

# Robot deployed Laser-Ultrasonic NDT system for inspection of large aircraft structures.

Vicki James<sup>1</sup>, Dave Carswell<sup>1</sup>, J Riise<sup>1</sup>, P. Ian Nicholson<sup>1</sup>, Norbert Graf<sup>2</sup>, Norbert Huber<sup>3</sup>, Martin Gärtner<sup>3</sup>, Bernhard Reitingner<sup>3</sup>, Edgar Scherleitner<sup>3</sup>, Peter Burgholzer<sup>3</sup>, Jon Phipps<sup>4</sup>, Dave Burns<sup>4</sup>, Ciro Incarnato<sup>5</sup>

<sup>1</sup> TWI Technology Centre Wales, UK

<sup>2</sup> InnoLas Laser GmbH, Germany

<sup>3</sup> RECENDT GmbH, Austria

<sup>4</sup> KUKA Systems UK Ltd, UK

<sup>5</sup> Leonardo S.p.A.

Corresponding author: Vicki.James@twi.co.uk

## **Abstract.**

The mandatory Non-Destructive Testing (NDT) by the aerospace industry for both present and future generation hybrid aircraft using thick composite structures poses many challenges for traditional inspection techniques. Laser Ultrasonic testing (LUT) deployed by a robot for inspection of modern aerospace composite components shows good promise. It is a non-contact method offering the possibility of fast scan times without the need for couplant. This paper presents the latest work-in-progress for the design and development of the system developed by the ACCURATE consortium. ACCURATE is an ongoing H2020 Clean Sky 2 part funded project to develop a laser ultrasound based NDT system prototype for fast and contactless testing of large carbon fibre reinforced polymer (CFRP) aircraft structures.

The approach is based on a non-contact laser generated and detected pulsed ultrasound technique with delivery of both the laser ultrasound excitation and detection pulses through flexible optical fibres. The backscattered light from the lasers is also collected into a fibre. The measurement head, which contains the two beam outputs and the light collection optics is raster scanned over the surface by a 6-axis robot arm. A balanced two wave mixing interferometer (B-TWM) is used for the demodulation of the ultrasonic waves.

The system has recently been used to scan a reference panel, and a scrap panel of fuselage, the latest test results are presented and show promising progress against the project objectives.

## **1. Introduction**

The overall goal of this project is to obtain the optimum technology for the non-destructive inspection of both present and future generation aircraft hybrid and thick composite structures, containing acoustic damping materials and materials which highly attenuate ultrasound [1], with high speed 100% volume coverage. The developed prototype system will be validated by deploying it to inspect fuselage Super panel demonstrators. This system is being developed under the Clean Sky 2 Programme AIR-WP B-4.3 – (More Affordable Composite Fuselage) Joint Technical Programme using hybrid materials technology. Alternative existing methods such as squirter Ultrasonic Testing (UT), thermography and X-ray Computed Tomography (XCT), respectively require couplant, have limited accuracy or are prohibitively expensive.

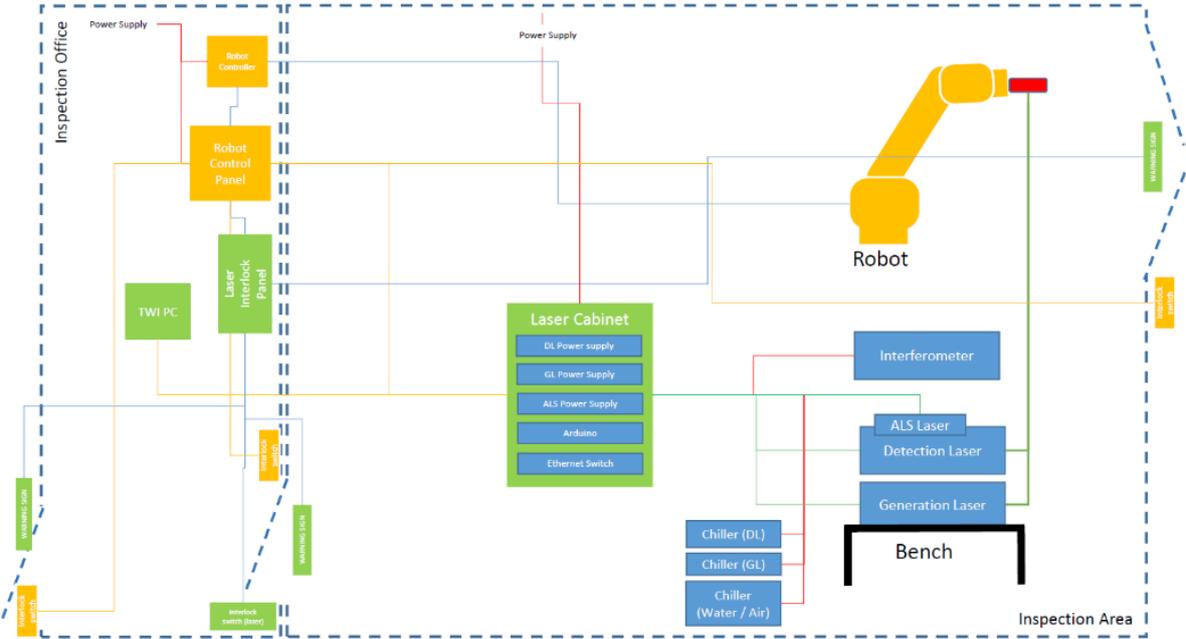
The advantages of a Laser UT system include, high speed inspection process, lightweight scanning head with small footprint, broadband UT frequency generation, low maintenance, high accuracy, non-contact, no couplant and Offline path planning and simulation for efficient working.

