❝ When the physical world meets, uniquely, the virtual world for a premium manufacturing, maintenance, and repair approach of the next generation aircraft composite structures ❞

GENEX Project – Overview and Composite Repair related Innovations

CRS&EF, Republic Polytechnic, Singapore, 24/9/2024

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George Kanterakis, GMI Aero (France)

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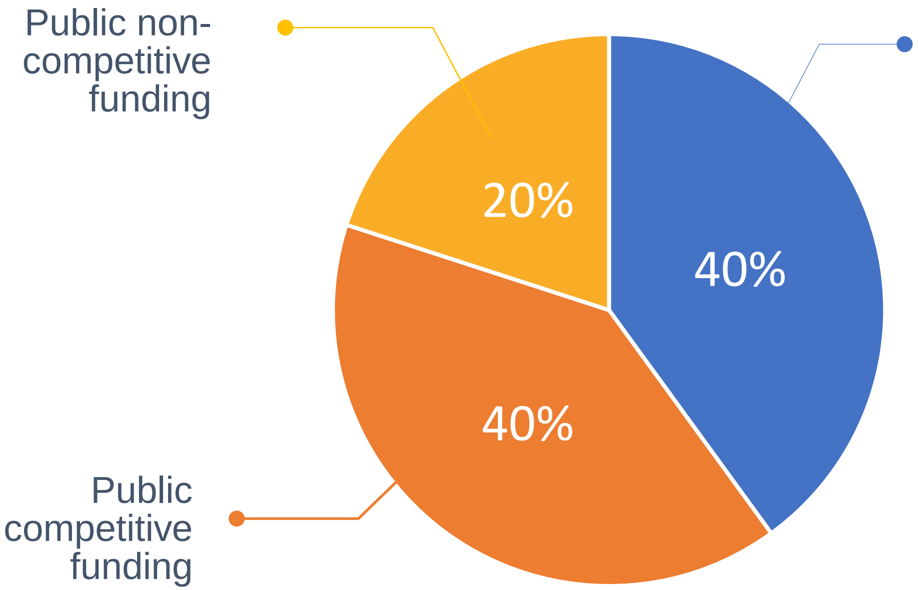
Aragón Institute of Technology (ITA)

Since 1984



70% R&D private contracts

30% technical support

57% European
28% National
15% Regional

20M€

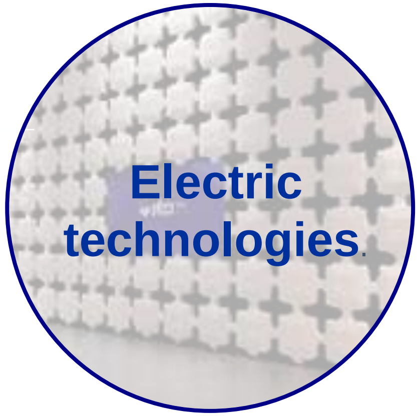
In 2023 we work on:

More tan 2.900 tests

More tan 200 private R&D projects

More tan 120 public R&D projects

A multidiciplinary team working for companies and society



We are the technological partner of:

AERnnova, asai, avanza, BD, B/S/H/, CAF, CEFA, exafan, ENAR, CONTAZARA, FERRUZ, Fersa, GRANDES VINOS, Irizar

libelium, MANN+HUMMEL, MONDO, MP, OROEL, pikolin, P&G, ruberte, SAICA, Schindler, ERMA, sesé, SIEMENS Gamesa

STADLER, STANDARD PROFIL, STELLANTIS, TATOMA, valoriza, Viscofan, WITTUR, YUDIGAR, zalux, ZEU, Z DATA LABS

“When the physical world meets, uniquely, the virtual world for a premium manufacturing, maintenance, and repair approach to the next-generation aircraft composite structures”

GENEX goals

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

To produce **eco-efficient materials** and processes, monitoring systems, and numerical models supporting **advanced manufacturing** of composite aircraft components.

To invent a methodology built on **coupled physics -and data-based- algorithms** to improve the assessment of fatigue damage and residual life estimation of the aircraft structure under variable usage scenarios.

To develop **pioneering digital-based processes** and **tools** to optimize **maintenance** and **repair** operations while assisting the digital transformation of composite repair.

To create **a multi-disciplinary digital twin** of the aircraft component, rendering feasible a continuously updated model of the aircraft lifecycle.

What

A multi-disciplinary digital twin enabling data management across the entire lifecycle of the next-generation aircraft composite structures

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About GENEX

HORIZON EUROPE

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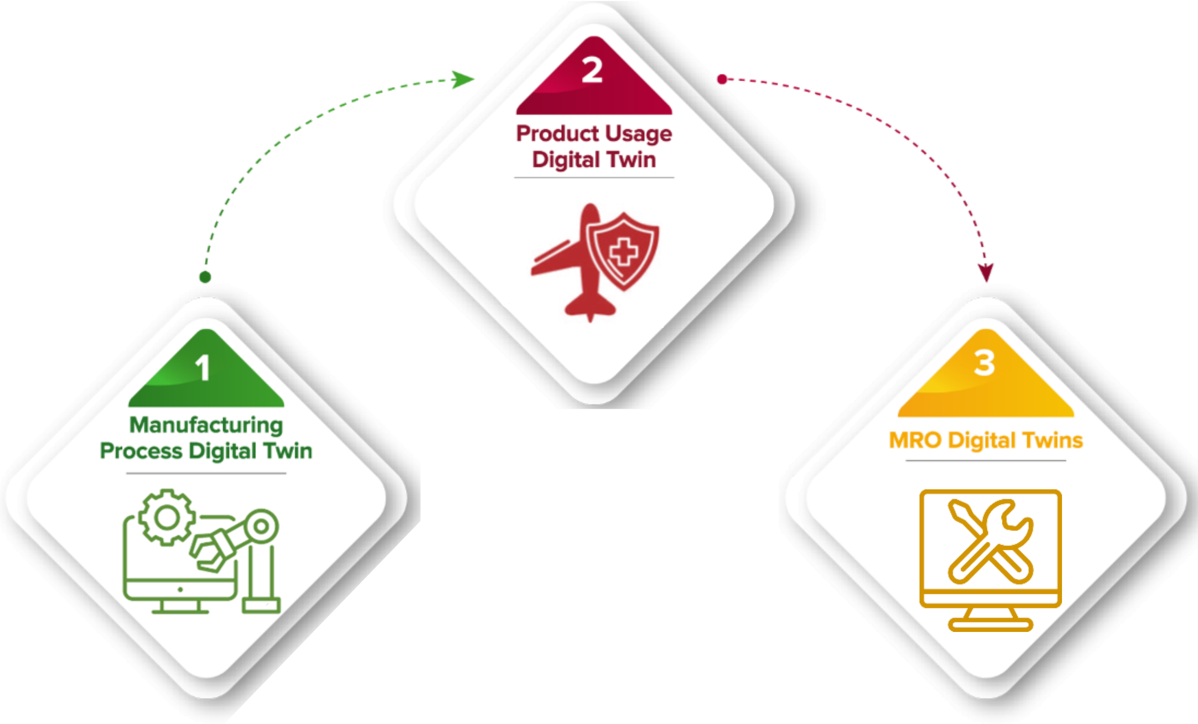
GENEX solution



