The Physics of Flight

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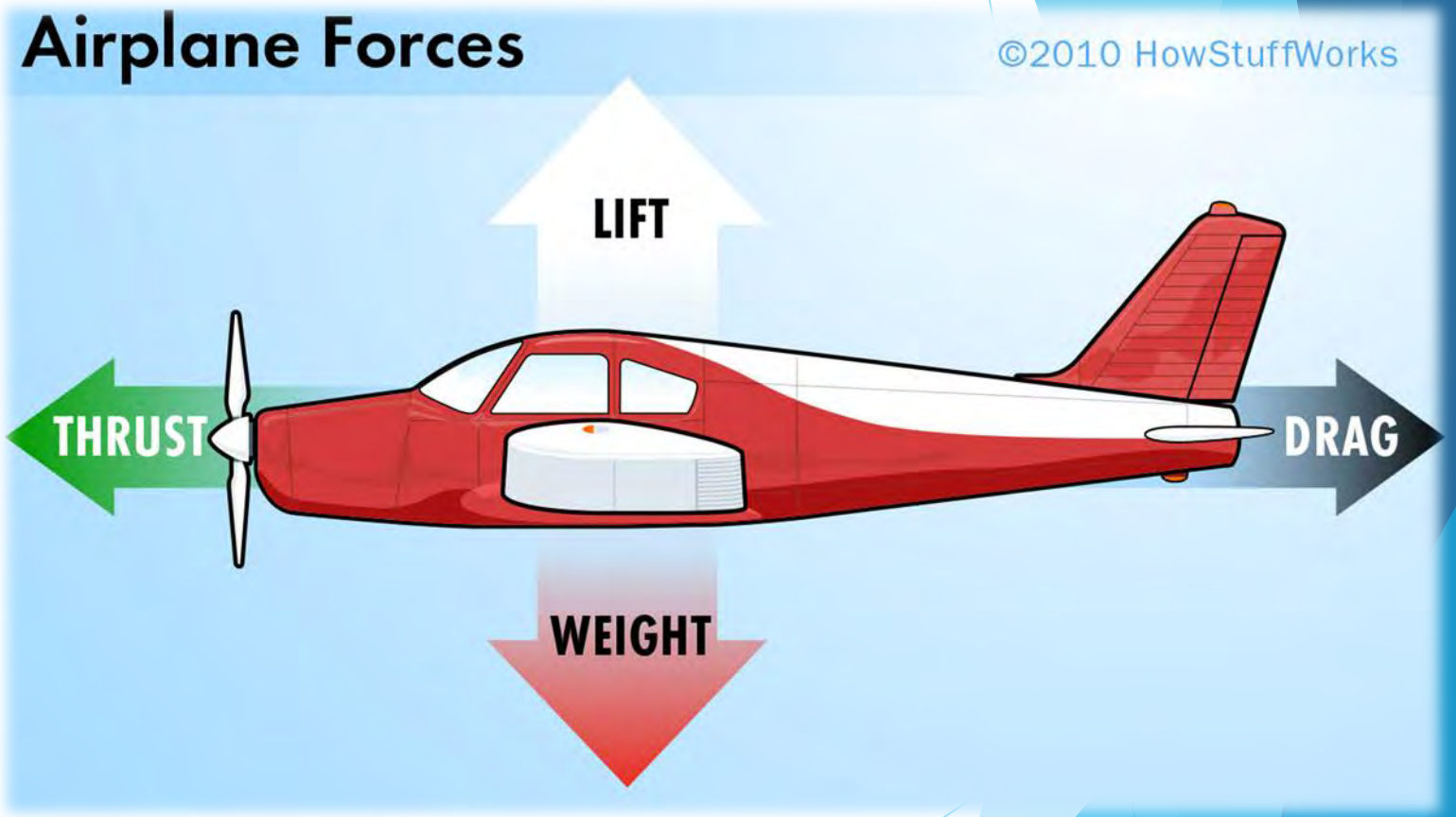
The Four Forces of flight

