September 2007

Evaluation of Small Scale Icing Tunnel Test Results 2007-01-3328

Sarah Barley

AIRBUS

Overview

- Introduction
- Ice Accretion Modelling
- Present Ice Protection System
- Options for Electro-thermal Ice Protection
- Assessment of Wing Sensitivity to Icing
- Icing Tunnel Model Tested
- Summary of Testing
- Assessment of Test Results
- Comparison of Test Data with Numerical Predictions
- Conclusions

Introduction

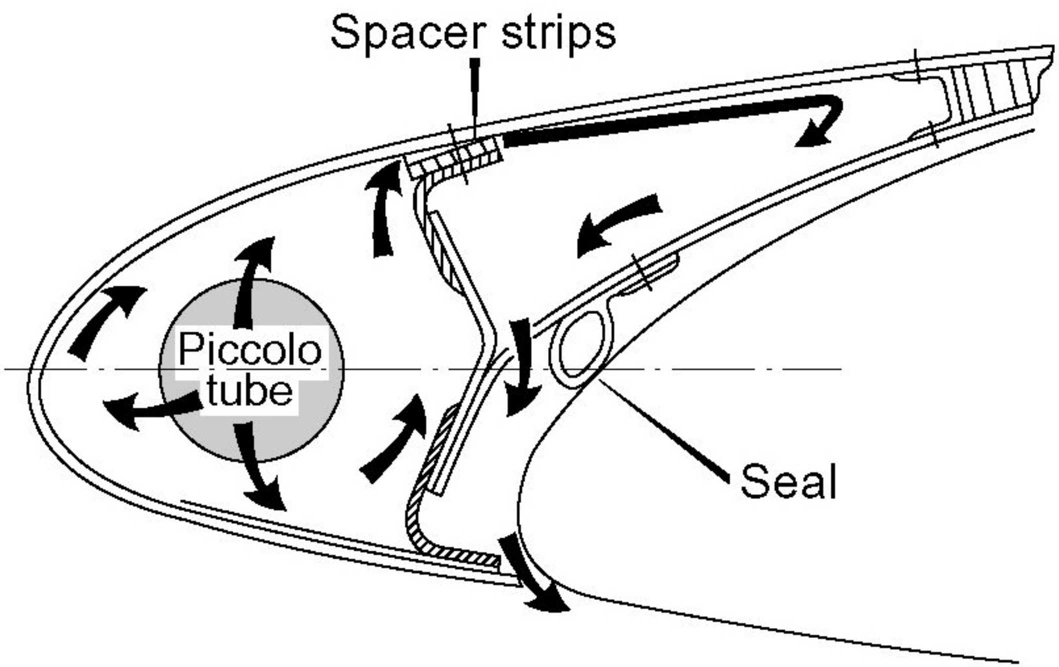
- Integrated Wing Advanced Technology Validation Programme (IWATVP)
  - Develop new wing technologies to:
    - Reduce production and maintenance time and costs
    - Reduce fuel burn and emissions
    - Reduce noise
    - Develop use of electrical technologies for wing systems, including ice protection
  - Removal of bleed air supply leads to need for electrical wing ice protection
    - Electro-thermal ice protection using heater mat technologies
    - Electro-mechanical ice protection using impulsive or expulsive techniques

Ice Accretion Modelling

- TRAJICE (TRAJectory and ICE accretion prediction)
  - Water catch calculations
    - Based upon geometry, droplet diameter, liquid water content, static temperature, velocity and angle of attack
  - Heat transfer and pressure coefficient calculations

- HRB2D (Heater Rotor Blade 2-Dimensional)
  - Heater mat performance predictions
    - Based upon heater mat specifications, operating approach
  - Partially validated code
    - Mostly based upon helicopter blades

Present Airbus Anti-Icing System



- Bleed air system
  - Air is distributed along leading edge and into slat interior
  - Heat transfer via direct impingement of hot air from piccolo tube and wall jet along upper surface
  - Difficult to focus or optimise heat into one region

