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Development of the Atmospheric Icing Patch (AIP) under the SENS4ICE programme

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Requirements

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- The presence of Supercooled Large Droplet (SLD) icing conditions in the atmosphere has been known for many years
  - Referred to in "*Recommended Values of Meteorological Factors to be Considered in the Design of Aircraft Ice-Prevention Equipment*", Jones, A.R. and Lewis, W., NACA-TN-1855, 1949 (referenced in Appendix C)
  - These requirements were incorporated into some standards such as the UK DEFSTAN 00-970
  - SLD not incorporated into the civil certification standards as it was believed that the requirements under Appendix C (standard icing) would provide a safe design
- The loss of American Eagle Flight 4184 at Roselawn resulted in SLD icing research programmes that defined additional icing certification standards under Appendix O for civil certification
- Existing and derivative designs can utilise existing clearances, but new designs are required to demonstrate compliance with these new standards

Requirements

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- Whilst some aircraft may be able to meet the challenges of full operation in Appendix O icing conditions, many aircraft may not be able to achieve compliance (especially in the short-term)
- The certification authorities acknowledged these challenges and included an option to demonstrate detection and safe exit from the SLD conditions
- In recognition of the significant challenges that the industry faces addressing SLD operation, the EU’s Horizon 2020 research programme funded the SENS4ICE programme led by DLR to develop:
  - Direct ice detection systems – with a focus on SLD conditions
  - Indirect ice detection system – systems that monitor changes in aircraft performance
  - Hybrid – a combination of Direct and Indirect detection that provides indication of the presence of both icing conditions and residual ice accretions on exit from icing

Background – Isothermal Ice Detection Probe (IIDP)

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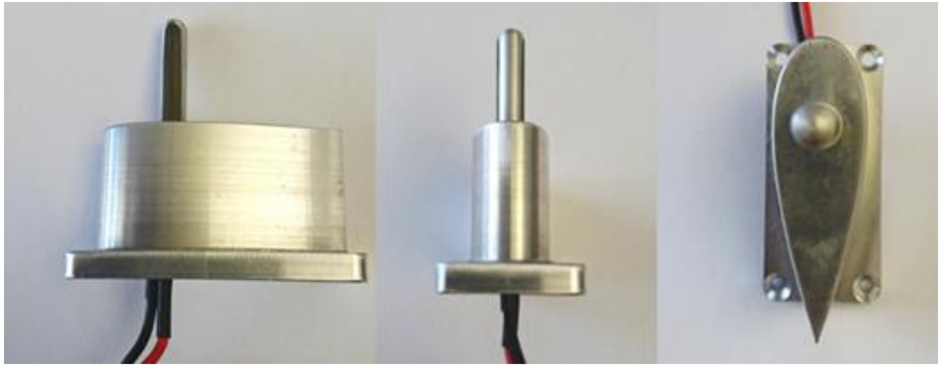
- During the early 2010's AeroTex performed initial development of an ice-detection probe for general icing condition detection called the Isothermal Ice Detection Probe (IIDP)



- Limited testing was performed to demonstrate the basic principle of the system
- It demonstrated that the system detects liquid water, even in conditions > $0^{o}C$
  - No issues associated with the Ludlam limit

Atmospheric Icing Patch (AIP) – Concept

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- Early in the SENS4ICE programme, it was obvious that a probe-based system would not provide the ability to easily differentiate between large droplet and small droplet icing conditions
- Based on our many years of experience across many areas of in-flight icing, the concept of the Atmosphere Icing Patch (AIP) was developed:
  - Recreate SLD identification based on visual cues
  - Conformal with the aircraft surface such that they do not affect the impingement or increase drag
  - Locate sensors in two general areas
    - Appendix C and Appendix O impingement
    - Only Appendix O impingement
  - Low power
  - Icing severity?

