GENEX

New end-to-end digital framework for optimized manufacturing & maintenance of next-generation aircraft composite structures

NEWSLETTER

ISSUE 2

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Dear reader,

I am glad to share with you Issue 2 of the GENEX Newsletter.

The "Next end-to-end digital framework for optimized manufacturing and maintenance of next-generation aircraft composite structures" GENEX is a 42-month Horizon Europe project launched on September 1, 2022. GENEX is led by ITA and commits to work towards EU goals by developing three pioneering technological assets which, through integration, will lead to a multi-disciplinary digital twin of the component throughout its lifecycle for the next generation aircraft composite structures. The project objectives have been achieved via the development of three main blocks of technological assets.

With the successful completion of most of the objectives, the project now transitions into a critical new phase: systems integration and verification. This stage will showcase the construction of a representative aircraft component and the seamless integration of all developed technologies into the project's intelligent IoT platform. This integration is designed to ensure a continuous, real-time data flow throughout the aircraft's lifecycle, underscoring the project's vision for a connected, intelligent, and future-ready aviation ecosystem.

Learn about the project by watching **Season 1 - Episode 1 of the GENEX Video Series.**

Enjoy this issue and join our community online through the GENEX website and social media pages!

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GENEX Objectives

Advanced and efficient manufacturing or recyclable composites

Integral health & usage monitoring system of aerostructures

Digitally-assisted repair processes & tools

A holistic approach to materials, processes, and technologies is key to **eco-efficient aerospace manufacturing**. Innovative monitoring systems and predictive models enhance precision and sustainability. These tools support the **advanced production of composite components.** The outcome is a data-driven, environmentally conscious aviation industry

Enhancing the reliability of aircraft structures under diverse operational conditions calls for a breakthrough in fatigue damage assessment. A novel methodology, combining **coupled physics** with **data-driven algorithms**, offers a powerful framework for predicting structural degradation.

By developing pioneering **digital-based processes** and **intelligent tools**, the industry is transforming how composite repairs are approached and executed. These advancements not only streamline maintenance and repair operations but also enhance accuracy, traceability, and turnaround times.

At the forefront of aerospace innovation, the integration of a **multidisciplinary digital twin** for aircraft components is revolutionizing lifecycle management. This cutting-edge approach enables the creation of a dynamic, continuously updated virtual model that mirrors the physical state and performance of the aircraft in real time. By synthesizing data from various engineering domains, the digital twin paves the way for smarter, more sustainable aviation.

Advanced and efficient manufacturing of recyclable composites

Eco-efficient composites manufacturing reaches new heights, led by AIMEN

In just the first 30 months, the GENEX project has made remarkable strides in advancing sustainable aerospace materials. The team has successfully developed eco-efficient composites and manufacturing processes, underpinned by cutting-edge monitoring systems and robust numerical modeling.

A breakthrough includes the development of an optimized out-of-autoclave manufacturing method for carbon-fibre-reinforced composite tapes. This process utilizes a novel thermoset resin with thermoplastic-like properties, known as 3R-resin, enhanced with embedded Fibre Optic Sensors (FOS) for real-time performance tracking.

Discover more about this innovative material and its transformative manufacturing process by watching **Shaping the future of Aviation Manufacturing: The GENEX approach (S01, E02)**, with Ibon Aranberri from CIDETEC.

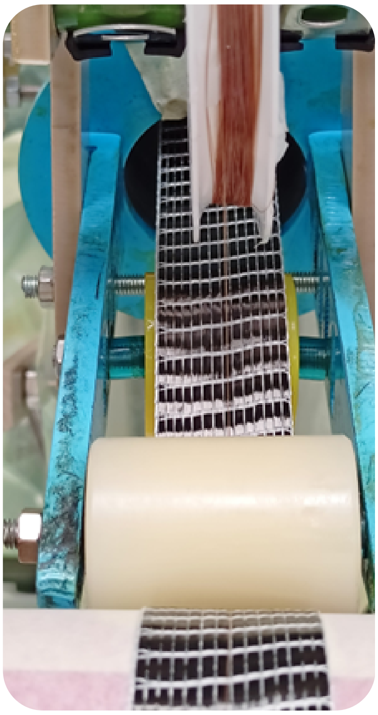


Figure 1. Embedded Fibre optic sensor (FOS)

"The fabrication of carbon fiber/3R resin prepregs was carried out at a process rate of 10 m/min with an 80°C bath temperature. These prepregs can be stored at room temperature without compromising their properties, making them ideal for producing high-strength aeronautical components."

Ibon Aranberri Askargorta
Senior Researcher, CIDETEC

Advancing AFP Process Optimization with AI and THz Monitoring

To enhance the precision and efficiency of the Automated Fibre Placement (AFP) process, a cutting-edge multi-physics simulation powered by artificial intelligence has been developed. This simulation ensures optimal curing conditions and a high degree of crystallinity in composite materials.

