Optimization of a nacelle electro-thermal ice protection system for icing wind tunnel testing

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Several accidents are caused by ice formation every year. Ice can form on exposed zones such as wing leading edges, engine intakes and Pitot tubes. Ice builds up on the engine intake could modify the air inflow leading to engine performance reduction. Furthermore, chunks of ice could get sucked into the engine damaging the fan blades. In-flight icing occurs when an aircraft flies through a cloud of supercooled water droplets. Their temperature is below freezing point, but they are still in the liquid phase. This state is called meta-equilibrium and is broken upon impact with a moving surface, leading to ice formation.

Modern aircraft are equipped with ice protection systems (IPS) to avoid, delay or remove ice accretion. IPS can operate in two different modes: anti-icing, which prevents ice formation, and de-icing, which is activated to remove an ice layer. A widely used technology is the pneumatic-thermal system, hot air is taken from the engine, and it is distributed in the inner surface of the nacelle leading edge to heat the surface. One of the main drawbacks of this system is that the extraction of hot air from the engine can negatively affect engine performances. Moreover, in the context of Green Aviation, aircraft manufacturers are moving towards hybrid or fully electric aircrafts, which implies the use of electric power for all on-board systems. In this framework, an electro-thermal IPS, which heats surfaces at risk of ice accretion exploiting the Joule effect, has been designed and optimized to replace the nacelle pneumatic-thermal system.

The design of the IPS comprises a set of four heater installed within the nacelle surface, Figure 1. The total length of the protected part was designed according to CS-25 APPENDIX O [1] icing condition requirements. The multi-layered heaters design was taken from the experimental work of Al-Khalil [2], the heating resistance is embedded inside a four-layer composite panel, Figure 2. The system was then optimized to minimize the power consumption. The design parameters were the heat flux provided by each heater and the length of three of the heaters, the fourth heater length is equal to the remaining portion of the protected region. Four different constraints have been considered for the optimization, controlling ice formation on the inboard, as indicated by certification specifications, and surface temperature on the protected region, to avoid material degradation. Ice formation and surface temperature were evaluated by means of the in-house developed PoliMIce framework for in-flight ice accretion and IPS simulation [3] [4]. To perform the optimization genetic algorithm was chosen for its capability of dealing with complex problems like nonlinear objective functions and multiple local minima. The constraints were handled by means of a linear penalty method.

The optimization procedure led to a reduction of power consumption by 33% with respect to the previously installed thermo-pneumatic IPS. Furthermore, engine performance is not affected in the case of the electro-thermal IPS. This energy saving resulted in an estimated reduction of specific fuel consumption of 3%, when operating the IPS in anti-icing mode.

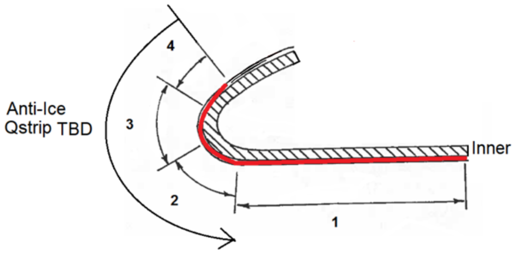

Figure 1 - Heaters position on the nacelle surface

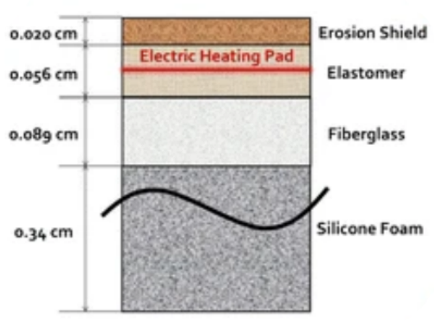

Figure 2 - Schematic view of heater layers

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