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SIEDIT Final Report

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TITLE

SIEDIT Final Report

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Checked: J. Mudway 29/05/13

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SUMMARY

This report describes the progress of the SIEDIT project between Month 1 and Month 25 of the 25 Month programme and fulfils the requirements of the second reporting period.

The report describes the progress made through the project, including the decision to switch from a Hybrid solution to a purely Electro-Thermal WIPS for the Full-Scale tests that took place in the NASA Glenn Icing Research Tunnel, Cleveland USA.

Call – SP1 – JTI-CS-2010-01 Project ID - 270591

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AMENDMENT RECORD

Date	Issue No.	Details
May 13	1	New Report

1. Introduction

The SIEDIT project is based around the development of a Hybrid Wing Ice Protection System combining electro-mechanical and electro-thermal ice protection systems into a unified system that uses the benefits of both systems. The intention is that the system runs as a de-ice system where the electro-thermal system would generate the run-back ice, which would form over the electro-expulsive system and will be shed using the actuator once sufficient thickness has built up.

The challenges to be tackled in SIEDIT are based around the integration of the two sub-systems into a complete leading edge in an effective manner. The integration will be demonstrated at a representative scale for testing in the NASA Glenn Icing Research Tunnel in October 2012.

2. Requirements

The system will be assessed against a number of performance criteria but has to meet certain technical requirements that are set by Airbus in order to generate a design that is realistic for future use. The top-level documents from Airbus will drive the initial design decisions on the system sizing and performance criteria. The rest of the system design will be driven by the requirements generated from the respective subsystems and the space envelope dictated by the wind tunnel model. The full set of requirements for the initial design work have been highlighted in Deliverable 1 "*DEV / R / 8522 / 304 - SIEDIT Design Requirements Document*". This document established the key drivers from the customer perspective and framed the technical problem-solving discussions around the means of meeting them with the two sub-systems.

3. Design

3.1 Hybrid System

From these requirements, it is necessary to establish the capabilities and key parameters of the individual sub-systems in order to start the initial design phase of the project.

The preliminary hybrid system sizing exercise was conducted prior to the project start and therefore required assessment against the characteristics of GKN Spraymat® technology for compatibility. This was completed and no issues regarding compatibility were identified.

From this sizing document, it was possible to look at the initial design of the integrated system and generate a first-pass assessment of the critical areas for system performance. These critical areas were taken forward for testing at sub-scale levels to verify the impact and to feed information into the design process.

The key issues identified at this stage were; the skin material covering the actuators, the interface region between sub-systems, and the arrangement of actuators to protect the required area.

It was initially assumed that it might be possible to combine the optimum configurations of both of the sub-systems, however during the initial design analysis phase; this was found not to be possible.

This was, in the main, due to materials used in the skin of the electro-expulsive system being incompatible with the requirements of the Spraymat® design for longevity. This required the candidate materials used in a Spraymat® to be tested for their impact on the electro-expulsive system performance and a suitable alternative chosen.

This testing also served to direct the management of the interface between sub-systems as the material covering the actuators is one of the key inputs. This work chose a PEEK-based laminate construction to protect the actuators and this was then taken into consideration for the interface design.

From the thermal modelling work conducted at this stage, it was clear that the un-protected region between the two systems had a significant effect on the performance and, therefore, had to be minimised. It was found that an unprotected region greater than 2 millimetres in the chordwise direction has a profound adverse effect on the system effectiveness. This distance sets the requirement for the interface region.

This requirement and the configurations that were possible to meet this requirement were then designed and tested within a sample wind tunnel configuration to assess the performance and benefits of each configuration. It was clear from the analysis of performance against all the criteria that the two configurations were suitable for the reduced scale leading edge demonstrator test in the GKN wind tunnel.

From this test more detailed analysis can take place and this influenced the final design of the full-scale specimen.

