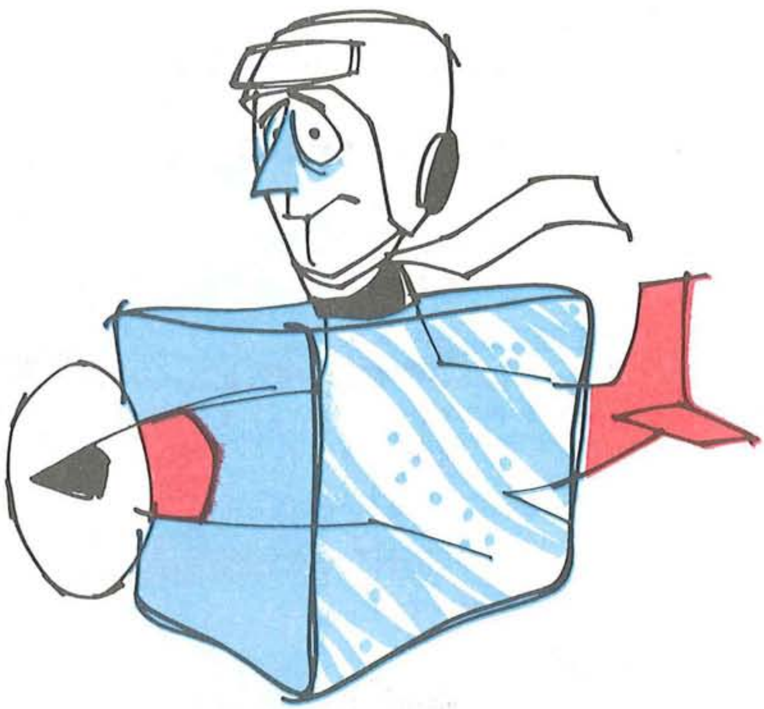


Chapter 10
ICING

Aircraft icing is one of the major weather hazards to aviation. Icing is a cumulative hazard. It reduces aircraft efficiency by increasing weight, reducing lift, decreasing thrust, and increasing drag. As shown in figure 89, each effect tends to either slow the aircraft or force it downward. Icing also seriously impairs aircraft engine performance. Other icing effects include false indications on flight instruments, loss of radio communications, and loss of operation of control surfaces, brakes, and landing gear.

In this chapter we discuss the principles of structural, induction system, and instrument icing and relate icing to cloud types and other factors. Although ground icing and frost are structural icing, we discuss them separately because of their different effect on an aircraft. And we wind up the chapter with a few operational pointers.

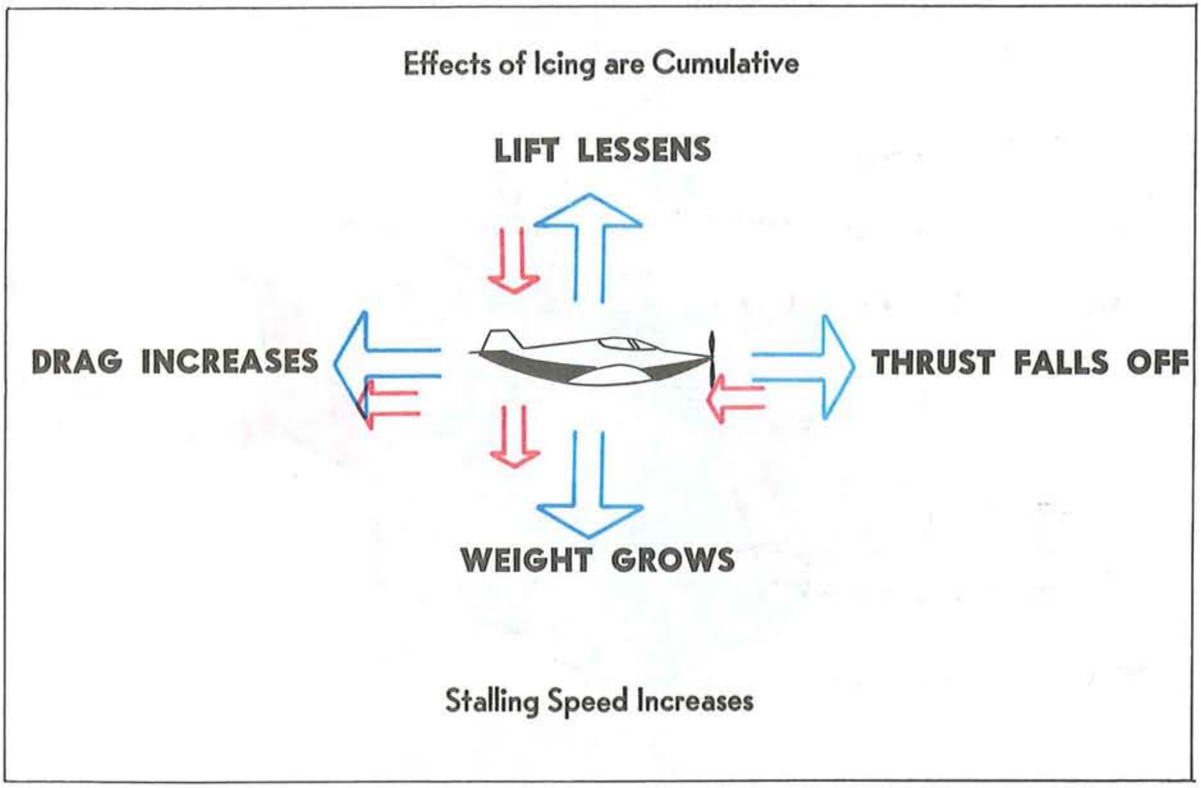


FIGURE 89. Effects of structural icing.

STRUCTURAL ICING

Two conditions are necessary for structural icing in flight: (1) the aircraft must be flying through visible water such as rain or cloud droplets, and (2) the temperature at the point where the moisture strikes the aircraft must be 0° C or colder. Aerodynamic cooling can lower temperature of an airfoil to 0° C even though the ambient temperature is a few degrees warmer.

Supercooled water increases the rate of icing and is essential to rapid accretion. Supercooled water is in an unstable liquid state; when an aircraft strikes a supercooled drop, part of the drop freezes instantaneously. The latent heat of fusion released by the freezing portion raises the temperature of the remaining portion to the melting point. Aerodynamic effects may cause the remaining portion to freeze. The way in which the remaining portion freezes determines the type of icing. The types of structural icing are clear, rime, and a mixture of the two. Each type has its identifying features.

CLEAR ICE

Clear ice forms when, after initial impact, the remaining liquid portion of the drop flows out over the aircraft surface gradually freezing as a smooth sheet of solid ice. This type forms when drops are large as in rain or in cumuliform clouds.

Figure 90 illustrates ice on the cross section of an airfoil, clear ice shown at the top. Figures 91 and 92 are photographs of clear structural icing. Clear ice is hard, heavy, and tenacious. Its removal by deicing equipment is especially difficult.

RIME ICE

Rime ice forms when drops are small, such as those in stratified clouds or light drizzle. The liquid portion remaining after initial impact freezes rapidly before the drop has time to spread over the aircraft surface. The small frozen droplets trap air between them giving the ice a white appearance as

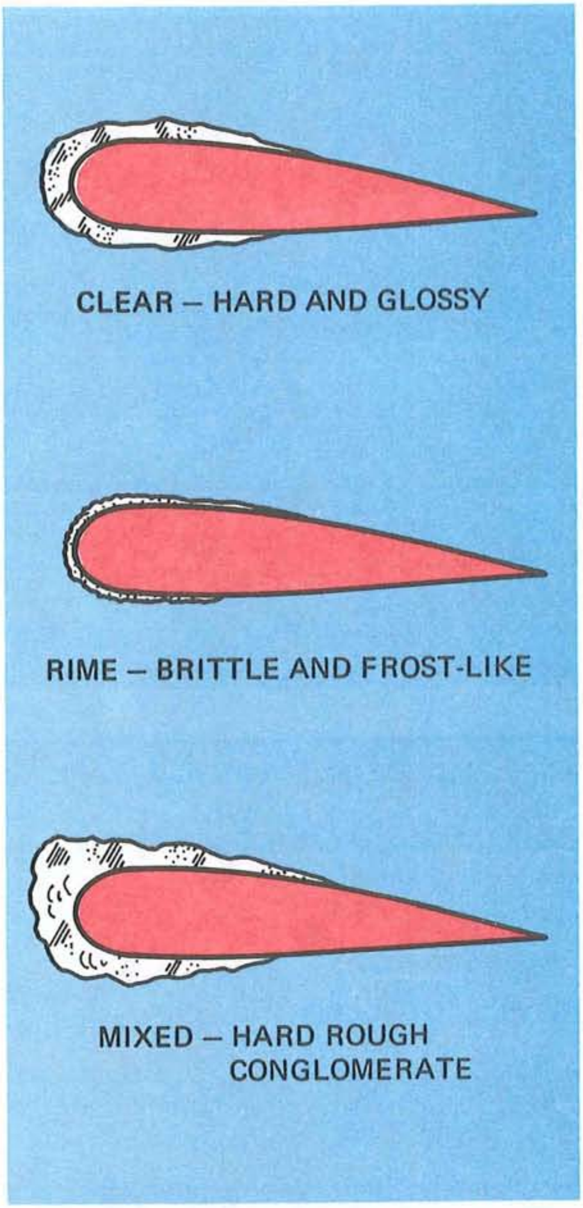


FIGURE 90. Clear, rime, and mixed icing on airfoils.

shown at the center of figure 90. Figure 93 is a photograph of rime.

Rime ice is lighter in weight than clear ice and its weight is of little significance. However, its irregular shape and rough surface make it very effective in decreasing aerodynamic efficiency of airfoils, thus reducing lift and increasing drag. Rime ice is brittle and more easily removed than clear ice.

MIXED CLEAR AND RIME ICING

Mixed ice forms when drops vary in size or when liquid drops are intermingled with snow or ice particles. It can form rapidly. Ice particles become imbedded in clear ice, building a very rough accumulation sometimes in a mushroom shape on leading edges as shown at the bottom of figure 90. Figure 94 is a photo of mixed icing built up on a pitot tube.

ICING INTENSITIES

By mutual agreement and for standardization the FAA, National Weather Service, the military aviation weather services, and aircraft operating organizations have classified aircraft structural icing into intensity categories. Section 16 of AVIATION WEATHER SERVICES (AC 00-45) has a table listing these intensities. The table is your guide in estimating how ice of a specific intensity will affect your aircraft. Use the table also in reporting ice when you encounter it.

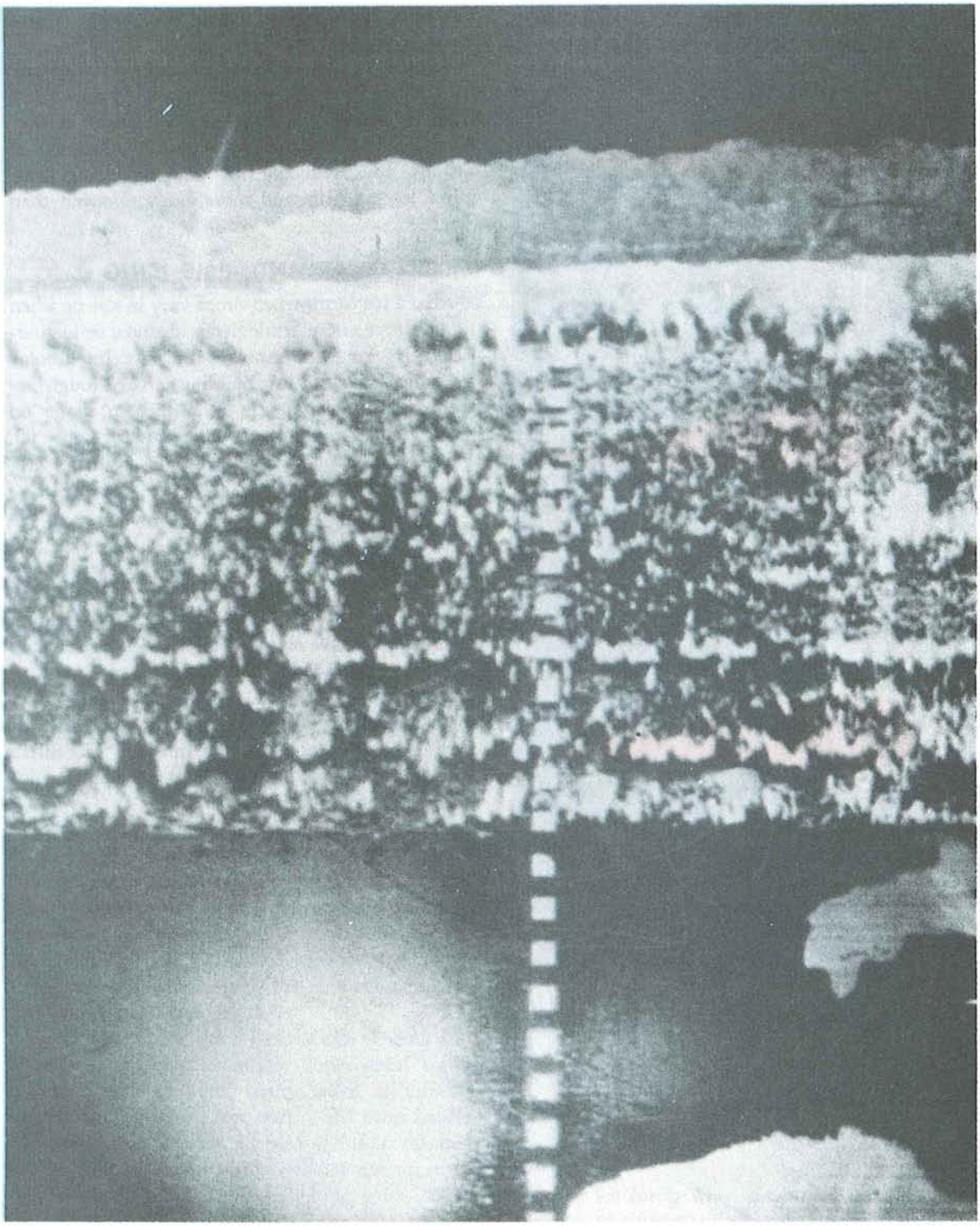


FIGURE 91. Clear wing icing (leading edge and underside). (Courtesy Dean T. Bowden, General Dynamics/Convair.)

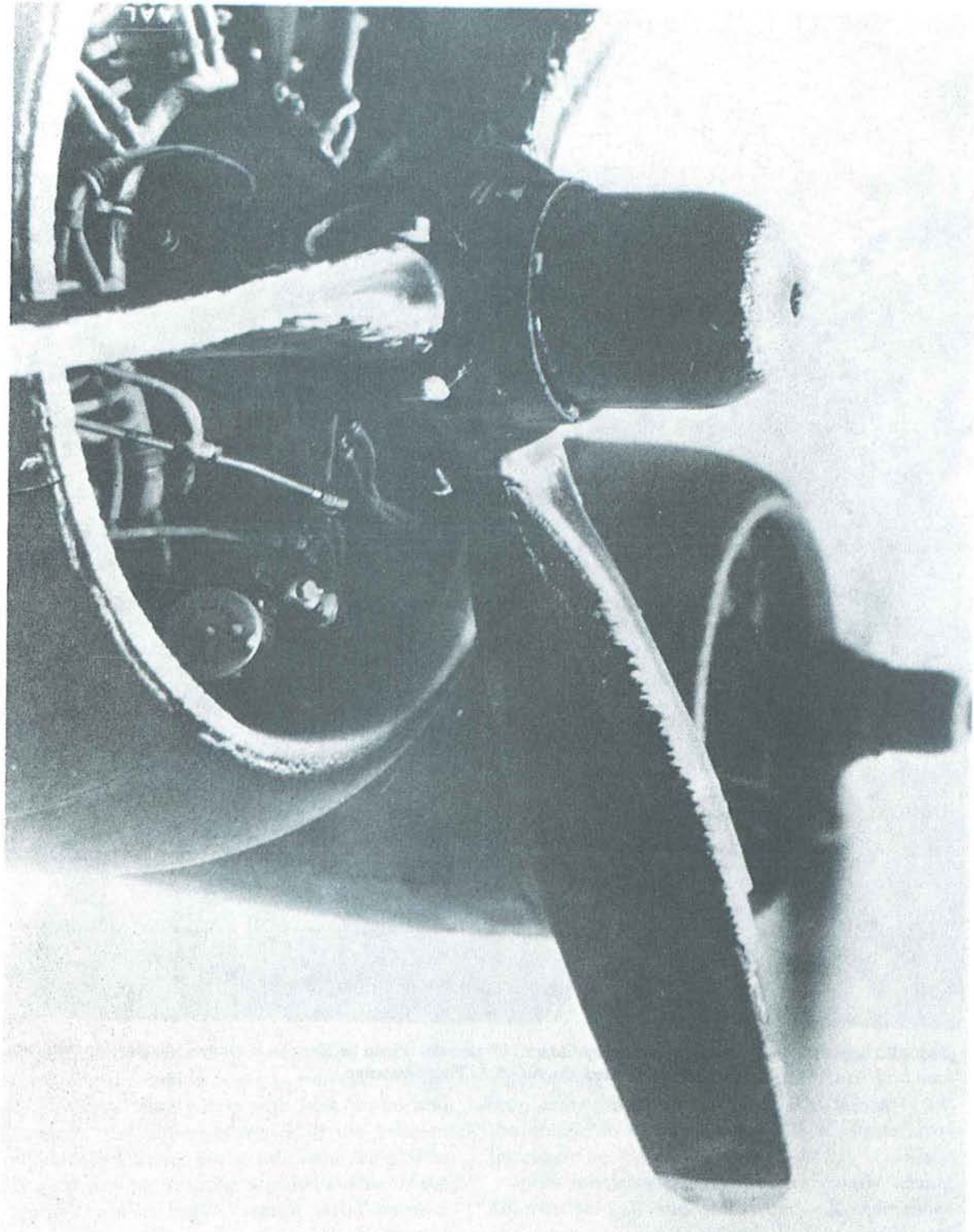


FIGURE 92. Propeller icing. Ice may form on propellers just as on any airfoil. It reduces propeller efficiency and may induce severe vibrations.