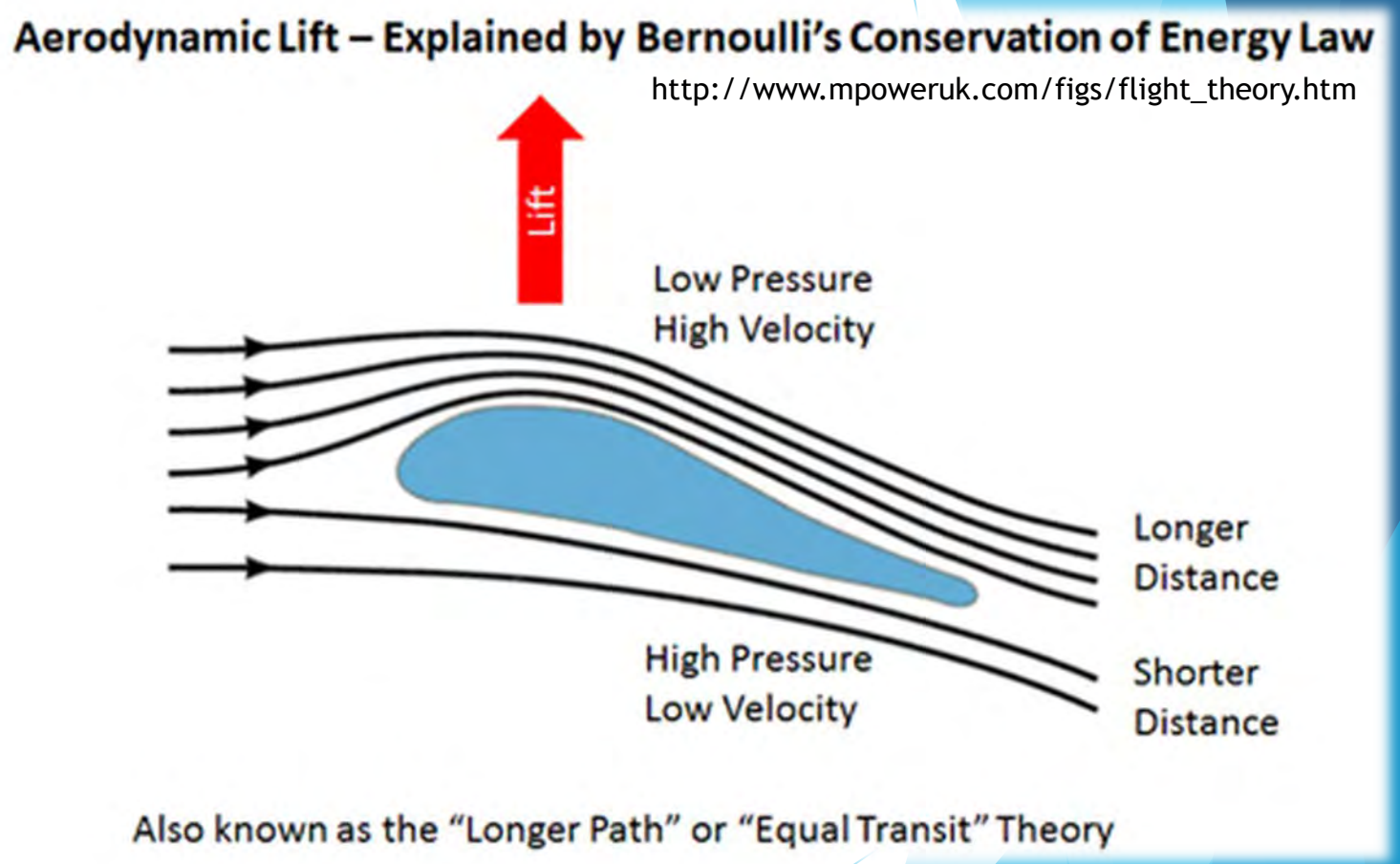
- Lift – Created by an airfoil.
  - Fixed wings – Forward movement from thrust.
  - Rotary Wings (‘copter) – Rotating propeller (prop) blades.
- Weight – Force of gravity which is opposed to lift.
- Thrust – Generated by the engine or motor.
- Drag – Opposed to thrust and caused by air pressure and friction between the aircraft and air.

These four forces combined are what determine the flight characteristics of an aircraft.