**2. Approach**

The technical approach is to use non-contact laser generated pulsed ultrasound (LUT) [2] with delivery of both the laser ultrasound excitation and detection pulses through flexible optical fibres, both of which are mounted on a 6 axis lightweight robot arm (KUKA Model KR30-L16 robot manipulator, a KL1000 Linear Track with 2700mm travel, and a KRC4 Robot Controller) to provide an area coverage (scan window) exceeding 1.5m x 1.5m from a single location of the robot base. The use of a 6 axis robotic arm for deployment of the optical head allows an unrivalled dextrous inspection solution compared to other LUT Systems. The end effector payload including the optical head is 10kg in weight. Combined with advantages gained through rapid and controllable acceleration and deceleration, the resultant vibrations to the optical head are minimised due to the reduced mass of the end effector. The robot arm is able to move on a rail track that runs the length of one side of a Super panel demonstrator. The robot arm scan window is sufficient for the whole Super panel to be scanned at speeds >8m<sup>2</sup> per hour with just 1 fixture rotation. Integration of the robot arm for deployment of the LUT NDE solution is based on the KUKA previous success in NDE collaborations between TWI and KUKA (IntACom [3]). Software synchronises the robot Cartesian location coordinates with the output of the optical head thereby allowing C-scans to be generated for the corresponding inspected area of the sample, LUT signal processing algorithms have been developed and used for (i) the reduction of coherent noise from fibres and (ii) random signal to noise ratio enhancement using LUT synthetic aperture focusing.