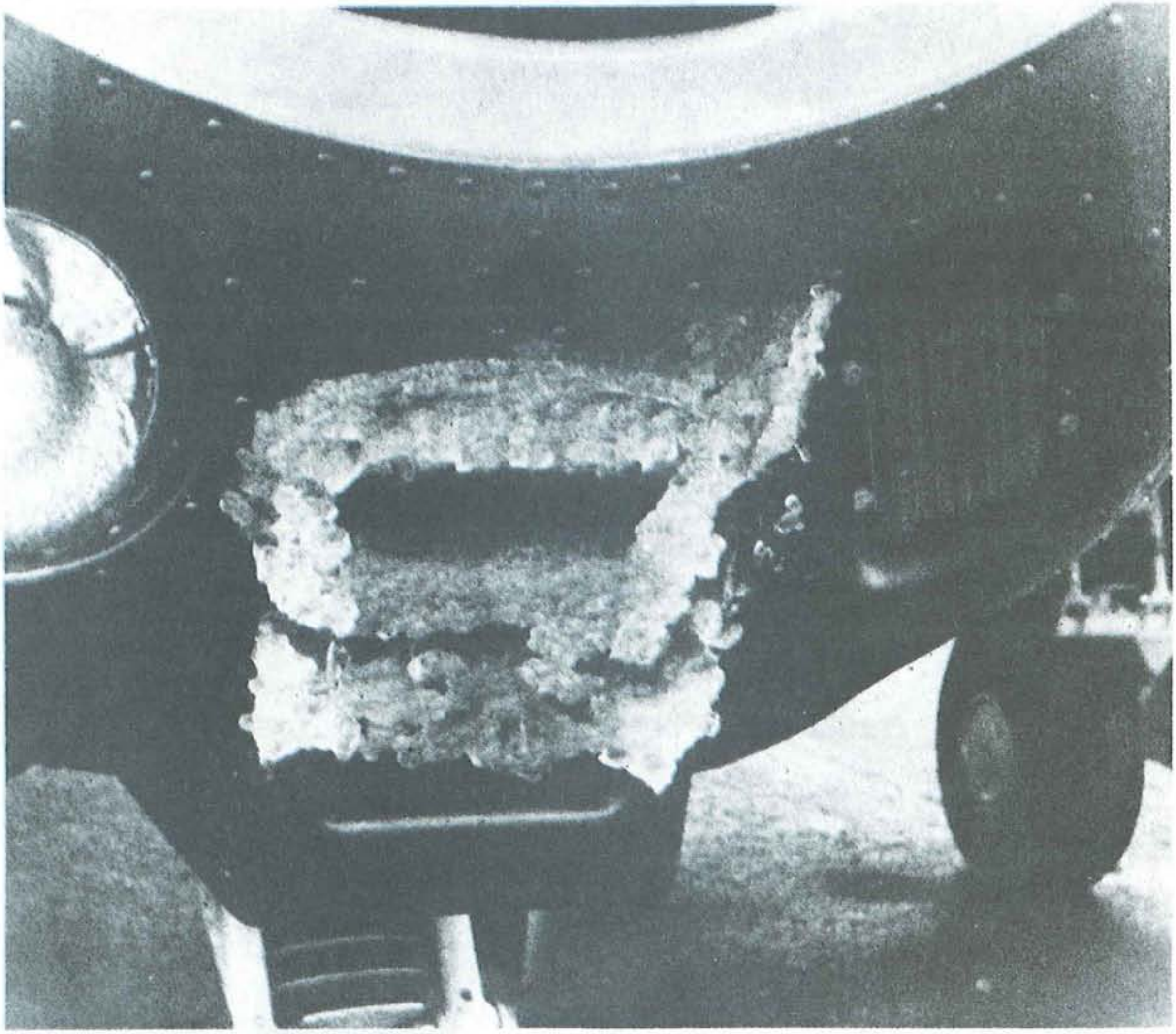


FIGURE 93. Rime icing on the nose of a Mooney "Mark 21" aircraft. (Photo by Norman Hoffman, Mooney Aircraft, Inc., courtesy the A.O.P.A. Pilot Magazine.)

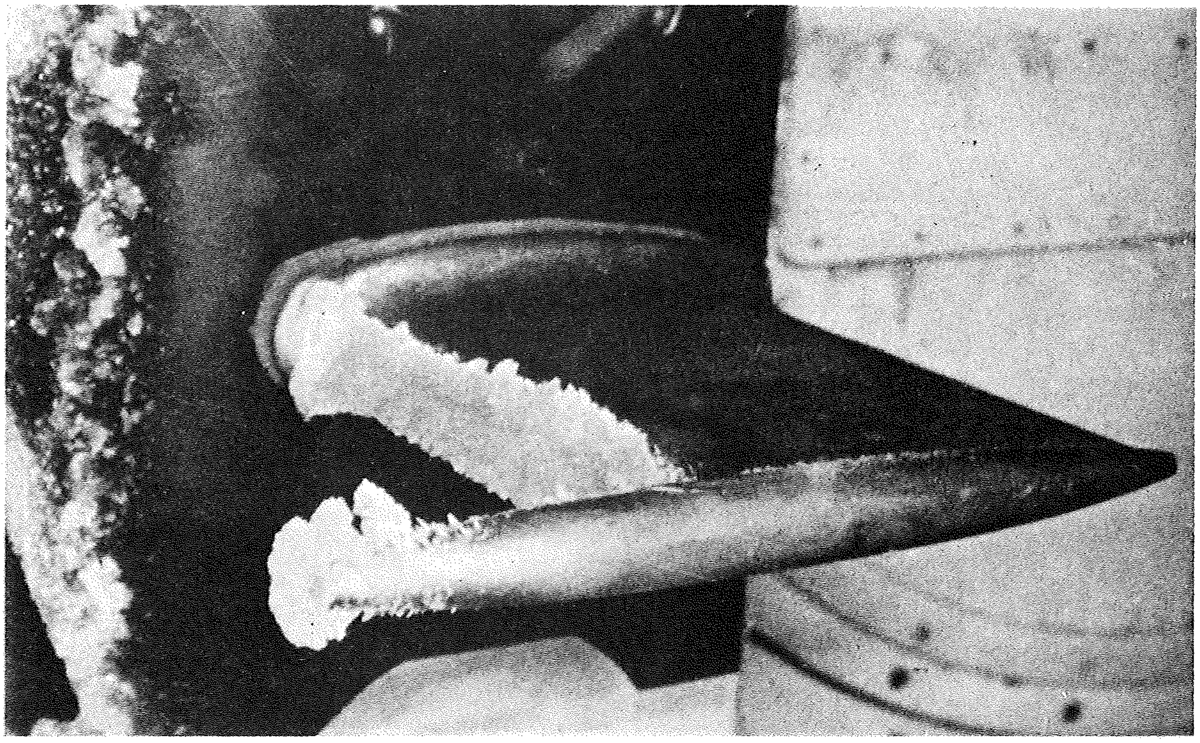


FIGURE 94. External icing on a pitot tube.

INDUCTION SYSTEM ICING

Ice frequently forms in the air intake of an engine robbing the engine of air to support combustion. This type icing occurs with both piston and jet engines, and almost everyone in the aviation community is familiar with carburetor icing. The downward moving piston in a piston engine or the compressor in a jet engine forms a partial vacuum in the intake. Adiabatic expansion in the partial vacuum cools the air. Ice forms when the temperature drops below freezing and sufficient moisture is present for sublimation. In piston engines, fuel evaporation produces additional cooling. Induction icing always lowers engine performance and can even reduce intake flow below that necessary for the engine to operate. Figure 95 illustrates carburetor icing.

Induction icing potential varies greatly among different aircraft and occurs under a wide range of meteorological conditions. It is primarily an engineering and operating problem rather than meteorological.

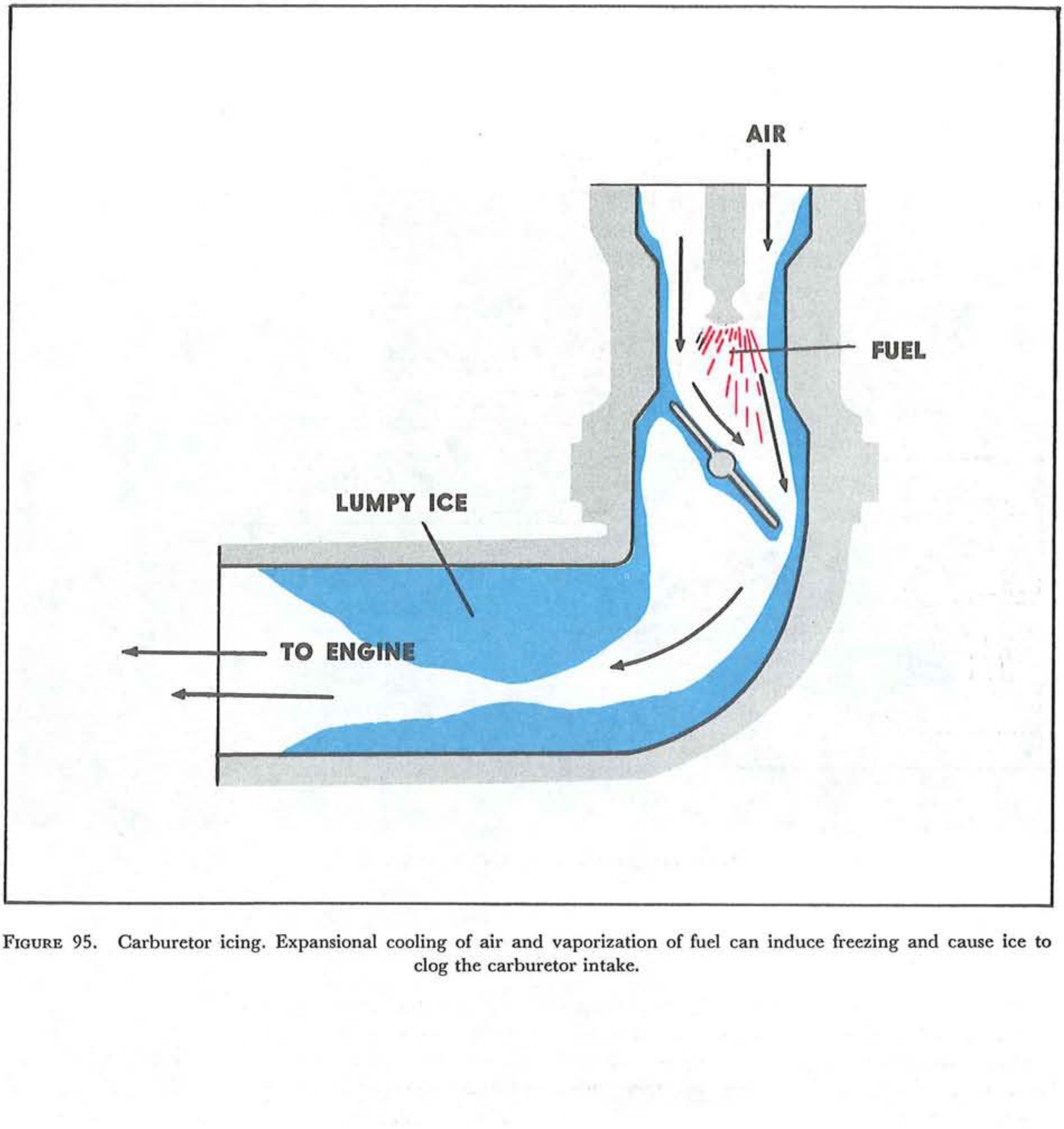


FIGURE 95. Carburetor icing. Expansional cooling of air and vaporization of fuel can induce freezing and cause ice to clog the carburetor intake.

INSTRUMENT ICING

Icing of the pitot tube as seen in figure 96 reduces ram air pressure on the airspeed indicator and renders the instrument unreliable. Most modern aircraft also have an outside static pressure port as part of the pitot-static system. Icing of the static pressure port reduces reliability of all instruments on the system—the airspeed, rate-of-climb, and the altimeter.

Ice forming on the radio antenna distorts its shape, increases drag, and imposes vibrations that may result in failure in the communications system of the aircraft. The severity of this icing depends upon the shape, location, and orientation of the antenna. Figure 97 is a photograph of clear ice on an antenna mast.

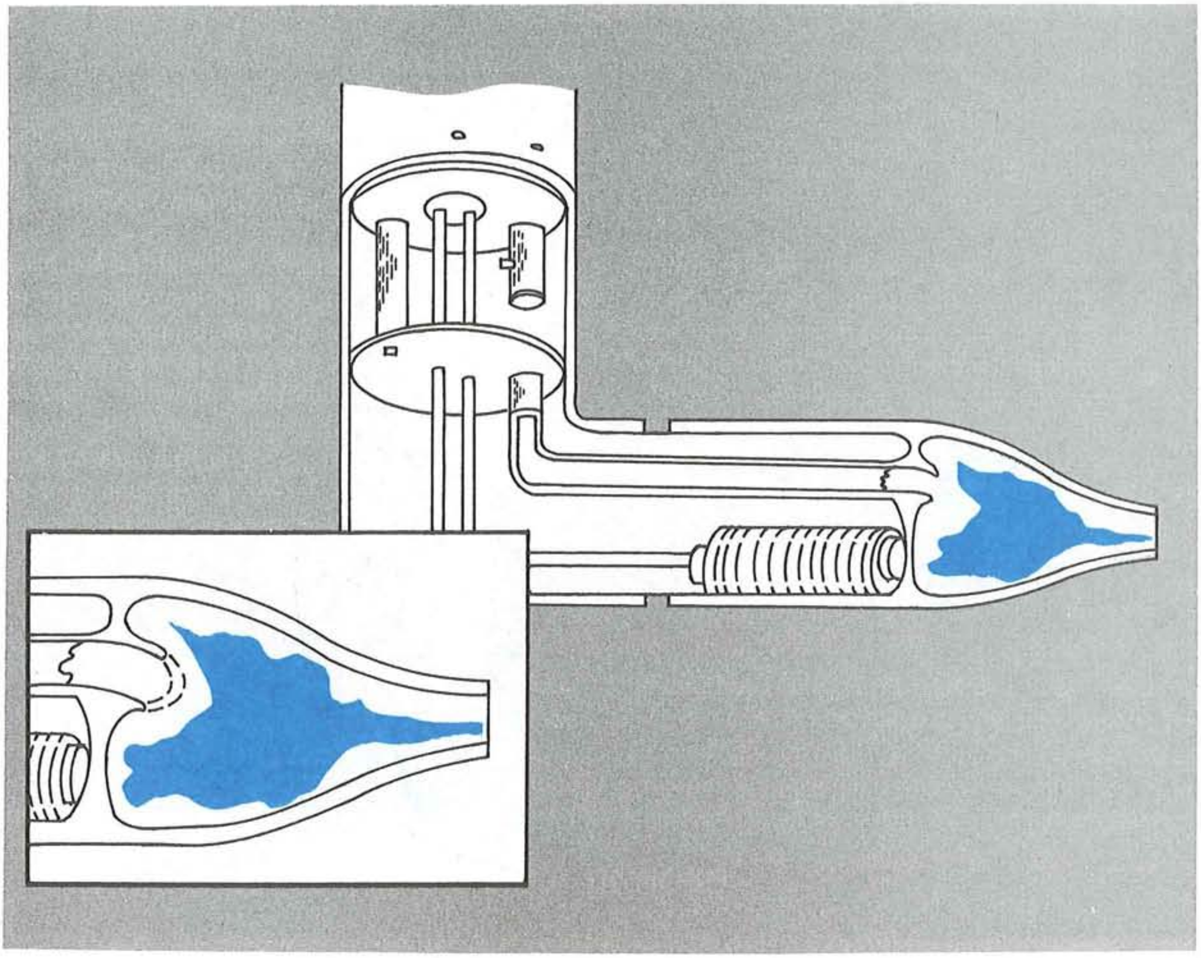


FIGURE 96. Internal pitot tube icing. It renders airspeed indicator unreliable.

ICING AND CLOUD TYPES

Basically, all clouds at subfreezing temperatures have icing potential. However, drop size, drop distribution, and aerodynamic effects of the aircraft influence ice formation. Ice may not form even though the potential exists.

The condition most favorable for very hazardous icing is the presence of many large, supercooled water drops. Conversely, an equal or lesser number of smaller droplets favors a slower rate of icing.

Small water droplets occur most often in fog and low-level clouds. Drizzle or very light rain is evidence of the presence of small drops in such clouds; but in many cases there is no precipitation at all. The most common type of icing found in lower-level stratus clouds is rime.

On the other hand, thick extensive stratified clouds that produce continuous rain such as altostratus and nimbostratus usually have an abundance of liquid water because of the relatively larger drop size and number. Such cloud systems in winter may cover thousands of square miles and present very serious icing conditions for protracted flights. Particularly in thick stratified clouds, concentrations of liquid water normally are greater with warmer temperatures. Thus, heaviest icing usually will be found at or slightly above the freezing level where temperature is never more than a few degrees below freezing. In layer type clouds, continuous icing conditions are rarely found to be more than 5,000 feet above the freezing level, and usually are two or three thousand feet thick.

