The Future of Aircraft De-Icing and Anti-Icing

Ice on aircraft represents a major threat to safe and efficient operation. It has been an issue addressed by the aerospace industry since the dawn of flight. Fortunately, systems for tackling icing have become increasingly effective. Nonetheless, there are still a number of issues.

Figure 1: Icing on an aircraft wing

The most common ice protection systems for aircraft fall into two major categories: de-icing systems and anti-icing systems. Pneumatic boots, one of the oldest methods of addressing icing, actively dislodges ice building up on airfoils. This approach is most common with smaller aircraft and those that do not produce enough bleed air for a more modern system. The heat from both engine bleed air and from electro-thermal systems can be used in a more passive approach, heating flight surfaces to prevent ice from forming. Electro-thermal ice protection systems can be used both as active and passive methods for ice removal and prevention. Finally, hydrophobic materials and anti-freeze chemical are also used to coat aircraft. This is the most passive method and is often best used in conjunction with other ice protection systems.

All of these methodologies are effective enough to ensure safe operation of aircraft. However, they can also represent excessive energy usage, especially pneumatic and bleed air systems. Furthermore, poor access to more advanced systems leaves smaller and utility aircraft woefully behind. Even electro-thermal anti-icing, used in some more electric aircraft, can suffer from the added strain placed on the electric power system. As such, new approaches must continue to be developed and implemented into aircraft in the future.

Electro-Conductive Textiles

Electrically conductive textiles could be used as a method to provide electro-thermal anti-icing/de-icing to both new aircraft and to ones currently lacking the functionality. These materials are developed by combining conductive materials with microfibers to create a mesh of conductive material[i]. By using this flexible semi-resistive material, heating elements can easily be added to flight surfaces. Similar technology in a composite material can actually be used as the flight surface itself.

In either instance, better heat distribution can be achieved thanks to the regularity of heating elements. This means that aircraft, especially those developed on the more electric architecture, can accomplish far superior anti-icing results.

Some electro-conductive textiles offer significant variability in terms of heat distribution, meaning that different gradients and patterns can be achieved[ii]. For aircraft, this can mean easily being able to apply greater heat to key areas such as airfoils as necessary.

Electro-conductive textiles are in their infancy[iii]. There are already some commercial applications; however, a large majority of them are fairly novel. Nonetheless, they show significant promise for use on aircraft.

Laser Pulse Technology

One emerging approach to anti-icing is to create ultra-hydrophobic materials using short laser pulse technology. This approach focuses on creating textured materials that make it physically difficult for ice to form on them[iv]. This texturing is on a nanoscopic level meaning that it removes any smooth surfaces that even a single droplet of water could attach to. As such, when atmospheric water droplets make contact with the textured materials, they rest on top of it, rather than spreading out and wetting the surface. This results in substantially lessened surface area and thus less friction[v]. When applied to a flight surface, droplets will are unable to remain attached to the flight surfaces, vastly reducing the amount of ice that can form.

This approach could be quite beneficial in that it could potentially be designed in such a way as to require less maintenance than anti-icing coatings. Furthermore, as an entirely passive solution, laser textured materials would not require in-flight power like bleed air, electro-thermal, and pneumatic solutions. However, this approach lacks the ability to actively remove ice. Thus, it would likely be best combined with another solution for maximum impact.

Currently this approach to anti-icing is still in the early stages. While a number of researchers have proven that not only is it a possible solutions, it would also be quite effective, it still lacks the consistency[vi] and robustness[vii] necessary to be commercially applicable. Furthermore, without further research and understanding of the processes necessary to use femptosecond laser technology to machine physical shapes, the full potential of the technology will not be realized. Nonetheless, the promise of this approach to be able to provide anti-icing capabilities to even the smallest aircraft suggests that it is worthwhile of continued research and development. Additionally, short pulse laser texturing can be applied to much broader materials science, providing a variety of benefits.