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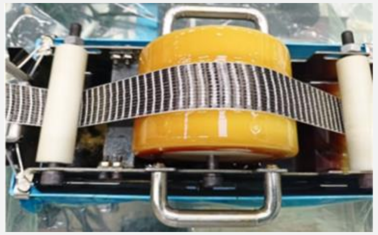
GENEX technologies

CF-3R tapes with customized Tg

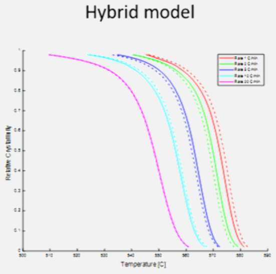


ATL process window

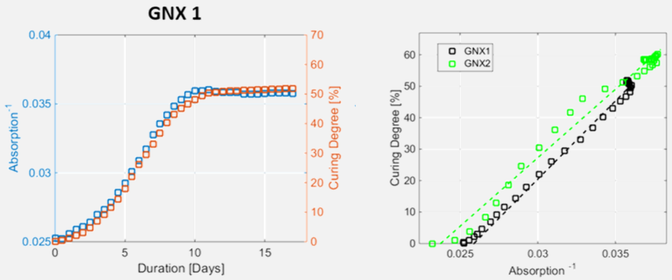
DoC & DoCr prediction

$$\frac{d\alpha}{dt} = f(t; \mathbf{p}) + \mathbf{g}(\mathbf{t}; \mathbf{p})$$

	$f(t;\mathbf{p})$	$\mathbf{g}(\mathbf{t};\mathbf{p})$
Physics-based	✓	✗
Data-Driven	✗	✓
Hybrid	✓	✓



THz monitoring of DoC & DoCr



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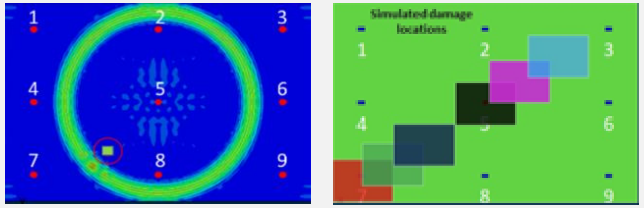
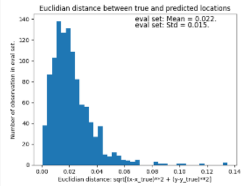
GENEX technologies

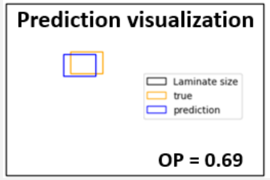
Validation

HPC - UGW Simulation



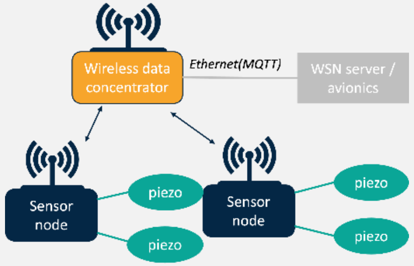
ML detection algorithms





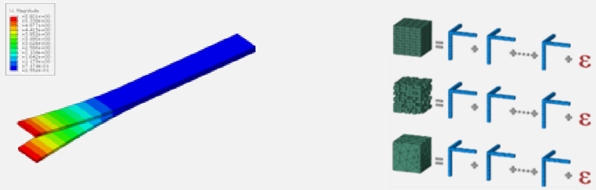
Sensor network optimization

Wireless communication



Characterization

Fracture & Fatigue ROM model



Remaining useful life prediction

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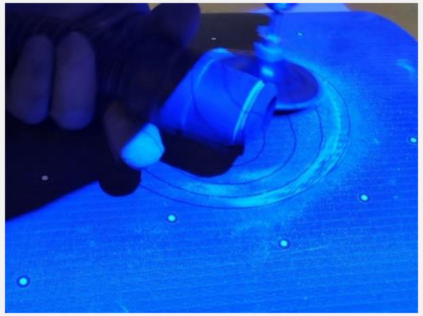
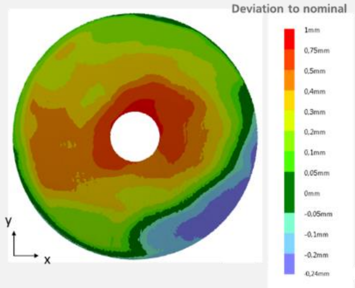
GENEX technologies

