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

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Requirements

- 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

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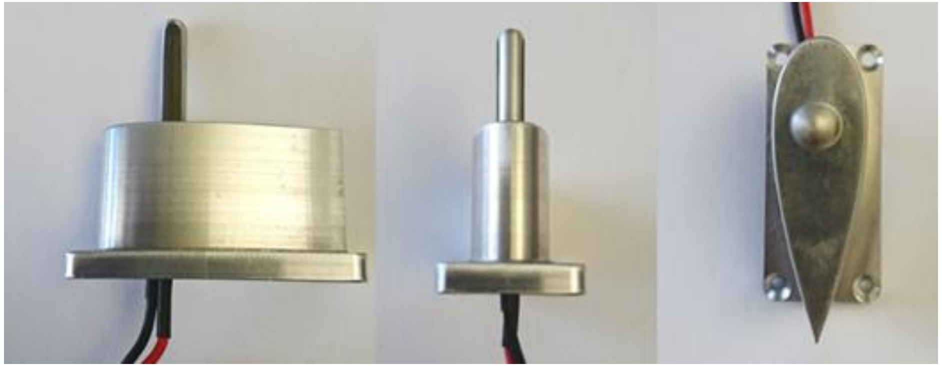
- During the early 2010's AeroTex performed initial development of an ice-detection probe for general icing condition detection called the Isothermal Ice Detection Probe (IIDP)



- 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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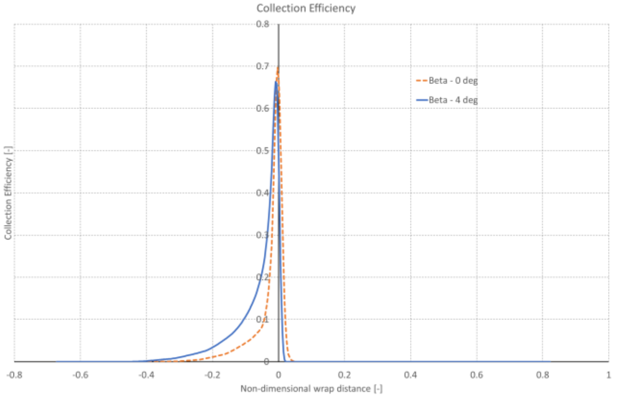
- Early in the SENS4ICE programme, it was obvious that a probe-based system would not provide the ability to easily differentiate between large droplet and small droplet icing conditions
- Based on our many years of experience across many areas of in-flight icing, the concept of the Atmosphere Icing 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?

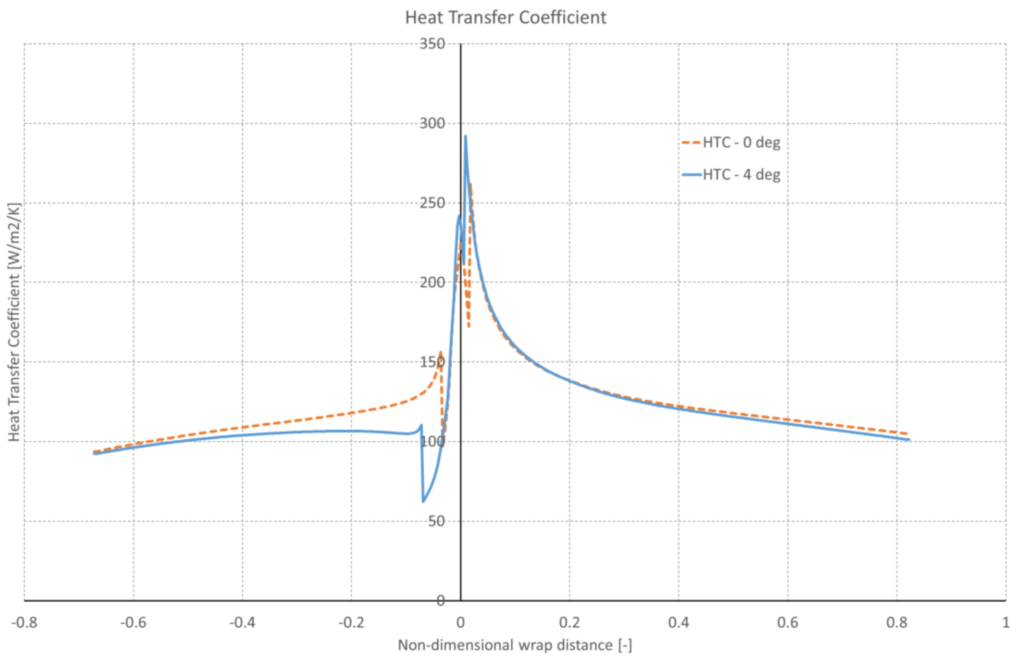
Atmospheric Icing Patch (AIP) – Location

