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Sources: Aircraft loos of control (S. R. Jacobson, NASA, 2010), Appendix C 'Icing Conditions' to CFR 14 Part 25, FAA, 2014, EASA SIB, Aircraft Icing Handbook, CAA, NZ and personal researches of writer.

What we need to know about ICING

Not having enough knowledge about in-flight icing and not trying to educating our self, will defiantly cause big problems, being capable of flying into icing condition won't make you a hero! Good airmanship always try to avoids flying in knowing icing condition.

Pilot. Seyed Alireza Amintabar

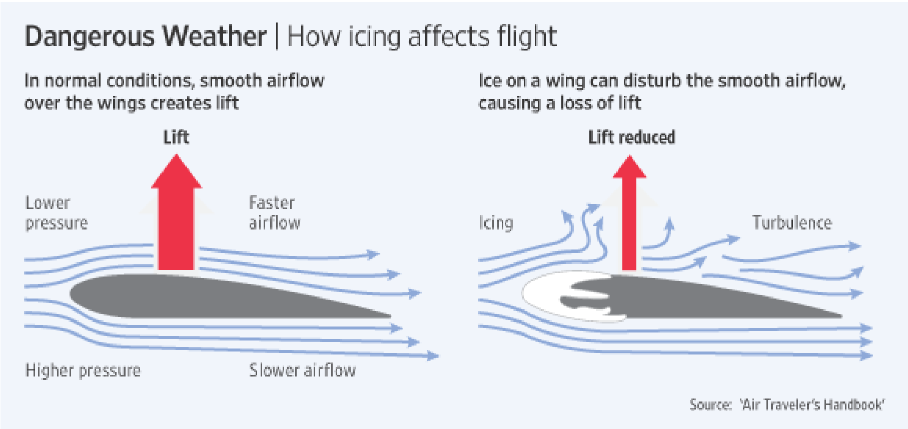
In-Flight Icing

In-Flight Airframe Icing occurs when super-cooled water freezes on impact with any part of the external structure of an aircraft during flight.

Although the nominal freezing point of water is 0°C, water in the atmosphere does not always freeze at that temperature and often exists as a "super-cooled" liquid. If the surface temperature of an aircraft structure is below zero, then moisture within the atmosphere may turn to ice as an immediate or secondary consequence of contact.

Considerable quantities of atmospheric water continue to exist in liquid form well below 0°C. The proportion of such super-cooled water decreases as the static air temperature drops until by about -40°C (except in Cumulonimbus Cloud where SLD may exist at even lower temperatures), almost all of it is in solid form. The size of super-cooled water droplets and the nature of the airflow around the aircraft surface, determine the extent to which these droplets will strike the surface. The size of a droplet will also affect what happens after such impact - for example larger droplets will often be broken up into smaller ones. Finally, since the size of a water droplet is broadly proportional to the mass of water it contains and this mass determines the time required for the physical change of state from liquid (water) to solid (ice) to occur, larger droplets which do not break up into smaller ones will take longer to freeze because of the greater release of latent heat and may form a surface layer of liquid water before this change of state occurs.

Airframe Icing **can lead to reduced performance, loss of lift by 30%, increases drag by 40%, altered controllability and ultimately stall and subsequent loss of control of the aircraft.**



Hazards arising from the presence of ice on an airframe include:

Adverse Aerodynamic Effects;

Ice accretion on critical parts of an airframe unprotected by a normally functioning anti-icing or de-icing system can modify the airflow pattern around airfoil surfaces such as wings and propeller blades leading to loss of lift, increased drag and a shift in the airfoil center of pressure. The latter effect may alter longitudinal stability and pitch trim requirements. Longitudinal stability may also be affected by a degradation of lift generated by the horizontal stabilizer. The modified airflow pattern may significantly alter the pressure distribution around flight control surfaces such as ailerons and elevators. If the control surface is unpowered, such changes in pressure distribution can eventually lead to commanded control deflections which the pilot may not be able to be overpower.

Blockage of pitot tubes and static vents;

Partial or complete blockage of the air inlet to any part of a pitot static system can produce errors in the readings of pressure instruments such as Altimeters, Airspeed indicators, and Vertical Speed Indicators. The most likely origin of such occurrences to otherwise serviceable systems has been the non-activation of the built-in electrical heating which these tubes and plates are provided with, although in some cases, the detail design of pitot heads has made them relatively more vulnerable to ice accretion even when functioning as certificated. It is now also recognized that the effects of high level ice crystal icing can have what are usually transient effects on the effectiveness of normally functioning pitot probe heating.

Radio communication problems;

Historically, ice forming on some types of unheated aerials has been the cause of degraded performance of radios but this has not been encountered in the case of modern radio equipment and aerials.

