does; it opposes thrust

4
This extra drag must be compensated for. Either the plane's airspeed will decrease, or power must be increased to maintain the same airspeed

2
The steeper the climb, the more "weight" is distributed in the aft direction

AN AIRPLANE'S FOUR FORCES IN A DESCENT

The steeper the angle of descent, the more the airplane's total weight (B), acts forward (D), in the direction of thrust (E). Drag (F) is aerodynamic drag. Lift (A) still acts perpendicular to the flight path (the relative wind). Lift (A), is still equal and opposite to that part of the weight (C) which acts 90 degrees to the flight path.



Thrust

PROPELLERS AS WINGS

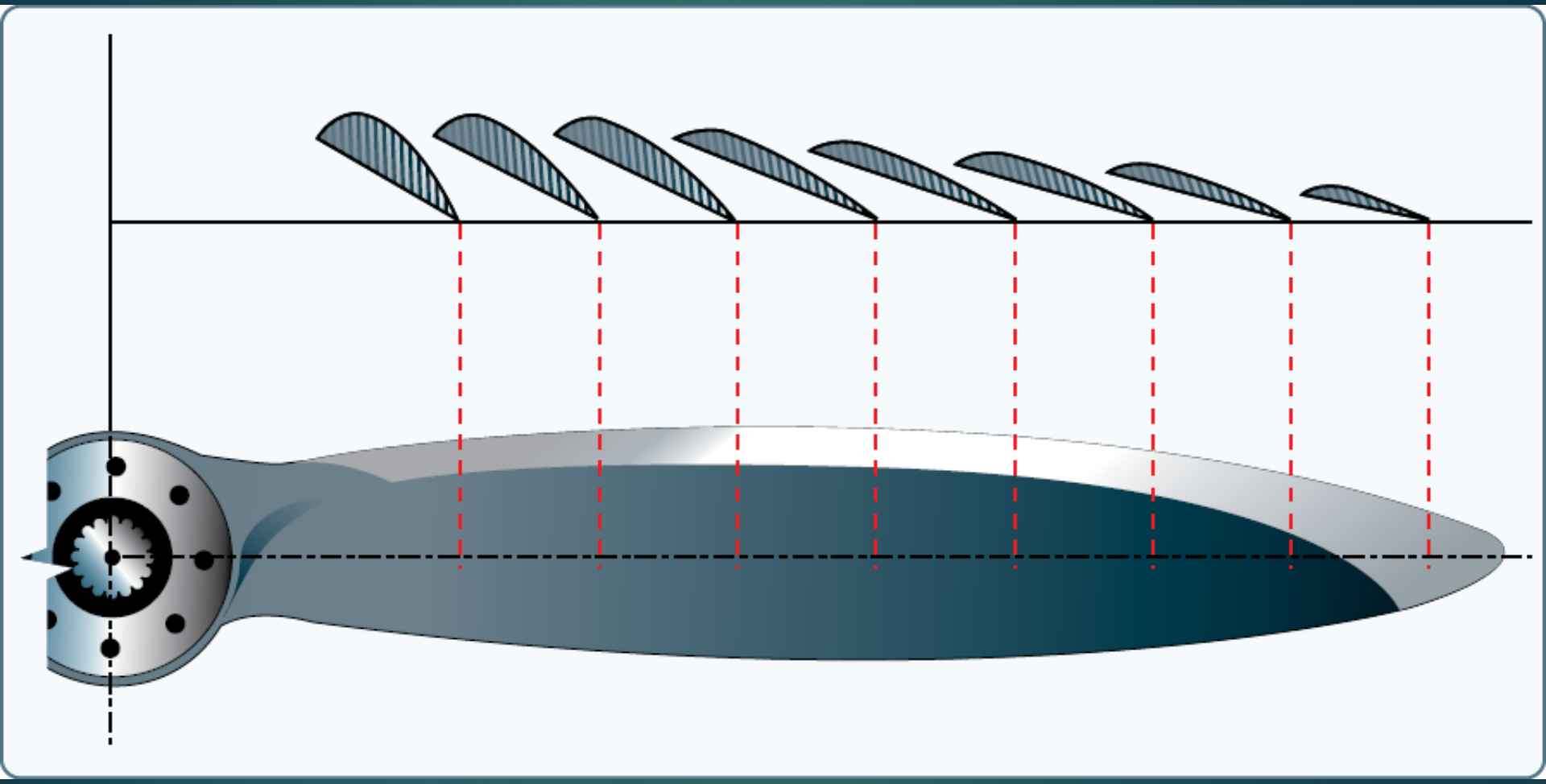
EFFECTS OF PRODUCING THRUST

Propellers

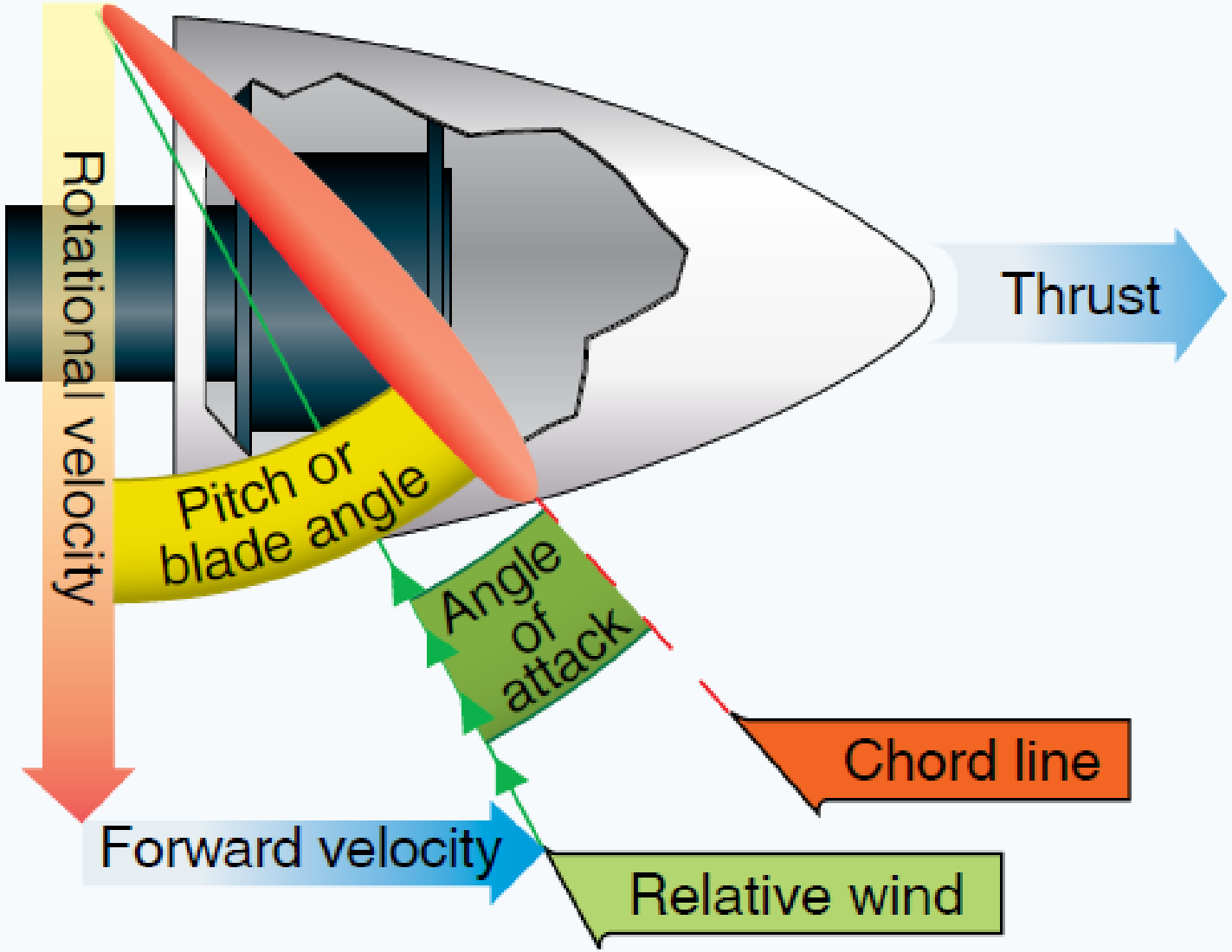
- Aircraft propeller consists of:
  - Two or more blades***
  - A central hub to which the blades are attached
- Aircraft propellers are
  - Rotating wings
  - Act like airfoils
  - Create the thrust that pulls/pushes the aircraft forward