- 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 forward regions can run aft and ice may then form in areas usually associated with SLD
  3. For thermal based systems, the heat transfer coefficient around the nose of an aerofoil changes significantly with angle-of-attack (particularly for high-lift), complicating correlations
  4. The presence of an ice protection system may modify the system response



Atmospheric Icing Patch (AIP) – Location

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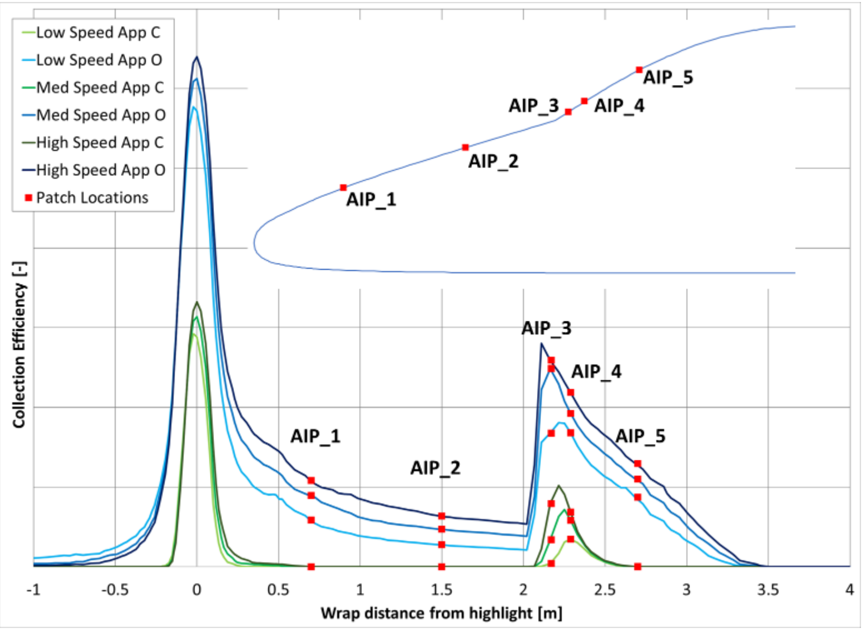
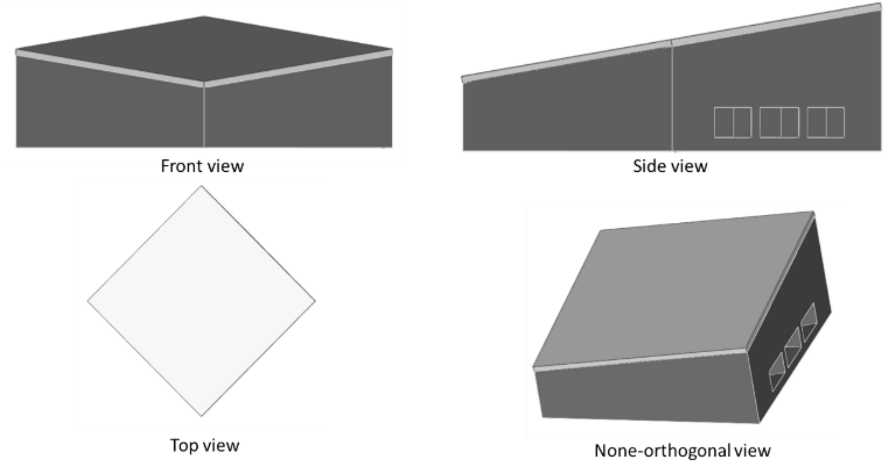
- Embraer provided data for Appendix C and Appendix O conditions along the centreline of the aircraft
- From this data we identified some key sensor installation locations:
  - AIP_1 and AIP_2 are located to detect Appendix O conditions only
  - AIP_3, AIP_4 and AIP_5 are located to detect both Appendix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