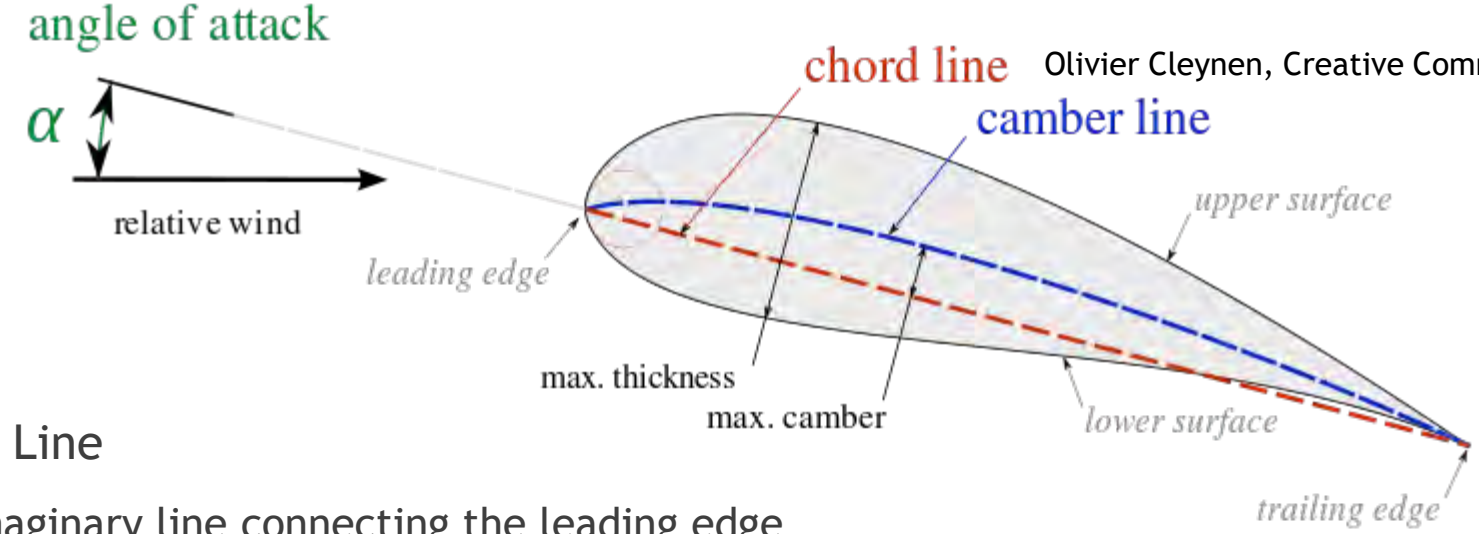


How is Lift Generated?

- Air is a fluid, like water but many time less dense.
- Bernoulli's Principle.
  - If fluid moving in a steady flow increases velocity its static pressure will be lowered.
  - Airfoils are curved so that the air must flow a longer distance on top than on bottom.
  - Since the air moving over the top of the wing must go further than the air under the wing in the same amount of time, a pressure differential is created.
  - Low pressure above the wing, and high pressure below.



Characteristics of an Airfoil



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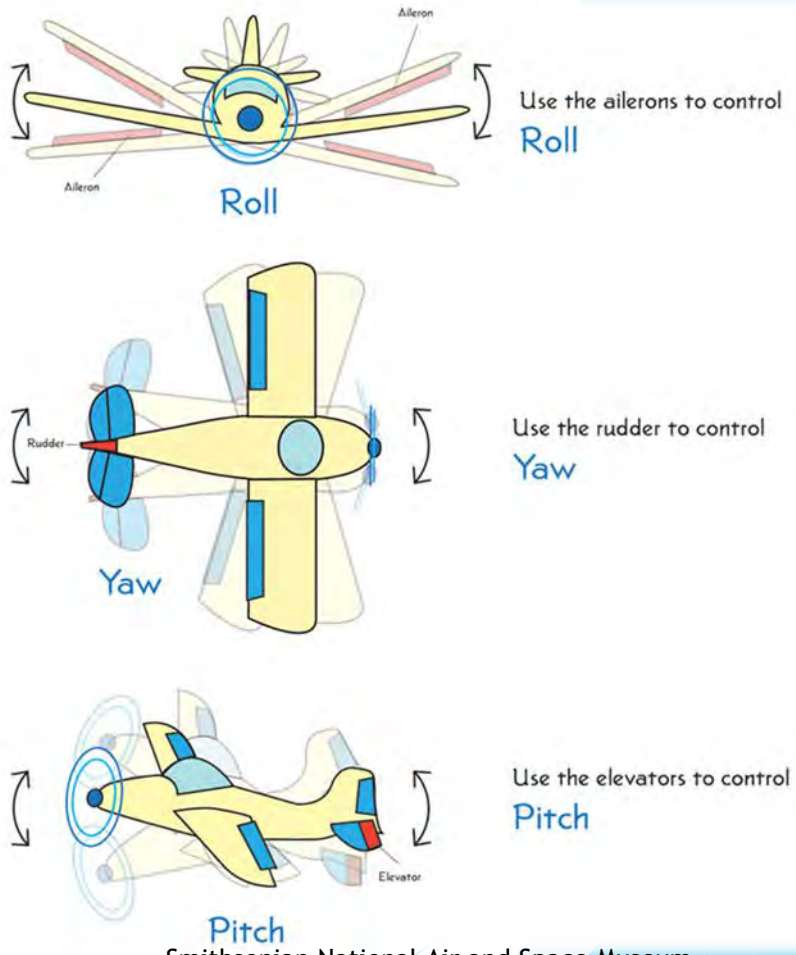
- Chord Line
  - Imaginary line connecting the leading edge of the airfoil to the trailing tip.
  - Often is not constant through the length of the airfoil.
- Camber
  - Describes the curvature of the airfoil.
  - Affects lift produced and stall speed.
  - Greater the camber = greater lift = greater thrust required.
  - Often is not constant through the length of the airfoil.
- Angle of Attack (α)
  - Angle between the chord line and the flow of air.
  - To a point, the great the α the greater the lift.
  - If the α is too high airflow separates from the airfoil and a stall results.