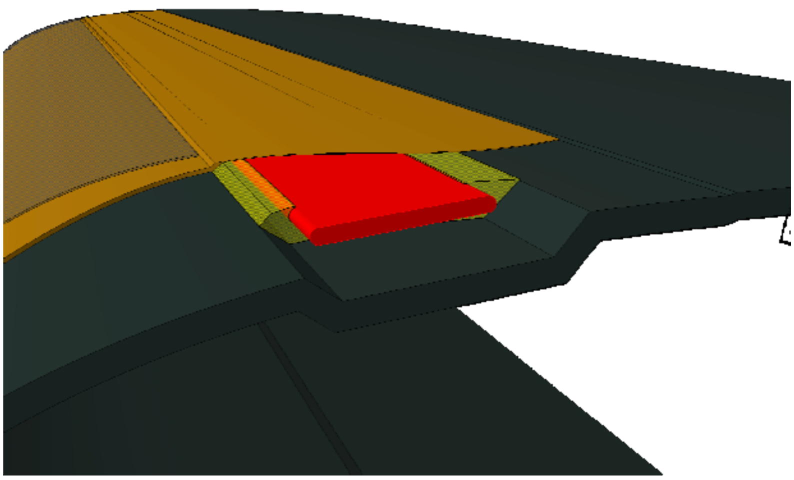

Figure 1: Current design configuration for heater mat-actuator interface

The design of the hybrid leading edge specimen was based around the use of the PEEK heater mat laminate merging over the actuators as shown in Figure 1. This design allowed for a single PEEK laminate to combine the functions of heater mat and skin layer, removing an interface in the critical region. It also allows the heater mat to continue as close to the actuator active areas as is possible, thus minimising the unprotected regions of the leading edge.

Design work on this configuration continued until January 2012, when GKN were notified that the Hybrid solution had failed an Airbus TRL 3 review and was thus not being considered for a slot in the full-scale wind tunnel test at NASA.

3.2 Electro-Thermal

Discussions that took place between GKN, Zodiac and Airbus through January and February 2012 covered a whole range of options regarding the route forward for this project, covering all options available to the team.

The result of these discussions was that Airbus wanted the partners to be involved in the test and, understanding that the timescales were short and therefore there were technical risks, accepted that the partners would tests an electro-thermal WIPS using Spraymat® heater mat technology utilising Zodiac control systems and algorithms. A concept of the system is shown in Figure 2.

As a consequence of this change, the planned reduced scale test was modified to test an electro-thermal system to allow Zodiac to generate the control laws required to run the system at full-scale. This required an urgent redesign and modification of the designs already completed in order to meet the required timescale.

