3.1 Publishable summary

SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND THE MAIN OBJECTIVES

Ice accumulation on aircrafts' wings generates severe problems in the vehicle performance mainly due to the combination of weight increase and lift reduction which in turn implies an increase on the energy consumption. This problem is faced nowadays by methods that vary from energetically evaporative anti-ice systems (prevention) to de-icing systems (corrective). The use of evaporative anti-ice systems is hampered nowadays due to the design of new fuel-efficient engines that limit the available amount of bleed air. As a result, more electric aircrafts using large generators to replace bleed air as an energy source have been developed. However, the amount of power that permits a full evaporative anti-icing electrically powered system is still out-of-availability of the current generators. In addition, in the green electric rotorcrafts no bleed air will be available, and therefore electric systems will have to be used. Therefore, spending research efforts in electrically efficient de-icing systems seems to be a good alternative. As regards the known de-icing systems, they are mainly divided into electro-thermal (thermal-based de-icers) and electro-mechanical (deformations-based de-icers) systems While the electro-thermal systems present several disadvantages in terms power needs and secondary effects in the de-icing process among others, the electro-mechanical systems are very well valued for their low power needs (in fact that they are "single points" actuators) and more important, they are non-intrusive to flow. In order to develop more efficient electro-mechanical de-icing systems, innovative technologies and concepts have to be investigated.

The SMARTERSHIELD project has contributed to this investigation by implementing a highly efficient new smart erosion shield. In order to do so, the following main objectives have been undertaken:

1. To investigate propose and review technical concepts and technologies and determine the best design concepts.
2. To find the key parameters and elementary design structure patterns.
3. To maximize the deformations with minimum energy and provide a high control capacity of the deformations.
4. To determine the best design concept.
5. To evolve the best design concept to achieve a highly optimized detail design of a erosion shield prototype.
6. Validate the proposed new design concepts and the prototypes design by means of FEA simulations and the necessary correlation process.
7. To manufacture and assembly erosion shield mock-ups.
8. To manufacture and assembly the testing bench for the mock-ups.
9. To test and validate the mock-ups.
10. To manufacture and assembly the erosion shield prototype.
11. To manufacture and assembly the testing bench for the prototype.
12. To test and validate the erosion shield prototype.

As a summary, the de-icing SMARTSHIELD system has been designed by means of engineering tools such as FEA and prototype design and validated by full-scale experimental tests. In order to maximize the deformations and its control and at the same time minimize the energy spent in the de-icing process, an investigation on the actuator technologies and materials design has been proposed as well.

A DESCRIPTION OF THE WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT AND THE MAIN RESULTS ACHIEVED SO FAR

The work performed to date since the beginning of the project has been summarized in the documents D1 "New concepts review", D2 "Design and evaluation of new concepts", D3 "Detail design and optimization" and D4 "Erosion shield prototype" that have been delivered.

Regarding the first deliverable, its main objective was to describe the evaluation of the proposed concepts as well as providing a selection that had to be analysed. Firstly, the detailed specifications were established. Parameters such as dimensions, applied boundaries, safety and environmental design criteria and manufacturing possibilities, were considered for the design and development of the erosion shield. Secondly, and in-depth state of the art was performed regarding the de-icing mechanisms. After recollecting all the previous information, the key concepts that would lead to an optimal erosion shield design were listed. Then, the indicators that would give an overall idea about the performance of the erosion shield were determined. After the inputs of the analysis were set, a list of concepts was evaluated through numerical analysis. The results indicated that three concepts were suitable for obtaining good performance of the erosion shield to be designed: anisotropic behaviour, vibration modes and buckling. For all the concepts, the varying parameters that would lead to an optimized erosion shield were, in general, geometrical (thickness, stiffeners) location of the actuators and fixation points, actuation sequence and manufacturing materials. Regarding the most relevant optimization field, it was concluded that the actuation sequence was the most influent parameter.

In relation to the second deliverable, its main objective is to evaluate and optimize the 3 best concepts by FEA, the selection of the best design solution, the development and implementation of the testing bench for mock-ups tests, the results of the experimental tests and the Finite Element model correlation. All these tasks have been carried out, and in addition to the evaluation of the concepts under efficiency (detached area/energy) and weight points of view, safety/controllability, complexity and material costs have been taken into account at the time of defining the best concept for the erosion shield design. According to the evaluation of all results the best concept has been found to be the anisotropic behaviour. Regarding the materials selection, for the already selected concept, it has been seen that the two best options are the aluminium plate with triangular stiffeners and the CFRP plate. In relation to the mock-ups testing and numerical simulation, the tests were successfully carried out. Nonetheless, the correlation of the experimental data and the numerical results did not give the expected level of accuracy. According to the boundaries of the problem and the manufactured samples, the problem must be attributed either to an erroneous manufacturing of the coupons or to a bad estimation of the properties of the CFRP used in the simulations.

