Design and realisation of a Wind Tunnel model for ice protection system demonstration

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***Abstract*— The present work focuses on the design and realization of a leading edge of a wind tunnel model, integrated with two Ice Protection Systems (IPS): an icephobic coating and an ultrasound piezoelectric system. The scope is to investigate these technologies acting separately and in synergy.**

The definition of the demonstrator, the design approach, the manufacture and integration process are in line with the development path at the basis of the National Project of "SMOS – Smart On board Systems", targeting innovative anti and de-icing low power architectures.

The work is organized in different sections. At first, the just mentioned Project is introduced, outlining its target, the technologies developed and the maturation path. Secondly, the two protection systems object of this work are illustrated and a discussion on their capability of working in synergy is presented. Then, the wind tunnel model is presented explaining the rational of the layout against the types of protection systems installed and the requirements of the tests. Finally, the manufacture of the module devoted to the piezoelectric and icephobic coating is described, giving details on the next steps of the research, that is to say, the experimental demonstration.

Keywords—ice protection, icephobic, piezoelectric, ultrasound, Lamb waves

I. INTRODUCTION

De-icing systems are aimed at removing ice after it has formed, while anti-icing systems try to avoid the ice forms, [1]. There are many pros and contra each of them, depending on many factors. For instance, in the former case the aircraft is allowed operating for the most of the time in icing conditions, but during and nearly after the action of the de-icing system. In turn, this fact necessitates a deep understanding of the consequences, and even the dynamics, the ice causes on the aircraft performance by both the designer and the pilot. On the other side, anti-icing systems shall need a continuous delivery of energy or chemicals to prevent ice accretion, which can be very expensive and not adequate for aircraft that do not have extra energy available during their typical mission. An alternative may be the use of chemical agents, which however show other drawbacks, [2]. Generally, such systems protect a very large number of aircraft parts, including leading edge of wings and tails, fuel tank vents, propeller surfaces, and even specific devices like pitot tubes, stall alarms, and windshields. Among the many issues associated to both de- and anti-icing systems, it is worth to mention the impact of the fluids residue on critical areas of the wings and stabilizers. It can rehydrate and expand in a gel-form that can in turn freeze, expand, and cause issues to flight control systems, [3].

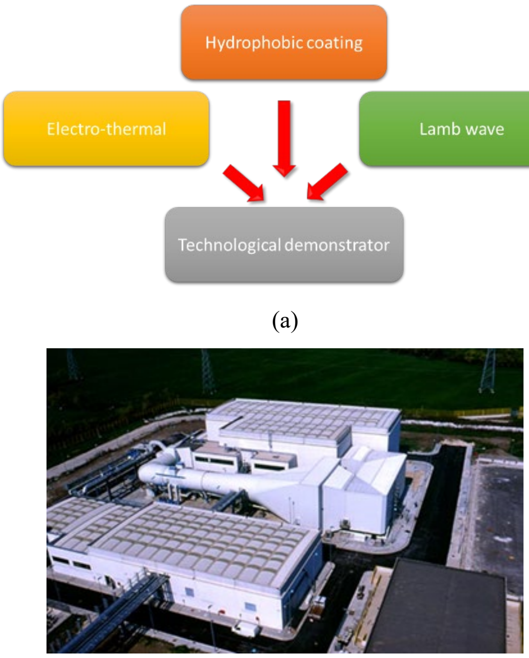
Many efforts have been being spent on ice protection. SENS4ICE, SOUNDofICE, ICE GENESIS are only some of projects in progress that have received funding from the European Union’s Horizon 2020 research and innovation programme. This demonstrates both the strong interest in aircraft icing and the effort to increase the flight safety in icing conditions, especially for the Supercooled Large Droplets (SLD) conditions.

In the framework of the National Aerospace Research PROgram (PRORA) funded by the Italian government, the Italian Aerospace Research Centre (CIRA) is carrying out the project titled SMart On-board System (SMOS), aimed at developing aircraft innovative technologies, among which those for energy efficient and lightweight de/anti-icing systems. The SMOS project foresees the development of onboard systems inherent technologies like the ones devoted to energy efficient and lightweight anti-icing/de-icing architectures.