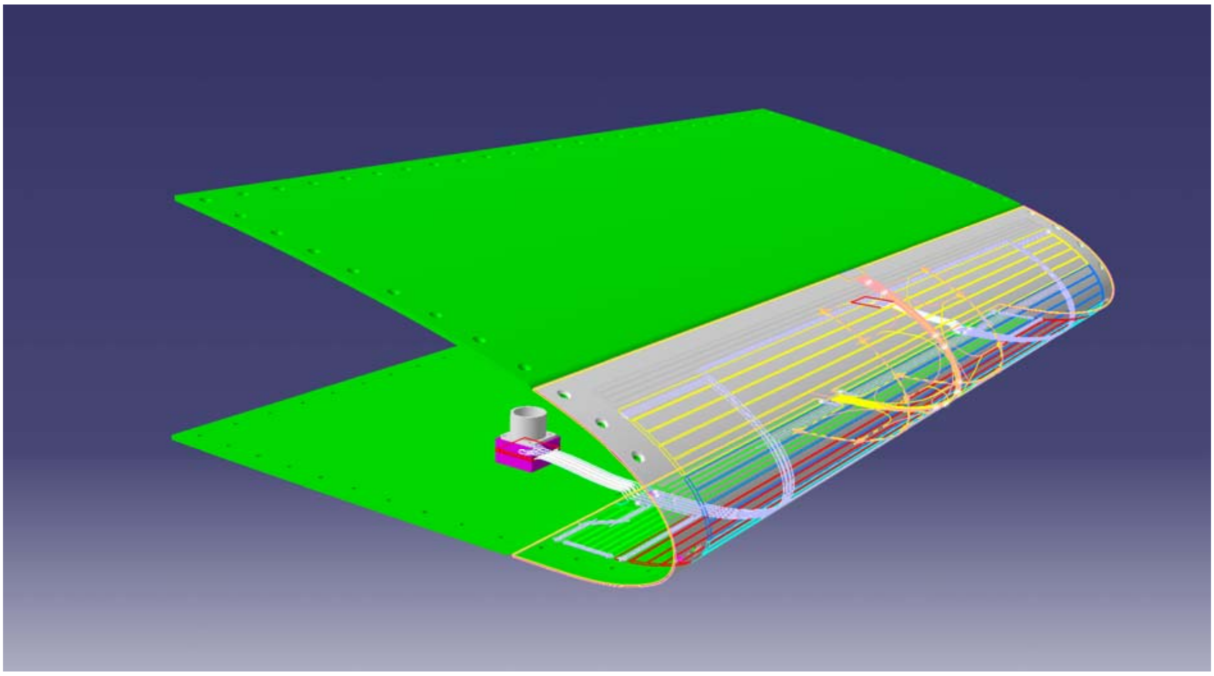

Figure 2: Electrothermal WIPS Concept showing element pattern, sensors location and connector

It also highlighted an additional technical risk in the programme, that of temperature measurement within the system. Due to the configuration of the components, the only locations in the thickness direction available for temperature measurement within the part were within the bondlines between the erosion shield and Heater mat, and between the heater mat and sub-structure. The risk with inserting sensors in these areas is that they can affect the efficiency of the system in these locations. The solution in this case was to propose a system with sensors only on the rear-most surface of the heater mat, to limit the effect on system performance.

The sensors chosen to achieve control in this manner required holes cutting in the substructure to allow their installation, as they were too large to fit within the bondline. The reduced scale model allowed this methodology to be trialled successfully and this was carried over into the full-scale design.

The reduced scale testing confirmed the issues regarding integration of sensors between the heater mat and erosion shield as significant so the design was proposed at CDR without sensors at this level in the mat. At the CDR, Airbus stated that sensors were required at this level and so a method was required to integrate them.

3.3 Sensor Integration

The concept for transitioning the sensor wires from the fine gauge sensor wire to a robust wiring loom was the subject of some discussion and brainstorming. The traditional method of soldering the sensor wires to kidney strips and soldering the loom wiring to the other end was not considered a robust solution to the problem. The key issues were considered to be the following:

- Wire gauge exiting the laminate
- Wire gauge of loom wires
- Access to the areas for soldering
- Manufacturability of the assembly
- Robustness of connection design

From this it was clear that the traditional solution would not meet the criteria. In particular, the use of sensors compatible with the bond line thickness intended between the erosion shield and heater mat would require a novel solution to provide connectivity.

From a range of solutions it was decided that the sensor wires would not transition between layers as this would increase the risk of damage to the sensitive wires. In order to make this achievable the transition between the layers was done using a FFC jumper cable, effectively serving as an extended kidney strip. To transition from the jumper cable to the wiring loom, a small circuit board was designed to transition between the jumper cable and a 37-way D-Plug to serve as the termination of the sensor wiring loom.

In order to facilitate this, the sensors and wires would be bonded to the heater mat prior to assembly with the skin and erosion shield so that the ribbon cable can be fed through the skin and supported in place. The jumper cable would then be plugged into the interface card during final assembly prior to acceptance testing. The jumper cable could also serve to allow for inspection of the sensors prior to this stage as it gives easier access to than would otherwise be the case. The concept is shown in Figure 3.

