AVIATION WEATHER

CAUSES OF WEATHER

1. Every physical process of weather is accompanied by, or is the result of, heat exchanges.

2. Unequal heating of the Earth's surface causes differences in pressure and, thus, altimeter settings.

    a. On weather maps, the lines drawn to connect points of equal pressure show pressure contours called isobars.

3. Three of the forces at work on winds are discussed below.

    a. The pressure gradient force causes wind to flow from an area of high pressure to one of low pressure.

        1) This flow is thus perpendicular to the isobars.

    b. Coriolis force deflects winds to the right in the Northern Hemisphere. Coriolis force is a result of the Earth's rotation.

        1) The Coriolis force is at a right angle to wind direction and directly proportional to wind speed. Its effect is more forceful at greater altitudes (above approximately 2,000 ft. AGL) because surface winds are slowed by friction.

        2) It deflects winds so strongly that they flow parallel to isobars.

    c. Friction with the Earth's surface weakens the wind.

        1) Since these winds are slower, they are less affected by Coriolis force. The pressure gradient becomes stronger than Coriolis force, and the wind flows across, rather than parallel to, the isobars.

        2) Friction is what causes winds to be greater at higher altitudes than at the surface.

4. An **air mass** is an extensive body of air having uniform moisture and temperature properties.

5. The average height of the layer of the Earth's atmosphere called the **troposphere** is about 37,000 ft. in mid-latitudes. It varies between approximately 25,000 ft. at the poles to 65,000 ft. at the equator.

6. The boundary between the troposphere and the stratosphere is the thin layer called the **tropopause.**

    a. Temperature and wind vary greatly in the vicinity of the tropopause.

    b. It is associated with an abrupt change in the temperature lapse rate.

7. The **stratosphere** is the layer of atmosphere above the tropopause.
    - a. It is characterized by low moisture content and absence of clouds.
    - b. It has relatively small changes in temperature with an increase in altitude.
8. The **jet stream** is a narrow, disjointed, wandering "river" of maximum winds.
    - a. It moves with pressure ridges and troughs in the upper atmosphere near the tropopause.
    - b. It blows from a generally westerly direction and, by definition, has a speed of 50 kt. or more.
    - c. The jet stream is normally weaker and farther north in the summer.
    - d. The jet stream is normally stronger and farther south in the winter.
9. A **front** is the zone of transition between two air masses of different temperature, humidity, and wind.
    - a. There is always a change in wind when you fly across a front.
    - b. The threat of low-level wind shear occurs just before the warm front passes the airport.
    - c. With a cold front, the most critical period for wind shear occurs just as or just after the cold front passes the airport.
10. Frontal waves and cyclones (and areas of low pressure) usually form in slow-moving cold fronts or in stationary fronts.
11. Squall lines usually develop ahead of a cold front.

STABILITY OF AIR MASSES

1. The **lapse rate** is a measure of how much temperature decreases (or possibly increases) with an increase in altitude. This is the actual temperature change associated with increases in altitude and sometimes is referred to as the **ambient lapse rate.**
    - a. In contrast to the ambient or actual lapse rate is the **adiabatic lapse rate.** The adiabatic, or "expansional cooling" lapse rate, is the temperature decrease due only to expansion of air as it rises. The adiabatic lapse rate means no heat gain or loss -- just a decrease in temperature because of expansion.
        - 1) The dry adiabatic lapse rate is 3°C per 1,000 ft.
        - 2) The adiabatic lapse rate varies from about 1.1°C to 2.8°C based on moisture content of the air.

        3) The average adiabatic lapse rate is 2°C per 1,000 ft.

2. The ambient lapse rate can thus be used by pilots to determine the stability of air masses.

    a. The greater the ambient lapse rate (more than 2°C per 1,000 ft.) and the higher the humidity, the more unstable the air -- and the more thunderstorms can be expected.

    b. Moist air is less stable than dry air because it cools adiabatically at a slower rate, which means that moist air must rise higher before its temperature cools to that of the air around it (i.e., cumulus build-up).