Atmospheric Icing Patch (AIP) – Location

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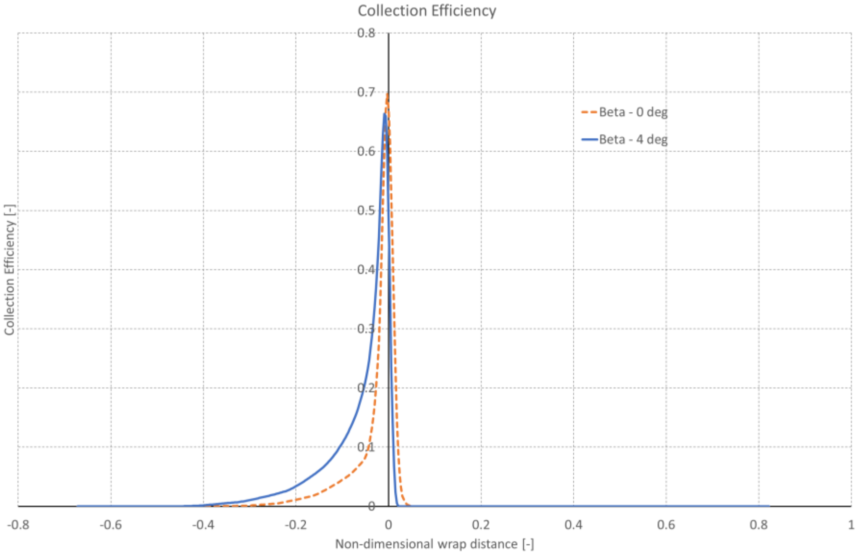
- Many sensors that use droplet impingement and ice growth for the detection mechanism are based on using the wing or a separate aerofoil shaped device
- These concepts encounter several challenges:
  1. The location of the impingement is very sensitive to changes in angle-of-attack particularly for high-lift
  2. At warm conditions, runback from f
     form in areas usually associated wi
  3. For thermal based systems, the hea
     aerofoil changes significantly with a
     complicating correlations
  4. The presence of an ice protection s



Atmospheric Icing Patch (AIP) – Location

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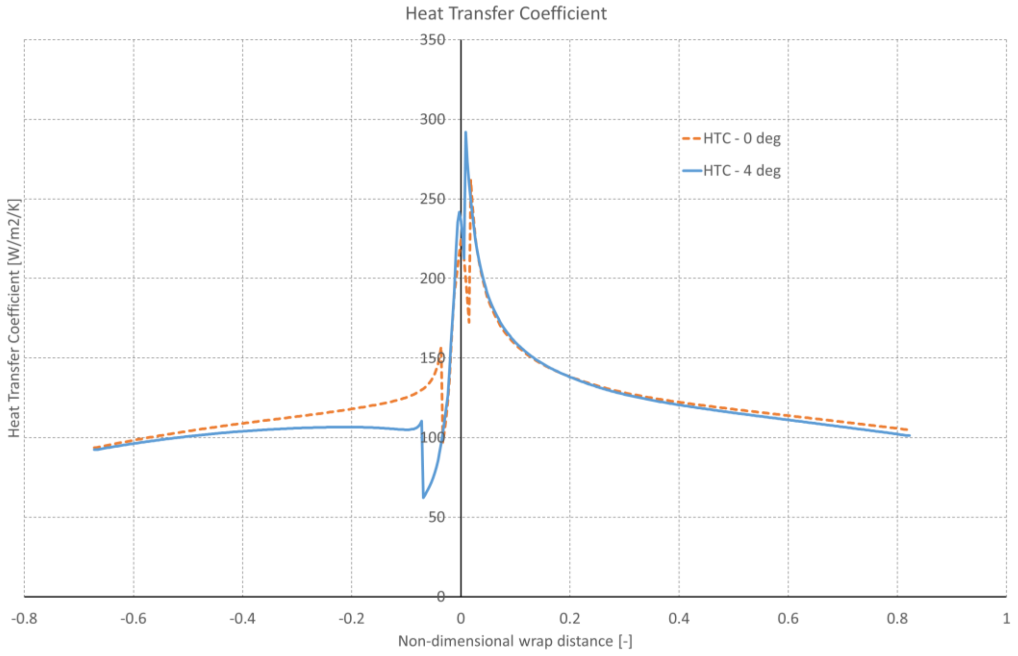
- HTC away from the high accelerations around the nose is reasonably consistent
  - No/low requirement for AoA correlation
- Consistent with visual cues used by pilots for the identification of SLD conditions can be based on a variety of indicators
  - ice growth further aft along a spinner
  - water impinging on the side screens of the cockpit