Propeller configurations

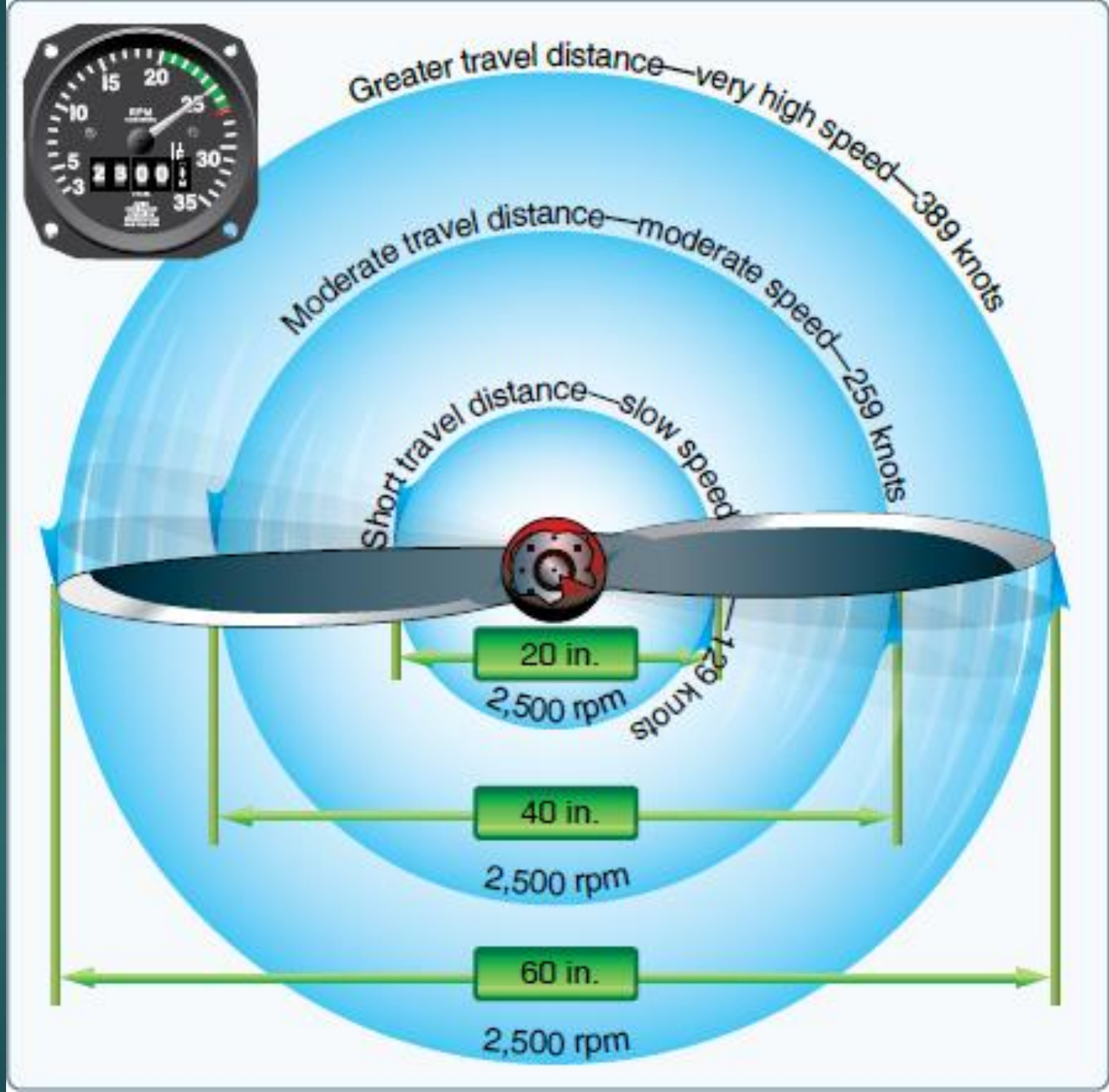
Airfoil sections of propeller blade



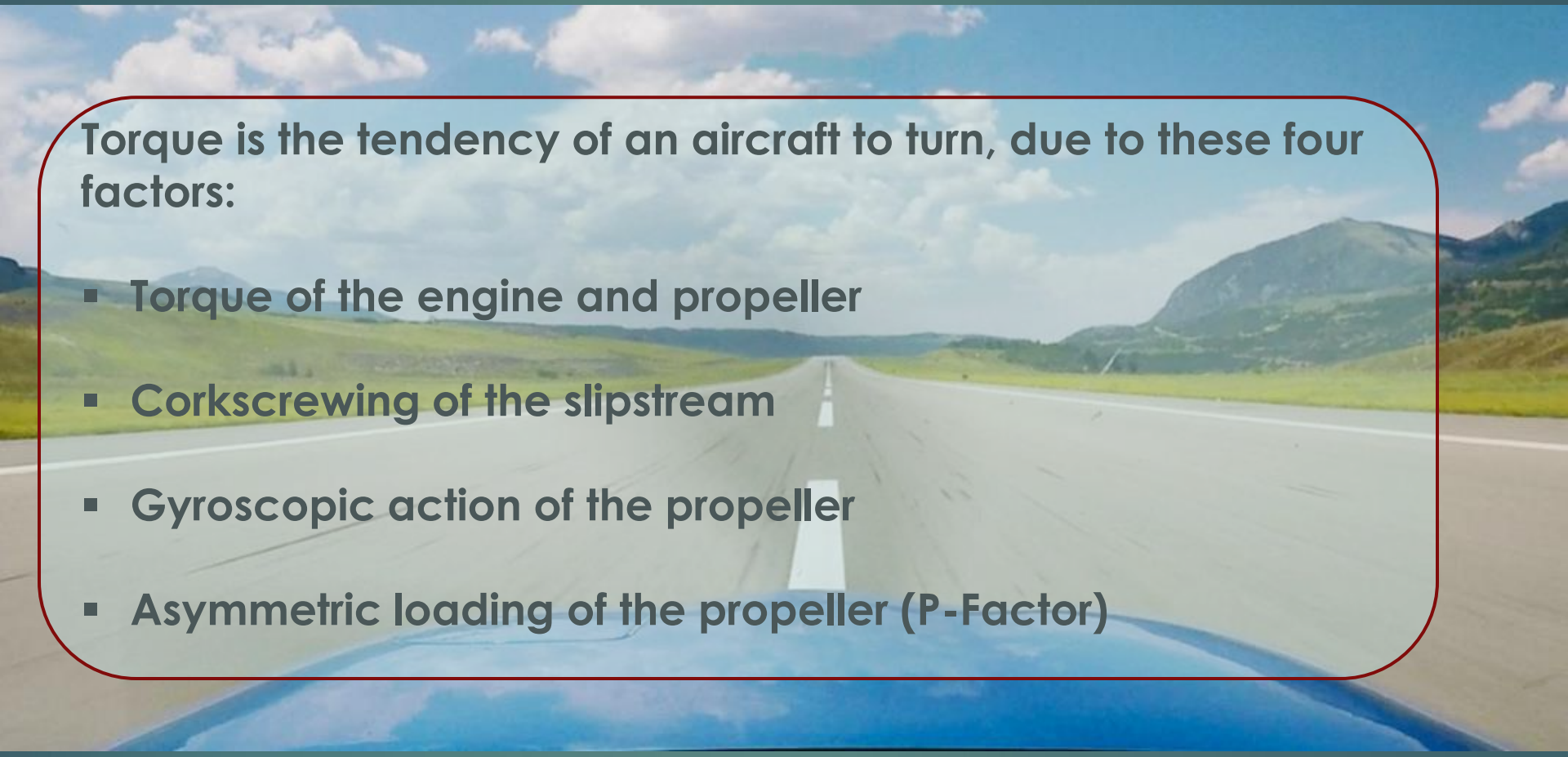
How a propeller cuts the air



Propeller "twist" creates a constant angle of attack even though the tips are moving much faster than the hub.



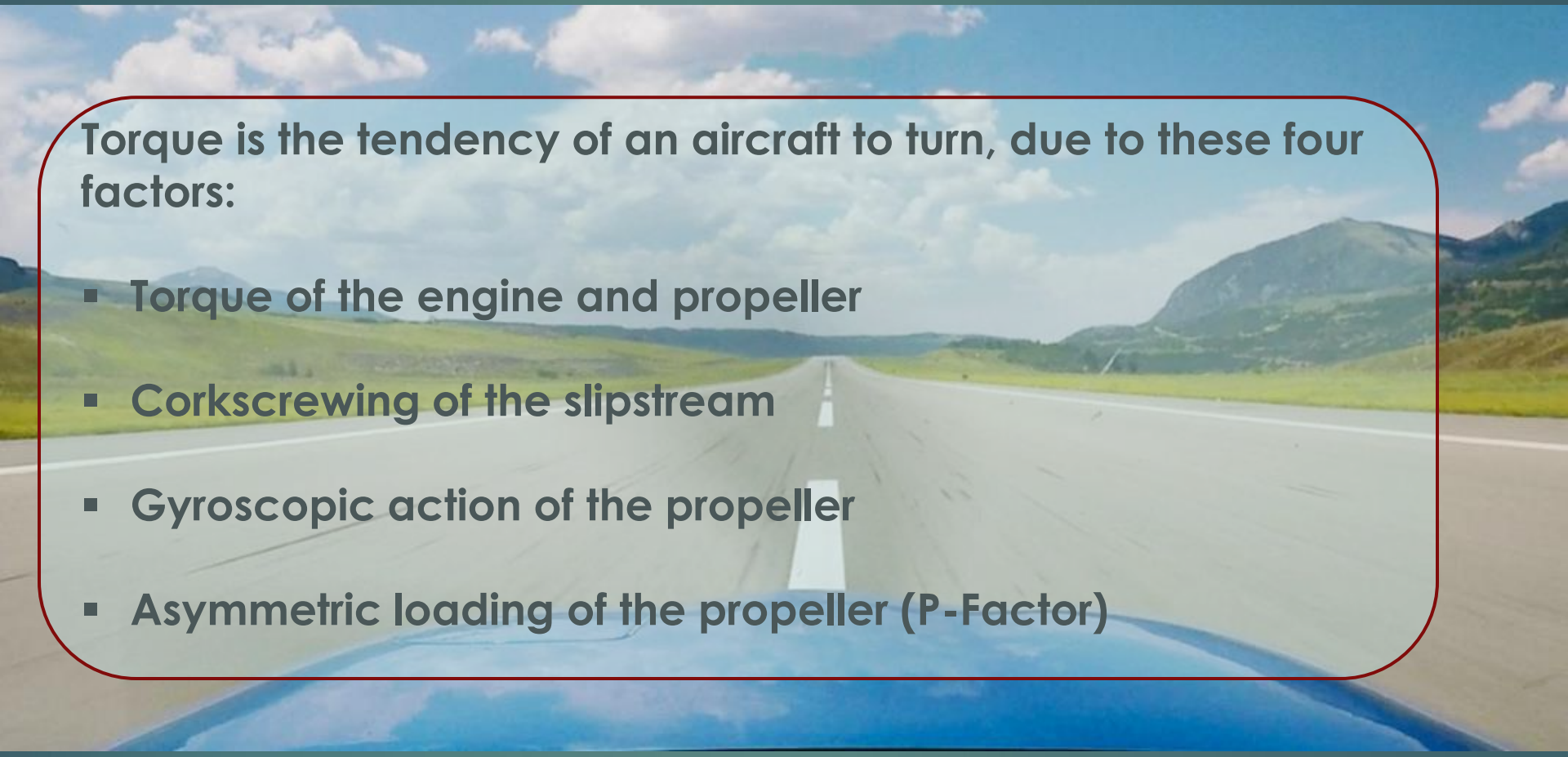
Propellers and Torque Tendencies



Torque is the tendency of an aircraft to turn, due to these four factors:

- **Torque of the engine and propeller**
- **Corkscrewing of the slipstream**
- **Gyroscopic action of the propeller**
- **Asymmetric loading of the propeller (P-Factor)**

Propellers and Torque Tendencies



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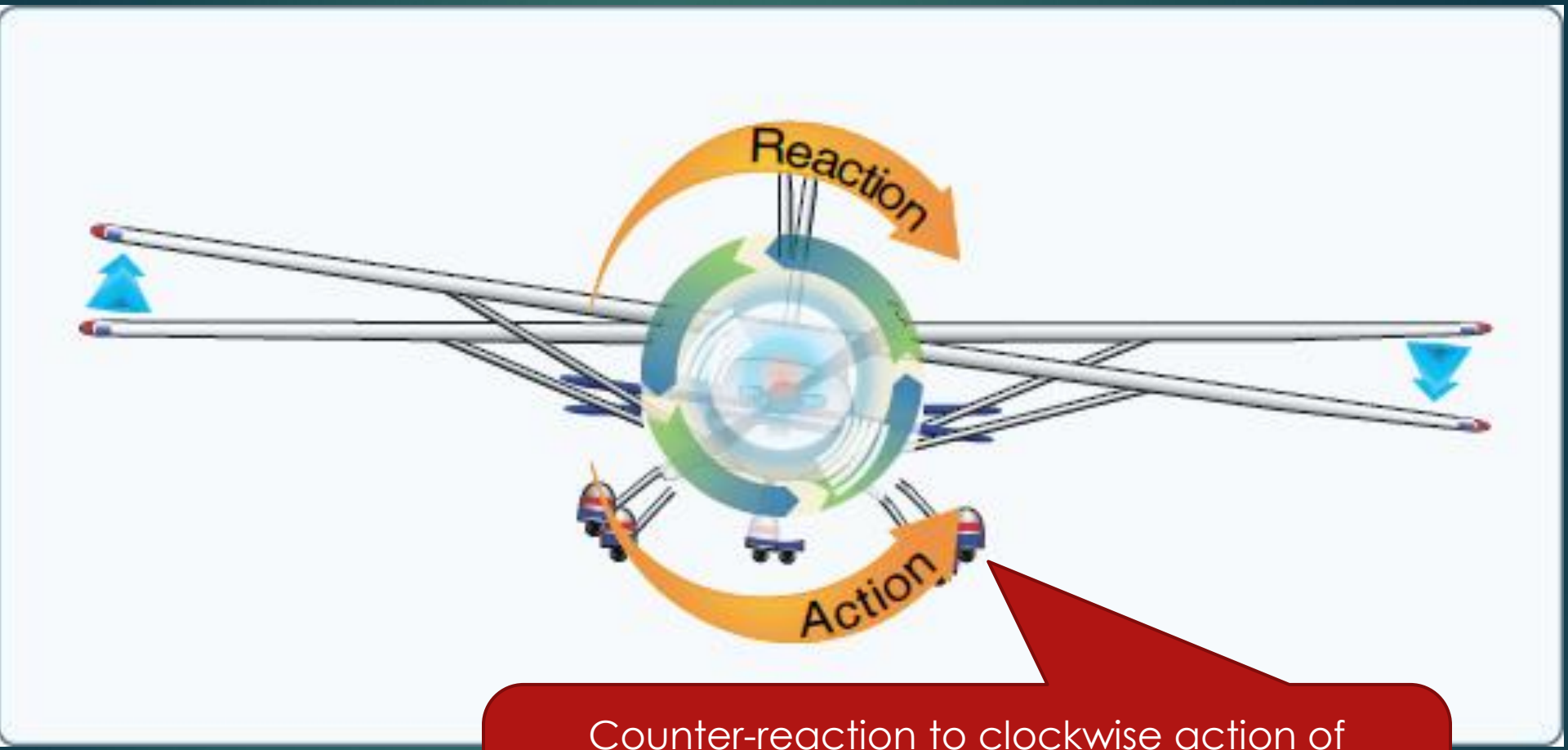
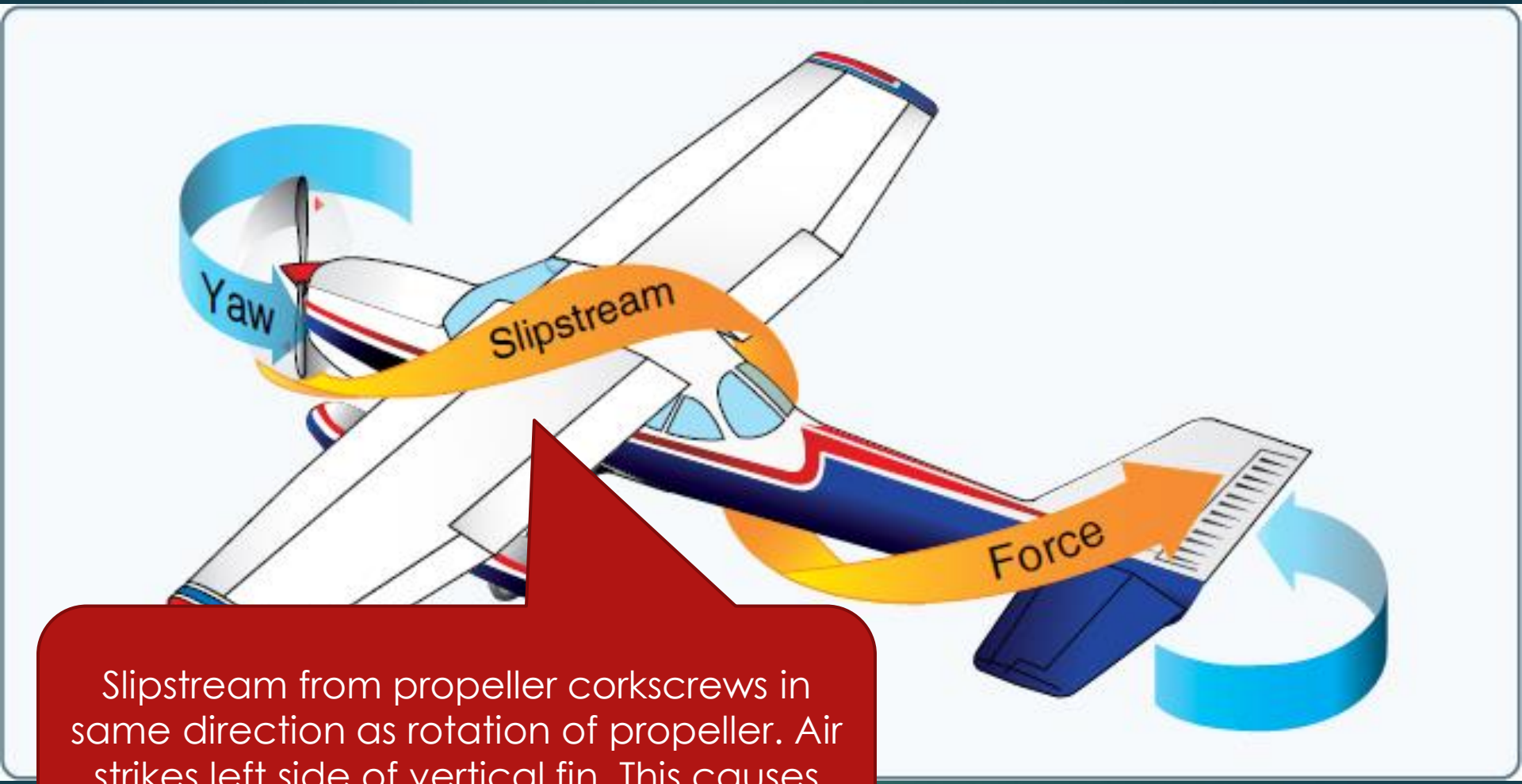
On most general aviation aircraft in the US the engine driveshaft and propeller turn clockwise from the point of view of pilot seated in the cockpit. The following assumes this is so.