Complementing this innovation, a pioneering in-line monitoring system based on terahertz (THz) spectroscopy has been introduced.

This system delivers real-time insights into the evolution of both curing and crystallinity levels, marking a significant step forward in intelligent manufacturing for aerospace applications.

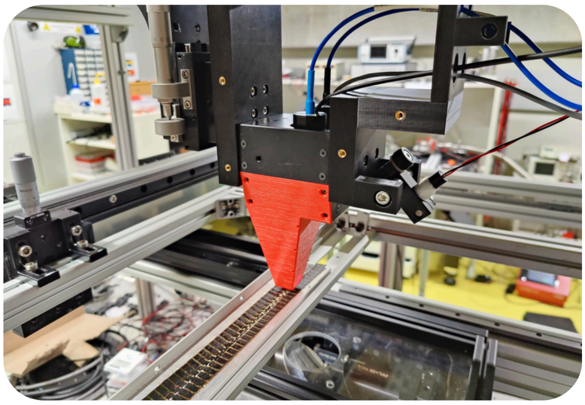


Figure 2. THz monitoring system in laboratory environment during tests on 3R resin tapes

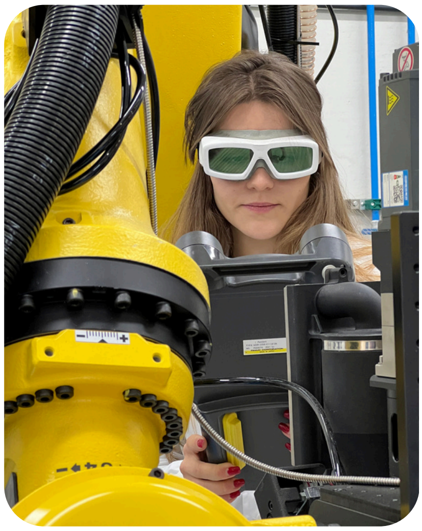


Figure 3. AFP cell operation for the in-situ consolidation of 3R-resin tapes and thermoplastic tapes.

"Through AFP there will be a reduction in the manufacturing costs of the composite laminates due to the use of low temperature curing 3R resins and commercial thermoplastics using energy efficient, near-zero waste, and out-of-autoclave processes"

Beatriz Simoes
Advanced Composites Technology
R&D division , AIMEN

AFP Process Optimized with FOS and Piezoelectric Sensing

The final process parameters for AFP using 3R-tapes, featuring embedded FOS and high-performance thermoplastic composites, have now been successfully optimized. This refined manufacturing approach also integrates piezoelectric sensors, enabling advanced structural health monitoring capabilities. These innovations mark a significant milestone in the evolution of intelligent composite manufacturing for next-generation aerospace applications.

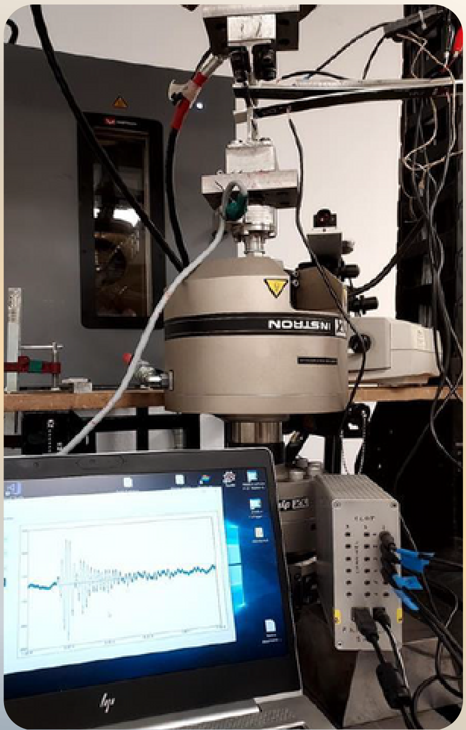
You can discover more info about the process by watching the video **Shaping the future of aviation manufacturing: The GENEX approach (S01, E03)** by AIMEN.

From Milestone to Momentum: Entering the Demonstration Phase - Next Steps

With all work package objectives successfully achieved, the project now advances to its next pivotal stage: demonstration and validation. This phase will feature the construction of a representative aircraft component and the seamless integration of all developed technologies into the project's IoT platform. This integration will enable continuous data flow across the entire aircraft lifecycle, reinforcing the project's commitment to intelligent, connected, and future-ready aviation systems.

Integral health and usage monitoring system of aerostructures

In the evolving landscape of aviation safety and performance, Health and Usage Monitoring & Management plays a pivotal role in ensuring aircraft reliability and mission readiness. By leveraging advanced data analytics and real-time diagnostics, this initiative empowers operators to proactively detect anomalies, optimize maintenance schedules, and extend the lifecycle of critical components. The integration of smart monitoring systems not only enhances flight safety but also contributes to cost efficiency and operational sustainability, marking a significant step forward in modern fleet management.