The upward currents in cumuliform clouds are

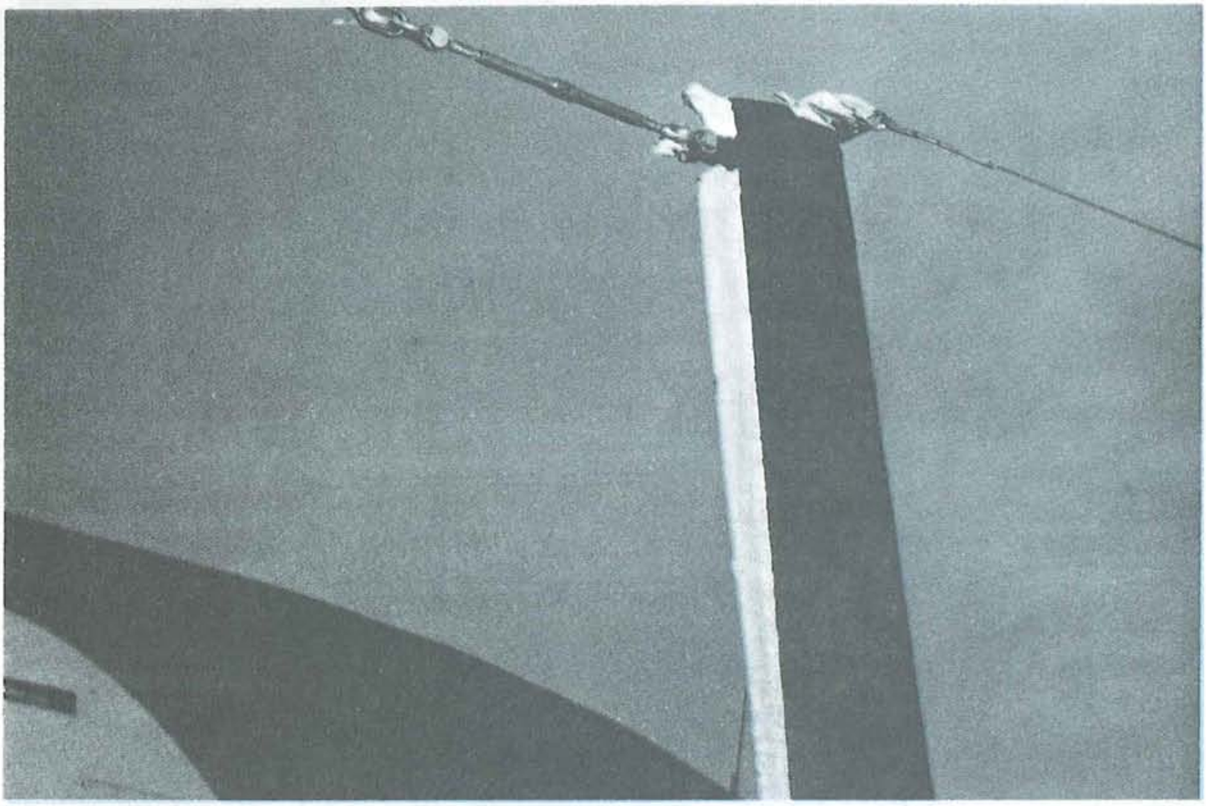


FIGURE 97. Clear ice on an aircraft antenna mast.

favorable for the formation and support of many large water drops. The size of raindrops and rainfall intensity normally experienced from showers and thunderstorms confirm this. When an aircraft enters the heavy water concentrations found in cumuliform clouds, the large drops break and spread rapidly over the leading edge of the airfoil forming a film of water. If temperatures are freezing or colder, the water freezes quickly to form a solid sheet of clear ice. Pilots usually avoid cumuliform clouds when possible. Consequently, icing reports from such clouds are rare and do not indicate the frequency with which it can occur.

The updrafts in cumuliform clouds carry large amounts of liquid water far above the freezing level. On rare occasions icing has been encountered in thunderstorm clouds at altitudes of 30,000 to 40,000 feet where the free air temperature was colder than minus 40° C.

While an upper limit of critical icing potential cannot be specified in cumuliform clouds, the cellular distribution of such clouds usually limits the horizontal extent of icing conditions. An exception, of course, may be found in a protracted flight through a broad zone of thunderstorms or heavy showers.

OTHER FACTORS IN ICING

In addition to the above, other factors also enter into icing. Some of the more important ones are discussed below.

FRONTS

A condition favorable for rapid accumulation of clear icing is freezing rain below a frontal surface. Rain forms above the frontal surface at temperatures warmer than freezing. Subsequently, it falls through air at temperatures below freezing and becomes supercooled. The supercooled drops freeze on impact with an aircraft surface. Figure 98 diagrams this type of icing. It may occur with either a warm front (top) or a cold front. The icing can be critical because of the large amount of supercooled water. Icing can also become serious in cumulonimbus clouds along a surface cold front, along a squall line, or embedded in the cloud shield of a warm front.

TERRAIN

Air blowing upslope is cooled adiabatically. When the air is cooled below the freezing point, the water becomes supercooled. In stable air blowing up a gradual slope, the cloud drops generally remain comparatively small since larger drops fall out as rain. Ice accumulation is rather slow and you should have ample time to get out of it before the accumulation becomes extremely dangerous. When air is unstable, convective clouds develop a more serious hazard as described in "Icing and Cloud Types."

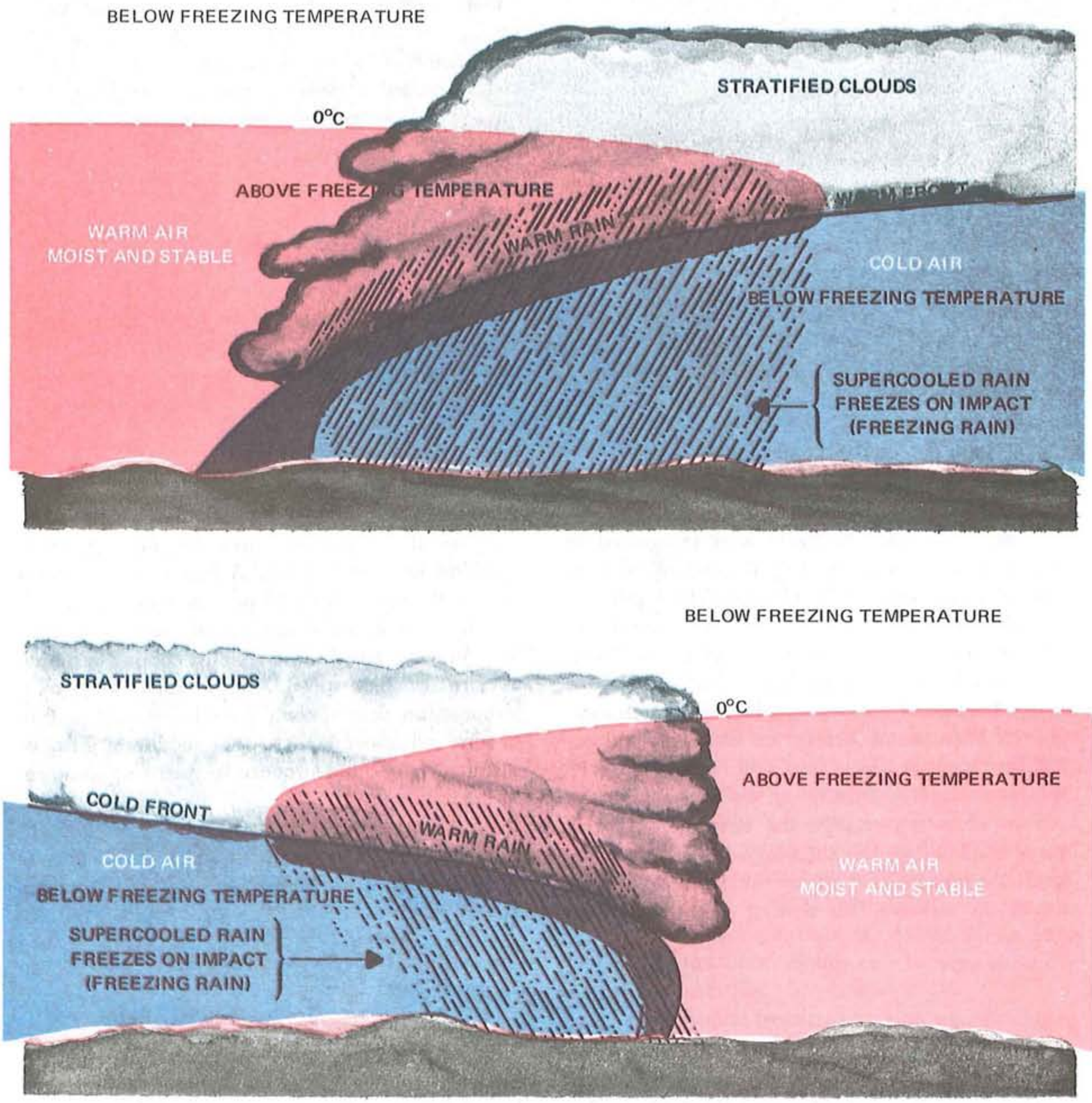


FIGURE 98. Freezing rain with a warm front (top) and a cold front (bottom). Rainfall through warm air aloft into subfreezing cold air near the ground. The rain becomes supercooled and freezes on impact.

Icing is more probable and more hazardous in mountainous regions than over other terrain. Mountain ranges cause rapid upward air motions on the windward side, and these vertical currents support large water drops. The movement of a frontal system across a mountain range often combines the normal frontal lift with the upslope effect of the mountains to create extremely hazardous icing zones.

Each mountainous region has preferred areas of icing depending upon the orientation of mountain ranges to the wind flow. The most dangerous icing takes place above the crests and to the windward side of the ridges. This zone usually extends about 5,000 feet above the tops of the mountains; but when clouds are cumuliform, the zone may extend much higher.

SEASONS

Icing may occur during any season of the year; but in temperate climates such as cover most of the contiguous United States, icing is more frequent in winter. The freezing level is nearer the ground in winter than in summer leaving a smaller low-level layer of airspace free of icing conditions. Cyclonic storms also are more frequent in winter, and the resulting cloud systems are more extensive. Polar regions have the most dangerous icing conditions in spring and fall. During the winter the air is normally too cold in the polar regions to contain heavy concentrations of moisture necessary for icing, and most cloud systems are stratiform and are composed of ice crystals.

GROUND ICING

Frost, ice pellets, frozen rain, or snow may accumulate on parked aircraft. You should remove all ice prior to takeoff, for it reduces flying efficiency of the aircraft. Water blown by propellers or splashed by wheels of an airplane as it taxis or runs through pools of water or mud may result in serious aircraft icing. Ice may form in wheel wells, brake mechanisms, flap hinges, etc., and prevent proper operation of these parts. Ice on runways and taxiways create traction and braking problems.

FROST

Frost is a hazard to flying long recognized in the aviation community. Experienced pilots have learned to remove all frost from airfoils prior to takeoff. Frost forms near the surface primarily in clear, stable air and with light winds—conditions which in all other respects make weather ideal for flying. Because of this, the real hazard is often minimized. Thin metal airfoils are especially vulnerable surfaces on which frost will form. Figure 99 is a photograph of frost on an airfoil.

Frost does not change the basic aerodynamic shape of the wing, but the roughness of its surface spoils the smooth flow of air thus causing a slowing of the airflow. This slowing of the air causes early air flow separation over the affected airfoil resulting in a loss of lift. A heavy coat of hard frost will cause a 5 to 10 percent increase in stall speed. Even a small amount of frost on airfoils may prevent an aircraft from becoming airborne at normal takeoff speed. Also possible is that, once airborne, an aircraft could have insufficient margin of airspeed above stall so that moderate gusts or turning flight could produce incipient or complete stalling.

Frost formation in flight offers a more complicated problem. The extent to which it will form is still a matter of conjecture. At most, it is comparatively rare.

IN CLOSING

Icing is where you find it. As with turbulence, icing may be local in extent and transient in character. Forecasters can identify regions in which icing is possible. However, they cannot define the precise small pockets in which it occurs. You should plan your flight to avoid those areas where icing probably will be heavier than your aircraft can handle. And you must be prepared to avoid or to escape the hazard when encountered en route.

FIGURE 99. Frost on an aircraft. Always remove ice or frost before attempting takeoff.

Here are a few specific points to remember:

1. Before takeoff, check weather for possible icing areas along your planned route. Check for pilot reports, and if possible talk to other pilots who have flown along your proposed route.
2. If your aircraft is not equipped with deicing or anti-icing equipment, avoid areas of icing. Water (clouds or precipitation) must be visible and outside air temperature must be near 0° C or colder for structural ice to form.
3. Always remove ice or frost from airfoils before attempting takeoff.
4. In cold weather, avoid, when possible, taxiing or taking off through mud, water, or slush. If you have taxied through any of these, make a preflight check to ensure freedom of controls.
5. When climbing out through an icing layer, climb at an airspeed a little faster than normal to avoid a stall.
6. Use deicing or anti-icing equipment when accumulations of ice are not too great. When such equipment becomes less than totally effective, change course or altitude to get out of the icing as rapidly as possible.
7. If your aircraft is not equipped with a pitot-static system deicer, be alert for erroneous readings from your airspeed indicator, rate-of-climb indicator, and altimeter.
8. In stratiform clouds, you can likely alleviate icing by changing to a flight level and above-freezing temperatures or to one colder than −10° C. An altitude change also may take you out of clouds. Rime icing in stratiform clouds can be very extensive horizontally.
9. In frontal freezing rain, you may be able to climb or descend to a layer warmer than freezing. Temperature is always warmer than freezing at some higher altitude. If you are going to climb, move quickly; procrastination may leave you with too much

ice. If you are going to descend, you must know the temperature and terrain below.

10. Avoid cumuliform clouds if at all possible. Clear ice may be encountered anywhere above the freezing level. Most rapid accumulations are usually at temperatures from 0° C to −15° C.
11. Avoid abrupt maneuvers when your aircraft is heavily coated with ice since the aircraft has lost some of its aerodynamic efficiency.
12. When "iced up," fly your landing approach with power.

The man on the ground has no way of observing actual icing conditions. His only confirmation of the existence or absence of icing comes from pilots. Help your fellow pilot and the weather service by sending pilot reports when you encounter icing or when icing is forecast but none encountered. Use the table in Section 16 of AVIATION WEATHER SERVICES as a guide in reporting intensities.

Chapter 11
THUNDERSTORMS

Many times you have to make decisions involving thunderstorms and flying. This chapter looks at where and when thunderstorms occur most frequently, explains what creates a storm, and looks inside the storm at what goes on and what it can do to an aircraft. The chapter also describes how you can use radar and suggests some do's and don'ts of thunderstorm flying.

WHERE AND WHEN?

In some tropical regions, thunderstorms occur year-round. In midlatitudes, they develop most frequently in spring, summer, and fall. Arctic regions occasionally experience thunderstorms during summer.

Figure 100 shows the average number of thunderstorms each year in the adjoining 48 States. Note the frequent occurrences in the south-central and southeastern States. The number of days on which thunderstorms occur varies widely from season to season as shown in figures 101 through 104. In general, thunderstorms are most frequent during July and August and least frequent in December and January.

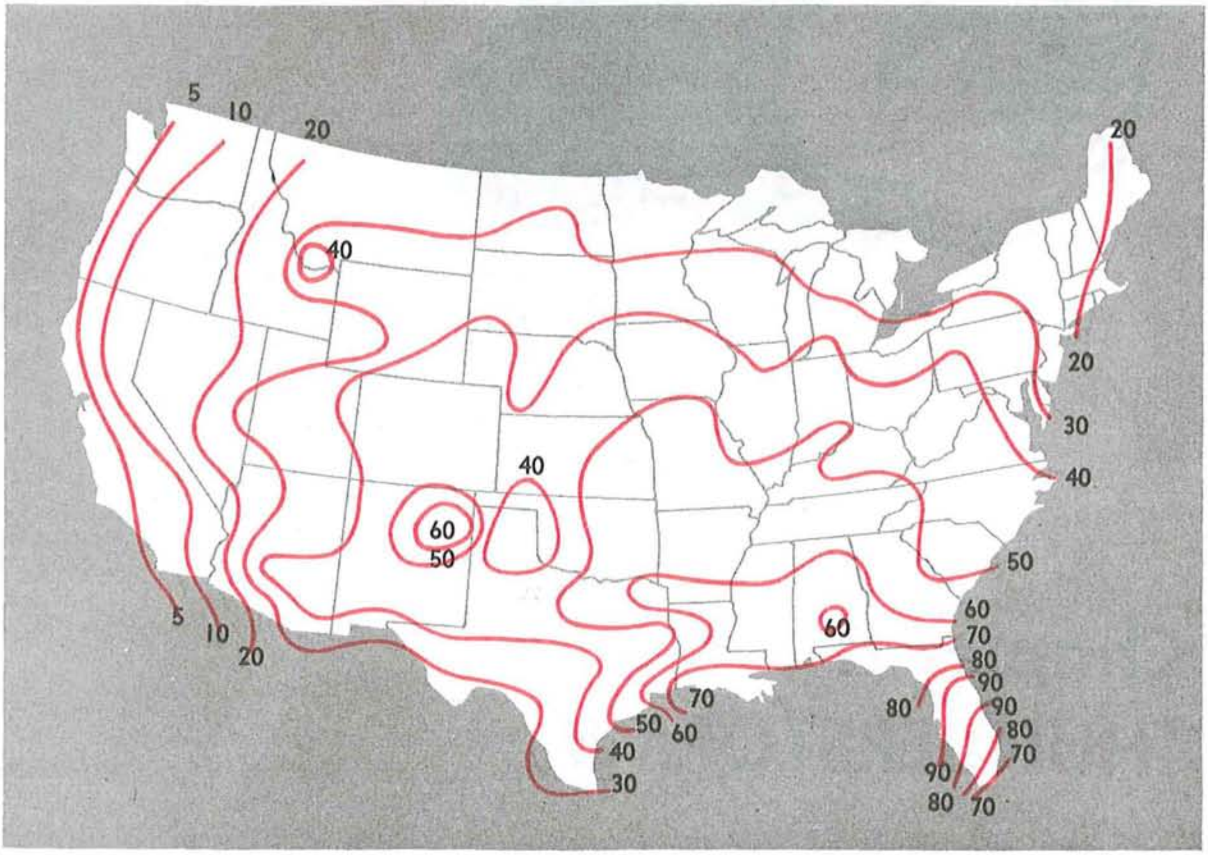


FIGURE 100. The average number of thunderstorms each year.

