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## EDITORIAL

Over the past two decades, Jet engine flameout and power loss at high altitudes have caught pilots off guard. Recent research studies are now giving a better understanding of these events and are attributed to high altitude ice crystals. In this issue, we look into this phenomenon in some detail and address procedures to avoid it.

Continuing on the winter operations, we discuss ground de-icing/anti-icing and taxi operations during snow and icing conditions.

As always, we look forward to your feedback, suggestions and contributions which can be sent to our office address given in this page. Happy reading and many more safe landings.

## HIGH-ALTITUDE JET ENGINE POWER-LOSS

*Dr.M.S.Rajamurthy*

On June 1, 2006, a Qatar Airways flight from Doha to Shanghai, an A330-200(A7-ACI) was on a descent to Shanghai. At FL210, both CF6-80E1 engines suffered flameout. The new aircraft had just been inducted to service. While there were thunderstorms in the area, the aircraft was not in cloud when the incident happened. The engines were relit "within about 1min", one immediately and the other very shortly after. The aircraft landed safely. When the incident occurred the A330's anti-icing and continuous ignition were functioning.

On August 5, 2006, another Qatar airways A330 had a power loss incident at FL330 in severe turbulence. This time, it was a single engine flame out. Auto relight was initiated as per Airbus manual. Engine relit within 45seconds. Flight continued to Osaka and was uneventful.

During 2004-2006, Raytheon Beechjet 400A had many power-loss incidents in the US.

– On July 12, 2004, a Beechjet 400A, departed Duncan, OK and was en route to Fort Myers, FL. About 100 miles west of Sarasota, FL while descending from FL410 in IMC the aircraft experienced a complete loss of power from both engines. After several attempts, the right engine was restarted and the aircraft landed at Sarasota, FL without further incident.

– On Nov.28, 2005, a Beechjet 400A, was on a flight from Indianapolis to Marco island, Florida. After cruising at FL350 for 45 minutes, due to clouds it ascended to FL400. After 30 minutes flight at FL400, ATC cleared the flight to FL380, where it remained for about 15 minutes. Further clearance was issued for pilot's discretionary descent to FL330.

Upon reducing power to initiate descent the crew heard a "popping" noise and both engines rolled back. The flight was operating in VMC in the vicinity of cumulonimbus

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buildups.

The crew declared an emergency, elected to divert to Jacksonville Airport, and initiated emergency procedures. All attempts to restart the engines were unsuccessful. The crew executed a successful emergency landing. After landing, the Captain attempted to restart the engine, and did observe some rotation, however stopped when the temperature did not rise.

– On June 14, 2006, a Beechjet 400A experienced a dual engine flame-out event near Norfolk, Virginia. This aircraft was enroute from Quonset Point, Rhode Island, to Charleston, South Carolina, at FL380 in the vicinity of convective weather associated with a tropical storm. Upon reducing power for descent, the engines reportedly flamed out. The pilots were able to get both engines restarted and the aircraft diverted successfully to Norfolk.

– On July 6, 2006, a Beechjet 400A enroute from Gwinnett County, Georgia, to Houston, Texas, experienced a single engine flameout while in cruise at FL400 near convective weather in the vicinity of Lake Charles, Louisiana. The pilot reported that the other engine also lost some power. The aircraft continued to Houston after restarting the engine.

Following factors were common to all the above Beechjet 400A incidents.

- The aircraft was near visible moisture and/or near convective activity.
- The aircraft was at or above FL380.
- Engine anti-ice was not in use at the time of power loss.
- Except for the right engine of one of these aircraft, which was removed as part of the investigation, all of the involved engines remained in situ on the aircraft and were returned to service. Subsequently, there has been no reported loss of power associated with any of those engines.

Based on the results of a study conducted by Pratt & Whitney Canada during the investigation, NTSB determined the probable cause of the Sarasota and Norfolk incidents was "high altitude ice crystals that had accreted on the compressor vanes and were ingested into the high-pressure compressor when the pilot retarded the power levers, causing compressor

surges and flameouts of both engines."