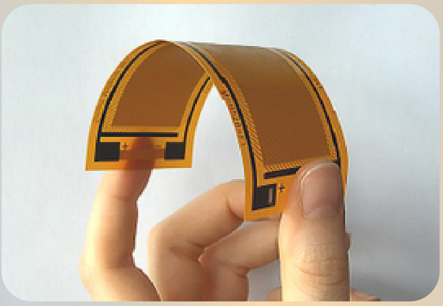
11th EWSHM 2024 Conference

Monitoring Techniques

UGW inspection

- Performs on-demand interrogation of a structure while the structure is still in service as an active method.
- Uses arrays of PWAS bonded to a structure for both transmitting and receiving ultrasonic waves to achieve damage detection.
- The flexibility of the MFC allows it to adhere to curved surfaces.

Javier Hernández Oliván
PhD candidate in Mechanical Engineering and R&D engineer



Presentation slides

AI-enhanced multiphysics solver revolutionizes composite damage detection

A cutting-edge, open-source multiphysics solver, built on the Finite Element Method (FEM) and optimized for High-Performance Computing (HPC) environments, has been successfully developed and validated. This advanced tool enables precise simulation of Ultrasonic Guided Wave (UGW) propagation in complex composite structures, setting a new benchmark in structural analysis.

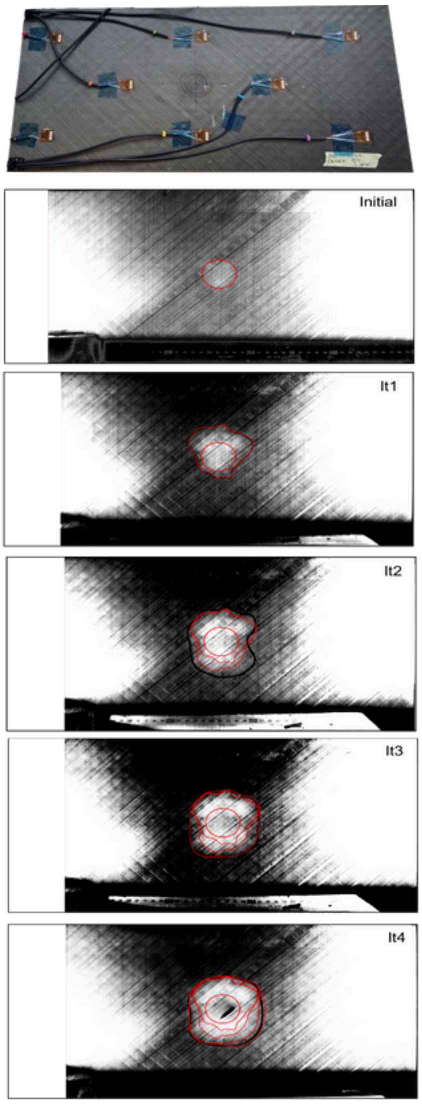


Figure 4 Experimental UGW inspection of delamination propagation on a thermoplastic test coupon.

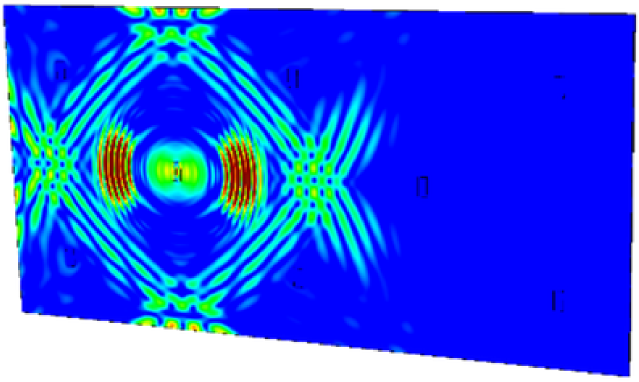


Figure 5. FEM simulation of the UGW propagation on a thermoplastic test coupon.

Leveraging the simulated data, a custom Deep Learning model has been designed and trained to accurately predict the location and size of delamination damage in composite materials (see **"AI-Powered structural health monitoring: Predicting fatigue damage in aircraft composites with ultrasonic guided wave inspections"** by IRES at the 14th EASN International Conference). This AI-driven approach represents a significant advancement in early damage detection, offering enhanced reliability, reduced inspection time, and improved maintenance planning for next-generation aerospace systems.

Discover more by watching **Shaping the future of Aviation Manufacturing: The GENEX approach (S01, E04)**, with Jose M. Royo and Carlos Mallor from ITA.

