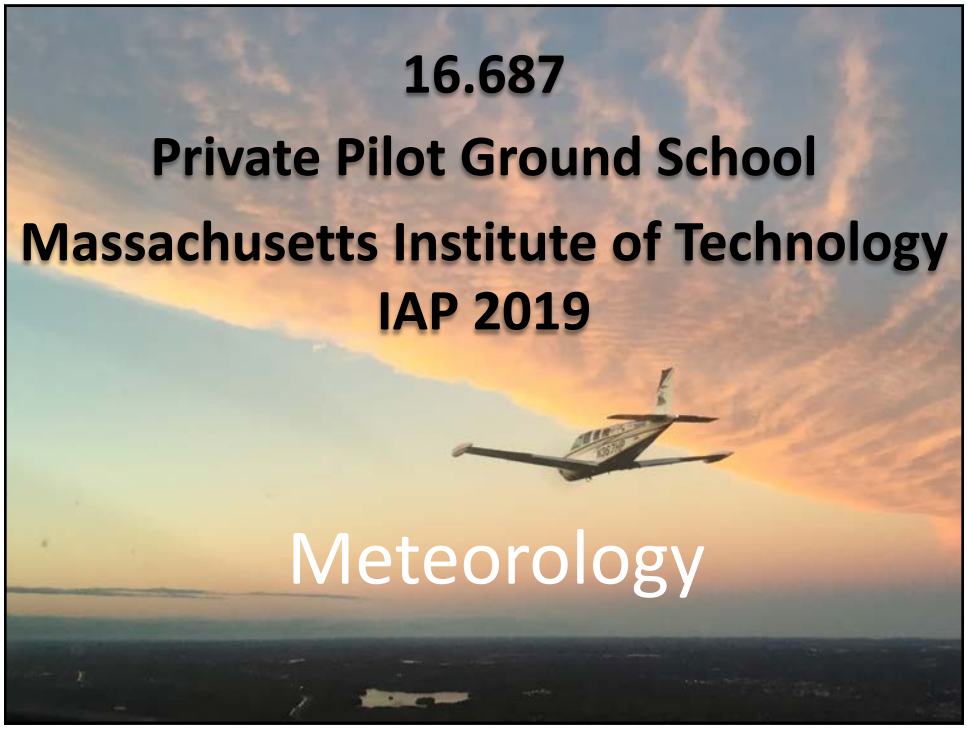

Outline

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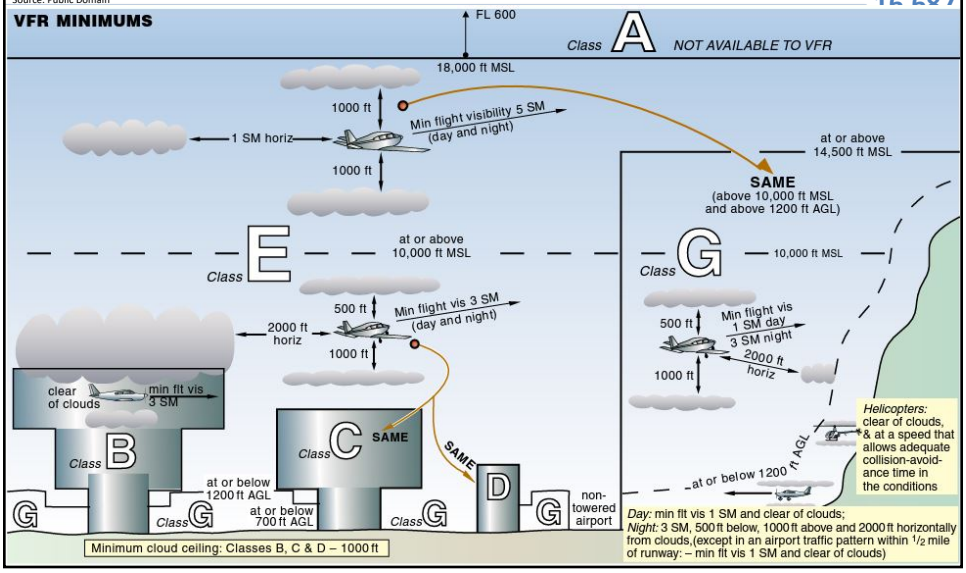
- Theory
- Patterns
- Hazards

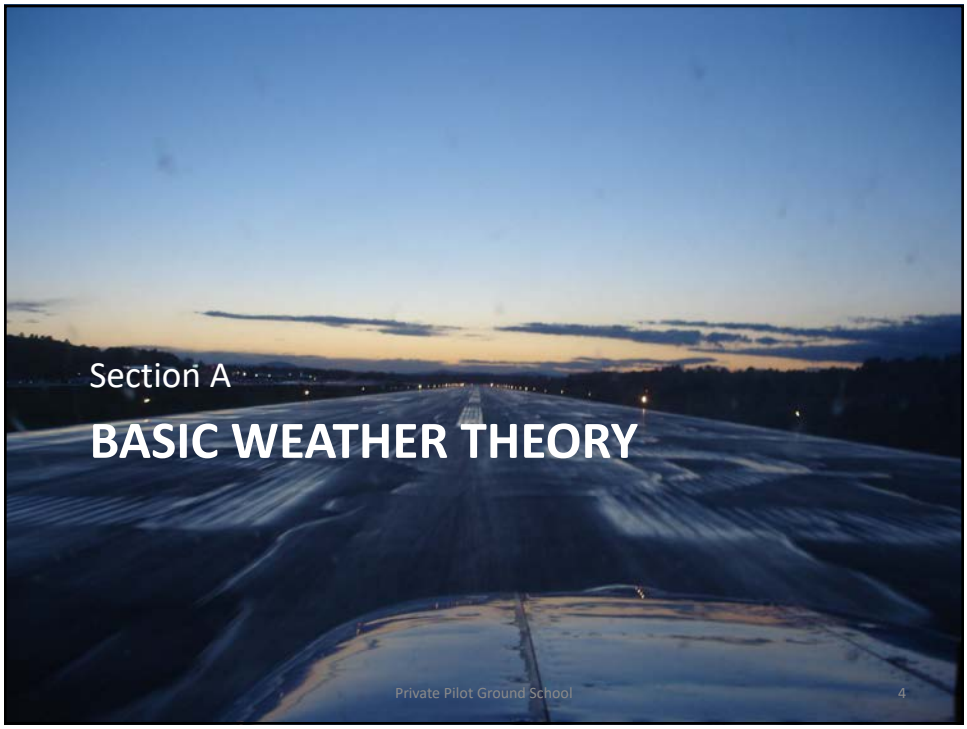
Goals:

- Fly within VFR weather minimums
- Understand the big hazards for both VFR and IFR