Torque Reaction: Newton's 3rd Law



Counter-reaction to clockwise action of engine/propeller puts more weight on left wheel, creating more friction. This causes plane to veer left.

Spiralling Slipstream

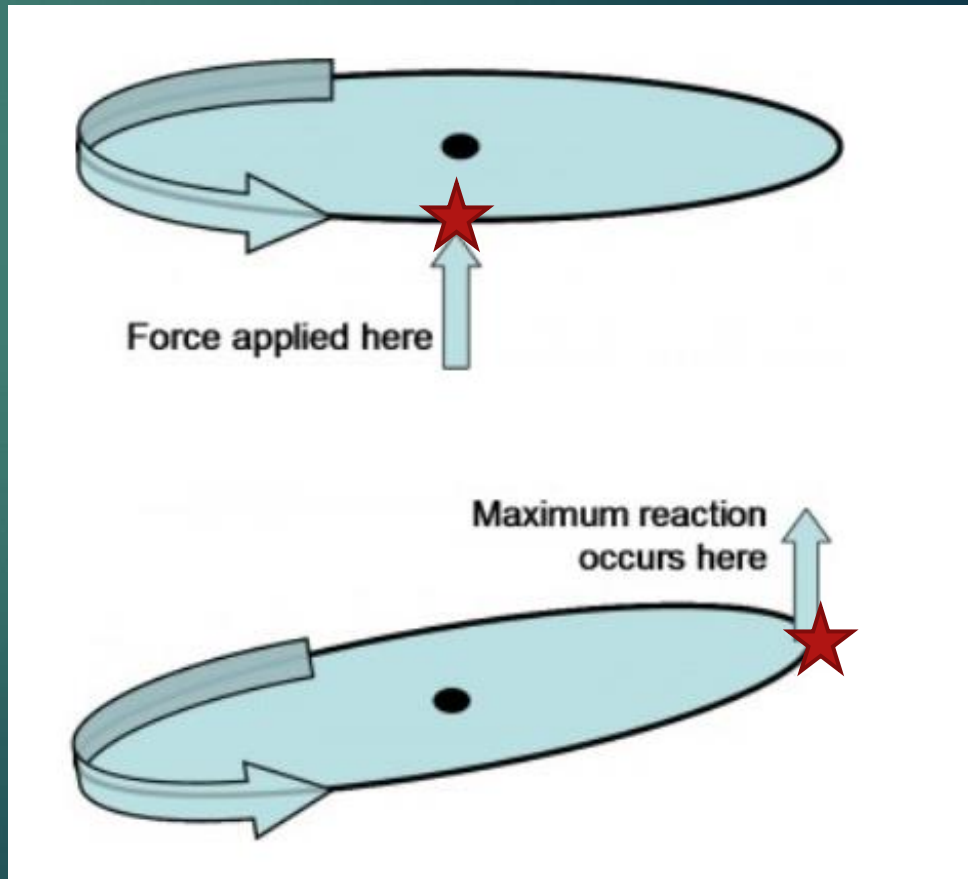


Slipstream from propeller corkscrews in same direction as rotation of propeller. Air strikes left side of vertical fin. This causes plane to veer left.

Gyroscopic Action

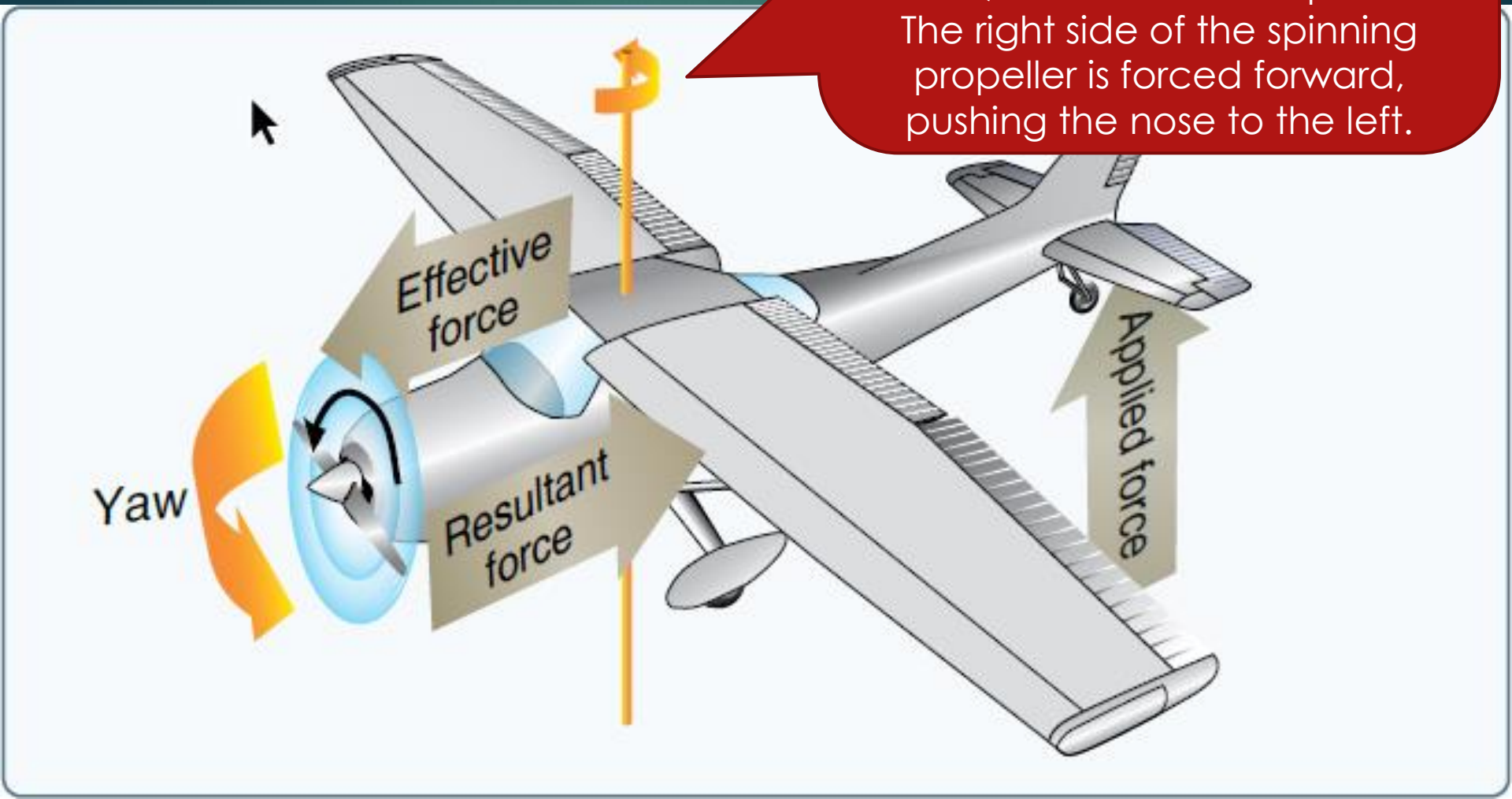
- Spinning engine and propeller are, in effect, a big gyroscope

- Gyroscopes exhibit the behavior that when a force is applied that affects the rotating edge, the maximum reaction to that action occurs 90 degrees later in the direction of rotation

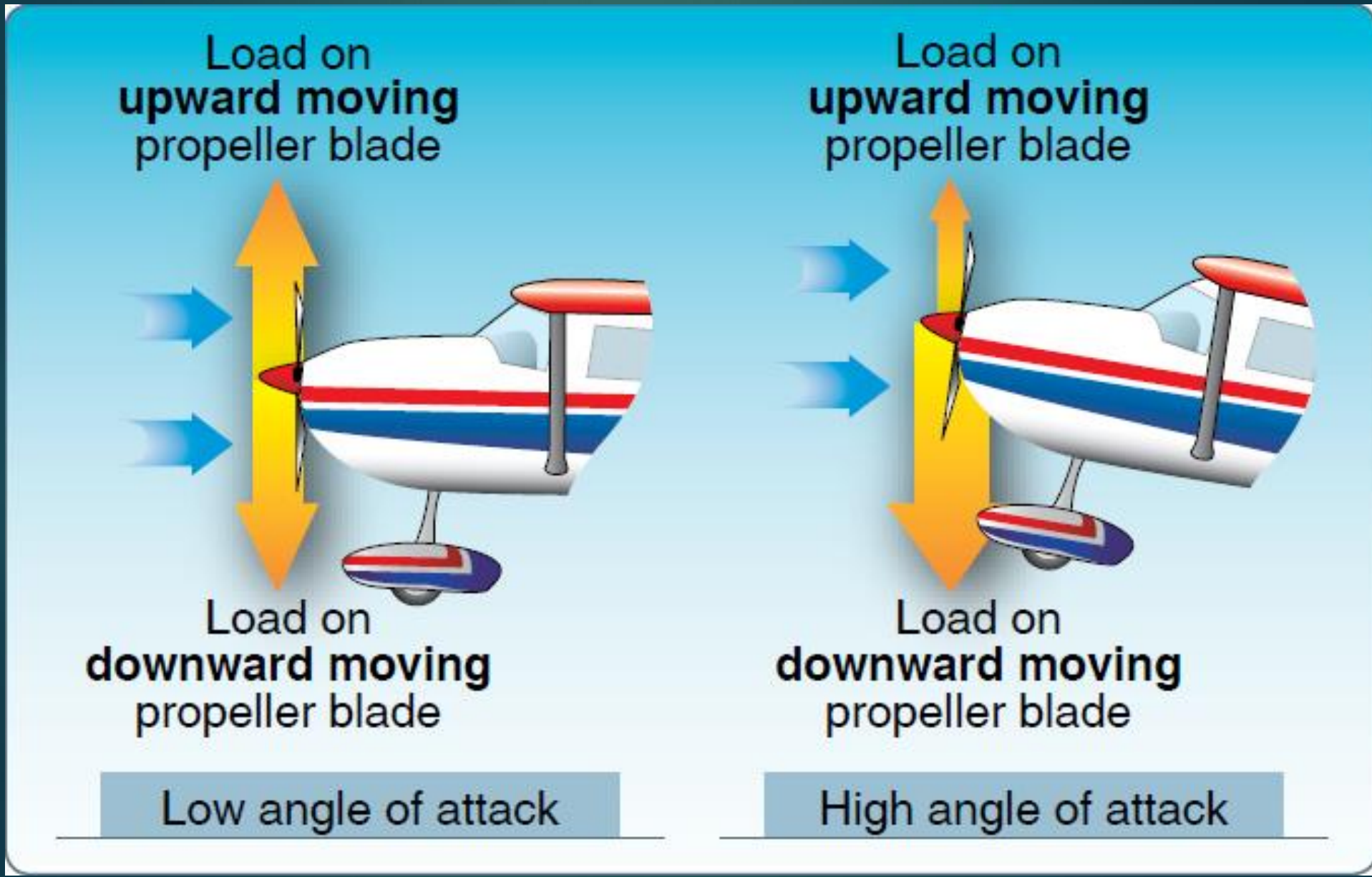


Gyroscopic Action

Changing the plane of rotation of the propeller (for instance when raising the tail during the takeoff roll) applies a force at the top of the rotation. The reaction occurs 90 degrees ahead, at the 3 o'clock position. The right side of the spinning propeller is forced forward, pushing the nose to the left.



