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PROJECT FINAL REPORT

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Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

Thomas Richards,
Design Engineer,
GKN Aerospace Services Ltd

Tel: +44 (0)1582 811 249
Fax:
E-mail: thomas.richards@gknaerospace.com

Project website address: http://on-wings.eu

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

4.1.1 Executive Summary

Aircraft ice-protection methods are diverse but all rely upon reliable ice-detection for their effective operation. At present, most aircraft icing sensors use an indirect means of ice detection which is nearly always mounted remotely from the ice accreting surfaces of importance, for example, wing leading edges and engine intakes. Furthermore, current ice detectors are insensitive and cannot distinguish between ice types. The ON-WINGS ice-detection system incorporates, for the first time, ice detection sensors capable of integration within the structure and capable of reliably detecting the presence, thickness and type of ice, including SLD and mixed phase ice, accreted on the surface.

The key objective of the ON-WINGS project was to demonstrate the technology required to provide a primary ice detector for safe flight in icing conditions, particularly in accordance with new FAA and EASA regulations.

The ON-WINGS sensor uses optical technology for ice detection and health monitoring. It is aero-conformal and can be flush mounted into any aerofoil; wing, rotor blade or engine nacelle. It offers the capability of a distributive array arrangement so, in conjunction with an intelligent ice-protection controller, it could activate individual ‘zones’ of an ice protection system, minimising ice-protection power demand by activating only those surfaces upon which ice has accreted.

We also report here the experimental and modelling work to correlate the characteristic optical scattering of different types of ice accreted in dynamic conditions in an icing tunnel with different Liquid Water Contents (LWC), and temperatures. The work demonstrates a correlation of the optical scattering length, in ice, with cloud temperature which can be used to determine the accretion rate as well as information such as LWC and other icing conditions. This method of ice detection has distinct advantages over indirect methods of detection. Aero-conformal ice detection gives information of icing on the wings and can lead to the development of a robust algorithm for determining ice severity, particularly on critical structures of aircraft.

A secondary objective of the project was to develop distributive temperature sensing and strain sensing system using optical fibres embedded in a composite structure. This demonstrated the technical feasibility of the measurement technique although the practical applications of the technology suffered from the significant shortcomings, the resolution of which was beyond the scope of the project. Therefore further development of the technology beyond TRL2 was not pursued. It was decided to terminate this particular work package as impractical and to concentrate instead on the Fixed Point Probe (FPP) ice detector development, which by then had a better defined route to exploitation.

Coincidentally, during these investigation, the ON-WINGS project had altered its focus from embedding optical fibres (and the ice detection sensor head being delivered) into the leading edge assembly of an aerofoil to further developing the FPP ice detector. These feasibility studies demonstrated that the challenges of incorporating optical fibres into a composite laminate would require far more development than was currently available in the state of the art. In particular, any future work should focus on the connector design for safely exiting the fibre from the laminate.

SUMMARY

The ON-WINGS ice detection technology has been developed to provide more accurate, more reliable and more capable detection of ice accretion and the icing environment. Accuracy and repeatability have been demonstrated in the GKN ATS Icing Research Tunnel and the detector has undergone limited environmental testing on a PZL W3 helicopter. The detection technology is extremely flexible in its location on an airframe and it enables the direct detection of ice accretion on the safety-critical aerodynamic surfaces.

PROJECT PARTNERS

GKN Aerospace Transparency Systems Luton, TWT GmbH Science & Innovation, University of Ioannina, University of Athens, AOS Technology Ltd, ESW Jenoptik, PZL Swidnik SA (AgustaWestland), Schlumberger (Sensor Highway) and Airbus France SAS.

4.1.2 Summary Description of the project context and objectives

Although aviation safety has improved over recent years, one key area still remains a major cause for concern – icing. In recent years there have been a number of serious accidents that were attributed to the accretion of ice on wings, resulting in loss of lift during final approach, and ultimately, the loss of the aircraft. With the projected increase in air traffic, the congestion in and around airports will necessitate longer holding patterns prior to landing, especially in adverse flight conditions. This will put aircraft at greater risk from ice accretion, as icing conditions are most critical at lower altitudes where the air liquid water content is higher. The increased activity of the aviation regulatory bodies in this area (e.g. the proposed changes to EASA CS-25 appendix C) has resulted more focused research and modelling of icing conditions, but to date, there has been little emphasis on improvements to ice protection and detection systems onboard the aircraft itself.

Icing conditions are part of a complex atmospheric phenomenon experienced by aircraft flying through moist cold air, resulting in the accumulation of ice on the leading edges of the aircraft. The rate at which the ice accretes on the aerofoil, the structure of the ice and most importantly its shape, are dependent on the ambient temperature, liquid water content of the air, the size of the water droplets, aerofoil shape and the airspeed of the aircraft. The ice can assume different shapes, the most dangerous of which are large forward-projecting structures known as “horns” which dramatically alter the airflow over the wing. This causes a significant change in the aerodynamic performance of the aerofoil, reducing lift, changing the aircraft handling characteristics, and can be difficult to predict, and thus to train pilots for taking corrective action. Icing accidents have resulted from experienced pilots reacting to what they believed to be a main wing-stall, when the aircraft was actually suffering a tail stall. In helicopters, icing is particularly critical as the thin aerofoil cross-sections of the main and tail rotors are more prone to icing, generally accreting large “horns”, which dramatically increase drag, demanding greater engine power and reduce lift and control of the aircraft. Another safety-critical area is the engine inlets as ice forming in this area poses a serious risk to the integrity of the fan blades, if it is allowed to accumulate into sections of large mass, as these can cause serious damage if they become detached (deliberately or otherwise) from the engine nacelle and drawn into the engine core. Thus it is important to know the aircraft surface to which ice is accreting, and the existing remote ice sensing methods do not aid this process. Engine nacelles may suffer from condensation ice. This is generally caused by rapid decent from high ‘cold soak’ altitudes into warm moist air. Currently, most ice detectors are fuselage mounted, and do not sense this type of icing condition.