VFR Weather Minimums

Source: Public Domain





The Atmosphere

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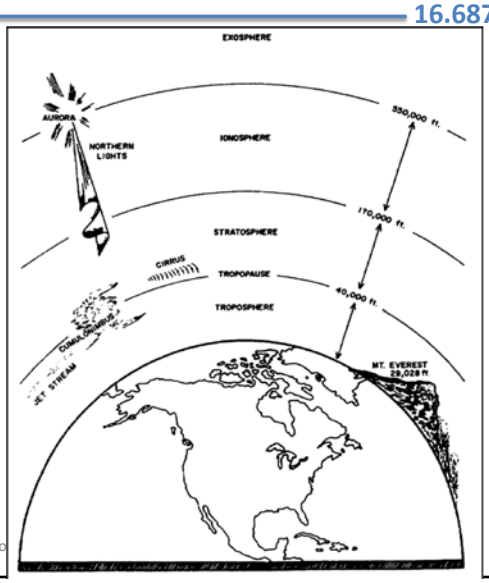
- Most of the weather occurs in the troposphere
  - 80% of the total mass of the atmosphere and nearly all water vapor is contained in this layer



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Vertical Structure

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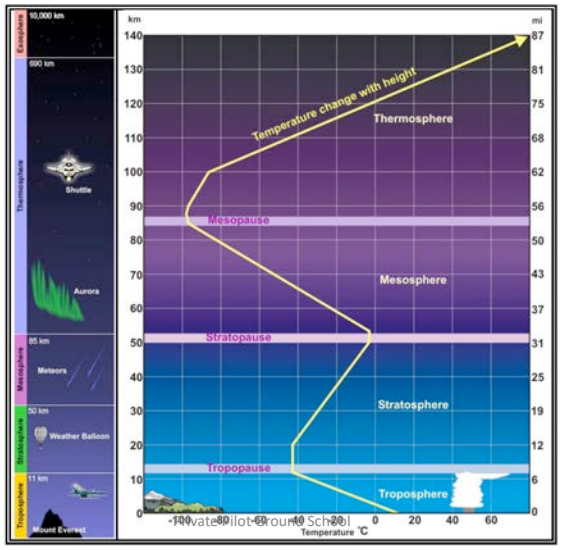

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Global Inequality

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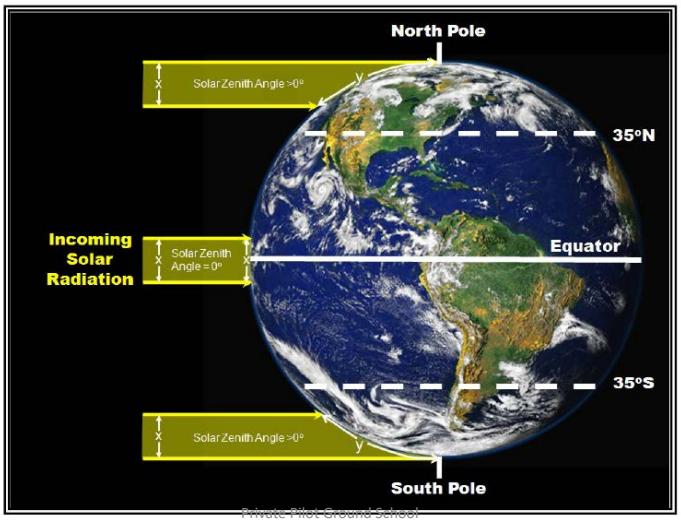

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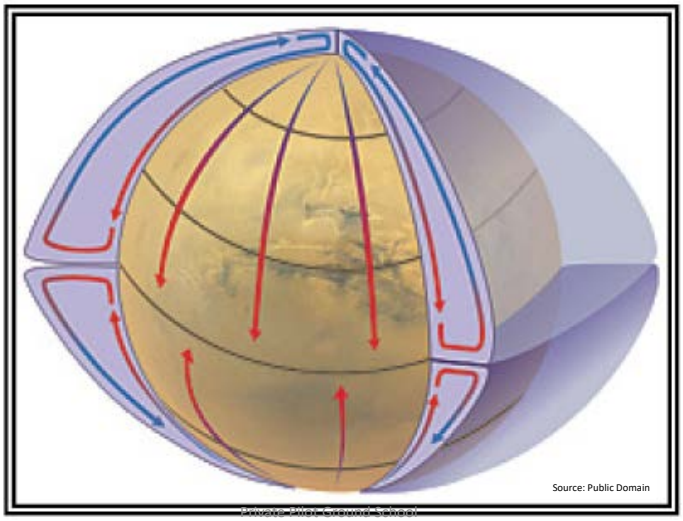
Non-Rotating, Non-Tilted, Waterless, Earth

16.687



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Add Water and Spin

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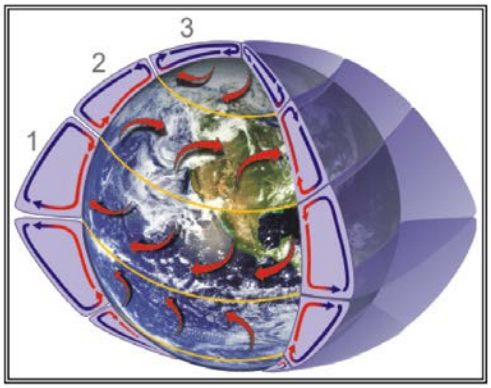
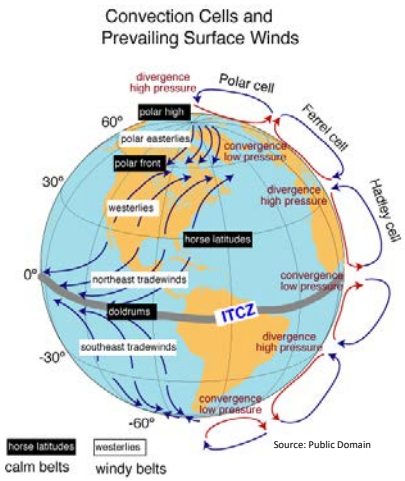
- High pressure at the North Pole
- Low pressure at 50-60 degrees N
- High pressure at 30 degrees N
- Low pressure at the Equator



Atmospheric Circulation

16.687

- *Atmospheric circulation*: movement of air relative to the earth's surface
- Every physical process of weather is accompanied by, or is the result of, a ***heat exchange.***
- Unequal heating of Earth surface modifies air density, creates circulation patterns, and causes altimeter settings to vary.

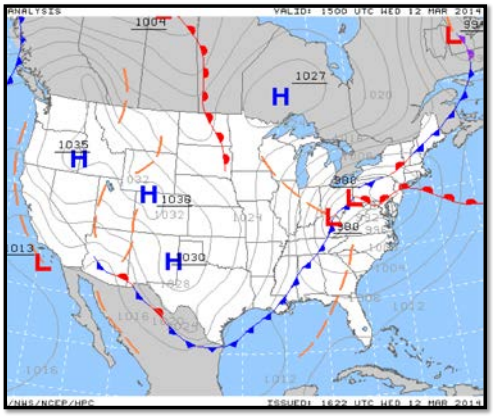


Atmospheric Pressure

16.687

- Isobars: Lines of equal pressure
- Pressure gradient: how closely the isobars are spaced
- Pressure gradient force causes wind
  - Air flows from high to low pressure
  - Wind speed depends on the strength of the pressure gradient

So wind blows from high to low?