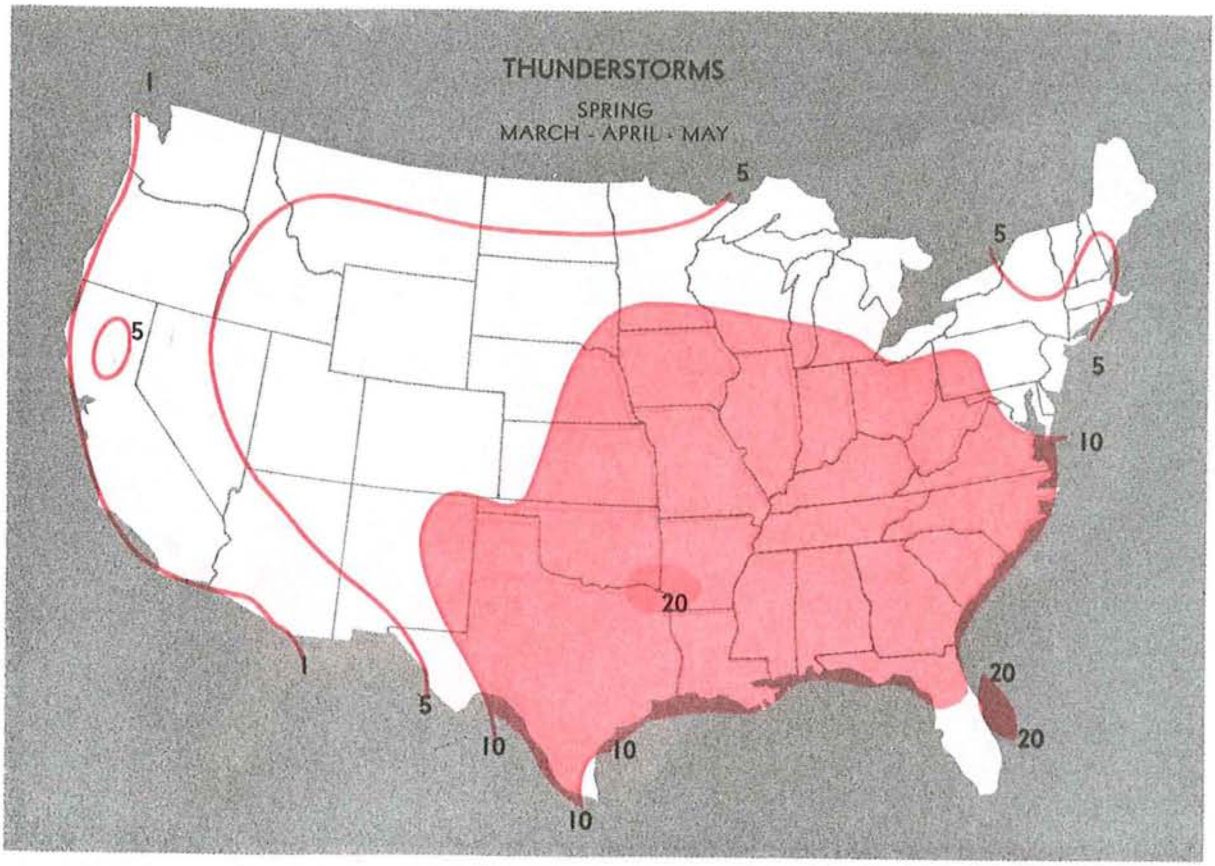


FIGURE 101. The average number of days with thunderstorms during spring.

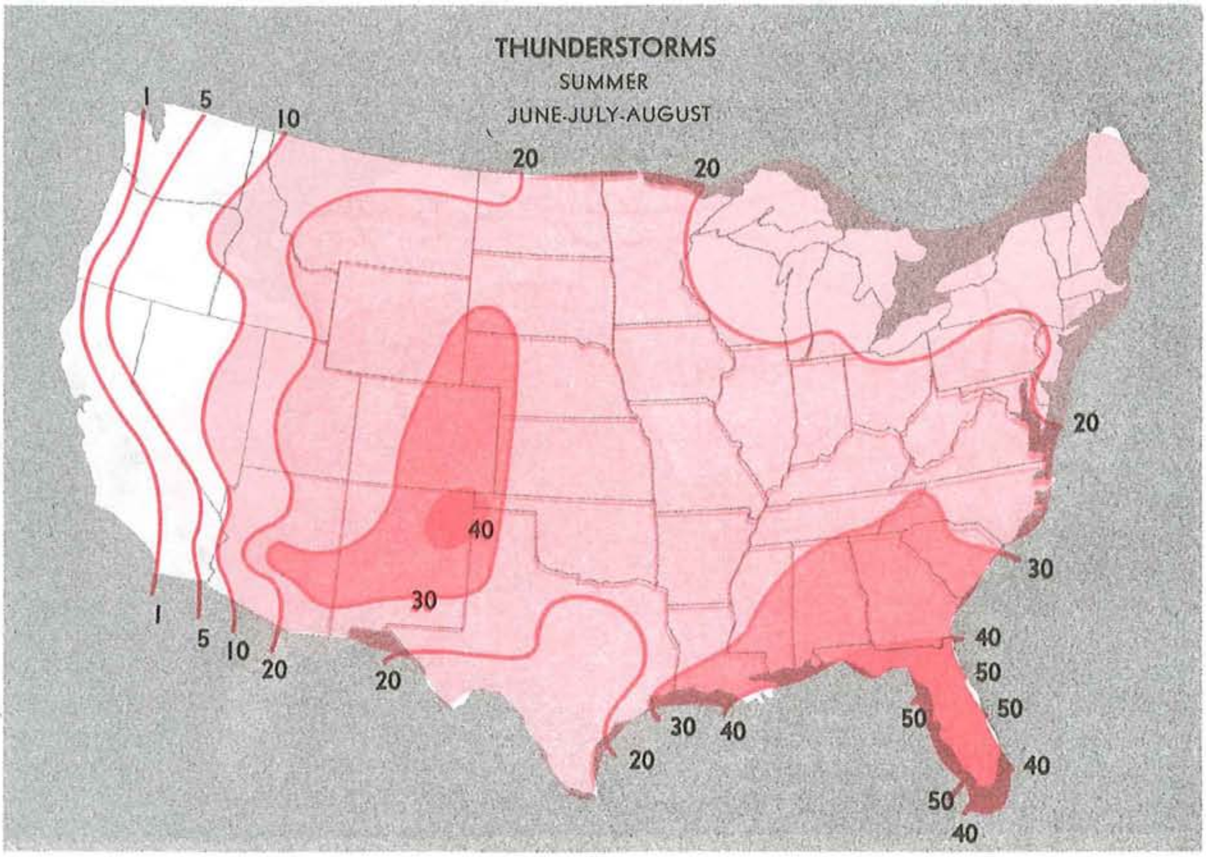


FIGURE 102. The average number of days with thunderstorms during summer.

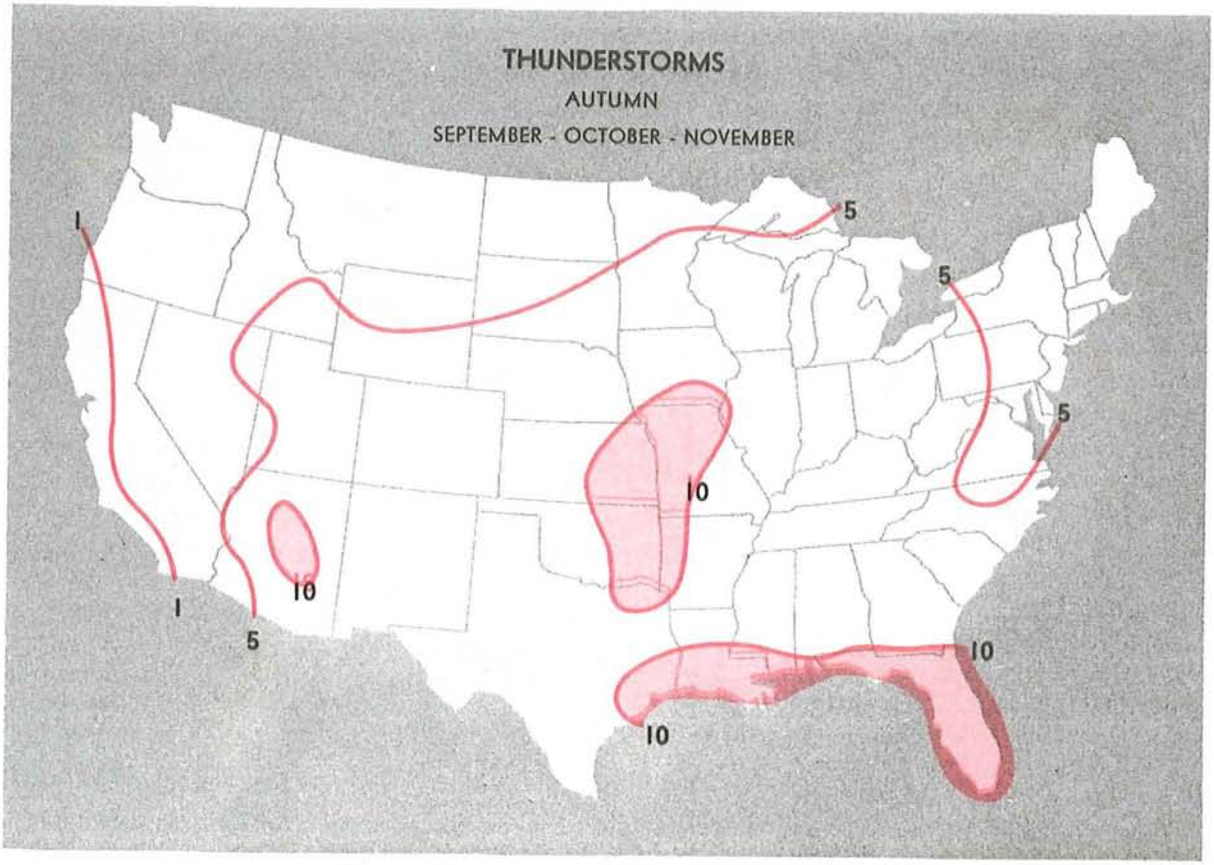


FIGURE 103. The average number of days with thunderstorms during fall.

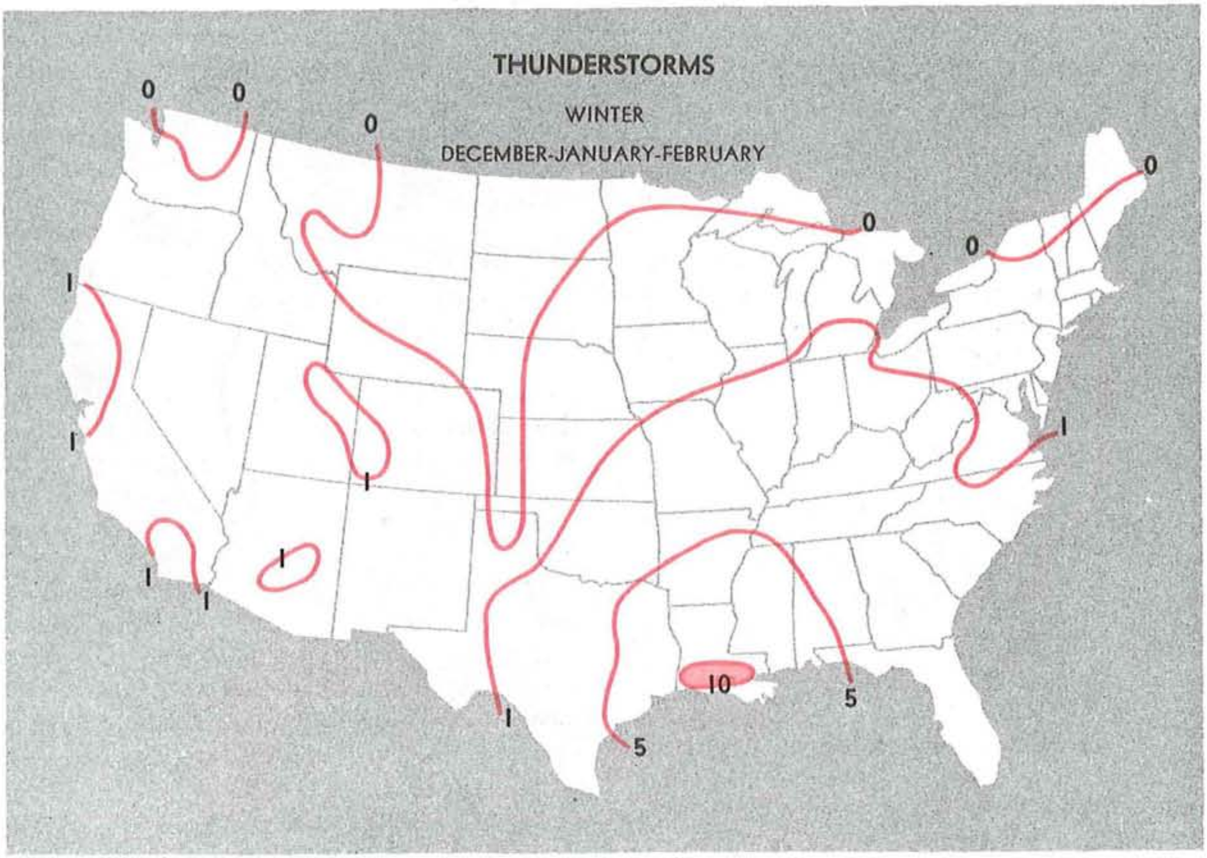


FIGURE 104. The average number of days with thunderstorms during winter.

THEY DON'T JUST HAPPEN

For a thunderstorm to form, the air must have (1) sufficient water vapor, (2) an unstable lapse rate, and (3) an initial upward boost (lifting) to start the storm process in motion. We discussed water vapor in chapter 5 and stability in chapter 6; but, what about lifting? Surface heating, converging winds, sloping terrain, a frontal surface, or any combination of these can provide the lift.

Thunderstorms have been a subject of considerable investigation for many years as they are today. Figuratively speaking, let's look inside a thunderstorm.

THE INSIDE STORY

Forced upward motion creates an initial updraft. Cooling in the updraft results in condensation and the beginning of a cumulus cloud. Condensation releases latent heat which partially offsets cooling in the saturated updraft and increases buoyancy within the cloud. This increased buoyancy drives the updraft still faster drawing more water vapor into the cloud; and, for awhile, the updraft becomes self-sustaining. All thunderstorms progress through a life cycle from their initial development through maturity and into degeneration.

LIFE CYCLE

A thunderstorm cell during its life cycle progresses through three stages—(1) the cumulus, (2) the mature, and (3) the dissipating. It is virtually impossible to visually detect the transition from one stage to another; the transition is subtle and by no means abrupt. Furthermore, a thunderstorm may be a cluster of cells in different stages of the life cycle.

The Cumulus Stage

Although most cumulus clouds do not grow into thunderstorms, every thunderstorm begins as a cumulus. The key feature of the cumulus stage is an updraft as illustrated in figure 105(A). The updraft varies in strength and extends from very near the surface to the cloud top. Growth rate of the cloud may exceed 3,000 feet per minute, so it is inadvisable to attempt to climb over rapidly building cumulus clouds.

Early during the cumulus stage, water droplets are quite small but grow to raindrop size as the cloud grows. The upwelling air carries the liquid water above the freezing level creating an icing hazard. As the raindrops grow still heavier, they fall. The cold rain drags air with it creating a cold downdraft coexisting with the updraft; the cell has reached the mature stage.

The Mature Stage

Precipitation beginning to fall from the cloud base is your signal that a downdraft has developed and a cell has entered the mature stage. Cold rain in the downdraft retards compressional heating, and the downdraft remains cooler than surrounding air. Therefore, its downward speed is accelerated and may exceed 2,500 feet per minute. The downrushing air spreads outward at the surface as shown in figure 105(B) producing strong, gusty surface winds, a sharp temperature drop, and a rapid rise in pressure. The surface wind surge is a "plow wind" and its leading edge is the "first gust."

Meanwhile, updrafts reach a maximum with speeds possibly exceeding 6,000 feet per minute. Updrafts and downdrafts in close proximity create strong vertical shear and a very turbulent environment. All thunderstorm hazards reach their greatest intensity during the mature stage.

