AC NO: 00-24A

DATE: 6/23/78

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: THUNDERSTORMS

1. PURPOSE. This advisory circular describes the hazards of thunderstorms to aviation and offers guidance to help prevent accidents caused by thunderstorms.

2. CANCELLATION. Advisory Circular 00-24, dated July 12, 1968, is canceled.

3. REFERENCES. Advisory Circulars 00-6A, 00-45A, and 00-50.

4. GENERAL. We all know what a thunderstorm looks like. Much has been written about the mechanics and life cycles of thunderstorms. They have been studied for many years; and while much has been learned, the studies continue because much is not known. Knowledge and weather radar have modified our attitudes toward thunderstorms, but one rule continues to be true--any storm recognizable as a thunderstorm should be considered hazardous until measurements have shown it to be safe. That means safe for you and your aircraft. Almost any thunderstorm can spell disaster for the wrong combination of aircraft and pilot.

5. HAZARDS. A thunderstorm packs just about every weather hazard known to aviation into one vicious bundle. Although the hazards occur in numerous combinations, let us look at the most hazardous combination of thunderstorms, the squall line, then we will examine the hazards individually.

a. Squall Lines. A squall line is a narrow band of active thunderstorms. Often it develops on or ahead of a cold front in moist, unstable air, but it may develop in unstable air far removed from any front. The line may be too long to detour easily and too wide and severe to penetrate. It often contains steady-state thunderstorms and presents the single most intense weather hazard to aircraft. It usually forms rapidly, generally reaching maximum intensity during the late afternoon and the first few hours of darkness.

Initiated by: AFS-224

b. Tornadoes.

(1) The most violent thunderstorms draw air into their cloud bases with great vigor. If the incoming air has any initial rotating motion, it often forms an extremely concentrated vortex from the surface well into the cloud. Meteorologists have estimated that wind in such a vortex can exceed 200 knots; pressure inside the vortex is quite low. The strong winds gather dust and debris and the low pressure generates a funnel-shaped cloud extending downward from the cumulo-nimbus base. If the cloud does not reach the surface, it is a "funnel cloud"; if it touches a land surface, it is a "tornado."

(2) Tornadoes occur with both isolated and squall line thunderstorms. Reports or forecasts of tornadoes indicate that atmospheric conditions are favorable for violent turbulence. An aircraft entering a tornado vortex is almost certain to suffer structural damage. Since the vortex extends well into the cloud, any pilot inadvertently caught on instruments in a severe thunderstorm could encounter a hidden vortex.

(3) Families of tornadoes have been observed as appendages of the main cloud extending several miles outward from the area of lightning and precipitation. Thus, any cloud connected to a severe thunderstorm carries a threat of violence.

c. Turbulence.

(1) Potentially hazardous turbulence is present in all thunderstorms, and a severe thunderstorm can destroy an aircraft. Strongest turbulence within the cloud occurs with shear between updrafts and downdrafts. Outside the cloud, shear turbulence has been encountered several thousand feet above and 20 miles laterally from a severe storm. A low level turbulent area is the shear zone associated with the gust front. Often, a "roll cloud" on the leading edge of a storm marks the top of the eddies in this shear and it signifies an extremely turbulent zone. Gust fronts often move far ahead (up to 15 miles) of associated precipitation. The gust front causes a rapid and sometimes drastic change in surface wind ahead of an approaching storm. Advisory Circular 00-50, "Low Level Wind Shear," explains in greater detail the hazards associated with gust fronts. Figure 1 shows a schematic cross section of a thunderstorm with areas outside the cloud where turbulence may be encountered.

(2) It is almost impossible to hold a constant altitude in a thunderstorm, and maneuvering in an attempt to do so produces greatly increased stress on the aircraft. It is understandable that the speed of the aircraft determines the rate of turbulence encounters. Stresses are least if the aircraft is held in a constant attitude and allowed to "ride the waves." To date, we have no sure way to pick "soft spots" in a thunderstorm.