Surface Hazard from Ice Shedding;

Ice shed during in-flight de-icing is not of a size which could create a hazard should it survive in frozen form until reaching the ground below. However, there has been a long history of ice falls from aircraft waste drain masts, a few of which have caused minor property damage and occasionally come close to hitting and injuring people. The drain masts involved are those from aircraft galleys or toilet compartments which are normally heated to prevent ice formation for some reason have not been operating as intended. Ice from toilet waste masts is often referred to as "blue ice". Most of these events have been recorded where there is a high density of long haul commercial air traffic inbound to a large airport which routinely overflies a densely populated residential area as it descends below the freezing level in the vicinity of the airport.

<u>The Airframe Ice accretion</u> on an aircraft structure can be distinguished as Rime Icing, Clear/Glaze Icing or a blend of the two referred to as Cloudy or Mixed Icing:

Rime Ice;

Rime ice is formed when small super-cooled water droplets freeze rapidly on contact with a sub-zero surface. The rapidity of the transition to a frozen state is because the droplets are small and the almost instant transition leads to the creation of a mixture of tiny ice particles and trapped air. The resultant ice deposit formed is rough and crystalline and opaque and because of its crystalline structure, is brittle. It appears white in colour when viewed from a distance - for example from the flight deck when on a wing leading edge.

Since rime ice forms on leading edges, it can affect the aerodynamic characteristics of both wings and horizontal stabilizers as well as restricting engine air inlets. Rime may begin to form as a rough coating of a leading edge but if accretion continues, irregular protrusions may develop forward into the airstream, although there are structural limits to how much "horn" development can occur.

Clear Ice;

Clear or Glaze ice is formed by larger super-cooled water droplets, of which only a small portion freezes immediately. This results in runback and progressive freezing of the remaining liquid and since the resultant frozen deposit contains relatively few air bubbles as a result, the accreted ice accretion is transparent or translucent. If the freezing process is sufficiently slow to allow the water to spread more evenly before freezing, the resultant transparent sheet of ice may be difficult to detect. The larger the droplets and the slower the freezing process, the more transparent the ice.

Occasionally, certain temperature and droplet size combinations can lead to the formation of a "double ram's horn" shape forward of the leading edge with protrusions from both the upper and lower leading edge surfaces. These horns have been observed to occur in a variety of forms in a wide range of locations along a leading edge and, because clear ice has a more robust structure than rime ice, they can reach larger sizes.

Cloudy or Mixed Ice;

This blend of the two accreted ice forms in the wide range of conditions between those which lead to mostly Rime or mostly Clear/Glaze Ice and is the most commonly encountered. Its appearance will be determined by the extent to which it has been formed from super-cooled water droplets of various sizes.

Some other terms which may be encountered in connection with airframe ice accretion include:

Super-cooled Large Droplets (SLD);

"Super-cooled large droplets (SLD) are defined as those with a diameter greater than 50 microns" - The World Meteorological Organization.

"Super-cooled Large Droplet (SLD).... (has) a diameter greater than 50 micrometers (0.05 mm). SLD conditions include freezing drizzle drops and freezing raindrops.2 - FAA AC 91-74A, Pilot's Guide to Flight in Icing Conditions

If a SLD is large enough, its mass will prevent the pressure wave traveling ahead of an airfoil from deflecting it. When this occurs, the droplet will impinge further aft than a typical cloud-sized droplet, possibly beyond the protected area and form clear ice.

Droplets of this size are typically found in areas of freezing rain and freezing drizzle. Weather radar is designed to detect large droplets since they are not only an indication of potential in-flight icing but also updrafts and wind shear.

Runback Ice;

Runback ice forms when super-cooled liquid water moves aft on the upper surface of the wing or tailplane beyond the protected area and then freezes as clear ice. Forms of ice accretion which are likely to be hazardous to continued safe flight can rapidly build up. Runback is usually attributable to the relatively large size of the SLD encountered but may occur also occur when a thermal ice protection system has insufficient heat to evaporate the quantity of super-cooled water impinging on the surface.

Intercycle Ice;

Intercycle ice is that which forms between cyclic activation of a mechanical or thermal de-ice system. Accumulation of some ice when these systems are not 'on' is an essential part of their functional design. The time interval between 'on' periods is usually selectable between at least two settings. Any ice remaining after a de-icing system of this type has been selected off is sometimes referred to as residual ice.

The adverse aerodynamic effects of accreted ice on the continued safe flight of an aircraft are a complex subject because of the many forms such ice accretion can take. In certain circumstances, very little surface roughness is required to generate significant aerodynamic effects and, as ice-load accumulates, there is often no aerodynamic warning of a departure from normal performance. Stall warning systems are designed to operate in relation to the angle of attack on a clean aeroplane and cannot be relied upon to activate usefully in the case of an ice-loaded airframe.