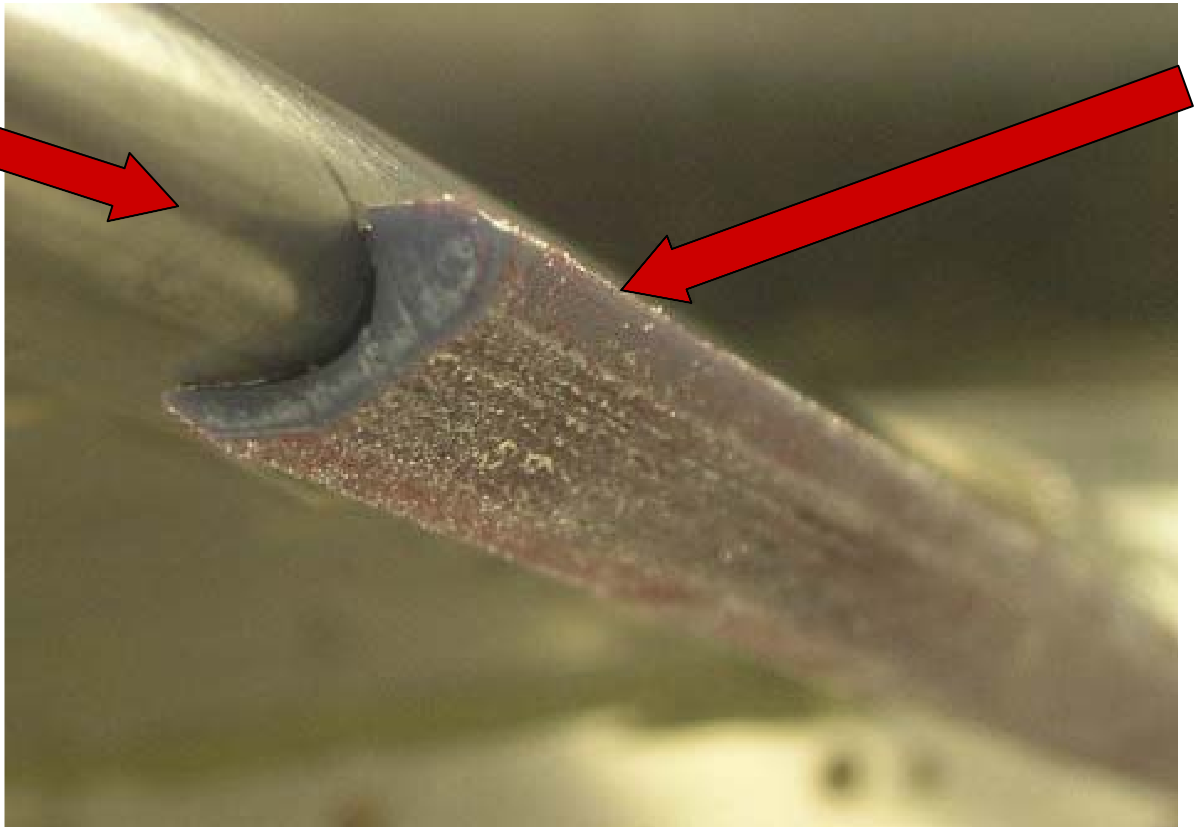
Options for Electro-thermal In-flight Ice Protection

- Anti-Icing
  - Protected area is maintained free of ice when flying in CS-25 Appendix C Continuous Maximum icing conditions
  - High power requirement to maintain fully evaporative surface
  - Aerodynamic characteristics of the wing protected area remain constant
- De-Icing
  - Ice is removed from the protected area intermittently during flight in icing conditions
  - Enables reduction in power required to operate system
  - Causes variations in the aerodynamic characteristics of the wing protected area
  - Requires clear understanding of wing sensitivity to ice accretion, both location and thickness

Assessment of Wing Sensitivity to Icing

- Wind tunnel testing with artificial ice shapes
  - Variations in ice shape location, thickness and surface roughness assessed
  - Preliminary limits of acceptability established

Leading edge of wind tunnel model wing



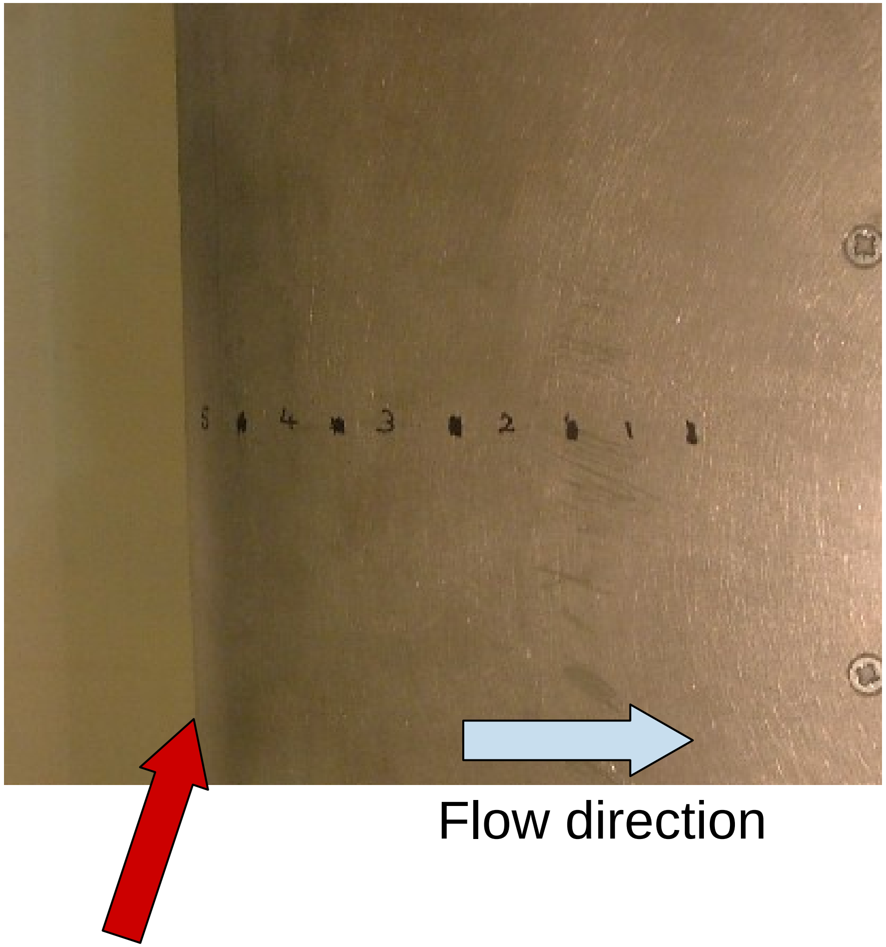
Artificial ice shape

Evaluation of Electro-thermal Heater Technology

- Test objectives
  - Initiate evaluation of heater mat operating characteristics
    - Transient thermal response
    - Uniformity of steady state temperature
  - Consider the effect of slat internal structure on the heater mat performance
    - Installation considerations
    - Cold spots
  - Develop understanding of factors affecting system operation in a de-icing mode
    - Sequencing
    - Wing incidence