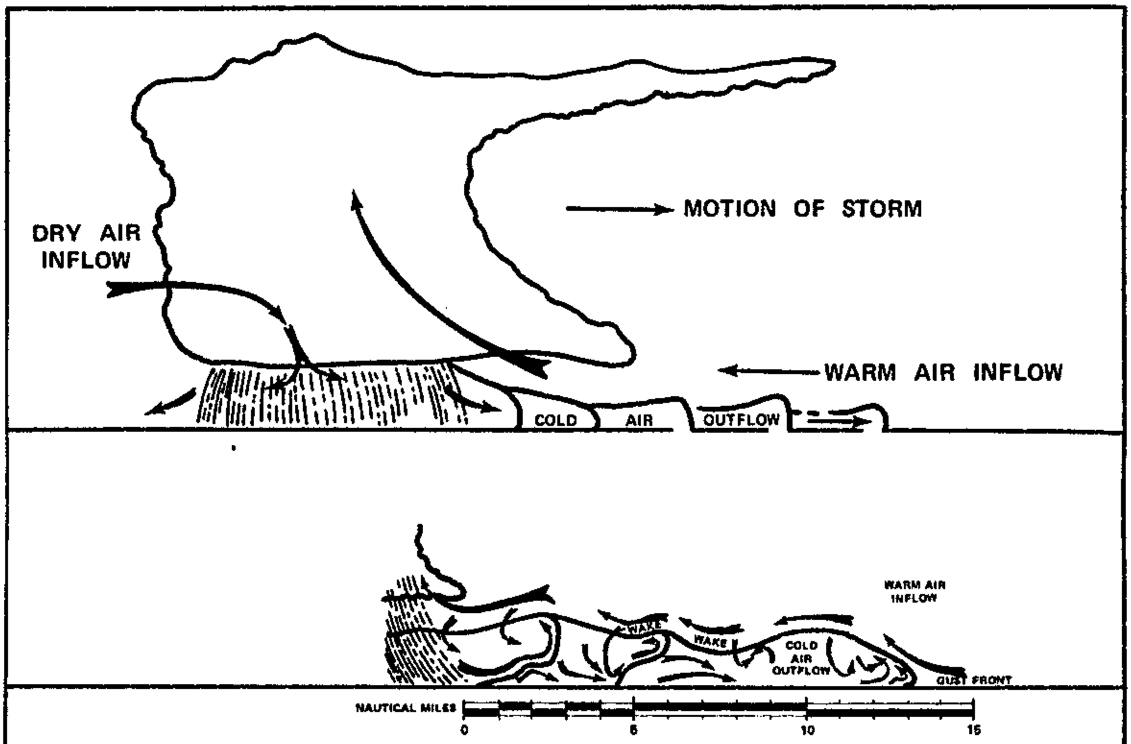

Fig. 1.

d. Icing.

(1) Updrafts in a thunderstorm support abundant liquid water; and when carried above the freezing level, the water becomes supercooled. When temperature in the upward current cools to about -15°C, much of the remaining water vapor sublimates as ice crystals; and above this level, at lower temperatures, the amount of supercooled water decreases.

(2) Supercooled water freezes on impact with an aircraft. Clear icing can occur at any altitude above the freezing level; but at high levels, icing may be rime or mixed rime and clear. The abundance of supercooled water makes clear icing very rapid between 0°C and -15°C and encounters can be frequent in a cluster of cells. Thunderstorm icing can be extremely hazardous.

e. Hail.

(1) Hail competes with turbulence as the greatest thunderstorm hazard to aircraft. Supercooled drops above the freezing level begin to freeze. Once a drop has frozen, other drops latch on and freeze to it, so the hailstone grows--sometimes into a huge iceball. Large hail occurs with severe thunderstorms that have built to great heights. Eventually, the

hailstones fall, possibly some distance from the storm core. Hail may be encountered in clear air several miles from dark thunderstorm clouds.

(2) As hailstones fall through air whose temperature is above $0^{\circ}C$, they begin to melt and precipitation may reach the ground as either hail or rain. Rain at the surface does not mean the absence of hail aloft. You should anticipate possible hail with any thunderstorm, especially beneath the anvil of a large cumulo-nimbus. Hailstones larger than one-half inch in diameter can significantly damage an aircraft in a few seconds.

f. Low Ceiling and Visibility. Generally, visibility is near zero within a thunderstorm cloud. Ceiling and visibility also may be restricted in precipitation and dust between the cloud base and the ground. The restrictions create the same problem as all ceiling and visibility restrictions; but the hazards are increased many fold when associated with the other thunderstorm hazards of turbulence, hail, and lightning which make precision instrument flying virtually impossible.

g. Effect on Altimeters. Pressure usually falls rapidly with the approach of a thunderstorm, then rises sharply with the onset of the first gust and arrival of the cold downdraft and heavy rain showers, falling back to normal as the storm moves on. This cycle of pressure change may occur in 15 minutes. If the pilot does not receive a corrected altimeter setting, his altimeter may be more than 100 feet in error.

h. Lightning. A lightning strike can puncture the skin of an aircraft and can damage communications and electronic navigational equipment. Lightning has been suspected of igniting fuel vapors causing explosion; however, serious accidents due to lightning strikes are extremely rare. Nearby lightning can blind the pilot rendering him momentarily unable to navigate either by instrument or by visual reference. Nearby lightning can also induce permanent errors in the magnetic compass. Lightning discharges, even distant ones, can disrupt radio communications on low and medium frequencies. Though lightning intensity and frequency have no simple relationship to other storm parameters, severe storms, as a rule, have a high frequency of lightning.

