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Aircraft De-Icing During Flight Using Pyrolytic Graphite Sheets Heated by Turbine Bleed and Exhaust Heat

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Abstract – *In most cold countries, aircrafts are often stalled because of formation of ice over the outer surfaces. This ice formation disrupts the aerodynamic flow around the aircraft and thereby increases the drag; this results in severe efficiency losses in terms of fuel consumption. Also, there is a risk of control systems failure, and engine failure in extreme cases. The current solutions to this problem, using anti-icing and de-icing fluids are extremely time-consuming. The usage of chemicals is not only costly but also their subsequent environmental impact has not been authoritatively measured. This paper highlights the use of a Pyrolytic graphite sheets which can be used in an alternative method for de-icing, in that it prevents the formation of ice in the first place by efficiently distributing heat, and heating critical zones using bleed heat expelled from the turbine during flight. It also gives a brief explanation of the process of ice formation and also highlights the properties of Pyrolytic graphite.*

Key Words: **Pyrolytic Graphite Sheets, Turbine Bleed Heat, Aircraft De-Icing, Ice Formation, Aircraft Anti-Icing, Heat Distribution, Thermal Conductivity, Rime Ice, Clear Ice, Mixed Ice, Aerodynamics, Fuel Efficiency**

1. INTRODUCTION

Modern aircrafts are subject to very low atmospheric temperatures because of the high altitude of flight. Typically a common commercial aircraft travels at speeds of 700 km/hr. and at an altitude of about 39000 ft. They encounter atmospheric temperatures of up to -56 ° C. These conditions become more severe as the altitude rises.

During flight, the water droplets present in the air settles on the relatively warm surfaces of the aircraft's outer surface. These water droplets, though below freezing temperature, exist as liquid because of a lack of a surface to freeze on. (Although this is only in certain cases till the condensation and atmospheric temperature are up to a limit; however, beyond that the ice is formed and precipitates as what we call "snowfall"). The cold atmospheric conditions quickly cause this ice to freeze and crystallize, now that they have a surface to freeze upon. Like a snowball rolling down the mountain, this ice paves the way for formation of more and more ice. Thus, layers of ice begin to accumulate over the surface of the aircraft.

Ice formation changes the shape of the aerofoil surfaces of the airplane. These are majorly the lift producing components: the wings and the tail. The effect of ice is that it increases the drag coefficient. Technically the formation of ice actually affects the angle of attack, increasing it in most of the cases. However, after a point the lift ceases to increase despite the increase in angle of attack. It is at this point that the resistance to flight is increase, ergo the drag coefficient increases and this at later stages leads to an aerodynamic stall [1]. This has grave consequences and poses a great safety risk. The formation of such ice also results in severe aerodynamic losses which decreases fuel efficiency, a critical concern for aircrafts.

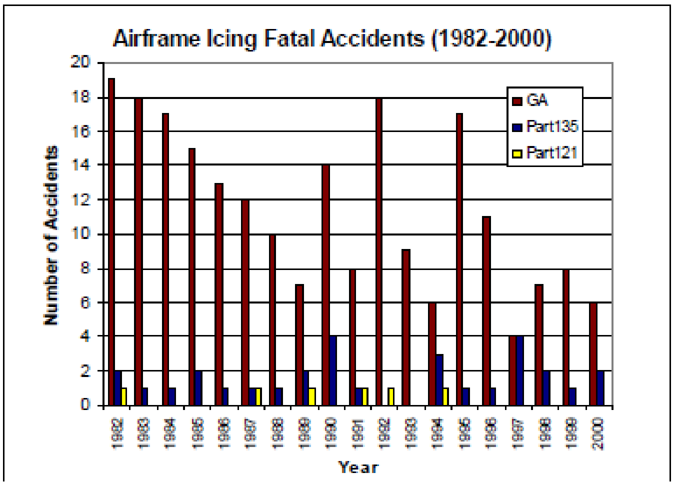

Chart -1.1: Airframe Icing Fatal Accidents (1982-200) [2]

2. TYPES OF ICE FORMATIONS

Depending on the conditions present outside of the aircraft, that is atmospheric conditions, and the altitude at which the plane flies, we encounter two major types of ice formations: rime ice, mixed ice and clean ice [3]. The major conditions which decide what kind of ice forms on the surfaces are the altitude at which altitude the aircraft flies, the area through which the aircraft passes through a cloud, weather, and shape of the plane structure. Likewise, we shall now understand these two types in further detail.