The aim of this paper is to present the activities carried out for the realization and development of the technology demonstrator (wind test model) of Lamb-wave and icephobic coating as ice protection systems.

II. REQUIREMENTS AND CONCEPTS

The SMOS project’s overall aim consists in the merging different ice protection strategies centered on different technologies: an electro-heater anti-icing, a passive hydrophobic coating, and a piezo-driven de-icing systems (Figure 1, (a)). All these systems will be tested in the CIRA’s Icing Wind Tunnel (IWT, Figure 1, (b)), separately and jointly, on a single technological demonstrator (Figure 2) that will allow to evaluate the performance of each solution in a relevant environment.



(a)

(b)

Figure 1, (a) Ice protection strategies; (b) CIRA’s Icing Wind Tunnel-IWT[4].

Conventional ice protection systems are considered reliable, but show some disadvantages such the need of high power consumption, additional weight and complexity. These protection systems include pneumatic deicing boots, thermal systems and glycol based fluid systems. Some unconventional ice protection systems rely on the action of actuators of diverse characteristics, placed in opportune locations in order to apply loads to detach or break the ice layers[4]. One of these is the Sonic Pulse Electro-Expulsive Deicer, based on a multiple winding actuator; the airstream sweeps away the ice and a sensor monitors the ice accretion and commands the deicer. The electro-impulse method is based on a sudden electromagnetic repulsive force generated by a capacitor, breaking the ice layer. The Electro-Expulsive separation system is based on the repulsive force between two magnetic layers bonded on the trailing edge and generating high acceleration motion which in turn breaks the ice. Another non-conventional approach is based Shape Memory Alloy (SMA) sheets which mounted to leading edge can be constructed and cause the ice to be detached from the surface[5]. The application of superhydrophobic/icephobic coatings is expected to reduce the permanence of water droplets impacting the surface, then reducing/delaying the ice formation, and/or to reduce the ice adhesion strength, so enhancing its removal[6]. In small aircrafts, drones and unmanned aircrafts, where no active IPSs can be employed, the passive coatings represent the unique allowable IPS; instead, for large aircrafts, the combination of active and passive IPS can be seen as a strategic instrument able to assure a high efficiency in a wide range of environmental conditions, by reducing the power consumption and then the CO_2 emissions [7][8]. The use of piezoelectric systems to drive Lamb waves has the aim of generating shear actions at the interface between ice accretion and the skin, with the effect of removing ice. The principle, the design approach, the implementation of suitable architectures, the benefits in terms of power consumption were demonstrated in many literature works. Among several active approaches suited for ice protection, ultrasounds gained the interest from the scientific community as it can be employed to instantaneously remove ice accretion from the contaminated surface [9]. The idea behind this approach is to generate a shear stress field on the surface such as to overcome the local adhesion strength at the interface between the structure and the ice and enable detachment of the external accretion. In addition, combining ultrasonic technology with passive approaches increasing the icephobicity of the surface, can promote de-icing in a more efficient way[10]. On top of that, the use of ultrasonic waves is well suited for timely detection of early emerging surface ice [11]. demonstrating this technology as a viable solution to design a comprehensive ice protection system.

III. DEVELOPMENT PATH

The wind test model consists of a wing section with constant chord along the wingspan and equal to 912 mm. The NACA0012 reference profile cross-section was considered; the test model is made of 3 parts (Figure 2, central pink structure, CWM, plus the two lateral yellow segments, CWS and FWS), depending on the IWT test chamber that will be used. Two aluminum leading edges (Figure 3) were manufactured for testing the Lamb-wave and hydrophobic technologies and will be installed in the central part of the model.