- 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

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- 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 <u>and</u>
  - 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

SENS4ICE Flight Test – Presented Data

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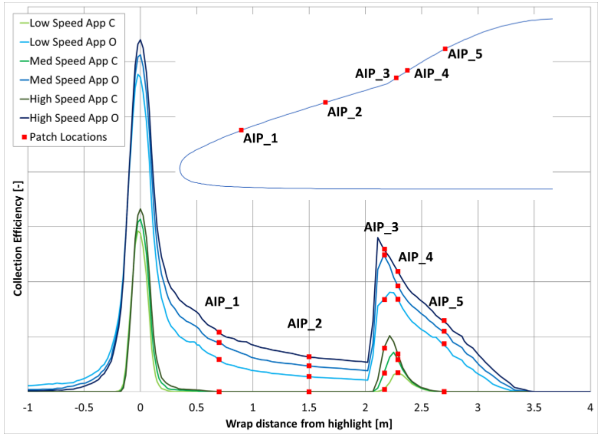
Logic modification

- 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

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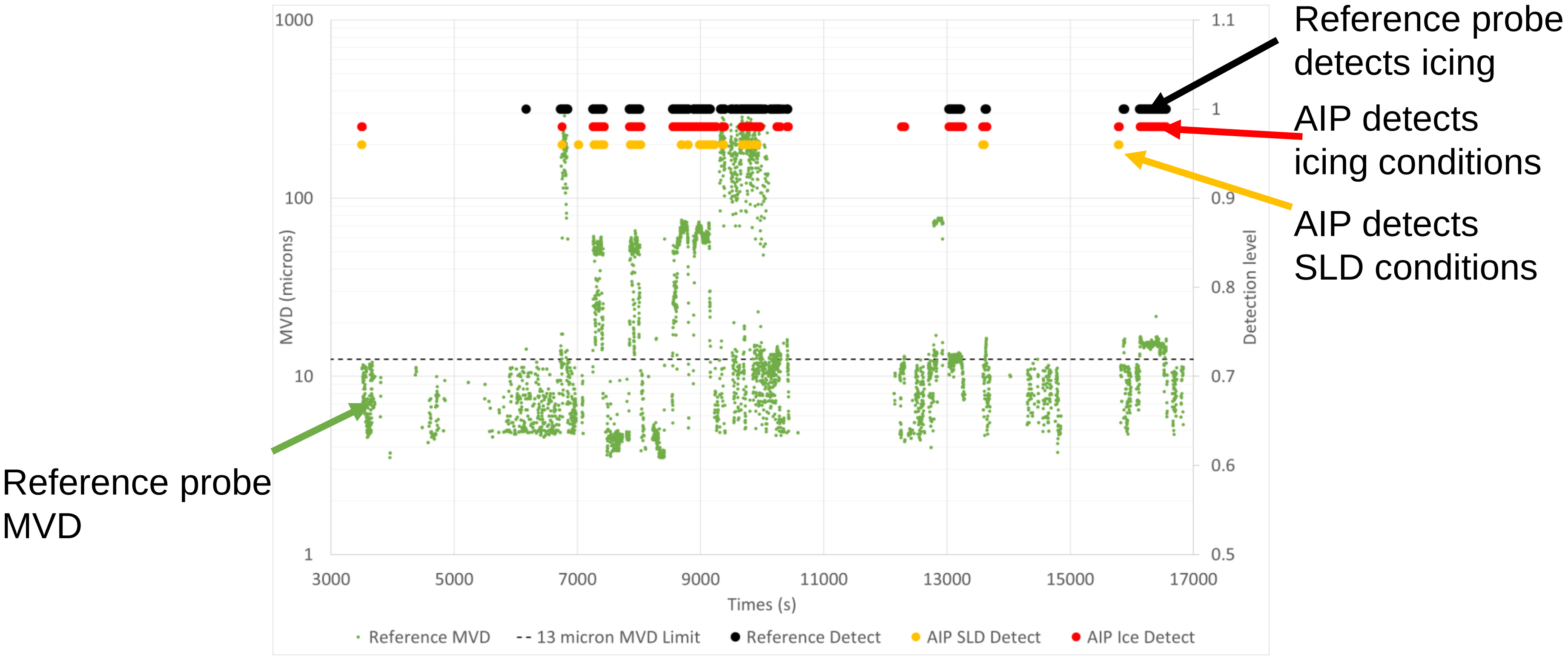