Source: Public Domain

Coriolis Effect

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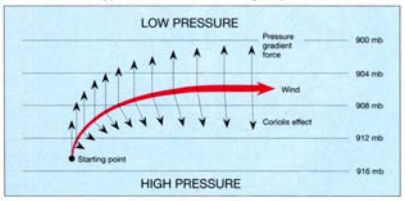
MIT Physics Department explains…

https://www.youtube.com/watch?v=dt_XJp77-mk

Coriolis Effect Cont'd

16.687

- Coriolis Force: inertia + rotating Earth
  - Northern Hemisphere: deflects moving air to the right
  - Significant when a parcel of air moves over large distances and the deflection varies with latitude
  - Coriolis Force + Pressure gradient create wind



Source: Public Domain

Trend is *Geostrophic*: Parallel to isobars

Wind along Isobars

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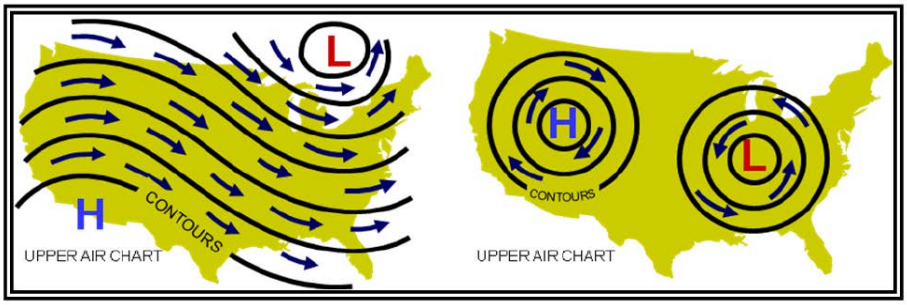

Where to test helicopters?

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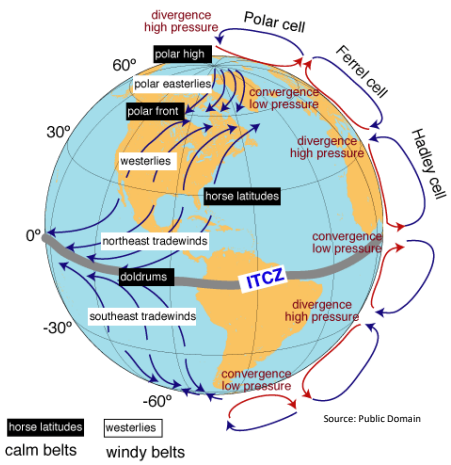
Convection Cells and
Prevailing Surface Winds



15

Friction below 2,000' AGL

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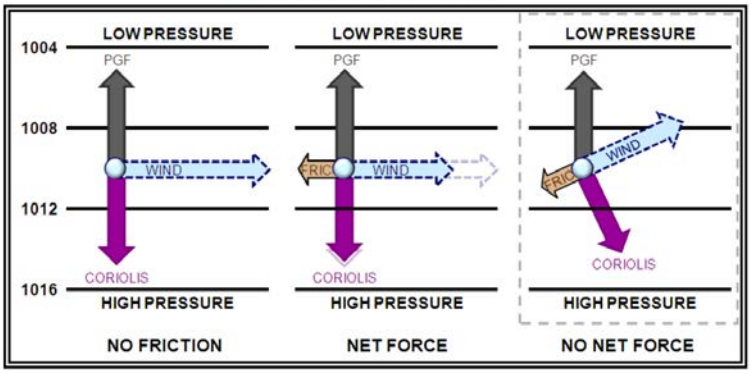
7.5 Surface Wind. At the surface of the Earth, all three forces come into play. As frictional force slows the wind speed, Coriolis force decreases. However, friction does not affect PGF. PGF and Coriolis force are no longer in balance. The stronger PGF turns the wind at an angle across the isobars toward lower pressure until the three forces balance, as shown in Figure 7-10.

Figure 7-10. Surface Wind Forces



Source: Public Domain

16

Vertical Circulation of Air

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- Now that you understand how air moves in the horizontal plane, lets look at how air circulates vertically
- Remember
  - COLD: **MORE DENSE**
  - WARM: **LESS DENSE**

Local Wind Patterns

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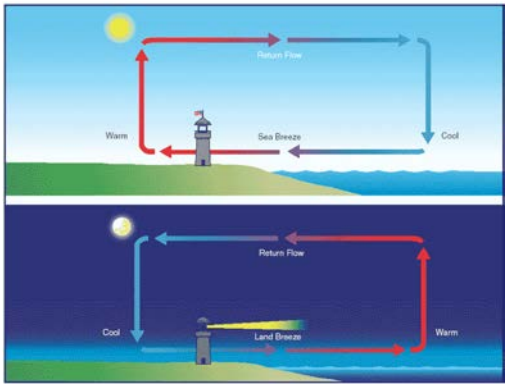
- Caused by terrain variations (mountains, valleys, water..)
- Cool air (high density) replaces warm air (low density)
- During the day, the land surfaces become warmer than adjacent water surfaces (opposite is true at night)



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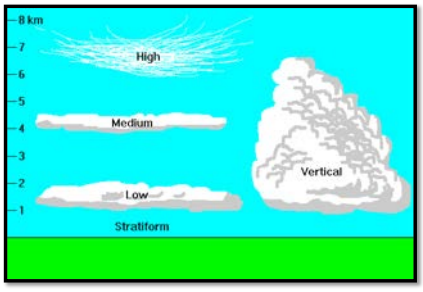
Section B

WEATHER PATTERNS

Atmospheric Stability

- Stable = limited vertical movement
  - Smooth air
  - Fair to poor visibility
  - Stratiform clouds
  - Steady precipitation
- Unstable = large vertical movement
  - Turbulent air
  - Good surface visibility
  - Cumulous clouds
  - Showery precipitation

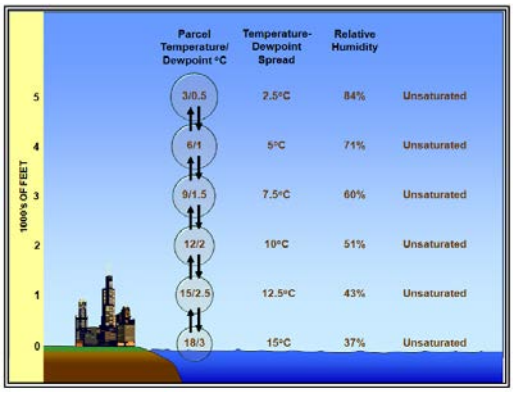


Source: Public Domain

Unsaturated Air Rises/Falls

16.687

- *Adiabatic*: "relating to or denoting a process or condition in which heat does not enter or leave the system concerned"
- Look at upward and downward moving air as an adiabatic process. Parcel of rising air:
  - Pressure ↓
  - Volume ↑
  - Temperature ↓
- Dry adiabatic lapse rate: 3°C (5.4°F) per 1000 ft (dewpoint lapsing at 0.5°C)



