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SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

AIP – Atmospheric Icing Patches

A distributed system for ice detection

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Virtual - 21/10/2021

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 824253

Contents

- AIP concept
- AIP development under SENS4ICE
- AIP testing at NRC
- Test conclusions and design updates

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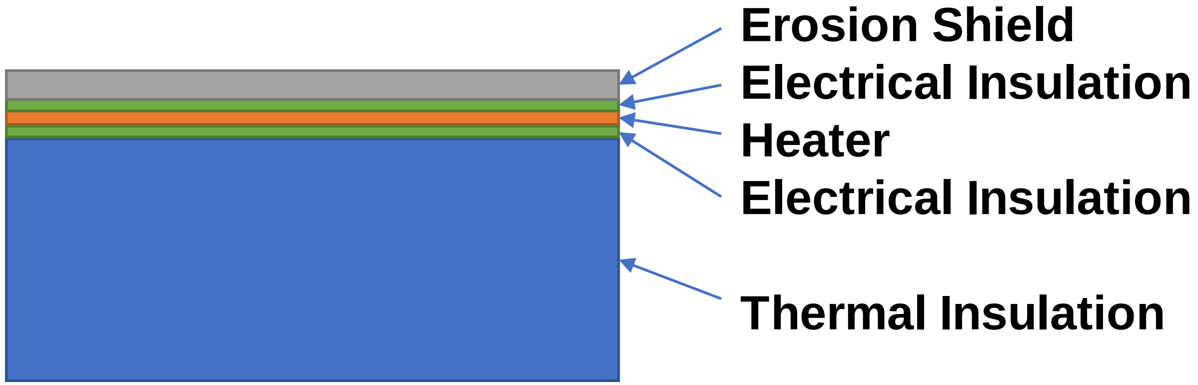
AIP Concept

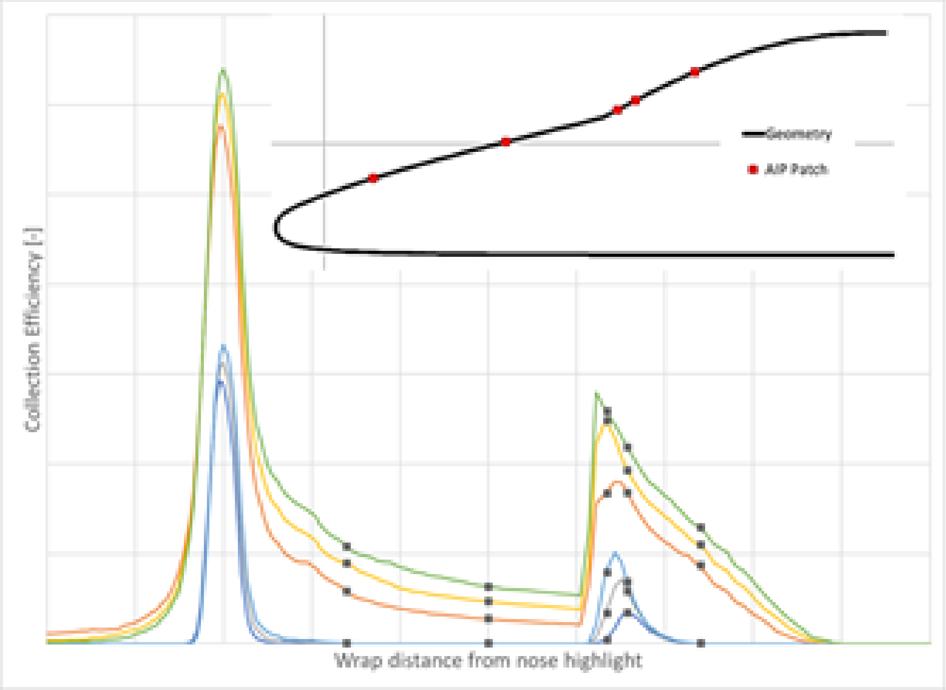
AIP Sensor Concept – Patches

- The Atmospheric Icing Patch (AIP) is designed to be a low power solution to ice detection with a wide application on a range of transport aircraft
- The sensor function is based on relating the power required for an iso-thermal heater patch to maintain a constant temperature
- The patches are small (20 x 20 x 6.5mm) and draw only 25W each – for jet applications
- The heater is intrinsically self-controlling and therefore only requires a power supply



AIP Sensor Concept - Patch Placement

- The primary ice detection patches shall be located in areas where droplets impinge under all conditions
  - Due to the low power consumption, multiple patches can be used for improved functionality across the droplet spectrum
- For SLD conditions the patches can be located such that they are only subject to impingement by larger droplets
  - Multiple sensors can be used for this function
  - By using many more sensors it becomes possible to differentiate between droplet sizes
- Power drawn can be related to the severity of the icing condition



