High Level Ice Crystal Icing: Effects on Engines

Description

A significant risk of temporary engine thrust loss has been found to exist if high densities of small ice crystals are encountered in very cold air. This hazard should not result in complete engine failure but may affect more than one engine simultaneously, and is likely to occur at a time when an aircraft is not being operated in flight conditions which can readily be
characterised as icing conditions in the applicable AFM. Aircraft and engine manufacturers have been considering an extension of the definition of icing conditions and have issued interim guidance to Operators.

**Ice Crystal Occurrence**

Satellite data has confirmed that areas of very small ice crystals in high concentrations exist within and in the vicinity of large scale convective weather systems. This is especially true in tropical latitudes where these systems are at their most extensive and can produce cloud tops as high as 50,000 feet because sea surface temperatures are at their highest and so more water is absorbed into the developing system. These ice crystals can remain long after the active convection which produced them has begun to decay. They are extremely small - probably only about 40 microns in diameter - and even at high concentrations, are unlikely to be evident visually even by day. With a radar reflectivity of only about 5% of that of average-sized raindrops, they will not appear on airborne weather radar displays either. At the very cold temperatures which prevail at the altitudes where they are found, they are most often encountered dry without any co-existing super-cooled water. This means that they will not adhere to the external airframe, or protrusions from it, even though these are considerably warmer than the ambient temperature due to kinetic heating. Consequently, they will not activate conventional ice detectors. The areas of abnormally high crystal concentration are believed to originate from columnar ascent in cumulonimbus cloud and can be expected to drift downwind from the main area of cloud tops. They are an entirely different phenomenon to the more ‘normal’ occurrence of the ice crystals which give rise to high level Cirrus, Cirrostratus and Cirrocumulus cloud which are at much lower concentrations and do not represent a similar hazard.

**Ice Crystal Effects**

When these small ice crystals enter the frontal air inlets of pure jet engines in sufficient quantity, they may be the cause of interruptions to the normal functioning of the engine. Initially, the crystals accrete on the warm surfaces within the engine and then, at discrete intervals, aggregate and detach in solid form, possibly then melting as they continue through the engine. Either can cause un-commanded thrust reduction and in the form of ice, engine damage can also result. Gradual thrust reduction follows obstruction of normal airflow by ice build up and consequential engine rpm reduction and TGT rise. Thrust lever movement is not effective and the ‘rollback’ may continue until a sub-idle condition is reached. Alternatively, disrupted airflow at the guide vanes may create an abnormal pressure gradient in the engine which can lead to a sudden airflow reversal.

The susceptibility of particular engine types to this phenomenon appears to vary even though they are all of similar overall design. The by-pass ratio is not a factor in engine type vulnerability and both old and new engine designs have been affected. It seems from analysis of recorded events that, generally, most have occurred during the early stages of descent when the ambient temperature is still very cold but thrust has been reduced to flight idle. Recorded events with high power set during the cruise seem to have occurred after a slow but steady build up of ice
during a much longer period of exposure to crystals than is required to cause effects in the flight idle/descent case.

It is currently being suggested that the localized areas of high ice crystal density which cause problems have up to 8 grams per cubic metre of ice water content compared to the current engine design standard for super cooled liquid water which is only 2 grams per cubic metre. In this case, the effect which these ice encounters appear to have had on engine function represents a new challenge rather than a failure to meet existing reliability standards.

As noted above, it now appears that some pitot static systems may be vulnerable to ingestion of small ice crystals at high altitude.

**Ice Crystal Avoidance**

The best environmental solution to aid avoidance of high concentrations of very small ice crystals at high altitude is to operate with even more margin than the typically recommended 20 nm from weather radar-detectable large convective cells and their characteristic downwind anvils. This strategy can be supported by considering the ice crystal risk when reviewing meteorological forecasts at the pre flight planning stage. There cannot be any forecast of the areas to avoid because they are by definition both localised and mobile and likely to be a feature of all large convective systems, certainly tropical oceanic or coastal ones. Operationally, the best advice will be found in the AFM and / or the Operations Manual but it will already be apparent that residual thrust greater than flight idle for the initial part of a descent may be worth considering.

A number of clues to ice crystal presence at densities likely to lead to unwanted effects which have been gleaned from past events include:

- Air temperature significantly above corresponding ISA temperatures
- Some turbulence but rarely more than light-to-moderate
- Areas of heavy rain below the freezing level
- The appearance of small droplets of moisture on the flight deck windscreens (from impact crystals melted by the screen heat)
- An early TAT annunciation error (the reading goes to zero due to ice accretion on probe)
- No evidence of any airframe icing

**Accidents and Incidents**

The following events on SKYbrary involve high level ice crystal icing:
B752, en-route, Central Mauritania, 2010 (WX LOC AW): On 25 August 2010, a Boeing 757-200 being operated by UK airline Astraeus on a passenger flight from Freetown Sierra Leone to London Heathrow was in the cruise at night in IMC at FL370 when vibration levels on both engines increased. When the prescribed ice shedding drill was followed, one engine malfunctioned and vibration on the other remained abnormally high and so a MAYDAY was declared and a diversion to Nouakchott, Mauritania was made without further event. None of the 103 occupants were injured and there was no engine damage.