Icing Tunnel Model Tested

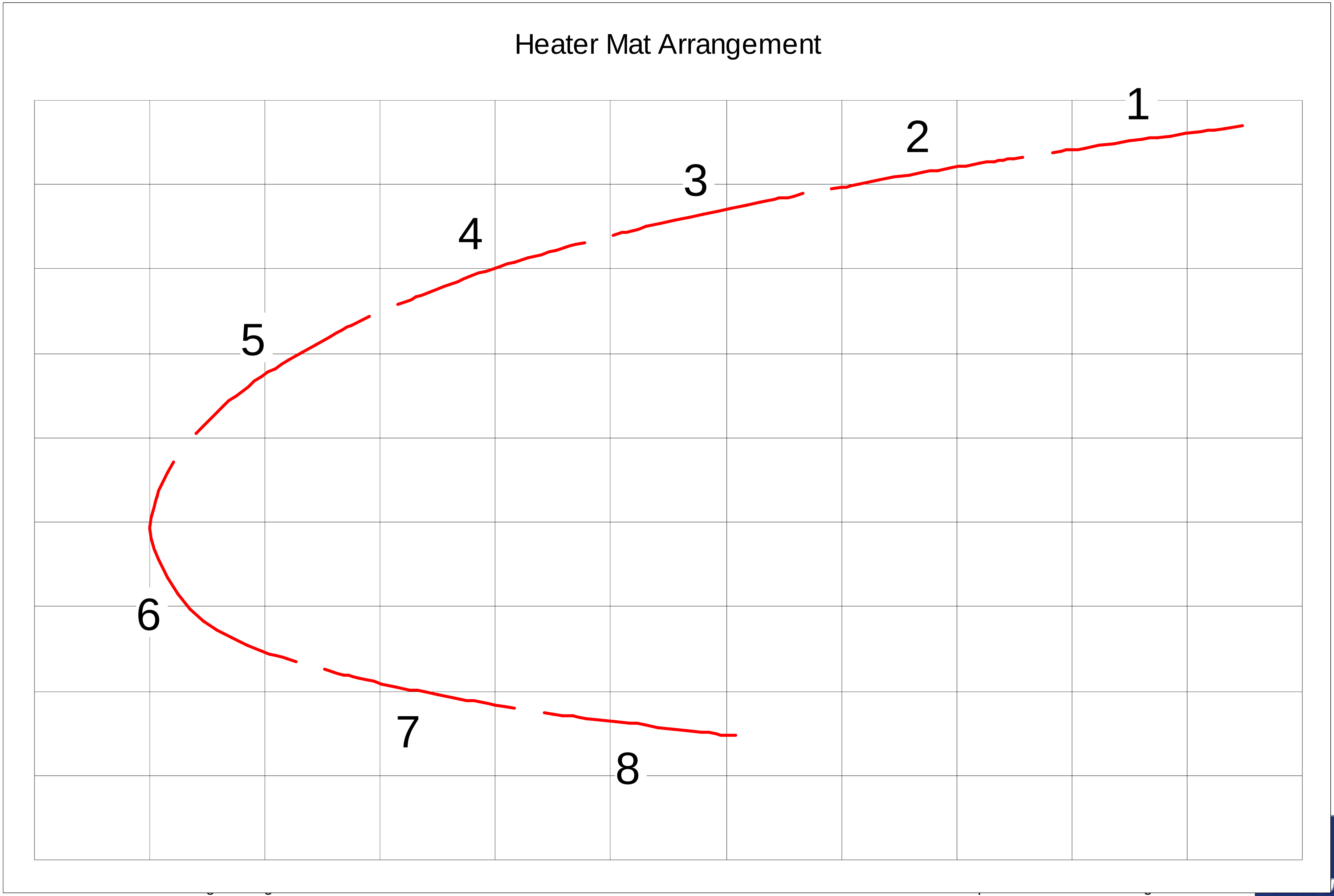
- 40% scaled model of mid-span section of an A320 wing
  - 3 different leading edges created for testing
  - Moveable flap section to facilitate pressure coefficient matching
  - Included some representation of internal structure
  - Heater mats bonded to the skin interior surface
  - 2 mm exterior skin thickness
  - Multiple GKN-ATS "Spraymat" heater elements



Flow direction

Leading edge of icing tunnel model

Example of Heater Mat Arrangement Used



Tunnel, Test Conditions, Control & Monitoring

- GKN-ATS icing facility
  - Tunnel working section used: 506 mm x 762 mm
  - Test model mounted vertically across shorter dimension
- RTDs provided monitoring of each individual heater mat temperature response
- Heater mat operation controlled externally
- Test conditions scaled to generate icing conditions approximately representative of full scale flight
  - Range of flight and icing conditions selected
  - Allowances were made for operation of an ice protection system in scaling process applied