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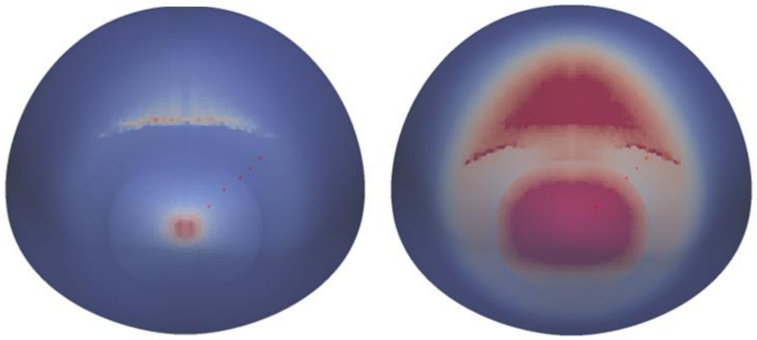
AIP Development under SENS4ICE

AIP Development – Simulation

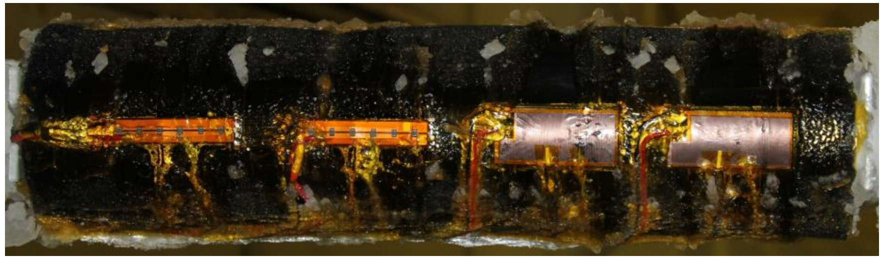
- Significant effort has been put in to simulation activities to determine and optimise the configuration of the sensor
  - Impingement analysis to determine the optimum location for the sensors to enable detection of both standard and large droplet icing conditions
  - The power and operating temperature required for the sensors were determined by performing steady state thermal analysis using the standard governing icing equations
  - Detailed simulation of the heater stack based on the worst case conditions to determine the thermal response/distribution and the power draw under dry and wet conditions



$$Q_{\mathrm{c}} - Q_{\mathrm{ke}} + Q_{\mathrm{e}} + Q_{\mathrm{sw}} = Q_{\mathrm{L}} + Q_{\mathrm{kew}} + Q_{\mathrm{srbw}}$$

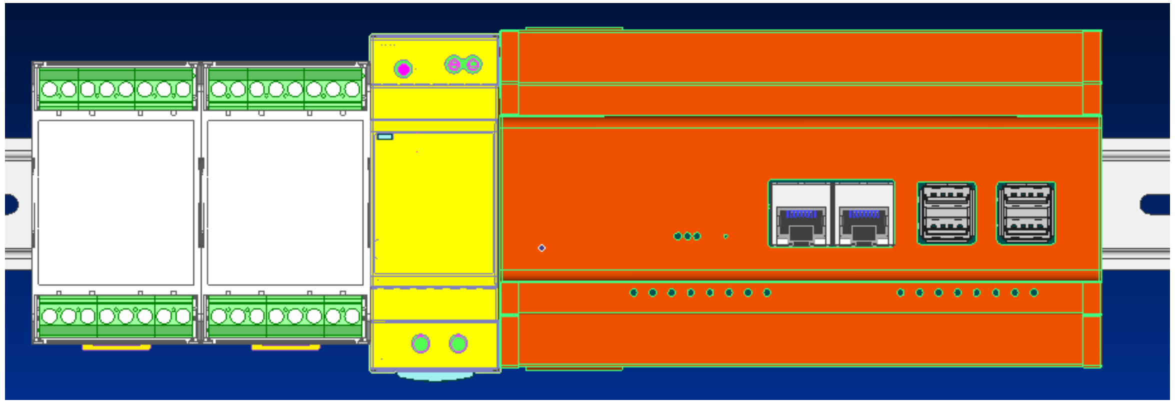
AIP Development – Testing

- Initial icing tests were performed in the RTA icing wind tunnel in Vienna (outside of the SENS4ICE programme)
  - These demonstrated the basic function of the AIP technology on a simplified geometry at low-speed
  - Different technologies were assessed
- Main icing wind tunnel tests were performed in the NRC AIWT facility in Ottawa
  - These tests demonstrated the technology on a configuration that is designed to be more representative of an aircraft nose
  - Secondary technologies were also assessed but these were complex to integrate and therefore are not taken forward
- Towards the end of 2021 further testing is to be performed at the TsAGI VSIO icing wind tunnel facility
  - This uses the heater technology to be used in flight