It is well known that ice accreting on the aerofoil has a variety of forms ranging from optically clear or glazed ice, to opaque white ice known as rime ice, and combinations of the two known as mixed phase ice. The loss of an American Eagle ATR-72 commuter flight in 1994 highlighted the significance of a third form, which can occur when an aircraft flies in freezing rain, known as SLD icing. A Super-cooled Large Droplet (SLD) is a large droplet of water, which is extremely cold, but still liquid. Although relatively little is known about the conditions that cause this type of ice, it is generally accepted these large droplets either freeze immediately on impact or break up into smallest droplets that can freeze further back on the aerofoil. Thus SLD ice can spread to a much larger part of the aerofoil and in some cases can extend well beyond the ice protected area of the wing and even into the moving parts such as slats and ailerons. In addition to the danger of frozen control surfaces, this type of ice can also pose a danger to large aircraft with supercritical wings as the rough SLD ice accreted on the wing, disrupts the laminar flow over the surface of reducing lift and increasing landing speeds and the potential for stall.

As aircraft technology moves towards higher operating efficiency, and lower unit cost per passenger mile, serious consideration is being given to the use of polymer composite fabrication whilst moving away from metallic structures. This makes airframes lighter, stronger, with less periodic inspection and maintenance. This change is also coupled with the move away from the use of ‘hot gas, used for powering ice protection systems. Engines operating at higher efficiencies can no longer tolerate the ‘bleed air’ concept currently used for ice protection of leading edge airfoils. As a result of this, aircraft are looking to use alternative ice protection systems. These range from Electro-thermal to Electro-mechanical systems or a hybrid between the two.

With such radical changes in airframe and systems technologies, the sensors used to activate such new systems also need radical overhaul.

There have been few new approaches to Ice detection systems in recent years, and technologies are still based on remote or indirect sensing systems. Also, the use of thermo-forming or thermo-set polymer composites for the airframe structures, into which the new thermal ice protection systems are embedded, may well put the mechanical integrity of such structures at risk, unless the thermal performance of the protection system can be monitored. This is even more critical if any mechanical damage occurs when the aircraft is on the ground. The most likely area for impacts is the wing leading edge, where the ice protection system is installed. If barely visible impact damage occurs here, then thermal run-away of the ice protection system may result.

Also to obtain the best operating efficiency of an ice protection system, the sensors used in its control, need to be co-located with the ice protection system itself. This ensures that any inter-connect wiring is kept to a minimum for weight purposes.

OBJECTIVES

The initial objective of the programme was to produce a robust fixed point optical ice detector sensor with the ultimate objective to develop and demonstrate sensor technology that is fully integrated into an ice protection system mounted in a composite structure which offers real time control. To this end the ON-WINGS project specified, designed, developed and integrated a smart aero-conformal point sensor, capable of detecting:

- **Presence of ice (and its absence)**
- **ice type**
- **ice thickness**
- **icing severity**

The secondary objectives were to design and test (at lower TRLs) advanced sensing concepts to provide a multi-zone based system, each with its dedicated sensor, and control electronics capable of measuring more attributes of an icing encounter (direct Liquid Water Content for example). The specifications, design development and icing tunnel testing programme, as well as the analysis of the results, would require full end-user participation.

As part of the advanced concepts:

a) **Use the point ice sensor to investigate parameters for detecting ice thickness.**
b) **Specify, design and develop a quasi-distributed fibre optic ice sensor which will be integrated in wing-slat coupon with electro-thermal heating capable of detecting the presence of ice at a multitude of points.**

Since the quasi-distributed fibre optic ice sensor requires the integration of optical fibres directly into the composite structure of a wing, the tertiary objective of the project was to investigate using optical fibres as part of a health monitoring system. Of particular interest was distributed temperature sensing of the heating zones of the ice protection heater mats to provide feedback to the electro-thermal control system, and protect the composite substructure from any adverse thermal influences.

As part of the advance concepts a “threshold” impact detection method was also investigated with the aim of detecting impacts that may lead to delamination of an electro-thermal ice protection system. Such delamination within the electro-thermal ice protection system may lead to thermal run-away of the heater element itself.

To achieve this, several technological challenges had to be addressed in the two key areas, namely in the ice sensing technology and associated data processing, and secondly the integration of the sensor technology into the ice-protected airframe structure.

4.1.3 Description of the Main S&T results/foreground

THE ON-WINGS ICE DETECTOR

The ice detection technology of the ON-WINGS system uses the optical properties of ice in order to determine its thickness, type and the onset of icing, by using the optical scattering of light in the ice volume.