Atmospheric Icing Patch (AIP) – Location

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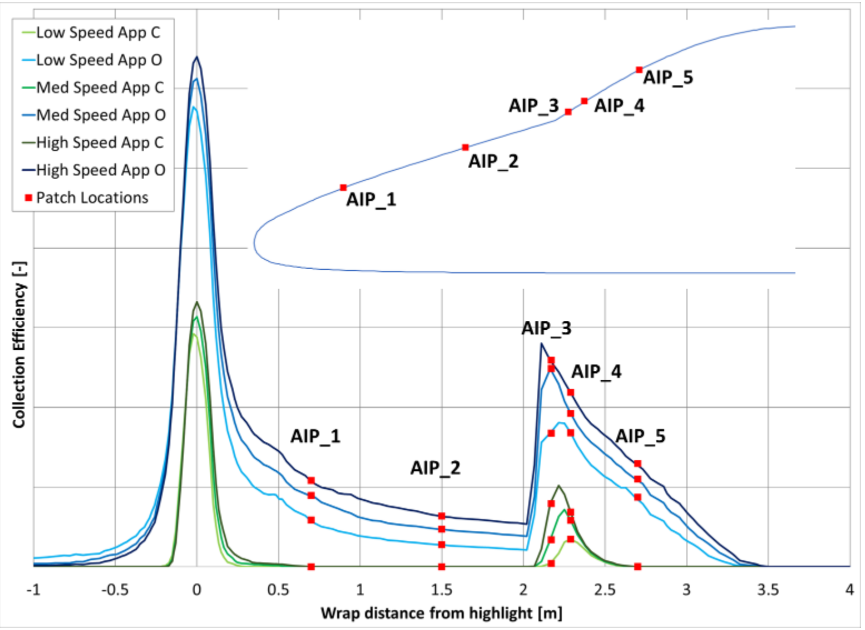
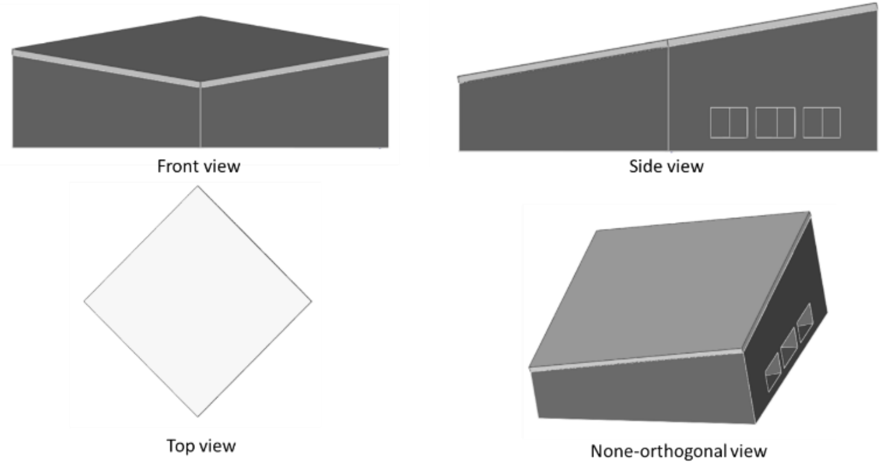
- Embraer provided data for Appendix C and Appendix O conditions along the centreline of the aircraft
- From this data we identified some key sensor installation locations:
  - AIP_1 and AIP_2 are located to detect Appendix O conditions only
  - AIP_3, AIP_4 and AIP_5 are located to detect both Appendix C and Appendix O conditions



Atmospheric Icing Patch (AIP) – Geometry

Planform

- ATX performed analysis based on power required to both overcome the HTC based heat losses and to keep the sensor clear of ice
- Also delivering low power targets for application on a range of platforms/products
  - e.g. UAM/drone/engine
- The resultant sensing element is just 22x22x10mm and 5g
  - Thickness required for SENS4ICE installation



