13.9.1. Severe turbulence and icing, heavy precipitation, lightning, windshear, and gusty surface winds may accompany thunderstorms. These hazards are so common they appear on the front of every DD Form l75-1, Flight Weather Briefing. Severe thunderstorms may produce large hail, damaging winds, and sometimes tornadoes.

13.9.2. Hazardous turbulence is present in all thunderstorms, and in a severe thunderstorm it can damage the airframe and cause serious injury to passengers and crew. The most violent turbulence occurs in the shear between updrafts and downdrafts. Outside the cloud, shear turbulence has been encountered several thousand feet above and as much as 20 miles from a severe storm. Severe turbulence can occur in the anvil 15 to 30 miles downwind. Remember, the storm cloud is only the visible portion of a turbulent system. Updrafts and downdrafts often extend outside the storm proper.

13.9.3. The shear zone between the cold air downdraft and surrounding air forms a low level turbulent area. When the shear zone reaches the surface and spreads out laterally ahead of the storm, it's called a gust-front. It often occurs 20 or more miles ahead of a mature storm. Thunderstorms with multiple downdrafts may form second or third gust fronts between the first and the cloud base. On average, horizontal wind direction changes 40 percent across the gust front, and wind speed may increase 50 percent between the surface and 1,500 feet. Thus, surface observations may not give a true estimate of the actual wind just above the surface.

13.9.4. A roll cloud on the leading edge of a storm often indicates eddies associated with this shear. The roll cloud is most prevalent with cold front or squall line thunderstorms and indicates an extremely turbulent zone. The first gust causes a rapid and sometimes drastic change in surface wind ahead of an approaching storm.

13.10. Thunderstorm Icing.

13.10.1. Where the free air temperatures are at or below freezing, icing should be expected. In general, icing is associated with temperatures from 0°C to -20°C. The most severe icing occurs from 0°C to -10°C, with the worst icing conditions usually found just above the freezing level between 0°C and -5°C. Since the freezing level is also the zone where heavy rainfall and turbulence most frequently occur, this particular altitude appears to be the most hazardous.

13.10.2. Hailstones are solid spheres of ice or irregular frozen conglomerates originating in the updraft/downdraft couplet of thunderstorms. Supercell thunderstorms contain enormous updrafts and downdrafts that permit large hailstones to grow by accretion over periods of many minutes. Hailstones can be spherical, conical, or quite irregular in shape (**Figure l3.8**). Hailstones are often tossed out of the chimney-effect updraft into downdrafts where the ice commences its descent as a potentially damaging missile. Baseball and softball sized hail is often reported with severe thunderstorms. Hailstorms have been known to precipitate hail measured over a foot deep. As a general rule, the larger the storm, the more likely it is to have hail. Hail has been encountered as high as 45,000 feet in completely clear air and may be carried up to 20 miles downwind from the storm core.

Figure 13.8. 7 ½ inch Diameter Hail.

13.11. Thunderstorm Hail.

13.11.1. The largest hailstone measured in the United States weighed nearly two pounds and was 18½ inches in circumference. Imagine the devastation to your aircraft if you were to fly through even softball-sized hail! Hailstones larger than ½ to ¾ of an inch cause significant aircraft damage in a few seconds. Figure 13.9 shows photographs of aircraft damaged after flights through hail.

Figure 13.9. Hail Damage to Aircraft.

13.12. Thunderstorm Lightning.

13.12.1. Lightning occurs at all levels in a thunderstorm. The majority of lightning discharges never strike the ground but occur between clouds or within a cloud (**Figure 13.10**). Lightning also occurs in the clear air around the top, sides and bottoms of storms. The proverbial "bolt out of the blue" (**Figure 13.11**) can still strike aircrews flying miles from a thunderstorm.

Figure 13.10. Lightning Variations.