Asymmetric Loading (P-factor)



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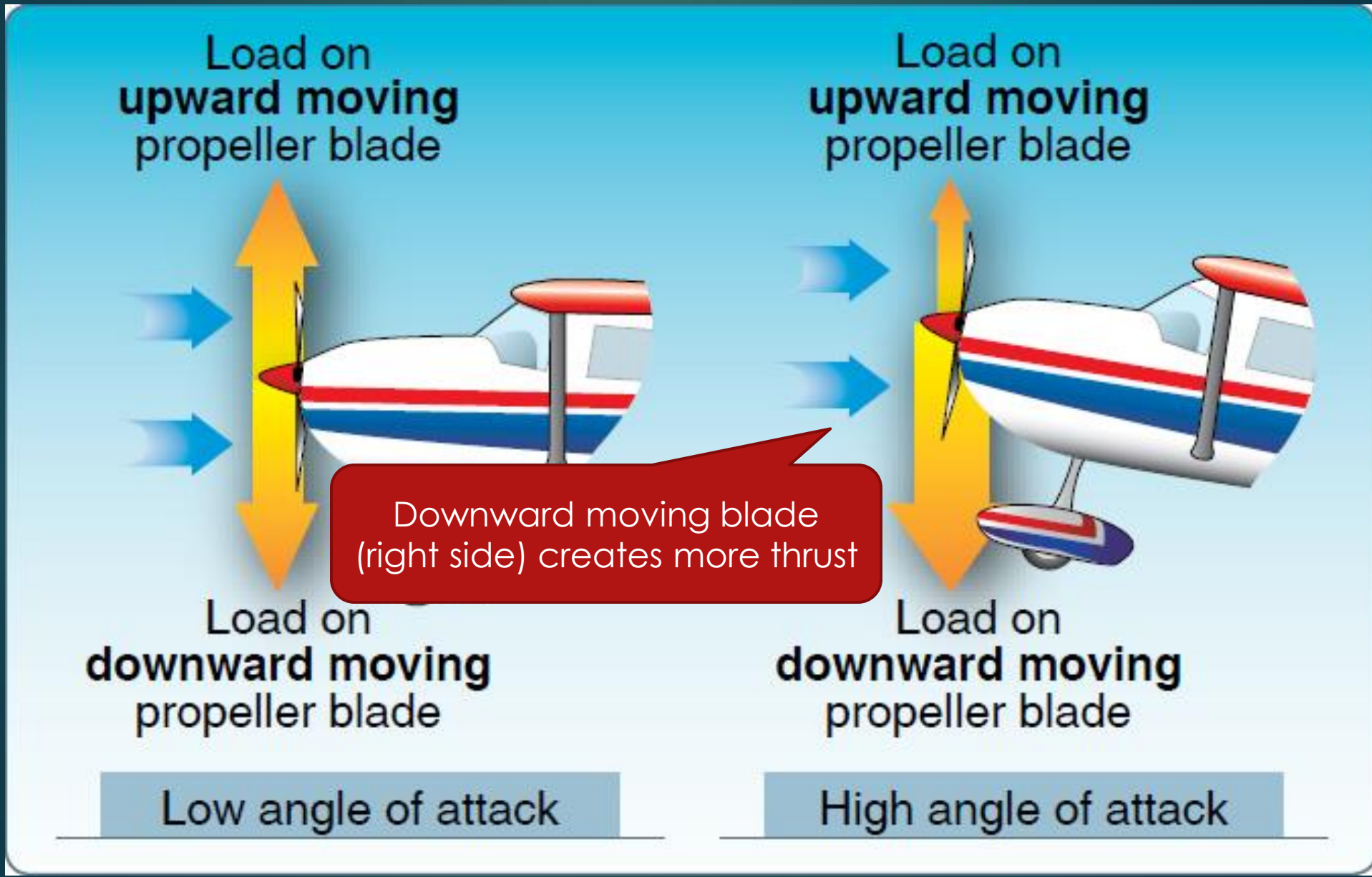


Drag

PARASITE DRAG

INDUCED DRAG

Definitions:

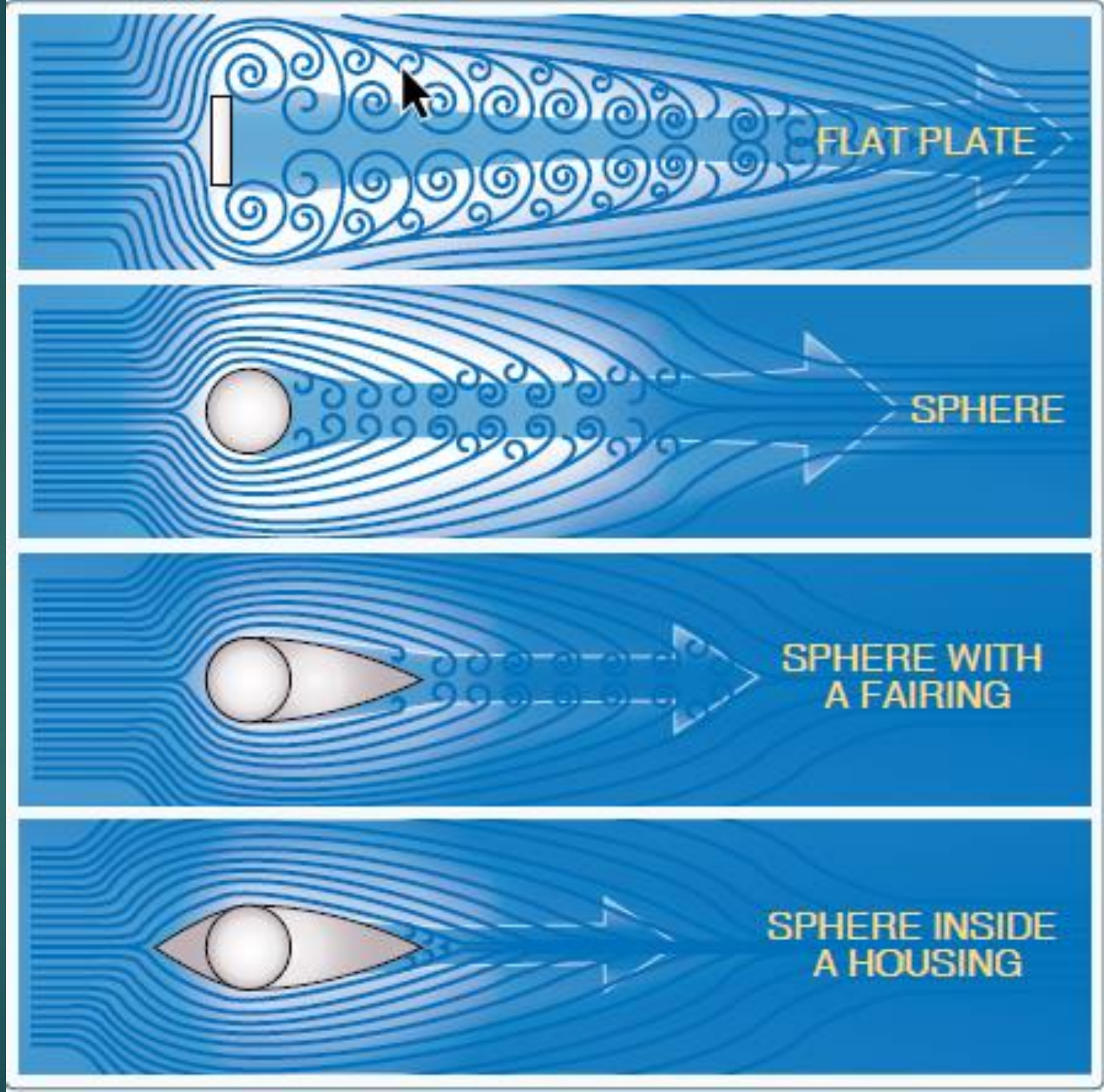
- Parasite Drag: that rearward force, opposing thrust, that is not a byproduct of producing lift
  - Displacement of air by body of aircraft
  - Turbulence in the airstream
  - Hindrance of air moving over the surface of the aircraft

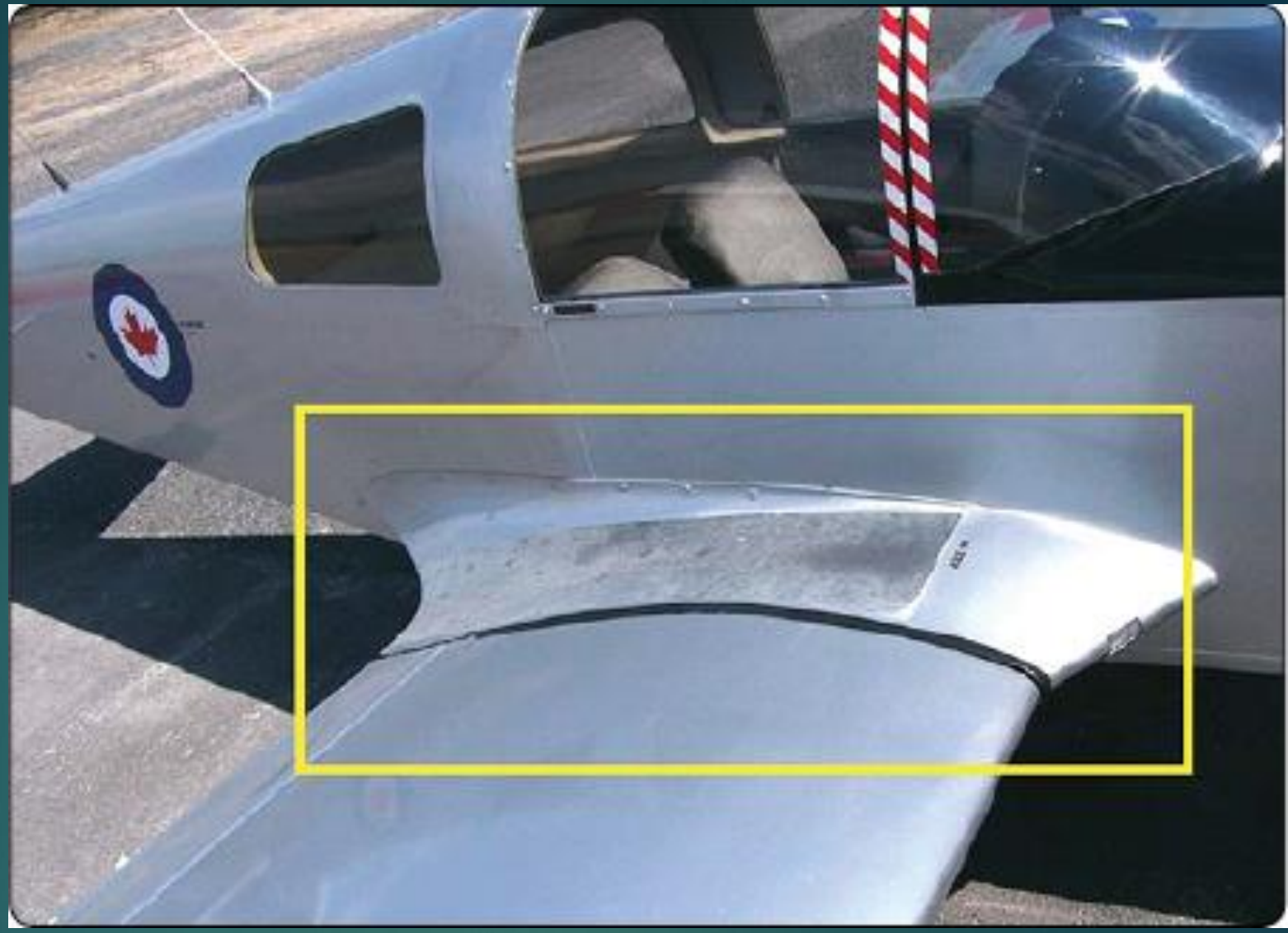
- Induced Drag: that rearward force that is produced as a necessary condition of developing lift