Atmospheric Icing Patch (AIP) – Data Processing

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- A system to process the data, control the patches and identify the presence of icing was produced
- The system communicated with the aircraft flight data stream to extract key parameters such as speed, temperature, altitude, AoA, WoW etc.
- As an additional safety feature for this experimental system, RTDs were embedded at the sensor-to-aircraft interface and were designed to switch off if the temperatures became excessive
- The detection logic was relatively simple:
  - If AIP_3 or AIP_4 or AIP_5 draw power above the correlated dry temperatures, icing conditions were detected
  - If AIP_1 or AIP_2 and AIP_3 or AIP_4 or AIP_5 were observed to draw power above the correlated dry temperatures, Appendix O conditions were detected

SENS4ICE Flight Test – Installation

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- Embraer bonded the AIP on to the outside of the aircraft and the wiring ran in through an entrance port in the forward bay
  - 3 times as many installed for the safety RTDs
- These were then plugged into an interface panel that was in-turn attached to the AIP data processing system
- Time constraints meant that the dry air calibration flights were not performed separately, so dry portions of the icing flight data are used

SENS4ICE Flight Test – Reference Data

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- Reference data against which the AIP could be assessed utilised a Cloud Combination Probe system that is widely used for reference flight testing
- The flight tests were performed between 22nd February and 10th March 2023
- As the SENS4ICE European flight test campaigns were performed the following April, there has not been time for DLR to fully process the data
- Therefore, raw data from the reference probe is presented with modifications as described on the following page

SENS4ICE Flight Test – Reference Data

- The raw data from the reference system identified some icing conditions that are not believed to be “true” icing conditions such as when exiting from cruise
- Under these conditions it was observed that the MVD was very small, therefore the presence of icing conditions from the reference probe were defined as:
  - LWC > 0.01 g/m^3 and
  - MVD > 13 microns
- With this filtering, most of what are believed to be false positive indications from the reference probe were removed

SENS4ICE Flight Test – Presented Data

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- The data to be presented is taken from a single return flight 1475-1 and -2
  - During the outbound flight SLD and one Appendix C icing condition were encountered
  - On the return flight Appendix C icing conditions were encountered
- The AIP processing is designed to only operate when the aircraft is in flight based on a weight-off-wheels indicator from the aircraft data acquisition system
  - Short false positive indications occur when the system is switched on as the system stabilizes on temperature
- During the return flight, the system was switched off whilst other systems were tested, this again produced false positive icing indications once the system was restarted
- The experimental AIP system does not currently include averaging or have a hold on the icing signal when exiting so the results are non-smooth