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Moist Air Rises/Falls

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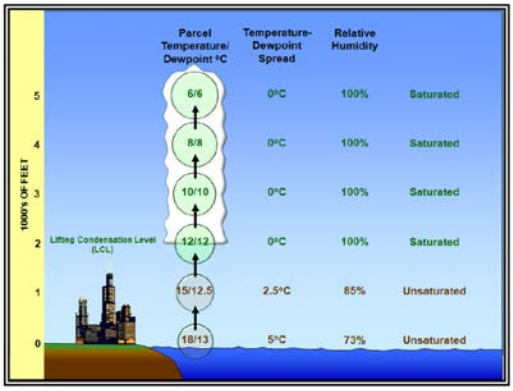
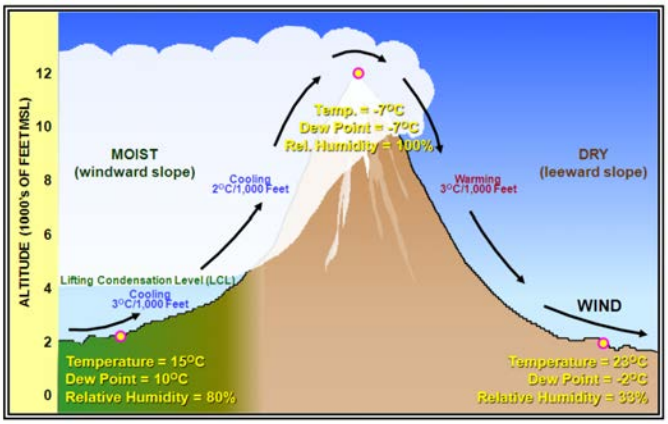
Moist adiabatic lapse rate: 2°C (3.6°F) per 1000 ft



Why would air rise or fall?

16.687

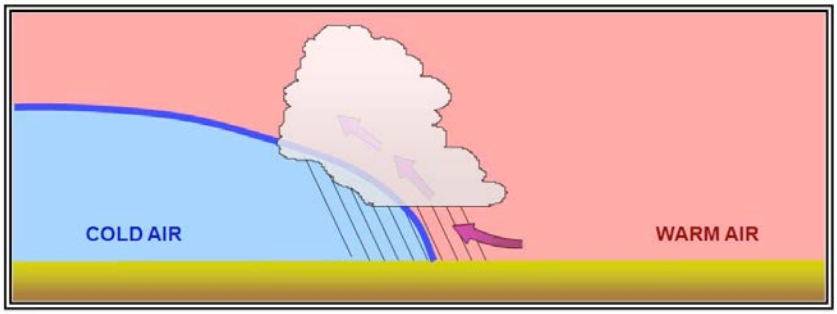
"I was pushed!" (orographic lifting)



I was pushed (II)

16.687

Figure 11-6. Frontal Lift



Stable Air

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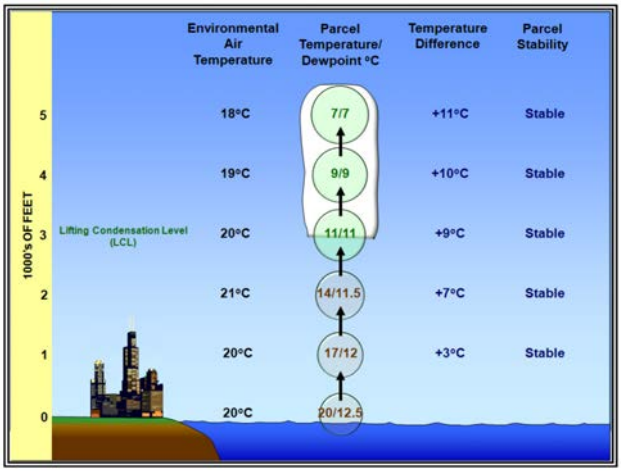
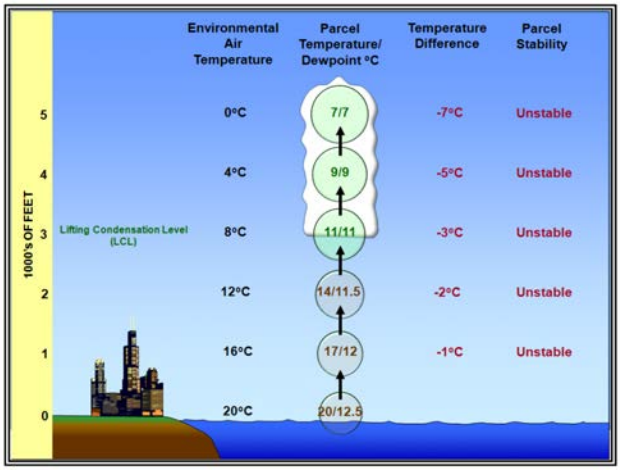


Unstable Air

16.687



Temperature Inversions

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- Increase in temperature as altitude is increased
  - Stable air with little or no wind and turbulence
- Most frequent type of ground (surface based) temperature inversion is produced by terrestrial radiation on a clear, relatively still night.
- Below the inversion (in higher humidity):
  - Smooth air
  - Poor visibility
  - Fog
  - Haze
  - Low clouds

Dewpoint

16.687

- Humidity is a measure of moisture in the air
  - Depends on air temperature
- Dewpoint: temperature to which air must be cooled in order to become saturated
  - Air reaches a state where it can hold no more water
  - Actual amount of water vapor depends on temperature (warm air holds more; see Hurricanes Katrina and Harvey (Houston))
- Clouds, fog, or dew form when **water vapor condenses**

Frost

16.687

- Frost:
  - temperature of the collecting surface is at or below the dewpoint of the surrounding air
  - **and** the dewpoint is below freezing (otherwise simply "dew")
- Acts like in-flight icing (so don't fly without removing):
  - Disrupts smooth flow over the airfoil → LESS LIFT!
  - May prevent aircraft from becoming airborne at normal takeoff airspeed

http://www.aero news.net/images/content/genav/2006/Wing Frost AOPA 0906a.jpg

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Cloud Collection

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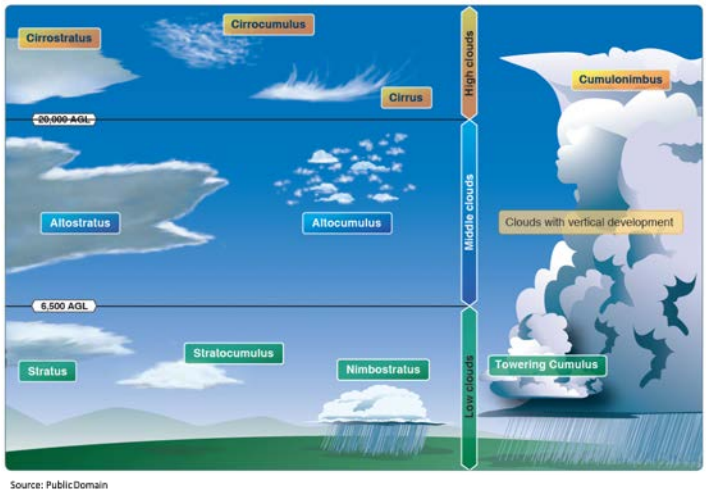