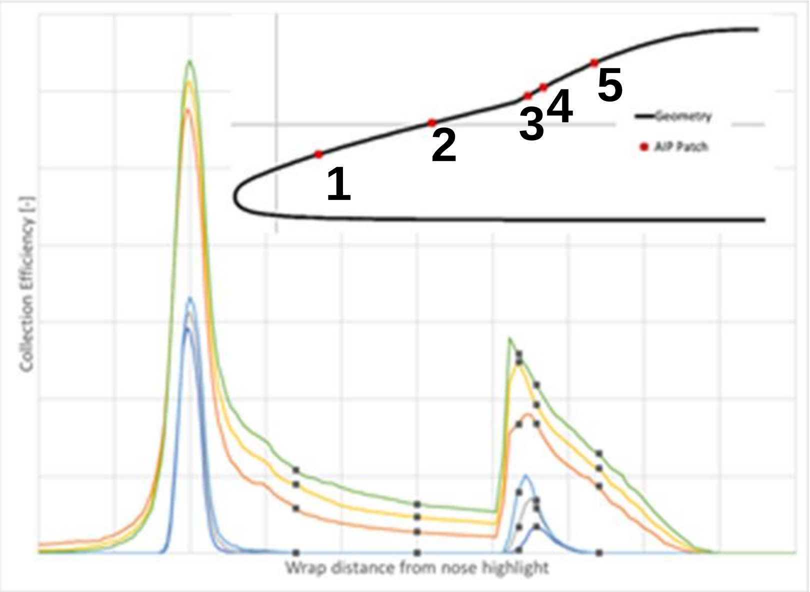
AIP Development – Hardware

- Heater Patches
  - Following on from the RTA and NRC tunnel tests, and using information from the simulation activities the design for the final AIP heater stack has been confirmed and production has started
- Processor
  - For SENS4ICE the processor is based on a Raspberry Pi architecture that takes sensor patch & aircraft signals over ethernet to give icing indication (Orange LRU)
  - The system also controls power switching for each patch
  - Power is supplied by a DC-DC power regulator (Yellow LRU)
  - The final concept will use an integrated chip to perform this function.
- Electronics (White LRUs)
  - The final system will use power monitoring only, however, for safety purposes, additional functions have been added
    - WoW isolation to prevent operation on ground
    - Individual patch isolation based on temperature sensors embedded in the heater patches
    - Manual power-off switch



AIP Development – Software Development

- Processing concept
  - Baseline
    - Dry Power – derived from aerodynamic simulation data that estimates the dry air HTC at the sensor locations for a range of flight conditions
    - Wet Power – based on the icing envelope and water impingement rates
    - Icing Indication – icing at a particular sensor location based on power drawn being greater than the dry power including a tolerance for some variability in the conditions
  - Model updating
    - Reference power models will be updated based on data that is gathered during pre-icing flight trials in dry air
  - Icing Indication
    - Basic icing conditions broken down to; No icing, standard icing or large droplet icing signal
    - If only sensors in the range 3 to 5 respond → standard icing conditions
    - If 1 or 2 respond as well as one in the range 3 to 5 → large droplet icing conditions
    - Icing severity based on power drawn in icing conditions
      - This will only be assessed post test
  - Safety
    - WoW – switch all patches on/off
    - Overtemperature – specific patch on/off



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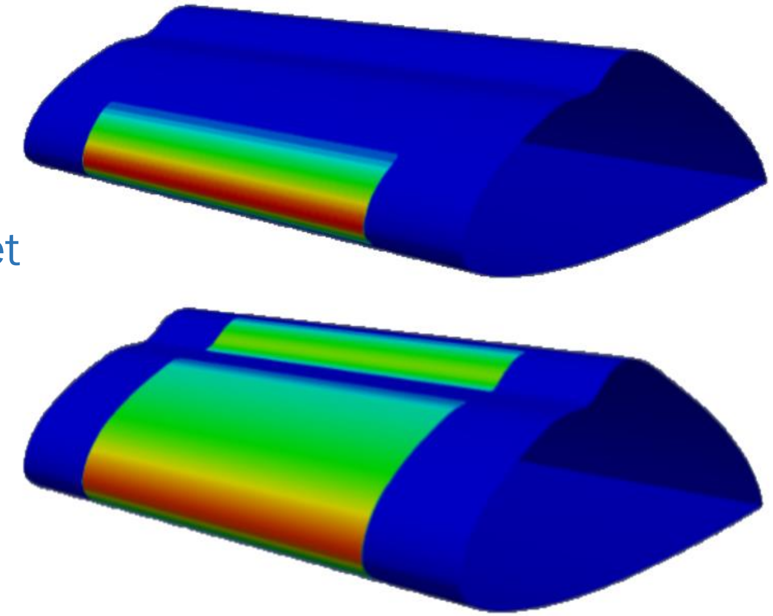
AIP Testing at NRC