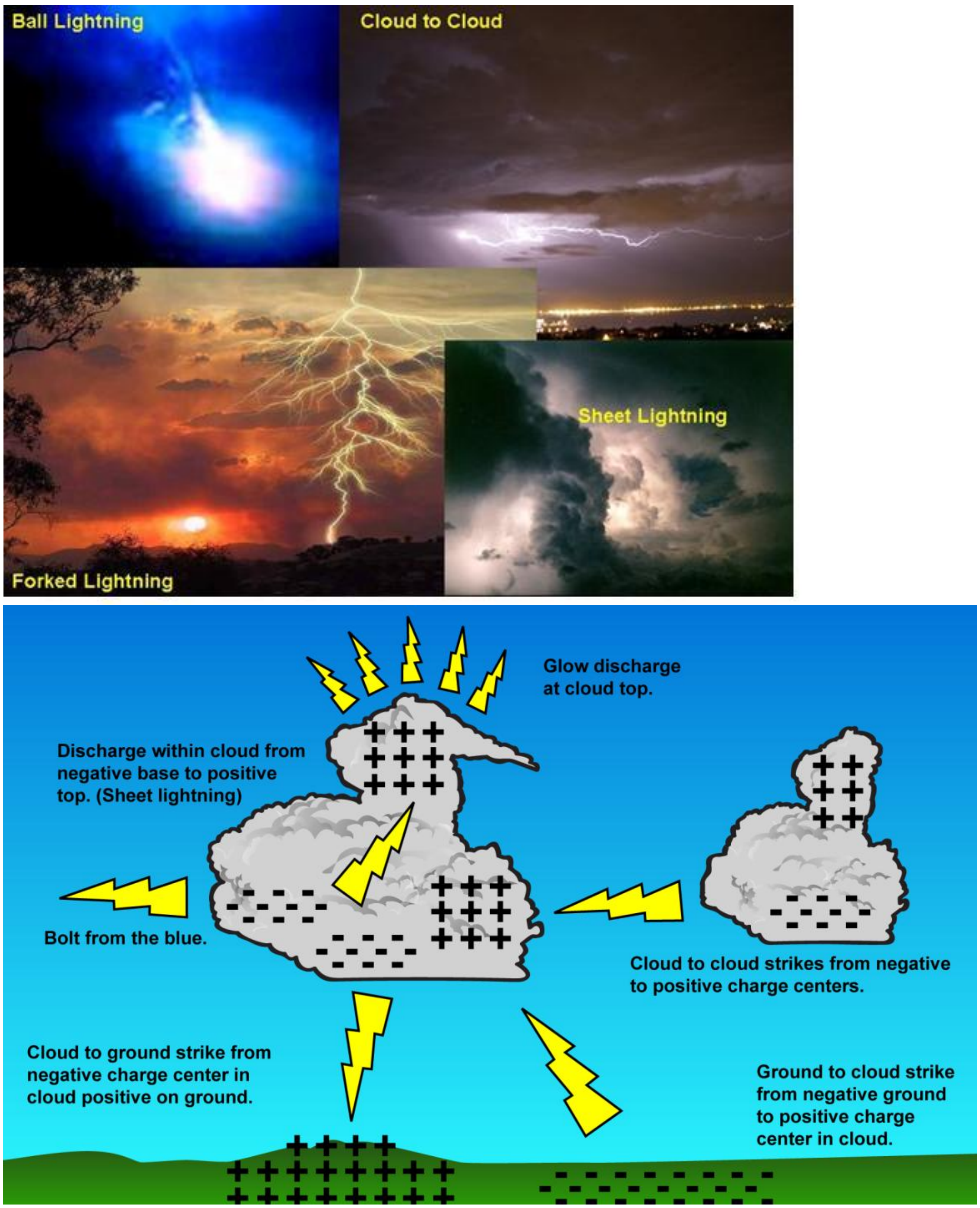


Figure 13.11. Lightning Bolt "Out of the Blue".

13.12.2. Electrostatic discharges are very similar to natural lightning but are triggered by the aircraft itself. Electrical charges build up on aircraft when they fly through clouds or precipitation (liquid or frozen) or even solid particles such as dust, haze, and ice. The aircraft's electrical field may then interact with charged areas of the atmosphere resulting in an electrostatic discharge. This discharge does not have to occur in a thunderstorm. Aircraft have reported damage from electrostatic discharges occurring in cirrus downwind of previous thunderstorm activity, in cumulus around a thunderstorm's periphery, and even in stratiform clouds and light rain showers. Electrostatic discharges usually cause minor physical damage and indirect effects such as electrical circuit upsets.