"Imagine a scenario where, just as you can sense a gust of wind or a sudden jolt, an aircraft can automatically detect and assess events that occur during a flight. It's a system that tells us not only what happened, but also where it happened and how severe it is"

Jose Manuel Royo
R&D Engineer, ITA

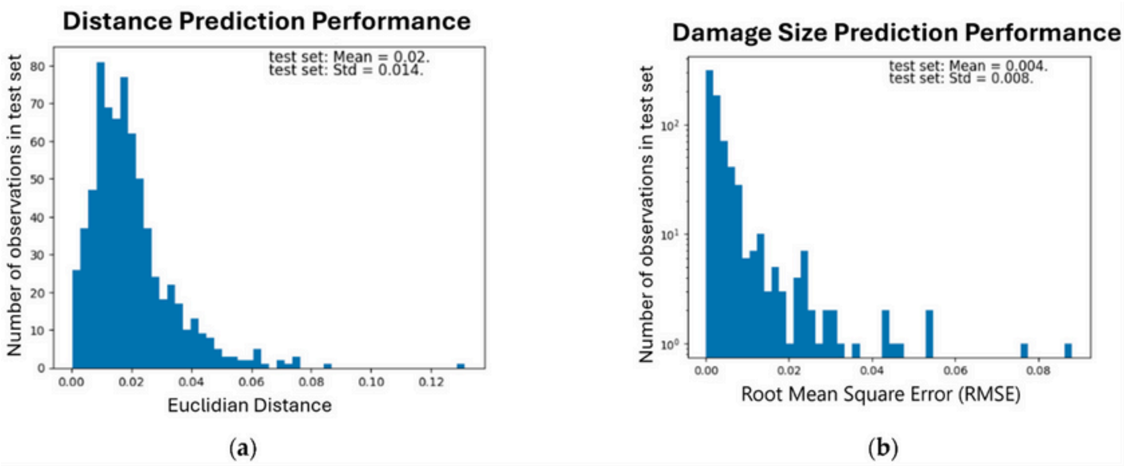


Figure 6. Distributions of performance metrics between the true and predicted damage locations and sizes using the AI toolbox.

Fracture Characterization and High-Fidelity Propagation

A comprehensive methodology for fracture propagation characterization and modeling have been successfully completed for both commercial thermoplastics and the innovative AFP-3R resin laminates. The results show strong agreement between experimental data and numerical simulations, offering valuable insights into damage evolution under operational loads.

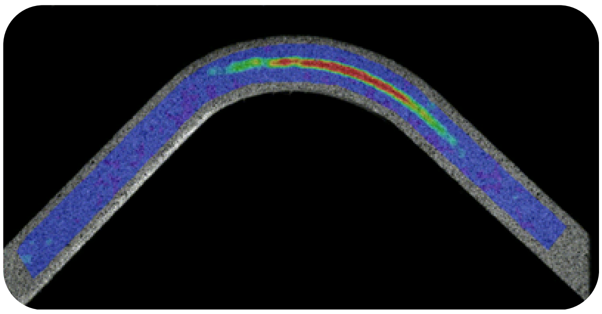


Figure 7. Experimental characterization of unfolding damage progression at sample level.

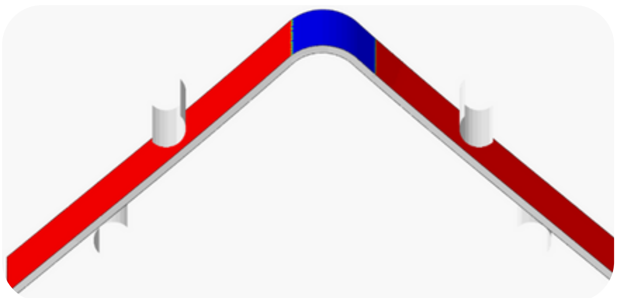


Figure 8. FEM simulation of unfolding damage progression at sample level.

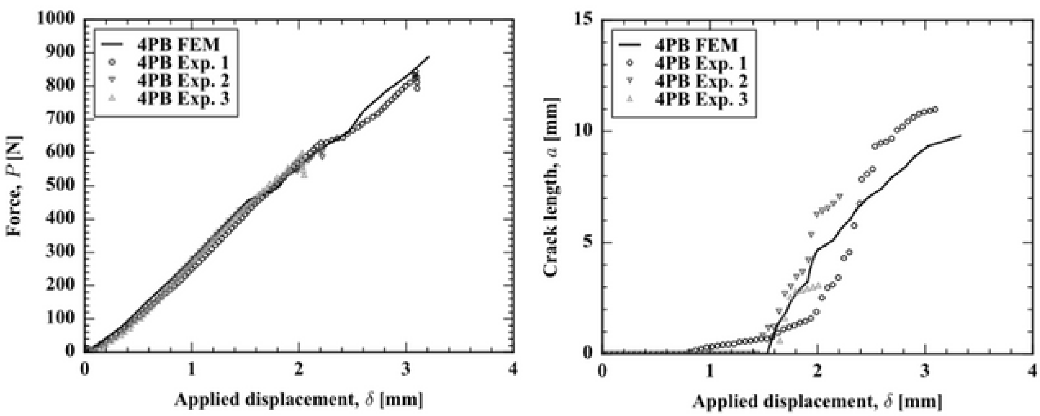


Figure 9. Validation of FEM model for unfolding damage progression at sample level.