AIP Testing Outcomes – The Test

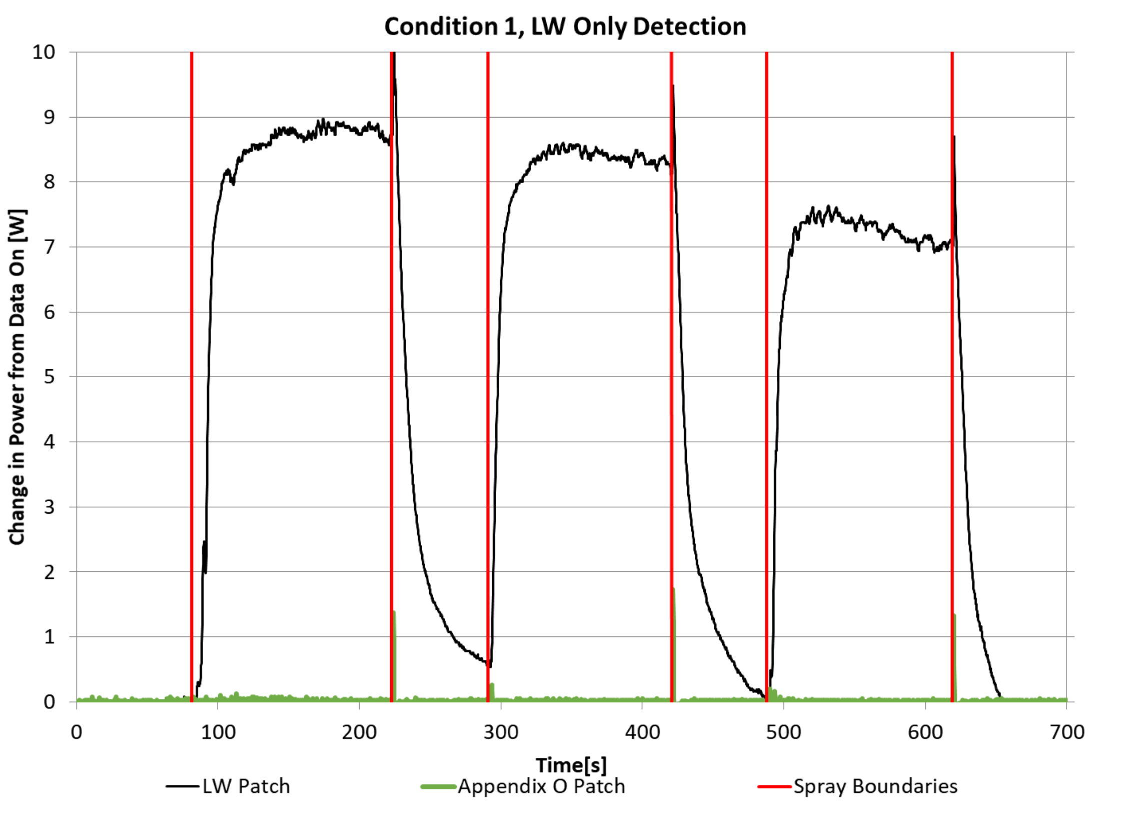
- Results from RTA facility were presented at the SAE meeting last year. The following results are the outcome from the NRC AIWT testing performed in Ottawa in April this year.
- Testing was conducted remotely with data, video and audio accessible over the internet
- Test model
  - The model is designed to be representative of a forward fuselage cross-section
  - Design differentiates between “small” and “large” droplets
    - “Large” droplets for this model are > 30 microns MVD due to model chord limitations
  - Patches placed at the LE to detect all icing conditions
  - Patches on the “bump” to detect Appendix O conditions