Source: PublicDomain

Private Pilot Ground School

30

Latin for Pilots

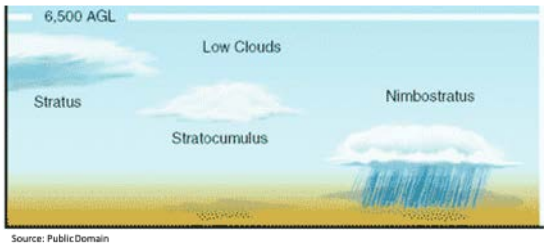
16.687

- Stratus: sheet-like clouds (Latin: “strewn”)
- Cumulus: puffy clouds (Latin: “heap”)
- Cirrus: wispy clouds (Latin: “a curl”)
- Nimbus: rain clouds (Latin: “cloud”)

Low Clouds

16.687

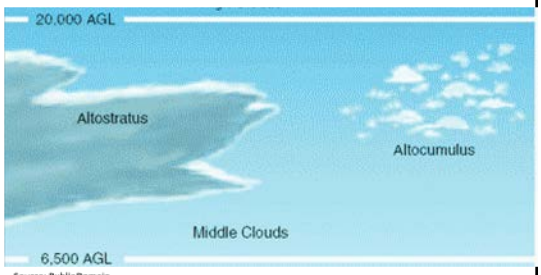
- Surface to 6,500 feet AGL.
- Usually consist entirely of water but sometimes can also be supercooled (ice hazard)
- Types:
  - Stratus
  - Stratocumulus
  - Nimbostratus
- Stratus clouds form when moist, stable air flows upslope



Middle Clouds

16.687

- Bases range from 6,500 ft to 20,000 ft AGL
- Composed of water, ice crystals, or supercooled water
  - may contain moderate turbulence and potentially severe icing
- Two main types:
  - Altostratus
  - Altocumulus

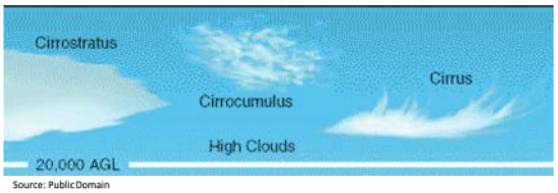


Source: Public Domain

High Clouds

16.687

- Start at 20,000 ft AGL
- Generally are white and gray
- Form in stable air
- Typically don't cause turbulence or icing hazard
- Three main types:
  - Cirrus
  - Cirrostratus
  - Cirrocumulus



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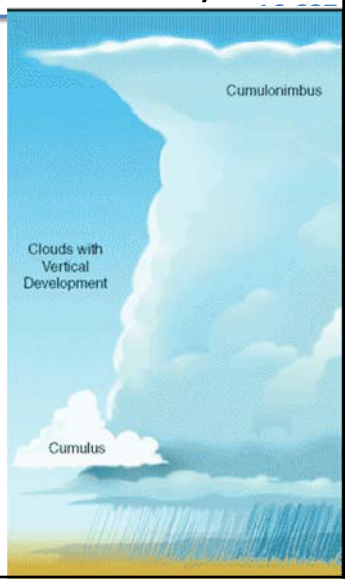
Clouds with Vertical Development (convective)

- Bad: *Cumulus*
  - Flat bottoms with dome shapes at the top
  - Shallow layer of instability
  - Turbulence but not too much icing or precipitation
- Worse: *Towering Cumulus*
  - billowing cauliflower tops
  - Deep area of unstable air
  - Heavy turbulence with icing and develop into thunderstorms
- Yet Worse: *Cumulonimbus*
  - gray-white to black in color
  - contain large amounts of moisture
  - Thunderstorms!
  - Very unstable (greatest turbulence)



Source: PublicDomain

Cloud Bases: Rule of Thumb

16.687

Cloud bases can be estimated by using lapse rate of 2.5°C (4.5°F) per 1,000 feet and the temperature dew point spread

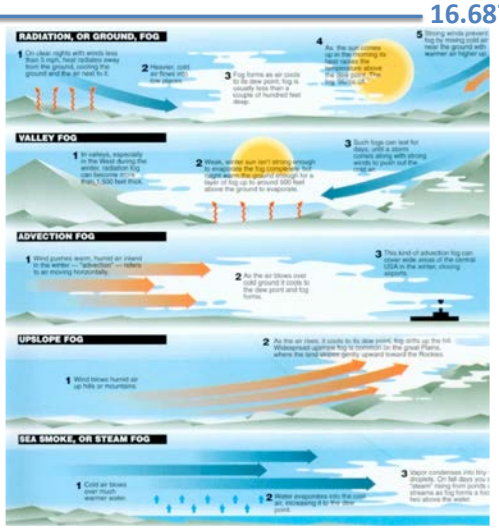
(Temperature – Dewpoint) ÷ 2.5 X 1,000

Why 2.5? Temp lapses at 3; Dewpoint at 0.5.

Fog (sm. temp/dewpoint spread)

16.687

- Radiation fog:
  - Forms in moist air over low, flat areas on clear, calm nights
  - Stable air with high pressure system (what you see early morning)
  - Doesn't like wind
- Advection Fog:
  - Warm, moist air moves over a cool surface (along coastlines)
  - Requires wind for formation
- Upslope Fog:
  - Moist, stable air is forced up a sloping land mass
  - Requires wind for formation
- Steam Fog:
  - Cold, dry air moves over comparatively warmer water (you can see them over thermal pools)
  - These water droplets can often freeze quickly
  - Low-level temperature and aircraft icing



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Ice Pellets and Inversions

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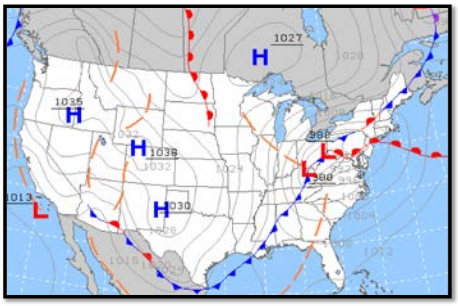
Ice pellets at the surface are an indication of a temperature inversion and freezing rain at higher altitudes.