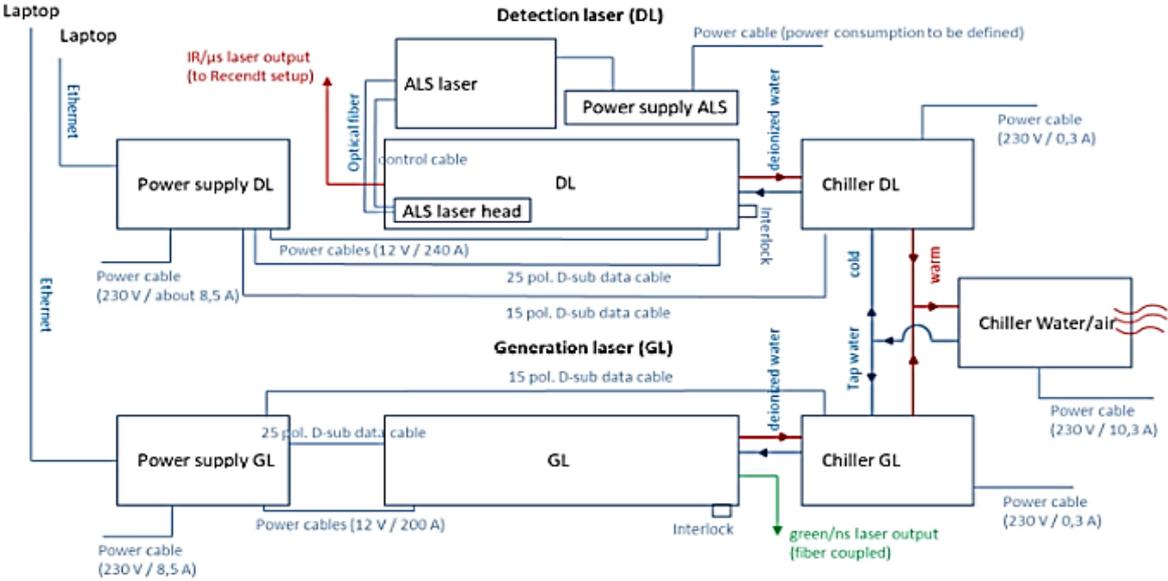
**3. System design**

The consortium created a schematic diagram for the laser cell and inspection office, incorporating the robot system and Laser system, the robot is controlled via the robot control panel and command pendant, whilst the laser system is controlled via the main computer and TWI ACCURATE software, see Figure 1. There are rigid safety systems in place via interlock door controls and emergency stop buttons inside and outside the inspection cell.



**Figure 1** Laser inspection office schematic cell

A schematic was also drawn up for the laser system, see Figure 2, including power supplies, chillers and additional chiller for extra capacity. The IR/ $\mu$ s laser output shown in figure 2 connects to the RECENTD equipment is the connection to the optical head which is attached to the end effector of the robot arm.



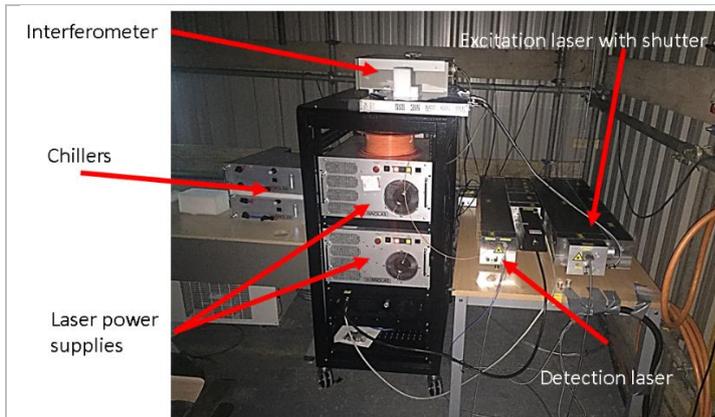
**Figure 2** Innolas laser system schematic

**4. Building the system**

The robot cell was constructed by KUKA, from metal sheeting, mounted on scaffolding poles fixed to a concrete floor. Wooden panelling was used outside of the laser cell for the inspection office walls. The roof of the cell was enclosed for laser safety, and the Fortress/Trojan interlock system was fully tested before any laser testing commenced.

The inspection office was furnished with the operator computer, KUKA robot interlock cabinet, TWI system interlock cabinet and cell video system. The inspection office also housed the robot controller and pendant, for remote control of the robot. All system response signals from the equipment to the inspection office were routed through low level protected mouse holes at the base of the cell, behind the TWI interlock cabinet.

Both the laser cell door and inspection office doors have Trojan interlock hasps and laser warning lights. The Fortress/Trojan safety interlock system has a key function, where the key must be removed from the panel shown in and inserted into the door hasp system on the cell door. This is a safety system for the robot, which can only operate in slow safety mode unless the key is in the door hasp; once the key is employed the robot can be run in fully automatic mode at production speed. The lasers, power supplies, chillers and Interferometer are mounted on tables and in cabinets, See Figure 3.



**Figure 3** Laser units, power supplies, chillers and the Interferometer



**Figure 4** Optical laser head on the end effector of the KUKA robot arm

A reference sample holding fixture was constructed in the laser cell. The laser emissions were routed through optical fibre cables, up the robot arm and into the optical laser head on the robot arm end effector, see Figure 4.