In the illustration in Figure E1.1, the ice is illuminated via a laser or other light source channelled through a single optical fibre (known as the source fibre). On each side of the source fibre is an array of 3 optical fibres (known as the receiver fibres) that collect any laser light reflected from within the ice volume back towards the surface of the sensor. The light is reflected back due to scattering, reflection and diffraction of light within the ice structure. This collected light is scattered or reflected from the micro-cracks and micro-bubbles trapped in the ice volume. Generally, ice has a very complex crystalline structure and it varies in appearance, hence in optical properties, depending on the differing crystal structure at various temperatures and upon the amount of air trapped within the ice during its formation.

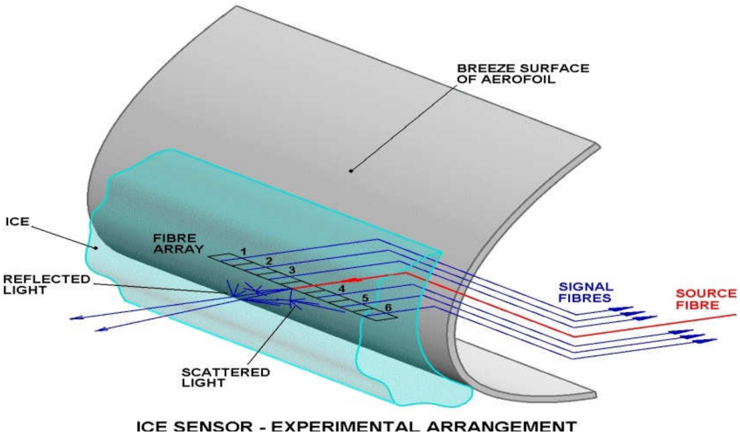


Figure E1.1: Schematic diagram showing how the ON-WINGS ice detector sensor works.

An algorithm developed for use with this detector has demonstrated that the optical signals can also be interrogated to measure the rate of ice accretion (and hence determine the severity of the icing encounter) and the thickness of the ice that has accreted as well as the presence of ice. The unique capability of the ON-WINGS sensor is that the fibres are mounted behind a window that can be shaped to match any aerodynamic surface. This allows the sensor to be flush-mounted with the leading edge of an aerofoil, enabling detection of ice on the actual surfaces where ice accretion is a safety hazard.

ICE DETECTION TECHNOLOGY

Sensor head

The sensor head consists of a single central source optical fibre with a linear array of three receiver optical fibres on each side, all encased in a metal cassette. The source fibre channels the light from a laser into the ice layer while the receiver fibres collect any light scattered back. The optical fibres are parallel to one another and equally spaced. The metal cassette can be designed to fit behind any leading edge structure. The ends of the optical fibres are protected from the external environment by a shaped window. An example of one of the aero-conformal sensor heads is shown mounted in the in Fixed Point Probe ice detector is shown in Figure E1.2.

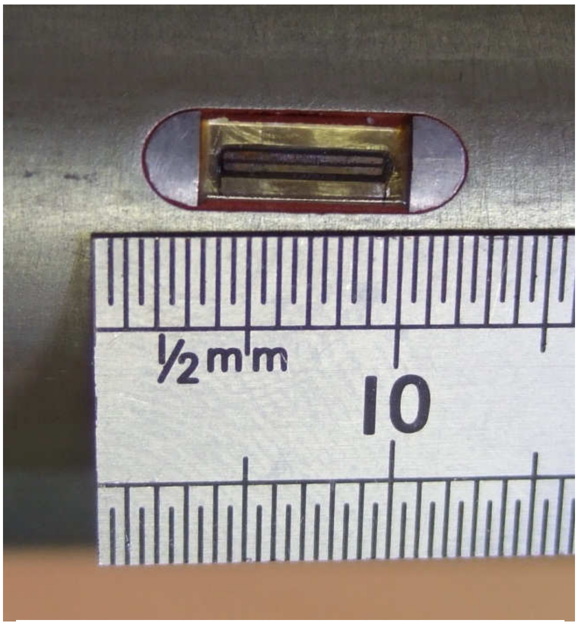


Figure E1.2: An aero-conformal sensor head.

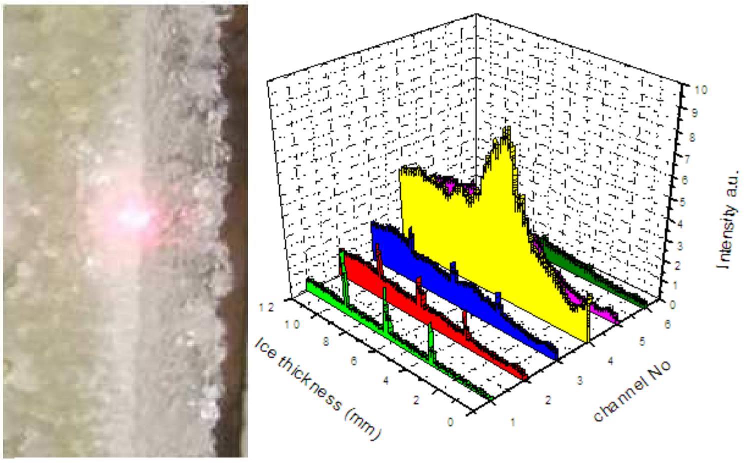
Data Acquisition

The optical signals are converted by opto-electronics to more useful electrical signals where they are amplified and processed by the data acquisition system (DAS). Here the detection software extracts the icing environment information from the raw optical data.