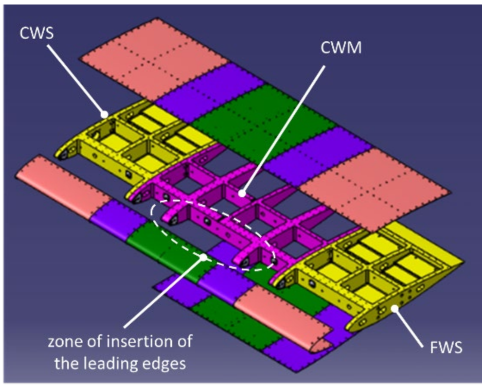
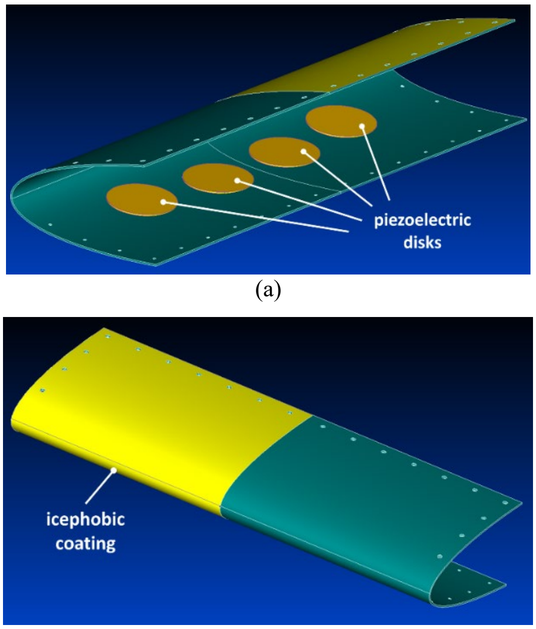


Figure 2. Wind Test Technological Demonstrator

Figure 3. Leading Edge for Lamb-wave test

Four piezoelectric disks with a diameter of 70 mm and a thickness of 1.8 mm were bonded on the bottom inner face of each leading edge. Each others were equally spaced along the span, and put at different distances from the leading edge line, in symmetry with respect the mid span plane of the segment. The icephobic coating was deposited onto one half the segment. This layout illustrated in Figure 4 allows to investigate the detachment capability of the two IPSs working alone and in synergy.



(a)

(b)

Figure 4. Layout of the piezoelectric disks (a) and of the icephobic coating (b) integrated onto a leading edge segment.

IV. MANUFACTURE PROCESS AND REALISATION

Each segment was constructed from a 2 mm thick aluminum sheet bent around a mold reproducing the leading region of a 0012 NACA airfoil with a total chord of 1 m. A cut was then performed along the entire span, on the top face of the segment, to temporally remove the aft part and have enough room for reworking the inner face of the leading edge. The scope of this operation was to mill the curved surface to obtain a flat area on which bonding the disks. Due to the high curvature and the relatively small thickness of the skin, it was not possible to arrive at a complete flat surface. On the contrary, the excavation process had to stop when a minimum thickness of 0.9 mm was achieved with the final result shown in Figure 5. After this operation, the cut part of the leading edge was welded to restore the initial configuration.

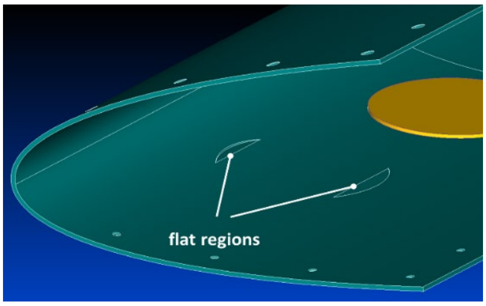


Figure 5. Detail of the interface between the piezoelectric disk and the skin obtained by milling.

The half exterior surface meant to be covered by the icephobic coating was sand blasted to achieve a roughness Ra= 4.0 ±0.7 µm (Figure 6), in order to facilitate and make stronger the adhesion of the lining. Figure 7 shows the optical microscopy at 140x of sand-blasted and untreated surfaces.