NTSB in its report on the Nov.28, 2005, Beechjet 400A dual engine power-loss incident, released in June 2008, determined that

*– the dual-engine flameout was due to high-altitude ice crystals that had accreted onto the JT15D-5 engines' compressor vanes and were ingested into the engine when the pilots retarded the power levers, resulting in compressor surges and rapid reduction in fuel flow due to temporary ice blockage of the combustion pressure return line, and additionally preventing an in-flight restart.*

*– Contributing to the cause of the dual-engine flameout was the lack of training on the hazards of high-altitude ice crystals to gas turbine engines and guidance to the pilots to activate the engine anti-ice system in conditions where high-altitude ice crystals may exist.*

A post-incident study showed that the ice crystals could partially melt passing through the low pressure compressor of the JT15D-5 engines due to an increase in temperature of the air being compressed.

The study indicated that with the engine anti-ice turned off, it was possible for the ice crystals to accrete on the leading edges of the front inner compressor stator leading edges. If a significant buildup of ice had occurred, any change in the airflow angle-of-incidence that would occur as power is reduced would cause any ice that had accreted on the leading edges of the stators to break away and would result in the engine surging and possibly flaming out.

The study further revealed that after engine had flamed out, the radiant heat from the oil tank, which is in the core of the engine, between low and high-pressure compressors, could cause the ice on the front inner compressor stators to melt, and the water could run back and freeze in the high-pressure compressor impeller, acting like a wedge to prevent engine rotation and restart.

The investigation report further said that research and flight tests have shown that ice-crystal icing can temporarily block an orifice designed to trap

water in the combustion chamber pressure signal(P3) line and cause an abnormally rapid drop in fuel flow to a level that will not support combustion.

On June 4, 2002, an MD-82 enroute from Denver to Fort Lauderdale, FL, cruising at FL330 with the autopilot and autothrottles engaged, suffered an *Uncommanded deceleration-rollback-of the engines.*

The crew did not notice the power reductions and the consequent increase in nose-up pitch trim and decrease in airspeed that occurred over a period of about five minutes. When the stick shaker activated, the captain disengaged the autopilot and pushed the control column and throttles forward. The engines initially did not respond, but the crew was able to restart them as the aircraft descended through FL170. The flight was diverted to Wichita, Kansas, and landed without further incident.

Although the MD-82 was clear of clouds when the incidents occurred, it had been flown in and out of IMC for the previous 50nm. The crew had not engaged anti-ice system, as required.

NTSB identified high altitude ice crystals as the cause of this incident.

The difference between inlet pressure and discharge pressure –EPR (Engine Pressure Ratio) - is used to measure and set power in the MD-82's P&W JT8D-219 engines. Blockage of inlet pressure probes resulted in erroneously high EPR measurements for which the autothrottle system responded by retarding the throttles.

Since 1999, jet-engine power loss events on both commuter and large transport aircraft have occurred in excess of 100. These have occurred mostly at altitudes higher than 22,000ft, the highest altitude where airframe icing is expected to exist.

Research has now revealed that the high altitude flameouts and power-loss events are attributable to high altitude ice crystals and the industry refers to this phenomenon as ice crystal icing.

#### References:

1. NTSB docket no. DCA06IA007. 6/30/2008.
2. Mark Lacagnina. "Ice crystal icing", AeroSafety World, June 2008.

## HIGH-ALTITUDE ICE CRYSTAL ICING

Adopted from Jeanne Mason's article "Engine Power Loss in Ice Crystal conditions" in Boeing Aero Qtrly. 04/07

Several engine power-loss and damage events have occurred in convective weather above altitudes typically associated with icing conditions. "Power-loss" is defined as engine instability such as a surge, stall, flameout, or rollback that results in a sub-idle operating condition.