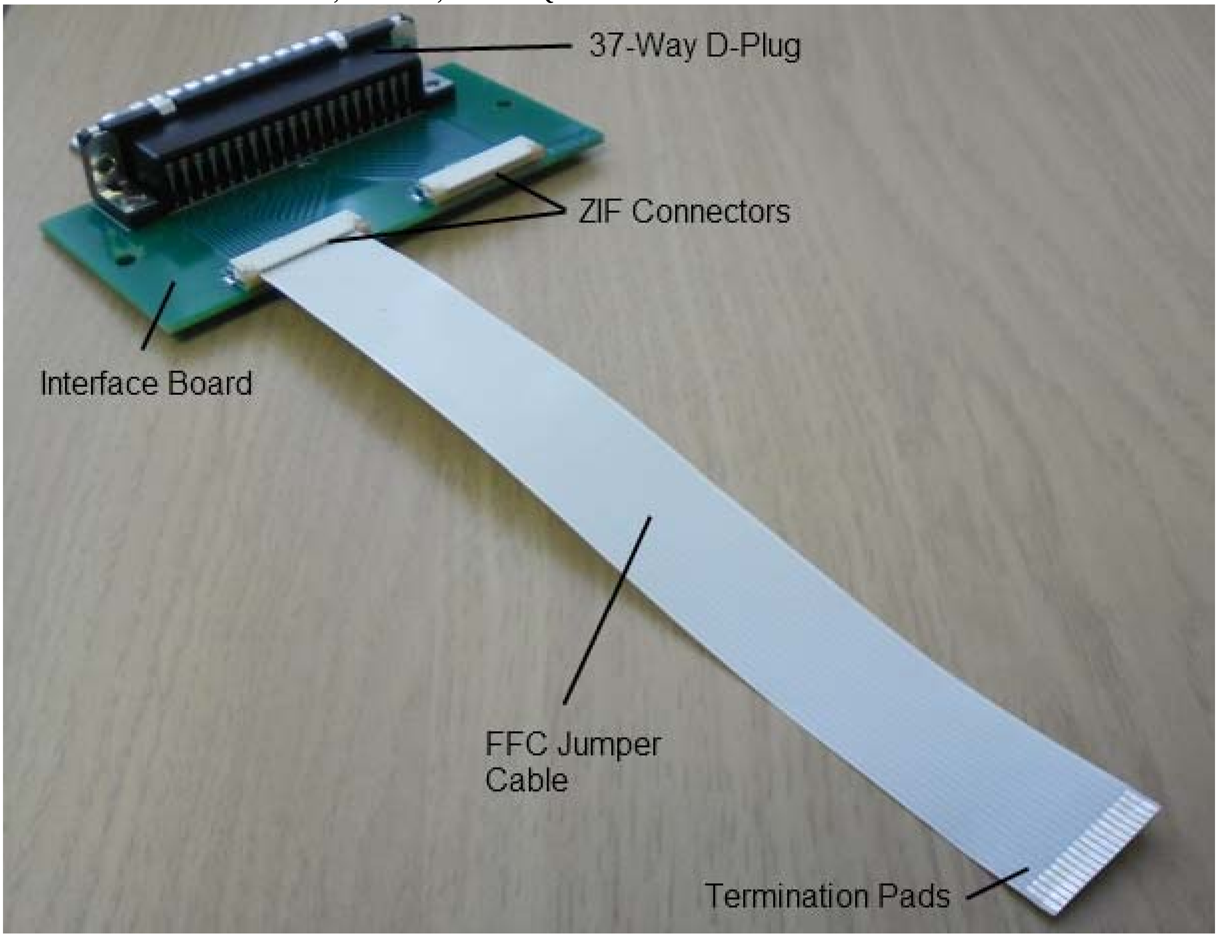

Figure 3: Sensor signal transition from terminal pads to wiring loom

For the sensors on the internal surface of the heater mat, it was clear that the more risk-free alternative would be to machine holes in the skin and fit the sensors late in the build to ensure reliability. These sensors would also feed into a jumper cable and then into an interface card to manage the transition to the wiring loom.

The sensor wiring looms would then exit the skeleton through separate cut-outs in the centre of the rear spar.

After exiting the wind tunnel model, the cables will interface with the Zodiac control and power modules.

3.4 Connector

Based on the pin spacing and service rating required for 540VDC operation, the power connectors have to be a MIL-STD-38999 Series II in a size 19 shell. The shell size dictates the pin arrangement and the connector block size based around the standard dimensions of this connector. Figure 4 shows the concept design for the power connector, of which there would be two in this concept. A standard 38999 connector body is mounted within a custom made, two-part block to provide the connection into the heater mat for power. The block is sealed by two gaskets either side of the power tongue to provide environmental sealing of the interface between block and heater mat.