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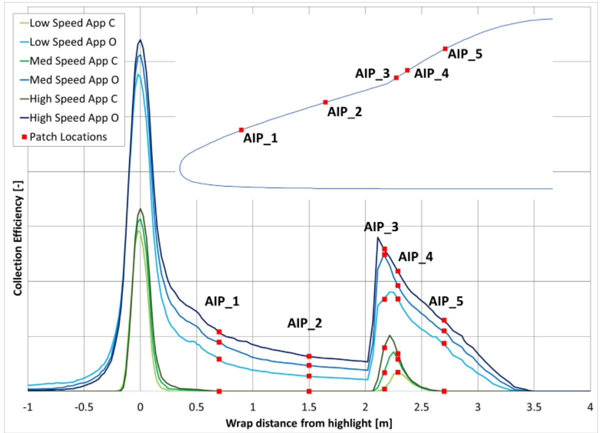
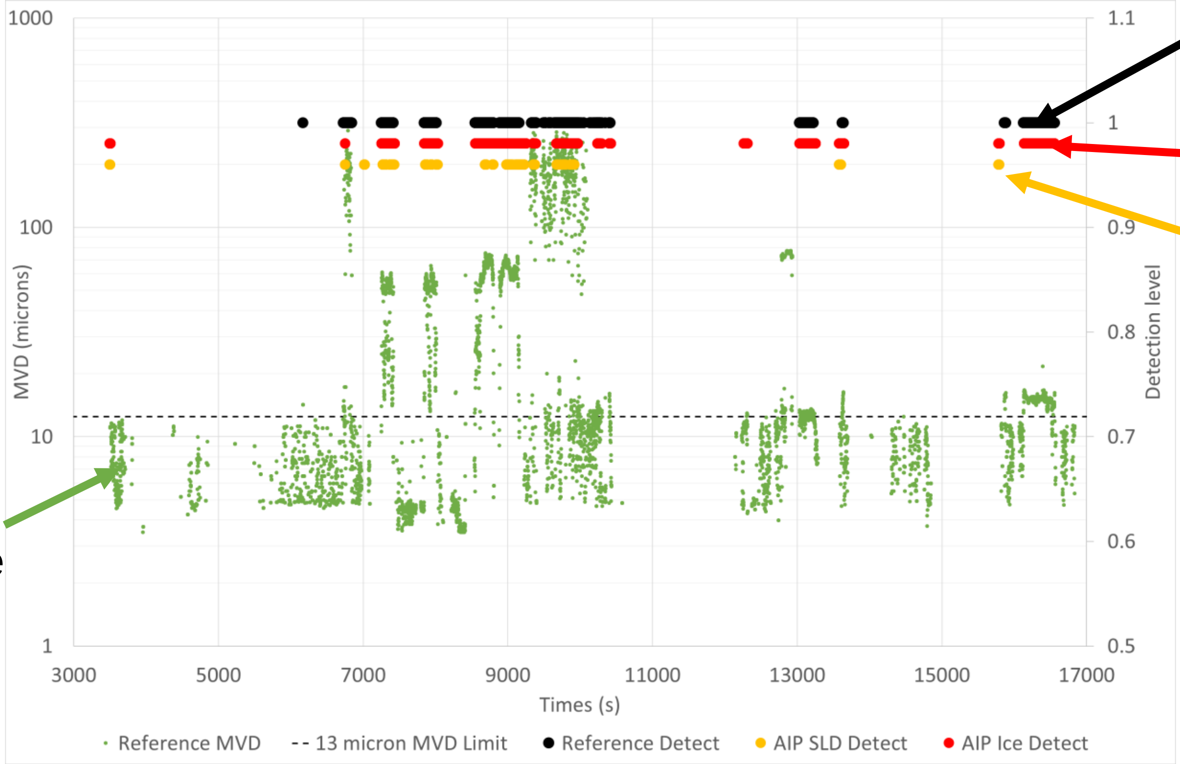
Logic modification

- The data presented is based on a modified logic
  - AIP_2 responded to small droplets which is likely to be associated with the sensor not being flush with the surface, therefore the sensor was removed from the detection logic
  - It was noted that AIP_5 did not respond significantly therefore this sensor could be ignored, but instead it was removed from the logic
  - It was noted that AIP_4 only responded when there were larger droplet but still within the Appendix C enveloped
- The updated logic therefore became
  - AIP_3 only → small MVD Appendix C conditions
  - AIP_3 & AIP_4 → large MVD Appendix C conditions
  - AIP_1, AIP_3 and AIP_4 → SLD conditions