Airmasses

16.687

- Large body of air with fairly uniform temperature and moisture content
  - E.g., Polar land airmass: cold, dry
  - E.g., Maritime tropical airmass: warm, moist



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Fronts

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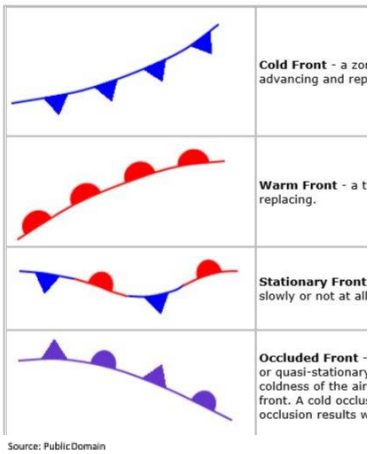
- Boundaries between airmasses

Types of Fronts:

- Cold front:
  - Cold air displaces warm air
  - Thunderstorms form along the cold front
- Warm front:
  - warm air is replacing cold air
- Stationary front:
  - No movement
  - Covers a large geographic area
- Occluded front:
  - Cold front overtakes warm front
  - Worst parts of both warm and cold fronts:
    - Turbulent air
    - Showers and/or continuous precipitation
    - Poor visibility



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Fronts

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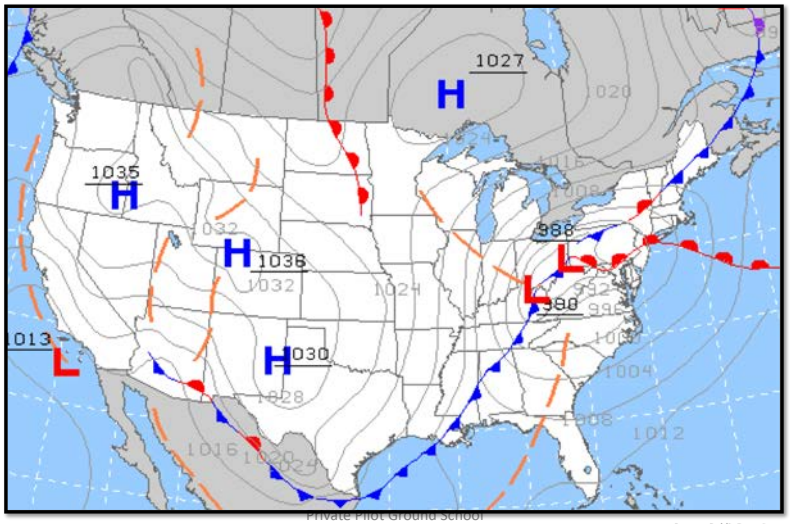

Source: Public Domain

Frontal Discontinuities

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- Temperature Change
- Wind Direction/Speed Change

Cold Front

16.687

Table 12.2 Typical Weather Conditions Associated with a Cold Front in the Northern Hemisphere

WEATHER ELEMENT	BEFORE PASSING	WHILE PASSING	AFTER PASSING
Winds	South or southwest	Gusty, shifting	West or northwest
Temperature	Warm	Sudden drop	Steadily dropping
Pressure	Falling steadily	Minimum, then sharp rise	Rising steadily
Clouds	Increasing Ci, Cs, then either Tcu* or CB	Tcu or Cb	Often Cu, Sc when ground is warm
Precipitation	Short period of showers	Heavy showers of rain or snow, sometimes with hail, thunder, and lightning	Decreasing intensity of showers, then clearing
Visibility	Fair to poor in haze	Poor, followed by improving	Good except in showers
Dew point	High; remains steady	Sharp drop	Lowering

*Tcu stands for towering cumulus, such as cumulus congestus; whereas Cb stands for cumulonimbus. Sc stands for stratocumulus.

http://clem.mscd.edu/~wagnerri/frontfigs.htm

Warm Front

16.687

Table 12.3 Typical Weather Conditions Associated with a Warm Front in the Northern Hemisphere

WEATHER ELEMENT	BEFORE PASSING	WHILE PASSING	AFTER PASSING
Winds	South or southeast	Variable	South or southwest
Temperature	Cool to cold, slow warming	Steady rise	Warmer, then steady
Pressure	Usually falling	Leveling off	Slight rise, followed by fall
Clouds	In this order: Ci, Cs, As, Ns, St, and fog; occasionally Cb in summer	Stratus type	Clearing with scattered Sc, especially in summer; occasionally Cb in summer
Precipitation	Light-to-moderate rain, snow, sleet, or drizzle; showers in summer	Drizzle or none	Usually none; sometimes light rain or showers
Visibility	Poor	Poor, but improving	Fair in haze
Dew point	Steady rise	Steady	Rise, then steady

http://clem.mscd.edu/~wagnerri/frontfigs.htm

22

Occluded Front

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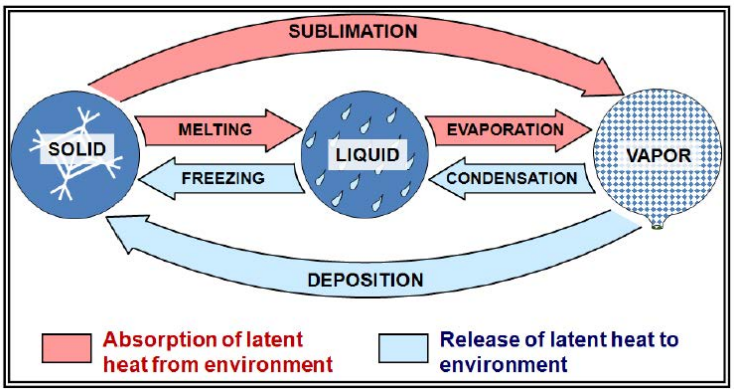
Table 12.4 Typical Weather Conditions Most Often Associated with Occluded Fronts in North America

WEATHER ELEMENT	BEFORE PASSING	WHILE PASSING	AFTER PASSING
Winds	East, southeast, or south	Variable	West or northwest
Temperature			
Cold type	Cold or cool	Dropping	Colder
Warm type	Cold	Rising	Milder
Pressure	Usually falling	Low point	Usually rising
Clouds	In this order: Ci, Cs, As, Ns	Ns, sometimes Tcu and Cb	Ns, As, or scattered Cu
Precipitation	Light, moderate, heavy precipitation	Light, moderate, or heavy continuous precipitation or showers	Light-to-moderate precipitation followed by general clearing
Visibility	Poor in precipitation	Poor in precipitation	Improving
Dew point	Steady	Usually slight drop, especially if cold-occluded	Slight drop, although may rise a bit if warm-occluded

http://clem.mscd.edu/~wagnerri/frontfigs.htm

An Energy Source?