6. WEATHER RADAR.

a. Weather radar detects droplets of precipitation size. Strength of the radar return (echo) depends on drop size and number. The greater the number of drops, the stronger is the echo; and the larger the drops, the stronger is the echo. Drop size determines echo intensity to a much greater extent than does drop number. Hailstones usually are covered with a film of water and, therefore, act as huge water droplets giving the strongest of all echoes.

b. Numerous methods have been used in an attempt to categorize the intensity of a thunderstorm. To standardize thunderstorm language between weather radar operators and pilots, the use of Video Integrator Processor (VIP) levels is being promoted.

c. The National Weather Service (NWS) radar observer is able to objectively determine storm intensity levels with VIP equipment. These radar echo intensity levels are on a scale of one to six. If the maximum VIP Levels are 1 "weak" and 2 "moderate," then light to moderate turbulence is possible with lightning. VIP Level 3 is "strong" and severe turbulence is possible with lightning. VIP Level 4 is "very strong" and severe turbulence is likely with lightning. VIP Level 5 is "intense" with severe turbulence, lightning, hail likely, and organized surface wind gusts. VIP Level 6 is "extreme" with severe turbulence, lightning, large hail, extensive surface wind gusts, and turbulence.

d. Thunderstorms build and dissipate rapidly. Therefore, do not attempt to plan a course between echoes. The best use of ground radar information is to isolate general areas and coverage of echoes. You must avoid individual storms from in-flight observations either by visual sighting or by airborne radar. It is better to avoid the whole thunderstorm area than to detour around individual storms unless they are scattered.

e. Airborne weather avoidance radar is, as its name implies, for avoiding severe weather--not for penetrating it. Whether to fly into an area of radar echoes depends on echo intensity, spacing between the echoes, and the capabilities of you and your aircraft. Remember that weather radar detects only precipitation drops; it does not detect turbulence. Therefore, the radar scope provides no assurance of avoiding turbulence. The radar scope also does not provide assurance of avoiding instrument weather from clouds and fog. Your scope may be clear between intense echoes; this clear area does not necessarily mean you can fly between the storms and maintain visual sighting of them.

f. The most intense echoes are extreme thunderstorms. Remember that while hail always gives a radar echo, it may fall several miles from the nearest visible cloud, and hazardous turbulence may extend to as much as 20 miles from the echo edge. Avoid the most intense echoes by at least 20 miles; that is, echoes should be separated by at least 40 miles before you fly between them. As echoes become weak, you can reduce the distance by which you avoid them.

7. DO'S AND DON'TS OF THUNDERSTORM FLYING.

a. Above all, remember this: never regard any thunderstorm lightly, even when radar observers report the echoes are of light intensity. Avoiding thunderstorms is the best policy. Following are some do's and don'ts of thunderstorm avoidance:

(1) Don't land or takeoff in the face of an approaching thunderstorm. A sudden gust front of low level turbulence could cause loss of control.

(2) Don't attempt to fly under a thunderstorm even if you can see through to the other side. Turbulence and wind shear under the storm could be disastrous.

(3) Don't fly without airborne radar into a cloud mass containing scattered embedded thunderstorms. Scattered thunderstorms not embedded usually can be visually circumnavigated.

(4) Don't trust the visual appearance to be a reliable indicator of the turbulence inside a thunderstorm.

(5) Do 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 cumulo-nimbus.

(6) Do circumnavigate the entire area if the area has 6/10 thunderstorm coverage.

(7) Do remember that vivid and frequent lightning indicates the probability of a severe thunderstorm.

(8) Do regard as extremely hazardous any thunderstorm with tops 35,000 feet or higher whether the top is visually sighted or determined by radar.

b. If you cannot avoid penetrating a thunderstorm, following are some do's BEFORE entering the storm:

(1) Tighten your safety belt, put on your shoulder harness if you have one, and secure all loose objects.

(2) Plan and hold your course to take you through the storm in a minimum time.

(3) To avoid the most critical icing, establish a penetration altitude below the freezing level or above the level of $-15^{\circ}C$.