SENS4ICE Flight Test – Test Data



Reference probe detects icing

AIP detects icing conditions

AIP detects SLD conditions

Reference probe MVD

SENS4ICE Flight Test – Test Data

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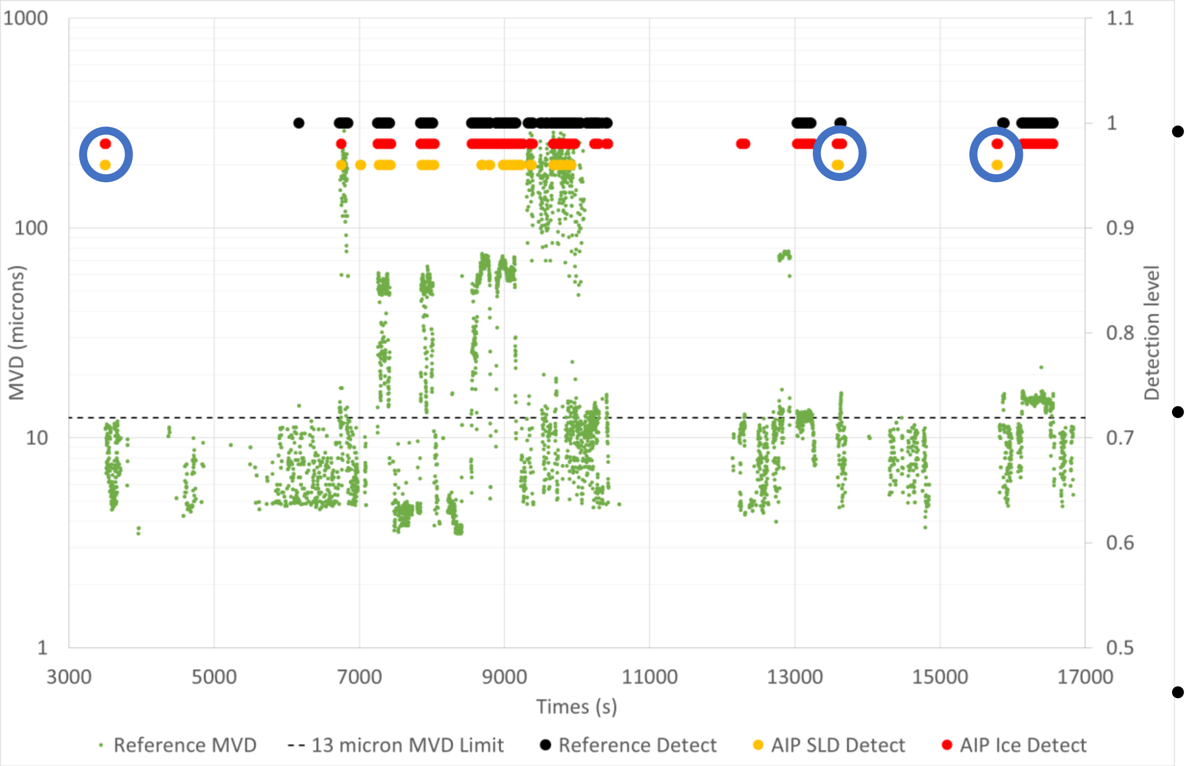

- AIP false positive when the system is starting up
- By comparing the red and black markers, it shows that the AIP system successfully identified the presence of icing
- By comparing the MVD with the yellow markers, the AIP is shown to successfully differentiate between SLD and small droplet conditions
- Averaging and icing signal hold would further improve correlation

SENS4ICE Flight Test – Test Data

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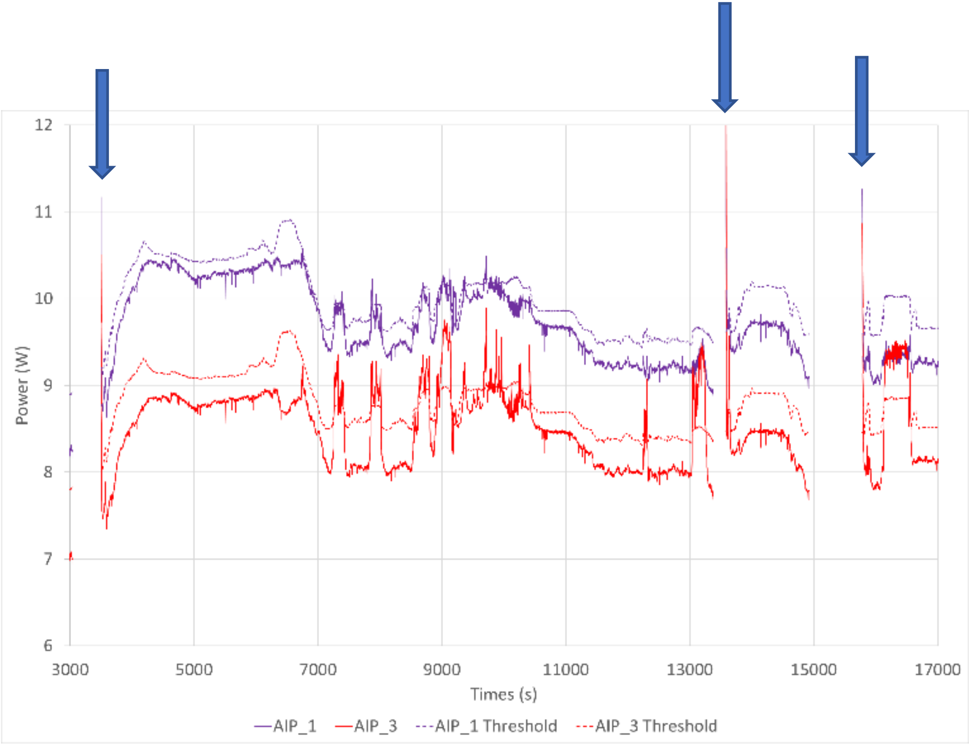
- Example AIP power response data for the flights are shown with the dotted line showing the dry air reference compared to the solid line measured data
- Icing is identified where the drawn power exceeds the threshold
- Some tolerance is included within the system which may be tightened if averaging and icing hold logic is used
- Peaks when the system is powered on can be seen