Parasite drag comes in three forms:

- Form drag
- Interference drag
- Skin friction

Form drag: generated by the airflow around the aircraft's shape





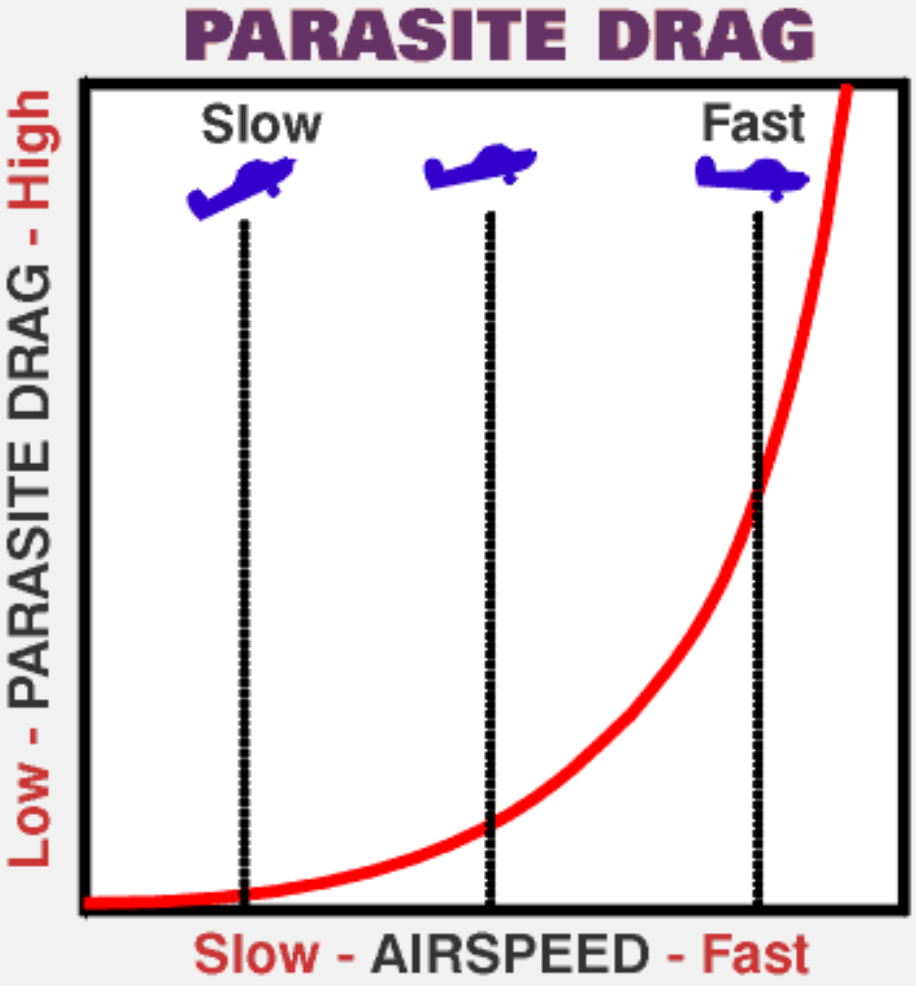
Interference drag: generated by intersection of airstreams that create eddy currents.

Skin friction drag: resistance to movement caused by friction of air molecules against the surface of the aircraft.

Anything that makes the surfaces smoother reduces friction drag:

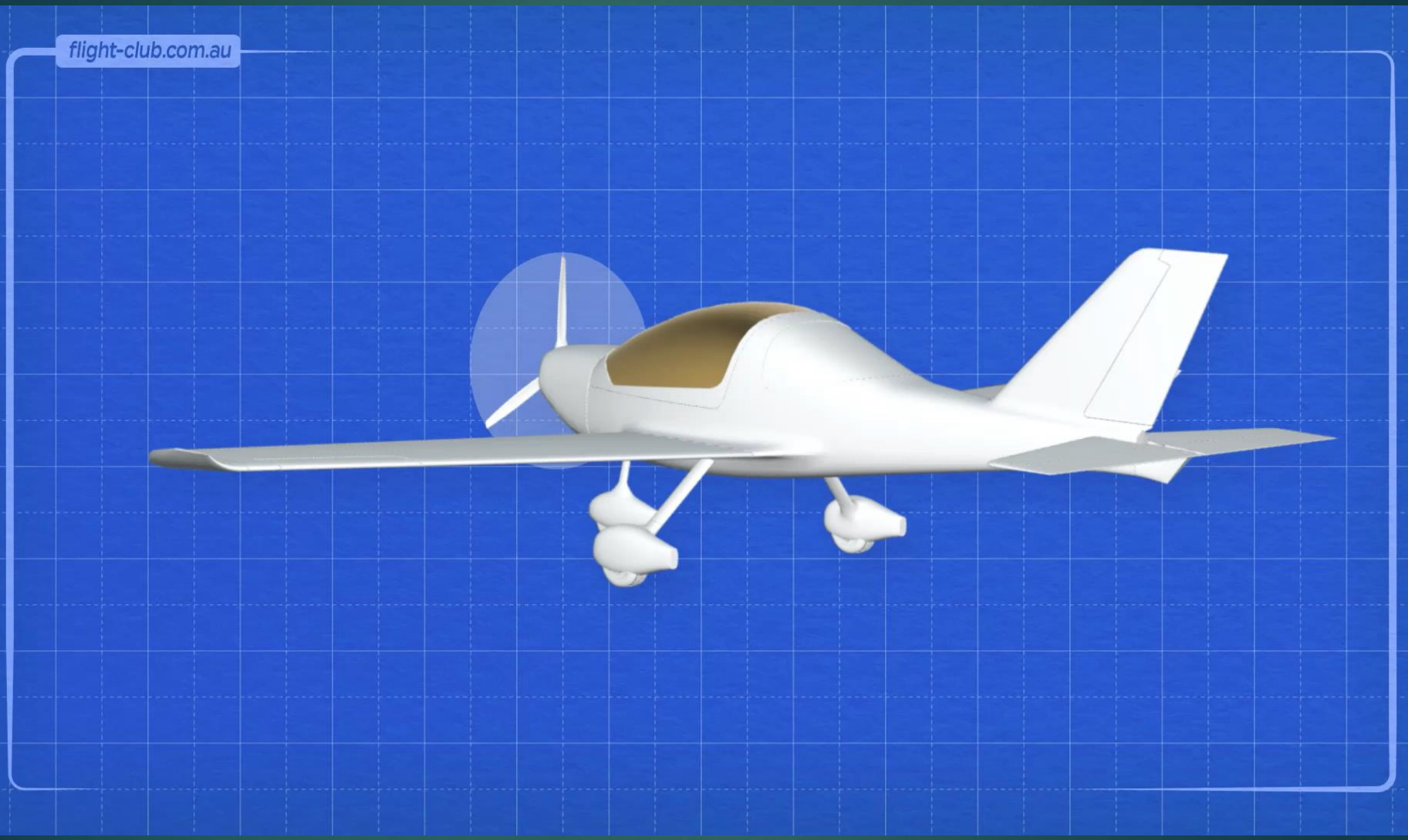
- Flush rivets
- Removal of protruding irregularities
- Smooth glossy finishes, such as paint
- Removal of dirt

