The Bureau of Meteorology

Aviation services

Airframe icing

Hazardous phenomena

Accumulation of ice on aircraft is a significant hazard to the safe and efficient operation of aircraft, as it can reduce aircraft performance in a number of different ways.

Introduction

Aircraft flying through cloud in sub-freezing temperatures between 0˚C and -40˚C (with the highest risk occurring between 0˚C and -15˚C) are likely to experience some degree of icing. A pilot can reduce the chance of icing becoming a serious problem by selecting appropriate flight routes, remaining alert to the possibility of ice formation and knowing how and when to operate de-icing and anti-icing equipment.

The risk of an icing encounter can be evaluated by considering:

- air temperature
- water droplet size and concentration
- shape and temperature of aircraft surfaces
- aircraft speed and the time spent in an icing environment.

Effects on aviation

In-flight icing is a serious hazard to aircraft because it can:

- alter the smooth flow of air over the aircraft
- reduce pilot visibility
- produce errors in instrument readings of air speed, altitude and vertical speed
- interfere with communications systems
- increase the stall speed by increasing its weight and changing the aerodynamics of the wing and tail
- increase drag and decrease lift (tests have shown that icing no thicker or rougher than a piece of coarse sandpaper can reduce lift by 30% and increase drag by 40%)
- make it almost impossible to operate control surfaces and landing gear
- cause propeller vibrations
- damage compressor blades of jet engines (chunks of ice can inject into the engine)
- reduce thrust or cause engine failure
- damage parts of the aircraft.

Aircraft icing categories	Description
Structural icing	• Forms on the exterior parts of the airframe • Occurs when water droplets (cloud or liquid precipitation) at temperatures below the freezing point (i.e. they are supercooled) freeze on impact with aircraft surfaces.
Induction system icing	• Forms in air intake of engines and in carburettors • Air intake icing usually requires the aircraft surface to be 0°C or colder with visible moisture present • Carburettor icing is most likely with air temperatures between 7°C and 21°C and relative humidity above 80%.
Instrument icing	• Forms on critical instruments and sensors, e.g. pitot tube, static ports, and antennae • Generally occurs in the same conditions as structural icing • Results in inaccurate airspeed, altitude, and other readings.

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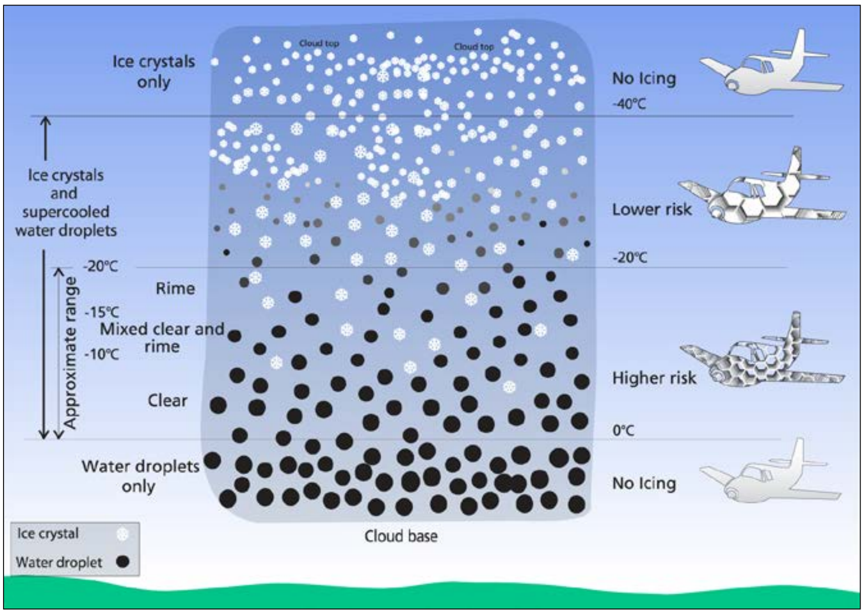
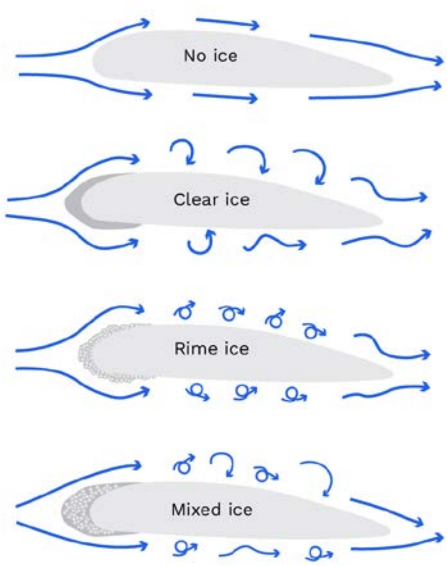
Icing severity