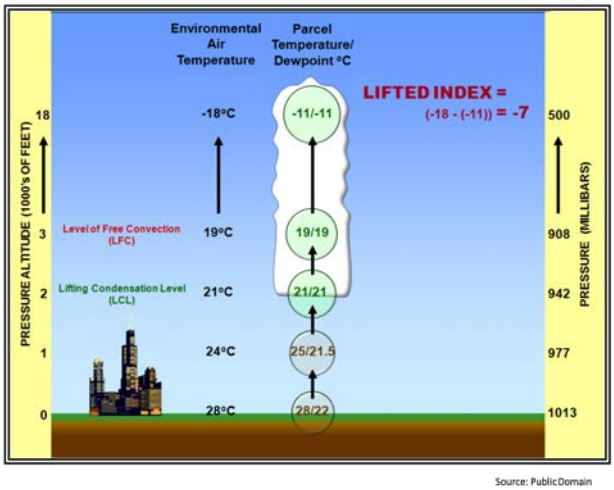
16.687



FAA Aviation Weather AC 00-6B, Figure 3-4

Unstable Air Threatens Gotham

16.687



Thunderstorms

16.687

- Cumulonimbus = greatest turbulence
  - Conditions for thunderstorm formation:
    - Lifting action
    - Unstable air
    - Moist air
- Squall Line: frontal band of thunderstorms
  - Produce the most intense weather hazards for aircraft!
  - Typically develops in front of a cold front

Source: Public Domain

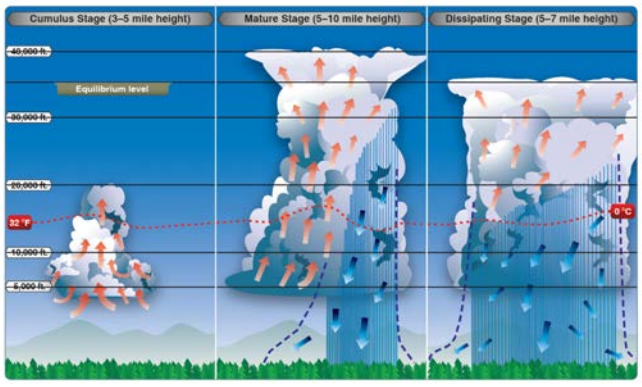
Thunderstorm Life Cycle

16.687

Cumulus → continuous updrafts

Mature → precipitation
- Greatest intensity

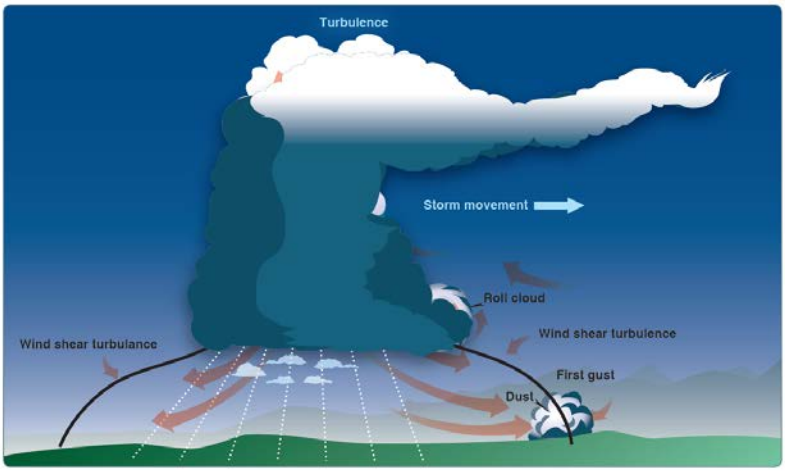
Dissipating → downdrafts



Source: Public Domain

Why the Gulfstream G650

16.687



Source: Public Domain

Thunderstorms Hazards

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Hazards:

- Severe Turbulence
- Lightning
- Tornadoes (funnel cloud down to sfc)
- Hail
- Icing
- Strong surface winds
- Microbursts
- Low level wind shear
- IMC

Damages:

- Structural
- Avionics
- Temporary blindness

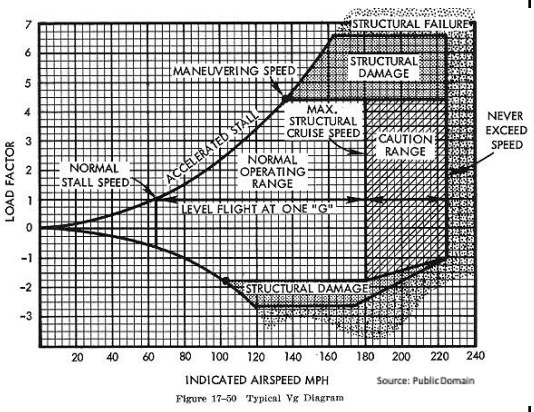

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Figure 17–50 Typical Vg Diagram

Microbursts

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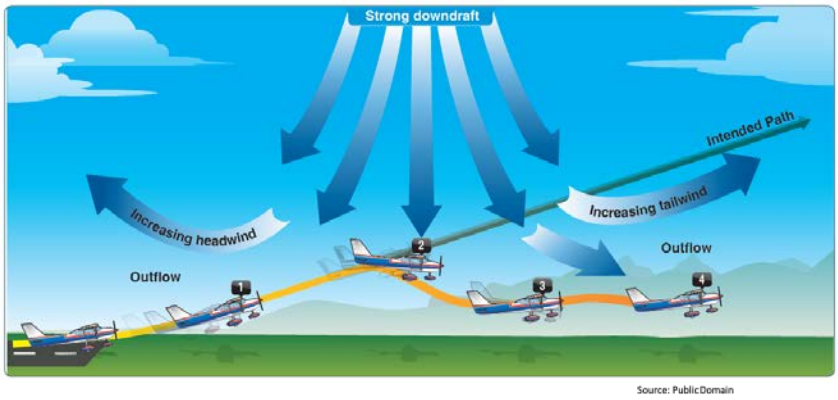
Lose 30-90 knots headwind, be in a 6,000 fpm downdraft: “seriously degrading performance” (PHAK 12-11).



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Thunderstorm Emergency Procedures

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- Flying through Pacific Ocean thunderstorms was common for B-29 bomber crews
- In 1999, before the age of datalink, AOPA published “Surviving a Ride in a Thunderstorm”
- The hero fighter and X-15 test pilot Scott Crossfield died in 2006 in a Cessna 210 (AOPA)
- Given NEXRAD datalink, better ATC weather and vigilance, and good flight planning, blundering into a thunderstorm should be a rare event.
- On other hand, get-there-itis remains uncured.