Virtual Sensor Network Optimization and Communication Node Achieved

Innovative concepts such as virtual transducers and virtual damage modeling have been developed to enhance sensor network optimization, specifically aimed at improving the detection of planar delaminations in complex structural components.

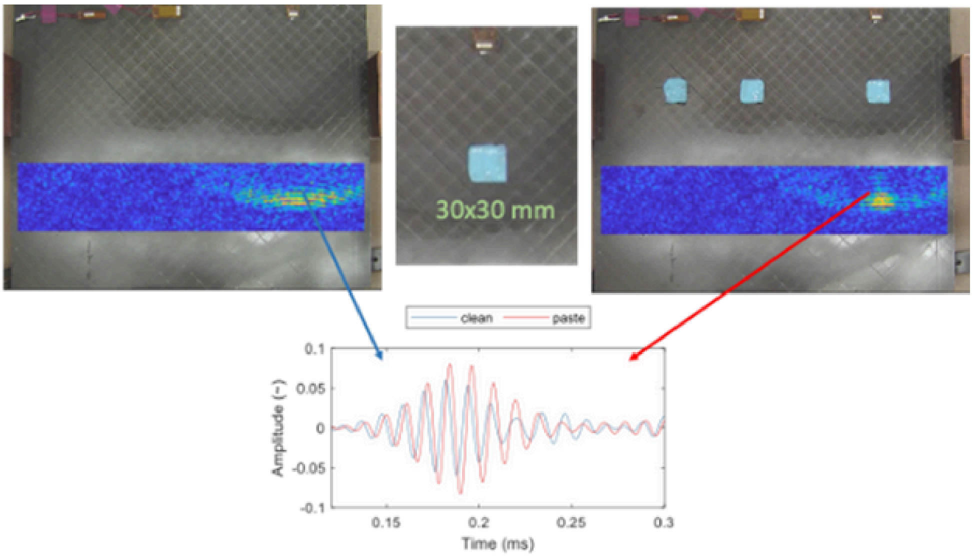


Figure 10. Virtual damage methodology to introduce an artificial delamination.

The design, simulation, and fabrication of a prototype sensor node for Ultrasonic Guided Wave (UGW) inspection have been successfully completed and tested. This node is engineered to interface seamlessly with the Structural Health Monitoring (SHM) sensor network, paving the way for robust and scalable field testing in real-world aviation environments.

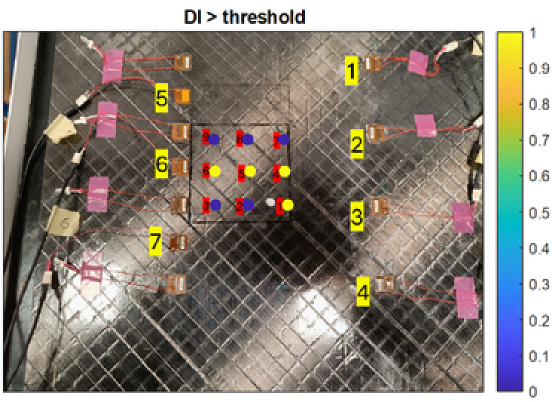


Figure 11.Validating the optimization of the sensor network

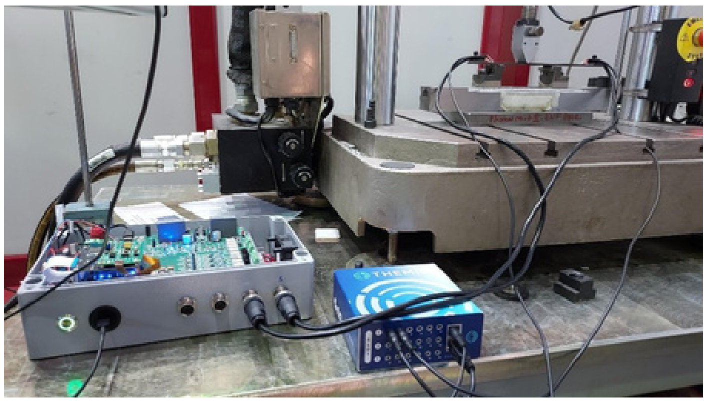


Figure 12. Testing of sensor node prototype for UGW inspection.

Advancing Toward Integrated UGW Inspection Capabilities - Next Steps

The next phase in our development roadmap focuses on the full integration of all models and algorithms within the intelligent industrial Internet of Things (IoT) framework. A key milestone will be establishing seamless interoperability between the GENEX platform and the communication node responsible for executing periodic Unmanned Ground Vehicle (UGV) inspections. Current efforts are focused on component-level demonstrations and validation, laying the groundwork for robust and scalable deployment in real-world aviation environments.

Digitally-assisted repair processes and tools

Precision Repair, Simplified:
Visual Assisted Scarfing System Validated

The Visual Assisted Scarfing System has successfully completed laboratory-scale validation, demonstrating its capability to enable even untrained personnel to produce highly precise repair scarfs. At the heart of the system lies a powerful principle: it captures the actual surface geometry and projects the deviation from the designed scarf directly onto the component, guiding the user in real time.