13.12.3. Lightning strikes and electrostatic discharges are the leading causes of reportable weather related aircraft accidents and incidents in the Air Force. They are encountered at nearly all temperatures and altitudes and affect all types of aircraft. Aircraft are struck or can trigger strikes in two types of weather conditions: electrically active clouds (thunderstorms) and electrically inactive (non-thunderstorm) clouds.

13.12.4. Research aircraft have shown that penetration of the upper reaches of a thunderstorm (35-40,000 feet with temperatures less than -40^{o}C) provides one of the greatest potentials for strikes and discharges. The majority of Air Force and commercial airline incidents, however, occur at lower altitudes in non-thunderstorm clouds and in areas outside of active thunderstorm cells. Aircraft probably trigger strikes and discharges of this type since they would not occur naturally without the aircraft. In most of these cases the aircraft operates in one or more of the following conditions:

13.12.4.1. Within 8^{o}C of the freezing level.

13.12.4.2. Within 5,000 feet of the freezing level.

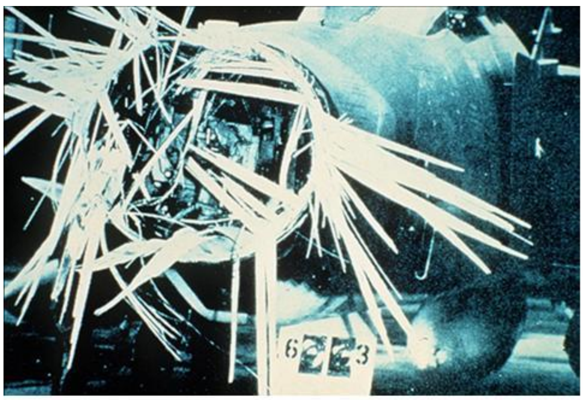
13.12.4.3. In light precipitation (including snow).

13.12.4.4. In clouds (including debris clouds).

13.12.4.5. In light or negligible turbulence.

13.12.5. Lightning strikes and electrostatic discharges have varied effects on aircraft and aircrews. Usually, structural damage is minor but sometimes severe structural damage can occur (**Figure 13.12**). Damage to aircraft electrical systems, instruments, avionics, and radar is also possible. Transient voltages and currents induced in the aircraft electrical systems, as well as direct lightning strikes, have caused bomb doors to open, activated wing folding motors, and made the accuracy of electronic flight control navigational systems questionable. After an electrostatic discharge or a lightning strike, consider all instruments invalid until proper operation is verified.

Figure 13.12. Major Structural Damage Resulting from Lightning Strike.



13.12.6. Aircrews are not immune to the effects of lightning strikes. Flash blindness can last up to 30 seconds, and the shock wave can cause some temporary hearing loss, if headphones or hearing loss protection gear are not worn. Some aircrews report electric shock and minor burns.

13.13. Tornadoes.

13.13.1. Tornadoes are violent, rotating columns of air that descend from cumulonimbus clouds (**Figure 13.13**) in funnel-like or tube-like shapes. If the circulation does not reach the surface, it is called a funnel cloud (**Figure 13.14**); if it touches water, it is called a waterspout (**Figure 13.15**). A tornado vortex is normally several hundred yards wide but can be up to 1 ½ miles wide. Within the tornado's funnel-shaped circulation, winds can reach 300 miles per hour, while the forward speed of the tornado can average 30-40 kts.

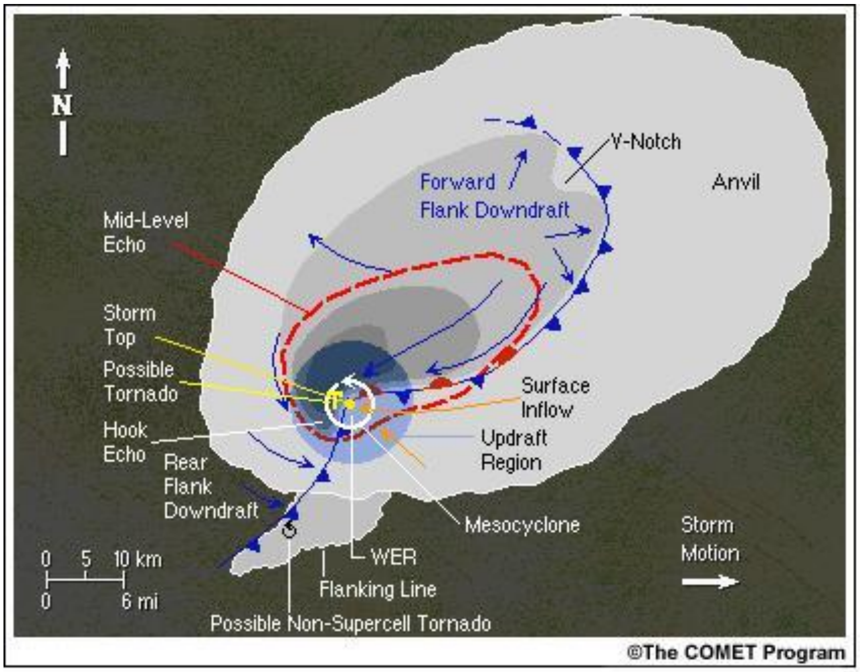
Figure 13.13. Tornado.