Controlling the Aircraft

- Roll, Yaw, and Pitch.
  - Control surfaces change the chord line, and thus the α.
  - Roll - Aileron
    - To roll left – left aileron up, right aileron down.
    - To roll right – left aileron down, right aileron up.
  - Yaw - rudder
    - Pivots the aircraft left and right.
    - Rubbers do not do much to turn the aircraft, after pressure on the rudder is release the aircraft mostly returns to its original orientation.
  - Pitch - Elevator
    - Moves up to ‘nose’ the aircraft up, and moves down to ‘nose’ the aircraft down.
- Flaps
  - Increase the (+) α.
  - Are not airbrakes.
  - Flaps allow the aircraft to increase (-) vertical speed without increasing airspeed or to increase lift for short/low speed takeoffs.



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How do Propellers Work?

- Propellers (props) are also airfoils.
- When spun by a engine or motor a prop produces lift in the same way as a wing.
- Turning the prop 90° this lift become thrust.
- The prop travels at different speeds down its length.
- Props also produce torque, a spinning force on the aircraft.
  - Fixed wing aircraft is corrected with the rudder.
  - Helicopters is controlled with the tail rotor and use it to control yaw.
  - With multi-copter this force is balanced between counter rotating props which are throttled independently to control yaw.

U.S. Navy

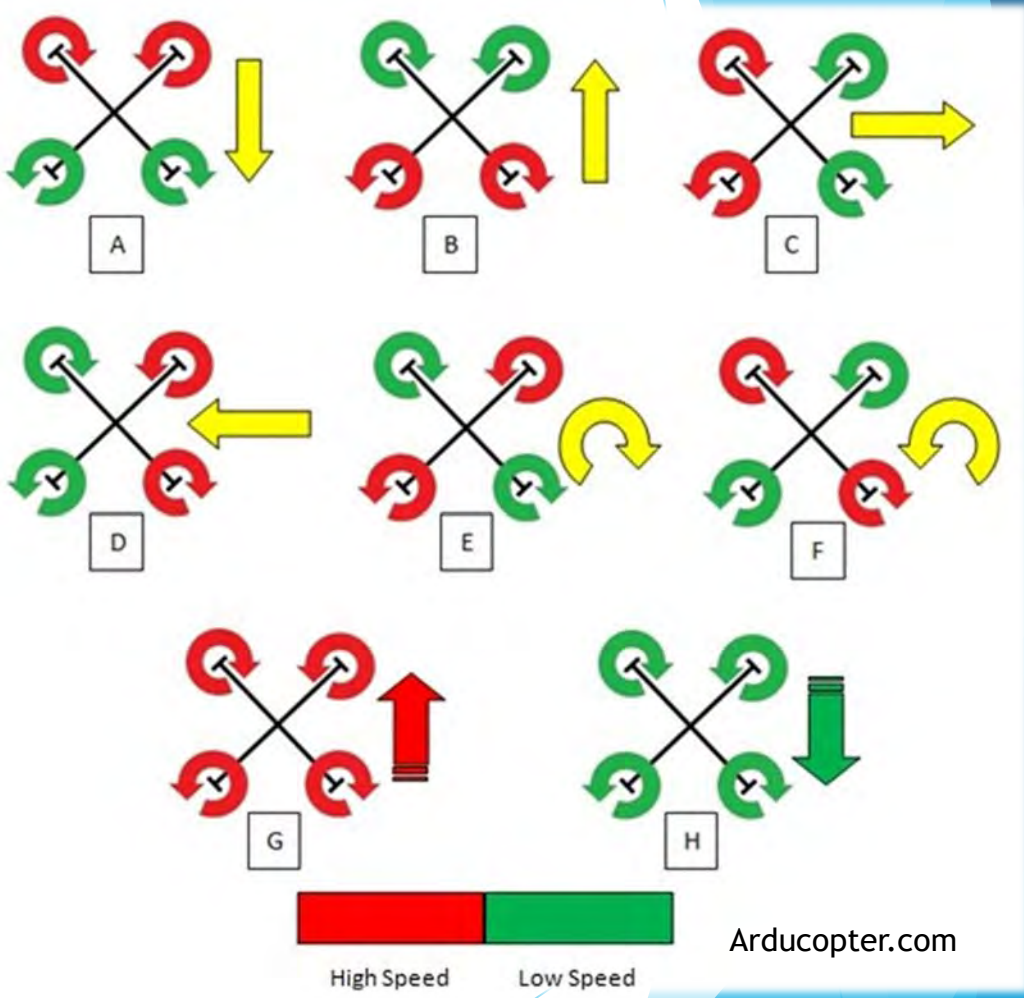
How do Propellers Work – Vortices

- Airfoils create vortices of swirling air as the air moves off of the airfoil, especially at the tip of the airfoil.