3. Cloud formation after lifting is determined by the stability of the air before lifting.

    a. Turbulence and clouds with vertical development (cumuliform) result when unstable air rises (due to convective currents).

    b. Moist, stable air moving up a mountain slope produces stratiform clouds as it cools.

        1) Unstable air moving up a mountain slope produces clouds with extensive vertical development.

4. When a cold air mass moves over a warm surface, heating from below provides unstable lifting action, giving rise to cumuliform clouds, turbulence, and good visibility.

5. The growth rate of precipitation is enhanced by upward air currents carrying water droplets upward where condensation increases droplet size.

6. Stable air characteristics

    a. Stratiform clouds and fog
    b. Smooth air
    c. Continuous (steady) precipitation
    d. Fair-to-poor visibility in haze and smoke

7. Unstable air characteristics

    a. Cumuliform clouds
    b. Turbulent air
    c. Showery precipitation
    d. Good visibility

TEMPERATURE INVERSIONS

1. Normally, temperature decreases as altitude increases. A temperature inversion occurs when temperature increases as altitude increases.

2. Temperature inversions usually result in a stable layer of warm air below the inversion.

3. A temperature inversion often develops near the ground on clear, cool nights when the wind is light.
    a. It is caused by terrestrial radiation.
4. Smooth air with restricted visibility (due to fog, haze, or low clouds) is usually found beneath a low-level temperature inversion.

TEMPERATURE, DEW POINT, AND FOG

1. When the temperature-dew point spread is 3°C (5°F) or less and decreasing, you should expect fog and/or low clouds.
2. Air temperature largely determines how much water vapor can be held by the air.
    a. **Dew point** is the temperature at which the air will be saturated with moisture, i.e., 100% humidity.
3. Frost forms when the temperature of the collecting surface (e.g., the airplane) is below the dew point of the surrounding air and the dew point is below freezing (O°C or 32°F).
4. Water vapor becomes visible as it condenses into clouds, fog, or dew.
    a. **Evaporation** is the conversion of liquid water to water vapor.
    b. **Sublimation** is the conversion of ice directly to water vapor.
    c. **Deposition** is the conversion of water vapor directly to ice.
5. **Radiation fog** is most likely to occur when there is a clear sky, little or no wind, and a small temperature-dew point spread over a land surface (especially low, flatland areas).
    a. As the ground cools rapidly due to radiation, the air close to the surface cools more quickly than slightly higher air.
        1) This is the most frequent type of surface-based temperature inversion.
    b. As the air reaches its dew point, radiation fog forms.
6. **Advection fog** forms as a result of moist air condensing as it moves over a colder surface (i.e., water or ground).
    a. It requires wind to force the movement.
    b. Advection fog is most likely to occur in coastal areas, when air moves inland from the coast in winter.
7. **Upslope fog** results from warm, moist air being cooled as it is forced up sloping terrain.

8. **Precipitation-induced fog** results from warm fronts (warmer air over cooler air), i.e., when warm rain or drizzle falls through the cooler air.

    a. Evaporation from the precipitation saturates the cooler air, causing fog.

9. Fog can also form easily in industrial areas where combustion pollution provides a high concentration of condensation nuclei (tiny particles on which moisture can condense as the air cools).

CLOUDS

1. Clouds are divided into four families based on their height:

    a. High clouds (consist of ice crystals and do not pose an icing threat)

    b. Middle clouds

    c. Low clouds

    d. Clouds with extensive vertical development

2. Lifting action, unstable air, and moisture are the ingredients for the formation of cumulonimbus clouds.

    a. Fair weather cumulus clouds form in convective currents and often indicate turbulence at and below the cloud level.

    b. Nimbus means rain cloud.

    c. Towering cumulus is an early stage of cumulonimbus.

    d. The greatest turbulence is in cumulonimbus clouds (thunderstorms).

3. Standing lenticular altocumulus clouds (ACSL) are almond or lens-shaped and form on the crests of waves created by barriers in the wind flow (e.g., on the leeward side of a mountain).

    a. The presence of these clouds indicates very strong turbulence.