Research has shown that strong convective weather (thunderstorm activity) can lift high concentrations of moisture to high altitudes where it can freeze into very small ice crystals, perhaps as small as 40 microns (the size of flour grains). These are the crystals that can affect an engine when flying through convective weather. The industry is using the phrase "Ice Crystal Icing" to describe these icing conditions, and to differentiate it from icing conditions due to supercooled liquid.

Ice crystals do not adhere to cold airframe surfaces because the ice crystals bounce off. However, the crystals can partially melt and stick to relatively warm engine surfaces.

"Glaciated conditions" refers to atmospheric conditions containing only ice crystals and no supercooled liquid. "Mixed phase conditions" refers to atmospheric conditions containing both ice crystals and supercooled liquid. Both glaciated and mixed phase conditions occur in convective clouds and have been present during engine power-loss and damage events.

On-board weather radar can detect large particles such as hail, rain, and large ice crystal masses (snowflakes). *Small particles, such as ice crystals in high concentrations near thunderstorms, are invisible to on-board weather radar, even though they may comprise the majority of the total mass of a cloud.*

Sophisticated satellite radar technology has been used to detect crystals smaller than the lower limit of on-board weather radar. Above the freezing level, where icing can occur in a deep convective cloud, satellite radar has confirmed that large particles, which can be detected by on-board weather radar, are only found near the convective precipitation core. Away from the

convective precipitation core, satellite radar has confirmed that small ice crystals, which are invisible to on-board weather radar, exist.

For this reason, flight in visible moisture near deep convective weather, even without radar returns, and at temperatures below freezing, is very likely to be in ice crystal conditions.

Ice building up on the inlet, fan, or spinner would likely shed outward into the fan bypass duct without causing a power loss. Therefore, in these power-loss events, it is reasonable to conclude that ice must have been building up in the engine core.

It is now believed that ice crystal icing can occur deep in the engine where surfaces are warmer than freez-

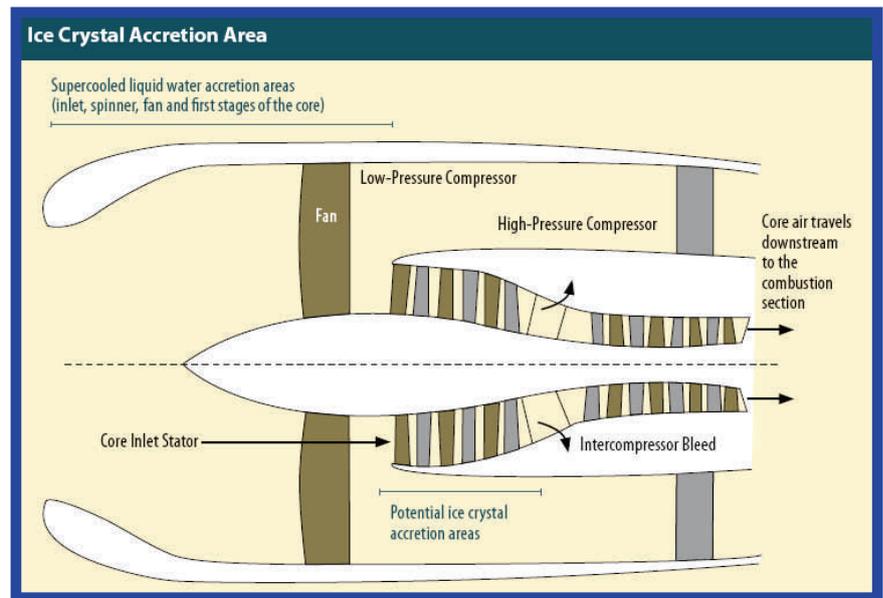
older generation jet engines and the new generation of jet engines (high bypass ratio engines with electronic engine controls) can be affected by ice crystal icing.

### Types of power-loss events

The actual mechanism for ice crystal-related engine power loss takes many forms, depending on the design characteristics of each particular engine type (see table below).