<u>Collection Efficiency</u>, often referred to as "Catch Rate", is a product of two factors:

Collision efficiency - determined by aerodynamics, and

Adhesion efficiency - determined by the adhesive qualities of the component surface.

Specifically, it is the fraction of the liquid water in the direct path of an aircraft component (aerofoil, antenna, windscreen etc.,) which is deposited as ice on that component whilst flying in icing conditions. Collection efficiency varies directly with both droplet size and aircraft speed and inversely with the geometric size of the collecting surface.

To a large degree, the rate at which ice accumulates on an aircraft depends upon the collection efficiency of the aircraft component involved. The size of the collecting surface of an aircraft component is described in terms of the curvature radius of its leading edge. Those components which have large curvature radii (canopies, windscreens, thick wings, etc.) collect only a small percentage of the cloud droplets, especially the smaller droplets, and, therefore, have a low collection efficiency. Conversely, components which have a small curvature radius (antenna masts, thin wings, etc.) deform the airflow less and permit a high proportion of droplets of all sizes to be caught. These components are said to have a high collection efficiency. Once ice begins to form, the shape of the collecting surface is modified by the ice itself, resulting in the curvature radius nearly always becoming smaller. Therefore, as ice accumulates, the collection efficiency increases leading to further and more rapid ice accumulation. On most aircraft, the curvature radius of the horizontal tail surface is smaller than that of the wing.

This can lead to tail plane icing before any ice accumulation on the wing and, in some cases, could lead to Ice Contaminated Tailplane Stall.

Droplet size has an effect on where ice will form. If the droplets are small, ice formation is limited to the leading edge radius. As droplet size increases, ice formation will extend aft of the leading edge radius but with medium size droplets will not normally extend aft of surfaces normally protected by aircraft ice protection systems. Ice formation from large droplets can extend aft of the protected surfaces. Freezing rain or freezing drizzle can result in ice formation extending aft to the point of maximum component projection into the air stream.

The faster the speed of the aircraft, the less chance there is for the droplets to be carried around the airfoil in the air stream. As a consequence, collection efficiency increases with aircraft speed.

<u>Icing in cloud precipitation;</u> clouds containing liquid water can present a significant icing environment if the temperature is 0 °C or less. Generally, cumuliform cloud structures will contain relatively large droplets which can lead to very rapid ice build-up. Stratiform cloud structures usually contain much smaller droplets, although the horizontal extent of icing conditions within a stratiform cloud may be such that that the accumulation in even a relatively short period of level flight can sometimes be considerable. The most significant ice accretion in any cloud can be expected to occur at temperatures below, but close to, 0˚C. In a stratiform cloud in temperate latitudes, the maximum ice accretion is often found near the top of the cloud and it may be unwise for some turboprop aircraft to remain at such an altitude for extended periods.

Any drizzle or rain which is encountered at temperatures of freezing or below is likely to generate significant ice accretion in a very short period of time, even if reasonable forward visibility prevails, and such conditions should be excited by any appropriate change of flight path.

Snow in itself does not present an icing threat, since the water is already frozen. However, snow can be mixed with liquid water, particularly cloud droplets, and, in some circumstances, can contribute to the accumulation of hazardous frozen deposits. This phenomenon may also occur in Cumulonimbus anvil clouds, where the ice crystals may be mixed with SLD to incur significant icing.

Types of In-flight Airframe Icing Accidents

There are two main origins of accidents and serious incidents involving airframe icing;

General aviation aircraft that are not equipped with ice protection systems but are flown in icing conditions may encounter enough icing at cruise altitudes to overwhelm the aircraft power reserve, leading to an inability to maintain altitude and/or airspeed. In mountainous terrain, this very often leads to a stall followed by a loss of control when the pilot attempts to maintain altitude over the high terrain. Alternatively, a collision with terrain may result when altitude cannot be maintained. Regardless of the type of terrain, any aircraft without airframe ice protection systems which is flown in icing conditions can quickly encounter a stall and loss of control due to the excessive drag and loss of lift which ice accretion can bring.

Aircraft, predominantly propeller-driven (Turbo prop/piston engine), which rely on wing and tail ice protection by de-icing, principally by pneumatic deicing boots, and are operated in icing conditions which exceed the capability of the protection. In these cases, if the angle of attack increases in the presence of an abnormal ice loading either as a result of attempting to maintain a climb with limited power and a relatively high load or, more suddenly, when configuration is changed during the approach to land, a stall and loss of control can result from which recovery may not be possible at low level.