Developed by DLR, the accompanying software supports the automatic generation of advanced repair geometries—including stepped, continuous, circular, elliptical, rectangular, and even freeform shapes.
This innovation is currently under close evaluation by the advisory board, with **Lufthansa Technical Training** playing a key role in its review.

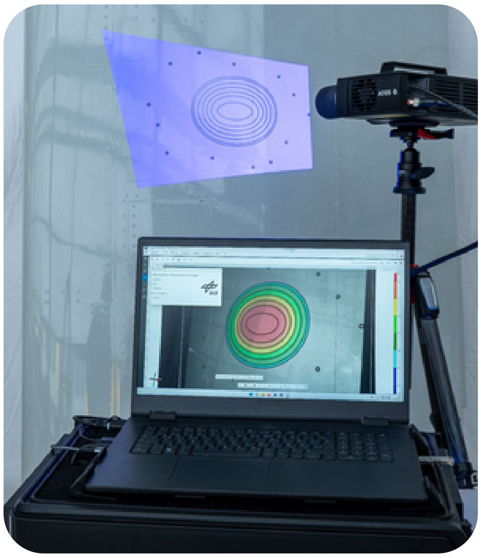


Figure 13. Setup of the Visual Assisted Scarfing (VAS) System projecting an elliptic scarf contour onto the surface of an Airbus A320 outboard flap.

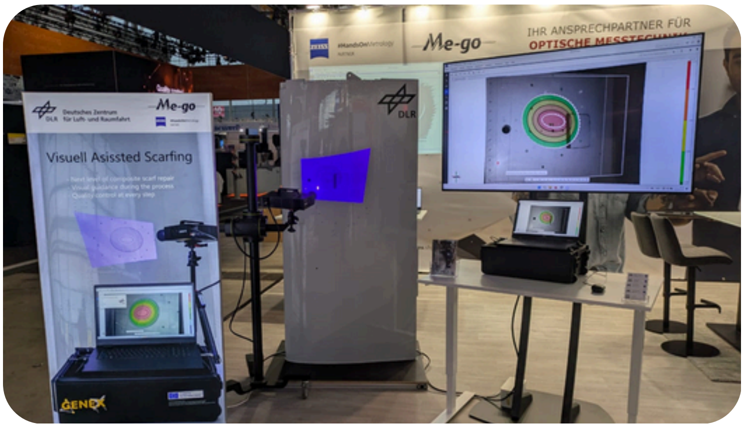


Figure 14. Booth of component supplier Me-Go with DLRs VAS system on the “Control 2025” fair in Stuttgart Germany

Figure 15. Setup of the VAS System projecting onto an Eurofighter Airbrake.

“We are devoted to developing pioneering digital-based processes and tools to optimize maintenance and repair operations while assisting the digital transformation of composite repair.”

Dirk Holzhueter
Engineer,DLR

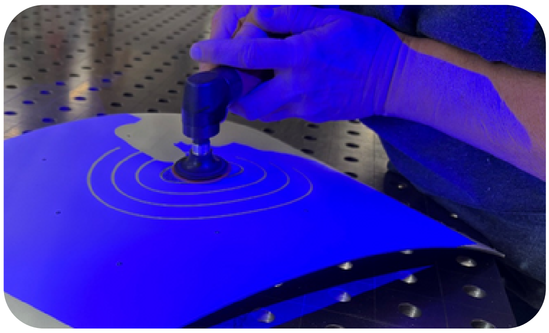


Figure 16. Manually grinding a sample with the VAS system.

Dual-Mode LIBS Module Validated for Precision Surface Analysis and Cleaning

AIMEN has successfully designed and implemented a versatile Laser-Induced Breakdown Spectroscopy (LIBS) module, validated through a series of LIBS and laser cleaning tests. Engineered for flexibility, the module supports two operational scenarios: integration within a laser cleaning workstation, enabling simultaneous analysis and cleaning, and deployment as a standalone system for inspecting larger samples. In both configurations, the system demonstrated robust performance.

Figure 17. (Left) Stand-alone and out-of-the-lab LIBS system implementation; (Right) Software interface for control and LIBS analysis

In one notable series of tests, a manually contaminated sample was accurately analyzed by the LIBS module, which identified oil-contaminated regions and effectively guided the cleaning process to restore the surface. These results affirm the module's potential for advanced, automated surface treatment in aerospace maintenance workflows.