The Dissipating Stage

Downdrafts characterize the dissipating stage of the thunderstorm cell as shown in figure 105(C) and the storm dies rapidly. When rain has ended and downdrafts have abated, the dissipating stage is complete. When all cells of the thunderstorm have completed this stage, only harmless cloud remnants remain.

HOW BIG?

Individual thunderstorms measure from less than 5 miles to more than 30 miles in diameter. Cloud bases range from a few hundred feet in very moist climates to 10,000 feet or higher in drier regions. Tops generally range from 25,000 to 45,000 feet but occasionally extend above 65,000 feet.

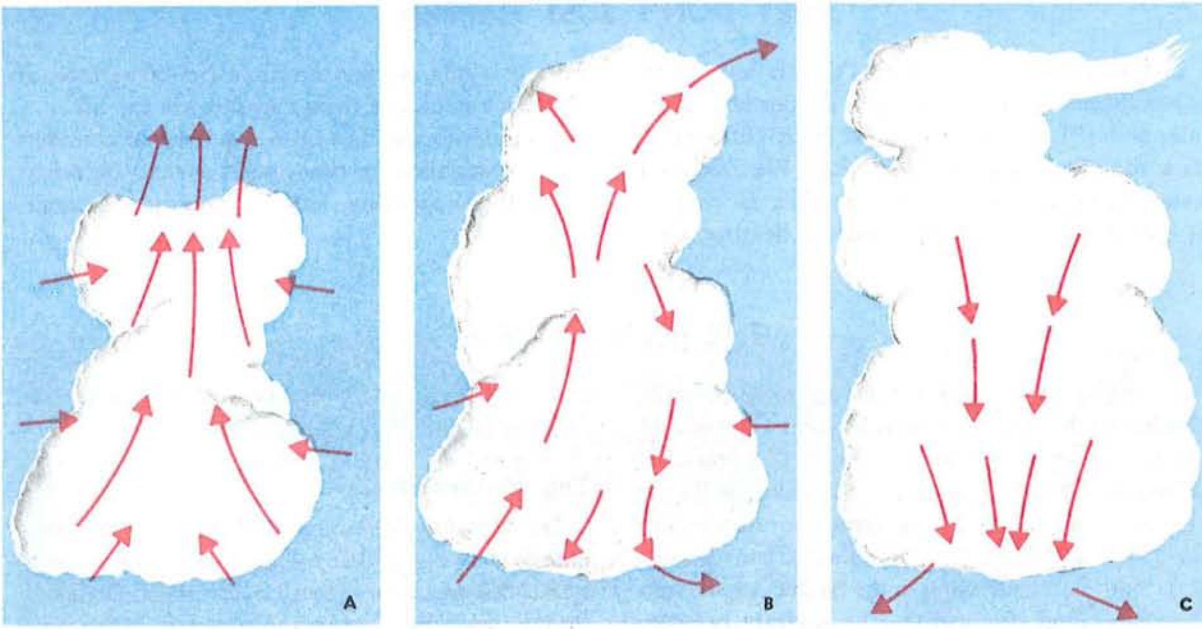


FIGURE 105. The stages of a thunderstorm. (A) is the cumulus stage; (B), the mature stage; and (C), the dissipating stage. Arrows depict air flow.

ROUGH AND ROUGHER

Duration of the mature stage is closely related to severity of the thunderstorm. Some storms occur at random in unstable air, last for only an hour or two, and produce only moderate gusts and rainfall. These are the "air mass" type, but even they are dangerously rough to fly through. Other thunderstorms form in lines, last for several hours, dump heavy rain and possibly hail, and produce strong, gusty winds and possibly tornadoes. These storms are the "steady state" type, usually are rougher than air mass storms, and virtually defy flight through them.

AIR MASS THUNDERSTORMS

Air mass thunderstorms most often result from surface heating. When the storm reaches the mature stage, rain falls through or immediately beside the updraft. Falling precipitation induces frictional drag, retards the updraft and reverses it to a downdraft. The storm is self-destructive. The downdraft and cool precipitation cool the lower portion of the storm and the underlying surface. Thus, it cuts off the inflow of water vapor; the storm runs out of energy and dies. A self-destructive cell usually has a life cycle of 20 minutes to 1½ hours.

Since air mass thunderstorms generally result from surface heating, they reach maximum intensity and frequency over land during middle and late afternoon. Off shore, they reach a maximum during late hours of darkness when land temperature is coolest and cool air flows off the land over the relatively warm water.

STEADY STATE THUNDERSTORMS

Steady state thunderstorms usually are associated with weather systems. Fronts, converging winds, and troughs aloft force upward motion spawning these storms which often form into squall lines. Afternoon heating intensifies them.

In a steady state storm, precipitation falls outside the updraft as shown in figure 106 allowing the updraft to continue unabated. Thus, the mature stage updrafts become stronger and last much longer than in air mass storms—hence, the name, "steady state." A steady state cell may persist for several hours.

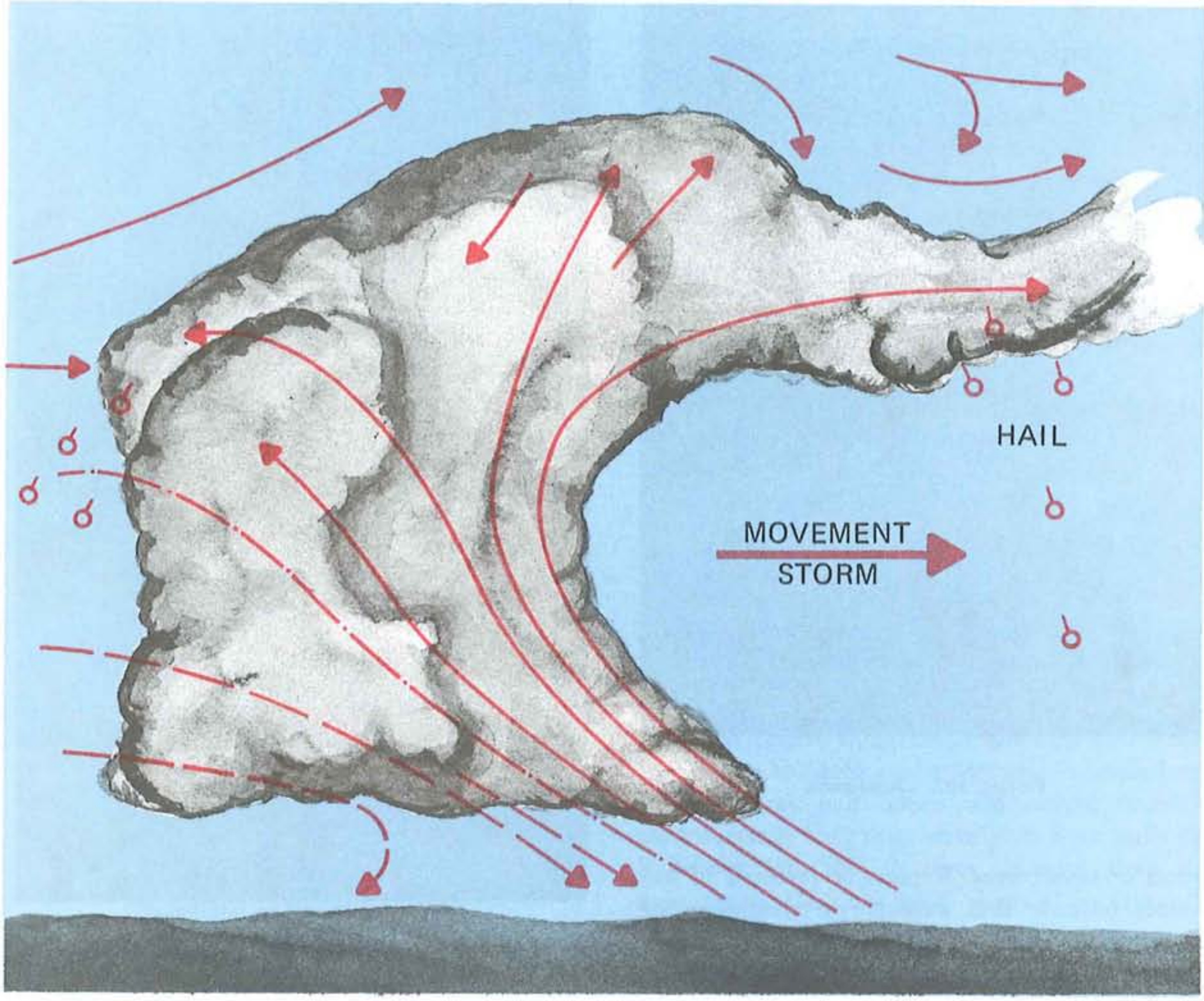


FIGURE 106. Schematic of the mature stage of a steady state thunderstorm cell showing a sloping updraft with the downdraft and precipitation outside the updraft not impeding it. The steady state mature cell may continue for many hours and deliver the most violent thunderstorm hazards.

HAZARDS

A thunderstorm packs just about every weather hazard known to aviation into one vicious bundle. Although the hazards occur in numerous combinations, let's separate them and examine each individually.

TORNADOES

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 cumulonimbus base. If the cloud does not reach the surface, it is a "funnel cloud," figure 109; if it touches a land surface, it is a "tornado," figure 107; if it touches water, it is a "water spout," figure 108.

Tornadoes occur with isolated thunderstorms at times, but much more frequently, they form with steady state thunderstorms associated with cold

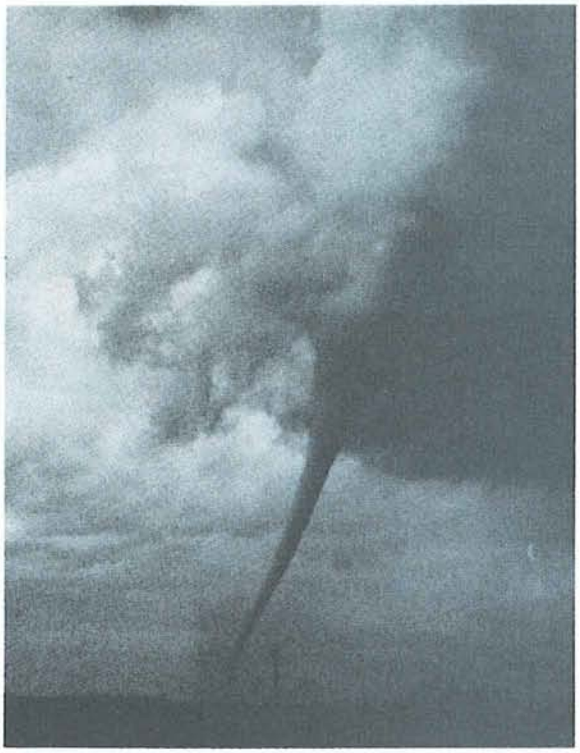


FIGURE 107. A tornado.

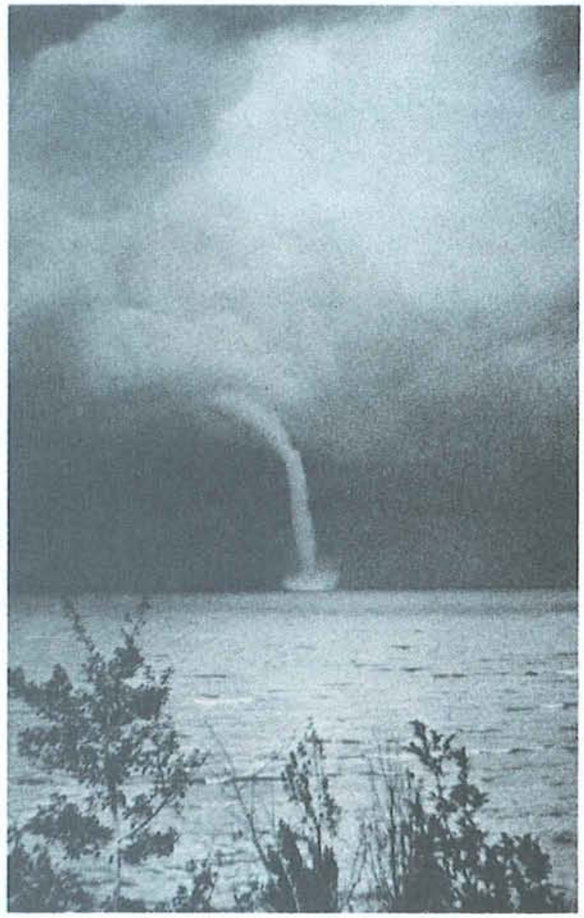


FIGURE 108. A waterspout.

fronts or squall lines. 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.

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.

Frequently, cumulonimbus mamma clouds occur in connection with violent thunderstorms and tornadoes. The cloud displays rounded, irregular pockets or festoons from its base and is a signpost of violent turbulence. Figure 110 is a photograph of a cumulonimbus mamma cloud. Surface aviation reports specifically mention this and other especially hazardous clouds.

Tornadoes occur most frequently in the Great Plains States east of the Rocky Mountains. Figure 111 shows, however, that they have occurred in every State.

SQUALL LINES

A *squall line* is a non-frontal, narrow band of active thunderstorms. Often it develops 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 easily detour and too wide and severe to penetrate. It often contains severe 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. Figure 112 is a photograph of an advancing squall line.

TURBULENCE

Hazardous turbulence is present in ***all*** thunderstorms; and in a severe thunderstorm, it can damage an airframe. Strongest turbulence within the cloud occurs with shear between updrafts and

FIGURE 109. Funnel clouds.
(Photograph by Paul Hexter, NWS.)

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 between the plow wind and surrounding air. Often, a "roll cloud" on the leading edge of a storm marks the eddies in this shear. The roll cloud is most prevalent with cold frontal or squall line thunderstorms and signifies an extremely turbulent zone. The first gust causes a rapid and sometimes drastic change in surface wind ahead of an approaching storm. Figure 113 shows a schematic cross section of a thunderstorm with areas outside the cloud where turbulence may be encountered.

It is almost impossible to hold a constant altitude in a thunderstorm, and maneuvering in an attempt to do so greatly increases stresses on the aircraft. Stresses will be 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.

ICING

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, the amount of supercooled water decreases.

Supercooled water freezes on impact with an aircraft (see chapter 10). 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.

HAIL

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 usually built to great heights. Eventually the hailstones fall, possibly some distance from the storm core. Hail has been observed in clear air several miles from the parent thunderstorm.

As hailstones fall through the melting level, 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 cumulonimbus. Hailstones larger than one-half inch in diameter can significantly damage an aircraft in a few seconds. Figure 114 is a photograph of an aircraft flown through a "hail" of a thunderstorm.

LOW CEILING AND VISIBILITY

Visibility generally is near zero within a thunderstorm cloud. Ceiling and visibility also can become 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.

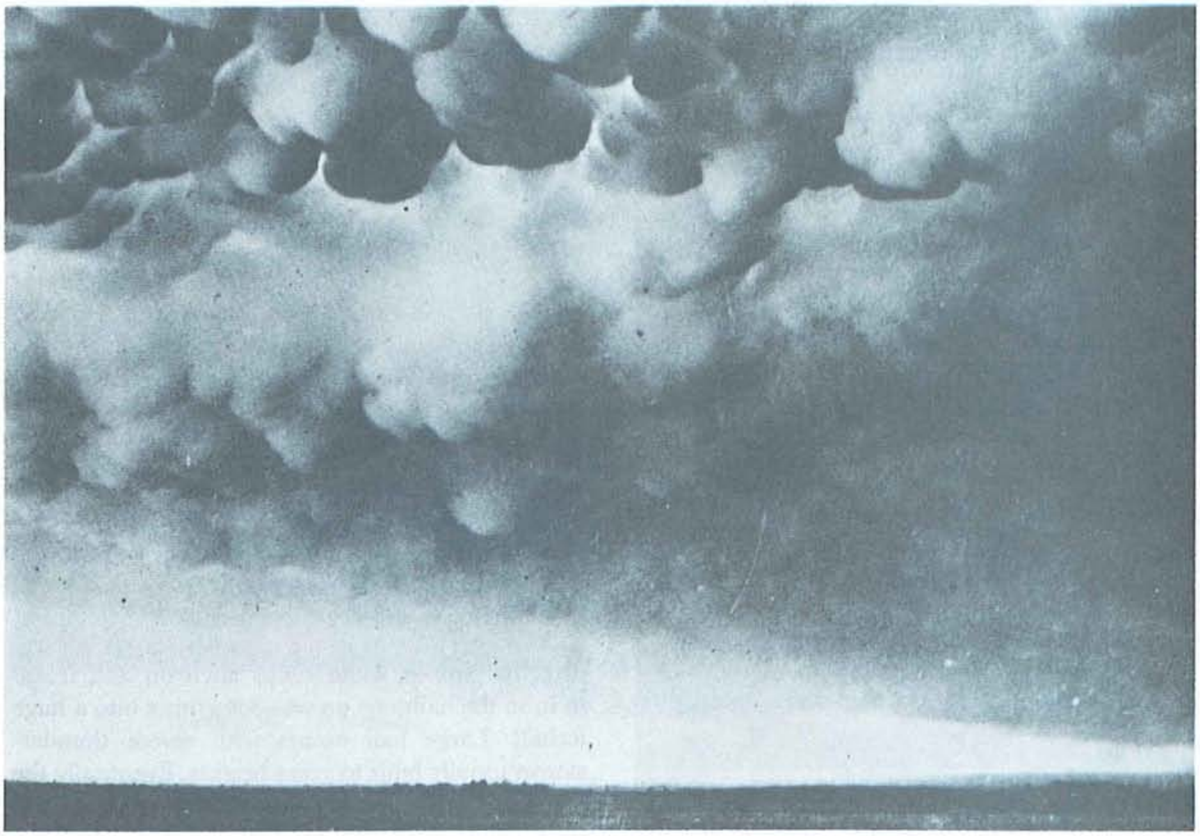


FIGURE 110. Cumulonimbus Mamma clouds, associated with cumulonimbus clouds, indicate extreme instability.