Solutions

Flight Planning; For aircraft without airframe ice protection systems, operation in icing conditions should be avoided. This can only be assured if operating in VMC and flight in freezing precipitation will not occur, or in IMC when temperatures will be above freezing and flight in freezing precipitation will not occur. It is particularly important that the cruise portion be planned so as to avoid icing at high altitudes above mountainous terrain.

Operation of Ice Protection Systems; Care should be taken to operate the wing and tailplane ice protection systems in accordance with the manufacturer's specification. There have been significant changes, in recent years, in procedures for effective operation of pneumatic ice protection systems and these instructions should not be ignored in favour of popular notions such as ice bridging.

Approach and Landing; Pilots operating ice-protected aircraft should consider the effects of any residual ice which may be present during approach and landing since it may degrade performance substantially and lead to abnormal responses to configuration changes.

Aircraft and in flight Icing RISK

Flight in 'icing conditions' brings two risks which are independent of each other. These are the possibility of ice accreting on the airframe and the possibility of ice affecting the normal operation of the powerplant(s) fitted to the airframe (because of ice formation in or around the air inlet path).

Of fundamental importance is whether or not the aircraft is certificated for flight in icing conditions. This information is contained in the AFM or, for a small aircraft, the Pilots Operating Handbook (POH) and is part of the Operating Limitations. Aircraft Limitations are often transcribed into an approved Company Operations Manual.

If an aircraft is not approved for flight in icing conditions, then flight should be planned to avoid them. However, if icing conditions are inadvertently entered, the only wholly safe option is to exit them as soon as possible. It is important to note that aircraft which are approved for instrument flight rules (IFR) operation are not necessarily also certificated for operation in icing conditions.

If an aircraft is certified for flight into known icing conditions then, for smaller aircraft, there may be specific AFM restrictions on such flight. For most larger aircraft however, there will not be any specific restrictions, but it can be safely assumed that icing certification never implies that operation in severe icing conditions is approved - or feasible. Freezing Rain and, to a lesser extent, Freezing Drizzle represent severe icing conditions, because clear ice is formed by Freezing Rain.

For any aircraft type which is certificated for flight in icing conditions, the AFM or POH will contain a manufacturer's definition of the threshold for 'Icing Conditions' for the purposes of the selection or activation of ice protection equipment. This is usually given as the presence of visible moisture and an Outside Air Temperature (OAT), Static Air Temperature (SAT) or Total Air Temperature (TAT) reading of less than a figure between +3°C and +10°C. Operation of anti-icing systems is never based upon the appearance of visible ice or on the flight deck annunciation of external ice detector activation, although de-icing systems may be. Visible moisture can be defined in flight as clouds, fog with visibility of 1500m or less, and precipitation. On the ground this can include standing water, slush or snow present on the taxiways or runways.

Although the limiting severity of icing conditions in which an aircraft can be operated vary, low performance aircraft are likely to be exposed to relatively more risk in flight through whatever icing conditions prevail. This factor alone tends to distinguish the significance of 'routine' icing exposure for jets versus turboprops. Whilst both may be similarly certificated for "flight in icing conditions", the effects of light or moderate icing is greatly reduced if less time is spent in it. However, if a low performance aircraft and a high performance aircraft fly the same trajectory through a portion of airspace containing light or moderate icing conditions, very similar amounts of ice will potentially accrete on both aircraft by the time they leave the icing conditions. The ice potentially accreting depends on the integral along the path of the aircraft of the liquid water content. For a given aircraft flying a given trajectory, increasing the airspeed will cause a higher proportion of the liquid water to accrete to the aircraft. Note though that if a high powered aircraft can climb more steeply than a low powered aircraft, and hence exit the icing layer in less time, the two trajectories are different and the high powered aircraft may well accrete less liquid water than the low powered aircraft. Additionally, the use of jet engine bleed air for anti-icing is much more effective than the cycling of pneumatic boots installed on the leading edges of most turboprops.

However, many aircraft certified for 'flight in icing conditions' do not have that term defined at its extreme and even in jet transports, severe icing should almost always be avoided - or exited promptly if unexpectedly encountered.

Consideration should also be given to the aircraft angle of attack during climb-out in icing conditions. A high angle of attack may result in ice forming aft of its leading edge, possibly to areas where there is no de/anti-ice system present.

The lower temperature limit for icing to occur is generally accepted at -40C, below which temperature no significant engine and/or wing icing occurs. However, icing can occur at temperatures below -40C in conjunction with cumulonimbus cloud, in particular in the anvil regions.