- When the airfoil is spinning (prop) the vortices from the top of the of the prop move outward. However the vortices from the bottom of the prop move inward.
- Ground Effect
  - When within ½ the airfoils length from the ground.
  - The vortices are deflected by the ground creating conditions of lower drag and greater lift.
  - This will cause a “floating” feeling when in ground effect.
- Dead Air
  - When descending, the vortices from the bottom of the prop can ‘gather’ at the hub and create an area of ‘dead air’.
  - This can cause wobbling and loss of lift.
  - The cause of many quadcopter crashes.
  - Prop-guards may cause ‘dead air’ at lower decent rates.
  - The Solution – Slower descents or keep some lateral movement.

Multicopter Movement.

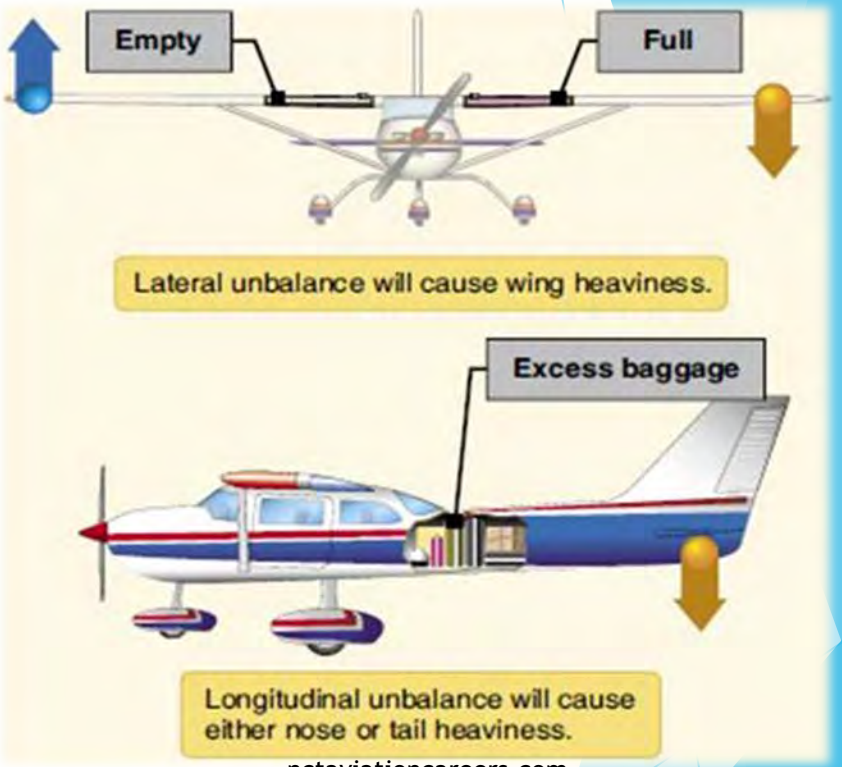
- Some motors spin clockwise and some spin counter-clockwise.
- Multicopter formats throttle the individual motors independently for control.
  A. Pitch up (move forwards) – Front motors throttle down, rear motors throttle up.
  B. Pitch down (move backwards) - Front motor throttle up, rear motors throttle down.
  C. Roll left (strafe left) - Left motors throttle down, right motors throttle up.
  D. Roll right (strafe right) – Left motors throttle up, right motors throttle down.
  E. Yaw left (turn right) – Clockwise motors throttle down, counter-clockwise motors throttle up.
  F. Yaw left (turn left) – Clockwise motors throttle up, counter-clockwise motors throttle down.
  G. H/G - Up/down – All motors throttle up/down equally.