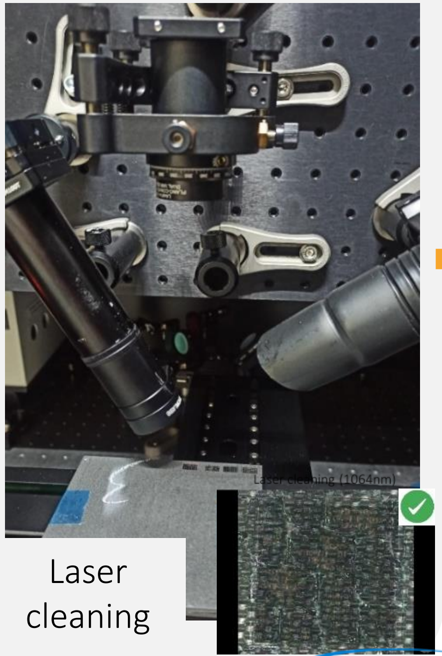
Visual assisted scarfing



Deviation of target

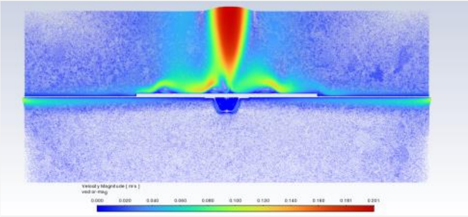


Portable LIBS cleaning system

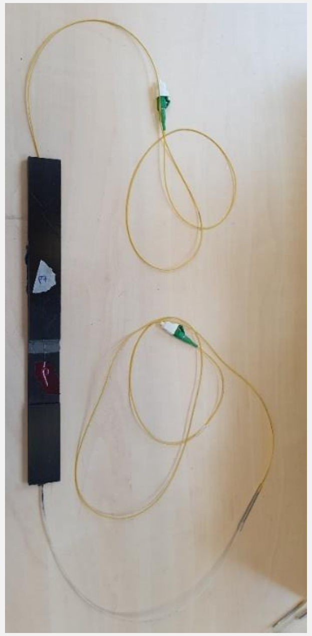


Laser cleaning

Online control of repair heating process



Smart bondlines



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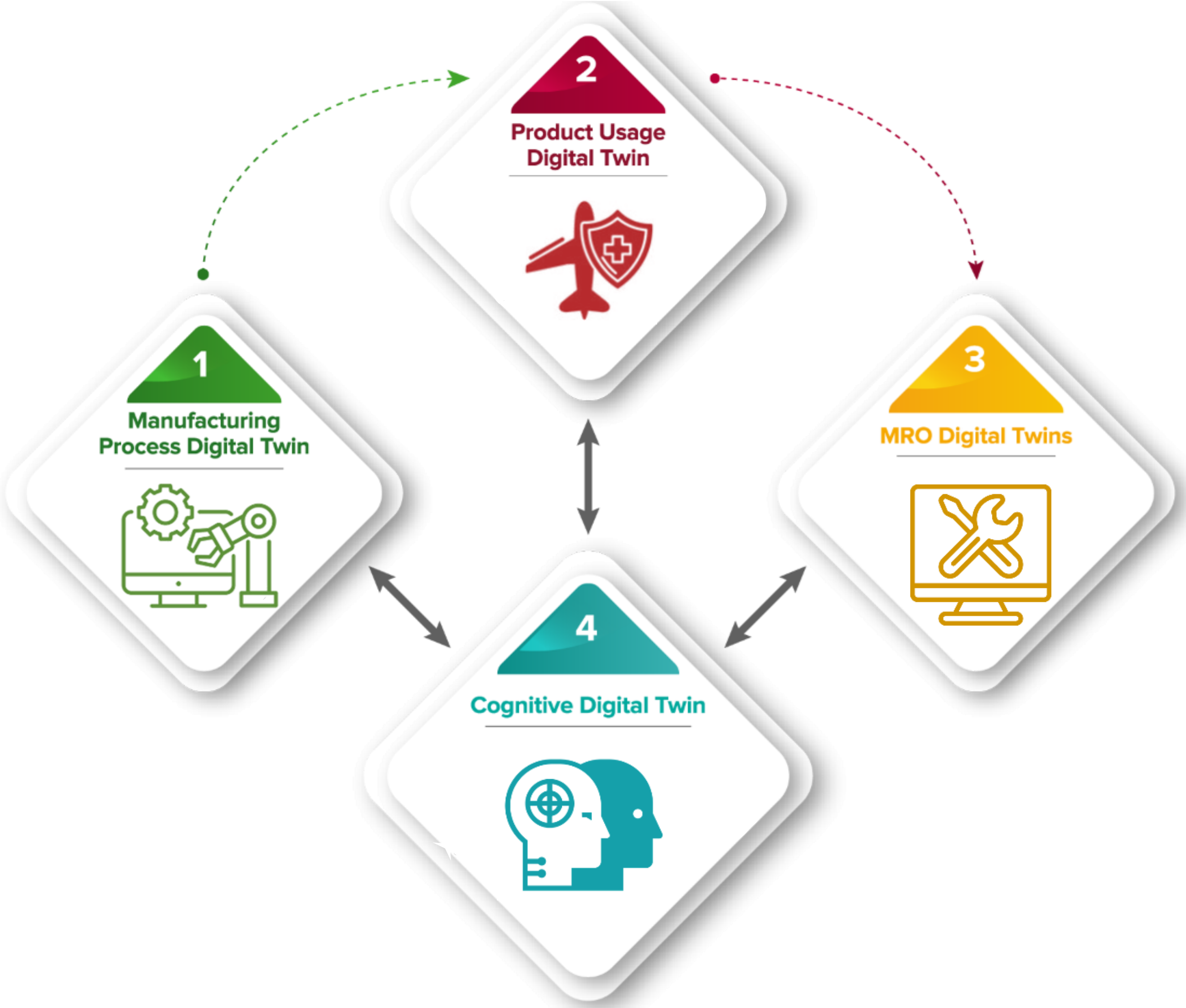
GENEX solution