(4) Verify that pitot heat is on and turn on carburetor heat or jet engine anti-ice. Icing can be rapid at any altitude and cause almost instantaneous power failure and/or loss of airspeed indication.

(5) Establish power settings for turbulence penetration airspeed recommended in your aircraft manual.

(6) Turn up cockpit lights to highest intensity to lessen temporary blindness from lightning.

(7) If using automatic pilot, disengage altitude hold mode and speed hold mode. The automatic altitude and speed controls will increase maneuvers of the aircraft thus increasing structural stress.

(8) If using airborne radar, tilt the antenna up and down occasionally. This will permit you to detect other thunderstorm activity at altitudes other than the one being flown.

c. Following are some do's and don'ts DURING the thunderstorm penetration:

(1) Do keep your eyes on your instruments. Looking outside the cockpit can increase danger of temporary blindness from lightning.

(2) Don't change power settings; maintain settings for the recommended turbulence penetration airspeed.

(3) Do maintain a constant attitude; let the aircraft "ride the waves." Maneuvers in trying to maintain constant altitude increase stress on the aircraft.

(4) Don't turn back once you are in the thunderstorm. A straight course through the storm most likely will get you out of the hazards most quickly. In addition, turning maneuvers increase stress on the aircraft.

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APPENDIX 1. NSSL THUNDERSTORM RESEARCH

The National Severe Storms Laboratory (NSSL) has, since 1964, been the focal point of our thunderstorm research. In-flight conditions obtained from thunderstorm penetrations by controlled, especially equipped high performance aircraft are compared by the NSSL with National Weather Service (NWS) type ground-based radar and with newly developed doppler radar. The following comments are based on NSSL's interpretation of information and experience from this research.

a. Relationships between Turbulence and Reflectivity. Weather radar reflects precipitation such as rain and hail, not turbulence. It has been found, however, that the intensity level of the precipitation reflection does correlate with the degree of turbulence in a thunderstorm. The most severe turbulence is not necessarily found at the same place that gives the greatest radar reflection.

b. Relationships between Turbulence and Altitude. The NSSL studies of thunderstorms extending to 60,000 feet show little variation of turbulence intensity with altitude.

c. Turbulence and Echo Intensity on NWS Radar (WSR-57). The frequency and severity of turbulence increases with the radar reflectivity, a measure of the intensity of echoes from storm targets at a standard range. Derived gust velocities exceeding 2,100 feet per minute (classified as severe turbulence) are commonly encountered in Level 3 storms. In Level 2 storms, gusts of intensity between 1,200 and 2,100 feet per minute (classified as moderate turbulence) are encountered approximately once for each 10 nautical miles of thunderstorm flight.

d. Turbulence in Relation to Distance from Storm Core. NSSL data indicates that the frequency and severity of turbulence encounters decrease slowly with distance from storm cores. Significantly, the data indicates that within 20 miles from the center of severe storm cores, moderate to severe turbulence is encountered at any altitude about one-fifth as often as in the cores of Level 3 or greater thunderstorms. Further, the data indicates that moderate turbulence is encountered at any altitude up to 10 miles from the center of Level 2 thunderstorms. SEVERE TURBULENCE IS OFTEN FOUND IN TENUOUS ANVIL CLOUDS 15 TO 20 MILES DOWNWIND FROM SEVERE STORM CORES. Our findings agree with meteorological reasoning that THE STORM CLOUD IS ONLY THE VISIBLE PORTION OF A TURBULENT SYSTEM WHOSE UPDRAFTS AND DOWNDRAFTS OFTEN EXTEND OUTSIDE OF THE STORM PROPER.

e. Turbulence in Relation to Distance from the Storm Edge. THE CLEAR AIR ON THE INFLOW SIDE OF A STORM IS A PLACE WHERE SEVERE TURBULENCE MAY OCCUR. At the edge of a cloud, the mixing of cloudy and clear air often produces strong temperature gradients associated with rapid variations of vertical velocity. Tornadic activity is found in a wide range of spatial relationships to the strong echoes with which they are commonly associated, but many of the most intense and enduring tornadoes occur on the south to west edges of severe storms. The tornado itself is often associated with only a weak echo. Echo hooks and appendages are useful qualitative indicators of tornado occurrence but are by no means infallible guides. Severe turbulence should be anticipated up to 20 miles from the radar edge of severe storms; these often have a well-defined radar echo boundary. This distance decreases to approximately 10 miles with weaker storms which may sometimes have indefinite radar echo boundaries. THEREFORE, AIRBORNE RADAR IS A PARTICULARLY USEFUL AID FOR PILOTS IN MAINTAINING A SAFE DISTANCE FROM SEVERE STORMS.