THUNDERSTORMS

1. Thunderstorms have three phases in their life cycle:

    a. **Cumulus --** the building stage of a thunderstorm when there are continuous updrafts

    b. **Mature --** the time of greatest intensity when there are both updrafts and downdrafts (causing severe wind shear and turbulence)

        1) The commencing of rain on the Earth's surface indicates the beginning of the mature stage of a thunderstorm.

    c. **Dissipating --** characterized predominantly by downdrafts; i.e., the phase of the storm raining itself out

2. A thunderstorm, by definition, always has lightning, because lightning causes thunder.

    a. Lightning strikes are most common when operating with an outside air temperature (OAT) of between -5°C and +soC.

3. Thunderstorms are produced by cumulonimbus clouds. They form when there is

    a. Sufficient water vapor

    b. An unstable lapse rate

    c. An initial upward boost (i.e., a lifting action) to start the process

4. Thunderstorms produce wind shear turbulence, a hazardous and invisible phenomenon, particularly for airplanes landing and taking off.

    a. If a thunderstorm is penetrated, a pilot should fly straight ahead, set power for recommended turbulence penetration airspeed, and attempt to maintain a level attitude.

5. The most severe thunderstorm conditions (heavy hail, destructive winds, tornadoes, etc.) are generally associated with squall line thunderstorms.

    a. A squall line is a nonfrontal, narrow band of thunderstorms usually ahead of a cold front.

6. A **squall** (not squall line) is defined as a sudden increase in wind speed of at least 16 kt., the speed rising to 22 kt. or more and lasting at least 1 min.

7. Embedded thunderstorms are obscured because they occur in very cloudy conditions or thick haze layers.

8. Airborne weather-avoidance radar detects only precipitation drops. It does not detect minute cloud droplets (i.e., clouds and fog).

    a. Thus, airborne weather-avoidance radar provides no assurance of avoiding instrument weather conditions.

ICING

1. Structural icing requires two conditions:

    a. Flight through visible moisture

    b. The temperature at freezing or below

2. Freezing rain usually causes the greatest accumulation of structural ice.

a. Freezing rain indicates that temperatures are above freezing at some higher altitude.

b. Supercooled Large Droplets (SLD) can accrue even if SLD droplets are not being observed at the surface.

1) A visible symptom of supercooled water droplets is a buildup of ice forward of an unheated propeller spinner, but not extending back past the blades.

3. Ice pellets are caused when rain droplets freeze at a higher altitude; i.e., freezing rain exists above.

4. Heavy, wet snow indicates the temperature is above freezing at your altitude.

a. Snow that is heavy and wet formed above you but is on the verge of melting.

5. Frost on wings disrupts the airflow over the wings, causing early airflow separation and resulting in a loss of lift. It should be removed before flight is attempted.

a. Small patches of ice or frost can result in localized, asymmetrical stalls on the wing, which can then result in roll control problems during liftoff.

b. The only way to ensure the wing is free of critical ice is to perform a tactile inspection. This type of inspection is valuable for detecting critical ice. By physically touching the surface, any fine contaminants not easily visible can be detected.

6. Test data indicate that ice, snow, or frost having a thickness and roughness similar to medium or coarse sandpaper on the leading edge and upper surface of a wing can reduce wing lift by as much as 30% and increase drag by 40%.

a. When ice does accumulate, it is harder to remove from the upper surface of the wing than the leading edge. Generally speaking, smooth ice on top of the wing is more dangerous than heavy accumulated icing on the leading edge.

7. With a standard (average) temperature lapse rate of 2°C per 1,000 ft., the freezing level can be determined by knowing the current temperature and elevation.

a. EXAMPLE: At a field elevation of 1,350 ft. MSL, the temperature is +soC. To reach the freezing level, the temperature must drop SoC. Thus the freezing level is 4,000 ft. (SOC+ 2°C/1 ,000 ft.) above field elevation, or 5,350 ft. MSL (1,350 + 4,000).