Diagram – Front of quadcopter is down.



Weight and Balance

- Weight
  - Is the force of gravity acting upon a mass.
  - For a aircraft to fly it must be able to produce enough lift to over come it weight.
  - The heavier the payload to lower the performance of the UAV.
  - Never exceed the manufactures maximum weight.
- Balance
  - The distribution of weight defines the aircrafts Center of Gravity (CG).
  - The manufacture sets specifications and limits for each types of aircrafts CG.
  - Moving the CG beyond those limits may lead to poor performance, lack of control authority, or even a crash.
  - Many UAV manuals do not include CG information. For multicopters, in general, keep the CG low and in the center.



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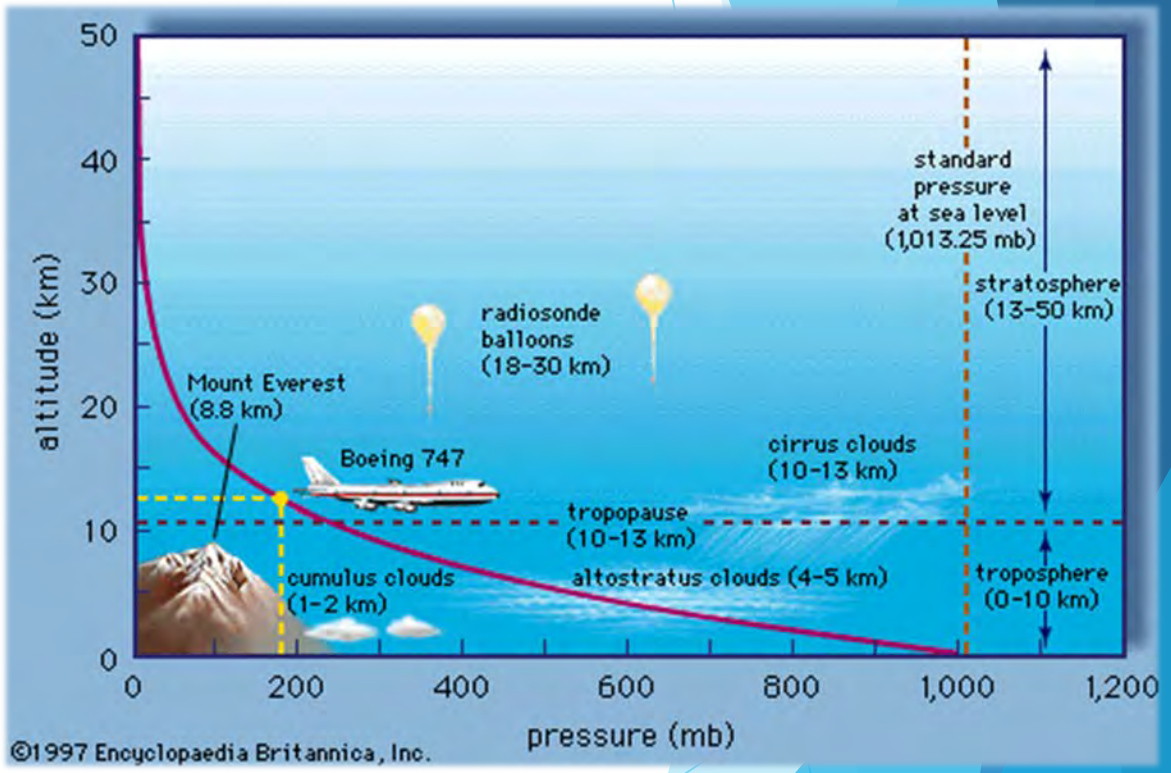
Meteorology – Air Pressure and Temperature