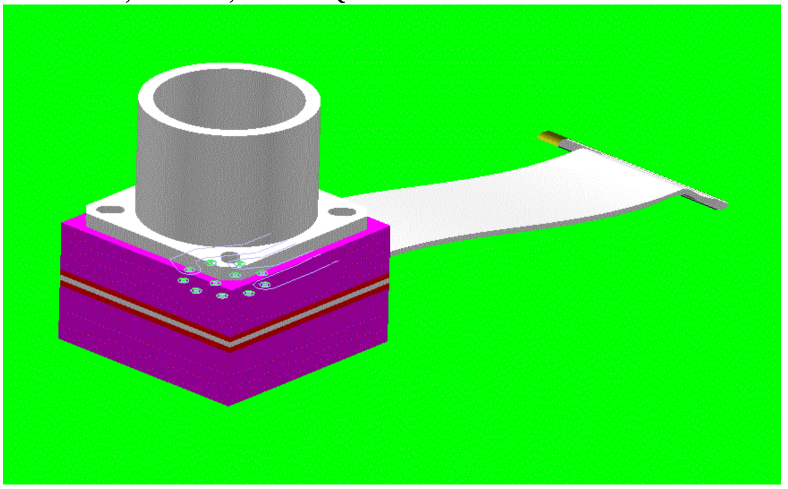

Figure 4: Connector block concept for power connectors

These power connectors are proposed to be sited in the end bays of the model to ensure relatively simple connector configuration and paying attention to potential wire routing limitations through the wind tunnel model. The blocks themselves will be bonded to the inside surface of the leading edge, on the flat lower surface to secure the connection.

The power loom splits into a Y-cable to allow a single bundle to pass through the afterbody but allows it to service both power connectors in the leading edge.

3.5 Overall Design

Shown in Figure 5 is the initial design concept based upon the constraints described above and the known requirements of a typical slat with respect to bird strike and structural requirements. It is intended that the skin will be supported by two full-chord ribs which are bolted to the rib feet and co-bonded to the internal skin surface. In conjunction with the skin, these ribs provide the required structural stiffness for the part.

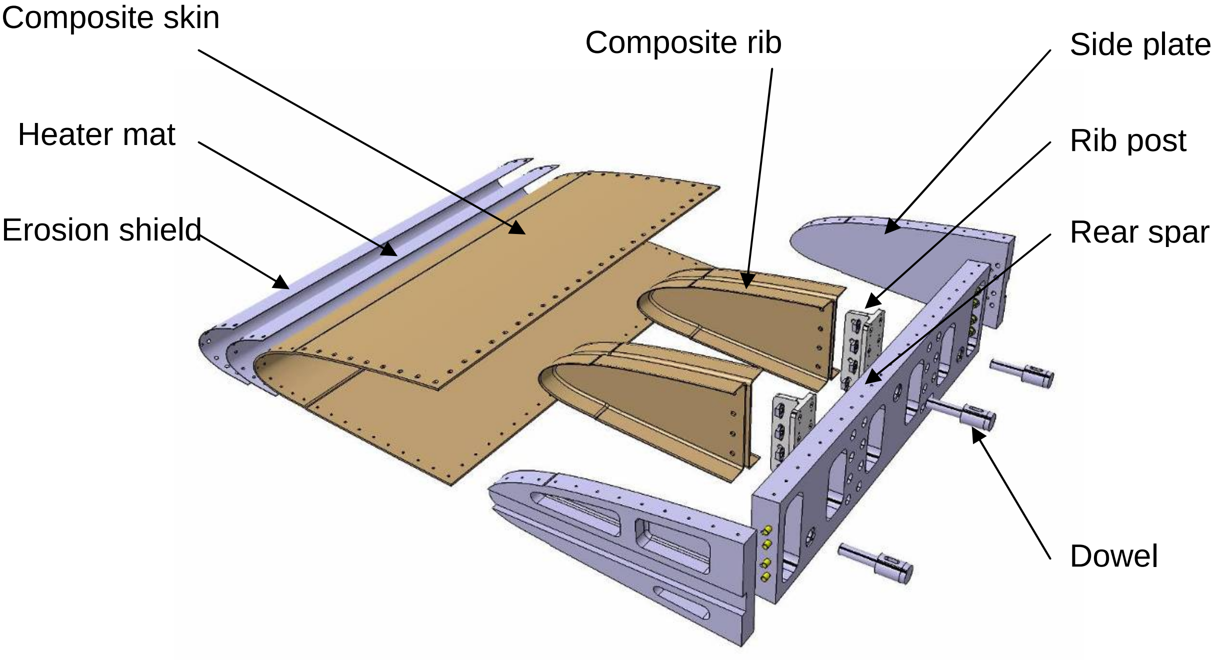

Figure 5: Design Concept of model leading edge

The ribs impact on the skeleton design and integration activities as it was determined through stress analysis that the ribs had to be anchored to the rear spar using metallic rib feet. The rib feet would, therefore, restrict the size of the cut-outs in the rear spar; in turn limiting internal access into the part once it was assembled.

