1. PUBLISHABLE SUMMARY

1.1. SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND THE MAIN OBJECTIVES

Commercial aircraft have been experiencing in-service events while flying in the vicinity of deep convective clouds since at least the early 1990s. Heated probes and engines are the areas of aircraft most prone to mixed phase and glaciated icing threat. In anticipation of regulation changes according to mixed phase and glaciated icing conditions, the HAIC project will provide the necessary Acceptable Means of Compliance (numerical and test capabilities) and appropriate ice particle detection/awareness technologies to the European Aeronautical industry for use on-board commercial aircraft in order to enhance safety when an aircraft is flying in such weather conditions.

HAIC will also develop international cooperation and collaboration thanks to the involvement of key international organisations and companies as partners of the project or through the advisory board.

The main objectives of the HAIC project are to allow the European aeronautical industry to face challenges related to the evolution of regulation regarding mixed phase and glaciated icing conditions by characterising high ice water content environments and developing the Acceptable Means of Compliance (test facilities and numerical tools) to improve aircraft operation in such weather conditions by developing appropriate detection and awareness technologies to be fitted on aircraft and being able to alert the flight crew, thus continuously enhancing international flight safety.

This can be broken down into the following scientific, technical and dissemination objectives:

1.1.1. Scientific and Technical Objectives

- Characterise, optimise, enhance and select the most sophisticated cloud microphysics probes to measure mixed phase and glaciated icing conditions during flight tests and to calibrate icing wind tunnels
  - To measure mixed phase and glaciated icing conditions (TWC, LWC, IWC, etc.) with an accuracy better than 10%
- Measure and characterise the microphysical properties of core or near-core regions of deep convective clouds, including cloud liquid and ice water contents, particle size distributions and particle shapes
  - To sample monsoon oceanic convection, oceanic tropical storms and more vigorous continental convection as safety permits
  - To get statistics of the 99^{th} percentile of Total Water Content averaged over a distance of 20 statute miles of a convective storm centre, with an accuracy of ± 20%
  - To state on Appendix D and P diagrams representativeness vs real atmosphere
- Upgrade European icing wind tunnels to allow reproduction of mixed phase and glaciated icing conditions to allow the European Aeronautical industry to perform equipment qualification
  - Achieve a TRL6 on the considered technologies
  - Simulate the considered flight and mixed phase and glaciated icing conditions (Mach number ~0.85, Altitude up to ~40kft, Static temperature down to -70°C, IMMD in the range 20-500 µm, IWC up to $20 g.m^{-3}$, mixed phase capability) with an accuracy at least equivalent to the current covered icing envelope i.e. 15%
  - Generate a detailed experimental database to validate numerical tools
- Understand and model involved physical phenomena and develop numerical tools to simulate the impact of mixed phase and glaciated icing conditions on aircraft components (mainly engines and probes) for supporting both design and certification phases
  - Achieve a TRL6 on the considered technologies
  - Provide models and tools able to simulate the considered icing envelope and associated impact on aircraft components with an accuracy at least equivalent to test facilities i.e. 15%
  - Perform an integrated cross-validation between in-flight measurements, wind-tunnel measurements and model predictions

- Develop and validate mixed phase and glaciated icing conditions awareness and detection technologies to alert the crew of flight in these particular icing conditions or to adapt the flight path well in advance in order to avoid such weather conditions
  - Achieve a TRL6 on the considered technologies.

1.1.2. Dissemination Objectives

- Assess the proposed mixed phase and glaciated icing environment as defined in Appendix D and P in light of the analysis of the research flight tests performed as part of the HAIC project and provide recommendations to the regulatory bodies (EASA and FAA).
- Develop international cooperation and collaboration thanks to the involvement of key international organisations and companies as partners of the project or through the Advisory Board.

1.2. WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT AND THE MAIN RESULTS ACHIEVED SO FAR

Started in August 2012, the usually very difficult launch and ramp-up phase of such a large project was completed successfully, and HAIC is now well on track and has achieved most of the objectives planned for the first year of the project.

As part of the SP1 Instrumentation, the requirements for F/T and IW/T instrumentation were defined in terms of liquid droplet, ice crystal and mass of water measurements as well as technical instrument properties. Cloud microphysical probes targeting the HAIC/HIWC international field campaign at Darwin in Q1 2014 were improved (e.g. mini-IKP from HIWC, 2D-S, HSI, CPSD,) and preliminary selection of the most sophisticated probes to achieve the objectives of the campaign was performed.

In SP2 High IWC Flight tests Campaigns, despite the shift of the Darwin campaign from Q1 2013 to Q1 2014, an effective, open-minded and efficient collaboration with HIWC project has been set-up and the HAIC and HIWC projects, with additional supports from FAA and EASA, will bring the SAFIRE Falcon 20 to Darwin to collect cloud data in deep convective clouds with the primary objective to provide 99th percentile total water content statistics and other relevant parameters of such clouds, as a function of distance scale, to industry and regulators.

In SP3 Space-borne Observation & Nowcasting of High IWC Regions, Airbus provided a preliminary set of in-service events from his database for further analysis by scientists from MET-FR, CNRS and KNMI with the objective to retrieve specific signature from geostationary and polar orbiting satellites of such icing conditions. Work is still on-going but it is plan to assess performances of MET-FR RDT product (Rapidly Developing Thunderstorm) in the framework of the HAIC/HIWC international field campaign at Darwin in Q1 2014.