PARASITE DRAG CURVE

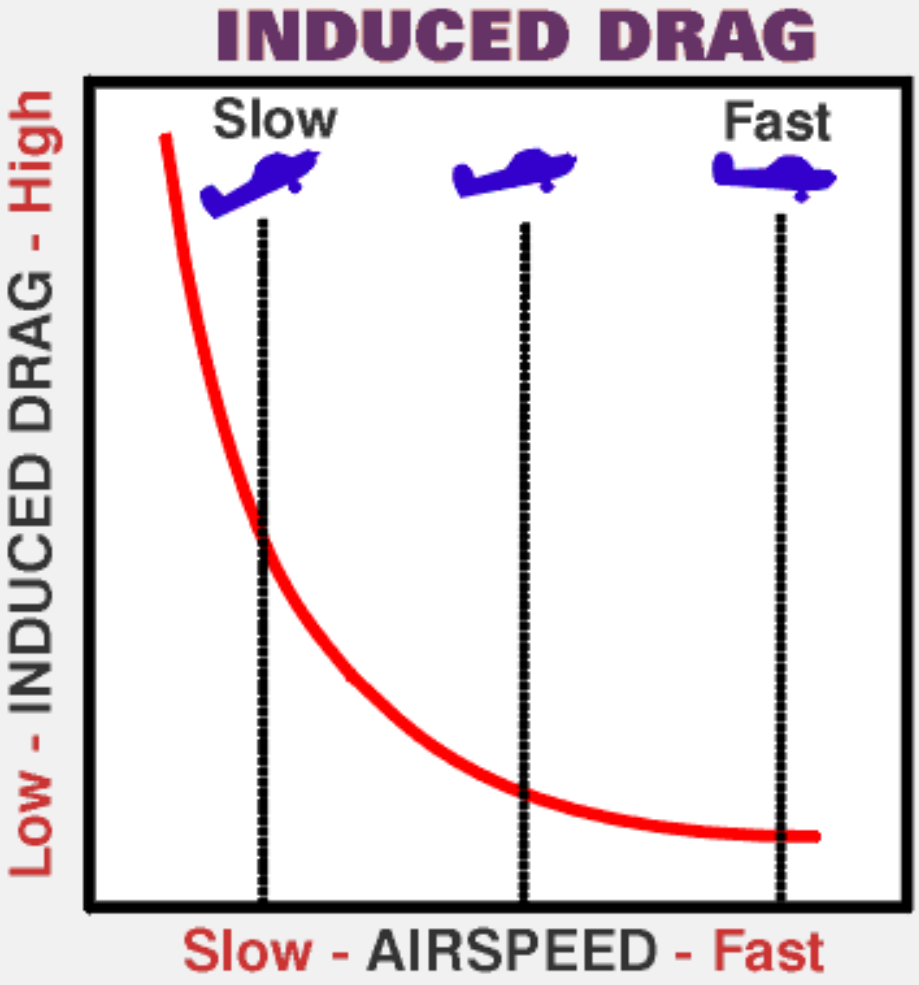


Induced Drag

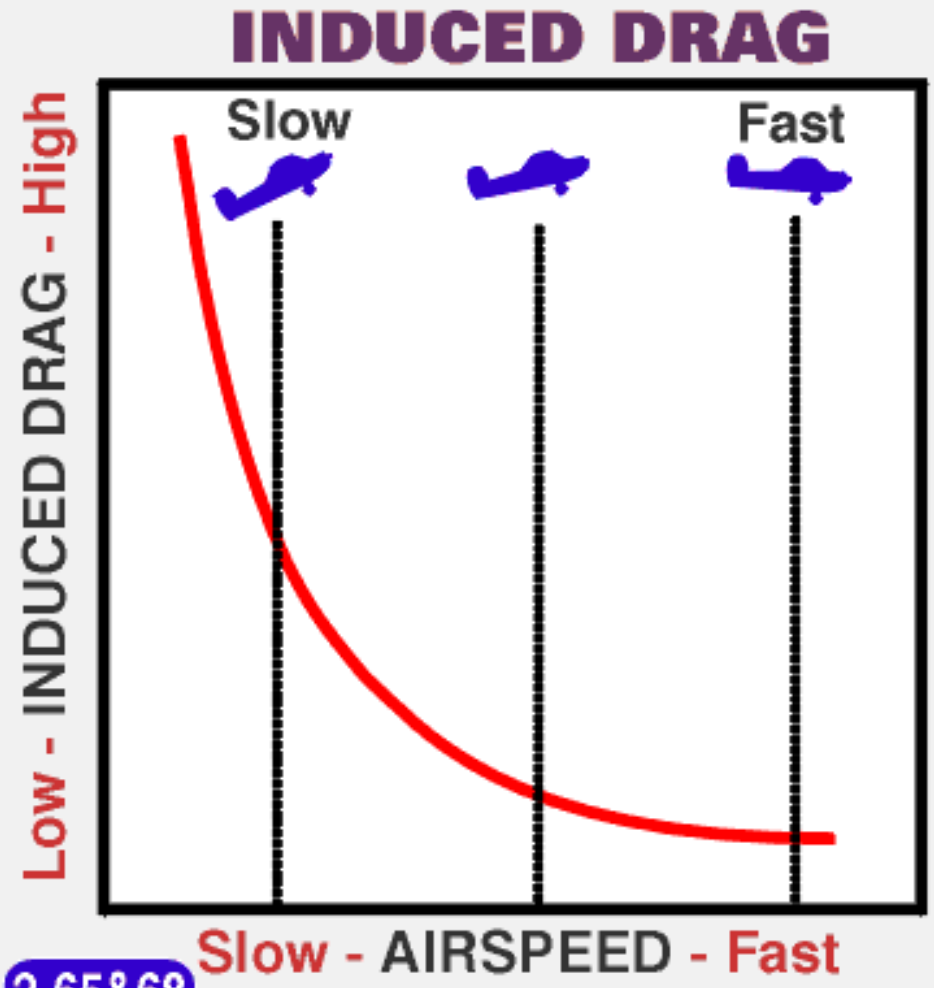
- No system that performs work is 100% efficient. This includes airfoils.
- The act of producing lift necessarily also produces drag as a byproduct

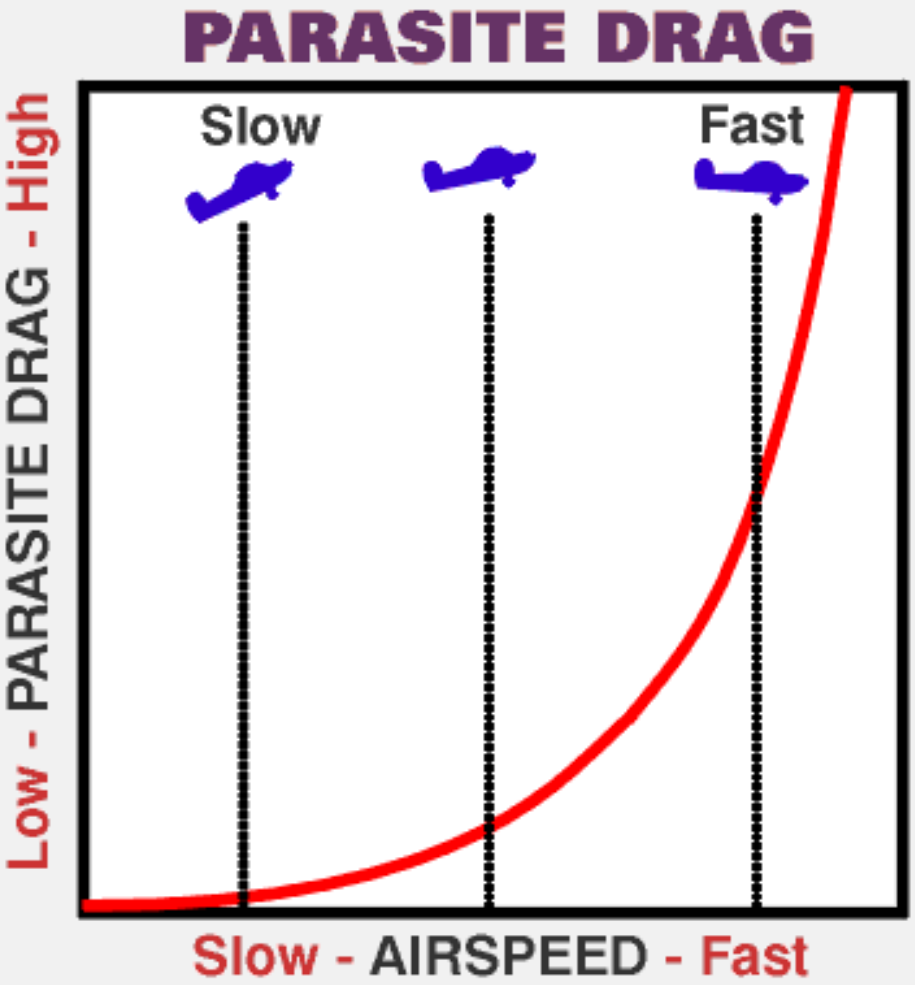

flight-club.com.au

INDUCED DRAG CURVE



INDUCED & PARASITE DRAG CURVES





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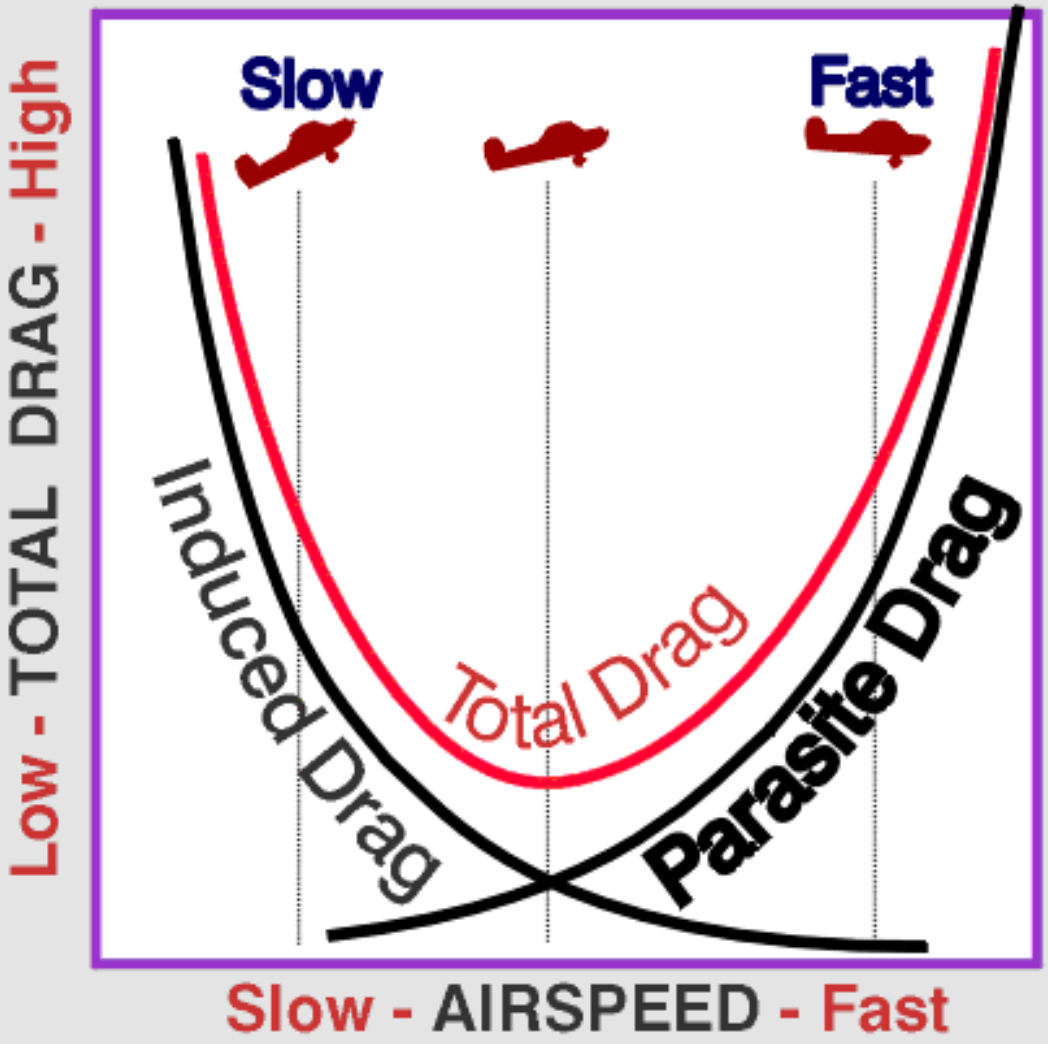
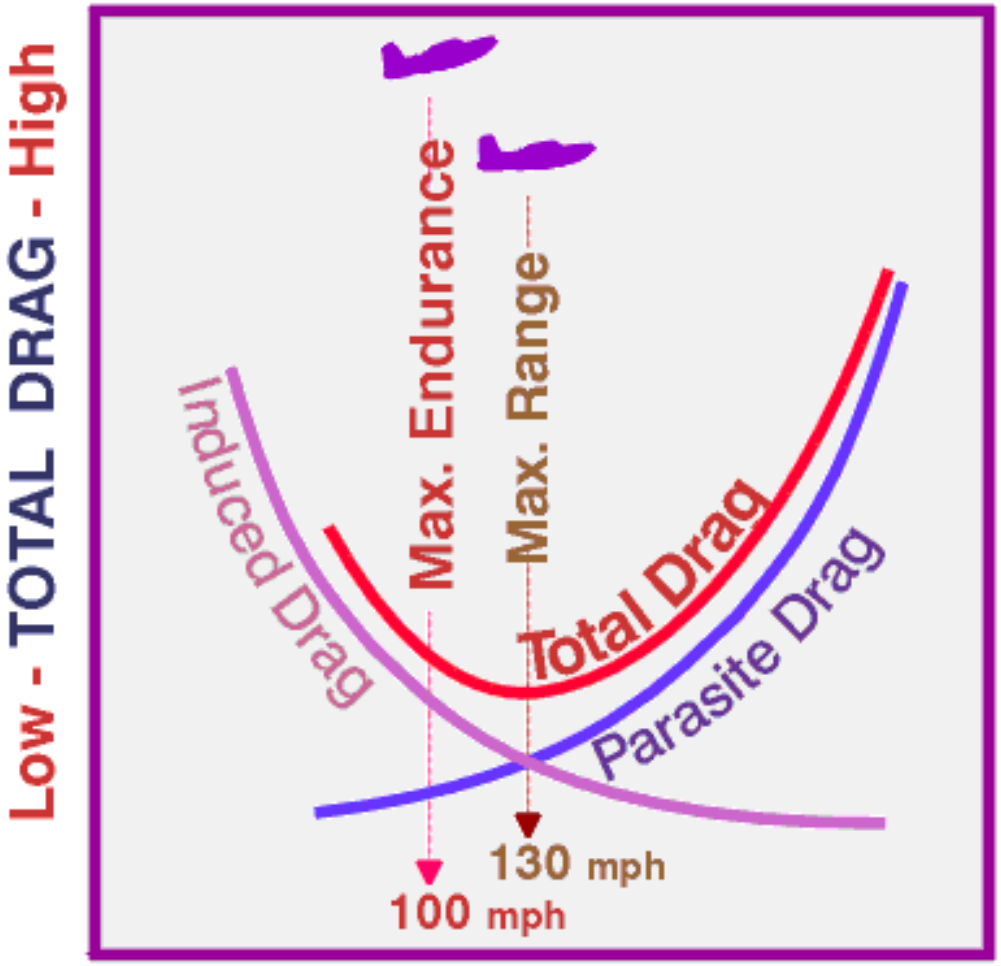
TOTAL DRAG

Parasite drag increases with increasing airspeed while induced drag decreases with increasing airspeed.