SENS4ICE Flight Test – Test Data

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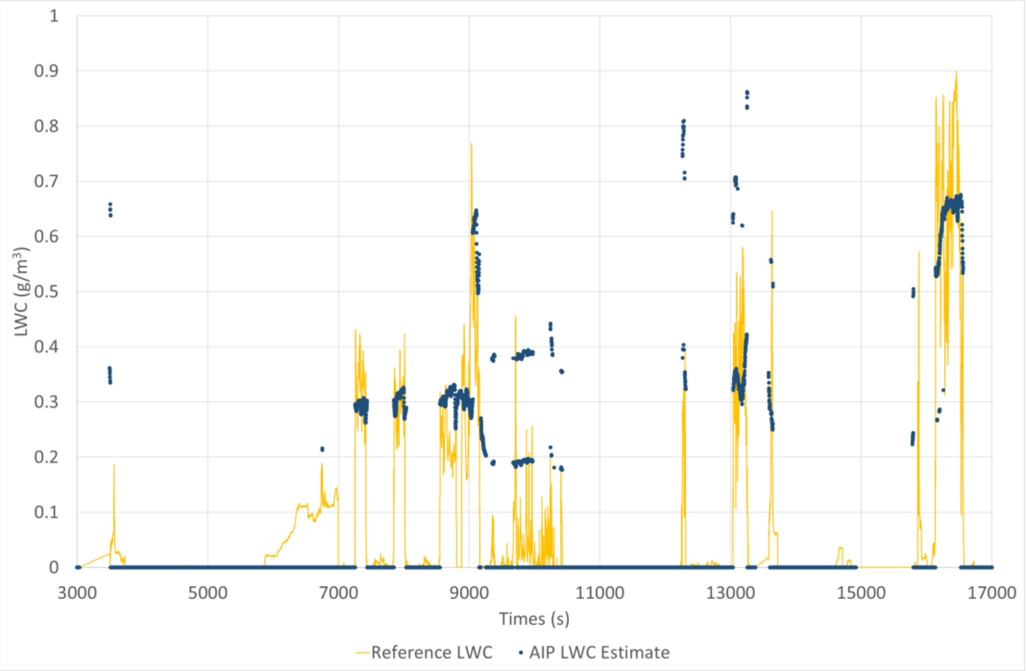
- A trial system to estimate the icing severity in the form of the LWC based on the excess power and approximated collection efficiency has been developed
- The logic combines the power with an assumed collection efficiency depending on the detect logic band is assumed
- Further work is needed to improve the function requiring higher operating temperatures



Conclusions

- This paper has presented results from a flight test of AeroTex's Atmospheric Icing Patch system on an Embraer Phenom 300 platform
- The results show an encouraging correlation against the reference probe and the overall design concept is proven to be both effective and low power
- Further processing of the data is required to identify where and how the system can be improved
- Work planned or underway:
  - better capture the icing severity
  - concept that can be easily integrated onto aircraft platforms
  - develop the data processing hardware & logic
  - work towards certification, e.g. environmental, robustness
  - adapt the technology to address ice crystal icing conditions
  - develop a modular system to address different end-user requirements

Thank you

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SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

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- A particular thanks goes to Embraer who have supported us through the integration and qualification phases of the programme
- We would like to dedicate this work to our colleague and friend Roger Gent, who sadly passed away last year but was instrumental in achieving the programme goals

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