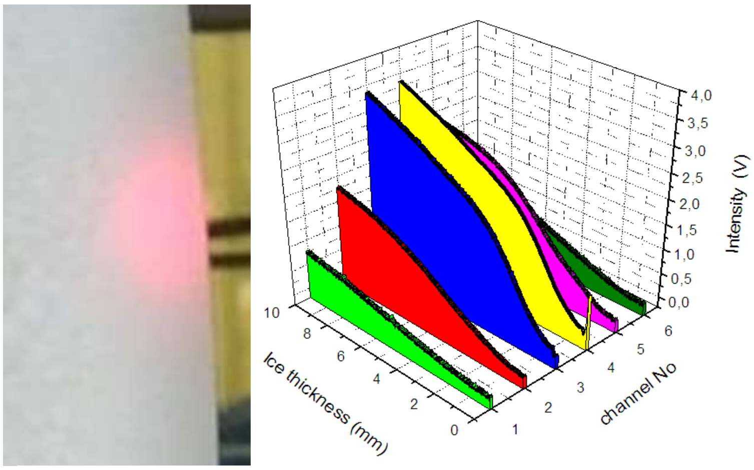
TESTING AND SUMMARY OF THE RESULTS

The aero-conformal sensor head required substantial testing in the GKN Aerospace Icing Research Tunnel in order to demonstrate repeatability of the results. The initial test work focussed on mounting the sensor head within an aerofoil and testing it repeatedly at -5 ºC, -15 ºC and -25 ºC. These temperatures were chosen since the type of ice which forms is different for each one. The Liquid Water Content (LWC), airspeed and droplet size were kept the same.

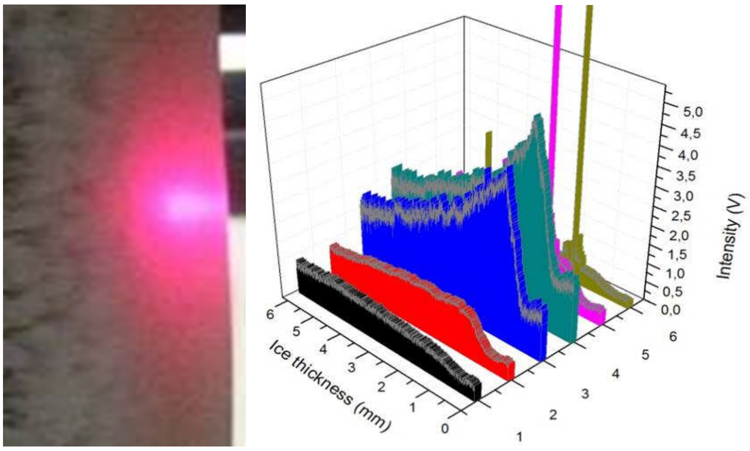
The results from these repeatability runs were fed back to the project partner responsible for the control software to initiate the software development. Example plots showing the difference in raw optical signal for type of ice and thickness of ice accretion is shown in Figure E1.3, with (a) for glazed ice, (b) for mixed ice (combining glazed and rime) and (c) for rime ice. On the graphs, the bottom right hand axis is for each of the six signal fibres (arranged three either side of the source (light emitting) fibre; the left hand axis is for the thickness of accreted ice and the right hand vertical axis is for the intensity of the detected light. On the glazed and rime graphs are sharp peaks in the detected light intensity. These are the result of a laser being shown across the IRT test section to independently verify the thickness of accreted ice on the sensor head. As the ice crosses the laser, some of the laser light is directed towards the sensor head. The photographs accompanying the graphs illustrate the appearance of the different ice types and how the light from the sensor head interacts with the accreted ice. It is these clear differences in the optical signals which allow the software controlling the sensor to determine the presence, type and thickness of ice.



(a) -5 °C Glazed Ice on top of the ON-WINGS ice sensor on the left, with the signal response on the right.



(b) -15 °C Mixed Phase Ice on top of the ON-WINGS ice sensor on the left, with the signal response on the right.



(c) -25 °C Rime Ice on top of the ON-WINGS ice sensor on the left, with the signal response on the right.

Figure E1.3 (a) (b and (c): Examples of the change in received optical signal based on differences in ice types.

Running in parallel to this work package was another aimed one aimed at improving the signal to noise ratio of the sensor head. Various types and sizes of optical fibre were used, and together with improved opto-electronics and Data Acquisition Systems (DAS), has resulted in a more sensitive head design that will be used on any future development of the aero-conformal sensor head.

The following section details the performance of the firmware developed to interpret the signal from the sensor head.

Base data for evaluation

The ice detection firmware was evaluated in a series of icing research wind tunnel tests, both online and offline. The results reported in this section are based on offline tests with 60 sensor recordings where optical sensor data is sampled at a rate of 1.5 samples per second. In addition, accretion of ice was co-registered and measured over time. Each test run comprises one recording of a complete ice accretion process from blank to around 10 mm.

For these recordings, LWC, droplet size and wind speed were kept constant over all 60 measurements. Air temperature was set to -5℃ for the first 20 measurements, -15℃ for the next 20 and -25℃ for the last 20. This is motivated by earlier observations that these temperatures reliably produce the characteristic ice types glaze, mixed ice and rime. With an n of 20 data sets recorded under constant conditions, statistically relevant conclusions can be drawn on the effect of ice thickness and ice type on the sensor signals. It also allows reliable evaluation of the ice detection system which must be able to cope with stochastic variances in the input data.

Presence of ice

Time from water on to first detection

During icing research wind tunnel tests, ice was always successfully detected within the first 24 seconds after beginning of onset for glaze ice, while mixed and rime ice was detected considerably faster. Removal of ice was detected almost immediately (< 2 seconds).