### Zones of occurrence

About 60 percent of recorded ice crystal power-loss events have occurred in Asia. This may be due to the fact that the highest sea surface temperatures occur in this region. Higher temperature air can hold more water. There is a heavy concentration of ice crystal



ing (see Engine diagram below). Both

Power-loss Type	Description	Effect	Recovery procedure
Surge/Stall*	Ice shed into compressor drives engine to surge, then stall causes rotor speeds to decay, and reducing airflow while combustor remains lit.	Thrust loss and high exhaust gas temperature.	Throttle to idle. Cycling of the fuel switch may be required to clear some stalls.
Flameout*	Ice shed into the combustor quenches the flame.	Thrust loss and all parameters dropping.	Ignition. Many vents self-recover due to auto-relight or having the ignition already on.
Engine Damage	Engine blades become damaged as shed ice impacts them.	Typically no effect at time of initial damage, but damaged blades may fail later causing vibration or engine stall.	As appropriate — refer to Quick Reference Handbook.

\* In every large transport power-loss event occurring due to stall and flameout that has been tracked to date, the engines were successfully restarted.

power-loss events between 20 and 40 degrees north latitude with a few events farther than 45 degrees from the equator.

While most engine power-loss events have occurred in descent, events have occurred in cruise and climb. This could be due to two factors. First, for icing to occur, the ambient temperature must be below the freezing level, and therefore icing tends to occur at the higher altitude associated with the descent phase. Second, the engine is least tolerant to ice shedding at idle power, which occurs in the descent phase. Icing at high power and high altitude is possible due to the existence of high concentrations of ice crystals for long distances, such as in the anvil of a large convective storm, and the fact that ice can build up on warm engine surfaces.

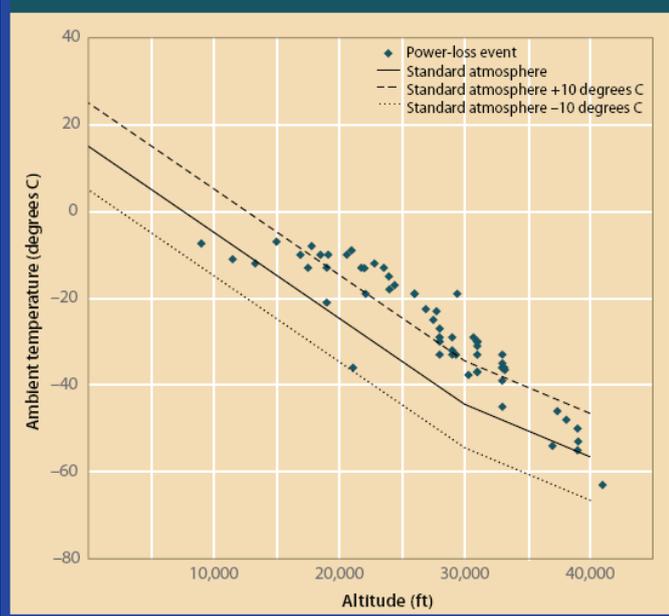
### Recognizing high ice crystal conditions

Researchers have identified several conditions that are connected to engine ice crystal icing events. The most important factors are:

- *High altitudes and cold temperatures.*

Commercial aircraft power-loss events associated with ice crystals have occurred at altitudes of 9,000 to 39,000ft, with a median of 26,800ft, and at ambient temperatures of  $-5^{\circ}\text{C}$  to  $-55^{\circ}\text{C}$  with a median of  $-27^{\circ}\text{C}$ . The diagram below shows events shown on altitude-ambient temperature. The engine power-loss events generally occur on days when the ambient temperature is warmer than the standard atmosphere.