2-36

RANGE & ENDURANCE SPEED FOR A TYPICAL HIGH PERFORMANCE AIRCRAFT



The Four Forces Again

- V SPEEDS
- FACTORS AFFECTING PERFORMANCE

Aerodynamic Speeds

	Name	Definition	Example Value (C-172)
Vx	Best angle of climb	Greatest gain in altitude per distance travelled over ground	53 mph
Vms	Minimum sink rate	Least altitude lost per unit of time	60 mph
Vbg	Best glide	Least altitude lost per distance travelled over ground	65 mph
Vy	Best rate of climb	Greatest gain in altitude per unit of time	73 mph

Some comparisons

Minimum Sink (powered)		**Best glide (unpowered)**	
Aircraft	Ratio	Aircraft	Ratio
House sparrow	4:1	Northern flying squirrel	2:1
Wright Flyer	8:1	Air Canada Flight 143 (Gimli Glider)	12:1
Herring gull	10:1	Hang glider	15:1
Airbus A320 (cruise)	20:1	Great frigatebird	22:1
Rutan Voyager	27:1	Eta glider	70:1

Some other measures

Name	Calculation	Characteristics as measure +
Wing loading	Gross weight/wing area	Higher max cruise speed Greater stability in turbulence Higher stall speed Longer TO/landing distance
Power loading	Gross weight/ horsepower	Lower fuel consumption Greater endurance Lower cruise speed Longer takeoff roll Lower climb rate
Carson speed	Best glide speed * 1.32	Cruise speed that delivers best fuel economy

Stability

- AXES OF STABILITY
- STATIC VS DYNAMIC STABILITY

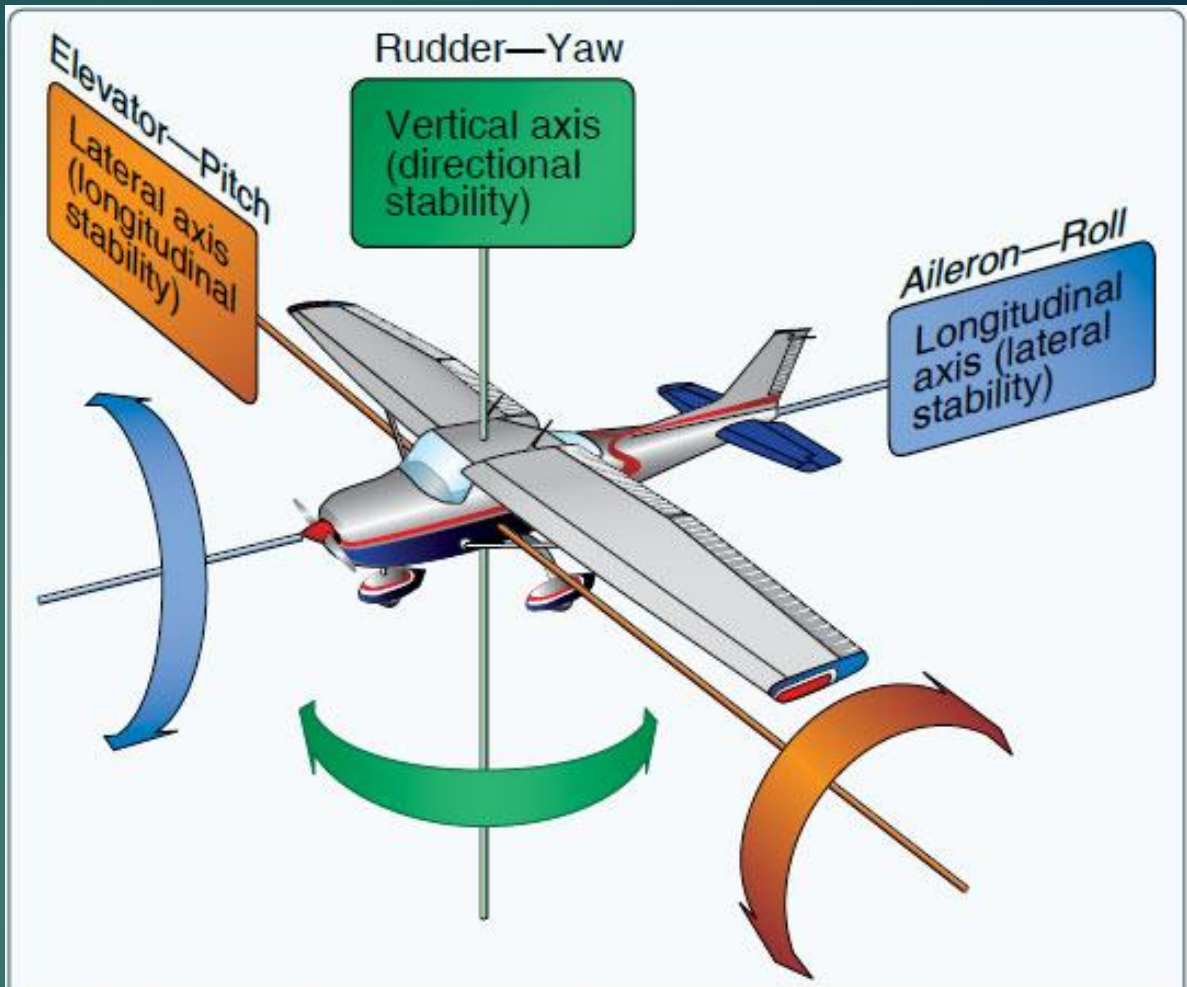
Stability: Definitions

- Stability is the way a body reacts in response to a disturbance of its equilibrium.
- In an aircraft, this means its tendency to correct for changed conditions and to return to or to continue on the original flight path.
- It is primarily an aircraft design characteristic.

Stability: Relevance

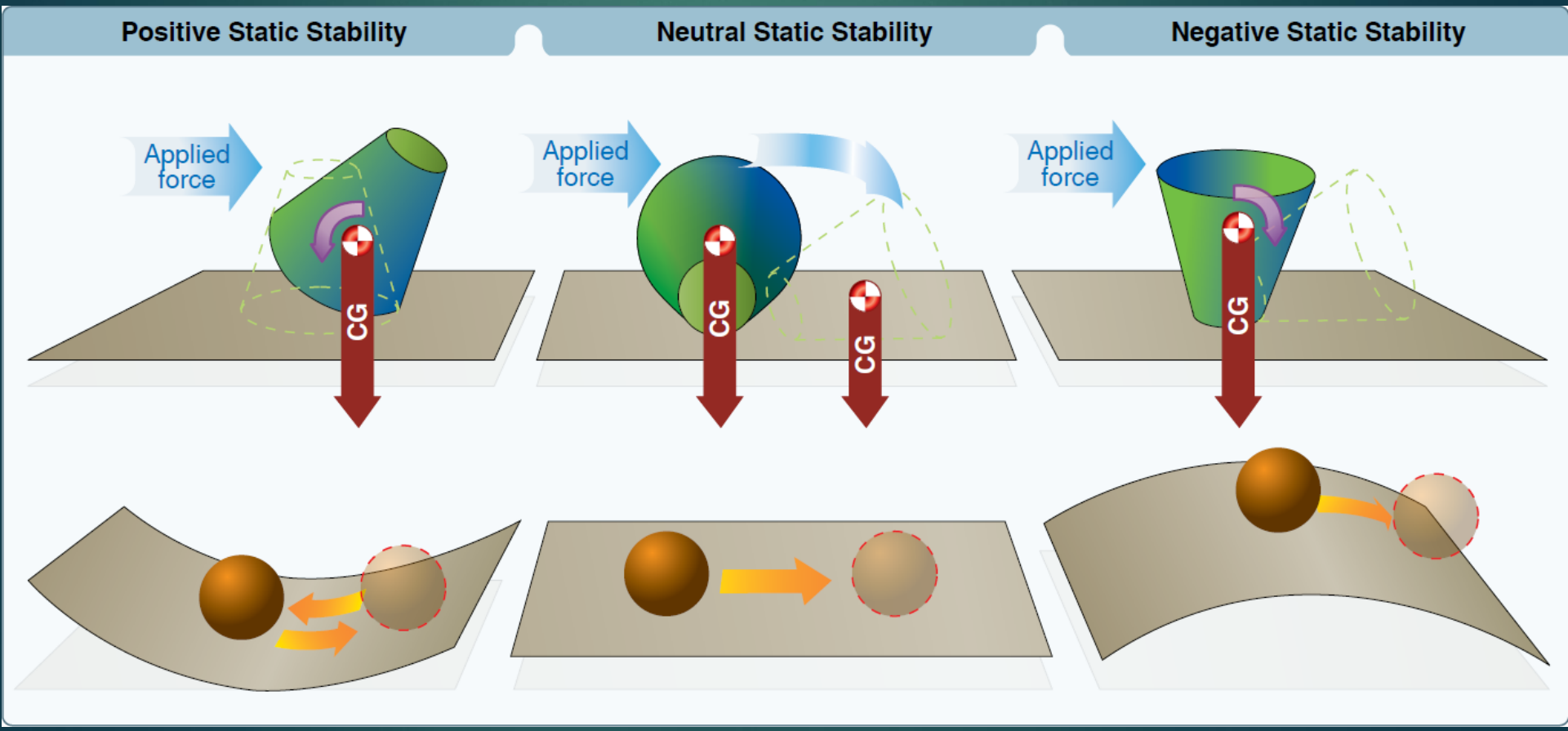
- If an aircraft is to be useful, it must be safely controllable without exceeding the pilot's strength or requiring exceptional flying ability.
- If an aircraft is to fly straight and steady along any arbitrary flight path, the forces acting on it must be in static equilibrium.
- There are two types of stability:
  - Static
  - Dynamic

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

Positive static stability	Neutral static stability	Negative static stability
The initial tendency of the aircraft to return to the original state of equilibrium after being disturbed	The initial tendency of the aircraft to remain in a new condition after its equilibrium has been disturbed	The initial tendency of the aircraft to continue away from the original state of equilibrium after being disturbed



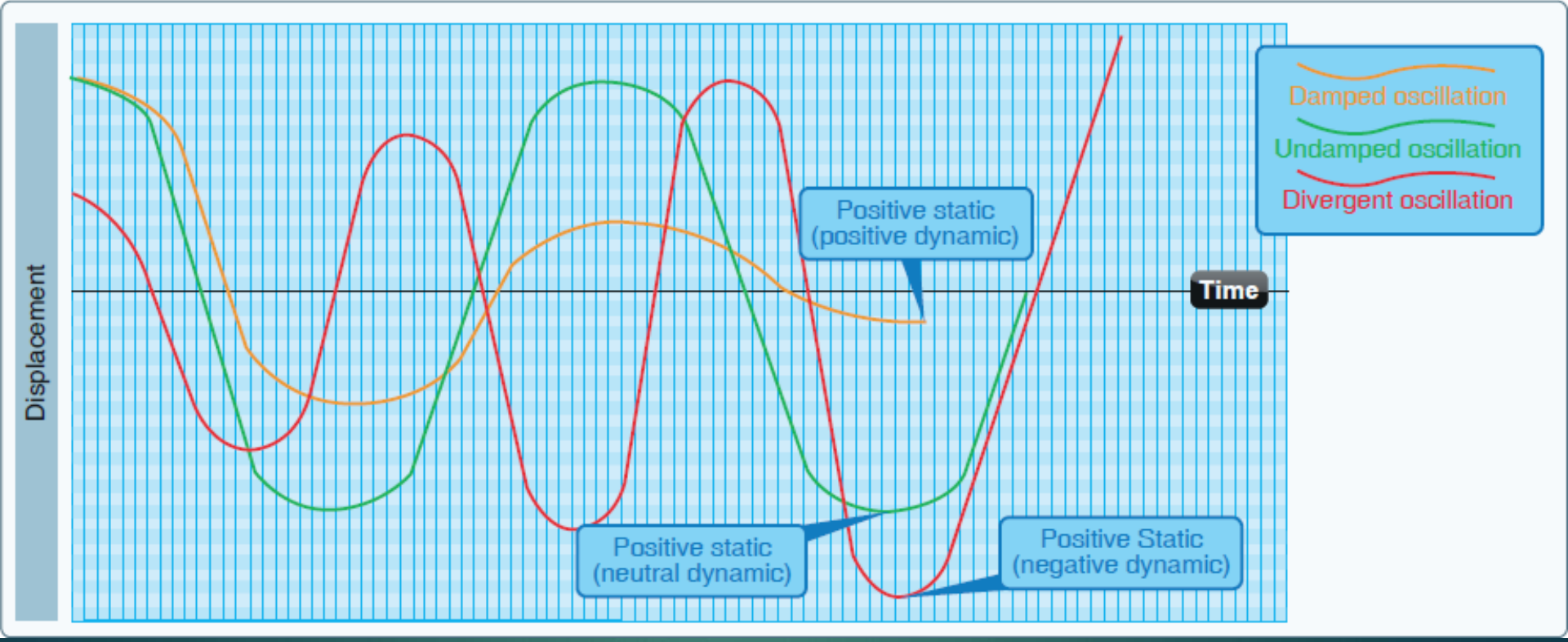
Dynamic Stability

- Dynamic stability refers to the aircraft response over time when disturbed from a given pitch, yaw, or bank

- Dynamic stability is only considered in a system that already exhibits positive static stability