Summary of Testing Conducted

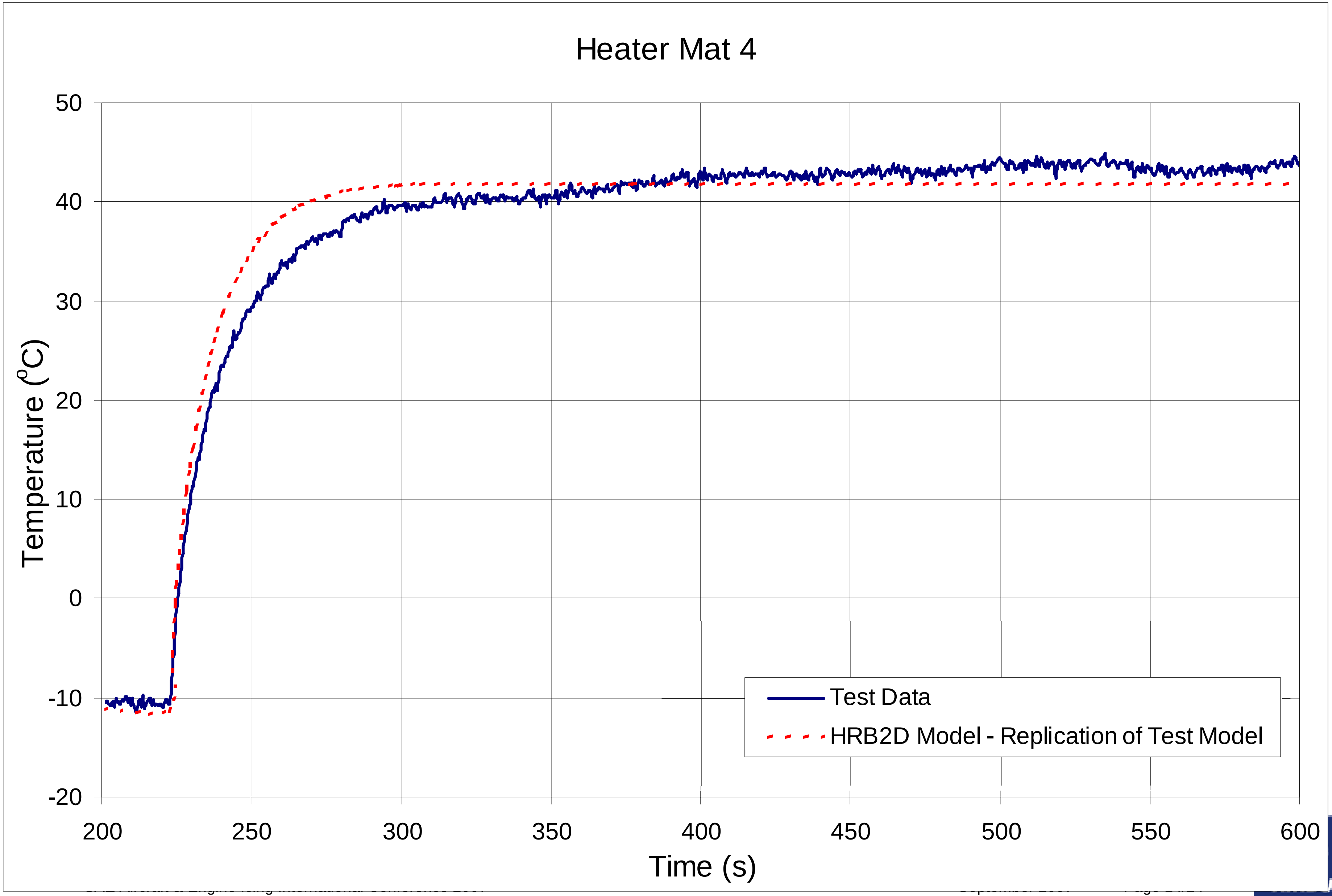
- Anti-Icing Tests
  - 12 test runs completed
  - Heater mat response characterisation and power intensity optimisation

- De-Icing Tests
  - 22 test runs completed
  - Variations in:
    - Heater mat combinations
    - Operating sequences
    - Power intensities
    - Angle of attack
  - Effect of lateral conduction observed during sequence operation

Numerical Modelling of Anti-Icing Testing

- Models were created using HRB2D to replicate the test data at each of the temperature sensor locations for selected test runs
  - Temperature profiles predicted for each sensor location correlated with the steady state test data to within ± 4 ºC
  - Differences were noted in the initial thermal response