Power-Loss Event Altitudes and Temperatures



- *The presence of convective clouds*

Convective weather of all sizes, from isolated cumulonimbus or thunderstorms to squall lines and tropical storms, can contain ice crystals. Convective clouds can contain deep updraft cores that can lift high concentrations of water thousands of feet into the atmosphere, during which water vapor is continually condensed and frozen as the temperature drops. In doing so, these updraft cores may produce localized regions of high ice water content which spread downwind. It is believed that these clouds can contain up to 8 grams per cubic meter of ice water content; by contrast, the design standard for supercooled liquid water for engines is 2 grams

per cubic meter.

- *Areas of visible moisture above the altitudes typically associated with icing conditions.*

This is indicated by an absence of significant airframe icing and the ice detector (when installed) not detecting ice, due to its ability to detect only supercooled liquid, not ice crystals.

In addition, the following conditions are typically found during engine ice crystal power-loss events.

- No pilot reports of weather radar returns at the event location.
- Temperature significantly warmer than standard atmosphere.
- Light-to-moderate turbulence.
- Areas of heavy rain below the freezing level.
- The appearance of precipitation on heated windshield, often reported as rain, due to tiny ice crystals melting. (Some pilots noted that the sound was different than rain striking the windshield and that when the landing lights were turned on, the particles looked different from rain.)
- Aircraft total air temperature (TAT) anomaly reading zero, or in error, due to ice crystal buildup at the sensing element. The TAT anomaly is due to building up of ice crystals in the area in which the sensing element resides, where they are partly melted by the heater, causing a  $0^{\circ}\text{C}$  reading. (In some cases, TAT gets stabilized at  $0^{\circ}\text{C}$  during a descent, and may be noticeable to pilots. In other cases, the error is more subtle, and not a reliable-enough indicator to provide early warning to pilots of high concentrations of ice crystals.)
- Lack of observations of significant airframe icing.

### Recommendations for flight near convection

Even when there are no radar returns, there may be significant moisture in the form of ice crystals at high altitudes. These are not visible to airborne radar. As a result, it is not possible to avoid all ice crystal conditions. However, normal thunderstorm avoidance procedures may help pilots avoid regions of high ice crystal content.

These avoidance procedures include:

- Avoiding flying in visible moisture over storm cells. Visible moisture at high altitude must be considered a threat since intense storm cells may produce high concentrations of ice crystals at cruise altitude.
- Flying upwind of storms when possible.
- Using the radar antenna tilt function to scan the reflectivity of storms ahead. Assess the height of the storms. Recognize that heavy rain below the freezing level typically indicates high concentrations of ice crystals above.

Avoiding storm reflectivity by 20 nautical miles has been commonly used as a recommended distance from convection. This may not be sufficient for avoidance of high concentrations of ice crystals, as they are not visible on airborne radar.

Boeing has included these recommendations in flight operations technical bulletins issued by on August 1, 2006 for its aircraft. (*Convective Weather Containing Ice Crystals Associated with Engine Power Loss and Damage - 747-400-55, 777-21*)

## WINTER OPERATIONS

*Dr.M.S.Rajamurthy*

During winter, it is important and imperative that robust procedures are in place for the operation of aircraft in icing conditions. It is the operator's responsibility to ensure that their aircraft are safe for the intended flight and all those involved with aircraft operations are kept up to date with the latest information concerning winter operations.

In the November issue we discussed the importance of ground de/anti-icing and the effect of runway de-icing fluids on carbon brakes.

Continuing on the subject, we bring here some more aspects of anti-icing fluids and taxi operations in snow and ice conditions.

The CAA, UK in its recent FODCOM (Flight Operations Division communication) on Winter Operations lists the following inadequacies that have been identified (though the list is not exhaustive):

- confusion between de-icing and anti-icing;
- non-adherence to Type-specific de-icing /anti-icing procedures;
- initial/recurrent training of flight and ground crews;
- incomplete aircraft de-icing;
- inadequate recording of de-icing/anti-icing processes in the aircraft Technical Log.
- In some cases, the operator's Operations Manual, Continued Airworthiness Management Exposition, and Line Maintenance procedures for de-icing/anti-icing and winter ground handling were inadequate.