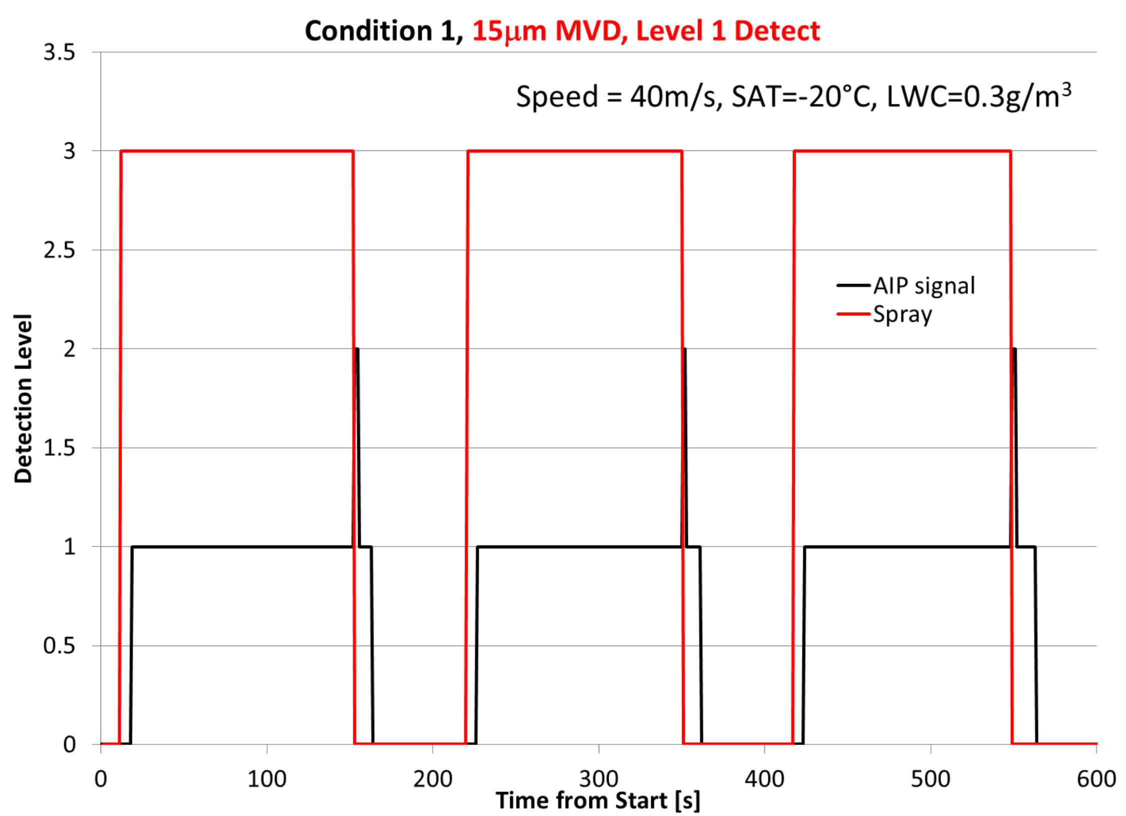


- Test conditions covered
  - Droplet sizes covering Appendix C and O plus unimodal large droplet
  - Speeds from 40 to 85m/s
  - Altitudes from sea level to 15,000ft
  - Temperatures from 0 to -30°C
  - LWC from 0.04 to 2.5 g/m^3
  - Single encounter, repeat encounter and endurance tests

AIP Testing – Results (1)