4. Testing

4.1 Wind Tunnel Test

The test campaign commenced with some dry air cases to assess the functionality of both the heater mat and control system in the Tunnel. Temperatures were recorded up to 140°C without out issues within the part. Functionality of the system was good.

Figure 6: Specimen shown during unheated trial runs at NASA Glenn Icing Research Tunnel

Testing of the De-ice cases at -9 and -15°C OAT (Outside Air Temperature) required the pulsing of certain zones in excess of 30W/sq in. This was accomplished without visible issues. It was observed that the mid span gap, representing the gap between protected slats or potential joins in the protection, was slowest to clear. This was verified through the use of the NASA thermal imaging system, which was running a live feed during the tests.

It was found that, on the third day of testing that there was an unexpected resistance shift on one of the zones, DI-LO2, which suggested the presence of a fault in that zone. It was decided that the remaining running on that day should be completed without powering this zone and that the part should be swapped out for the spare on completion of the day's testing. Unheated runs showed a good, even ice accretion across the span of the part.

The back-up part was installed and completed the day testing without issues. Thermal imaging highlighted a potential warm area corresponding to one of the internal connection sites within the heater mat. Subsequent testing revealed that the mid-span junction was delaying the ice shedding on the upper surface, and that the right hand side of the part appeared to be warmer than the left. This was identified as something to be checked during the post-test teardown of the parts.

During running on the final day, the DI-UP1 zone showing the hotspot failed. This was identified through a significant resistance shift and a grounding fault within the assembly.

At this point, testing of the ice protection strategy finished due the failures of both test specimens.

4.2 Post-Test Teardown

On the specimens return to GKN, each of the parts underwent a post-test teardown procedure to establish key performance parameters and root cause analysis of failures.

In order to generate the largest amount of data from the specimens, the teardown procedure has two main aspects – non-destructive inspection and destructive inspection.

Non-Destructive Inspection

The non-destructive inspection conducted first and included the following stages:
- Electrical Inspection
- Insulation Test
- Tap Test
- Ultrasonic Inspection
- X-ray

The electrical inspection highlighted a resistance shift in some zones when compared to the pre-test measurements. This can contributed to by insulation faults within the circuit.

Insulation tested showed that the zones that failed in the tunnel test were not to the required standard, remaining zones showed good insulation.

The tap test and ultrasonic inspection were conducted to establish the presence of any voids or dis-bonds within the test specimen structure. In most areas it demonstrated that there was a good bond between the different layers of the structure, however some areas were highlighted as having a different response to the surrounding areas. These did not behave in the same manner as a void and so they were noted for further inspection during the destructive phase of the inspection.

X-rays of the complete part were taken in an effort to establish any additional areas that required inspection in the destructive phase, the location of the sensors relative to the elements and each other, and any gross areas that indicated failures.

Detailed analyses of the x-rays showed that the sensors were aligned as intended with respect to the intended element legs and positions (see Figure 7). This ensures that representative temperature measurements were taken at the intended locations. This was of particular concern as the integration of the sensors had a high degree of risk – the key risks being sensor failure and voiding within the bond line, causing sub-optimal performance. The method of mounting them after the final part assembly minimised these risks but required careful design and alignment of the cutouts in the carbon skin to ensure these were aligned properly. There was also the possibility of misalignment within the cut-out, both relative to the element position and relative to the heater mat surface (sensor tilted or not parallel to the heater mat surface).