Accuracy of correct detection

Both onset and shedding of ice has always been detected correctly during the tests.

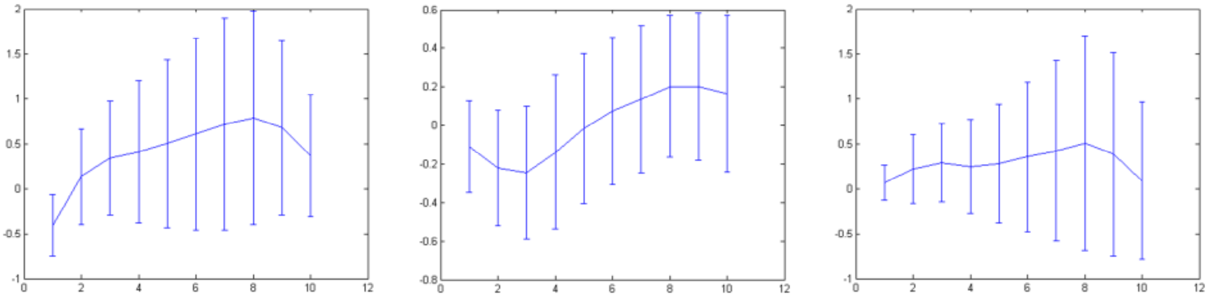
The thickness of ice that is needed to accrete before its presence is detected

Tests reveal that ice is detected after accretion of 1 mm of glaze ice or 0.7 mm of mixed or rime ice.

Thickness measurements

Performance for each ice type

Figure E1.4 shows a supplementary error bar plot putting error in relation to total ice thickness.

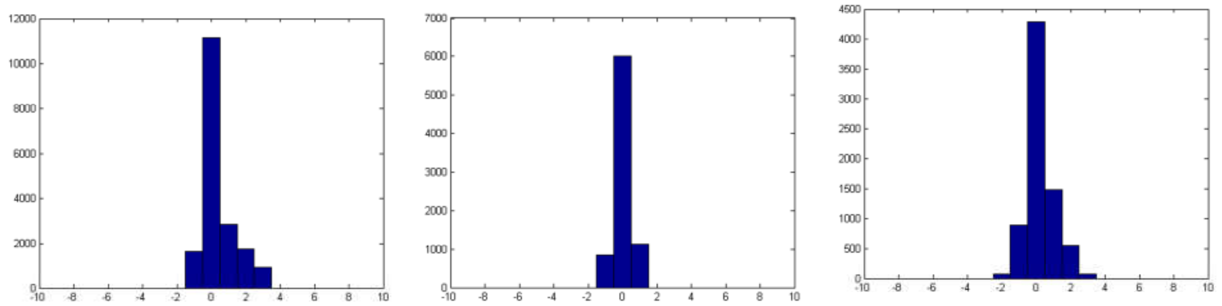


OAT = -5°C OAT = -15°C OAT = -25°C

Figure E1.4: Error bar plot of ice thickness reconstruction error (in mm) versus real ice thickness (in mm). Plots are distinguished by real OAT. Lines indicate mean error, bars indicate standard deviation of error.

A general tolerance on any thickness measurement -

Concerning reconstruction of ice thickness, the achieved precision differed slightly between ice types. For glazed ice, there are even few outliers that deviate by more than 2 mm, but only in the thickness range > 6 mm which is never reached with an active ice protection system. In the range of interest (up to 3 mm), it stays within a tolerance of 1 mm. Corresponding histograms are presented in Figure . They show that errors are distributed normally, with standard deviations below 1 mm.



OAT = -5°C
μ = 0.4111, σ = 0.9394

OAT = -15°C
μ = -0.028, σ = 0.3941

OAT = -25°C
μ = 0.2637, σ = 0.8052

Figure E1.5: Deviation in mm of reconstructed ice thickness from real ice thickness, over all recorded time samples of 20 measurement runs for -5°C (glaze), -15°C (mixed) and -25°C (rime). The y-axis denotes total number of samples falling in the category of the corresponding error range.

Ice type

Classification capabilities

The algorithm has been tested and evaluated with respect to the identification of three types of ice:

- glazed, a watery and inhomogeneous type of ice typically experienced around -5°C
- mixed phase, a very clear form of ice typically experienced around -15°C
- rime, a white ice of comb-like structure typically experienced around -25°C

Accuracy in which it can determine ice type

A minimum of 1 mm of accreted ice is necessary to allow any ice type classification.

- Between 1 mm and 2 mm, ice type is classified correctly for ~70% of the recorded ice accretion measurements.
- Between 2 mm and 3 mm, all test samples with mixed and rime ice were classified correctly and ~75% of the glaze ice samples could be classified correctly.
- After 3 mm of ice accretion, ice type was classified correctly for all tested samples.