- Example Appendix C system response



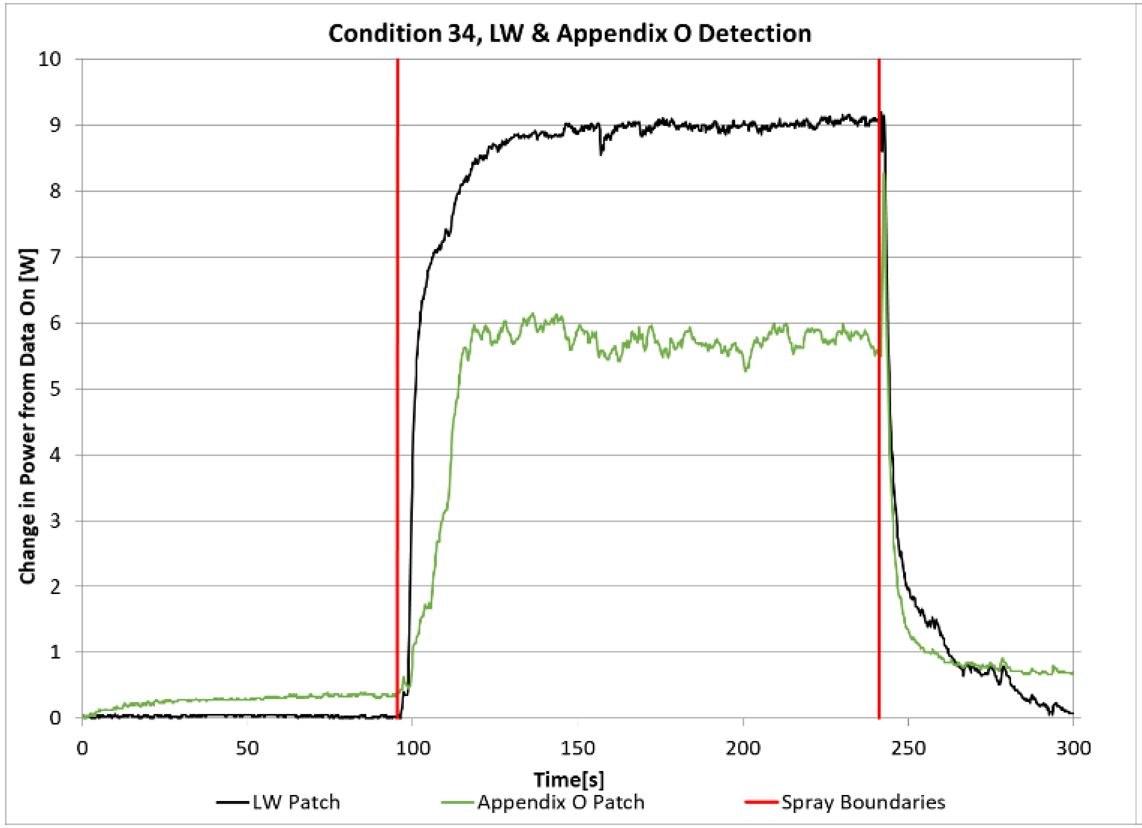


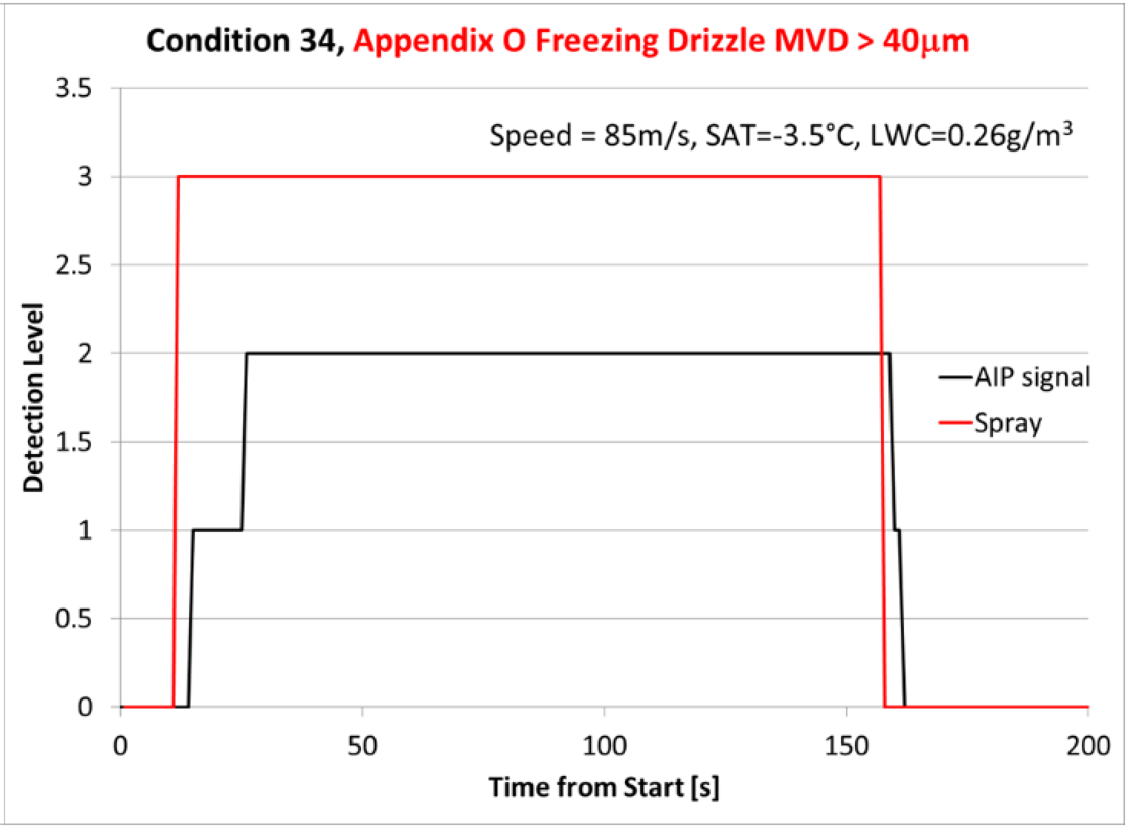
40.1m/s, -20C, 15µm MVD, 0.3g/m³, 0ft

Broad spectrum spray purge at the end of each cycle detected

AIP Testing – Results (2)