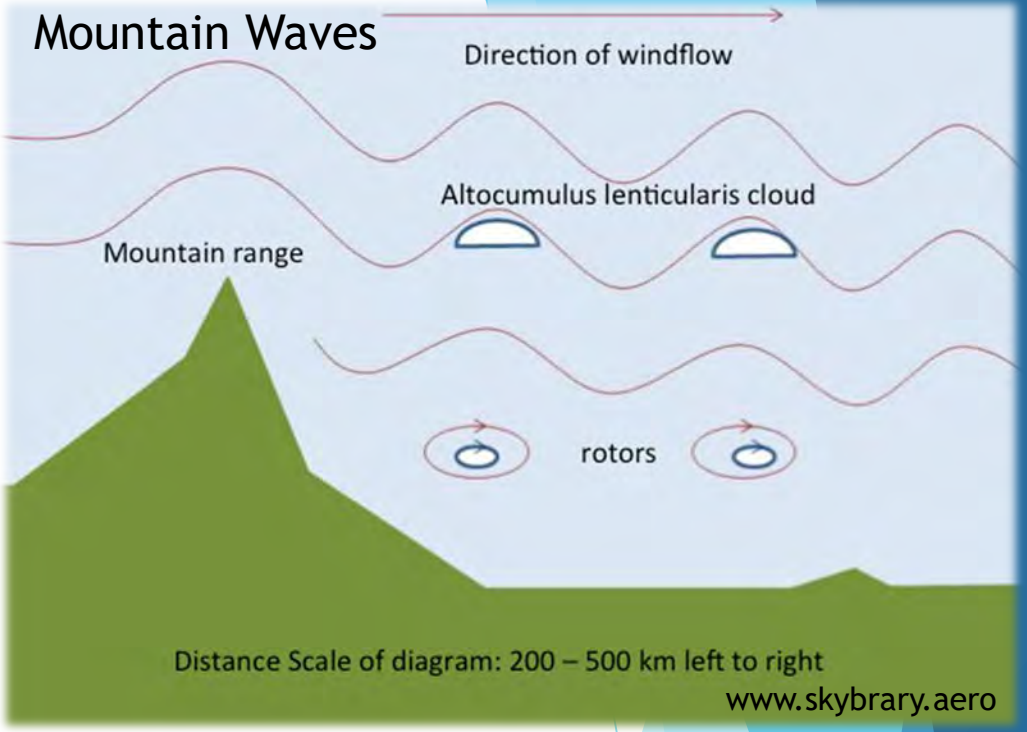
- **Air pressure and temperature are inversely related.
- **As air gets warmer its pressure decreases.
- **As air gets cooler its pressure increases.
- As altitude increases the forces of gravity acting upon it decreases, which causes both the pressure and temperature to decrease.
- What does this mean for aircraft?
  - Lower air density means less thrust is produced by combustion engines.
  - Lower air pressure causes airfoils to produce less lift, or thrust for propellers.
  - Warm air/high altitude = poorer performance
  - Cold air/lower altitude = higher performance.



** If the air is in a container the inverse is true.

Meteorology - Wind

- Clear days are often windy.
- Winds tend to be calmer in the morning, and stronger as the day gets warmer.
- Wind speed may be different at different altitudes.
  - Always check winds aloft.
- Winds aloft, as low as tree top level, may be very different from the wind speed at the ground.
- Winds around mountains, buildings, and even trees can be rather turbulent.
- Mountain Wave Turbulence – Winds in excess of 15 kts. crossing over a mountain or ridge line may oscillations a long way from the cause.
  - Often create detached lenticular clouds.
  - Up and down drafts as high as 2,000 ft./min vertically.
  - Rotors, or spinning pockets of air bellow.