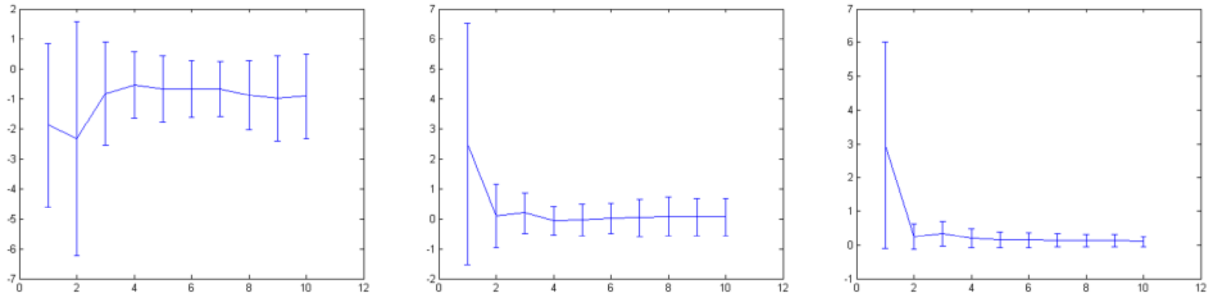
LWC

As an extension to the present version, LWC and wind speed estimation can be integrated. Assumably, LWC and wind speed have an impact on ice accretion rate, from which they could be reconstructed once this impact is quantified, e.g. through corresponding additional wind tunnel tests with variable LWC and wind speed.

OAT

Accuracy of inferred OAT

Accuracy of inferred OAT differs in precision depending on ice type, but it also works significantly better when there is a thicker layer of ice on the sensor. If there is little or no ice on the sensor, reconstruction of inferred OAT is not possible. It is therefore reasonable to also evaluate ice type reconstruction error depending on ice thickness. This is illustrated in Figure .



OAT = -5°C OAT = -15°C OAT = -25°C

Figure E1.6: Error bar plot of inferred OAT (deviation in ℃) versus ice thickness (in mm). Plots are distinguished by real OAT. Lines indicate mean error, bars indicate standard deviation of error.

Higher accuracy is achieved for lower temperatures. Most importantly, this analysis reveals that inferred OAT becomes very accurate for thickness levels >3 mm. This means that at the time when the ice protection system should initiate heating, a relatively accurate estimate of the OAT is available so as to configure an optimal level of heater power.

At the highest temperatures (-5℃, glazed ice), the errors standard deviation stabilizes at <1.5℃, with a mean offset of -1℃. For mixed ice (-15℃), standard deviation improves to ~0.6℃ in the same thickness range. Rime ice (-25℃) allows the most accurate estimation with a standard deviation of <0.3 ℃ with an systematic offset of <0.2 ℃.

Icing severity

Accuracy in measuring rate of ice accretion

Ice needs to be detected to allow measuring the ice accretion rate. The error in measured ice accretion rate (versus real accretion rate) is then observed to be normally distributed, with a standard deviation of ~0,15 mm per mm of accreted ice.

APPLICATIONS OF THE ON-WINGS TECHNOLOGY

Fixed Point Probe (FPP)

Currently, the combination of the sensor head, algorithm and Data Acquisition System in a probe form is the simplest and most mature configuration of the ON-WINGS technology. This probe configuration contains two sensor heads, one mounted on the leading edge and another mounted at an angle offset from the leading edge. The offset sensor is required since, at higher temperatures, (around 0ºC to -5ºC) water may run back from the leading edge before freezing, and cooling due to adiabatic expansion of the airflow means that ice may accrete first aft of the stagnation line. The second sensor can also act as a back-up should the leading edge sensor be obscured. The FPP contains heaters to de-ice the probe in order to start a new detection cycle. Even this simplest configuration of the ON-WINGS technology offers a significant improvement in capability regarding existing ice detectors, as shown by the key capabilities list below.

Fixed Point Probe Key capabilities:

Presence of ice, ice thickness and rate of accretion (also known as icing severity) and ice type.

A FPP was fabricated and tested on a PZL W-3SA helicopter, as well as in the GKN Icing Research Tunnel (IRT). However, because of delays in availability of the aircraft, the first flight test was not in icing conditions. However, a second flight test was conducted at the end of 2012 in natural icing conditions.

A more compact FPP has been designed to be more representative of a production instrument and is currently used for testing in the GKN IRT. It should be noted that the span of the aerofoil containing the sensor heads is merely to ensure that the sensing elements are outside of any boundary-layer effects. The span is otherwise quite arbitrary and may be reduced as required.

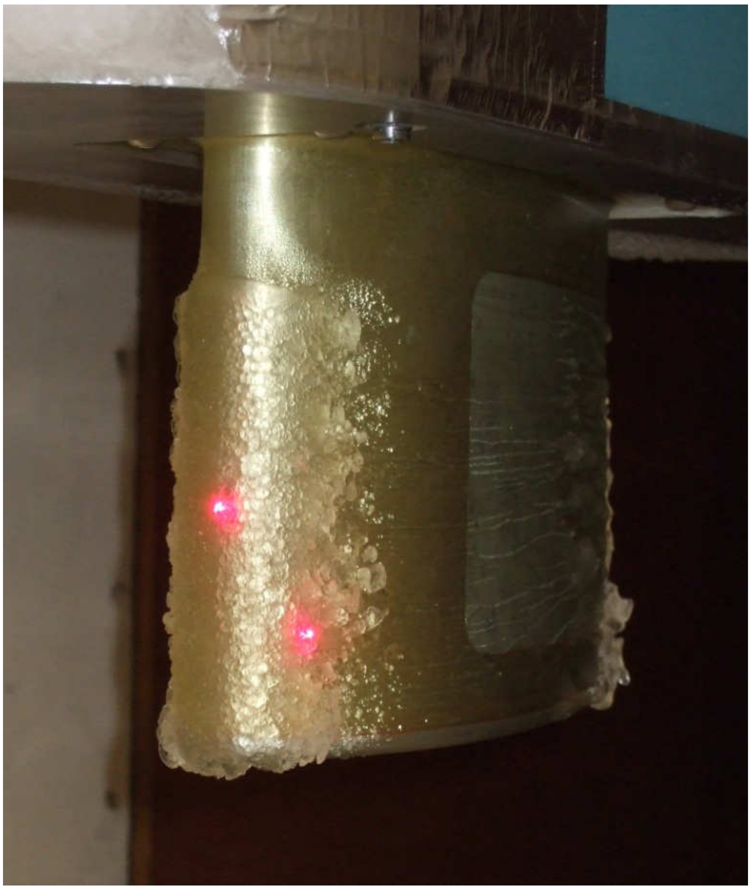


Figure E1.7: FPP in the GKN Aerospace IRT after a test run at -5℃.