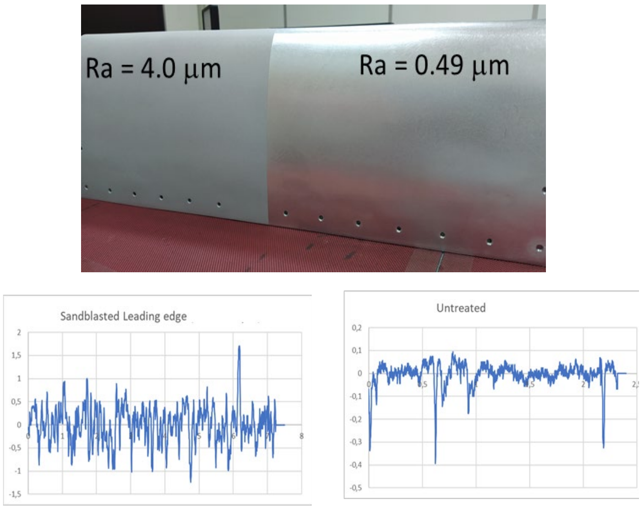
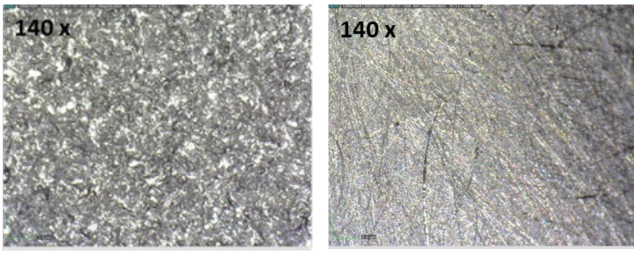


Figure 6. Roughness profiles of sand-blasted and untreated surfaces.

The water contact angle at 23°C of sand-blasted surface has been assessed as 0°, as displayed in Figure 8. This half-side of the leading edge will be coated with the superhydrophobic/icephobic coating developed at CIRA [12] and then tested.

Electrical cabling was soldered on the two faces of the disks. A detail of the connections is shown in Figure 9. Note that to reduce the thickness of the tin solder to minimize contact problem with the metallic skin, the wires of the cable were spread onto the disks and welded in different zones.



(a) (b)

Figure 7. Optical microscopy at 140x of sand-blasted (a) and untreated (b) surfaces.

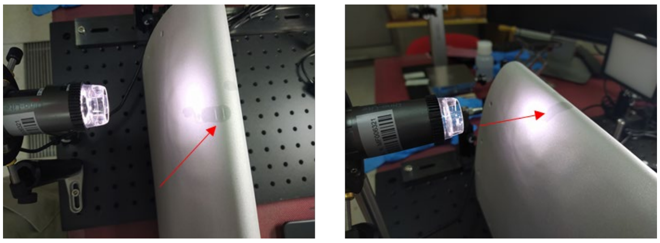


Figure 8: Water droplet images on the sand-blasted surface; the contact angle was assessed as 0°.

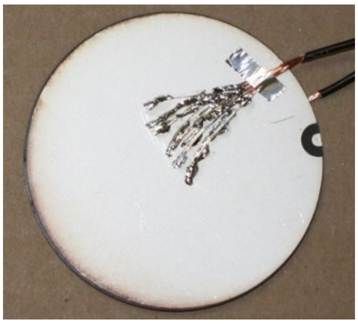


Figure 9. Detail of the cabling connection on the disks.

Piezoelectric disks were bonded to the leading edge through M-Bond 300, a two-component polyester adhesive, and cured at room temperature (see Figure 10).

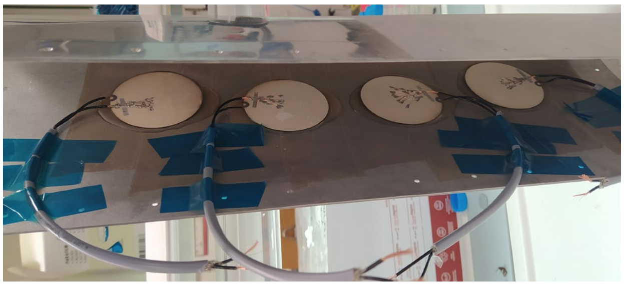


Figure 10. Picture of the leading edge after the piezoelectric disks were bonded.

V. NEXT STEPS

A first experimental campaign will be carried out in the laboratories at the premises of CIRA using a high stability temperature-controlled environment. The experimental campaign is conceived to demonstrate the feasibility of the ultrasonic technology onto a curved support, acting with and without an icephobic coating. This will contribute to the identification of a configuration optimized for the final demonstration in the ice wind tunnel facility. A particular attention is given to the surface treatment effect on the required system power, letting ice grows up on both the sand-blasted and untreated surfaces. Details about planned tests are listed in Table 1.