Turbulence

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- Three other categories of turbulence:
  - Low-level
  - Clear air
  - Mountain wave
- The effect can vary anywhere from light bumps to severe jolts

Low level turbulence

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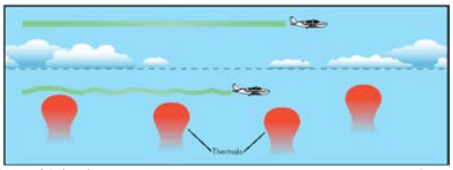
- Caused by surface heating or friction (less than 15,000 ft MSL)
  - Mechanical:
    - Winds blowing around hangars, trees, buildings
  - Convective:
    - Thermal turbulence
    - When moisture present, towering cumulus clouds indicate a presence of convective turbulence
  - Frontal:
    - Just ahead of the cold front when updrafts occur
  - Wake Turbulence:
    - See Next Slide



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Wake Turbulence

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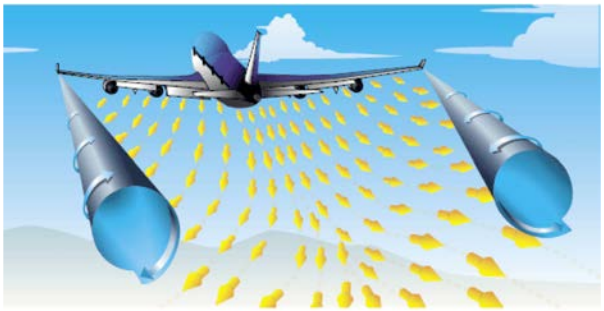
- Wing tip vortices are created when an airplane generates **lift**
- Greatest vortex when aircraft heavy, slow, and in clean configuration
- Tend to sink below the aircraft flight path
- Most hazardous during light, quartering tailwind



Source: PublicDomain

- Land or takeoff (when large a/c in front of you)
  - beyond the touchdown point
  - before the liftoff point

Pop Quiz

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- When landing behind a large aircraft, the pilot should avoid wake turbulence by staying…
  - A. Above the large aircraft's final approach path and landing beyond the large aircraft's touchdown point
  - B. Below the large aircraft's final approach path and landing before the large aircraft's touchdown point
  - C. Above the large aircraft's final approach path and landing before the large aircraft's touchdown point

Pop Quiz

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- When landing behind a large aircraft, the pilot should avoid wake turbulence by staying…
  - A. Above the large aircraft's final approach path and landing beyond the large aircraft's touchdown point
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  - C. Above the large aircraft's final approach path and landing before the large aircraft's touchdown point

Clear Air Turbulence and Mountain Wave Turbulence

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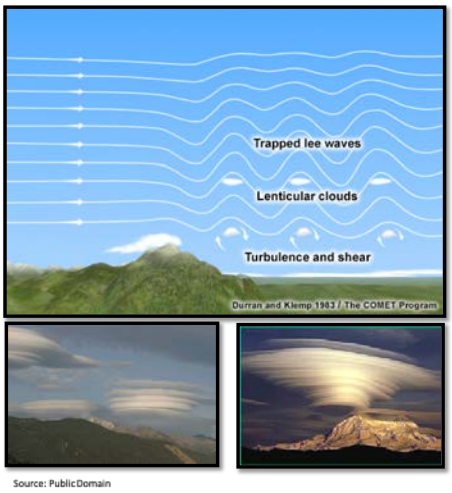
- Clear Air Turbulence (CAT):
  - High altitude phenomenon
  - Thin layers
  - Sudden bursts
- Mountain Wave Turbulence:
  - Expect it when winds across a ridge are 40 knots or greater and the air is stable
  - Crests of mountain waves may be marked by lens-shaped, or lenticular clouds
    - Lenticular clouds can look stationary but may contain winds of > 50 knots!



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Structural Icing

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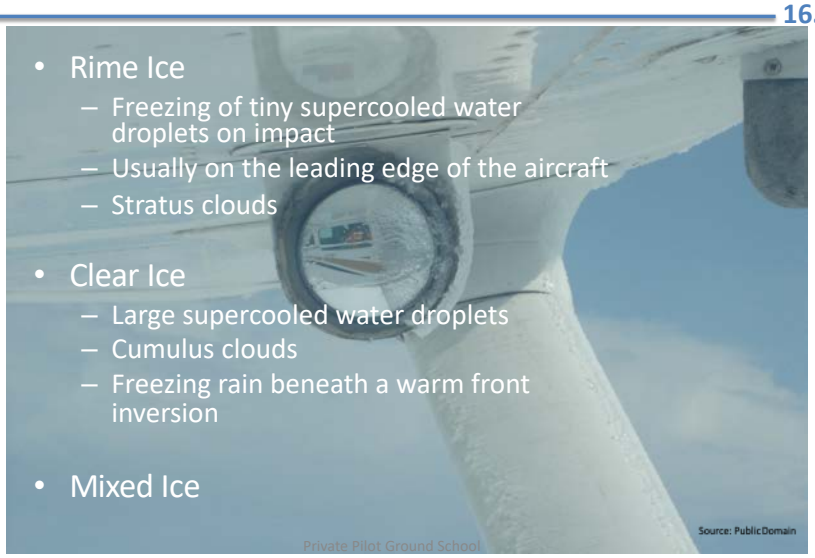
- Rime Ice
  - Freezing of tiny supercooled water droplets on impact
  - Usually on the leading edge of the aircraft
  - Stratus clouds
- Clear Ice
  - Large supercooled water droplets
  - Cumulus clouds
  - Freezing rain beneath a warm front inversion
- Mixed Ice



Structural Icing

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Clear Icing

Source: Public Domain

Rime Icing

Recognition: Flight Characteristics

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30% decrease in lift + 40% increase in drag

- Increase in stall speed
- Decrease in critical Angle of Attack
- Loss of aileron/elevator effectiveness
- Tailplane Stall
- Autopilot can mask symptoms

Source: Public Domain

Requirements for Icing Formation

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- Surface
- Near freezing temperatures (-10C to 0C is the worst)
- **Visible Moisture!**

Avoiding Icing Encounters

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First best: Fly in cold weather only if you can remain clear of clouds. Check winds aloft forecast for temps.

Second best: If no Icing AIRMET issued, go through a cold cloud only if there is above-freezing air below (ice melts quickly).

Response to Icing

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- CLIMB
- ALTER COURSE
- DESCEND

On Approach to Land:

- More power on final (+ 10-15 kts)
- No flaps
- Gentle turns
- Higher than usual approach

See NASA video titled "Icing for General Aviation Pilots"

How do transportation airplanes handle this?

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All-weather airplanes are certified for flight into known icing (FIKI):

- Pump glycol (antifreeze) mixture out from prop hub and wing leading edges. (TKS/CAV)
- Heat prop and crack ice off leading edges with rubber boots. (Turboprops)
- Heat engine cowls and wing/tail leading edges with hot bleed air from turbojet compressor.

Windshield is heated electrically, as are the pitot-static probes.

Additional Info

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Reading:

- Pilot Handbook of Aeronautical Knowledge: Chapter 12
- Aeronautical Information Manual: Chapter 7
- FAA AC 00-6B, *Aviation Weather*
- FAA AC 0045H, *Aviation Weather Services*

Videos:

- Ambushed by Ice: https://youtu.be/GMmpUuAeEpM
- VFR into IMC: https://youtu.be/W0lWsqAwYwY

What did we learn?

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- Meteorology is complex!
- Sun, heat exchange, and Coriolis Effect drive the big picture (plus friction below 2,000’ AGL)
- Fog? Look at temperature/dewpoint split
- Thunderstorms? Look at lapse rate
- Avoid thunderstorms and icing

Questions?

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