Aircraft Icing

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Abstract

Aircraft icing is a serious problem. Structural ice forms on the aircraft when outside temperature is at or below freezing. Ice forms on the different parts on the aircraft. Ice accretion increases drag and fuel consumption and decreases lift and aerodynamic efficiency of an aircraft. It can also damage the entire airframe. Aircraft accidents in icing conditions are the results of degradation in performance and control due to aerodynamic effects of the ice. On 31st October 1994, American Eagle Flight 4184 was crashed because of this icing problem. Control was lost and 68 people were killed. In order to avoid these problems, ice protection systems and de-icing fluids are used. Pilot report also plays a vital role in preventing these problems.

Keywords – *Aircraft Icing, Clear Ice, De-icing, Methods to remove Ice, Rime Ice.*

1. INTRODUCTION

Aircraft icing is a serious problem. Ice accumulates on the aircraft when outside temperature is at or below freezing. Ice forms on the different parts of the aircraft [03]. Ice accumulations which are hazardous to flight can form on leading edges of wings, tail assembly, wind shield, external radome and antennas, propeller blades, pitot tube. Ice which collects on the leading edges of wings and tail assembly can alter the shape of airfoil. Airfoils are perfectly designed to permit a smooth flow of air from top and bottom surfaces. When ice first appears on the wings, it has no serious effect. But gradually it built forward along with top and bottom surfaces. As the ice reaches the points of maximum camber, the shape of the airfoil has been drastically changed. It disrupts the airfoil completely. As a result, drag increases and lift reduces. Flight tests have shown that ice accumulations on the leading edges or upper surface of the wing which are not thicker or rougher than a piece of coarse sandpaper can reduce lift by 30 % and increase drag up to 40%. Larger accretions can reduce lift even further and increase drag by 80% or more [06]. Ice can also accumulate on the wind shields which can affect the pilot's visibility. It may form a heavy coating on radome and seriously interfere in the operation of airborne radar. Ice collects on external antennas and may not only cause malfunctioning of radio equipment but under extreme conditions may disrupt the radio communications completely. It is important to see ice forming on the spinning propeller blades but ice can be seen on the hub dome. So presence of ice on the hub dome is an indication of propeller icing. Another indication since propeller ice usually forms unevenly is exaggerated vibration of the engine and the sound of ice being thrown from the propeller against the fuselage. Ice may form in the pitot tube. Ice accretion in the pitot tube gives the inaccurate reading of airflow to the pilot. Even at temperature above freezing, carburetor icing may occur. This may occur when flying through the clear air at temperature as high as 25°C if there is sufficient moisture. Carburetor ice gradually closes the throttle. It does not cause rough engine operation but as the ice slowly constrict the air passage, it does result in loss of power and air speed. There are two types of ice which accumulate on the aircraft. They are classified according to their appearance. Ice accretions on the aircraft increase drag and fuel consumption and decrease lift and aerodynamic efficiency. It can damage the entire airframe. Aircraft accidents also occur due to degradation in the performance and control of the aircraft in icing condition. On 31st October 1994, American Eagle Flight 4184 was crashed because of this icing problem. Control was lost and 68 people were killed [06]. To avoid theses icing problems, ice protection system and de-icing fluids are used. Pilot report also helps avoiding these problems.

2. TYPES OF ICE

Structural ice adheres to the external surface of aircraft when outside temperature is at or below freezing. This structural ice is classified according to its appearance [06].

2.1 Rime Ice: Rime ice has a milky white appearance. It is easily removable. Rime ice occurs when tiny, super-cooled water droplets freeze on contact with a surface whose temperature is below freezing. It often forms on leading edges and can affect the aerodynamics of an airfoil or the airflow into the engine intake. Temperature range for the formation of rime ice is -10°C to -20°C.

2.2 Clear Ice: Clear ice is also called as glaze ice. It generally follows the contours of the surface. After further accumulation, it can form ridges. It is hard to remove. It is most likely to form in freezing rain, a phenomena comprising raindrops that spread out and freeze on contact with the cold airframe. Clear ice can alter the aerodynamic shape of airfoil and reduce or destroy their effectiveness.

3. AMERICAN EAGLE FLIGHT

On October 31, 1994, American Eagle Flight 4184, an ATR 72, crashed after flying into unknown icing conditions The first pilot of Flight 4184 was Orlando Aguiar, 29. He was an experienced pilot with almost 8,000 hours of flight time. Colleagues described Aguiar's flying skills in positive terms. Second pilot was Jeffrey Gagliano, 30. He, too, was a competent pilot and had an experience of more than 5,000 hours of flight time.