In SP4 High IWC Detection & Awareness Technology, definition of high level specification for mixed phase and glaciated icing condition detection and awareness technologies was completed and active research and development has been initiated with the definition of technology concept. Indeed, major milestones were achieved with the conduction of Key TRL2 gate reviews for the technologies investigated as part of the project. They all assessed conclusive by the decision panel. Finally, The Strategic TRL2 gate review for detection technologies leads to the downselection of 5 out of 6 Detection technologies in accordance with downselection process agreed in the DoW and aiming at promoting most promising and most mature technologies as risk management.

In SP5 High IWC Test Capability Enhancement, requirements for test facilities operating envelopes (altitude, temperature, velocity, crystals characteristics, Ice Water Content, Total Water Content, etc.) have been defined but still need to be completed with in-flight data regarding the ice crystals microphysical properties. A state of the art review on ice crystals generation including an assessment of the gap between artificial and natural ice crystals properties was performed. Finally, some prototypes of ice crystals generator devices have been developed and tested. Preliminary results show that it is possible to generate ice crystals with various median sizes, aspect ratios and crystal densities. Tests to characterize the ice crystals produced have been carried out, including an inter-comparison of the methods.

Finally SP6 High IWC Tools & Simulation Development, achieved the definition of requirements for the development of icing numerical tools, performed comprehensive literature review to better understand ice particle trajectory, impingement and accretion physical phenomena and existing associated modelling and has initiated laboratory tests at EADS IW, TUD and TSAGI to fill the remaining gaps in existing knowledge.

1.3. EXPECTED FINAL RESULTS AND THEIR POTENTIAL IMPACTS AND USE (INCLUDING SOCIO-ECONOMIC IMPACT AND THE WIDER SOCIETAL IMPLICATIONS OF THE PROJECT SO FAR)

Operational safety related research activities are a major research topic which has been dominant throughout the ACARE Strategic Research Agendas 1 and 2 which provides the Aeronautics Research agenda up to 2020. “Flight path 2050” also emphasises the importance of safety and the mastering of all aeronautical aspects (Aircraft & operational safety, ATM, Infrastructures, Test and simulation facilities and certification) related to weather hazards.

The HAIC project will significantly contribute to this objective through the delivery of the following expected results:

- A characterisation of the microphysical properties of core or near-core regions of deep convective clouds based on a unique flight test dataset in deep oceanic convective storms
- A set of experimental and numerical capabilities as Acceptable Means of Compliance (AMC) for the qualification and certification of future aircraft products (mainly probes and engines)
  - Four complementary upgraded European icing test facilities (TRL6) with improved representativeness of simulated mixed phase and glaciated icing conditions and covering the whole flight and icing envelope
  - A unique European numerical model for ice particle trajectory, impingement and accretion and mature research and industrial simulation tools (TRL6)
- A set of awareness and detection technologies to be fitted on aircraft and able to alert the flight crew when an aircraft is flying in such weather conditions
  - A pre-operational space-borne remote detection and nowcasting application of glaciated icing conditions (TRL6) based on imagery of geostationary MSG-SEVIRI satellite observations, validated with space-borne active and passive cloud observations from LEO and GEO missions and integrated into a pre-operational application for detection of Rapidly Developing Thunderstorm (RDT) over the Tropical Atlantic
  - An upgraded on-board weather radar (TRL6), based on current state-of-the-art X-band airborne weather radar equipment, to raise awareness to the flight crew of the encounter of glaciated icing conditions
  - Two to four mixed phase and glaciated icing conditions detectors (TRL6) to alert the flight crew in these particular icing conditions
- An assessment of the representativeness of the proposed mixed phase and glaciated icing environment as defined in Appendix D and P and a set of recommendations to regulatory bodies (EASA/FAA) in light of the atmosphere characterisation performed as part of the project

Indeed, HAIC will provide aircraft manufacturers with enhanced understanding, measurement and modelling capacities of near icing or icing conditions at high altitude. All these capacities will in turn permit the effective industrialization and integration of appropriate detection and awareness technologies on new aircraft products and possibly on existing aircraft fleet and the effective development and qualification of new air data probes and engines.

HAIC will also cover standardisation at international and European level through SAE or EUROCAE regarding pitot probes qualification requirements (SAE AS8006, EUROCAE ETSO C16a), test facility calibration methodology (SAE ARP5905) or operational performance for inflight icing detection systems (SAE AS5498).

These contributions will allow improving aircraft operation in such icing conditions and thus to enhance international flight safety.

Finally, HAIC is promoting cooperation with international working groups and international collaboration. HAIC and many of its partners, as members of several dominant international working groups, will disseminate much of the HAIC results to working groups such as the EIWG, EUROCAE WG89 or SAE AC-9C. Also, on top of the HAIC/HIWC international collaboration to collect cloud data in deep convective clouds, five partners from Australia, Canada and the United States are directly involved in the project. Lastly, several other US based organisations (FAA, Boeing, NASA, GE, Goodrich, etc.) have accepted to join the HAIC advisory board.