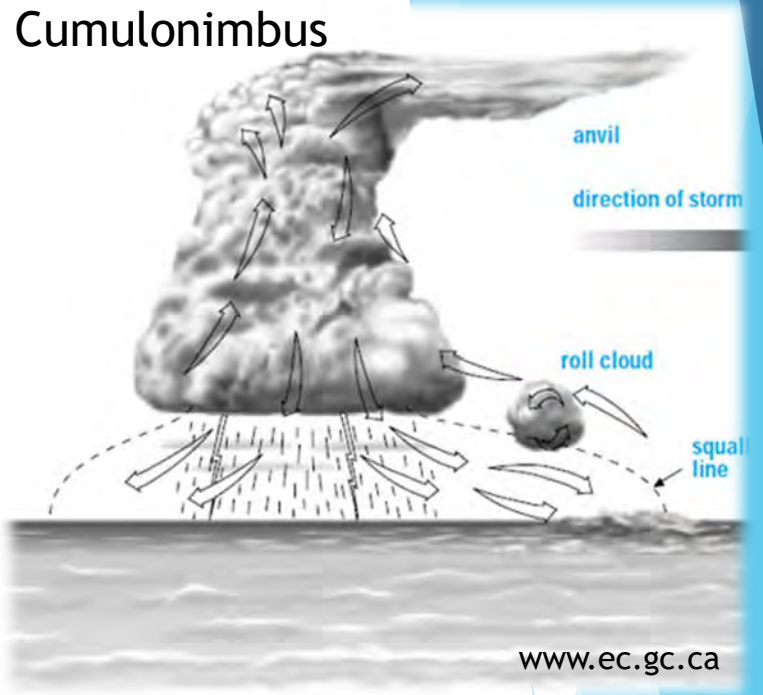
The Effects of Wind on sUAS

- Since sUAS are so light, wind has a huge effect on them.
- Respect your UAVs maximum wind ratings. Better yet, don't get near them.
- High winds cause:
  - Higher energy consumption and lower flight times.
  - Difficult takeoffs and landings. 'Copters tend to tilt/flip over.
  - Fixed wing UAVs will have to "crab" into the wind.
  - May cause images or data to be distorted or blurry.
- Our UAVs max wind tolerance is 28 mph.
- I don't fly beyond 24 mph.
- I don't expect to gather data beyond 15 mph.

Meteorology - Clouds

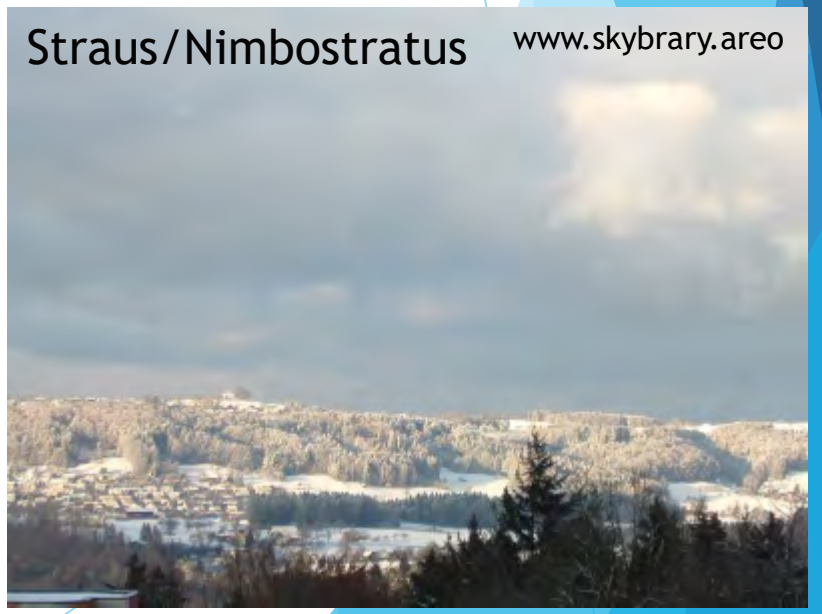
- Cumulonimbus
  - Thunderstorms!
  - Anvil at the top and St. Elmo's fire possible.
  - Associated with strong winds (50 kts.), turbulence, updrafts around the edges, and downdrafts under the cloud.
  - Turbulence can cause loss of control.
  - Electrostatic discharge can interfere with communications.
- Lenticular Clouds
  - Created when wind encounter surface obstructions.
    - Man-made (buildings and bridges), hills, mountains, and valleys.
    - Always indicates areas of high turbulence.
    - Can hide mountain tops!
    - Stay away!

Cumulonimbus



Meteorology – Clouds Cont.

- Mammatus
  - Rounded downward facing clouds.
  - Unlike most clouds, created by sinking air.
    - Down drafts!
  - Even if at high altitudes, may indicate poor flying conditions.
  - Often hiding thunderstorms above.
- Stratus or Nimbostratus
  - Often hazy which indicates rain or snow.
  - Less often associated with turbulence or downdrafts.
  - Often winds are calmer, but visibility is low.



Weather sources

- https://www.uavforecast.com
- https://www.wunderground.com
- http://www.accuweather.com/
- https://www.aviationweather.gov/
- https://www.duats.com/

Questions?