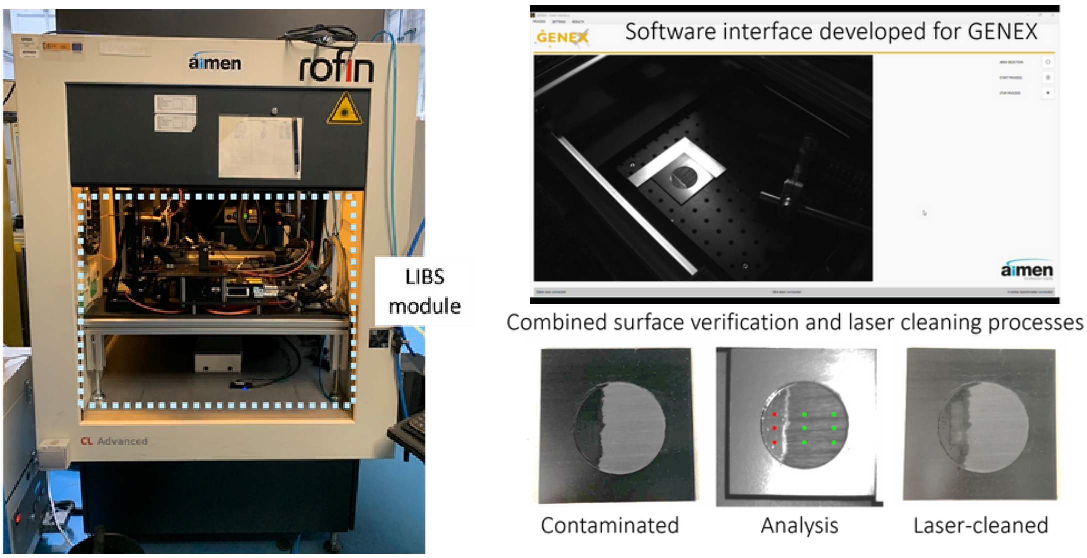


Figure 18. Combined LIBS module and laser cleaning. Control and analysis GUI detects contaminated areas. Processed samples were contaminated and correctly analyzed and cleaned.

"Developing a Laser Induced Breakdown Spectroscopy (LIBS) system for surface characterization analysis"

Optimized Heating Blanket Configuration for Omega-Stiffened Panel Repairs

The development of a tailored heating blanket configuration for omega-stiffened panel repairs has reached a significant milestone. A sophisticated FE model was created to simulate the thermal behavior of the repair process with high precision, and its accuracy was validated through experimental testing.

Building on this foundation, a fast and reliable Reduced Order Model (ROM) was established, capable of accurately reproducing temperature distributions during single-blanket repairs.

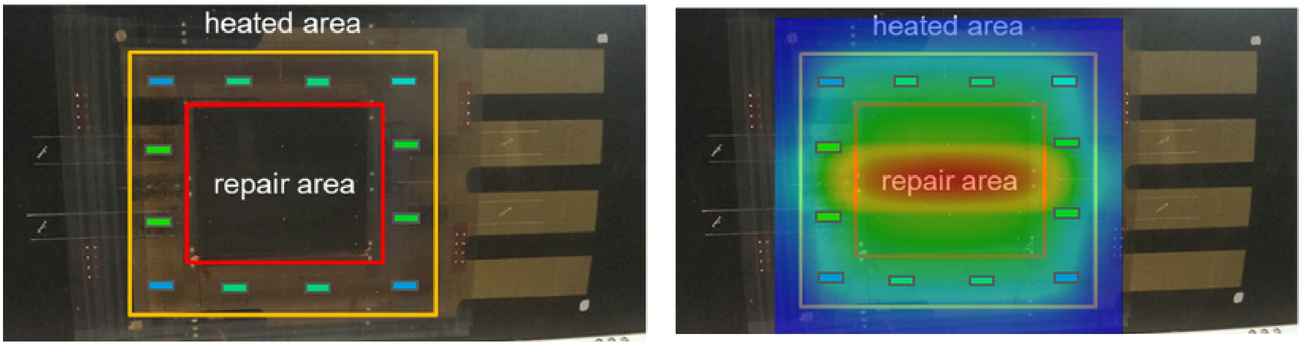
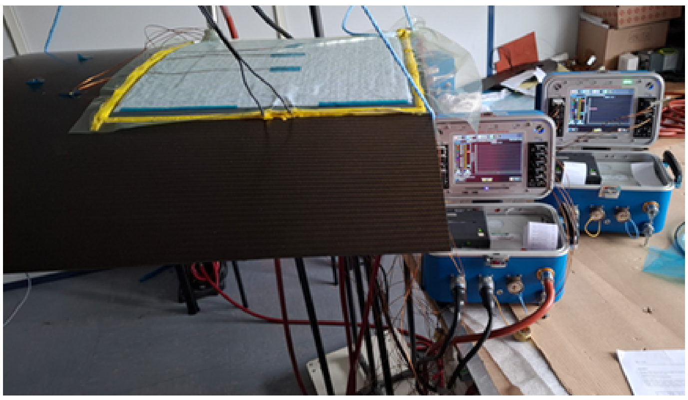


Figure 19. Comparison of the temperature distribution of a repair: (Left) Discrete temperature measurements without the GENEX solution ; (Right) Virtual continuous heatmap updated in almost real time with the GENEX solution.