Distributed Temperature Sensing System

In parallel with the scattered light detection technology, the Consortium developed a distributed and quasi-distributed temperature monitoring system using embedded optical fibres. Although it successfully demonstrated very good spatial and temporal resolution, the practical difficulties of terminating embedded fibres in the aerofoil rendered the technique unsuitable for aircraft use at this stage of development.

The work package required a high-speed (<1s), fine spatial resolution (<0.5 m) distributed temperature sensing system. A comparison of the time-correlated single-photon counting method and the multi-channel photon counting methods concluded that neither was capable of delivering the required performance, although the latter would be more effective in most cases. A performance model of the direct detection followed analog-to-digital conversion with real data digital signal averaging was built. It was concluded that this approach would likely meet the requirements of this work package.

A prototype was constructed using a new source, receiver, improved-efficiency optics and a new acquisition card. It was commissioned and it was verified that its metrology met the requirements of the project. A route to integrating the results into an ice protection system was provided. Nevertheless, part of the development work was focussed on resolving any manufacturing issues that needed to be overcome before the ON-WINGS technology being developed could be used in a production component. In particular, the team investigated the challenges of incorporating fibre optics into an epoxy glass fibre reinforced composite (in this case Type 6 Spraymat®). This development work was required since the aim was to integrate the optical fibres into a Spraymat® heater mat so that the temperature of the heater elements could be monitored to detect any overheating. However, none of the solutions examined was practical for use with the Test Bed Aerofoil assemblies and numerous problems were encountered with broken or damaged optical fibres during all phases of manufacture and assembly.

Therefore, it was considered that this feasibility study, whilst acknowledging that the detection technologies supporting the study were sound, showed that the physical process of embedding fibres would require much greater development for aircraft use than allowed by the scope of this project. Further applications outside the aircraft industry may be very encouraging.

Structural Health Monitoring System

In a similar development but using fundamentally different measurement techniques, the Consortium developed a distributed strain monitoring system using embedded optical fibres. Although this, too, demonstrated the technical feasibility of the measurement technique, the practical applications of the technology suffered from the same shortcomings as the distributed temperature measurement technology. In view of these difficulties, resolution of which was beyond the scope of the project, further development of the technology beyond TRL2 was not pursued. It was therefore decided to terminate this particular work package as impractical and to concentrate instead on the FPP development, which by then had a better defined route to exploitation.

Coincidentally, during these investigation, the ON-WINGS project had altered its focus from embedding optical fibres (and the ice detection sensor head being delivered) into the leading edge assembly of an aerofoil to further developing the Fixed Point Probe (FPP) ice detector. These feasibility studies demonstrated that the challenges of incorporating optical fibres into a composite laminate would require far more development than was currently available in the state of the art. In particular, any future work should focus on the connector design for safely exiting the fibre from the laminate.

Integrated Ice Protection System

The original goal of the ON-WINGS technology was to embed a sensor head directly into a leading-edge electrothermal heater mat so that the heater mat would only be activated when ice was directly accreting on it. This requirement is due to the fact that currently available ice detectors have to be mounted remotely from the aerodynamically critical surfaces (wings, tail, and engine nacelles) since they are not aero-conformal. This means that extensive flight testing and modelling must be performed to calibrate what the ice detector indicates compared with ice actually accreted upon the aerodynamic surfaces of concern. This remote location can lead to the aircraft’s ice protection system being activated unnecessarily, adversely affecting the fuel economy.

The activation of an Ice Protection System based upon local aero-conformal ice detection was tested in November 2012 in the GKN IRT on a representative aerofoil demonstrator, known in the project as the Test Bed Aerofoil (TBA). The demonstration part consisted of a GKN Spraymat® electrothermal heater mat mounted behind a metallic erosion shield with the heater elements controlled by two leading edge mounted sensor heads, as shown in Figure E1.8. An IPS controller, provided by ESW GmbH, one of our research project partners, delivered modulated power to the heated zone based on the actual presence of ice accreting on the aerofoil surface, as detected by the sensor heads.

Figure E1.8: Test Bed Aerofoil in the GKN Aerospace IRT. This was fitted with two aero-conformal sensor heads.

4.1.4 Potential Impact of the ON-WINGS project

A summary of the main dissemination activities

The ON-WINGS project has successfully demonstrated an aero-conformal ice detection sensor head capable of being integrated in a wide variety of aircraft surfaces, or in a fuselage mounted probe mounted remotely from the main aerodynamic surfaces. Further, the project team has used two of these sensors as part of a real time control system of an electro-thermal ice protection system (IPS) mounted in an aerofoil test section in the GKN Aerospace Icing Research Tunnel (IRT).