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 altimeter setting is not corrected, the indicated altitude may be in error by over 100 feet.

THUNDERSTORM ELECTRICITY

Electricity generated by thunderstorms is rarely a great hazard to aircraft, but it may cause damage and is annoying to flight crews. Lightning is the most spectacular of the electrical discharges.

Lightning

A lightning strike can puncture the skin of an aircraft and can damage communication 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.

A few pointers on lightning:

1. The more frequent the lightning, the more severe the thunderstorm.

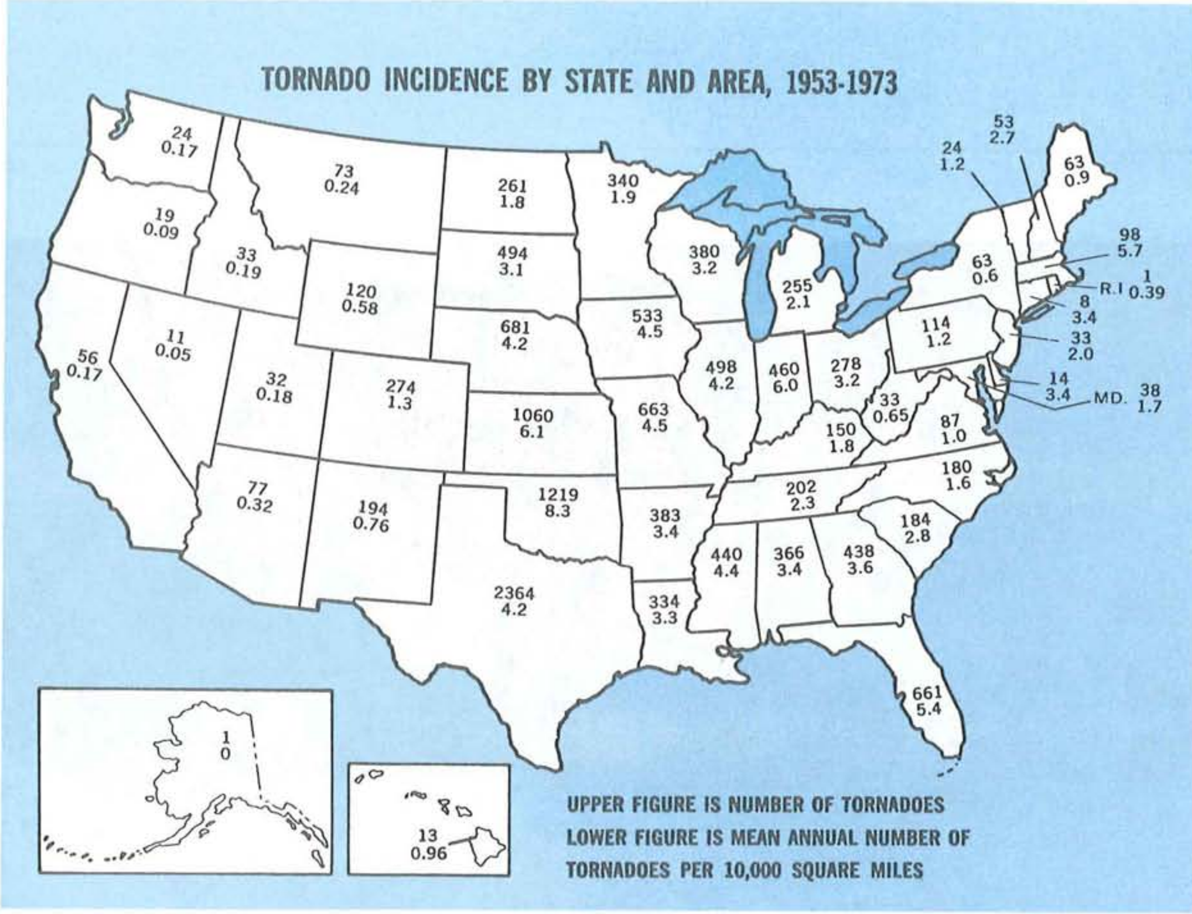


FIGURE 111. Tornado incidence by State and area.

2. Increasing frequency of lightning indicates a growing thunderstorm.
3. Decreasing lightning indicates a storm nearing the dissipating stage.
4. At night, frequent distant flashes playing along a large sector of the horizon suggest a probable squall line.

Precipitation Static

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

The corona discharge is weakly luminous and may be seen at night. Although it has a rather eerie appearance, it is harmless. It was named "St. Elmo's Fire" by Mediterranean sailors, who saw the brushy discharge at the top of ship masts.

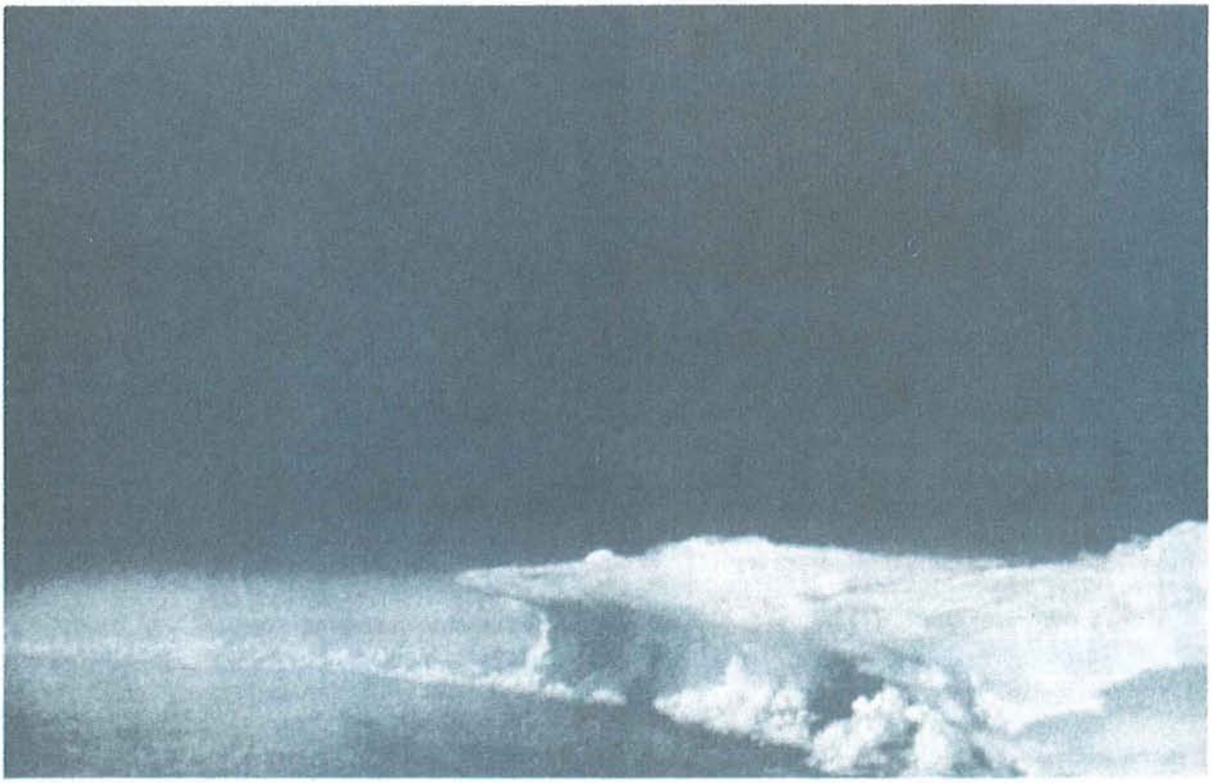


FIGURE 112. Squall line thunderstorms.

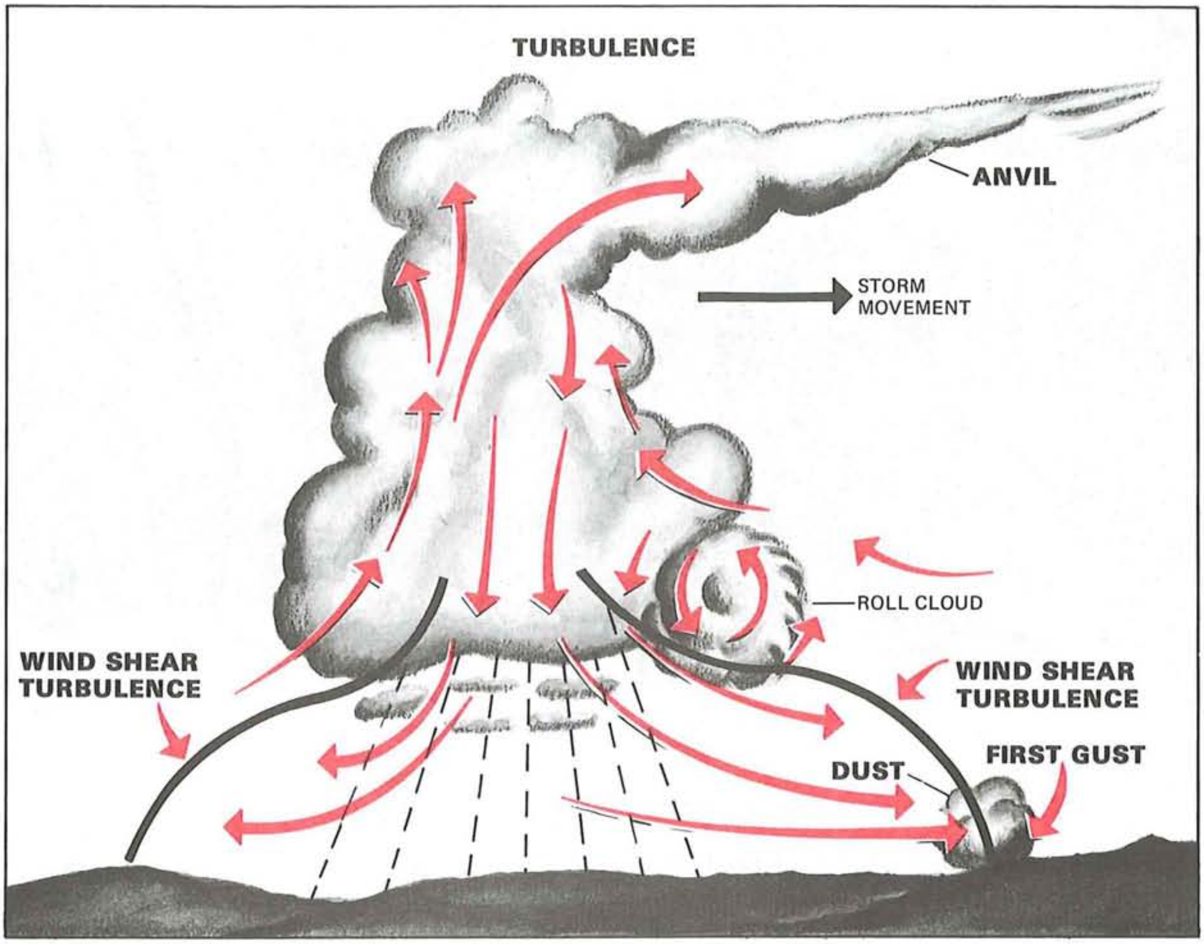


FIGURE 113. Schematic cross section of a thunderstorm. Note areas outside the main cloud where turbulence may be encountered.

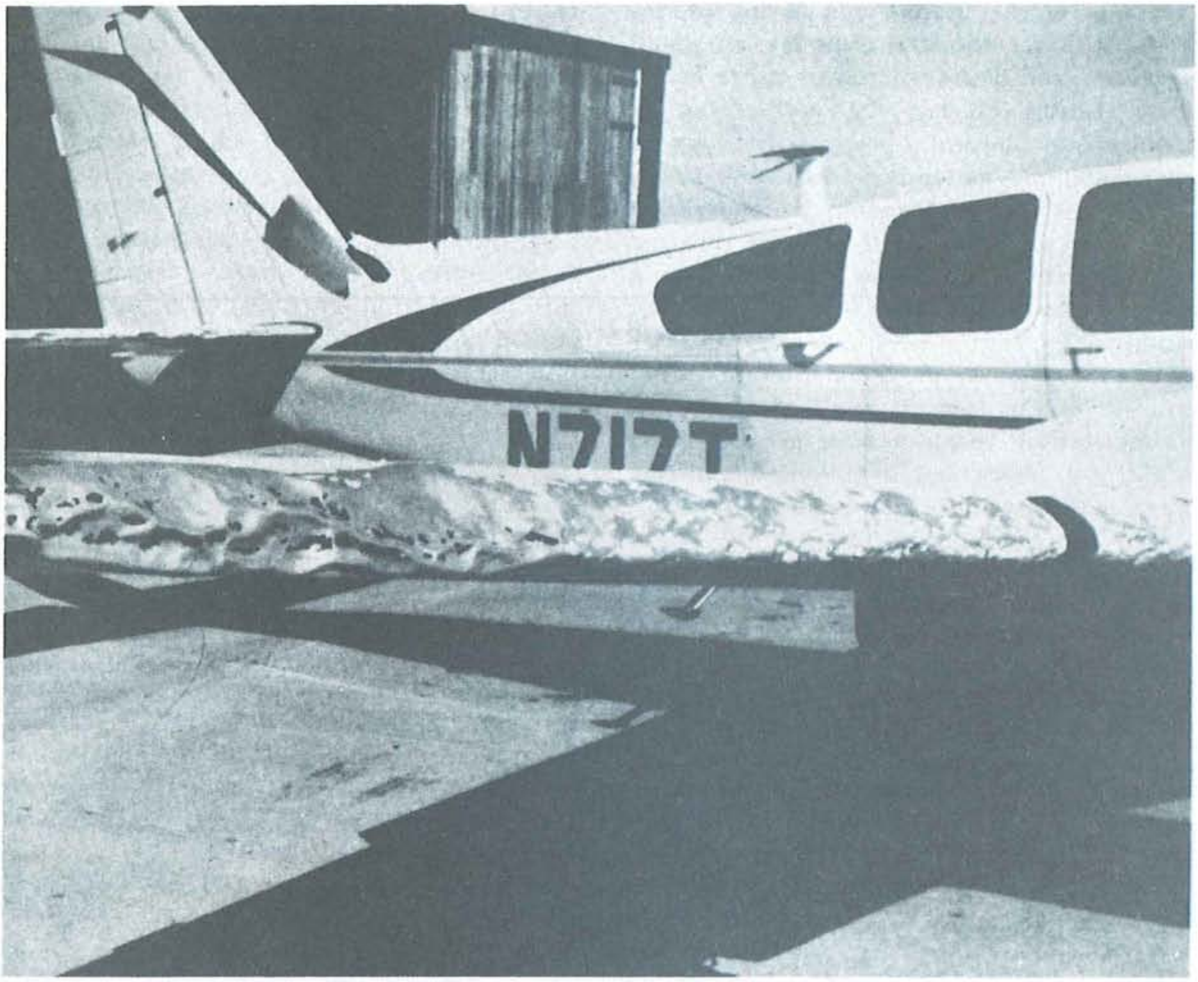


FIGURE 114. Hail damage to an aircraft.

THUNDERSTORMS AND RADAR

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.

Meteorologists have shown that drop size is almost directly proportional to rainfall rate; and the greatest rainfall rate is in thunderstorms. Therefore, the strongest echoes are thunderstorms. Hailstones usually are covered with a film of water and, therefore, act as huge water droplets giving the strongest of all echoes. Showers show less intense echoes; and gentle rain and snow return the weakest of all echoes. Figure 115 is a photograph of a ground based radar scope.

Since the strongest echoes identify thunderstorms, they also mark the areas of greatest hazards. Radar information can be valuable both from ground based radar for preflight planning and from airborne radar for severe weather avoidance.

Thunderstorms build and dissipate rapidly, and they also may move rapidly. Therefore, **do not attempt to preflight plan a course between echoes.** The best use of ground radar information is to isolate general areas and coverage of echoes. You must evade individual storms from inflight observations either by visual sighting or by airborne radar.