Figure 13.14. Funnel Cloud.

Figure 13.15. Waterspout.

13.13.2. Observed as appendages of the main cloud, families of tornadoes or tornadic vortices may extend 20 miles from the lightning and precipitation areas (**Figure 13.16**). They may last from a few minutes to hours. These vortices usually occur on the storm's southern or south western flank. Innocent looking cumulus trailing the thunderstorm may mask tornadic vortices and the vortex may not be visible to unwary aircrews. The invisible vortices may be revealed only by swirls in the cloud base or dust whirls boiling along the ground, but may be strong enough to cause severe structural damage to the aircraft.

Figure 13.16. Anatomy of a Funnel Cloud.



13.13.3. Airborne radar isn't much help in spotting tornadoes. It returns echoes of significant precipitation but doesn't display a spinning column of air for your guidance while flying around the thunderstorms. It must be emphasized that just plain eyeballing and radar scanning a line of CBs won't tell you which thunderstorm is hiding a tornado. Be cautious on approach and departure, under or through lines of thunderstorms. The hazards tend to increase with altitude in the clouds because of the convergence of the vortices upward in the cloud line. The effect upon the aircraft may range from a thump to catastrophic airframe failure in major encounters.

13.13.4. Pressure usually falls rapidly with approaching thunderstorms, rises sharply with the onset of the gust front and rain showers, and returns to normal as the storm moves on. This pressure change cycle can occur in 15 minutes. If the altimeter setting is not corrected, the indicated altitude may be in error by hundreds of feet.

13.14. Identifying a Thunderstorm.

13.14.1. Precipitation static is a steady, high level of noise in radio receivers caused by intense, continual electrical discharges from sharp metallic points and edges of flying aircraft. It is often encountered in the vicinity of thunderstorms. When an aircraft flies through an area containing clouds, precipitation, or a concentration of solid particles (ice, sand, dust, and such), it accumulates a charge of static electricity. The electricity discharges onto a nearby surface, or into the air, causing a noisy disturbance at lower radio frequencies.

13.14.2. Mammatus clouds (**Figure 13.17**) often precede severe activity, generally as a part of the underside of the thunderstorm anvil in front of the storm. The lower-based roll cloud is in advance of the thunderstorm and appears as a dark, ominous, boiling, cloud mass. The roll cloud area often contains severe turbulence and signals the leading edge of the thunderstorm gust front boundary.

Figure 13.17. Mammatus Clouds.

13.15. Avoiding a Thunderstorm.

13.15.1. If conditions will not permit you to circumnavigate a thunderstorm, you have only two alternatives; divert to the closest unaffected airfield (and wait until the storm passes) or go through the thunderstorm, but only as a last resort if required by your mission. Ask yourself, "Is going through the thunderstorm worth losing the aircraft; or my life?"

13.15.2. The method you use to get past a thunderstorm depends on the following considerations. Therefore, as you approach a thunderstorm, take your time and size up the situation to ensure the method you attempt (based on the rules of thumb and the techniques found below) will be the proper one and you won't have to do any second-guessing once you are on your way.

13.15.3. In estimating the situation, you must analyze the nature of the terrain, altitude of the base of the storm, altitude of the top, number of storms in the area and their location in relation to each other, size and intensity of these storms, direction and velocity of the movement of the storm, location of your destination and an alternate airport, and type of aircraft you are flying. (Including its service ceiling and range). **WARNING:** The following guidance is not to be construed as a recommendation to fly through, under, over, or near a thunderstorm. It is given to provide information only in case your mission is so critical to national defense that it warrants the very real risk of losing the aircraft and personnel on board, or, as happens in some cases, you encounter a thunderstorm that is embedded in other clouds.