### Use of Anti-Icing Fluids

- The use of anti-icing fluids (Type II, III and IV) to de-ice exposes the aircraft to significantly more thickening agent than would be the case if de-icing fluid (Type I) were used to de-ice the aircraft.
- To ensure the aerodynamic integrity of an aircraft, the wing, tailplane and other surfaces need to be kept free of frost, snow and ice.
- Prior to flight the operator, in conditions conducive to the formation of such contamination, or after contamination has occurred, has the aircraft

sprayed with de-icing and anti-icing fluids. Some of these anti-icing fluids have been found to be the cause of control restrictions on certain aircraft types.

- The preventative effect of de-icing and anti-icing fluids lasts for only a limited period, and this period is known as the "holdover time". To maximize the holdover time, fluids can be thickened to reduce the flow of the fluid off the aircraft surface. These fluids are referred to as Type II, Type III and Type IV fluids. During the take-off run most of the fluid is shed from the wing by aerodynamic shear forces, but some can be drawn into and accumulate in the aerodynamic quiet areas between structure and control surface regions as a result of the pressure changes over the wings and tailplane. In addition, when applied and left for prolonged periods, as a preventative measure, the fluid migrates into the control surface regions.
- The fluid eventually dries out and degrades, where it loses its anti-icing properties and becomes hygroscopic, leaving white gel-like residues of the thickening agent. In a moist environment these residues rehydrate and freeze as the aircraft enters temperatures below the freezing point of the mixture, e.g. during the climb. The frozen residue can restrict the movement of the aircraft flying controls and in extreme cases this can lead to the controls being jammed.
- This problem predominantly occurs in aeroplanes with non-powered flying controls, although incidents have occurred on aeroplanes with powered flying controls. For aeroplanes with powered flying controls, the incidents have been fewer in number and any control restrictions experienced have been more easily overcome.

### Recommendations

- Operators should review their winter operations manual guidance and training packages for personnel involved in winter operations, to ensure that the most up to date and relevant information is made available to all

those involved with the operation and de-icing/anti-icing of aircraft during the winter period.

- When the climatic conditions require the use of de-icing and/or anti-icing fluids, operators of aeroplanes with non-powered flying controls are strongly recommended to incorporate the following information into their guidance and procedures:

a) Use Type I fluid to de-ice whenever possible and at their main bases.

b) If it is necessary to use Type II, Type III or Type IV anti-icing fluids to de-ice, due to non-availability of Type I or non-thickened type fluid, or when Type II, Type III or Type IV holdover times are required because of active precipitation or active frost, then the actions detailed in subparagraphs (c) and (d) below should be carried out.

c) Thickened anti-icing fluids should not be used to de-ice more than 60 minutes prior to the scheduled departure time.

d) Maintenance action stipulated by the manufacturer and from experience should be conducted to detect and remove residues within three calendar days of the application of thickened anti-icing fluids.

### Aircraft Taxi Operations

FAA has issued a SAFO (Safety Alert For Operators) emphasizing the importance of conservative aircraft taxi operations in snow and ice weather conditions.

In the last winter, during December 1, 2007 - January 31, 2008, there were eight cases of 14 CFR, part 121 turbo-jet airplanes (1 each B-737, 757, 767, 1 MD-83, and 4 CL-65) departing the paved surfaces of airports during taxi operations due to loss of brake effectiveness and or steering control due to ice and/or snow accumulations on the surface.

In several cases, the aircraft departed the end of the runway after completing a safe landing and slowing to a stabilized taxi speed. In other cases, aircraft were unable to negotiate taxiways while taxiing to the runway or ramp. In all these cases, the pilots

were operating at speeds which allowed sliding on the slippery taxiway or runway surface until coming to rest at least partially off the pavement, and stuck in snow.