- Example Appendix O system response

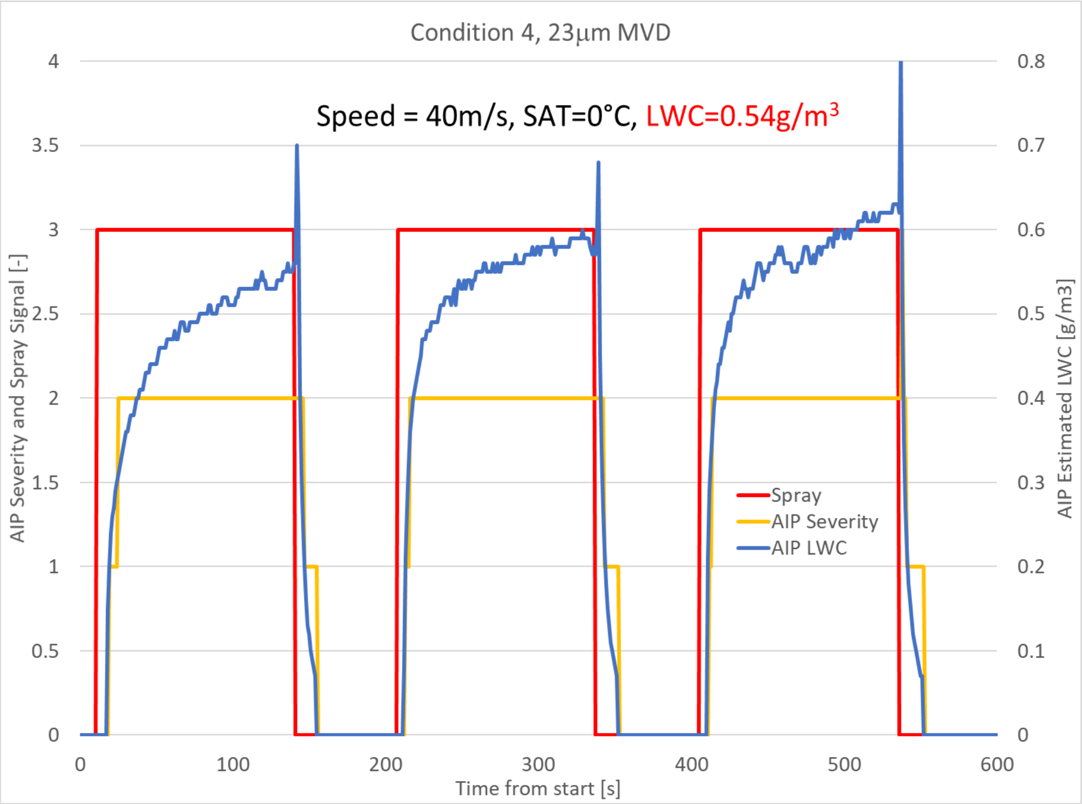




84.9m/s, -3.5C, 110µm FZDZ-, 0.26g/m^3, 0ft

AIP Testing – Results (3)

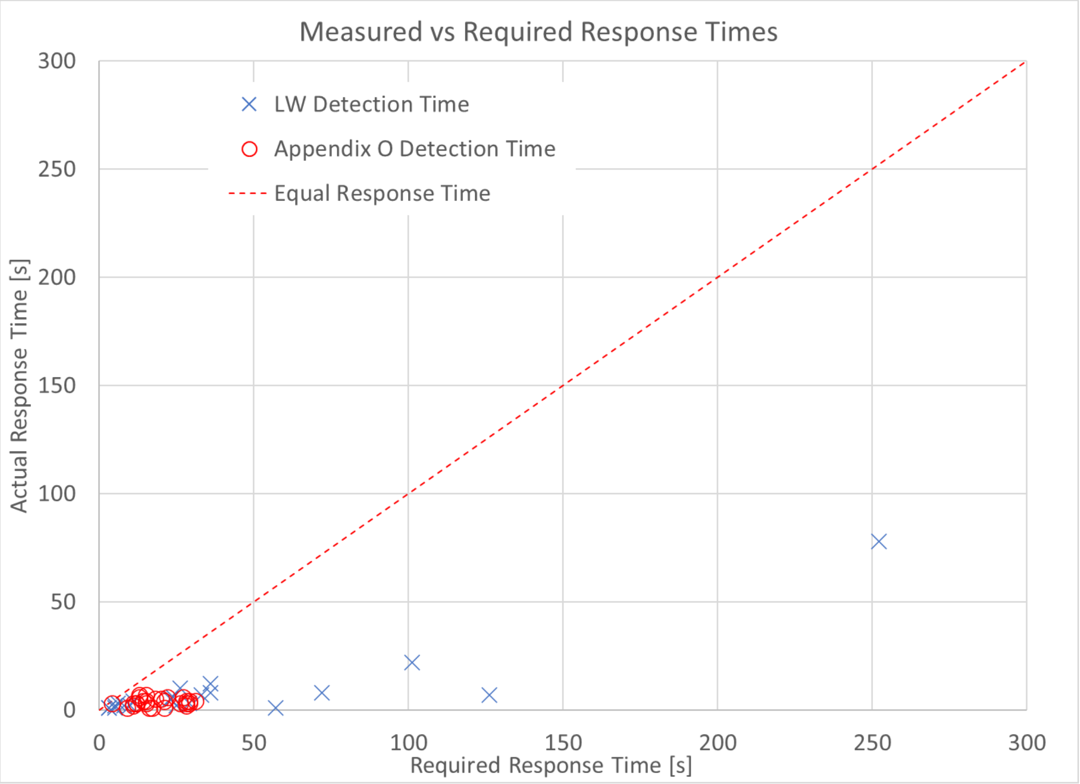
- LWC severity indications
  - A post test assessment was made of using the power draw to estimate the LWC and hence icing severity
    - Light - <0.3g/m^3
    - Moderate - >0.3g/m^3 & <0.8g/m^3
    - Severe - >0.8g/m^3
  - Analysis made use of simulation to account for impingement rate at sensor locations for the specific conditions
    - Assumes excess power is proportional to LWC (not linear dependence due to running wet in IM LWC)