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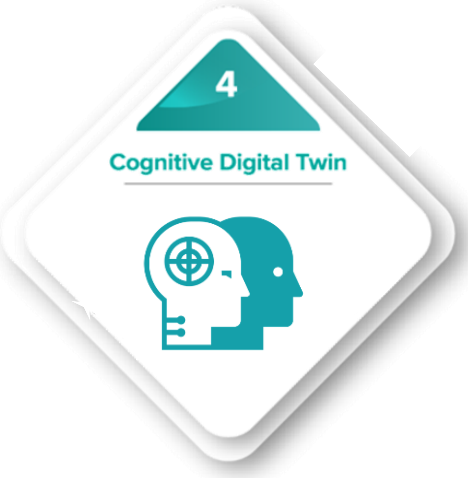
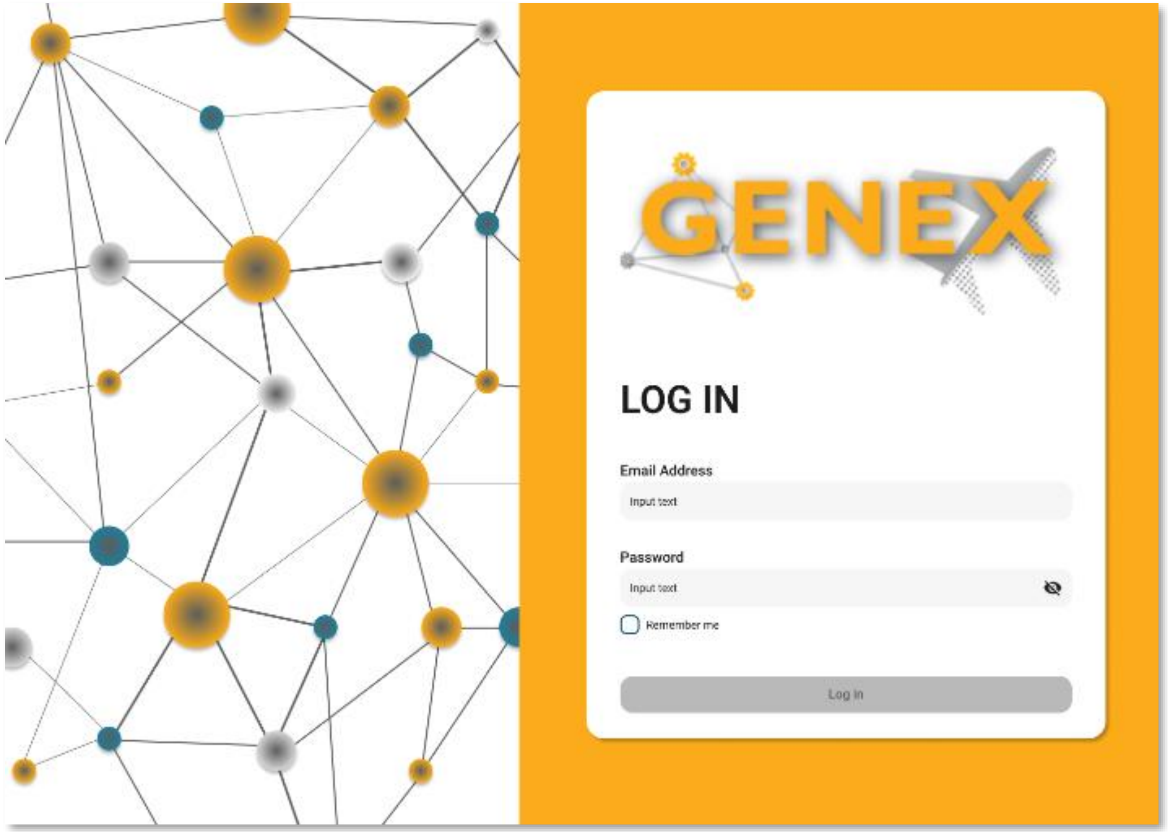
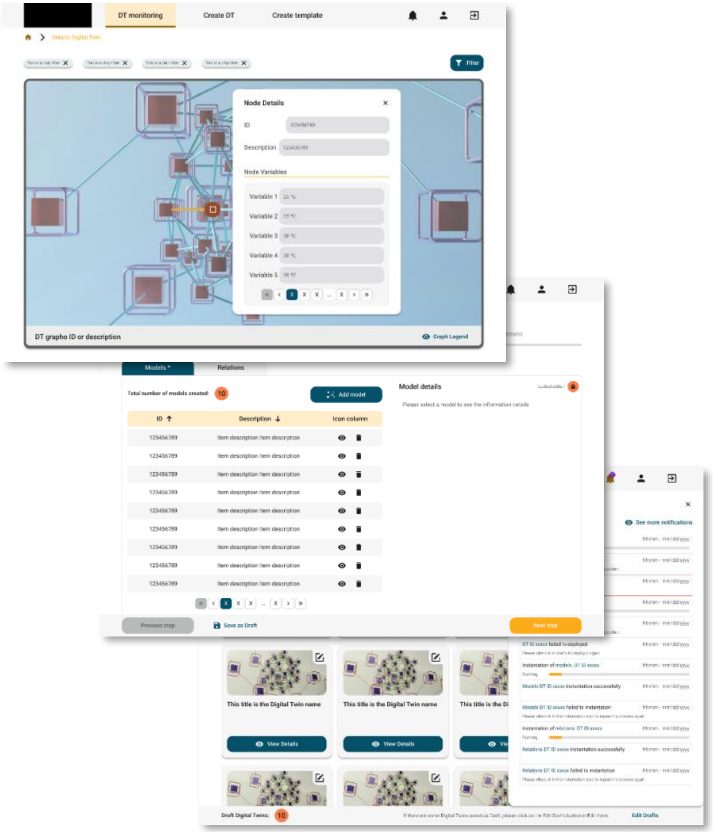
GENEX technologies







Capgemini engineering

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GENEX technology transfer to the industry

GENEX industrial partners

AERnnova

ZIEGLER® AEROSPACE

GMI AERO

Advisory board

EASA European Aviation Safety Agency

Lufthansa Technical Training

Guidelines for:

- MRO assessment
- Composite repair certification

LCA/LCC

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“When the physical world meets, uniquely, the virtual world for a premium manufacturing, maintenance, and repair approach of the next generation aircraft composite structures”

WP4 Digitally-assisted repair processes and tools

CRS&EF, Republic Polytechnic, Singapore, 24/9/2024

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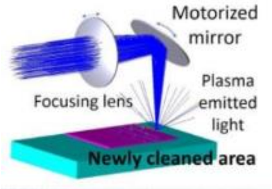
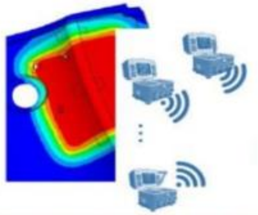
Main Objectives

This WP is aimed at developing **new digital-based processes and tools to support, automating and improving the efficiency and performance of repairing operations** applied during **the bonded scarf repair of composite laminate prototypes**, specifically to develop…

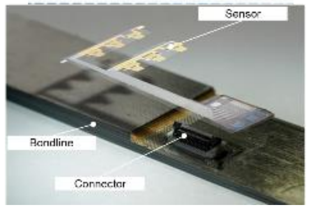
… an advanced and customizable **visual assistance system to support manual scarf repair operations** in order to indicate the operator the deviation between the actual and the nominal scarf geometry.



… a novel **laser-assisted coupled with laser-induced breakdown spectroscopy module** for a**dvanced cleaning** and **improved control of surface preparation** enabling an optimum bonding of the composite patch.



… innovative **digital-based methodologies for improved design of the composite repair heating blanket** and enabling adaptative control of the repair heating process.



… a **smart composite repair patch for detecting and stopping cracks** to ensure the integrity and quality of the repair patch during the lifetime of the aircraft structure.

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Structure & Participants

WP4
Digitally-assisted repair processes and tools
DLR

- **T4.1 Visual assistance system for manual composite scarf repair** — DLR
- T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair — AIMEN
- T4.3 Digital transformative composite repair heating — ITA
- T4.4 Smart bonded composite repair solution — DLR

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KPIs

- **30% reduction of repairing time** due to process digitalization and improved performance of composite repair
- **Up to 40% increase of the fatigue resistance** of adhesively bonded joints by combining advanced AR tools and laser ablation surface systems, enhanced heating repair and smart control of the repair joint.