SENS4ICE Flight Test – Test Data

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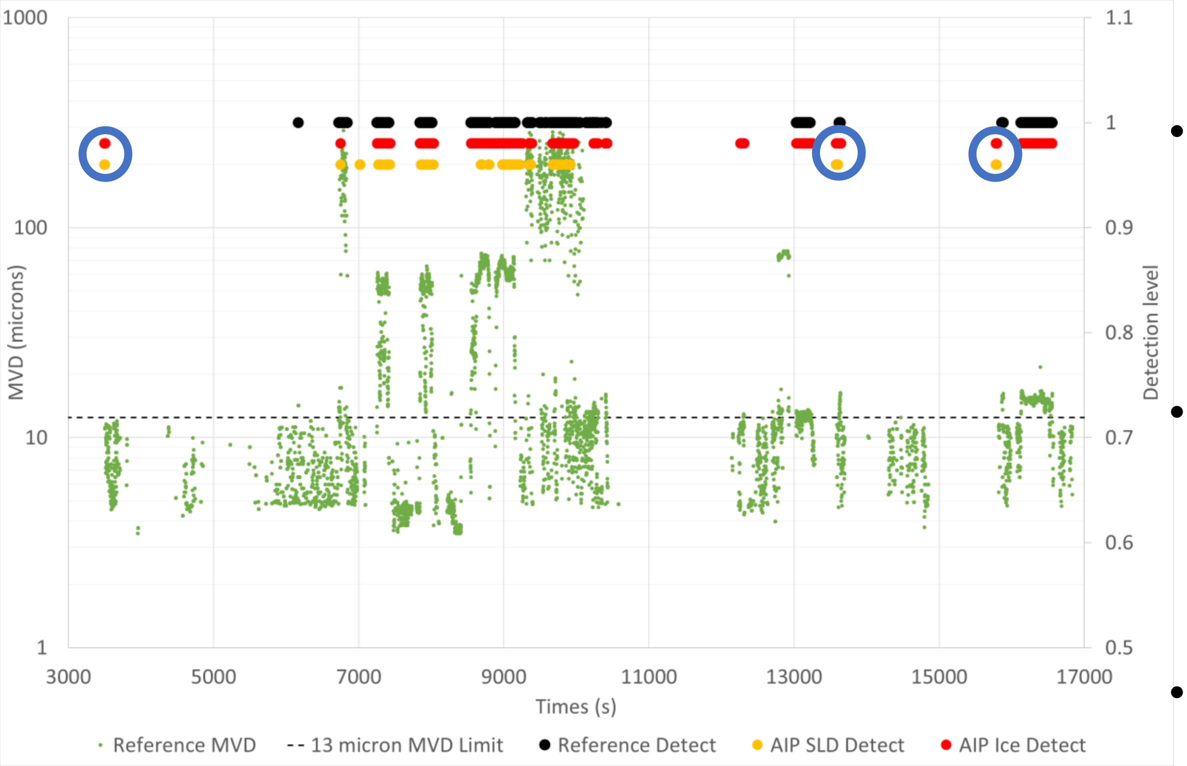