Severity	Rate of accumulation	Aircraft effects
Trace	Perceptible, but no significant accumulation	Not hazardous and de-icing/anti-icing equipment is generally not utilised
Light	Significant accumulation if flight is prolonged in an icing environment (i.e. more than 1 hour)	Occasional use of de-icing/anti-icing equipment removes or prevents accumulation
Moderate	Significant accumulation over a short period of flight	Use of de-icing/anti-icing equipment or diversion is necessary
Severe	Rapid, dangerous accumulation	De-icing/anti-icing equipment fails to reduce or control the hazard; immediate diversion is necessary

Icing types

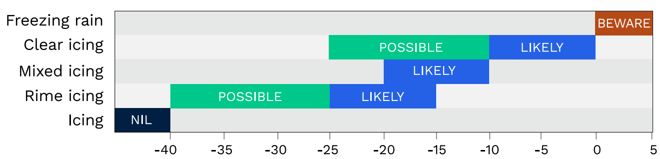


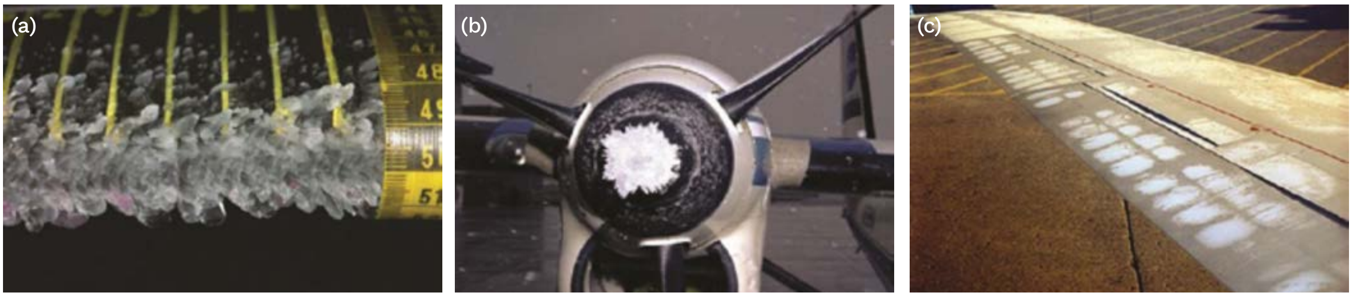


Clear (or glaze) ice forms most readily in temperatures between 0˚C and -10˚C but can occur, with reduced intensity, at temperatures as low as -25˚C. It is formed when large, supercooled water droplets freeze relatively slowly upon impact with a surface. The water droplets extend along the surface, allowing air bubbles to escape, producing a transparent ice sheet. After further accumulation, ridges may form. Clear ice is most commonly experienced in cumuliform cloud, where large supercooled water droplets are often encountered, and below cloud in freezing precipitation. The latter can cause the most severe forms of clear icing and may result in an aircraft becoming enshrouded in a clear ice layer in a matter of seconds. Such conditions can occur ahead of a warm front or sometimes behind a cold front when warm moist air aloft overruns sub-zero air at lower levels. The rain falling from or through the warm air into sub-zero air can become supercooled and flow over exposed surfaces, freezing as clear ice.

Rime ice is formed by small water droplets freezing quickly upon impact, trapping air inside the ice, giving it a white, opaque and lumpy appearance. Because this ice freezes quickly, it is usually confined to the leading edge of the wing. It may be encountered anywhere between 0˚C and -40˚C, but most frequently forms in the temperature range of -10˚C to -20˚C in stratiform clouds, although cumuliform clouds may also produce rime at temperatures below -10˚C. Much of it can be removed by de-icing and prevented by anti-icing.

Mixed ice, a combination of clear ice and rime ice, is the most frequent form of icing because different sized water droplets commonly occur in cloud. It is most likely to form in the temperature range of -10˚C to -15˚C, when the water droplets vary in size or are mixed with snow, ice pellets or small hail.





(a) 'Artificially' created clear ice. (b) Two types of icing are distinguished: the white rapid deposit of rime ice on the cone's nose and the clear ice, which spreads out before freezing. (c) Hoar frost on a parked aircraft. Credit: Meteo France & WMO 2005

Hoar frost is not specific to a particular temperature range. It is a white and feathery crystalline deposit, which can occur in clear air when an aircraft passes quickly from sub-zero dry air to warm moist air, with the water vapour in the warmer air changing directly to ice. It can, for example, occur on a frosty, calm morning when an aircraft, which has cooled to below freezing, takes off into warmer and moister air, causing the water vapour to deposit as ice on the windscreen and canopy. The ice will quickly disappear if the aircraft remains in the warmer environment, however it can cause significant problems in the interim, with the build-up of the ice on the windscreen greatly reducing visibility. It can disrupt the smooth airflow over the wing, inducing early separation of the airflow over the upper surface. Hoar frost can also occur on parked aircraft when the temperature is sub-zero and the humidity is close to saturation point.