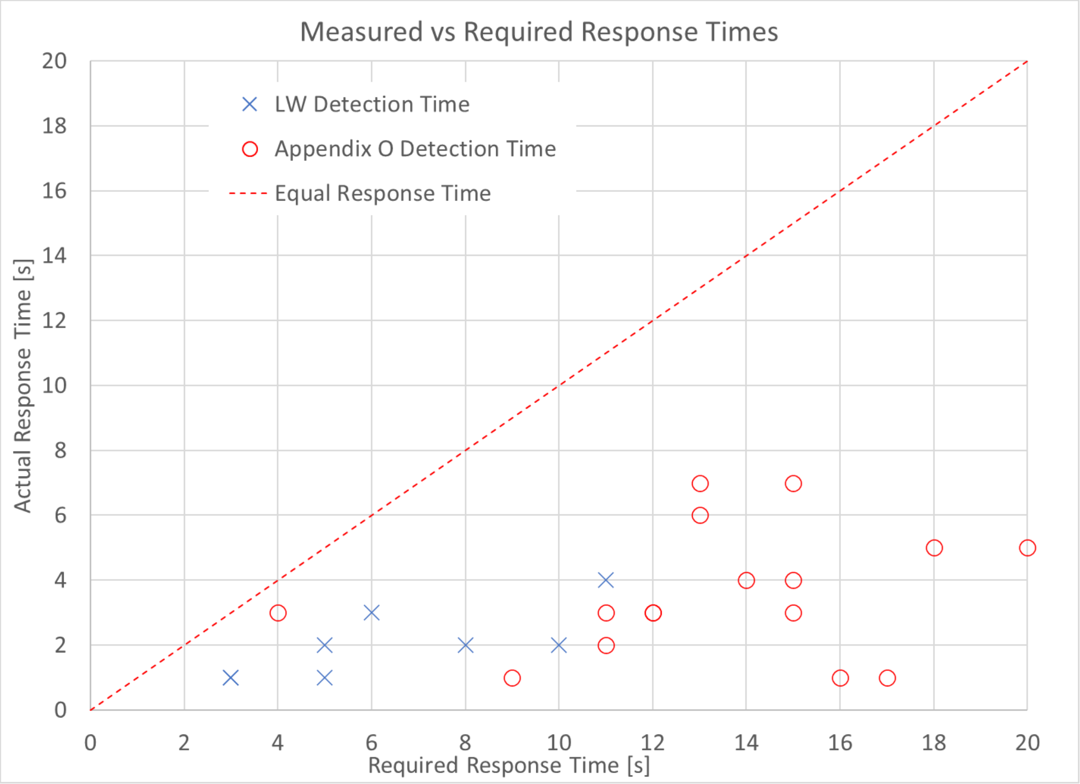


40.1m/s, 0C, 23µm MVD, 0.54g/m^3, 0ft

AIP Testing – Results (4)

- Sensor response times vs required response times
  - Sensor easily met the requirements





AIP Testing – Issues

- Conformal Heater
  - The test patches were conformal to the surface (<1mm thick) and therefore the aft “bump” heaters were therefore susceptible to detecting runback in warm, small droplet, high LWC conditions
- Operating Temperature
  - The test patches were relatively large and had a low operating temperature which meant that the water was not fully evaporated in some conditions and therefore built up aft of the patch
  - In conditions where the water in not fully evaporated, this will impact on the calculation of the LWC

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Test Conclusions and Design Updates

Test Conclusions & Design Updates

- Conclusions
  - The AIP always detected the presence of water down to very low LWC values (0.04g/m^3)
  - There were no nuisance signals during spray off time
  - The sensor responds rapidly to changes in conditions being within the ARP requirements and even detecting the change in conditions due to the spray purge at the end of an encounter
  - Issues were encountered related to the sensor thickness and operating temperature
- Design Updates
  - Based on the outcome of the NRC tests the following issues are addressed in the final design ready for the SENS4ICE flight test on the Embraer Phenom platform
    - Patches will be ~6.5mm thick
      - Preventing direct runback being detected
      - Sensors are less susceptible to accretions affecting the sensor response
      - Any residual water will be stripped-off the surface preventing accretions forming aft of the heater
    - Operating temperatures at the heater will be ~125°C which will mean the sensors are fully evaporative
      - Improved LWC measurement
      - Prevent runback forming aft of the heater
    - Diamond configuration to minimise water pooling in front of the sensor and helping water to run around the sensor body

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If you have any questions about this presentation please contact me on ian.roberts@aerotex.co.uk

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