2.1 Rime Ice

Rime ice forms when the droplets are small. When these droplets impact the surface of the plane which is at 0° C, they

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instantly freeze without spreading out. This rapid freezing traps small amount of air in it giving it a white appearance. Rime ice is lighter than clear ice; however, its highly irregular nature of shape severely affects the aerodynamic flow of air over the areas where it forms. It is usually brittle and easy to remove.

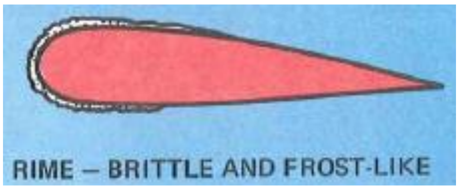

Fig -2.1.1: Rime Ice [3]

2.2 Clear Ice

Whenever the drops are sufficiently large, the drops, after impact on the surface, have enough time to spread out and then freeze. Thus, a smooth sheet of ice is formed. This ice is hard and difficult to remove. Although it doesn't affect the aerodynamic flow to a great extent, it can potentially damage control surfaces.

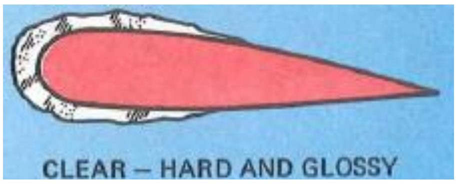

Fig -2.2.1: Clear Ice [3]

2.3 Mixed Ice

Mixed ice forms when the droplets in the air are of different sizes. This leads to formation of rime ice crystals imbedded in the clear ice formations, making this ice grow rapidly and difficult to remove. Mixed is most commonly encountered and poses a greater risk.

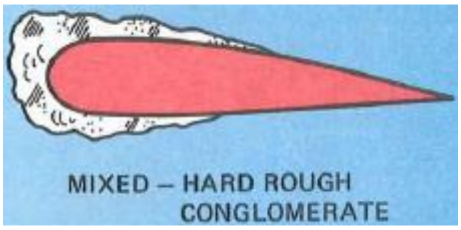

Fig -2.3.1: Mixed Ice [3]

3. CURRENT PRACTICES FOR DE-ICING

There are majorly 3 Aircraft De-icing procedures followed around the world: Aircraft de-icing fluids (ADF) [6], hot water de-icing [7] and forced water de-icing [7]. These are usually focused on removing ice after the plane lands or while it is parked in a hangar. Alternatively, aircrafts also use anti-icing agents to prevent ice formation.

One important point to be noted here is that these methods use chemicals like propylene-glycol based ADFs, etc. These pose a great environmental risk and for the same reason there are laws set by environmental protective agencies. In the United States, all airlines are required to obtain permissions from the National Pollutant Discharge Elimination System (NPDES) [4].

The Environmental Protection Agency (EPA) has reported the following statistics about the current USA chemical oxygen demand (COD). COD is a primary environmental characteristic of aircraft de-icing. The following is an image of the total ADF discharge from various airports all over USA.

Airport Hub Size	ADF Application Site COD Discharge (pounds/year)
Large	70,287,571
Medium	28,433,086
Small	9,863,368
Nonhub	17,382,976
General Aviation/Cargo	2,412,898
Total	**128,379,900**

Fig -3.1: COD Discharge for various types of airports

These discharges affect the environment severely, in that they affect the balance and purity of groundwater resources, foaming near water bodies, negative impacts on aquatic life and so on [5].

Apart from the environmental impact, de-icing process currently used take a lot of time, thus increasing on ground time of airplanes. Also, these methods tend to be resource intensive. It is, therefore imperative to use better methods to de-icing and even prevent formation of ice in the first place.