8. When conditions favoring the formation of ice are present, pilots should check for ice accumulation prior to flight by using a flashlight to scan the surface of the airframe and watch for light reflections.

a. Ice on the surface of the wing is virtually undetectable and causes a reduction in lift over the wing.

b. Narrow objects tend to pick up ice that is visually detectable. Ice accumulation on the air temperature probe or on a pitot tube (of a high-wing airplane) would be the first area that the pilot would observe ice buildup.

9. Ice tends to accumulate on small and narrow parts of the aircraft before others. The most susceptible surface of the airframe to accumulate icing is the tail plane due to its position being outside the visual range as well as its thin, simple shape.

    a. A tail plane stall as the result of ice accumulation is most likely to occur during the extension of the flaps to the landing position. Thus, tailplane stalls due to icing are mostly likely during the approach and landing phase of flight.

    b. Any of the following symptoms, occurring singly or in combination, may be a warning of tailplane icing:

        1) Elevator control pulsing, oscillations, or vibrations

        2) Abnormal nose-down trim change

        3) Any other unusual or abnormal pitch anomalies (possibly resulting in pilot induced oscillations)

        4) Reduction or loss of elevator effectiveness

        5) Sudden change in elevator force (control would move nose-down if unrestrained)

        6) Sudden uncommanded nose-down pitch

    c. To recover from a tail plane stall, you should retract the flaps to the last safe position and increase power only to the extent that you compensate for the loss of lift created from retracting the flaps.

        1) Over-increasing the power can aggravate and deepen a tailplane stall in some aircraft.

10. Another serious result of icing is uncommanded roll due to ice accumulation forward of the ailerons.

    a. The following procedures apply if you experience roll upset while flying in icing conditions:

        1) Reduce the angle of attack (AOA) by reducing the aircraft pitch. If in a turn, roll wings level.

        2) Set appropriate power and monitor the airspeed/AOA. A controlled descent is a vastly better alternative than an uncontrolled descent.

        3) If flaps are extended, do not retract them unless it can be determined that the upper surface of the airfoil is clear of ice, because retracting the flaps will increase the AOA at a given airspeed.

        4) Verify that wing ice protection is functioning normally and symmetrically by visual observation of the left and right wing. If not, follow manufacturer's instructions.

11. If you detect icing accumulation in flight, especially if the aircraft is not equipped with a deicing system, you should leave the area of precipitation, if you are able, or fly to an altitude where the ambient temperature is above freezing.

    a. Be aware that warmer temperatures are not always found at lower altitudes. In the case of a temperature inversion, for instance, warmer air will be above rather than below.

12. In an aircraft equipped with a pneumatic deicing system, the appropriate technique for removing ice is to operate the pneumatic deicing system several times.

    a. This technique will clear accumulated ice as well as residual ice left behind between system cycles.

    b. The FAA recommends that the deicing system be activated at the first indication of icing rather than after any significant amount of ice is allowed to accumulate.

        1) Because some residual ice continues to adhere between pneumatic boot system cycles, the wing is never entirely "clean."

        2) The amount of residual ice increases as airspeed and/or temperature decrease due to the more favorable conditions for ice accumulation associated with these conditions.

        3) At airspeeds typical of small airplanes, it may take many boot cycles to effectively shed the ice.

13. Supercooled Large Droplets (SLD) are supercooled droplets with a diameter greater than 50 micrometers (0.05 mm). SLD conditions include freezing drizzle drops and freezing raindrops.

    a. Ice may become visible on the upper or lower surface of the wing, aft of the active part of the deicing boots. Pilots should look for irregular or jagged lines of ice or for pieces of ice shedding off the airplane. During night operations, adequate illumination should be used to observe all areas. On most airplanes, the last inch of the deicing boot is inactive.

    b. Vigilance for SLD ice accretions should be exercised when flying into or over areas reporting precipitation at the surface, such as rain, freezing rain, sleet, ice pellets, drizzle, freezing drizzle, or snow, where temperatures are near freezing.

    c. Pilots should be aware that SLD could occur aloft without any SLD precipitation on the surface.

    d. Current weather information can miss SLD, so it is important to know and watch for cues on the airplane.