A crucial requirement which applies to all aircraft is that, at rotation on take-off, the wings and empennage must be completely free of frozen deposits. Prior use of appropriate ground de/anti-icing fluids may be required to achieve this. A typical anti icing product will give a specified time period in which it is effective (holdover period). After the holdover time elapses the aircraft must receive another treatment before it can safely take off. The holdover period is effected by the prevailing conditions like temperature and type of precipitation. Holdover period validity does not guarantee no ice accretion or reformation within that time. Visual inspections may be needed to ascertain that no ice has reformed or accreted, but such inspections may be difficult, particularly for larger aircraft - where critical lifting surfaces are not visible from the cockpit and even the cabin, and at night. It should be noted that de-/anti-icing fluids provide either no, or at best very limited, protection against freezing rain [link] or freezing drizzle [link], so that if such precipitation is occurring, departures are generally prohibited by air operators for safety reasons.

Finally, whilst certification for flight in icing conditions requires evidence that an aircraft can operate safely within a specified flight envelope, it is often extremely difficult to objectively establish the actual icing conditions which exist. This is because crucial parts of the airframe are not readily visible to the flight crew, and even when they are, the reliability of visual inspection is poor. This is particularly so at night.

Certification for flight in icing

intended does not necessarily imply fitness for or approval of continuous operations in icing conditions. In many cases, especially for smaller general aviation aircraft, it may be intended to allow for just a temporary period of operation in icing conditions during which the horizontal or vertical extent of the icing is vacated. The way in which 'icing conditions' are defined for large (transport) aircraft has in recent years come under close scrutiny on both sides of the Atlantic because it has become apparent that icing can occur at static air temperatures much colder than those adopted in the longstanding current definitions.

There are three principal aspects:

1. **Airframe and systems ice protection;**

It is important to note that there is no direct correlation between the presence of ice protection equipment and certification for flight in icing conditions. Ice protection equipment has existed for considerably longer than standards for icing certification and any such equipment has historically been included in the overall certification process. Many smaller aircraft still in service have thus been designed

and manufactured with ice protection equipment installed, or had it added in accordance with a Supplementary Type Certificate prior to the introduction of an icing certification standard. Although some manufacturers have subsequently opted to obtain icing certification for older designs of general aviation aircraft, others have not. The idea of certificating the ice protection system as a part of the type design while not certificating that type for flight into known icing is still considered by the FAA to be a valid design strategy for small general aviation aircraft. An example of this approach is the US-built Cirrus SR-22.

Prior to the existence of certification standards for icing certification, an ice protection system was approved as part of the type design process by ensuring that it did not prejudice safe operation. For example, Part 3 of the former US Civil Aeronautics Regulations required that a means existed to ensure that pneumatic de-ice boots would deflate following usage. It was left to the equipment requirements contained within the operating rules to specify what equipage was required for flight into known icing. Some vestiges of these equipment requirements for small aircraft are still included in operating rules today which has been known to lead to considerable confusion.

Type Certification of large (transport) fixed wing aircraft is nowadays accomplished under 14 CFR 25.1419 by the FAA or under CS 25.1419 by EASA. In their current version, these require that an aircraft should be able to "operate safely" when the stated definition of icing conditions exist. Although there are methods for determining whether the ice protection provided is adequate, there is currently no requirement to quantify aircraft handling and performance degradations. The meaning of the expression "operate safely" has been the subject of much debate, particular in the USA.

2- Aircraft handling and performance;

In the US at present, FAR 23.1419 and FAR/CS 25.21(g) are the only requirements that specify a quantitative definition of the term "operate safely". These rules require that an aircraft should be able to comply with certain requirements of Subpart B of either Part 23 or Part 25, respectively, while operating within the engineering standard for atmospheric icing. However, Parts 27 and 29 have no such definition associated with the rule.

US FAR 25.21(g) was added to the regulations in 2007. The Subpart B requirements to FAR 23.1419 were added in 1993, although it wasn't until 2000 that this new regulation was incorporated into the certification basis of a new aircraft design. It is therefore important to consider that, of the existing designs that have been certificated for flight in icing, most have been accepted using only a qualitative evaluation of the aircraft handling characteristics and performance degradation in icing. Quantitative thresholds in both performance and handling degradations, beyond which the design would not be accepted for icing certification, have only recently begun to be specified.

3- Powerplant ice protection;

Although airframe certification for flight in icing for the airframe is optional, all turbine engines must be certificated for operation in icing conditions on the basis that inadvertent icing encounters are always possible, even for aircraft not certificated for flight in such conditions. Turbine engine certification has historically been focused on inlet ice protection which is addressed in CS E-780 in CFR14- Part 33.68 with reference currently made, as in the airframe case, to Appendix C conditions.

Just as the 'discovery' of the SLD hazard for airframes led to a recognition of the limitations of the definition of icing conditions in Appendix C, a similar 'discovery' of the hazardous effects of Ice Crystal

Icing on turbine engines has led to the investigation of this phenomenon in order to inform an effective extension of current certification requirements. Fortunately, the trigger here has been serious incidents rather than fatal accidents.