To address more complex scenarios, a procedure was developed to estimate temperature fields for multi-blanket configurations. This was coupled with an optimization algorithm that determines the most effective blanket arrangement for any given repair condition.



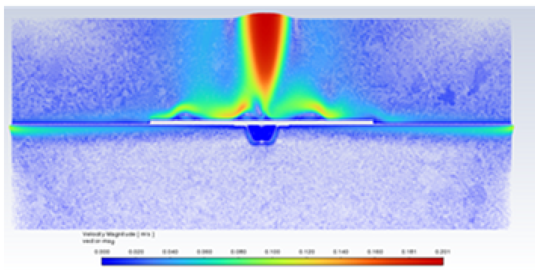


Figure 20. CFD Simulation of temperature during the heating of the repair including convection effects.

All these capabilities have been seamlessly integrated into a user-friendly desktop application, streamlining advanced thermal repair planning for aerospace maintenance professionals.

Integrated Crack Detection and Arrest System Advances Toward Aerospace Readiness

DLR has made significant progress in combining crack detection with crack-arresting materials, marking a promising step forward in structural health monitoring. A fibre optic strain sensing system was successfully implemented, demonstrating high-precision tracking of crack propagation.

In parallel, a novel crack-sensing material was validated for performance under low-temperature conditions, enhancing fatigue resistance under both peel and shear loading.

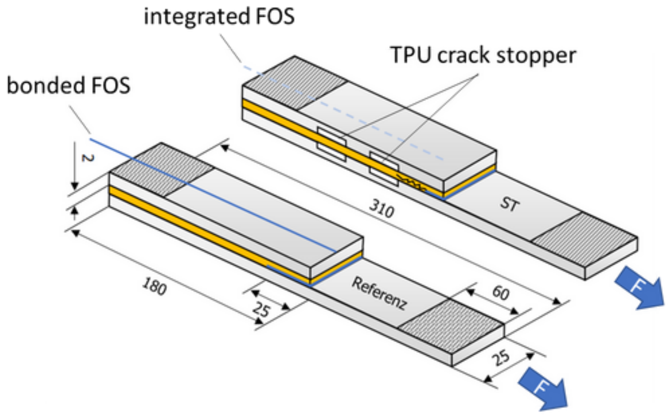


Figure 21. Design of Reference Crack Lap Shear Specimen (left) and specimen with integrated crack stopper and crack sensor.

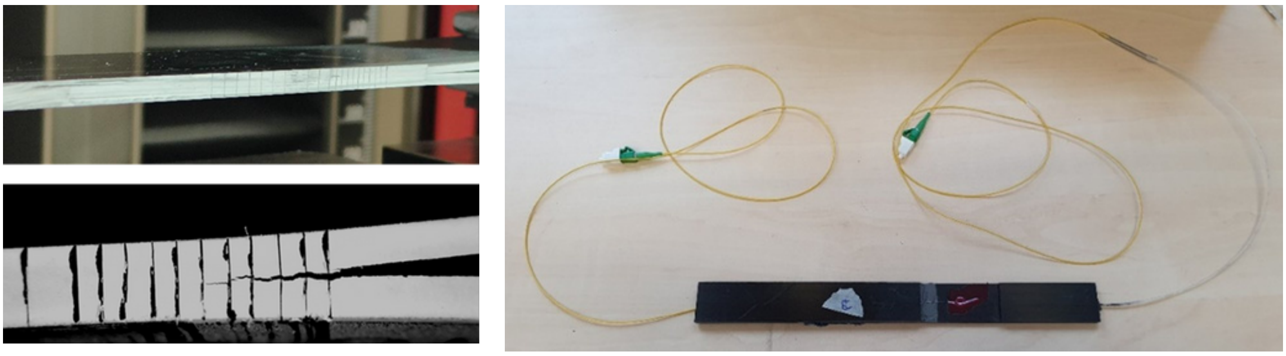


Figure 22.Double Cantilever Beam Specimen with integrated crack stopper and sensor while test (left) and prior to test (right).

Notably, static peel resistance improved by 30% compared to the reference configuration. The integration of these two technologies paves the way for a dual-function system capable of both detecting and mitigating crack growth, an innovation with strong potential for future aerospace applications.

Towards Intelligent Repair Integration: Advancing Validation and Digital Twin Connectivity - Next Steps

A series of validation trials is planned to quantify both the time savings and the precision achieved in manufactured repairs. These efforts will be supported by the integration of a dedicated software interface, enabling seamless upload of process data to the digital twin platform. In parallel, additional validation trials will focus on contamination detection, with measurement results also being captured and stored within the digital twin environment.

The outcomes, ranging from optimized heating blanket designs to advanced repair control strategies, will be adapted for integration into the digital platform under the IoT platform. Further testing will include fatigue loading trials of the newly developed crack-stopping material and fibre optic crack sensor, aiming to validate system performance under operational stress. To demonstrate real-world feasibility, a manufacturing demonstrator is also planned, targeting integration on curved scarf repair geometries.

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