14. Pilots may consider periodically disengaging the autopilot and hand flying the airplane when operating in icing conditions.

    a. If this is not desirable due to cockpit workload levels, pilots should monitor the autopilot closely for abnormal trim, trim rate, or airplane attitude.

    b. As ice builds up on aircraft without auto-throttles, the autopilot will attempt to hold altitude without regard for airspeed, leading to a potential stall situation.

WIND SHEAR

1. **Wind shear** is any change in wind velocity (speed and/or direction).

    a. If the change is abrupt and of more than slight magnitude, it can be an extreme hazard to flight.

    b. A characteristic of low-level wind shear associated with a low-level temperature inversion is an increase in airspeed during climbout and while on approach.

        1) To reduce the risk of inadvertent stalls, pilots are advised to improve their awareness of normal climbout pitch attitude and to put less emphasis on strict airspeed control.

2. Wind shear can occur at any level in the atmosphere and be horizontal and/or vertical; i.e., it occurs wherever adjacent air flows in different directions and/or at different speeds.

3. Wind shear is an atmospheric condition that may be associated with a low-level temperature inversion, a jet stream, or a frontal zone.

4. **Light turbulence** momentarily causes slight, erratic changes in altitude and/or attitude.

5. Severe **turbulence** and wind shear may be found on all sides of a thunderstorm, including directly beneath it and as much as 20 mi. laterally.

6. Hazardous wind shear is commonly encountered near the ground during periods of strong temperature inversion and near thunderstorms.

    a. Expect wind shear in a temperature inversion whenever wind speed at 2,000 to 4,000 ft. AGL is 25 kt. or more.

    b. When going through the inversion, allow airspeed to go above normal climb and approach speed.

MICROBURSTS

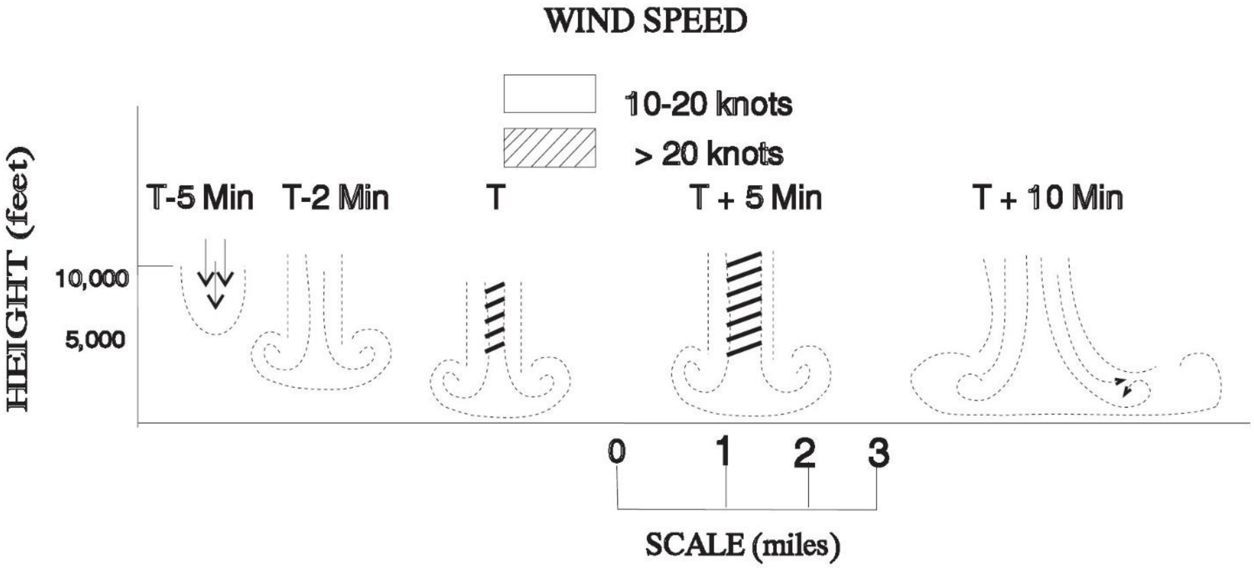
1. Microbursts are small-scale intense downdrafts that, on reaching the surface, spread outward in all directions from the downdraft center. This causes the presence of both vertical and horizontal wind shears that can be extremely hazardous to all types and categories of aircraft, especially at low altitudes.