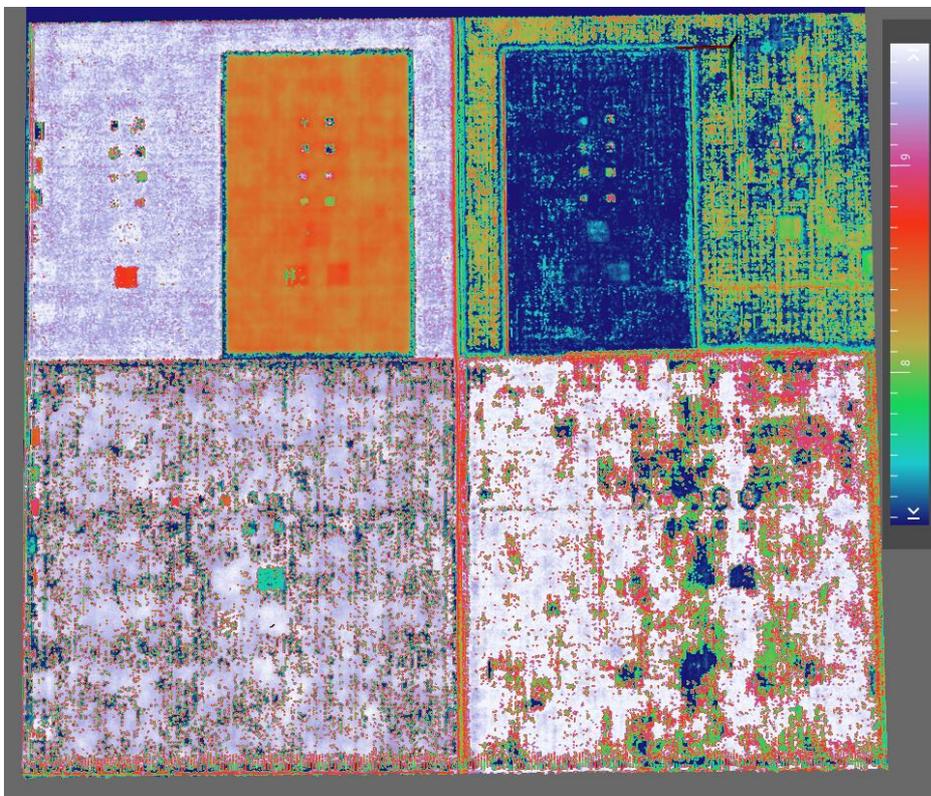
The robot and track were set up in the cell, and a temporary reference sample frame was built at sufficient distance from the robot track to enable a full range of movement for the Super panel parts. Lights were erected inside the cell to assist with remote control of the robot operations and enable video recording. Figure 5 shows the typical view from the video cameras installed in the cell. This assists with monitoring the remote operations once all of the safety doors are interlocked and all operators are outside the cell.



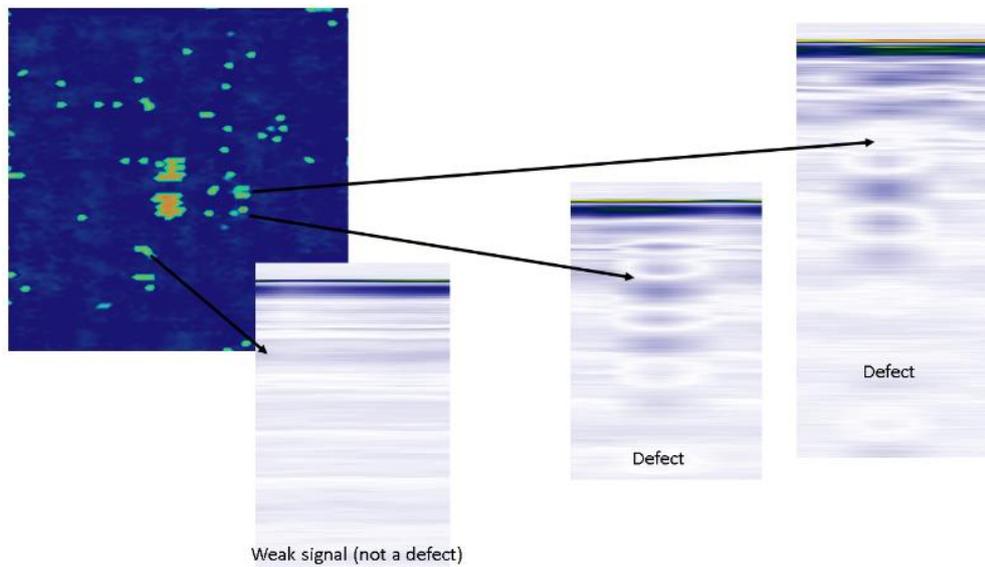
**Figure 5** Video camera setup on the viewing monitor of the inspection office

## 5. Results

Figure 6 shows a full Time of Flight (TOF) scan for a CS2 reference panel sample (size: 61.5 cm x 62.5 cm). The results shown are the best of 24 full scans that were performed over five, one week long, testing sessions at KUKA Halesowen; these sessions were attended by representatives from all consortium companies. The inspection gate has been adjusted to highlight flaws in the top left-hand quadrant of the sample. Of the 125 flaws present in the CS2 reference sample, 75 flaws could be visualised in the TOF scan, which is roughly 60% of the flaws present in the sample. The LUT method suffered from high levels of noise and attenuation in the thin elastomeric region of the sample (mid-section, right side). See Figure 7 for in depth analysis of the scan. The developed software has the function to interrogate individual flaw indications by means of a drop cursor, which can be moved around on the part. The scan section, C-scan (top view) shows strong and weak flaw indications. When these indications are interrogated the B-scan (section through part at the given point) clearly displays which indications are flaws, and which are not for that point of the part.