Table 1. Test matrix for laboratory experiments

Test no.	Temperature	Treatment	Ice	Piezoelectric
1	+25°C	Yes/No	No	Outer ones
2	+25°C	Yes/No	No	Inner ones
3	-10°C	Yes/No	No	Outer ones
4	-10°C	Yes/No	No	Inner ones
5	-10°C	Yes/No	Yes	Outer ones
6	-10°C	Yes/No	Yes	Inner ones

For the laboratory test campaign, the piezoceramic actuators will be connected both with a board, devoted to electromechanical impedance measurements [13], and with an arbitrary waveform generator, through an amplifier and an impedance matcher. All devices are managed by a control unit, where the signals transmitted and received are generated and processed, respectively. About the operations performed by such unit, a brief description is provided in the following. For the prescribed frequency range, the unit evaluates the impedance of the assembly “ice-structure-transducers”. In order to improve the power transfer from the amplifier to the piezoceramic actuators an impedance matching network is adopted. Finally, the signal generator provides the proper stimulus, which is powered through the amplifier, supplying the actuators. A schematic representation of the discussed deicing system is depicted in Figure 11.

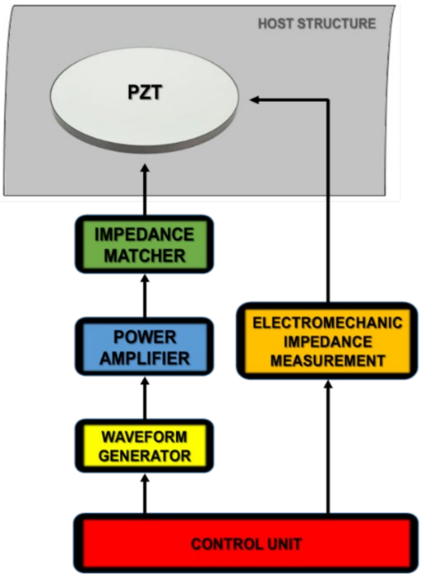


Figure 11. De-icing system schematization.

In a near future a possible intermediate experimental test campaign will be performed in the ice wind tunnel test prior the final demonstration. The objective of the intermediate test campaign will be to perform a fine tuning of the ultrasonic technology in a more representative and realistic icing conditions. The subsequent final demonstration in IWT will involve the three different technologies separately and jointly on a single technological demonstrator.

VI. CONCLUDING REMARKS

In this paper the activities for the development of a laboratory and WT demonstrator were illustrated. The scope of the activity was to realize a leading edge demonstrator integrated with two ice protection systems, one active, based on piezoelectric technology and another one passive, constituted by a icephobic coating. The target was to investigate both the systems working independently each-others and in synergy. The scope of the project was at first illustrated, giving an overview of the technologies developed. Secondly, attention was paid on the working principle of the two technologies investigated. Thirdly the realization approach was faced, giving basic and operational details of both the protection systems. Finally an overview of the upcoming test campaign was provided.

The proposed system has the major advantage to protect the target surfaces along the entire fight with a modest amount of energy consumption, because of the implementation of a coating inhibiting the ice formation, therefore limiting the intervention of the anti-icing system only in certain circumstances. With this regard, the inclusion of an ice-detection device may be crucial. The use of an integrated mechanical system for de-icing purposes, further limit the energy expense at the minimum amount required for the operation, with an extremely prompt action, without the usual times correlated to thermal inertia, in the case of heat-based systems. Therefore, it can be easily applied to smaller aircraft, expanding the volume of the technology exploitation, and the market, and the affected customers. Furthermore, its timely and targeted action may avoid the removal of big fragments, which could cause issue on jet engines (if ingested), propeller blades (if hit), and the same aircraft surfaces (aft parts and fuselage). Nowadays, the most common ice protection solution is represented by the electrothermal method, but it characterizes also the most energy-intensive systems. As highlighted in this work, the combination of electromechanical and chemical methods represents instead an answer to the question of how to develop a practical low-energy consumption system. As a consequence, it needs to investigate on this approach in order to aim its reliability. Therefore, in the next future, experiments to increase the effectiveness of the described deicing system will be performed.

ACKNOWLEDGMENT

The presented activity was carried out in the framework of the SMart On-board System (SMOS) project within the National Aerospace Research PROgram (PRORA) funded by the Italian government.

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