Nano-Tube Technology

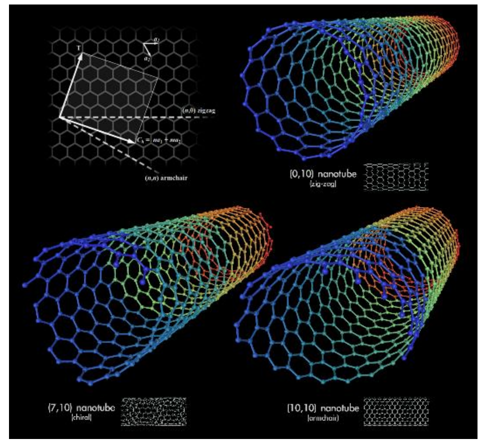

Figure 2: Carbon nano-tube structure

Another approach to aircraft anti-icing is to use conductive coatings containing carbon nano-tube fibers[viii]. This can be used as an electro-thermal anti-icing system. A power source can be connected to this coating, heating it to prevent the buildup of ice across the flight surface.

This is already in use by the military to provide anti-icing functionality to unmanned aircraft[ix]. They are even evaluating it for a prototype robotic exoskeleton. Another experimental application of this material is on the blades of wind-turbines[x]. Like aircraft, these blades can suffer significantly from icing when used in wintery conditions. Although the use so far has only been as a proof of concept, it is clear that this same idea would work as well for the blades of turbines as for aircraft flight surfaces.

The benefits of nano-tube coating are significant. As an electro-thermal approach, it greatly reduces the energy requirements for ice prevention when compared to traditional methods such as bleed air and pneumatic boots. In fact, it is even more energy efficient than existing electro-thermal systems which rely on heating elements. Additionally, it is very lightweight and extremely strong. This means that it could potentially be applied to smaller aircraft, reducing their reliance on pneumatic systems; hence why this technology is already in use on unmanned aircraft. The material's strength would also greatly reduce the need for regular maintenance compared to currently used methodologies.

Nano-tube technology has recently been developed to a stage where its enormous potential is clear. It can even be used in limited practical applications. Unfortunately for the time being, it is extremely expensive, to the point where it would not be a feasible option for coating aircraft[xi]. Nonetheless it is a worthy area of research.

Early in 2013, Saab filed for a patent for the application of such a coating to aircraft wings in order to eliminate the need for chemical coating used today[xii]. The incredible versatility of carbon nano-tube technology makes it attractive to many different industries; as such, it is likely that continued research will quickly reduce the cost of manufacturing.

Integrated Ice Protection Systems

Today the vast majority of ice protection systems are independent systems adhered to the flight surfaces in some form. This can be either in the form of a coating or a system within the aircraft such as mechanical and electric anti-icing solutions. However, as materials science progresses and more and more aircraft parts are made from composite materials, integrating ice protection systems directly into the body of the aircraft is becoming both more possible and more attractive.

Such an approach can offer a number of benefits. In particular the energy consumption of operation is significantly lower for such a system[xiii]. By building heating elements into specifically designed composite materials, inefficiencies in heat distribution can be nearly eliminated.

Currently there is a clear need for such technology. Development of aircraft such as the Boeing 787 and Airbus A350 XWB have resulted in an incubation period for such technologies[xiv]. However, in order to become truly commercially applicable, integrated ice protection must be more cost efficient to create and implement.

Conclusion

Although the current status of ice protection can achieve an acceptable level of safety, there is still plenty of room for improvement. In particular, current methods require significant maintenance and heavily involve de-icing and coating by ground crews. This not only increases maintenance costs, it also causes logistical hold ups that may otherwise be avoided. Furthermore, poor robustness increases the chance of unnoticed fault causing safety hazard, particularly in noncommercial aircraft.

Fortunately, advances in areas such as electro-conductive textiles, small pulse laser texturing, carbon nano-tube technology, and integrated ice protection systems offer a lot of promise to the future success of ice prevention. Although these technologies are still in their early stages, their consistent applicability to many different industries suggests that they will develop at an ever increasing rate. From textured hydrophobic materials to highly conductive nano-tubes, the aircraft of tomorrow will certainly be well prepared for icy conditions.

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