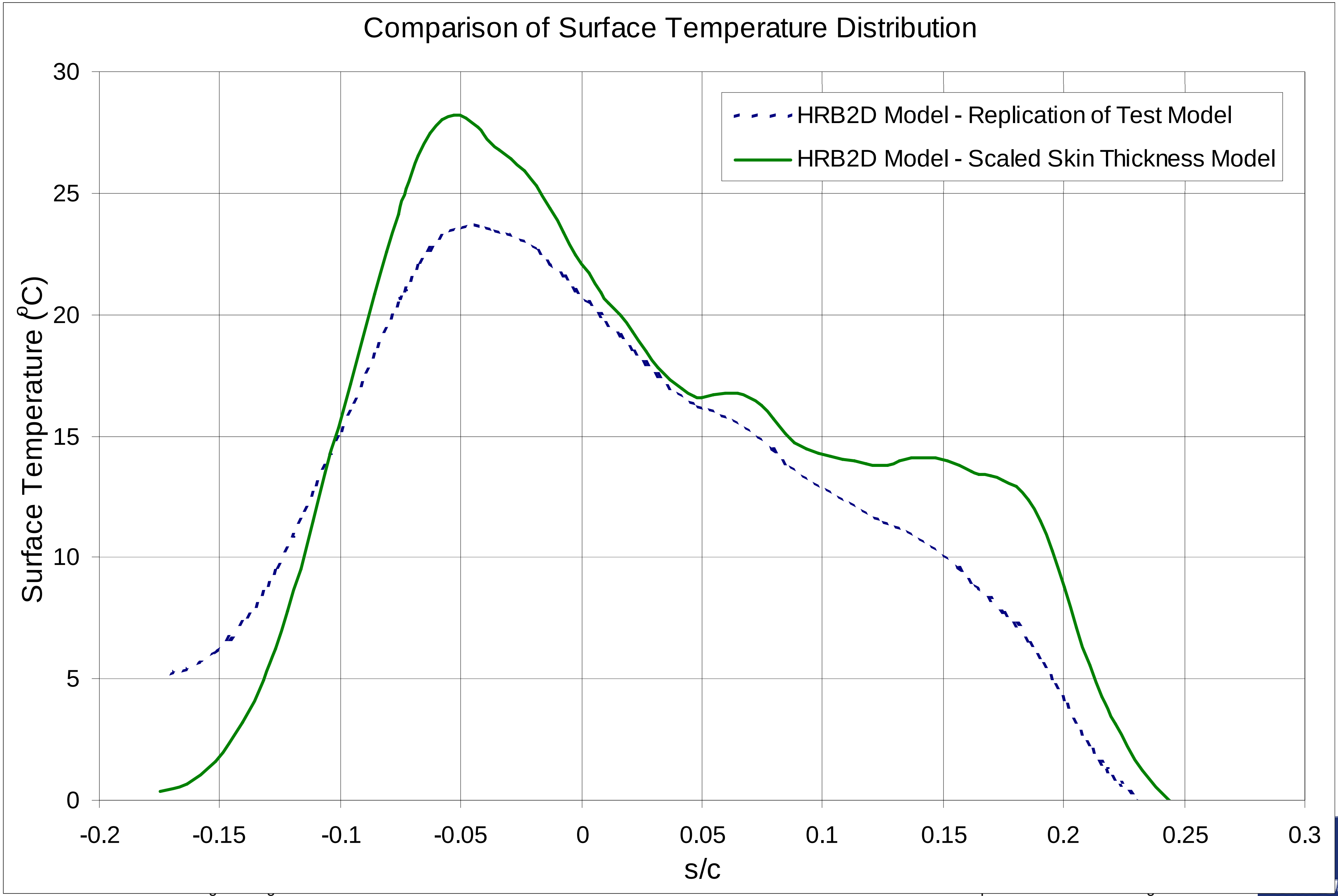
Comparison of Anti-Icing Test and Numerical Data



Further Assessment of Anti-Icing Testing

- Correlation of temperature predictions at all sensor locations led to reasonable confidence in surface temperature data predicted by HRB2D
- Lateral conduction was observed during the de-icing tests
- Model tested was 40% scaled representation of an A320 mid span section
  - Model skin thickness was 2 mm
  - A 40% scaled skin thickness would be 0.8 mm
- Further models were created using HRB2D with this thinner skin thickness