Referring to the third deliverable, its main objective is to determine an optimized final design of an erosion shield in comparison to a non optimized design with quasi-static deformation ice detachment capability. In order to fulfil this global objective, some partial goals have been undertaken: Discriminate the most suitable stringers-panel configuration, evaluate the performance of the chosen configurations when actuated either by two or by four application points, determine the best value of all input parameters for an optimal behaviour in terms of overall performance, especially when detaching ice and energy cost, evaluate the validity of the numerical models and asses the structural integrity of the final design. The optimization carried out was performed in terms of detached area, applied energy, mass and maximum VM stress. Next, two candidate points have been selected as optimum cases. These cases have been tested to structural integrity verification. Lastly, one of the optimal cases has been rejected and a panel with curved stringers and two actuators has been selected as a final optimal case.

Regarding to the last deliverable, its main objective is to design a test to check the panel proposed in the previous deliverable. In order to fulfil this global objective, some partial goals have been undertaken: To design a test bench to achieve the boundary conditions (BC) simulated, to test the erosion shield proposed in the previous deliverable and to validate the followed methodology and the results obtained by the virtual tests. A non direct correlation with the erosion shield prototype and the virtual test computed has been observed. However, the work methodology is robust and can be used in the futures projects. The possible interpretations for the non direct correlation real-virtual test are: The creation of the regular ice layer is difficult and this affects to the stiffness of the ice and the interaction of the surface-ice is not well defined.

DESCRIPTION OF THE EXPECTED FINAL RESULTS AND THEIR POTENTIAL IMPACTS AND USE

This project was aimed to design a new smart erosion shield that addresses all the challenges associated with this development and proposes innovative solutions. Various aspects on how to achieve the best erosion shield in terms of efficiency, cost, reliability, design and functionality have been investigated. SMARTERSHIELD solutions include:

i. The utilization of a number of actuators based on piezoelectric, solenoid or wire technology.
ii. Using innovative materials and structural solutions such as mesostructures and biomaterials to induce controlled deformations without actuators.
iii. Numerical calculations and simulations to optimize the design of the new erosion shield.
iv. Icing and de-icing experimental tests.

The development of the smart erosion shield solutions in terms of environmental, economical and social impacts have been carried out.

In terms of environment, aviation contributes approximately 2% of the total man made CO_2, and the EU has set the target to reduce emissions by 85-90% below 1990 levels by 2050. This includes a reduction of at least 60% of greenhouse gasses (GHG). Even though this project does not directly tackle this issue, it contributes to the reduction of emissions. The aerodynamic design of the aircraft has direct contribution to fuel efficiency and consequently the amount of emission. The new erosion shield developed within the SMARTERSHIELD project has contributed to the reduction of emissions.

Moreover, SMARTERSHIELD contributes to the European transport policy which is in line with the Euro 2020 initiative in working towards "resource efficient Europe". This is achieved by facilitating economic progress, enhancing competitiveness and offering high quality mobility while using resources more efficiently. In addition, the project is geared towards developing solutions to reduce cost by using new methods for more efficient systems that require minimal maintenance and replacement. These new methods contribute in a more efficient use of energy.

In terms of socio-economics, SMARTERSHILED has enhanced European competitiveness and facilitate economic progress. The European Air Transport sector has an annual turnover of more than € 95 billion and employs over half a million people directly with another 2.6 million indirect jobs. The participation of local partners such as TR COMPOSITES to this project is profitable to gain high added value from the development of the new erosion shield in terms increased revenue, sales, new market opportunities and job creation. SMARTERSHIELD results have also contributed to enhancing the safety of aircrafts with new safer and more efficient technologies. Other markets that could take profit of the new solutions developed in the SMARTERSHIELD project are the wind turbines (WT) sectors.

WT operating in cold regions or at high altitudes are frequently facing icing conditions during winter operation, and at the same time, the best sites for wind farm installation are located at higher altitudes, as wind speed generally increases by 0.1m/s per 100m of altitude for the first 1000m. Therefore, wind farms installed in some of the best wind sites around the world are facing possible icing events. SMARTERSHIELD project has been useful to explore how this technology can be used in other systems and sectors as well. The application of the new erosion shield could be transferred for instance to Rotorcraft industry to produce energetic efficient de-icing systems for helicopter blades. In terms of aircraft safety, Europe has a good record, and it aims to be the safest region in aviation.