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T4.1
Visual assistance system for manual composite scarf repair

DLR

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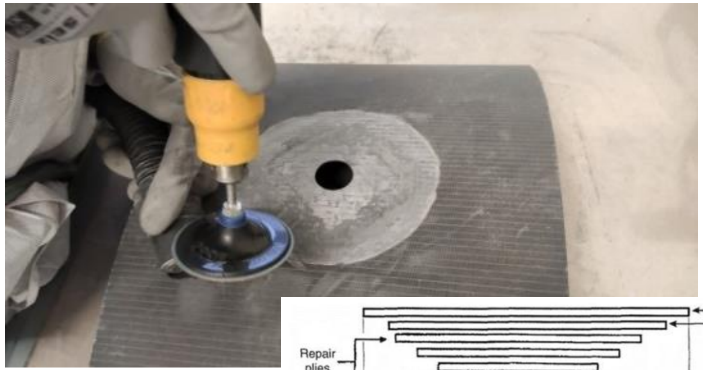
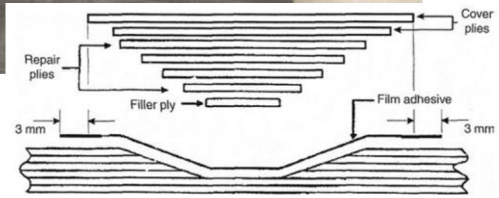
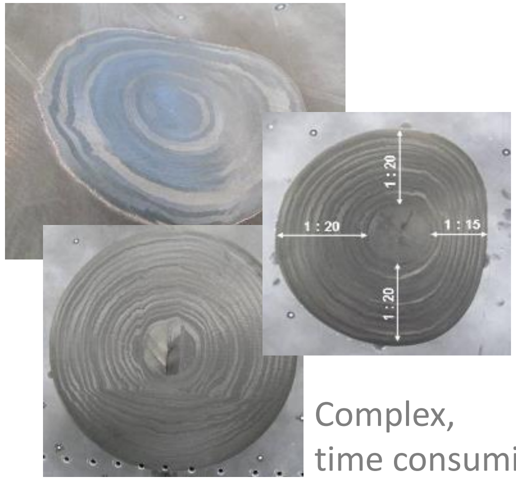
T 4.1 – Motivation

Visual assisted scarfing system (T4.1)

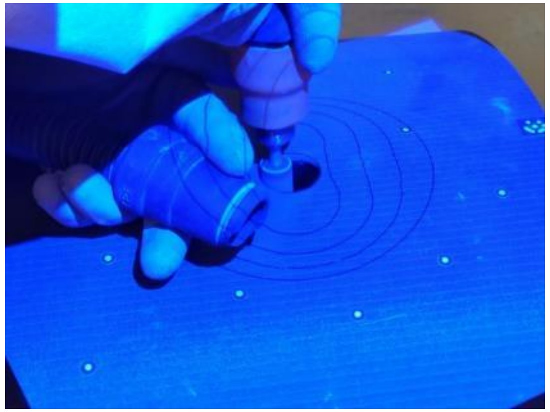


Manual scarfing





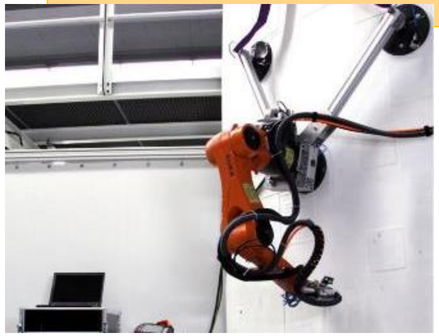
Complex,
time consuming



Assistance System for the laborer

– complex scarfs
– curved geometries
– Large repairs
– Support for additional processes

State of the art **Genex**



Robotic Automation
- no business case
- high invest and labor costs

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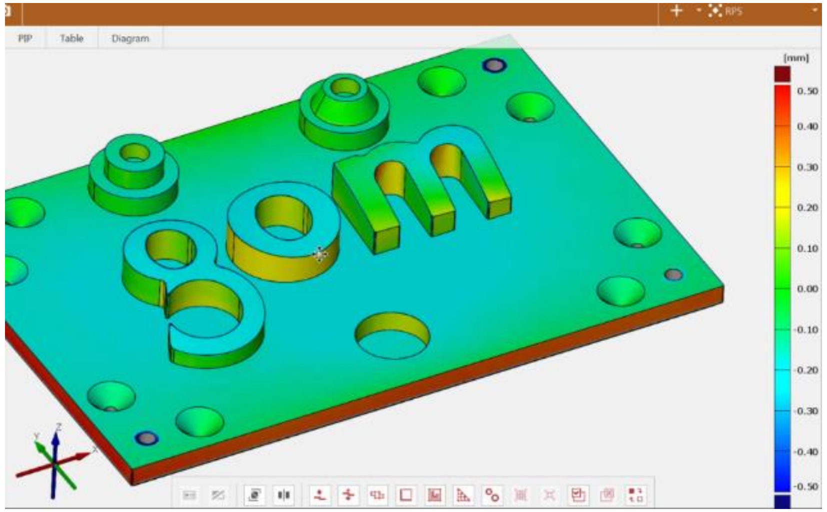
T4.1 –Assessment of hardware

Zeiss ATOS 5

- Scanning and projection in one system
- Dust proof housing for commercial use
- Mobile system for in field repair operation
- Flexible and adaptive software interface
- Suitable field of view for repair purposes



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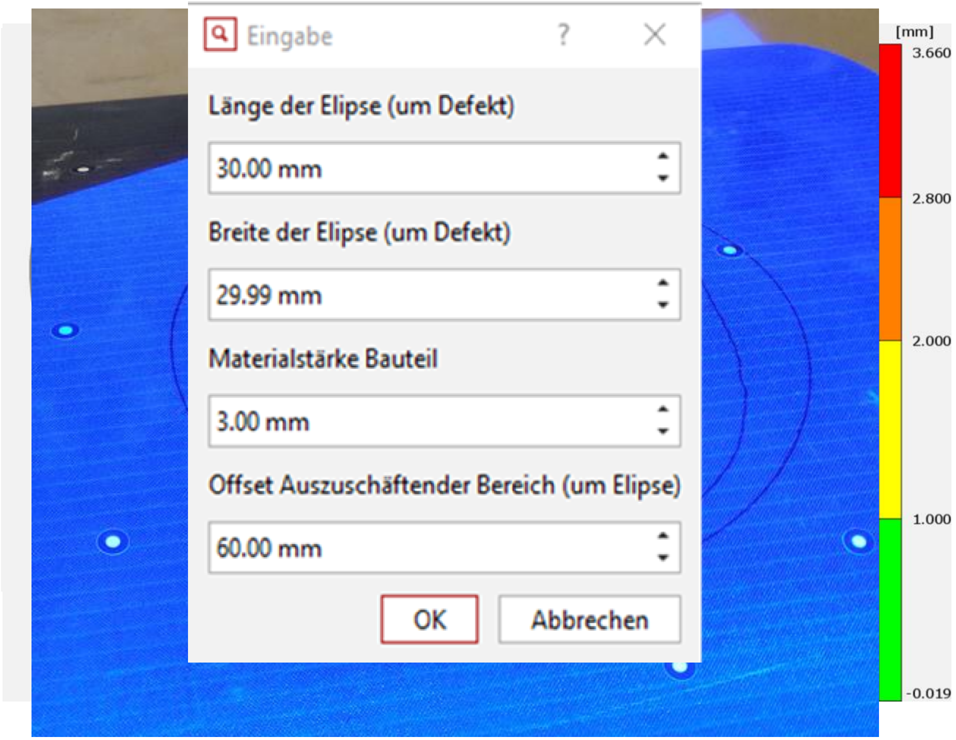
T4.1 – User Interface development