The engineering standard

for atmospheric icing is specified in Appendix C of CS 25 / 14 CFR Part Part 25 has been broadly in its present form since it was first developed in the United States and introduced there in 1955 under the former Civil Aeronautics Board before being transferred into FAR Part 25.1419 in 1965. It consists of two envelopes, the continuous maximum and the intermittent maximum. These envelopes are defined by liquid water content, droplet size and air temperature, and specify a horizontal extent for each condition. Between the two, 99.9% of the atmospheric icing environment is characterized. Smaller aircraft first became subject to a comparable standard only with the advent of FAR Part 23 in 1973.

Appendix C did not address the presence of super-cooled large droplets (SLD) - water droplets which persist in subfreezing temperatures and have a median diameter usually defined as greater than 40 microns. Their occurrence is characterized as freezing drizzle where droplet diameters are between 40 and 200 µm and freezing rain where droplet diameters exceed 200 µm. However, because Appendix C was conceived as an engineering standard rather than a certification specification, it is not technically correct to state that operations in SLD lie outside of the bounds of certification even though they are not considered by the criteria used for the design and evaluation of ice protection systems. This is particularly true for the chord-wise extent of the protected surface on a wing or tailplane, which is predicated on Appendix C conditions.

Following the fatal loss of control accident to a large twin turboprop at Roselawn, Indiana in 1994, there was a recognition that SLD could be extremely hazardous and a concerted international effort to improve understanding of their effects and develop corresponding responses occurred. It was claimed during this work that, since 1978, SLD had been involved in around a third of all aerodynamic icing accidents to aircraft of all sizes in the United States. There is now comprehensive guidance on the identification of these conditions in the AFMs of all aircraft engaged in public transport and certificated for operation in icing conditions and work in both Europe and the USA to define an additional certification standard to cover the SLD case is nearing completion.

Interface between Certification and Operating Rules?

There has, in the past, been a degree of ambiguity in the relationship between operating rules and type certification requirements for flight in icing conditions. EASA uses the term “certificated and equipped” to preclude such confusion in the case small aircraft that, whilst equipped with some ice protection equipment, have never been certificated for flight in icing conditions. Under US operating rules, most of the focus is on icing intensity and equipment requirements and only in the Part 135 requirements for helicopters is there a specific requirement for icing certification D

Prior to the introduction of an icing certification standard into CFR 14 Part 23, the FAA standard applicable to small aircraft, a Flight Standards document entitled “Flight Control Hazards and Protection from Icing” specifically permitted such aircraft to enter known light icing provided that certain ice protection equipment requirements were met. However, this 'dispensation' disappeared once Part 23 had incorporated the Appendix C criteria defining icing conditions and the FAA stipulated that any subsequently manufactured aircraft that not certificated under Part 23.1419 must be placarded to

indicate that flight into known icing was prohibited. However, this placarding requirement has never been retrospectively applied to any Part 23 aircraft manufactured prior to 1973, even if a type remained in production after this.

In-Flight Icing: Quick guidance for Controllers

There is no set of ready, out-of-the-box rules to be followed universally. As with any unusual or emergency situation, controllers should exercise their best judgment and expertise when dealing with the apparent consequences of in-flight icing. A generic checklist for handling unusual situations is readily available but it is not intended to be exhaustive and is best used in conjunction with local ATC procedures.

In-flight icing poses serious threat to the safety of a flight. Water droplets accumulate on the airframe as ice under specific conditions. The ice deposits alter the wing profile and disrupt the flow of air. This drastically changes flight parameters such as lift, drag, controllability, etc. As drag increases, lift rapidly decreases - a natural pilot action to compensate for this would be to apply power and increase angle of attack to maintain level, however this leads to even faster ice accumulation as larger airframe surface is exposed. Ice formations on wing and control surfaces can lead to increased stall speed, sudden uncontrolled pitch or roll with difficult recovery and, potentially, eventual loss of control.

Moderate or severe icing conditions could overwhelm the anti-ice system commonly fitted on modern aircraft. Safe continuation of the flight could become impossible.

Type and speed of ice formation is, in part, a function of the variables of the cloud liquid water content, the mean effective diameter of the cloud droplets and the ambient air temperature.
The shape of the aerofoil and the speed of the aircraft also directly affect the rate of ice accretion.
The following table shows the risk classification, depending on the cloud type and temperature:

In-flight icing risk	Cumulus clouds	Stratiform clouds	Rain and drizzle
High	0° to -20°C	0° to -15°C	0°C and below
Medium	-20° to -40°C	-15° to -30°C	
Low	< than -40°C	< than -30°C	

Figure 1: In-flight icing risk in various atmospheric conditions.