The flight route was from Indianapolis International Airport, Indiana to O'Hare International Airport, Chicago, Illinois. While flying, the plane encountered freezing rain, a dangerous icing conditions where supercooled droplets rapidly cause an intense ice builtup. This freezing rain damaged the external antennas and broke the communication between the pilot and the air traffic control units. Due to the damaged external antennas and malfunctioning of radio equipment, pilot could not get the information about the exact atmosphere. As the contact was lost, the plane crashed into Soybean field near Roselawn, Indiana, killing 68 people. This incident was the first loss of an ATR 72 aircraft, and remains the highest death toll of any aviation accident involving an ATR 72 anywhere in the world.

4. METHODS TO REMOVE ICE

If an ice or other contaminants are present on the aircraft prior to takeoff, they must be removed from the critical surfaces. Ice removal takes place in following ways:

1) To use a broom or brush to remove snow.

2) Application of hot water to remove ice.

3) Position the aircraft towards the sun to maximize heating of snow and ice covered surfaces.

4) Use of infrared heating to melt and remove contaminants.

5) Put the aircraft into a heated hanger until snow and ice have melted.

5. DE-ICING OF AIRCRAFT

To remove and prevent ice formation on aircraft before takeoff, de-icing fluids are used. These fluids are composed of a freezing point depressant usually glycol, a surfactant and a corrosion inhibitors. All commercial fluids are qualified to SAE (Society of Automotive Engineers) specifications, which test for aerodynamic acceptance, anti-icing endurance, corrosion inhibition, material compatibility, fluid stability and environment. Recently, fluids with other freezing point depressants have been developed. The other freezing point depressants include: acetates and formate salts, sorbitol and other undisclosed freezing point depressants. Acetates and formats, which came out in the early 1990s, led to corrosion of airframes. Next, came a sorbitol, or sugar, based fluids in the early 2000s. It passed all the required tests including corrosion test. But then in the field test, where the fluid was heated as per the usual use, there were problems with foam, sticky and slippery residues. This does not occur with glycol-based fluids since glycol is a liquid. In order to avoid these corrosion and foam problems, nowadays, de-icing fluids composed of ethylene glycol and propylene glycol are used. Propylene glycol based fluids are more common due to the fact that it is less toxic than ethylene glycol [01]. The Society of Automotive Engineers published four standard types of aviation de-icing fluids:

Type – I fluids have low viscosity. They provide short term protection and quickly flow off surfaces after use. They are sprayed at high pressure (55-80°C). They are dyed orange for an identification purpose.

Type – II fluids are pseudoplastic, which means they contain thickening agent to prevent their immediate flow off aircraft surfaces. The fluid film remains in place until the aircraft attains 100 knots (186 km/hr), at which point the viscosity breaks down. This fluid is useful for large size aircraft. These fluids are light yellow in color.

Type – III fluids are used for slow speed aircraft (speed less than 100 knots). These fluids are also light yellow in color.

Type – IV fluids are similar to type – II fluids. But, these fluids provide longer holdover time. They are dyed green for an identification purpose.

5.1 Chemical Composition: The main component of de-icing fluid is ethylene glycol or propylene glycol. The exact composition of a particular brand of fluid is generally held as confidential information and other ingredients also vary depending on the manufacturer.
Based on chemical analysis, five main classes of additives have been identified which are widely used among manufacturer:
1. Benzotriazole and methyl-substituted benzotriazole, used as corrosion inhibitor/fire retardants to reduce flammability resulting from the corrosion of metal components carrying a direct current.

2. Alkylphenol and alkylphenol ethoxylates, non-ionic surfactants used to surface tension.

3. Triethanolamine used as a pH buffer.

4. High molecular weight, non-linear polymers, used to increase visco-elasticity.

5. Coloured dyes, such as xanthene, triphenyl methane and anthroquinone used for identification colour.
5.2 Usage: The amount of fluid necessary to de-ice an aircraft depends on different factors. De-icing a large commercial aircraft consumes 500 US gallons (1,900 liters) to 1,000 US gallons (3,800 liters) of diluted fluid.The cost of fluid varies widely due to market conditions. The amount de-icing fluid companies charge is generally in the range of $8 to $12 per diluted gallon.
5.3 Toxicity: Toxicity of de-icing fluid is an environmental concern and research is underway to find less toxic non-glycol-based alternatives.