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

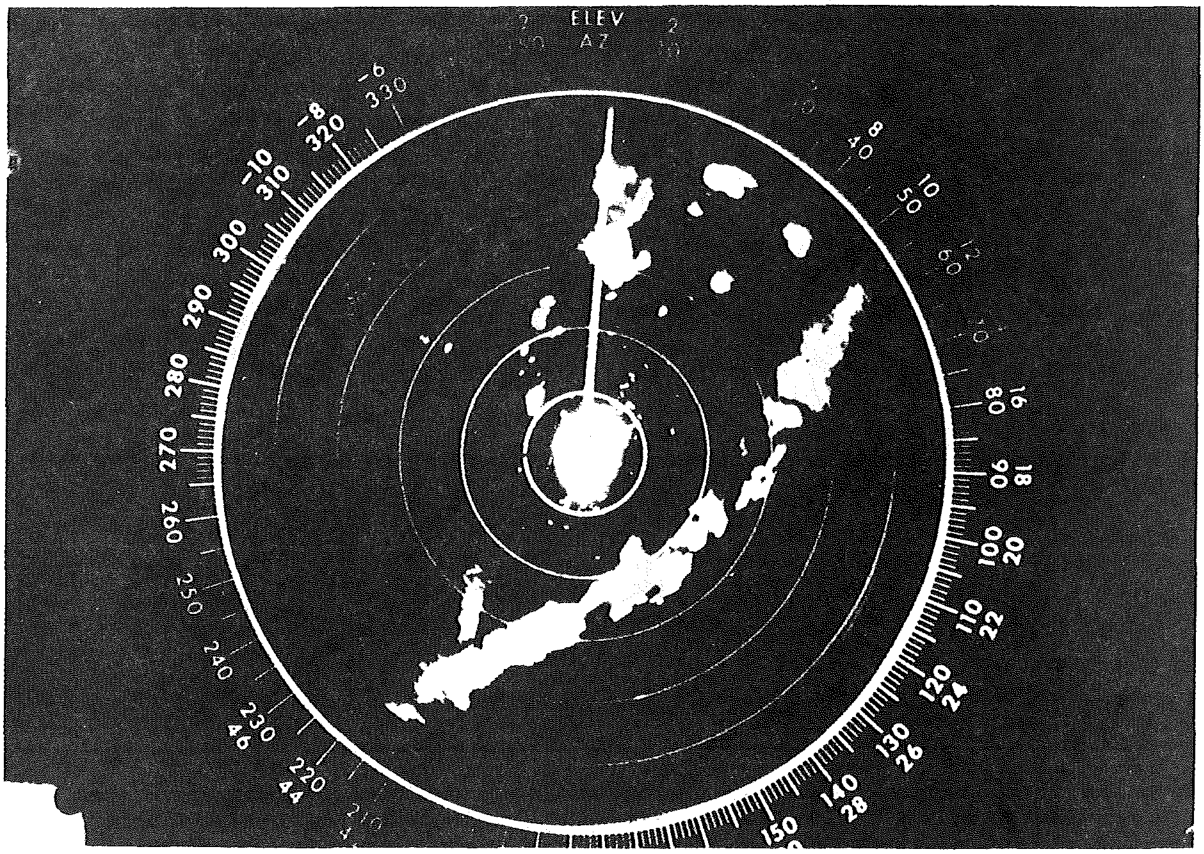


FIGURE 115. Radar photograph of a line of thunderstorms.

aircraft. Remember that weather radar detects only precipitation drops; it does not detect minute cloud droplets. Therefore, ***the radar scope provides no assurance of avoiding instrument weather in 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.

The most intense echoes are severe thunderstorms. Remember that hail may fall several miles from the cloud, and hazardous turbulence may extend as much as 20 miles from the cloud. 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 diminish in intensity, you can reduce the distance by which you avoid them. Figure 116 illustrates use of airborne radar in avoiding thunderstorms.

DO'S AND DON'TS OF THUNDERSTORM FLYING

Above all, remember this: ***never regard any thunderstorm as "light"*** 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 take off in the face of an approaching thunderstorm. A sudden wind shift or 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 under the storm could be disastrous.
3. Don't try to circumnavigate thunderstorms covering 6/10 of an area or more either visually or by airborne radar.
4. Don't fly without airborne radar into a cloud mass containing scattered embedded

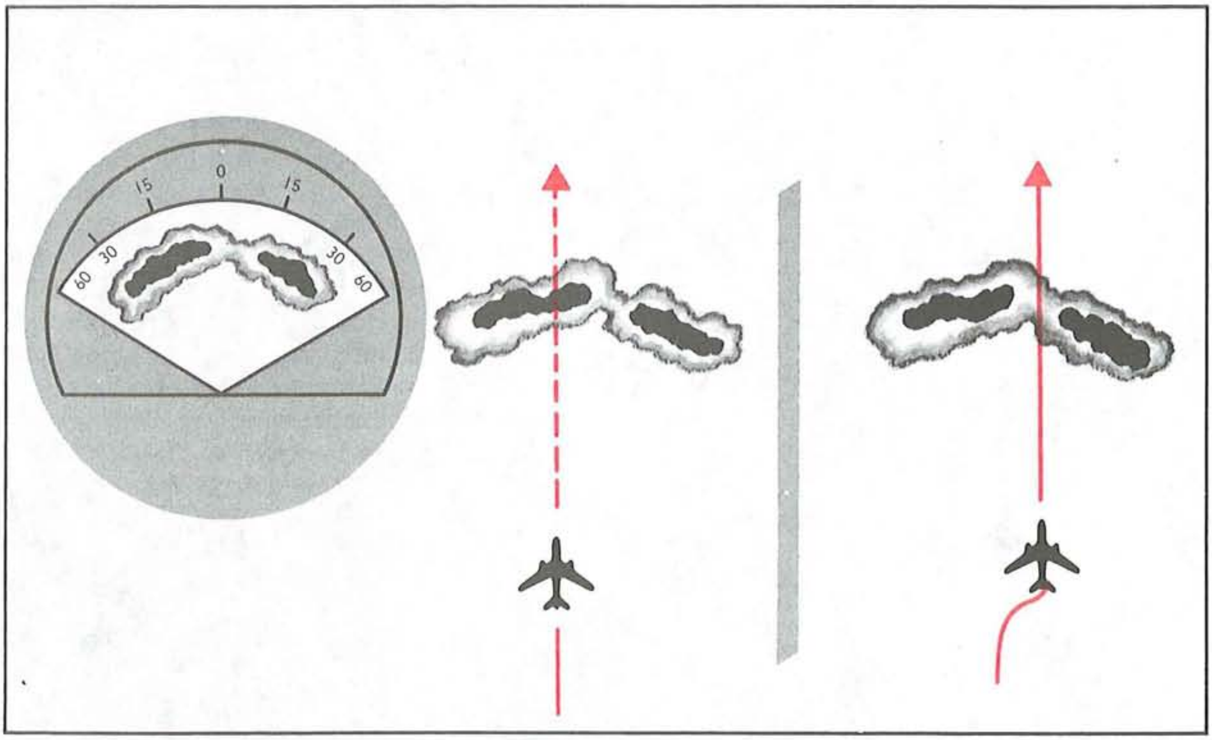


FIGURE 116. Use of airborne radar to avoid heavy precipitation and turbulence. When echoes are extremely intense, avoid the most intense echoes by at least 20 miles. You should avoid flying between these very intense echoes unless they are separated by at least 40 miles. Hazardous turbulence and hail often extend several miles from the storm centers.

thunderstorms. Scattered thunderstorms not embedded usually can be visually circumnavigated.

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 cumulonimbus.
6. Do clear the top of a known or suspected severe thunderstorm by at least 1,000 feet altitude for each 10 knots of wind speed at the cloud top. This would exceed the altitude capability of most aircraft.
7. Do remember that vivid and frequent lightning indicates a severe thunderstorm.
8. Do regard as severe any thunderstorm with tops 35,000 feet or higher whether the top is visually sighted or determined by radar.

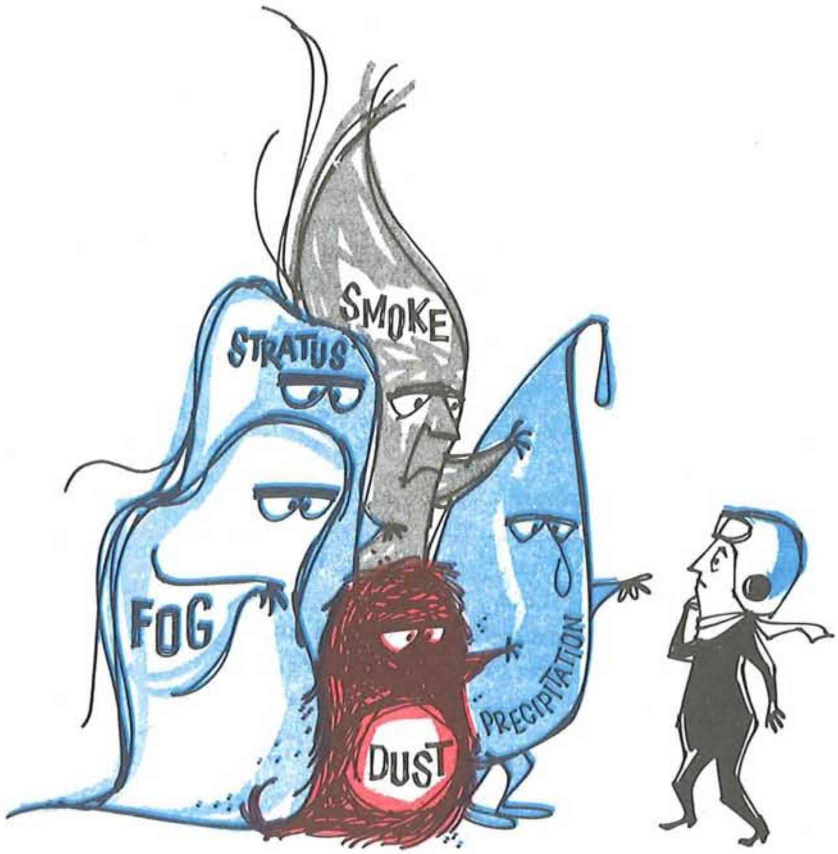
If you ***cannot*** avoid penetrating a thunderstorm, following are some Do's ***Before*** entering the storm:

1. Tighten your safety belt, put on your shoulder harness if you have one, and secure all loose objects.
2. Plan your course to take you through the storm in a minimum time and *hold* it.
3. To avoid the most critical icing, establish a penetration altitude below the freezing level or above the level of $-15°$ C.
4. Turn on pitot heat and carburetor or jet inlet heat. Icing can be rapid at any altitude and cause almost instantaneous power failure or loss of airspeed indication.
5. Establish power settings for reduced turbulence penetration airspeed recommended in your aircraft manual. Reduced airspeed lessens the structural stresses on the aircraft.
6. Turn up cockpit lights to highest intensity to lessen danger of 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 stresses.
8. If using airborne radar, tilt your antenna

up and down occasionally. Tilting it up may detect a hail shaft that will reach a point on your course by the time you do. Tilting it down may detect a growing thunderstorm cell that may reach your altitude.

Following are some Do's and Don'ts ***During*** 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 reduced airspeed.
3. Do maintain a constant *attitude;* let the aircraft "ride the waves." Maneuvers in trying to maintain constant altitude increase stresses 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 stresses on the aircraft.



Chapter 12
COMMON IFR PRODUCERS

Most aircraft accidents related to low ceilings and visibilities involve pilots who are not instrument qualified. These pilots attempt flight by visual reference into weather that is suitable at best only for instrument flight. When you lose sight of the visual horizon, your senses deceive you; you lose sense of direction—you can't tell up from down. You may doubt that *you* will lose your sense of direction, but one good scare has changed the thinking of many a pilot. ***"Continued VFR into adverse weather" is the cause of about 25 percent of all fatal general aviation accidents.***

Minimum values of ceiling and visibility determine Visual Flight Rules. Lower ceiling and/or visibility require instrument flight. Ceiling is the maximum height from which a pilot can maintain VFR in reference to the ground. Visibility is how far he can see. AVIATION WEATHER SERVICES (AC 00-45) contains details of ceiling and visibility reports.

Don't let yourself be caught in the statistics of "continued VFR into adverse weather." IFR producers are fog, low clouds, haze, smoke, blowing obstructions to vision, and precipitation. Fog and low stratus restrict navigation by visual reference more often than all other weather parameters.

FOG

Fog is a surface based cloud composed of either water droplets or ice crystals. Fog is the most frequent cause of surface visibility below 3 miles, and is one of the most common and persistent weather hazards encountered in aviation. The rapidity with which fog can form makes it especially hazardous. It is not unusual for visibility to drop from VFR to less than a mile in a few minutes. It is primarily a hazard during takeoff and landing, but it is also important to VFR pilots who must maintain visual reference to the ground.

Small temperature-dew point spread is essential for fog to form. Therefore, fog is prevalent in coastal areas where moisture is abundant. However, fog can occur anywhere. Abundant condensation nuclei enhances the formation of fog. Thus, fog is prevalent in industrial areas where by-products of combustion provide a high concentration of these nuclei. Fog occurs most frequently in the colder months, but the season and frequency of occurrence vary from one area to another.

Fog may form (1) by cooling air to its dew point, or (2) by adding moisture to air near the ground. Fog is classified by the way it forms. Formation may involve more than one process.

RADIATION FOG

Radiation fog is relatively shallow fog. It may be dense enough to hide the entire sky or may conceal only part of the sky. "Ground fog" is a form of radiation fog. As viewed by a pilot in flight, dense radiation fog may obliterate the entire surface below him; a less dense fog may permit his observation of a small portion of the surface directly below him. Tall objects such as buildings, hills, and towers may protrude upward through ground fog giving the pilot fixed references for VFR flight. Figure 117 illustrates ground fog as seen from the air.

Conditions favorable for radiation fog are clear sky, little or no wind, and small temperature-dew point spread (high relative humidity). The fog forms almost exclusively at night or near daybreak. Terrestrial radiation cools the ground; in turn, the cool ground cools the air in contact with it. When the air is cooled to its dew point, fog forms. When rain soaks the ground, followed by clearing skies,

radiation fog is not uncommon the following morning.

Radiation fog is restricted to land because water surfaces cool little from nighttime radiation. It is shallow when wind is calm. Winds up to about 5 knots mix the air slightly and tend to deepen the fog by spreading the cooling through a deeper layer. Stronger winds disperse the fog or mix the air through a still deeper layer with stratus clouds forming at the top of the mixing layer.

Ground fog usually "burns off" rather rapidly after sunrise. Other radiation fog generally clears before noon unless clouds move in over the fog.

ADVECTION FOG

Advection fog forms when moist air moves over colder ground or water. It is most common along coastal areas but often develops deep in continental areas. At sea it is called "sea fog." Advection fog deepens as wind speed increases up to about 15 knots. Wind much stronger than 15 knots lifts the fog into a layer of low stratus or stratocumulus.

The west coast of the United States is quite vulnerable to advection fog. This fog frequently forms offshore as a result of cold water as shown in figure 118 and then is carried inland by the wind. During the winter, advection fog over the central and eastern United States results when moist air from the Gulf of Mexico spreads northward over cold ground as shown in figure 119. The fog may extend as far north as the Great Lakes. Water areas in northern latitudes have frequent dense sea fog in summer as a result of warm, moist, tropical air flowing northward over colder Arctic waters.

A pilot will notice little difference between flying over advection fog and over radiation fog except that skies may be cloudy above the advection fog. Also, advection fog is usually more extensive and much more persistent than radiation fog. Advection fog can move in rapidly regardless of the time of day or night.

UPSLOPE FOG

Upslope fog forms as a result of moist, stable air being cooled adiabatically as it moves up sloping terrain. Once the upslope wind ceases, the fog dissipates. Unlike radiation fog, it can form under cloudy skies. Upslope fog is common along the

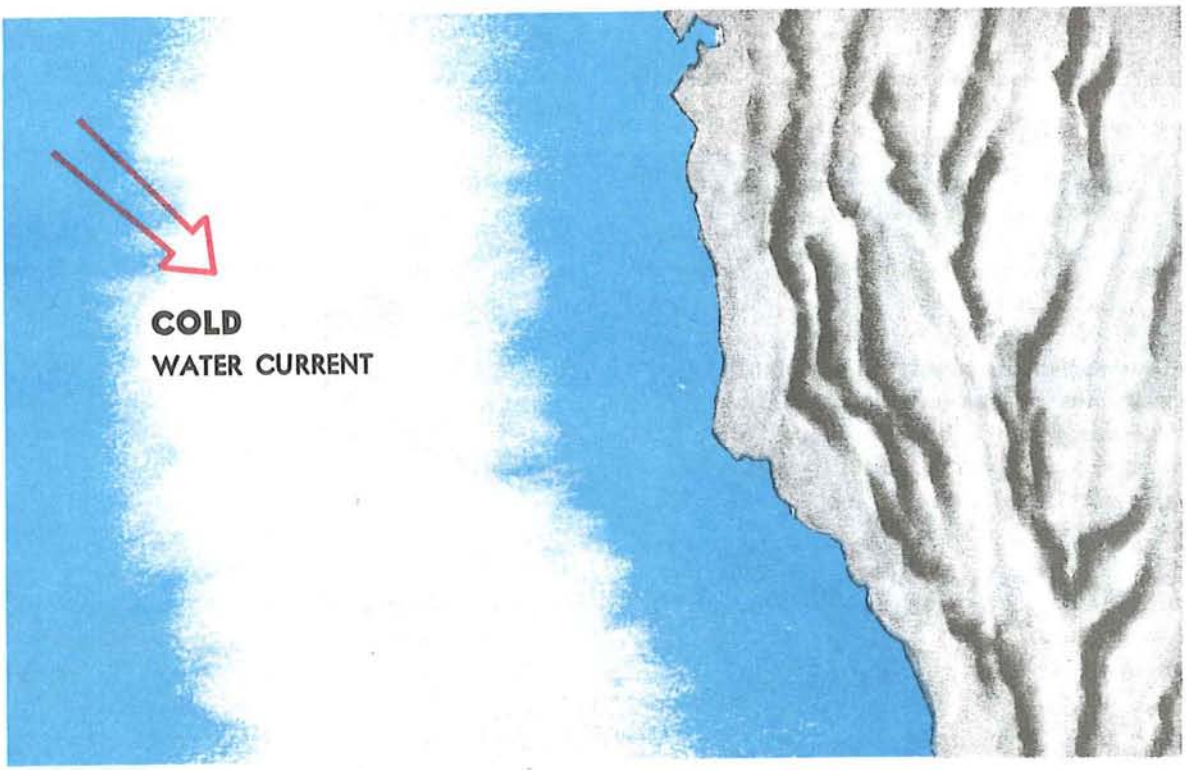


FIGURE 118. Advection fog off the coast of California.