According to studies conducted on icing-related incidents and accidents, "the worst continuous icing conditions are found near the freezing level in heavy stratified clouds, or in rain, with icing possible up to 8,000 ft higher. Icing is rare above this higher altitude as the droplets in the clouds are already frozen. In cumuliform clouds with strong updrafts, however large water droplets may be carried to high altitudes and structural icing is possible up to very high altitudes. Further, in cumuliform cloud the freezing level may be distorted upwards in updrafts and downwards in downdrafts, often by many thousands of feet. This leads to the potential for severe icing to occur at almost any level.

- **Trace: Ice becomes perceptible. Rate of accumulation of ice is slightly greater than the rate of loss due to sublimation.**
- **Light: The rate of accumulation may create a problem for flight in this environment for one hour. Unless encountered for one hour or more, de-icing/anti-icing equipment and/or heading or altitude change not required.**
- **Moderate: The rate of accumulation is such that even short encounters become potentially hazardous. De-icing/anti-icing required to remove/prevent accumulation or heading or attitude change required.**
- **Severe: The rate of accumulation is such that de-icing/ anti-icing equipment fails to reduce or control the hazard. De-icing/anti-icing required, immediate heading or altitude change required.**

In-flight icing could lead to many problems, quite different in nature, such as:

- **Reduced lift - Increased drag**
- **Commanded and uncontrolled roll - roll upset**
- **Higher stall speed at lower angles of attack**
- **Structural damage due induced vibration**

The stress level for the crew on a flight with icing conditions is significantly higher than during a routine one. The pilots should maintain high situational awareness and closely monitor ice formation as immediate diversion could be necessary.

The procedures for avoiding icing conditions include autopilot disengagement, change in altitude/heading or both and search for areas clear of clouds or with warmer temperature. All these pose significant amount of workload to the crew.

Once the first signs of flow disruptions are shown, the crew will put all efforts and attention to regain control. Therefore, during this phase an ATCO could expect broken, incoherent communication with the aircraft.

Suggested Controller's Actions

Best practice embedded in the ASSIST principle could be followed
(A - Acknowledge; S - Separate, S - Silence; I - Inform, S - Support, T - Time):

A - acknowledge the problem, ask for the crews' intentions
S - separate the aircraft from other traffic, provide accurate and optimal vectors
S - silence the non-urgent calls (as required)
I - inform other aircraft and all concerned parties according to local procedures of the reported icing
S - support the flight experiencing icing with any information requested and deemed necessary
T - provide, in a timely fashion, a revised clearance to move the affected aircraft out of the icing conditions.

In addition, the controller might be required to:

- **Take all necessary action to safeguard all aircraft concerned**
- **Suggest a heading**
- **State the minimum safe altitude**
- **Provide separation or issue essential traffic information, as appropriate**
- **Make an emergency broadcast**

Expect

- **Immediate change of level and/or heading**
- **Limitation in rate of climb/descent**
- **Higher speed**

Remember

In icing conditions:

- **Avoid holding - or provide holding flight levels/altitudes away from the 0°C isotherm**
- **Enable continuous climb after departure - plan ahead - correct coordination between Twr/App/Control will ensure unrestricted climb**
- **Keep safety strip clear - due to higher stall speed, aircraft experiencing severe/moderate icing are likely to maintain a higher approach speed. Tower controllers should keep runway safety strips clear during such landings.**
- **AIREP to other ACFT, other units and MET - ATCOs should relay all pilot's reports for adverse MET conditions to other aircraft concerned and to the meteorological office. Often, even the less time-consuming 'resume' on the operating frequency provides valuable information for the pilots.**

In icing conditions it may be appropriate to remind trainees or less experienced pilots of turboprop aircraft to:

- **Check anti-icing and de-icing systems**
- **Pitot heating**
- **Stall warner heating**
- **Carburetor heating**
- **Propeller heating / de-icing**
- **Wing anti-ice / de-ice**
- **Windshield heating**
- **Descent with higher power setting to increase bleed air supply**
- **Higher approach/landing speed due to increase of stalling speed**