The project team has also demonstrated increased spatial resolution (below 0.5 m) of a fibre optic distributed temperature monitoring system.

In order to disseminate these results, the consortium has undertaken a wide range of activities. It is worth noting before proceeding further that the consortium was limited as to what information could be disclosed during various stages of the project by the amount of intellectual property protection that was in place.

Initial dissemination activities revolved around generating end user feedback in order to help guide the project. At the Aerodays 2011 conference, the project's mid-term workshop was held with an audience invited from the aviation community including manufacturers and government bodies such as EASA. The feedback provided during this and subsequent private meetings resulted in a clearer route for developing the ice detection side of the technology being developer (which will be mentioned later in this section). The project team interacted with other Framework 7 funded programmes, including the DAPHNE project which was focussing on developing a common standard for the integration of fibre optics in aircraft.

The project team has presented the research conducted during the project at various international conferences, the full list of which is given in Section 4.2 of this report. The final major dissemination event planned by the project team was the project close out workshop. This was to be hosted by GKN Aerospace at one of their UK sites. The European aircraft icing community is small, and unfortunately the majority of the invitees to the event could not attend the date set for the meeting due to prior commitments on that date. However, all of the manufacturers invited requested private briefings with GKN instead for commercial confidentiality reasons. Consequently, GKN cancelled the event and instead arranged private meetings with the manufacturers in order to promote the ON-WINGS technology. This has attracted some strong interest and again helped to define the exploitation route in aerospace for this technology.

Exploitation of the results in Aerospace and the impact of the ON-WINGS technology

The guidance received from the aviation industry and other end users of the ON-WINGS technology has altered the approach of exploiting this technology within aerospace. As made clear in the project brief, the original objective was to mount the aero-conformal ice detector within an aircraft's important aerodynamic surfaces to enable direct measurement of ice accretion in these areas. However, the end users preferred a more cautious approach of introducing this technology onto aircraft. This led to a focus on a probe incorporating the aero-conformal sensor head as the initial way of introducing the ON-WINGS technology to the market. It was felt that while the original goal of a wing mounted ice detector was correct, developing a probe first reduced the risk of introducing what is new technology onto an aircraft, and would be viewed more favourably by the airframers since they already know how to qualify ice detector probes mounted on the fuselage.

Defining a route to market and exploitation strategy is complicated by the fact that the ON-WINGS technology is modular, and different components can be combined to create different products. The core (and most advanced) technology is the aero-conformal sensor head, opto-electronics and firmware which has been tested in what the project calls the Fixed Point Probe (FPP). There have been two design iterations of the FPP during the project known as FPP1 and FPP2.

The goal of using an aero-conformal sensor head to help an advanced Ice Protection System (IPS) Controller operate an electrothermal heater mat was successfully demonstrated during the project, thus showing that the original goal of a wing mounted ice detector integrated with an IPS is achievable. However, as stated previously, the feedback from airframers briefed on the technology is that they would prefer to see a fuselage-mounted probe introduced first. In order to be appropriate for flight-test, the FPP needs further development. This development will take the aero-conformal FPP from a TRL 4 to TRL 6. Further development beyond TRL 6 will depend upon the FPP performance during any flight trial.

The long term impact of this technology, when it is successfully introduced into the market, will be safer and more efficient operation of aircraft during flight into known icing conditions. When the sensor is integrated into the aircraft structure, flight safety will be improved by () directly monitoring the important aerodynamic surfaces for ice accretion, rather than monitoring remotely on the fuselage. Ice accretion can cause lost of lift and control and has been directly linked to a number of fatal aviation accidents. Improvements in efficiency may be achieved by enabling the Ice Protection System to be activated only when (and where) ice has actually accreted on the important aerodynamic surfaces. Current operational best practice causes the IPS to be activated once the fuselage mounted probe detects ice. However, as a safety measure, this probe is designed to be more vulnerable to ice accretion than the critical aerodynamic surfaces, for example, the wing. This means, however, that the IPS can be activated when there is no ice actually accreting on the wing, which is an unnecessary use of energy provided by the engines. Clearly, more intelligent, more directed use of the IPS can reduce fuel consumption of the aircraft.

As the only aero-conformal ice detection system currently available, this technology helps European industry achieve two key goals set by the European Commission – creating greener, more environmentally friendly aircraft and increasing aircraft operational safety.

Exploitation and impact on other industries

As mentioned previously, the project team succeeded in increasing the spatial resolution of a Distributed Temperature Sensor (DTS) which uses an optical fibre with Fibre Bragg Gratings. Resolution was improved from about 1 m to significantly better than 0.5 m. The requirement to do this was directly driven by the off-shore industry for monitoring subsea infrastructure.

Downhole, there are some thin-layer beds whose thickness means that the present DTS cannot resolve the existing producing layers, or layers that are being injected with (e.g.) water for pressure support (to keep the reservoir flowing when the natural pressure starts to decline). If some layers have very high permeability compared with others, the water will flow entirely into the “thief” zone with two consequences. Firstly, the pressure is not supported elsewhere and secondly, the high-pressure water will break through into the producing wells. Consequently, all that happens is that water is circulated from injector to producer when what is required is oil production, not injected water circulation.

It can therefore be seen that the DTS technology refined during the ON-WINGS programme will play a direct part in increasing the productivity of subsea drilling operations, as well as enhancing safety by improving real time sensing.

ON-WINGS PROJECT LOGOS:

ON-WINGS

ON-WINGS

On-Wing Ice Detection and Monitoring System