Numerical Simulation and Parametric Analysis of Electro-Thermal Anti-icing and De-icing systems

E. Iuliano[1] and M. Ferraiuolo[1]

[1]CIRA-Italian Aerospace Research Centre, Italy
e-mail: e.iuliano@cira.it, m.ferraiuolo@cira.it

ABSTRACT

Aircraft icing still represents a threat for in-flight safety as even the formation of thin irregular accretion on wing, engine part or probe surfaces may dramatically impact the operation of the component. Hence, the design of reliable ice protection systems is critical and the effectiveness of such devices are required to be thoroughly demonstrated by strict regulations (14 CFR 25.1419 by the FAA or under CS 25.1419 by EASA). Numerical simulation represents a crucial step towards the design process and the reduction of the experimental testing. The paper proposes a coupled methodology able to simulate and optimize the performance of an electro-thermal anti-icing and de-icing system in an integrated fashion: in fact, the classical tool chain related to icing simulation (aerodynamics, water catch and impact, mass and energy surface balance) is coupled to the thermal analysis through the surface substrate and the ice thickness. In general, the substrate consists of a multi-layered composite with different properties for each layer and embedded heaters (resistors) at interfaces between layers.

The current practice is to size the anti-icing system by evaluating the most critical icing conditions through ice accretion simulation, verifying that no ice is formed on the surface and, finally, estimating the required heating power. In the present approach, the ice protection simulation is not decoupled from the ice accretion simulation, but a single computational workflow is considered, able to operate in two different modes. In the first mode (de-icing mode), the ice shape is numerically evaluated and then the “de-icer” module, based on a FEM approach, is used to estimate the power of the electro-thermal resistors required to melt the ice layers closer to the surface, once fixed the resistors location pattern. In other words, the design parameters are the resistors patterns location, the objective is the required power and the constraint is the melting of the ice layers. On the other hand, in anti-icing mode, the distribution of surface heat flux required to have no ice on the surface (both a running wet and a full evaporative anti-icing systems can be considered) is numerically evaluated and then the FEM module is launched to estimate the power of the heated elements to sustain the required heat flux distribution. Here, the design parameters are still the resistors patterns location and the objective is the required power, but the constraint is matching a pre-defined surface distribution of heat fluxes. In both cases, optimization techniques can be used to find the heater configuration which minimizes the heating power while satisfying the constraint.

Validation results obtained on benchmark test cases, drawn from NASA database [1,2], will be detailed in the final version of the paper. Moreover, an example of application of the proposed methodology to the parametric analysis and design of the heaters pattern will be proposed, showing the potential savings in power consumption thanks to a proper arrangement of the heater elements.

REFERENCES

[1] K Al-Khalil, D Miller, W Wright, “Validation of NASA Thermal Ice Protection Computer Codes, Part 3: The Validation of Antice”, AIAA-97-0051, May 2001

[2] W Wright, K Al-Khalil, D Miller, “Validation of NASA Thermal Ice Protection Computer Codes, Part 2: LEWICE/Thermal”, NASA TM 107397