6. ICE PROTECTION SYSTEM

6.1 Pneumatic De-icing Boots: A de-icing boot is a type of ice protection system installed on the aircraft surface to permit mechanical de-icing in flight. Such boots are generally installed on the leading edges of wings and the control surfaces like horizontal and vertical stabilizers as these areas are most likely to accumulate ice and any contamination could severely affect the aircraft's performance. De-icing boots were invented by B.F.Goodrich Corporation in 1923 in Akron, Ohio. De-icing boots consists of thick rubber membrane that is installed over a surface to be de-iced. As the atmospheric icing occurs and ice builds up, a pneumatic system inflates the boot with a compressed air. This expansion in size cracks any ice that has accumulated, and this ice is blown away into the airflow. The boots are then deflated to return the wing or surface to its optimal shape. Boots need to be replaced after regular intervals (after 2-3 years) and require proper maintenance. Holes in the boot may create air leaks that will decrease the effectiveness of the boots. De-icing boots are suitable for small and medium size aircrafts.
6.2 Electro-thermal System: Electro-thermal system uses resistive circuits buried in the airframe structure to generate heat when a current is applied. The heat can be generated continuously to protect the aircraft from icing. The Boeing 787 Dreamliner is an example of a commercial airframe to use electro-thermal ice protection.

7. PILOT REPORT

A pilot report or PIREP is a report of actual weather conditions encountered by an aircraft in flight. This information, which is in encoded form, usually given with radio equipment to other weather offices and air traffic service units. Although the actual form of pilot report may differ from one country to another, the standards and the criteria will remain almost the same. At a minimum the pilot report must contain a header, aircraft location, time, flight level, and aircraft type. In recent years, a pilot report will also include UA or UUA to identify the pilot report as routine or urgent.
Following data is included in a pilot report (Mandatory):
1) UA or UUA used to identify the pilot report as routine or urgent (Note: In Canada this is indicated by the prefix PIREP: "UACN01" for an urgent pilot report or "UACN10" for a normal pilot report.

2) /OV location of the pilot report, in relation to geographical co-ordinates.

3) /TM time the pilot report was received from the pilot (Universal Co-ordinated Time).

4) /FL flight level or altitude above sea level at the time the pilot report is filed.

5) /TP aircraft type.

Following data is optional which to be included in a pilot report:
1) /SK sky cover, it is used to report cloud layer amounts and height of the cloud base.

2) /TA ambient temperature; very important for pilot report.

3) /WV wind velocity.

4) /TB turbulence.

5) /IC icing.

6) /RM remarks.

7) /WX flight visibility and weather.

Example of pilot reports
UACN10 CYQT 192128
YZ WG
UA /OV YSP 090025 /TM
2120 /FL050 /TP BE99 /SK
020BKN040 110OVC /TA -14
/WV 030045 /TB MDT CAT
060-080 /IC LGT RIME 020-040
/RM LGT FZRA INC
Decoded as:
Routine upper air report from Thunder Bay issued at 21:28 hours on the 19th of the month. YZ is Toronto and WG is Winnipeg: these are the Flight Information Regions where the Pilot report was issued. Aircraft observation was 25 nautical miles (46 km) east (90° radial) of the Marathon. The aircraft was at 5,000 feet (1,500 meters) and is a Beech 99. The clouds were broken at 2,000 feet (610 meters) and an overcast layer at 11,000 feet (3,400 meters). The temperature is −14°C and the winds are from the north-east at 45 knots (83 km/hr). There is moderate clear air turbulence between 6,000 feet (1,800 meters) and 8,000 feet (2,400 meters). There is light rime icing between 2,000 feet (610 meters) and 4,000 feet (1,200 meters). This would indicate that the icing is picked up in the cloud. The remarks section says that light freezing rain was encountered in the cloud.

8. LEARNING

Ice accretion increases drag and fuel consumption and decreases drag and aerodynamic efficiency. It damages the entire airframe. To avoid such things, new de-icing fluids which are non-toxic should have developed. Non-toxic fluids will keep the environment safe. In addition to this, ice detecting sensors should have also developed which will detect the ice on the different parts of the aircraft when the aircraft is in flight to avoid icing hazards.

9. REFERENCES

[1] . Beisswenger A., Laforte C. and Perron J., “Issues and Testing of Non-Glycol Aircraft Ground Deicing Fluids”, SAE International, June 2011.

[2]. Bragg M., Hutchison T., Merret J., Oltman R., Pokhariyal D., “Effects of Ice Accretion on Aircraft Flight Dynamics”, University of Illinois, January 2000.

[3] . Sand W., Cooper W., Politovich M., Veal D., “Icing Conditions Encountered by a Research Aircraft”, Journal of Climate and Applied Meteorology, vol. 23, October 1984, p.p. 1427-1440.

[4]. Bain M., Gayet J., “Aircraft Measurements of icing in supercooled and ice crystal clouds”, Journal of Applied Meteorology, 1982, p.p. 631-641.

[5]. Wiener, E.L. and Curry, R.E., “Flight-deck automation: Promises and Problems,” Ergonomics, 23(10), pp. 995-1011, 1980.

[6]. Aircraft Icing Reference Book, Civil Aviation Authority, New Zealand.

[7]. Crocker D., Dictionary of Aviation, Second Edition.