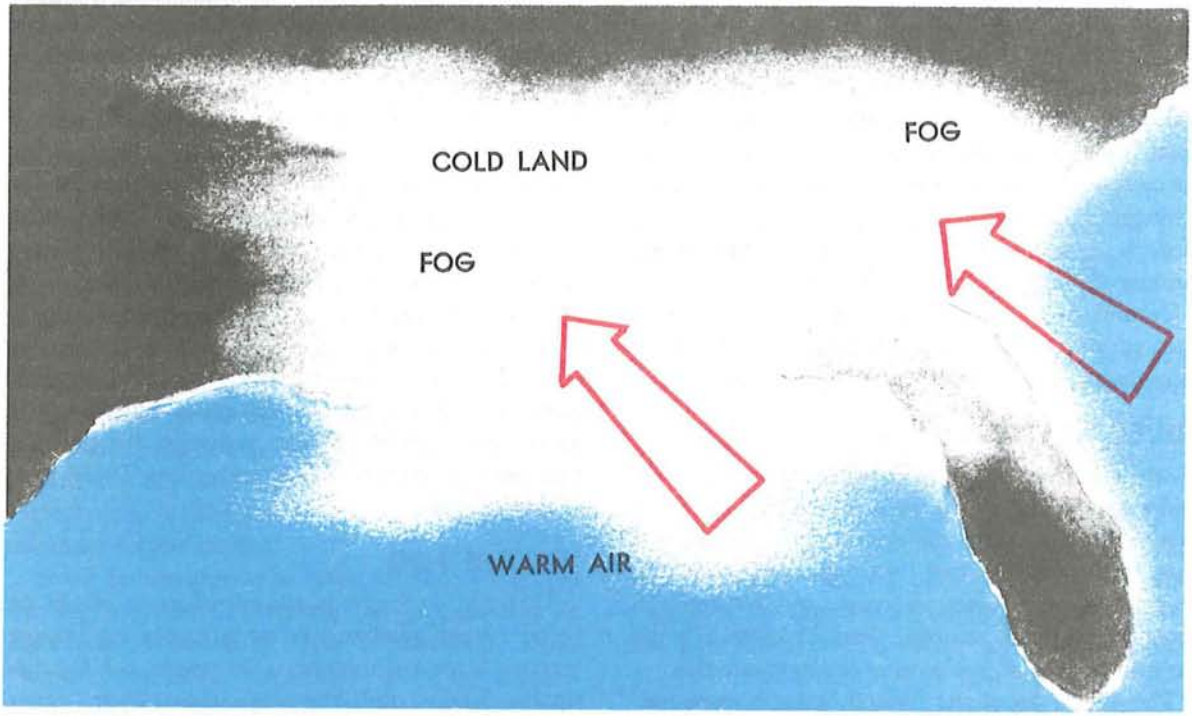


FIGURE 119. Advection fog over the southeastern United States and Gulf Coast. The fog often may spread to the Great Lakes and northern Appalachians.

eastern slopes of the Rockies and somewhat less frequent east of the Appalachians. Upslope fog often is quite dense and extends to high altitudes.

PRECIPITATION-INDUCED FOG

When relatively warm rain or drizzle falls through cool air, evaporation from the precipitation saturates the cool air and forms fog. Precipitation-induced fog can become quite dense and continue for an extended period of time. This fog may extend over large areas, completely suspending air operations. It is most commonly associated with warm fronts, but can occur with slow moving cold fronts and with stationary fronts.

Fog induced by precipitation is in itself hazardous as is any fog. It is especially critical, however, because it occurs in the proximity of precipitation and other possible hazards such as icing, turbulence, and thunderstorms.

ICE FOG

Ice fog occurs in cold weather when the temperature is much below freezing and water vapor sublimates directly as ice crystals. Conditions favorable for its formation are the same as for radiation fog except for cold temperature, usually −25° F or colder. It occurs mostly in the Arctic regions, but is not unknown in middle latitudes during the cold season. Ice fog can be quite blinding to someone flying into the sun.

LOW STRATUS CLOUDS

Stratus clouds, like fog, are composed of extremely small water droplets or ice crystals suspended in air. An observer on a mountain in a stratus layer would call it fog. Stratus and fog frequently exist together. In many cases there is no real line of distinction between the fog and stratus; rather, one gradually merges into the other. Flight visibility may approach zero in stratus clouds. Stratus tends to be lowest during night and early morning, lifting or dissipating due to solar heating during the late morning or afternoon. Low stratus clouds often occur when moist air mixes with a colder air mass or in any situation where temperature-dew point spread is small.

HAZE AND SMOKE

Haze is a concentration of salt particles or other dry particles not readily classified as dust or other phenomenon. It occurs in stable air, is usually only a few thousand feet thick, but sometimes may extend as high as 15,000 feet. Haze layers often have definite tops above which horizontal visibility is good. However, downward visibility from above a haze layer is poor, especially on a slant. Visibility in haze varies greatly depending upon whether the pilot is facing the sun. Landing an aircraft into the sun is often hazardous if haze is present.

Smoke concentrations form primarily in industrial areas when air is stable. It is most prevalent at night or early morning under a temperature inversion but it can persist throughout the day. Figure 120 illustrates smoke trapped under a temperature inversion.

When skies are clear above haze or smoke, visibility generally improves during the day; however, the improvement is slower than the clearing of fog. Fog evaporates, but haze or smoke must be dispersed by movement of air. Haze or smoke may be blown away; or heating during the day may cause convective mixing spreading the smoke or haze to a higher altitude, decreasing the concentration near the surface. At night or early morning, radiation fog or stratus clouds often combine with haze or smoke. The fog and stratus may clear rather rapidly during the day but the haze and smoke will linger. A heavy cloud cover above haze or smoke may block sunlight preventing dissipation; visibility will improve little, if any, during the day.

BLOWING RESTRICTIONS TO VISIBILITY

Strong wind lifts blowing dust in both stable and unstable air. When air is unstable, dust is lifted to great heights (as much as 15,000 feet) and may be spread over wide areas by upper winds. Visibility is restricted both at the surface and aloft. When air is stable, dust does not extend to as great a height as in unstable air and usually is not as widespread. Dust, once airborne, may remain suspended and restrict visibility for several hours after the wind subsides. Figure 121 is a photograph of a dust storm moving in with an approaching cold front.

Blowing sand is more local than blowing dust; the sand is seldom lifted above 50 feet. However, visibilities within it may be near zero. Blowing sand

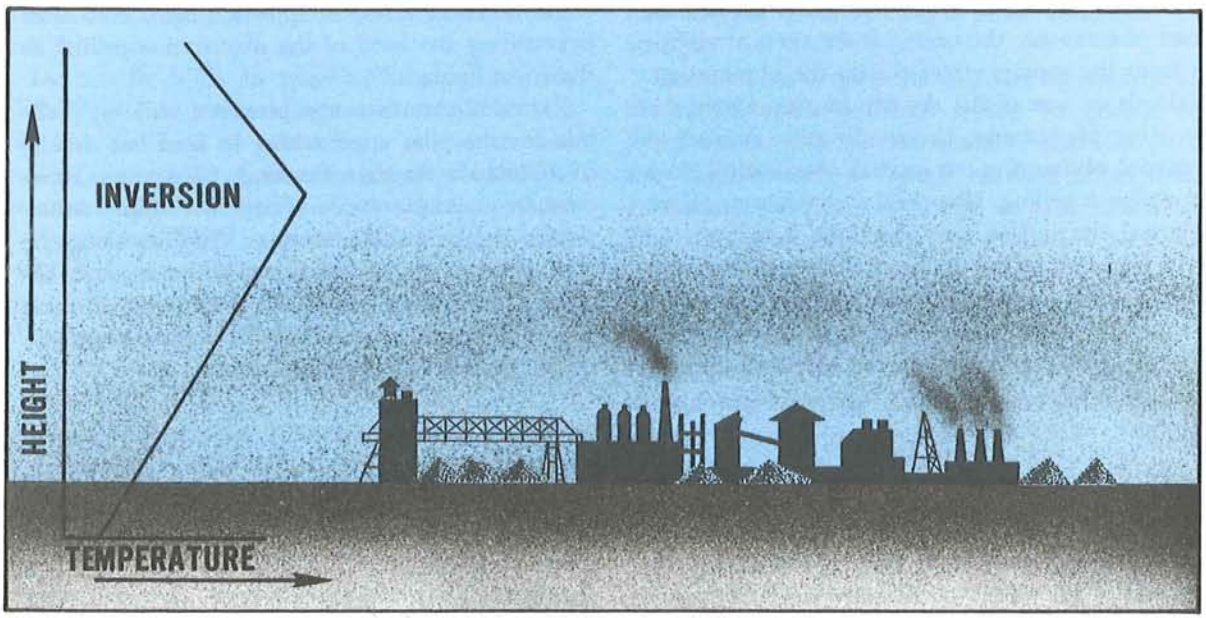


FIGURE 120. Smoke trapped in stagnant air under an inversion.

may occur in any dry area where loose sand is exposed to strong wind.

Blowing snow can be troublesome. Visibility at ground level often will be near zero and the sky may become obscured when the particles are raised to great heights.

FIGURE 121. Aerial photograph of blowing dust approaching with a cold front. The dust cloud outlines the leading surface of the advancing cold air.

PRECIPITATION

Rain, drizzle, and snow are the forms of precipitation which most commonly present ceiling and/or visibility problems. Drizzle or snow restricts visibility to a greater degree than rain. Drizzle falls in stable air and, therefore, often accompanies fog, haze, or smoke, frequently resulting in extremely poor visibility. Visibility may be reduced to zero in heavy snow. Rain seldom reduces surface visibility below 1 mile except in brief, heavy showers, but rain does limit cockpit visibility. When rain streams over the aircraft windshield, freezes on it, or fogs over the inside surface, the pilot's visibility to the outside is greatly reduced.

OBSCURED OR PARTIALLY OBSCURED SKY

To be classified as obscuring phenomena, smoke, haze, fog, precipitation, or other visibility restricting phenomena must extend upward from the surface. When the sky is totally hidden by the surface based phenomena, the ceiling is the vertical visibility from the ground upward into the obscuration. If clouds or part of the sky can be seen above the obscuring phenomena, the condition is defined as a partial obscuration; a partial obscuration does not define a ceiling. However, a cloud layer above a partial obscuration may constitute a ceiling.

An obscured ceiling differs from a cloud ceiling. With a cloud ceiling you normally can see the ground and runway once you descend below the cloud base. However, with an obscured ceiling, the obscuring phenomena restricts visibility between your altitude and the ground, and you have restricted slant visibility. Thus, you cannot always clearly see the runway or approach lights even after penetrating the level of the obscuration ceiling as shown in figure 122.

Partial obscurations also present a visibility problem for the pilot approaching to land but usually to a lesser degree than the total obscuration. However, be especially aware of erratic visibility reduction in the partial obscuration. Visibility along the runway or on the approach can instantaneously become zero. This abrupt and unexpected reduction in visibility can be extremely hazardous especially on touchdown.

IN CLOSING

In your preflight preparation, be aware of or alert for phenomena that may produce IFR or marginal VFR flight conditions. Current charts and special analyses along with forecast and prognostic charts are your best sources of information. You may get your preflight weather from a briefer; or, you may rely on recorded briefings; and you always have your own inflight observations. No weather observation is more current or more accurate than the one you make through your cockpit

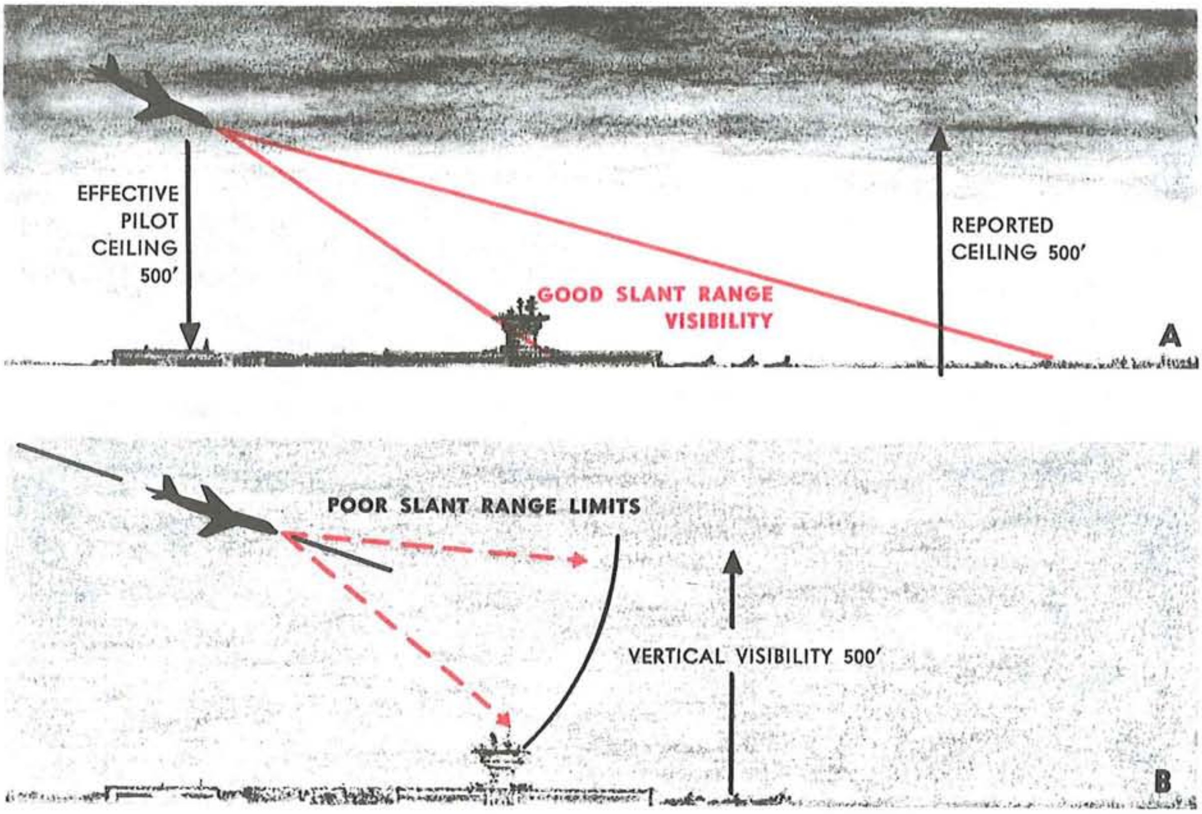


FIGURE 122. Difference between the ceiling caused by a surface-based obscuration (B) and the ceiling caused by a layer aloft (A). When visibility is not restricted, slant range vision is good upon breaking out of the base of a layer aloft.

window. In any event, your understanding of IFR producers will help you make better preflight and inflight decisions.

Do not fly VFR in weather suitable only for IFR. If you do, you endanger not only your own life but the lives of others both in the air and on the ground. Remember, the single cause of the greatest number of general aviation fatal accidents is "continued VFR into adverse weather." The most common cause is vertigo, but you also run the risk of flying into unseen obstructions. Furthermore, pilots who attempt to fly VFR under conditions below VFR minimums are violating Federal Aviation Regulations.

The threat of flying VFR into adverse weather is far greater than many pilots might realize. A pilot may press onward into lowering ceiling and visibility complacent in thinking that better weather still lies behind him. Eventually, conditions are too low to proceed; he no longer can see a horizon ahead. But when he attempts to turn around, he finds so little difference in conditions that he cannot re-establish a visual horizon. He continued too far into adverse weather; he is a prime candidate for vertigo.

Don't let an overwhelming desire to reach your destination entice you into taking the chance of flying too far into adverse weather. The IFR pilot may think it easier to "sneak" through rather than go through the rigors of getting an IFR clearance. The VFR pilot may think, "if I can only make it a little farther." If you can go IFR, get a clearance ***before*** you lose your horizon. If you must stay VFR, do a 180 while you still have a horizon. The 180 is not the maneuver of cowards. ***Any pilot knows how to make a 180; a good pilot knows when.***

Be especially alert for development of:

1. Fog the following morning when at dusk temperature–dew point spread is 15° F or less, skies are clear, and winds are light.
2. Fog when moist air is flowing from a relatively warm surface to a colder surface.

3. Fog when temperature-dew point spread is 5° F or less and decreasing.
4. Fog or low stratus when a moderate or stronger moist wind is blowing over an extended upslope. (Temperature and dew point converge at about 4° F for every 1,000 feet the air is lifted.)
5. Steam fog when air is blowing from a cold surface (either land or water) over warmer water.
6. Fog when rain or drizzle falls through cool air. This is especially prevalent during winter ahead of a warm front and behind a stationary front or stagnating cold front.
7. Low stratus clouds whenever there is an influx of low level moisture overriding a shallow cold air mass.
8. Low visibilities from haze and smoke when a high pressure area stagnates over an industrial area.
9. Low visibilities due to blowing dust or sand over semiarid or arid regions when winds are strong and the atmosphere is unstable. This is especially prevalent in spring. If the dust extends upward to moderate or greater heights, it can be carried many miles beyond its source.
10. Low visibility due to snow or drizzle.
11. An undercast when you must make a VFR descent.

Expect little if any improvement in visibility when:

1. Fog exists below heavily overcast skies.
2. Fog occurs with rain or drizzle and precipitation is forecast to continue.
3. Dust extends to high levels and no frontal passage or precipitation is forecast.
4. Smoke or haze exists under heavily overcast skies.
5. A stationary high persists over industrial areas.