4. IN-FLIGHT DE-ICING USING PYROLYTIC GRAPHITE SHEETS

It is much more efficient, as a whole, if we could prevent formation of ice altogether. One such method can be heating the critical areas where ice forms during flight. Various methods like joule heating of panels are already being incorporated. However, a much better and cheaper method is using the bleed heat from the aircraft turbine to heat sheets of Pyrolytic graphite which are strategically placed at the critical zones.

4.1 Properties of Pyrolytic Graphite

Pyrolytic Highly Oriented Graphite Sheet (PGS) is made of graphite with a structure that is close to a single crystal. It is manufactures by heat decomposition of polymeric film. In a nutshell, it is a competitive conductive sheet with a high thermal conductivity and flexibility. Given below is a chart to compare the thermal properties of certain types of PGSs with other common materials.

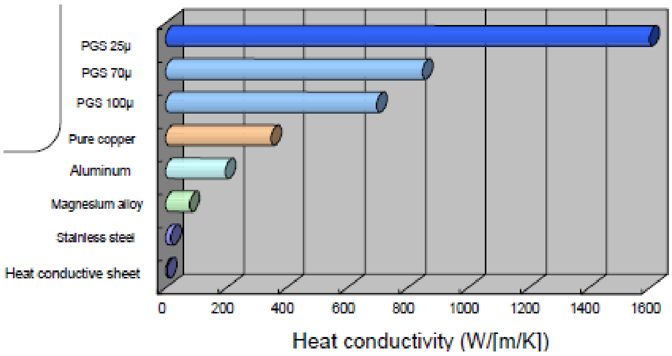

Fig -4.1.1: Heat conductivity comparison [8]

4.2 Critical Zones of an Aircraft

Through empirical findings, a few regions have been identified which are prone to icing. These areas are: leading edge of the wings and the tail, the nose, air intake ducts, and engine carburetor.

4.3 De-icing Using Bleed Heat

There is a lot of waste heat generated while the aircraft is flying. This is primarily the heat expelled from the engines. In this new alternative to prevent icing, it is suggested that this heat be bleed or routed back to the critical zones using Pyrolytic graphite sheets. This heat will be well distributed because of the inherent high thermal conductivity of the PGSs. The heat will melt the contact layer of ice and the aircraft surface. The velocity of the aircraft and the motion of air over the surfaces will provide a "washing off" effect on the ice continuously during flight. This will essentially prevent formation of ice altogether on the outer surfaces.

PGSs are great conductors of heat and transfer heat very efficiently. The bleed heat or waste heat collected can be easily routed using PGSs. PGSs are already being used to transfer heat quickly to heat sinks, thus it is possible to do the same here. One concern is the melting of these sheets. However, PGSs have a melting point of 3650°C [9]. The normal temperatures at the exhaust of a jet engine are about 2000°C [10]. This gives a sufficient buffer to directly collect exhaust heat and route it for de-icing purpose.

PGSs have a very low density of about 2.22 g/cc [9]. Since we only need a thin layer over a few surfaces, the total additional weight will be not more than 20-40 kg maximum. Moreover, PGSs have good tensile and flexural strength of 80 MPa and 120 MPa respectively [9]. This provides sufficient resistance to any impacts or stresses during the flight, for example, hail impacts and other such events.

5. CONLCUSION

The time consuming processes, currently used for de-icing, along with their environmental impacts exacerbated by the high costs involved, render them a bad choice. Alternatively, the advantages of using a continuous in-flight de-icing system seem to outweigh the disadvantages. The main advantages are that this process is sort of recycling the waste exhaust heat from the jet engines. Moreover, this system is natural, in the sense; it makes use of natural heat transfer process of conduction, thereby eliminating the use of additional power or energy (like in joule heating de-icing). Additionally, by not allowing ice to form during flight, we will reduce grounded flight time on the airports during cold seasons. One possible disadvantage of this system can be the cost of the PGSs but with improved manufacturing abilities and development in mass production, the costs will certainly come down. In conclusion, it is imperative that better, efficient and cheaper alternatives be used to de-ice rather than inefficient, un-environment friendly chemicals. Given that all the knowledge and resources to implement such a system are presently available, it shouldn't be difficult to bring this to fruition.

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