User Interface development Test

1. Surface scan –
   coded with reference points
2. Input of scarf details
3. Calculation of nominal geometry
4. Calculation deviation and contour lines
5. Project result on surface



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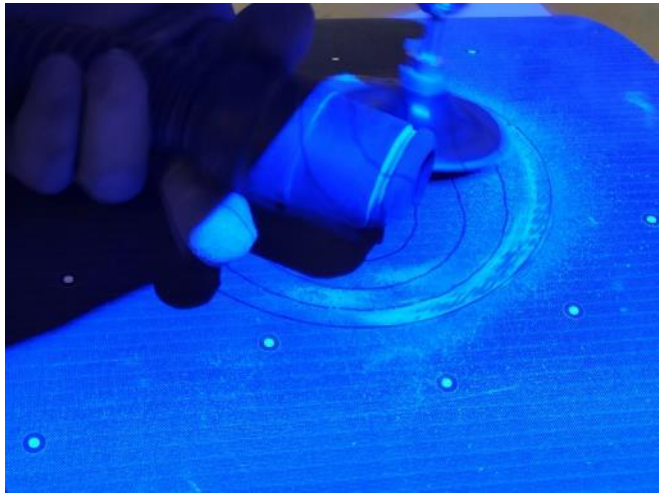
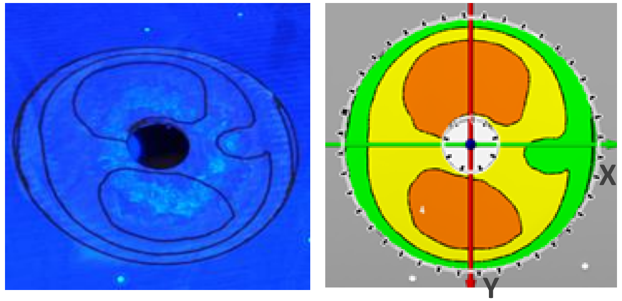
T4.1 - Pilot Test 1

Baseline Process

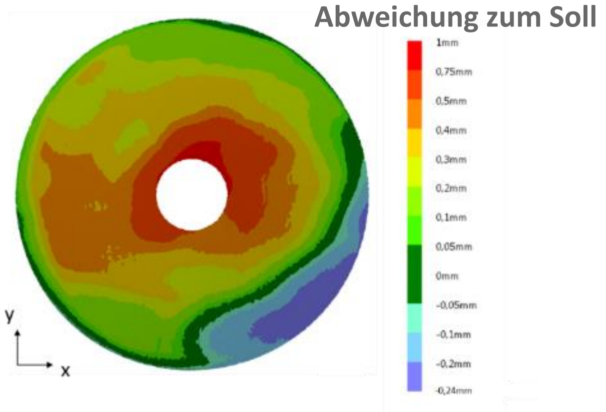
VS.



With digital Assistance



In-situ deviation analysis



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Defining the Data Reference

- Detailing the required input files

- Defining the output data

No.	Name of Signal / Data Source	Comment
1	VAS_CS_LOC	Local Coordinate System CS for Positions of geometry
2	VAS_OUTER_CONTOUR_DEFINITION	Outer Definition of repair contour in locals CS as spline
3	VAS_INNER_CONTOUR_DEFINITION	INNER Definition of repair contour in locals CS as spline
4	VAS_ASBUILD_MEASUREMENT_IMG	Deviation of as build geometry and target geometry as image
5	VAS_ORIGINAL_GEOEMTRY	Scanned geometry of repair site
6	VAS_ASBUILD_MEASUREMENT_GEOMETRY	Scanned geometry after process end
7	VAS_CS_LOC_REFERENCE_POINTS	List of Reference points used for process
8		

1	VAS_CS_LOC	ASCII, 3 Points: ORIGIN P1, X_AXIS P2, Y_AXIS P3
2	VAS_OUTER_CONTOUR_DEFINITION	ASCII, List of Points as *.csv
3	VAS_INNER_CONTOUR_DEFINITION	ASCII, List of Points as *.csv
4	VAS_ASBUILD_MEASUREMENT_IMG	Binary, image, jpg
5	VAS_ORIGINAL_GEOEMTRY	ASCII, *.stl, triangulated surface
6	VA	
7	VA	
8	VA	

No.	Name of Signal / Data Source	Description
1	VAS_CS_LOC	Local Coordinate System CS for Positions of geometry
2	VAS_OUTER_CONTOUR_DEFINITION	Outer Definition of repair contour in locals CS as spline
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5		
6		
7		
8		

No.	Name of Signal / Data Source	Size
1	VAS_CS_LOC	~1kb
2	VAS_OUTER_CONTOUR_DEFINITION	~10kb
3	VAS_INNER_CONTOUR_DEFINITION	~10kb
4	VAS_ASBUILD_MEASUREMENT_IMG	~2 Mb
5	VAS_ORIGINAL_GEOEMTRY	Typical Resolution ~8Gb per m^2 -> More coarse possible
6	VAS_ASBUILD_MEASUREMENT_GEOMETRY	Typical Resolution ~8Gb per m^2 -> More coarse possible
7	VAS_CS_LOC_REFERENCE_POINTS	~1kb
8	VAS_SENSOR_TYPE	~1kb