13.15.4. When you expect to fly over a storm, obtain your altitude before approaching it, so you are on top of the cloud shelf around the storm and can inspect the storm line before selecting your course. A rule of thumb is to fly an additional 1,000 feet higher for every 10 knots of wind speed at cloud top level. This rule doesn't, however, guarantee your safety. Remember, if the storm is in its growth stage, your altitude may not be sufficient to clear the storm as it continues its rapid growth.

13.15.5. The altitude necessary to fly around the tops or over the saddlebacks between thunderstorms will vary with the season and the latitude in which you encounter the storm. In higher latitudes (north of 60^o), 25,000 feet may be sufficient, but remember the 25,000-foot storm in higher latitudes can be as violent as the 50,000-foot storm close to the equator. In the tropics, the height of the saddlebacks may be above the service ceiling of your aircraft.

13.15.6. If you inadvertently enter a thunderstorm, don't turn around. If you do, you'll fly through the same hazards again. Hold your original course. Use your airborne radar to determine the shallowest or weakest part of the storm. Heavy precipitation may attenuate (absorb) your radar energy, making you believe you are safe when you are actually headed into the most violent part of the storm.

13.15.7. **Aircrew Notes.**

13.15.7.1. *Maintain turbulence-penetration airspeed before entering a thunderstorm.*

13.15.7.2. *If lightning threatens to blind you temporarily, turn your cockpit or thunderstorm lights to full power. Keep your eyes on the instrument panel and consider lowering your seat.*

13.15.7.3. *If St. Elmo's fire (static electricity) forms on the windshield, the wings and the periphery of the engines, reduce your airspeed and the fire will usually go away. Always follow flight manual procedures to maintain your flight safety margin.*

13.15.7.4. *St. Elmo's fire may appear in various colors such as reddish and bluish (reddish for a positive charge and bluish for a negative charge). It may appear outside or even inside the aircraft as a small dot of static electricity or large areas of "electrical arcing." Some pilots have even reported it as large peacock feathers arcing off the nose of the aircraft. (St. Elmo's fire is not a hazard to flight, but may interfere with radio communication in the form of static.) St. Elmo's fire is also a warning sign of a potential static discharge or lightning strike.*

13.15.8. Isolated air mass thunderstorms and orographic thunderstorms (those created by updrafts around rough terrain) are usually local and should be flown around. The added mileage and time are usually of little consequence. Thunderstorms can be circumnavigated at low, high, or intermediate levels, depending upon the set of circumstances they present. In any case, it is vital to determine the direction in which a line of storms is moving and to fly between the storm centers, heading in at a right angle. For individual cells, you should fly with the rotation of the storm. Since most storms rotate counterclockwise in the Northern Hemisphere, if you are traveling eastward, fly on the south side of the storm; if you are flying westward, fly on the north side of the storm. Remember, storms generally move from southwest to northeast in the Northern Hemisphere. Therefore, if you are flying on the north side of the storm, be sure to give it a wide berth to compensate for its movement.

13.15.9. At intermediate levels, keep either blue sky or light spots in the clouds in sight ahead of you. This may cause you to alter course a little from time to time to miss the storm centers, but don't wander around. In circumnavigating at intermediate levels, it is a good plan to stay on top of intermediate clouds where you can keep the structure of the main cloud in view. Once you have entered the storm area, if the hole closes up ahead of you and you have to go on instruments, don't change course. Stick to your original right angle course and go through. Don't alter your course on account of turbulence, rain, or hail because you may find yourself flying through the same hazards again.

13.15.10. If the terrain is flat or you are over the open sea, flying underneath the storm may seem to be one of the easiest ways to negotiate a thunderstorm, but it's one of the most dangerous methods because of violent downdrafts, microbursts, wind shear, icing, and hail. Familiarity with thunderstorm dynamics is essential, especially where you will encounter updrafts and downdrafts (refer back to **Figure 13.6**). If your fuel range is short and/or your service ceiling is low, this may be the only method open to you if your divert base is on the other side of the storm. The "Underneath" method should not be attempted in mountainous country.