Comparison of Surface Temperature Distribution

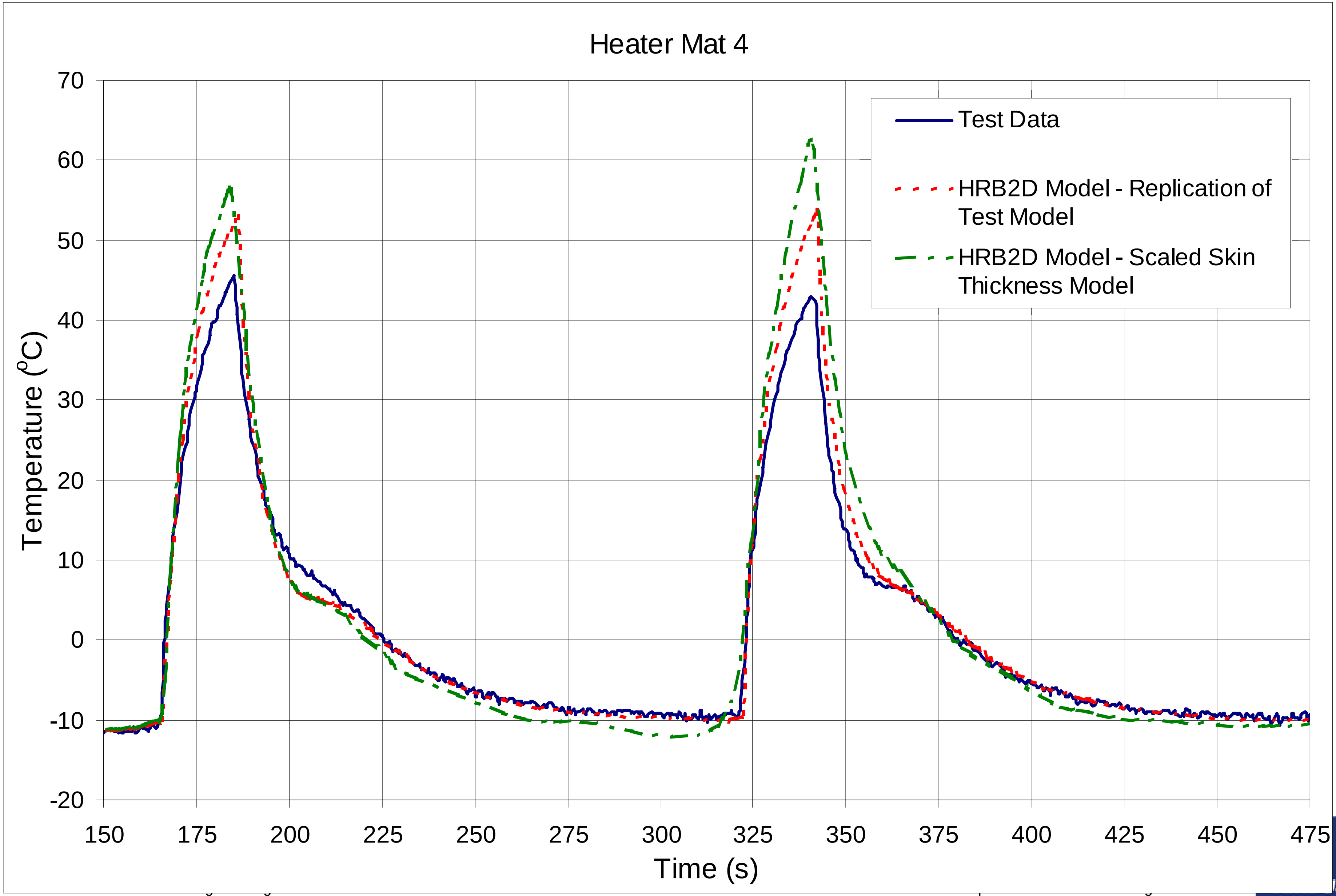


Numerical Modelling of De-Icing Testing

- Models were created using HRB2D to replicate the test data at each of the temperature sensor locations for selected test runs
  - Temperature profiles predicted for each sensor location correlated with test data to within ± 8 ^{o}C
  - Time taken to reach maximum temperature for individual heater mat operation correlated well
  - Differences were noted in the maximum temperatures and thermal gradient predicted