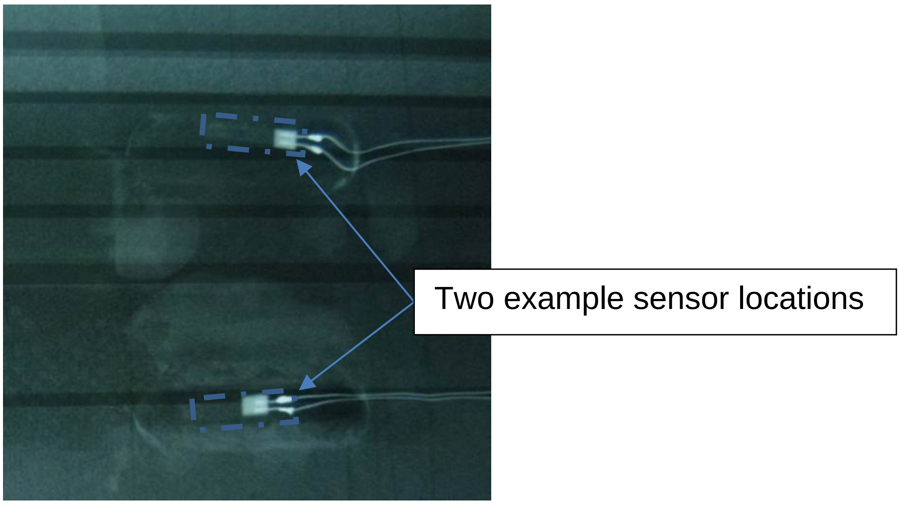

Figure 7: X-Ray taken from outside surface though a section of SIEDIT 1 showing sensor positioning

Further inspection of the x-rays suggested that there were no obvious additional issues identified within the test components and so no new areas for destructive analysis were added to the plan.

Destructive Inspection

The destructive inspection of the part was focussed on assessing the build standard of the parts as tested and investigating the cause of the zone failures identified.

This was achieved in two stages; the first was to take sections through the part at four locations to assess the bondlines for any issues and verify the sensor positions in the through-thickness plane. The second was to remove the erosion shield over the failed zones and conduct a visual inspection for the locus of failure and any identifiable causes of failure.

In the first instance, the sections were cut as shown in Figure 8 to include both sensored and un-sensored regions to assess the impact of the sensors on the profile.

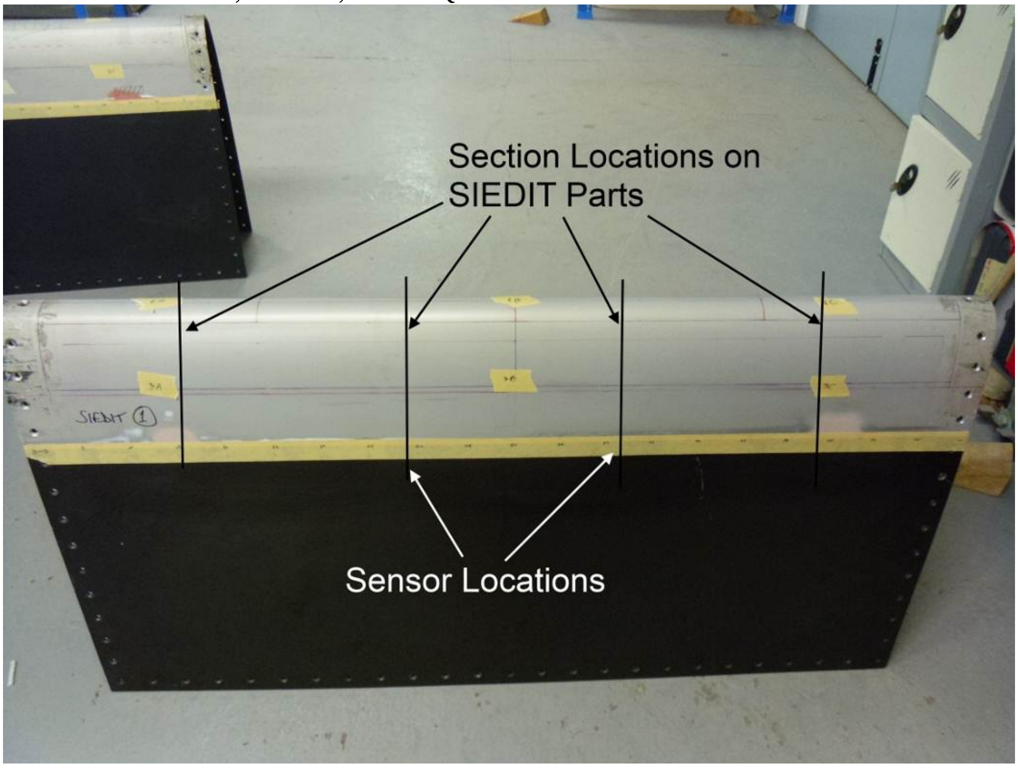

Figure 8: Un-sectioned SIEDIT Test Part

The second stage was to attempt to locate the failures in the identified zones in each specimen. On removal of the erosion shield from each of the specimens, it was clearly identifiable as to where the failures had occurred within the heater mat. The small burns shown in Figure 9 are typical of the evidence found on the inspection of both parts and are indicative of a burnout within the heater mat, specifically within the internal connections between element and busbar return.