Cloud types and weather systems

The distribution of supercooled water droplets and ice within a cloud varies with temperature. In general, the largest supercooled droplets are found at temperatures just below 0˚C, i.e. at altitudes just above the freezing level (FZLVL). The size of the supercooled droplets tends to decrease with decreasing temperatures and/or increasing altitude.

The rate of ice accumulation is directly proportional to the amount of supercooled liquid water present. In clouds, the worst-case scenario is most likely to occur in towering cumulus and cumulonimbus due to their vertical extent, the abundant supply of moisture and the large droplet size found in these cloud types.

Frontal systems force one air mass up and over another. Although the lifting over a moving cold air mass can have a broad extent, the more intense lifting caused by a cold front tends to be limited to narrow bands of clouds tens of kilometres wide near the surface frontal location. Fronts in general can be areas of enhanced icing due to the presence of convection and ample moisture.

Cyclonic circulations generate convergence of air near the centre of low-pressure systems, producing large-scale (over hundreds or even thousands of kilometres) rising motion and resultant cloud formation. The extensive nature, both vertically and horizontally, of a synoptic-scale cyclone can result in long exposures of aircraft to icing conditions.

Orographic lifting over hills or mountains is likely to increase both the depth of a cloud layer and the liquid concentration within the cloud. Icing may therefore occur more rapidly in elevated areas. The severity will be increased if frontal systems are also in the vicinity.

Warm air advection, often associated with poleward moving air, results in large-scale upward motion. In Australia, cloud resulting from warm air advection is often recognisable in the form of a north-west cloud band. Icing can be severe due to its widespread nature and with upward motion providing a constant supply of liquid water.

Code	Cloud type	Icing threat
CI, CS, CC	Cirriform	Nil to light
CB	Cumulonimbus	Possible severe clear ice
TCU	Towering cumulus	Possible severe clear ice
AS	Altostratus	Light to moderate rime; clear ice possible in lower levels
AC	Altocumulus	Light to moderate rime
NS	Nimbostratus	Moderate mixed icing in lower levels
SC	Stratocumulus	Moderate rime when freezing level is low enough
CU	Cumulus	Light to moderate clear ice
ST	Stratus	Nil to light rime

High ice water content (HIWC)

High ice water content (HIWC) is the name for atmospheric conditions where there are high concentrations of ice crystals. HIWC usually occurs at temperatures below -20˚C, where there tends to be a reduction in supercooled liquid water and an increased ratio of ice particles. These ice crystals tend to have low radar reflectivity and are typically associated with deep convection in the tropics and subtropics.

Convective updrafts, associated with large convective cells, have the ability to lift high concentrations of moisture to high altitudes where it can freeze into very small ice crystals. The term "icing conditions" typically refers to weather conditions where supercooled liquid droplets form ice on cold airframe surfaces such as the wings and fuselage. Ice crystals, regardless of size, will not adhere to a cold airframe of a plane. However, small ice crystals have the ability to partially melt and stick to warmer engine surfaces. The ingestion of very small ice crystals into the core of the engine causes the ice crystals to melt as they impact on the warm internal engine components. An increasing collection of supercooled liquid produces a thin film over parts of the engine, enabling the further capture of ice crystals. Over time, ice crystals aggregate and reduce the internal temperature of the engine, leading to engine power loss or other malfunctions.

Monitoring and detection

A pilot in command of an aircraft must make a special AIREP as soon as practicable after encountering or observing:

- any moderate icing, where a change of heading and/or altitude may be considered desirable
- severe icing, where an immediate change of heading and/or altitude is considered essential.

Pilots should keep in mind that icing may occur when their aircraft is flying through supercooled cloud or precipitation and the ambient air temperature is below 0˚C. Early signs of aircraft icing may include ice accretion on the windows, wipers, antennae, propeller, engine inlets and other surfaces, or inaccurate airspeed and altitude readings.

Meteorologists use a range of tools to identify, observe and monitor icing, including:

- AIREPs
- satellite imagery, including infrared temperature measurements
- weather RADAR
- synoptic charts
- vertical wind, moisture and temperature profiles.

Forecasts and warnings

The Bureau of Meteorology provides a number of forecasts and warnings containing information on the timing, severity and extent of icing conditions. These include:

- Graphical area forecasts (GAF) – provide an icing forecast below 10,000 feet, based on cloud type, temperature and synoptic-scale influences, where TS/CB/TCU will always imply severe icing and any cloud above the freezing level will imply moderate icing.
- AIRMET and graphical AIRMET – provide warning of areas below 10,000 feet expected to contain moderate icing conditions, if it is not already contained in the GAF.
- Significant weather charts (SIGWX) – both mid (FL100 to FL250) and high (FL250 to FL600) level charts contain icing forecasts in a graphical format.
- SIGMET and graphical SIGMET – provide warning of areas (horizontal and vertical extent) expected to contain severe icing conditions, either observed or forecast.

Further aviation educational resources produced by the Bureau of Meteorology can be found at www.bom.gov.au/aviation/knowledge-centre.

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