2. Parent clouds producing microburst activity can be any of the low or middle layer convective cloud types.

    a. Microbursts commonly occur within the heavy rain portion of thunderstorms but also occur in much weaker, benign-appearing convective cells that have little or no precipitation reaching the ground.

3. The life cycle of a microburst as it descends in a convective rain shaft is illustrated below.

    a. "T" is the time the microburst strikes the ground.



Vertical cross section of the evolution of a microburst wind field. T is the time of initial divergence at the surface. The shading refers to the vector wind speeds. Figure adapted from Wilson et al., 1984, Microburst Wind Structure and Evaluation of Doppler Radar for Wind Shear Detection, DOT/FAA Report No. DOT/FAA/PM-84/29, National Technical Information Service, Springfield, VA 37 pp.

4. Characteristics of microbursts include

    a. Size. The microburst downdraft is typically less than 1 mi. in diameter as it descends from the cloud base to about 1,000-3,000 ft. above the ground.

        1) In the transition zone near the ground, the downdraft changes to a horizontal outflow that can extend to approximately 2 *112* mi. in diameter.

    b. Intensity. The downdrafts can be as strong as 6,000 fpm.

        1) Horizontal winds near the surface can be as strong as 45 kt., resulting in a 90-kt. shear (headwind to tailwind change for a traversing aircraft) across the microburst.

        2) These strong horizontal winds occur within a few hundred feet of the ground.

    c. Visual signs. Microbursts can be found almost anywhere there is convective activity.

        1) They may be embedded in heavy rain associated with a thunderstorm or in light rain in benign-appearing virga.

        2) When there is little or no precipitation at the surface accompanying the microburst, a ring of blowing dust may be the only visual clue of its existence.

    d. Duration. An individual microburst will seldom last longer than 15 min. from the time it strikes the ground until dissipation.

        1) An important consideration for pilots is that the microburst intensifies for about 5 min. after it strikes the ground, with the maximum-intensity winds lasting approximately 2 to 4 min.

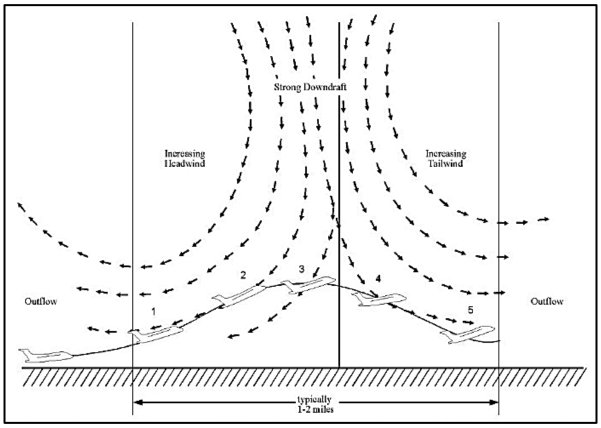
        2) Once microburst activity starts, multiple microbursts in the same general area are not uncommon and should be expected.

        3) Sometimes microbursts are concentrated into a line structure, and under these conditions, activity may continue for as long as an hour.

5. Microburst wind shear may create a severe hazard for aircraft within 1,000 ft. of the ground, particularly during the approach to landing and landing and takeoff phases.

    a. The aircraft may encounter a headwind (performance increasing) followed by a downdraft and tailwind (both performance decreasing), possibly resulting in terrain impact.

    b. See Figure below.



A microburst encounter during takeoff. The airplane first encounters a headwind and experiences increasing performance (1), this is followed in short succession by a decreasing headwind component (2), a downdraft (3), and finally a strong tailwind (4), where 2 through 5 all result in decreasing performance of the airplane. Position (5) represents an extreme situation just prior to impact. Figure courtesy of Walter Frost, FWG Associates, Inc., Tullahoma, Tennessee.