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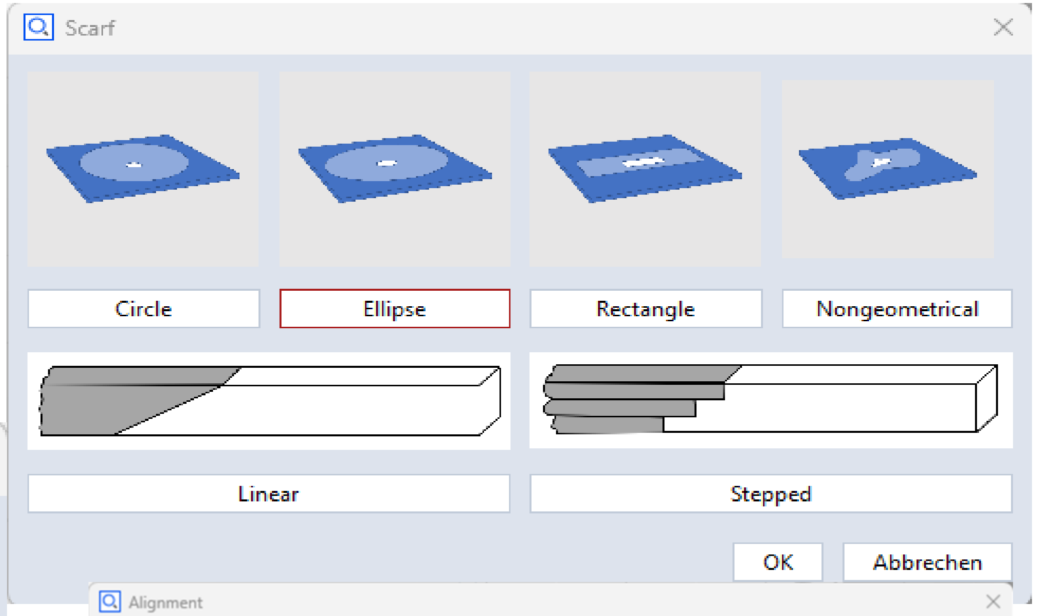
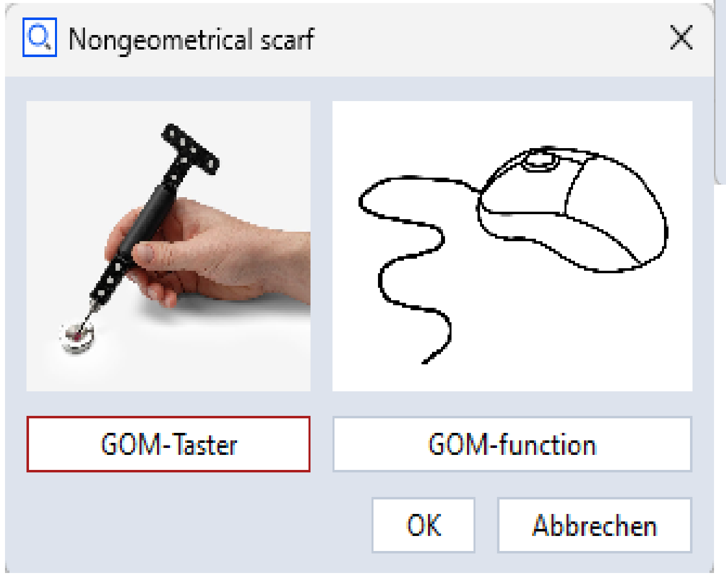
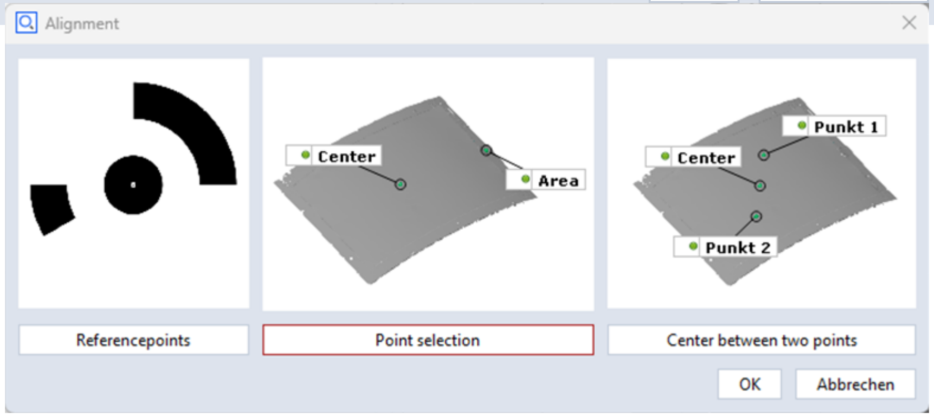
T4.1 –M24 – Software User Interface

- Defining a workflow for different repair types
  - circlular; elliptical, rectangle and non geometrical
  - either linear or stepped
- Developing the user Interface
- Bug fixing







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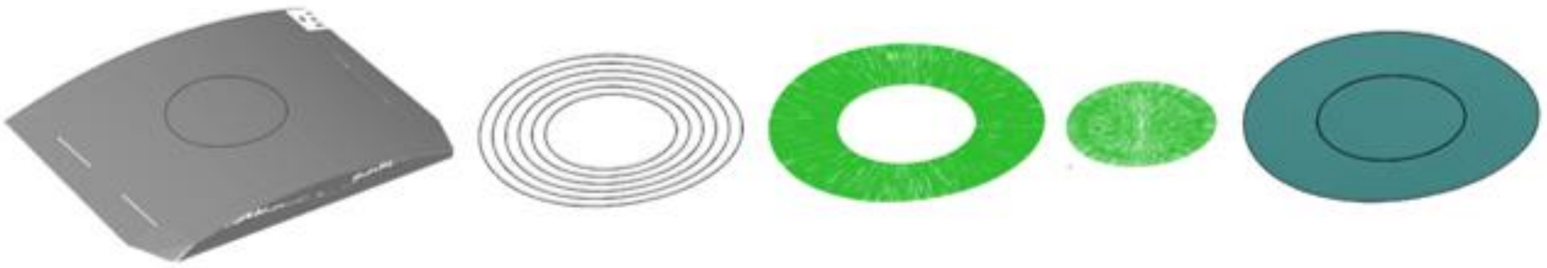
T4.1 –M24 - Improving the automatic scarf generation



(1) (2) (3) (4) (5)

1. Scanned surface
2. Projected surface curves matched to scarf ratio
3. Point cloud of scarf contour
4. Point cloud of repair ground
5. Exportable CAD scarf contour

