IN-FLIGHT ICING

1. Introduction

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

2. Description

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.

Atmospheric water exists in liquid form well below 0°C.
The proportion of such super cooled water decreases as the static air temperature drops around -40°C (except in Cumulonimbus Cloud).

The size of water droplets and the airflow characteristics around the aircraft surface determine the extent to which these droplets will strike the surface.
The size of a water droplet determines the time required for the physical change of state from liquid (water) to solid (ice) to occur (larger droplets will take longer to freeze)

3. Airframe Icing Effects

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

- Reduced performance
- Reduced lift - Increased drag
- Uncommanded and uncontrolled roll (altered controllability)
- Subsequent loss of control of the aircraft
- Higher stall speed at lower angles of attack
- Ultimately stall
- Structural damage due induced vibration

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

3.1. 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 centre 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 stabiliser.
The modified airflow pattern may significantly alter the pressure distribution around flight control surfaces such as ailerons and elevators.

When 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.

3.2. 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.

Such occurrences could be the non-activation of the built-in electrical heating which these tubes and plates are provided with.

4. The Airframe Ice Accretion Process

Ice accretion on an aircraft structure can be distinguished as:

- Rime Icing
- Clear/Glaze Icing
- Cloudy or Mixed Icing

4.1. 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.

Rime ice can affect the aerodynamic characteristics of wings and horizontal stabilisers 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.

4.2. 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.

4.3. 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

Some other terms which may be encountered in connection with airframe ice accretion include supercooled large droplets (SLD).

SLD are defined as those with a diameter greater than 50 microns. They are typically found in areas of freezing rain and freezing drizzle.

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.

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.

4.4. 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 continue safe flight can rapidly build up.

Runback may occur when a thermal ice protection system has insufficient heat to evaporate the quantity of super cooled water impinging on the surface.

4.5. Intercycle Ice

Intercycle ice is that which forms between cyclic activation of a mechanical or thermal de-ice system.

Any ice remaining after a de-icing system of this type has been selected off is sometimes referred to as residual ice. These de-icing systems create normal accumulation of some ice when these systems are not ‘ON’.

5. Icing in Clouds and Precipitation

Any cloud containing liquid water can present a significant icing environment if the temperature is 0 °C or less. The most significant ice accretion can be expected to occur at temperatures below, but close to, 0˚C

Typical icing threats can be found in some specific weather conditions:

- Cumuliform cloud structures usually contain relatively large droplets which can lead to very rapid ice build-up.
- Stratiform cloud structures usually contain much smaller droplets which can lead sometimes a considerable ice accumulation in even a relatively short period of level flight.
- Any drizzle or rain, when temperature is below 0°C, can generate significant ice accretion in a very short period of time, 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 can contribute to the accumulation of hazardous frozen deposits.

Accumulation of hazardous frozen deposits may also occur in cumulonimbus anvil clouds, where the ice crystals may be mixed with SLD to incur significant icing.
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.

6. 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. 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
- Aircraft, predominantly propeller-driven, which rely on wing and tail ice protection by de-icing, principally by pneumatic de-icing boots, and are operated in icing conditions which exceed the capability of the protection

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.
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, a stall and loss of control can result from which recovery may not be possible at low level.

7. Solutions

For aircraft without airframe ice protection systems, operation in icing conditions should be avoided.

It is important that the route planned is made to avoid icing at high altitudes above mountainous terrain.

The operation of the ice protection systems shall be in accordance with the manufacturer's specification.

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.