13.15.11. If your equipment permits, fly over the top of the main body of a thunderstorm or between the saddlebacks. To elect this method, you must be sure of your aircraft, sure of your knowledge of the storm, and sure of yourself. Remember, you should clear the top by at least 1,000 feet of altitude for each 10 knots of wind speed at the cloud top. Flying over the top is preferable to flying underneath; however, this may exceed the service ceiling of your aircraft. You must know the intensity of the storm, its extent, and the direction in which it is moving. You must also know that your fuel supply is adequate, and the service ceiling of your aircraft is sufficient to get you as high as you need to go. Some storms develop higher than 60,000 feet in the mid-latitudes and tropics. **NOTE:** Most thunderstorms build faster than an aircraft can climb. Attempting to out-climb one can be deadly, especially since you won't know the growth capability of the thunderstorm until you try to "race" it. Obviously this has a good possibility of putting you into a dangerous position with potentially few escape options. By flying close to the thunderstorm you are also increasing your chances of a lightning strike or damage from hail thrown out the top of the thunderstorm.

13.15.12. In flying over the saddlebacks or around the anvils, remember that the higher you go, the less turbulence you will encounter. The thunderstorm anvil is created as the jet stream shears off the top of the thunderstorm. Winds are generally strong there, and hailstones can be carried as much as 20 miles downstream--in the clear air! Do not fly in, under, or downwind of the anvil top; this is a favorite place for hailstones.

13.15.13. If you have no alternative but to fly through a thunderstorm, try to avoid the center of the storm or area where the most violent turbulence is apparent. Select a course where the thunderstorm is visibly least turbulent and where there will be the least possibility of hail; slow the aircraft to turbulence penetration airspeed (hopefully, you are already at this speed);

don't change course! When entering the front of a thunderstorm, you will encounter updrafts and downdrafts. Prepare yourself by going in with enough altitude to keep from being forced into the ground during a downdraft. Your minimum penetration altitude should be 4,000 to 6,000 feet AGL above the highest terrain in the area. The flight manual for each type of aircraft gives the correct turbulence penetration speed. In the absence of this information, a good rule of thumb is to fly about 50 percent above stall speed. Once inside the storm, let the plane ride out the updrafts and downdrafts and concentrate on maintaining a level attitude. The attitude gyro is the primary attitude instrument because rapidly changing pressure conditions within the storm will result in erratic variations in altitude, airspeed, and rate of climb, which cause unreliable readings. Since the attitude gyro is independent of the pitot static system, its indications should be considered valid. If using autopilot, disengage the altitude hold mode and speed hold mode. (If used, they will increase aircraft maneuvers and structural stress.) **WARNING:** When you fly through a thunderstorm, the hazards that you face are extreme. You will be betting the aircraft, your life, and the lives of your crew members on the forces of nature. This must be the only remaining alternative!

13.15.14. If you must penetrate a storm area, comply with thunderstorm avoidance rules and follow the general flight procedures listed below:

13.15.14.1. Don't try and circumnavigate thunderstorms covering 6/10 or more of an area.

13.15.14.2. Don't fly into or under the cirrus anvil. Severe hail damage can result.

13.15.14.3. Don't turn around. Attempting to do so will keep you in the storm longer, increase stress on the aircraft, increase the possibility of stall and may result in spatial disorientation and/or an unusual attitude.

13.15.14.4. Don't penetrate in close formation.

13.15.14.5. Avoid by at least 20 miles, any thunderstorm identified as severe or giving an intense radar echo. This is especially true under the anvil of a large cumulonimbus.

13.15.14.6. Get your aircraft ready for thunderstorm penetration prior to entry by setting instrument and cockpit lights full bright, pitot heat on, and safety belts and shoulder harnesses tightened and locked.

13.15.14.7. Change power settings to establish turbulence penetration airspeed. This airspeed reduces the hazard of exceeding stress limitations.

13.15.14.8. Choose a heading minimizing travel time in the storm.

13.15.14.9. Try to maintain a constant attitude, but ride out the updrafts and downdrafts. Trying to maintain an exact altitude during strong updrafts and downdrafts will increase stress on your aircraft.

13.15.14.10. Penetrate the storm below the freezing level or above -15^{o}C to avoid severe icing hazards.