f. Turbulence above Storm Tops. Flight data shows a relationship between turbulence above storm tops and the speed of upper tropospheric winds. WHEN THE WINDS AT STORM TOP EXCEED 100 KNOTS, THERE ARE TIMES WHEN SIGNIFICANT TURBULENCE MAY BE EXPERIENCED AS MUCH AS 10,000 FEET ABOVE THE CLOUD TOPS. THIS VALUE MAY BE DECREASED 1,000 FEET FOR EACH 10-KNOT REDUCTION OF WIND SPEED. This is especially important for clouds whose height exceeds the height of the tropopause. It should be noted that flight above severe thunderstorms is an academic consideration for today's civil aircraft in most cases, since these storms usually extend to 40,000 feet and above.

g. Turbulence below Cloud Base. While there is a little evidence that maximum turbulence exists at middle heights in storms (FL 200-300), turbulence beneath a storm is not to be minimized. This is especially true when the relative humidity is low in any air layer between the surface and 15,000 feet. Then the lower altitudes may be characterized by strong outflowing winds and severe turbulence where thunderstorms are present. Therefore, THE SAME TURBULENCE CONSIDERATIONS WHICH APPLY TO FLIGHT AT HIGH ALTITUDES NEAR STORMS APPLY TO LOW LEVELS AS WELL.

h. Maximum Storm Tops. Photogrammetric data indicates that the maximum height attained by thunderstorm clouds is approximately 63,000 feet. Such very tall storm tops have not been explored by direct means, but meteorological judgments indicate the probable existence of large hail and strong vertical drafts to within a few thousand feet of the top of these isolated stratosphere-penetrating storms. THEREFORE, IT APPEARS IMPORTANT TO AVOID SUCH VERY TALL STORMS AT ALL ALTITUDES.

i. Hail in Thunderstorms. The occurrence of HAIL IS MUCH MORE CLEARLY IDENTIFIED WITH THE INTENSITY OF ECHOES THAN IS TURBULENCE. AVOIDANCE OF MODERATE AND SEVERE STORMS SHOULD ALWAYS BE ASSOCIATED WITH THE AVOIDANCE OF DAMAGING HAIL.

j. Visual Appearance of Storms and Associated Turbulence Within Them. On numerous occasions, flights at NSSL have indicated that NO USEFUL CORRELATION EXISTS BETWEEN THE EXTERNAL VISUAL APPEARANCE OF THUNDERSTORMS AND THE TURBULENCE AND HAIL WITHIN THEM.

k. Modification of Criteria when Severe Storms and Rapid Development are Evident. During severe storm situations, radar echo intensities may grow by a factor of ten each minute, and cloud tops by 7,000 feet per minute. THEREFORE, NO FLIGHT PATH THROUGH SUCH A FIELD OF STRONG OR VERY STRONG

STORMS SEPARATED BY 20-30 MILES OR LESS MAY BE CONSIDERED TO REMAIN FREE FROM SEVERE TURBULENCE.

l. Extrapolation to Different Climes. General comment: Severe storms are associated with an atmospheric stratification marked by large values of moisture in low levels, relative dryness in middle levels, and strong wind shear. It is well known that this stratification of moisture permits excessive magnitudes of convective instability to exist for an indefinite period until rapid overturning of air is triggered by a suitable disturbance. Regions of the atmosphere which are either very dry or very moist throughout substantial depths cannot harbor great convective instability. Rather, a more nearly neutral thermal stratification is maintained, partially through a process of regular atmospheric overturning.

Desert Areas. In desert areas, storms should be avoided on the same basis as described in the above paragraphs. While nonstorm turbulence may, in general, be expected more frequently over desert areas during daylight hours than elsewhere, THE SAME TURBULENCE CONSIDERATIONS PREVAIL IN THE VICINITY OF THUNDERSTORMS.

Tropical-Humid Climates. When the atmosphere is moist and only slightly unstable through a great depth, strong radar echoes may be received from towering clouds which do not contain vertical velocities as strong as those of storms over the U.S. plains. Then it is a matter of the pilot being informed with respect to the general atmospheric conditions accompanying storms, for it is well known that PRACTICALLY ALL GEOGRAPHIC AREAS HAVING THUNDERSTORMS ARE OCCASIONALLY VISITED BY SEVERE ONES.

m. Use of Airborne Radar. Airborne radar is a valuable tool; HOWEVER, ITS USE IS PRINCIPALLY AS AN INDICATOR OF STORM LOCATIONS FOR AVOIDANCE PURPOSES WHILE EN ROUTE.

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