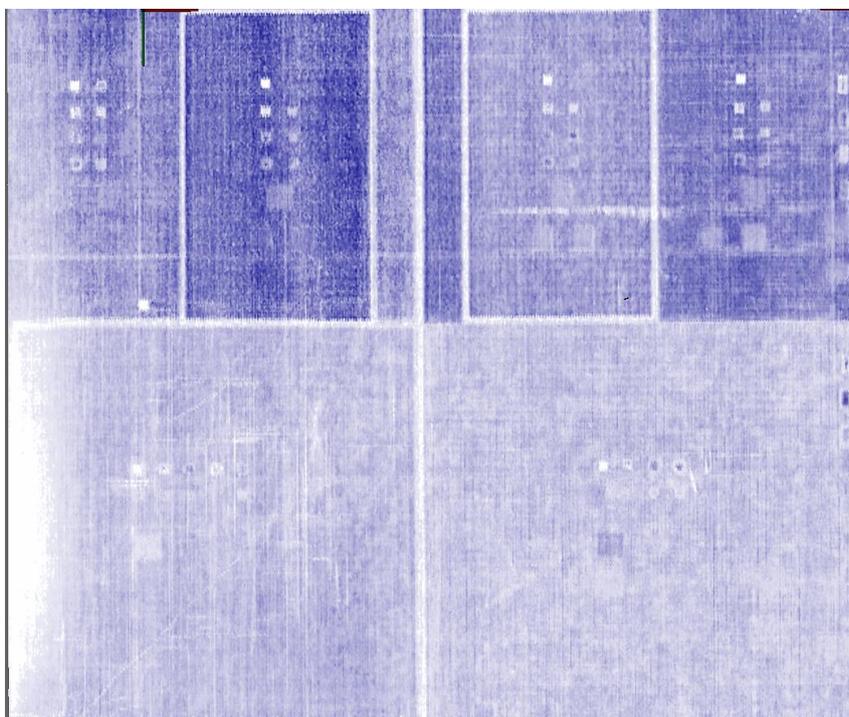


**Figure 6** Scan result of CS2 panel with laser power of 20W and a robot speed of 0.4m/s



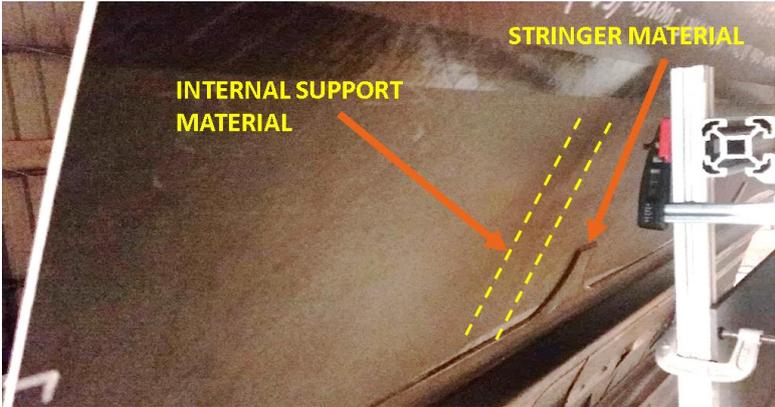
**Figure 7** C-scan and B-scan data of flaws

Within the ACCURATE software a function has been developed to view the C-scans in histogram filtering format. Histogram Analysis can be used to calculate two thresholds. One to hide data that does not display an indication, signals picked up in regular areas. Second to highlight data of equal/higher amplitude than the user's defined indication, hiding signals that are lower, therefore only displaying points of data that raise concern to the user. The C-scan from Figure 6 has been subjected to this filtering, see Figure 8 for the resultant image.

