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.
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
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.)
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.
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 altocumulus 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
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.
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.