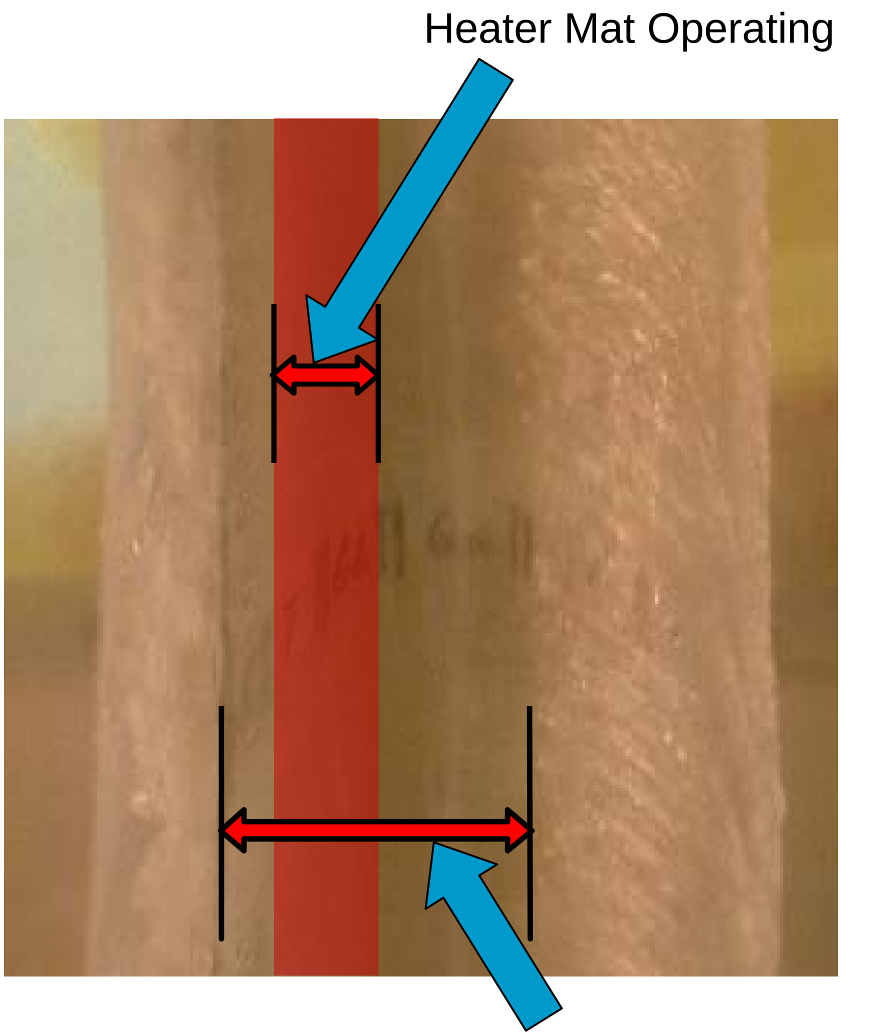
AIRBUS

Comparison of De-Icing Test and Numerical Data

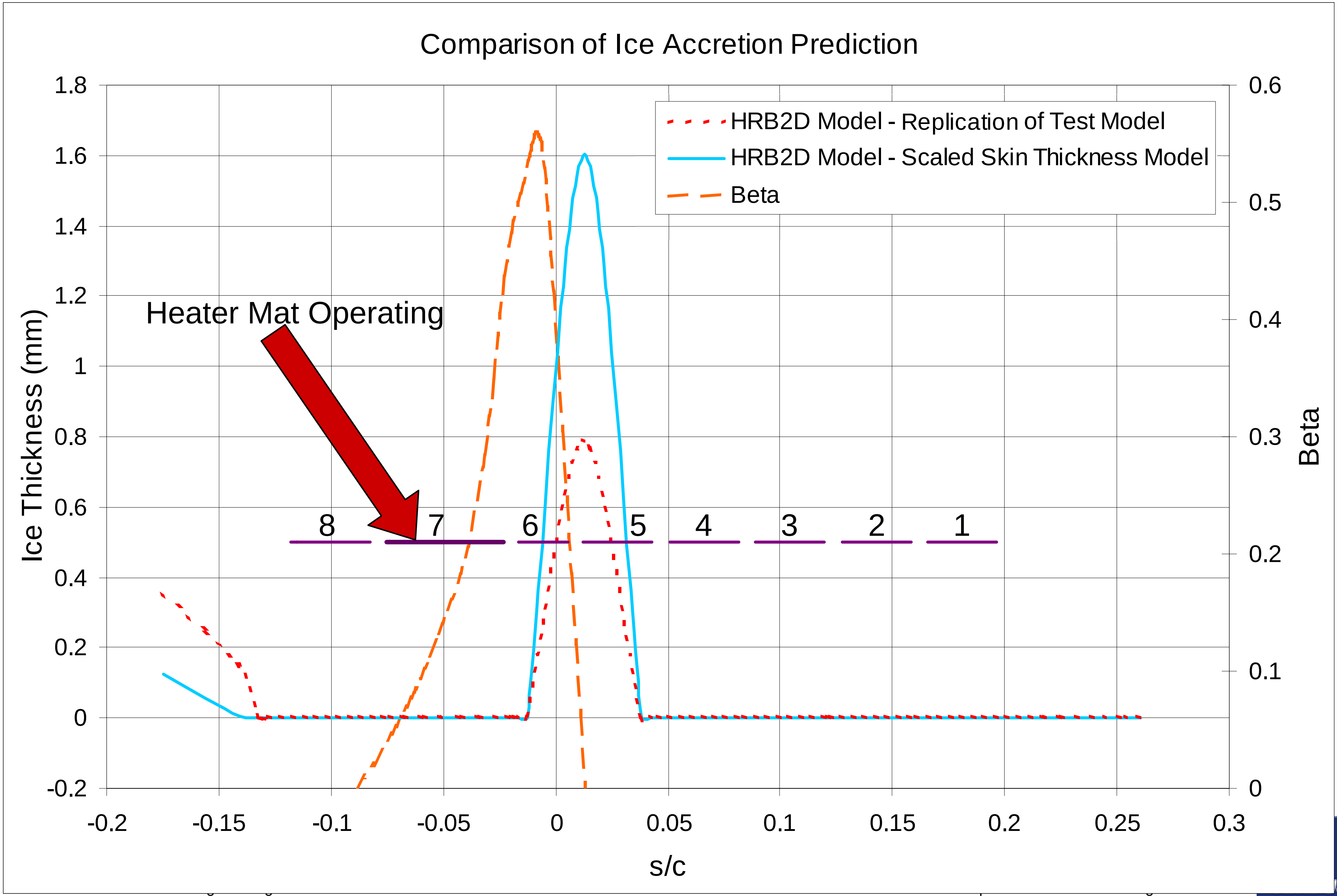


Further Assessment of De-Icing Testing

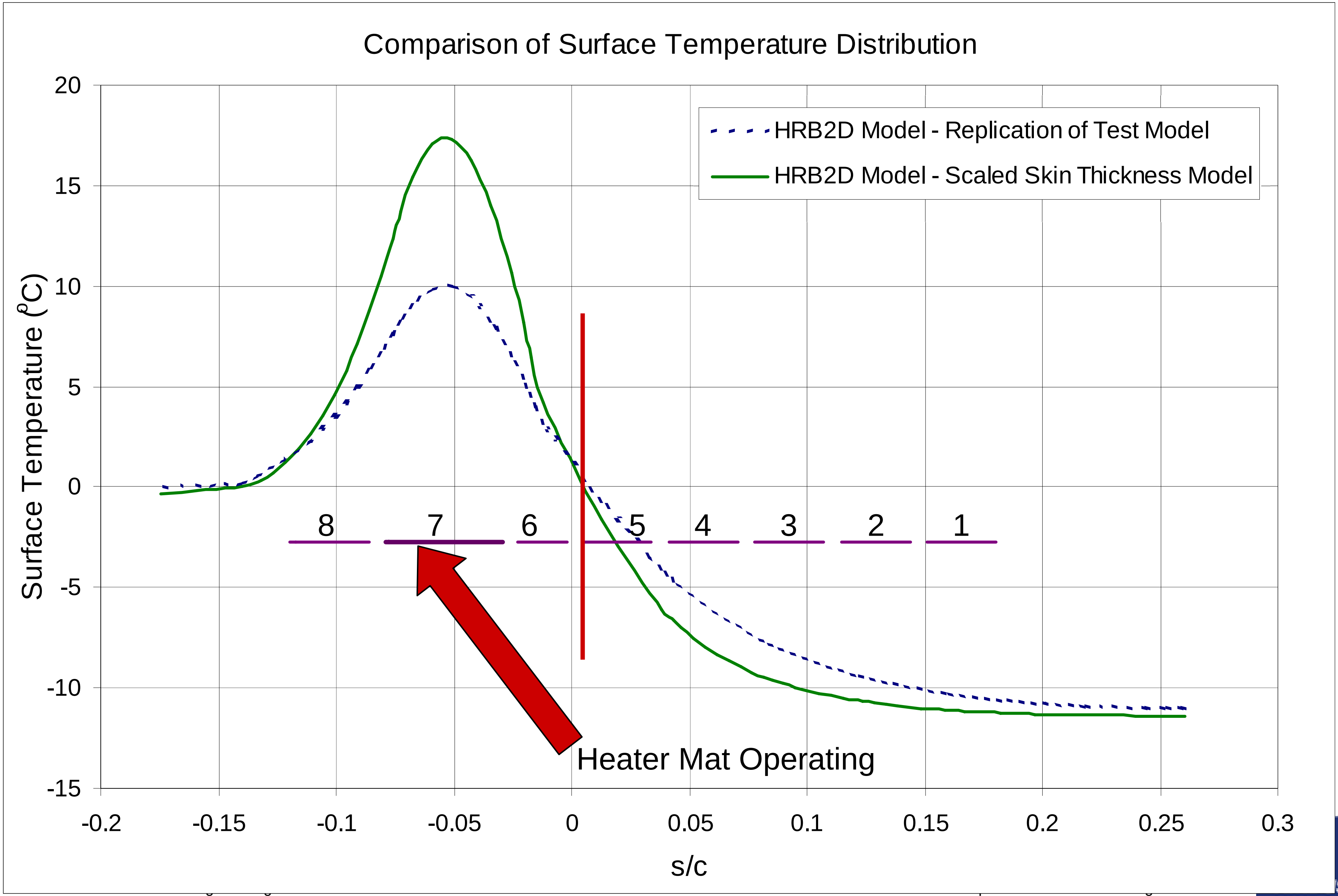
- Significant lateral conduction observed
  - Area free of ice spanned three heater mats
  - Thought to have modified the shedding behaviour observed
  - Thought to have modified the transient thermal response



Comparison of Ice Accretion Prediction



Comparison of Surface Temperature Distribution

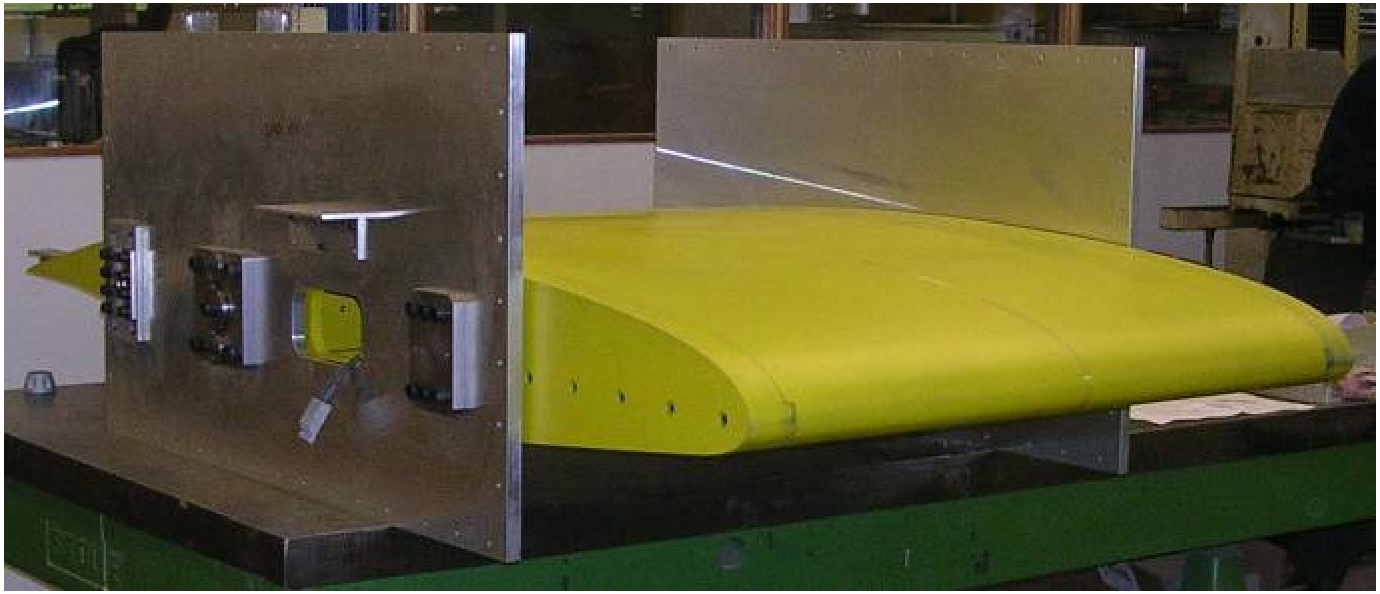


Conclusions

- The effect of model skin thickness may influence the performance of an electrothermal ice protection system during a small scale icing tunnel test
- HRB2D shown to predict thermal response to an acceptable level of accuracy
- Prediction of surface temperature with different skin thicknesses suggests initial testing may have exhibited a conservative response

Next Steps

- Full-scale icing tunnel testing at the CIRA icing wind tunnel
- Further modelling using HRB2D based upon the test data generated



AIRBUS

AN EADS COMPANY