Additionally, in this same time period, two other events related to snow and ice accumulation on the surface occurred. In one event, a B-757 turned off the taxiway and onto a vehicle roadway, and subsequently became stuck in the snow. In another event, a C-208 landed between the taxiway and runway of an airport, resulting in substantial damage. *In both cases, the surfaces were obscured by snow, and the pilots apparently mistook unusable surfaces for the desired taxiway and runway.*

#### Departures From Paved Surfaces

These events are not related to airplane landing performance requirements for operation on contaminated runways, rather, these events are related to taxi handling and braking effectiveness at taxi speeds in slippery conditions. The number of events and the wide range of aircraft involved underscore the importance of operators and pilots ensuring that aircraft are taxied at speeds which are appropriate to slippery conditions.

In light of these events, air opera-

tors and pilots should review their criteria for suspending operations in ice and snow surface conditions. In such conditions, it is expected that airport capacity will be reduced. The key is to provide a safe operating environment, even if that environment is limited. Leaving the airport paved surface, especially without full steering and braking control, presents an unacceptable hazard, both to the aircraft off the pavement as well as others on the ground and, depending on where the stuck aircraft is, in the air (i.e. if the ground navigation signal is influenced by proximity of aircraft on the ground).

#### Obscuration of Surfaces by Snow and/or Ice.

Accumulations of snow and ice can obscure airport surfaces and make it difficult to distinguish usable surfaces from those that are unusable. Flight crews should verify the identification of airport surfaces by all available means in conditions where the surface is obscured. Such means include marshalers, follow-me vehicles, and progressive taxi or ramp instructions. Airborne aircraft should use all available tools to support identification of landing surfaces, such as an instrument landing system (ILS) localizer, lighting and signage.

#### Recommended Action

All Directors of Operations and Chief Pilots should ensure that training and operational procedures provide for pilot's use of appropriate speeds during taxi operations so as to minimize the risk of sliding on slippery surfaces covered by ice and/or snow. Additionally, this training for pilots should include the conspicuity of surfaces, references to distinguish usable from unusable surfaces, and discussion on when to consider suspending aircraft operations when airport surfaces are unacceptable for taxi operations due to surface snow and ice contamination.

#### **References:**

1. "Winter Operations", FODCOM 33/2008, CAA, UK.
2. "Aircraft Taxi operations during snow and ice conditions", FAA SAFO 08012, May 20, 2008.

### **Revised FAA definition of Severe Icing**

- *The rate of ice accumulations is such that ice protection systems fail to remove the accumulation of ice and ice accumulates in locations not normally prone to icing, such areas aft of protected surfaces and any other areas identified by the manufacturer. Immediate exist from the condition is necessary.*

## **WEB WATCH**

<http://www.aea.be> - The Association of European Airlines (AEA) is one of the several organizations providing guidance material for de-icing/anti-icing of aircrafts on ground. Their manuals on the subject can be accessed here.

## **PHOTO OF THE MONTH**

### **De-icing**

Dec.08, 2006, Ivalo (IVL/EFIV), Finland  
Monarch Airlines Boeing 757-2T7, G-MONB  
De-icing in progress in a heavy snowfall.



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**The Confidential Aviation Hazard Reporting System (CAHRS)** provides a means of reporting hazards and risks in the aviation system before there is loss of life, injury or damage. It is open to anyone who wishes to submit a hazard report or safety deficiencies confidentially and non-punitively. Reports help to identify deficiencies and provide safety enhancement in areas of aviation. CAHRS forms can be collected at different location of KAC (i.e. Flight Dispatch) Premises. Completed forms can be dropped in FS&QA allocated box at Flight Dispatch or e-mailed to [kwioeku@kuwaitairways.com](mailto:kwioeku@kuwaitairways.com) or faxed to 00965-4749823 or mail to Flight Safety and Quality Assurance office, Operations Department, P.O. Box 394, Safat 13004, Kuwait Airways -Kuwait.