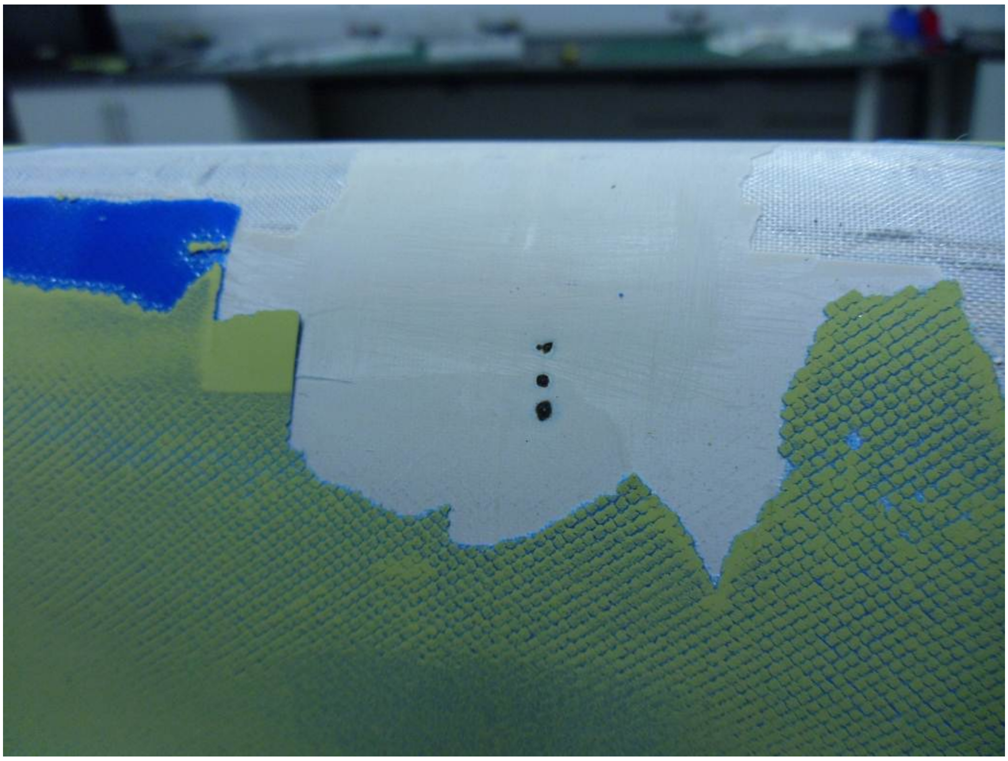

Figure 9: Burn marks found after removal of the Erosion Shield on SIEDIT #2

The internal connections are not a failure mode that has been previously identified in sub-scale testing but a root cause investigation is underway on this issue.

It would appear that there may have been a previously unidentified weakness with the connections that was related to the increase in power density required by the tunnel test. The outcome of this preliminary conclusion would be to conduct some further trials at higher power densities to assess any limitations.

This investigation work falls outside the timescale for inclusion within the SIEDIT programme and are therefore not included in this report

5. Conclusion

The project achieved the key technical milestone of providing functional test samples for the Wind Tunnel Test at NASA Glenn. That they were not in the configuration intended at the start of the programme can be attributed to the development of new technologies and pushing the technological boundaries. This scope change also caused the biggest risk to the programme through the dramatic compression of timelines associated with the extremely late technology shift.

That said, prior to this change there had been valuable learning generated from the challenge of integrating the two types of ice-protection system into a single unit. These highlighted the challenges going forward that would need serious consideration in order to fully mature the concept, namely the interactions at the interface between the systems, both at an icing performance level and that of system robustness.

These aspects lend themselves to a future programme of work between the partners, potentially under another EU project.