AIP false positive when the system is starting up

- 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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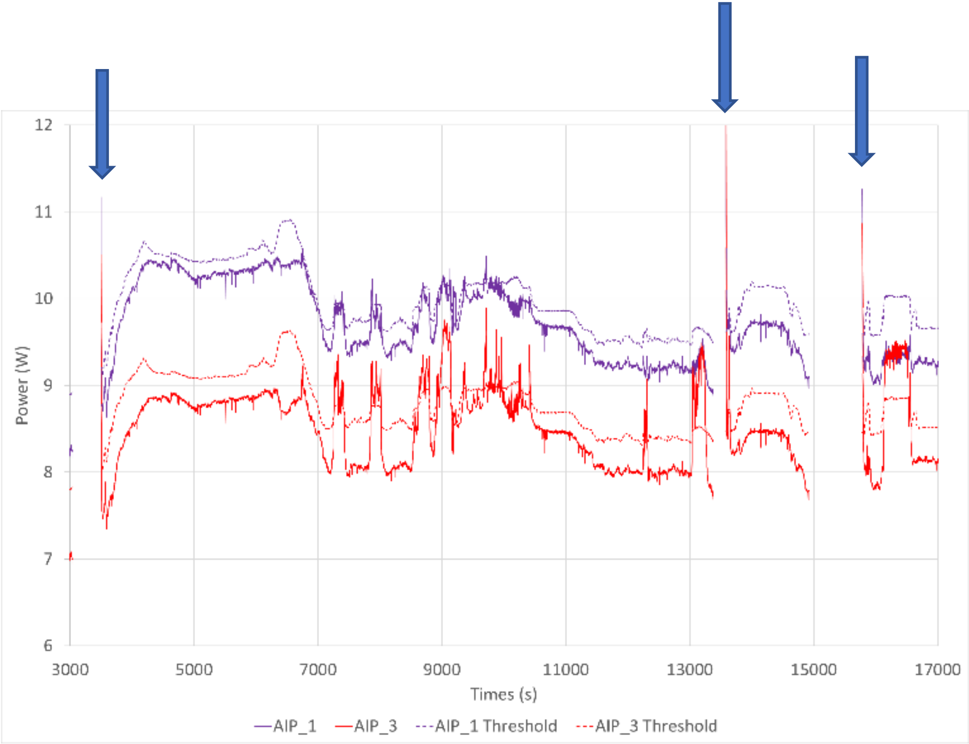
- Example AIP power response data for the flights are shown with the dotted line showing the dry air reference compared to the solid line measured data
- Icing is identified where the drawn power exceeds the threshold
- Some tolerance is included within the system which may be tightened if averaging 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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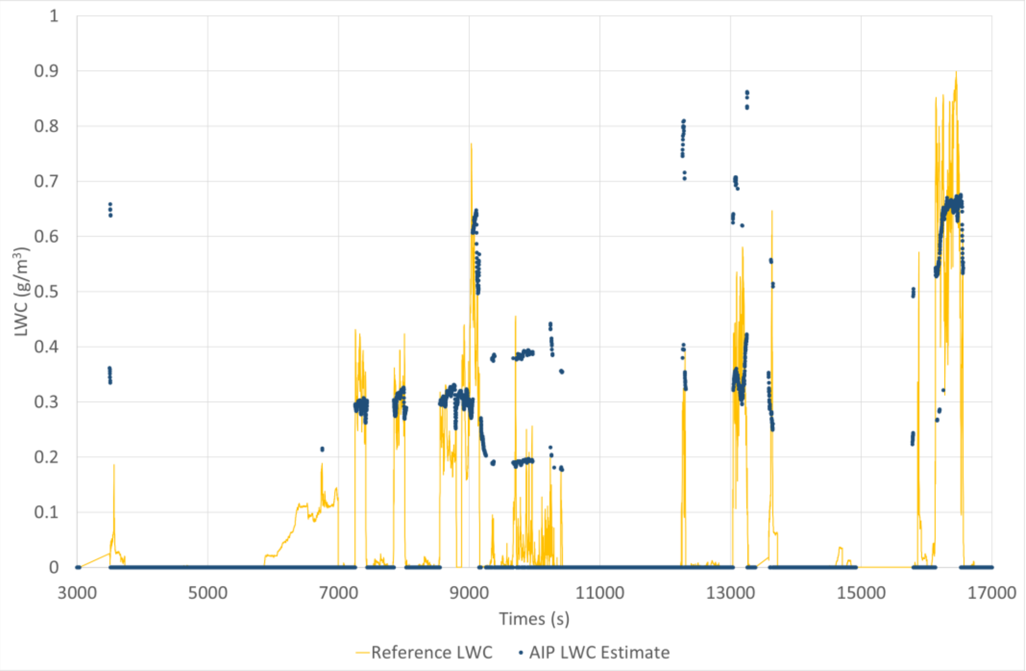
- A trial system to estimate the icing severity in the form of the LWC based on the excess power and approximated collection efficiency has been developed
- The logic combines the power with an assumed collection efficiency depending on the detect logic band is assumed
- Further work is needed to improve the function requiring higher operating temperatures



Conclusions

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- 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

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Thank you

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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