Dynamic Stability

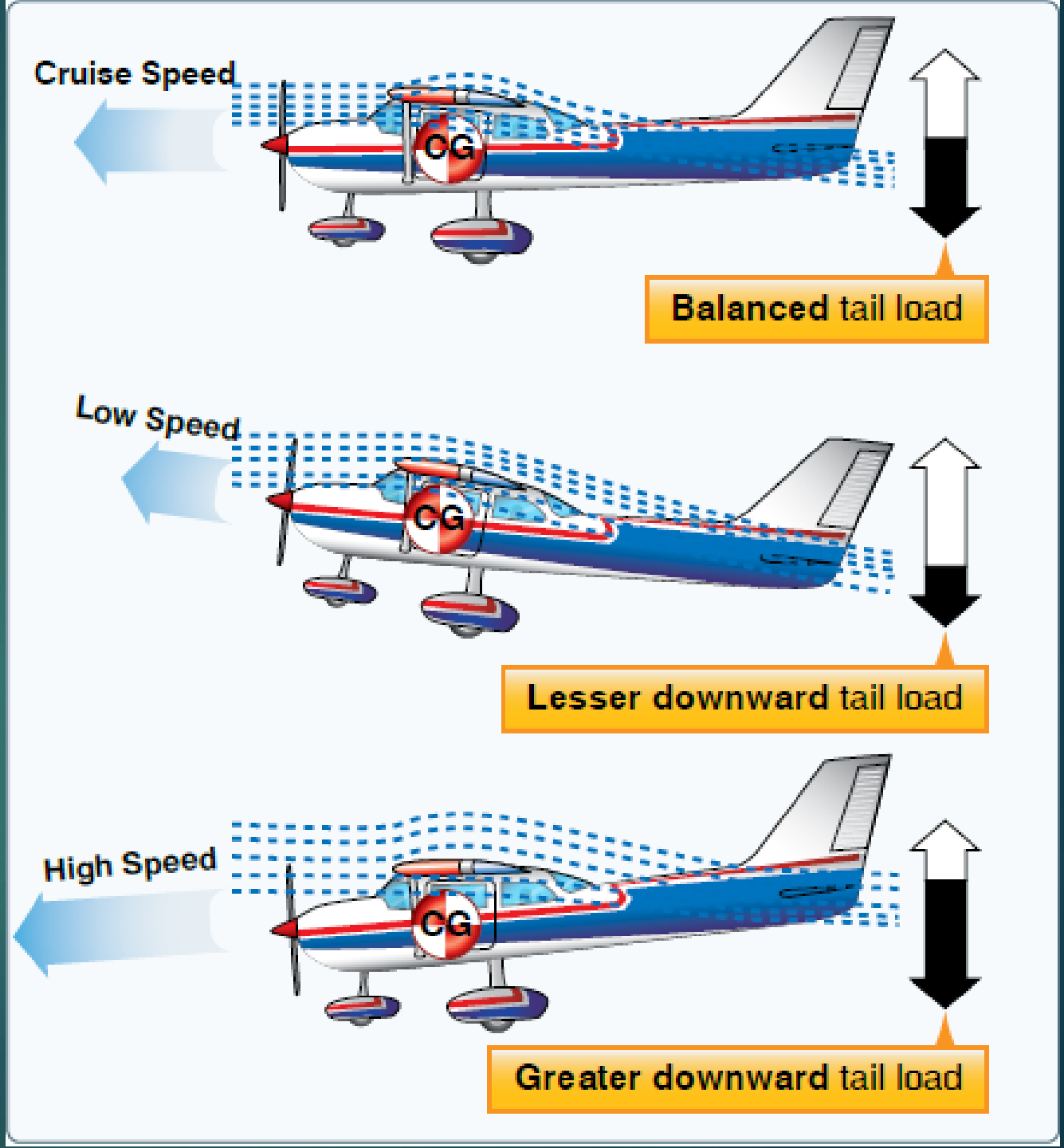
- Positive: the motion of the displaced object decreases in amplitude and returns toward the equilibrium state.
- Neutral : once displaced, the displaced object neither decreases nor increases in amplitude.
- Negative: the motion of the displaced object increases and becomes more divergent.


Displacement
Time
Damped oscillation
Undamped oscillation
Divergent oscillation
Positive static
(positive dynamic)
Positive static
(neutral dynamic)
Positive Static
(negative dynamic)

Longitudinal Stability (Pitch)

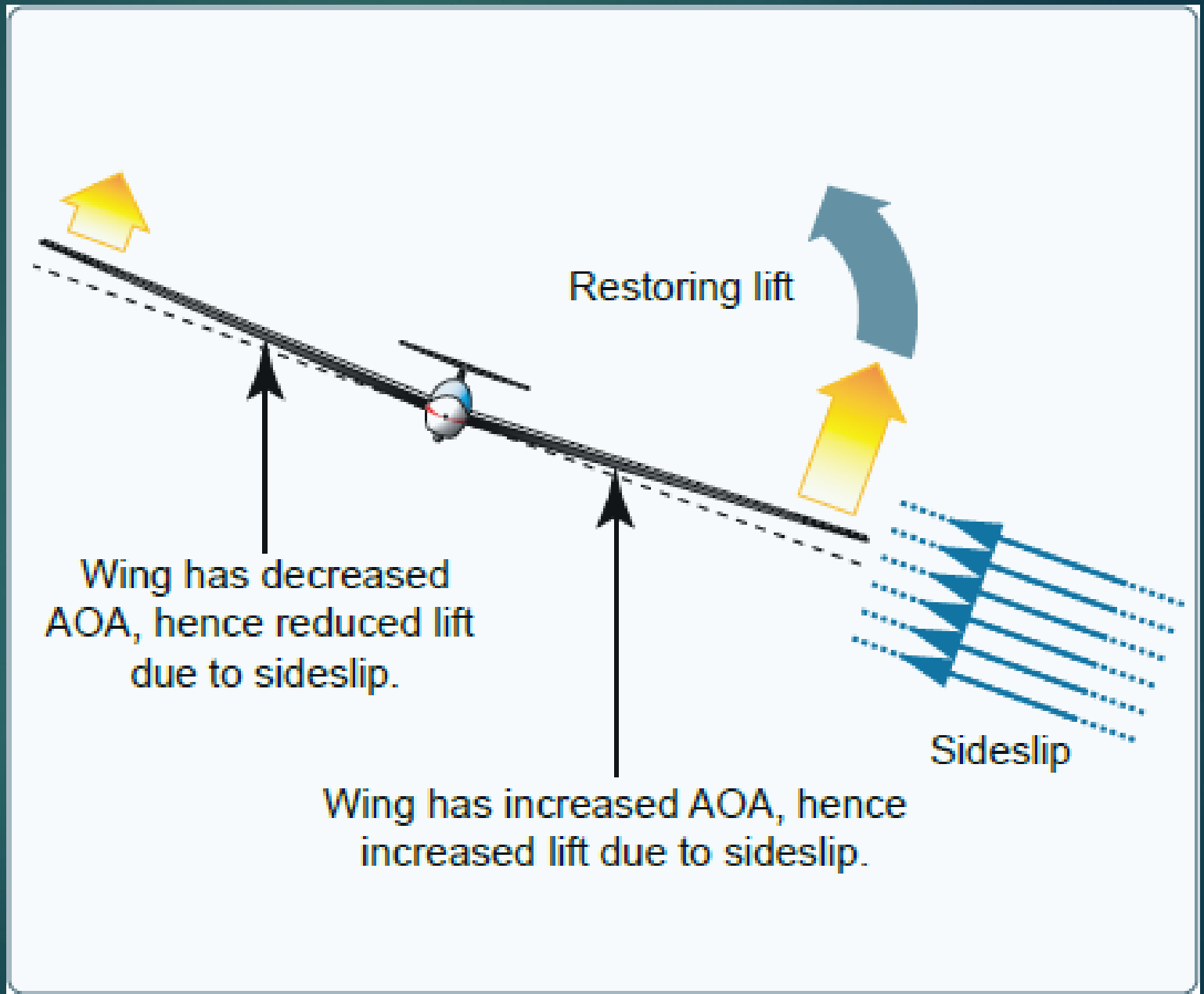
If nose is raised, airspeed slows and downwash over tail is decreased, causing nose to fall again.

The opposite happens if the nose is lowered.



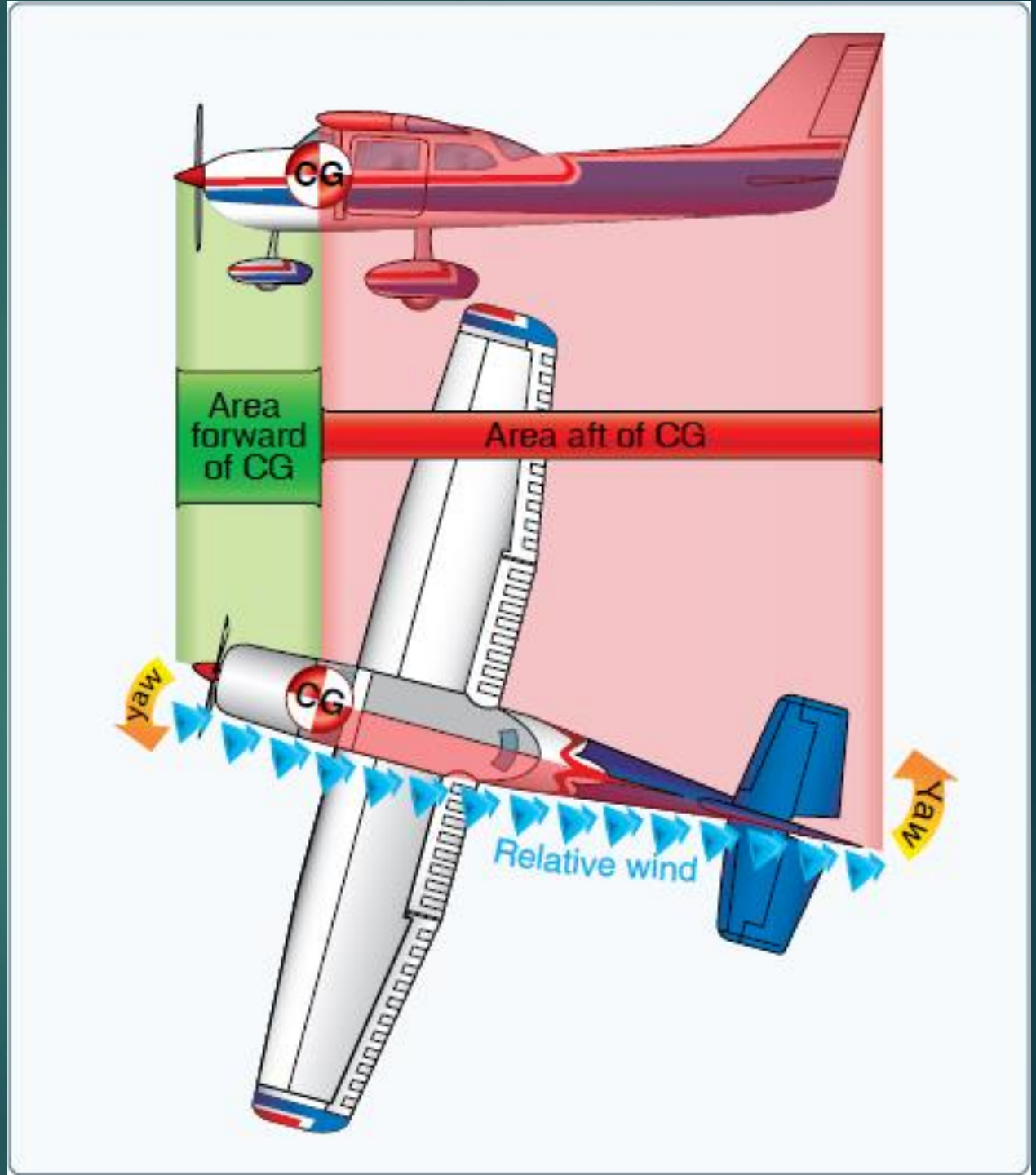
Lateral Stability (Roll)

Dihedral angle built into wings corrects a roll disturbance. The low wing has a greater angle of attack, creates more lift, and the plane levels itself.



Directional Stability (Yaw)

The vertical tail surface and side of the fuselage aft of the center of gravity counteract a yaw disturbance and push the nose back to its original heading, in much the same way a weathervane orients itself to the relative wind.



Next Session: Feb 9

- Quiz: Aerodynamics of Lift
- Presentation: Flight Instruments
- Reading:
  - Machado Chapter 5
  - Pilot's Handbook Chapter 8