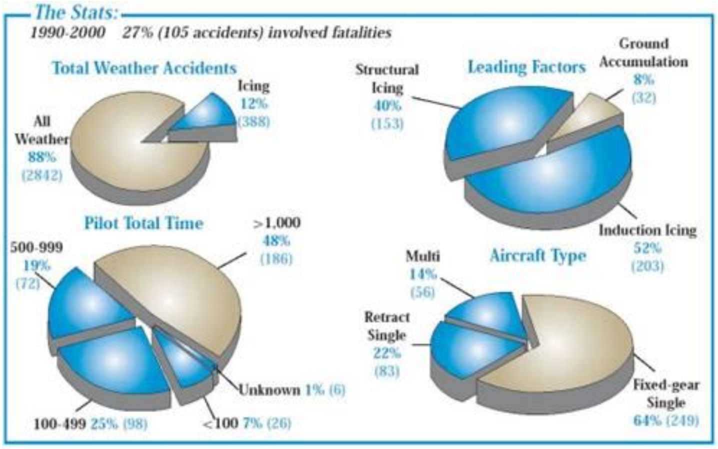
Defences

- **Pre-flight information - Crews should be supplied with latest weather information - they should also take the meteo-conditions into consideration while preparing for the flight.**
- **Anti-icing, De-icing - Anti-icing and de-icing procedures should be performed with full compliance to the requirements. The tower controller should take into account the hold-over time that is reported by the crew.**
- **Personal awareness - ATCOs should stay alert for any extraordinary climb/descent. They should be ready to provide climb/descent to affected traffic and allow space for horizontal maneuvers. The aircraft, experiencing severe icing would certainly need increased separation as its flying characteristics would be degraded.**
- **Information dissemination - The controller should pass all reports for adverse icing conditions to the incoming traffic. He/she should also pass this information to the meteorological office for further processing and dissemination.**

Accidents & Incidents

- **B752, en route, western Ireland, 2013 (On 20 October 2013, a Boeing 757-200 Co-Pilot believed his aircraft was at risk of stalling when he saw a sudden low airspeed indication on his display during a night descent and reacted by increasing thrust and making abrupt pitch-down inputs. Other airspeed indications remained unaffected. The Captain took control and recovery to normal flight followed. The excursion involved a significant Vmo exceedance, damage to and consequent failure of one of the hydraulic systems and passengers and cabin crew injuries. The false airspeed reading was attributed by the Investigation to transient Ice Crystal Icing affecting one of the pitot probes.)**
- **ATP, en-route, Oxford UK, 1991 (On 11 August 1991, an British Aerospace ATP, during climb to flight level (FL) 160 in icing conditions, experienced a significant degradation of performance due to propeller icing accompanied by severe vibration that rendered the electronic flight instruments partially unreadable. As the aircraft descended below cloud, control was regained and the flight continued uneventfully.)**
- **C208, vicinity Pelee Island Canada, 2004 (On 17 January, 2004 a Cessna 208 Caravan operated by Georgian Express, took off from Pellee Island, Ontario, Canada, at a weight significantly greater than maximum permitted and with ice visible on the airframe. Shortly after take-off, the pilot lost control of the aircraft and it crashed into a frozen lake.)**
- **JS41, en-route, North West of Aberdeen UK, 2008 (On 9 April 2008, a BAe Jetstream 41 departed Aberdeen in snow and freezing conditions after the Captain had elected not to have the airframe de/anti iced having noted had noted the delay this would incur. During the climb in IMC, pitch control became problematic and an emergency was declared. Full control was subsequently regained in warmer air. The Investigation concluded that it was highly likely that prior to take off, slush and/or ice had been present on the horizontal tail surfaces and that, as the aircraft entered colder air at altitude, this contamination had restricted the mechanical pitch control.)**
- **SF34, en-route, northern North Sea UK, 2014 (On 3 October 2014, the crew of a Saab 340 in the cruise at FL150 in day IMC did not recognize that severe icing conditions had been encountered**

early enough to make a fully-controlled exit from them and although recovery from the subsequent stall was successful, it was achieved "in a non-standard manner". The Investigation concluded that although both mountain wave effects and severe icing had contributed to the incident, the latter had been the main cause. Both crew understanding of airframe icing risk and supporting Operator and Manufacturer documentation on the subject were considered deficient.)



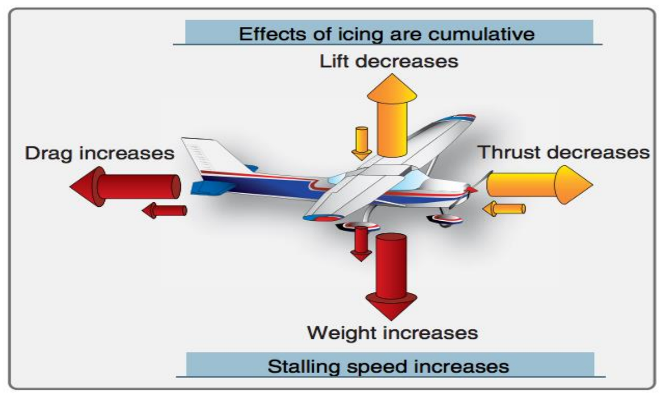


Figure 15-2. *Effects of structural icing.*