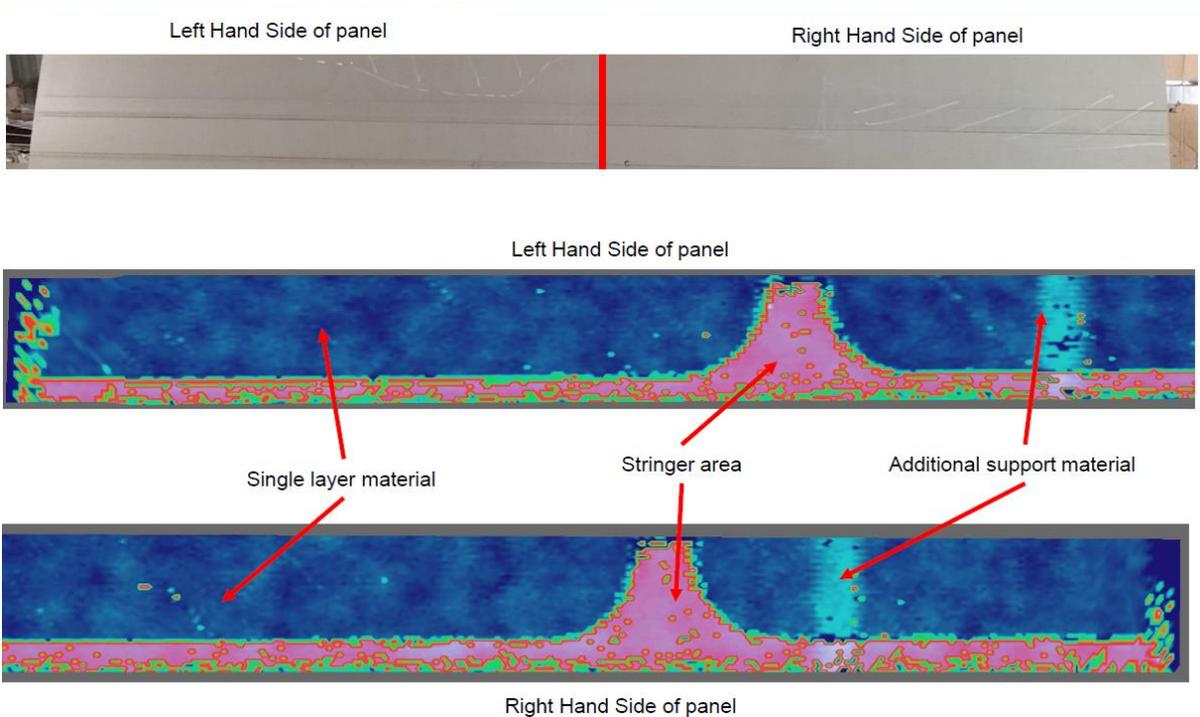


**Figure 8** Histogram filtering function of scan result of CS2 panel with laser power of 20W and a robot speed of 0.4m/s

A scrap piece of Super panel (size: 170 cm x 120 cm) was also made available for the test scans at KUKA Halesowen to further test the ACCURATe system. Figure 9 shows the construction of this scrap panel, which was manufactured from a main front panel with stringer material bonded to it at the rear for additional support, internal support material is also present. Figure 10 clearly shows the resulting scan reveals the component parts of the panel. The colours indicate thickness and from the acquired data the position of the stringer and small sections of support material are clearly visible. It should be noted that this scrap part has been subjected to previous mechanical testing, and as such is not representative of the manufacturing quality of new parts.



**Figure 9** Scrap Super panel construction



**Figure 10** Test scan of a scrap portion of Super panel

## **6. Conclusions**

A prototype LUT system has been developed, designed and built in accordance with the deliverables and objective of the first stage of the project. We have seen encouraging results from the pre validation testing. The system has recently been used to scan a reference panel, and a scrap panel of fuselage and the latest test results prove promising progress against the project objectives.

Of the 125 flaws present in the CS2 reference sample, 75 flaws could be visualized in the TOF scan, which is roughly 60% of the flaws present in the sample. For the missing flaws, the LUT method suffered from high levels of noise and attenuation in the thin elastomeric region of the sample. RECENDT are presently working on an electrical amplification method, to improve the Signal to noise ratio of the system, and this should improve flaw detectability.

The robot selection with its payload capability and combined controllability for acceleration and deceleration has yielded repeatable data results and there is no evidence of mechanical vibrations on the optical head and subsequently no discernable noise introduced from vibrations in the acquired C-Scan images. The developed software integrates all the different system modules together and offers the operator an intuitive user experience.

The next stages in the project are to conduct further trials with a view to quantifying detected flaw size and measurement speed and to install the system at the Leonardo Aircraft premises in Naples, in order to validate the system against full Super panel fuselage parts.

## **Acknowledgments**

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## **References**

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