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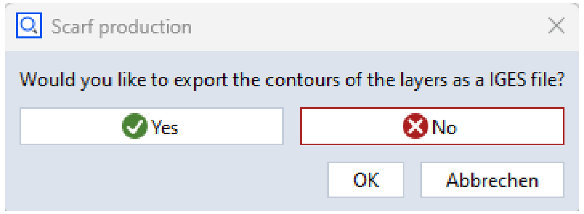
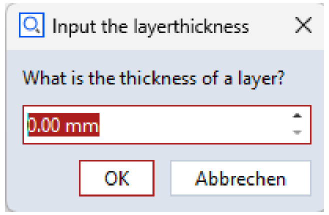
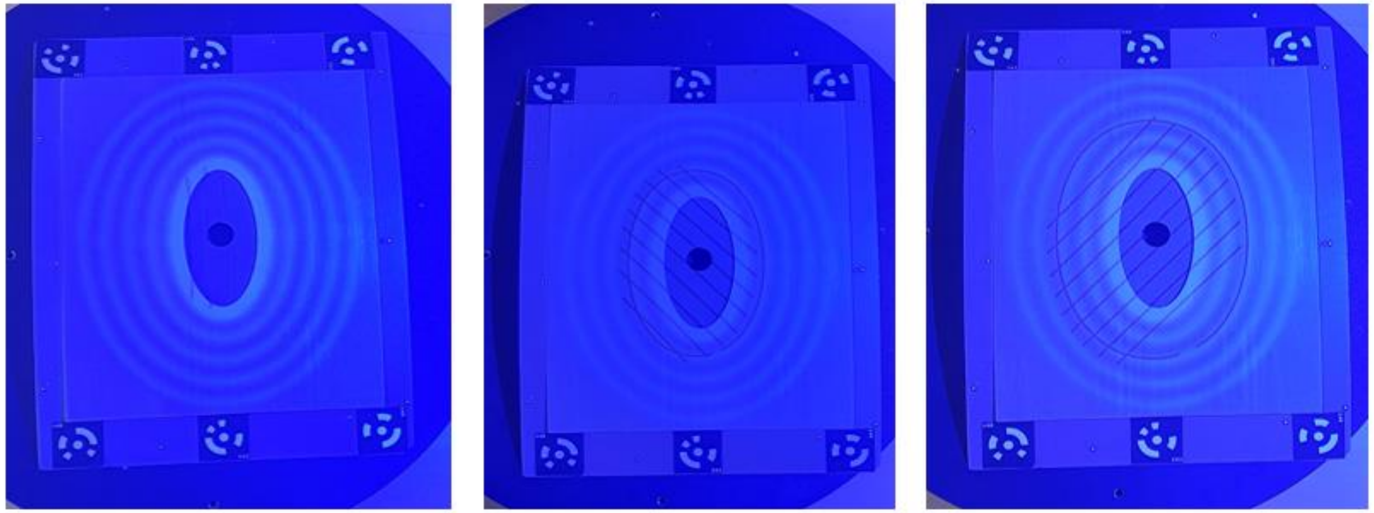
T4.1 – M24 –Patch placement guidance

- Implementing a supported patch placement feature
  - Automatic generation of ply cutting files
  - Projection of Ply contour and orientation







(1) (2) (3)

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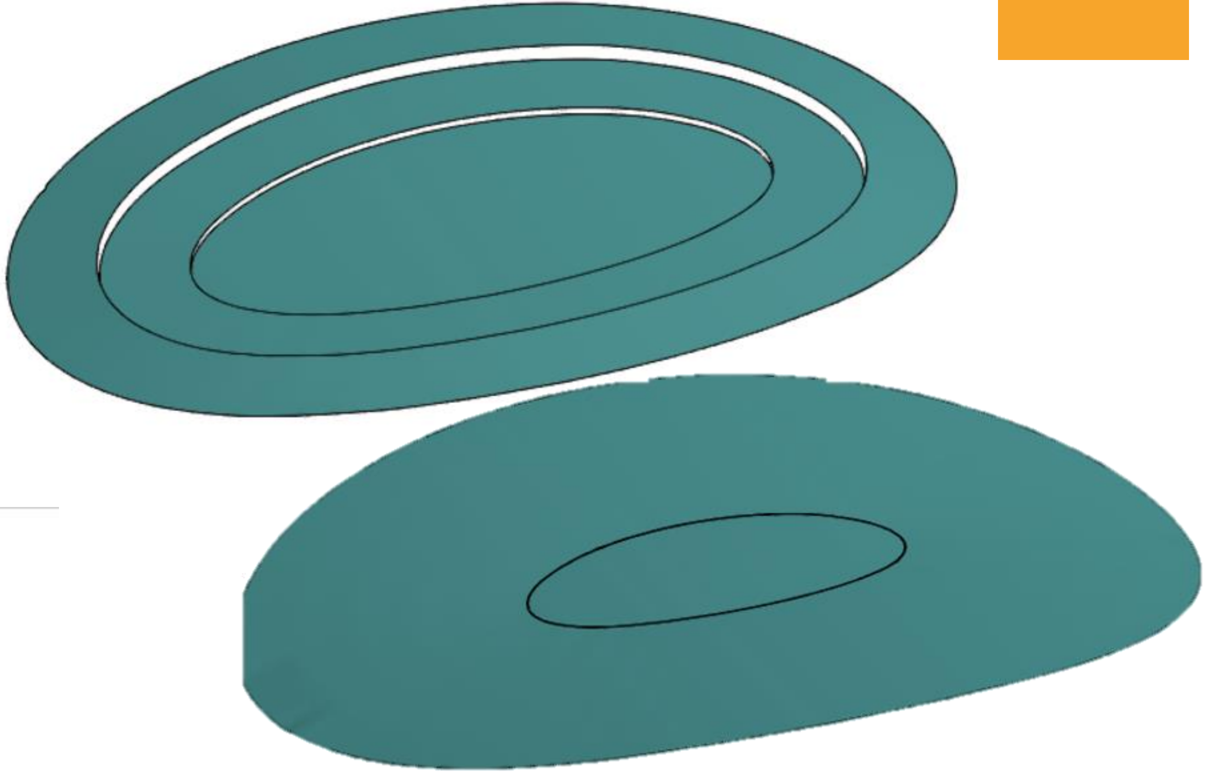
T4.1 – M24 – Export possibilities

- Working on report and data export functionality
  - CAD export of scarf contour
  - PDF report during scarfing



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Layer 1.igs	09.09.2024 09:54	IGS-Datei	19 KB
Layer 2.igs	09.09.2024 09:54	IGS-Datei	18 KB
Layer 3.igs	09.09.2024 09:54	IGS-Datei	20 KB
Layer 4.igs	09.09.2024 09:54	IGS-Datei	22 KB
Layer 5.igs	09.09.2024 09:54	IGS-Datei	24 KB
Layer 6.igs	09.09.2024 09:54	IGS-Datei	27 KB
Scan.refxml	09.09.2024 09:52	REFXML-Datei	10 KB

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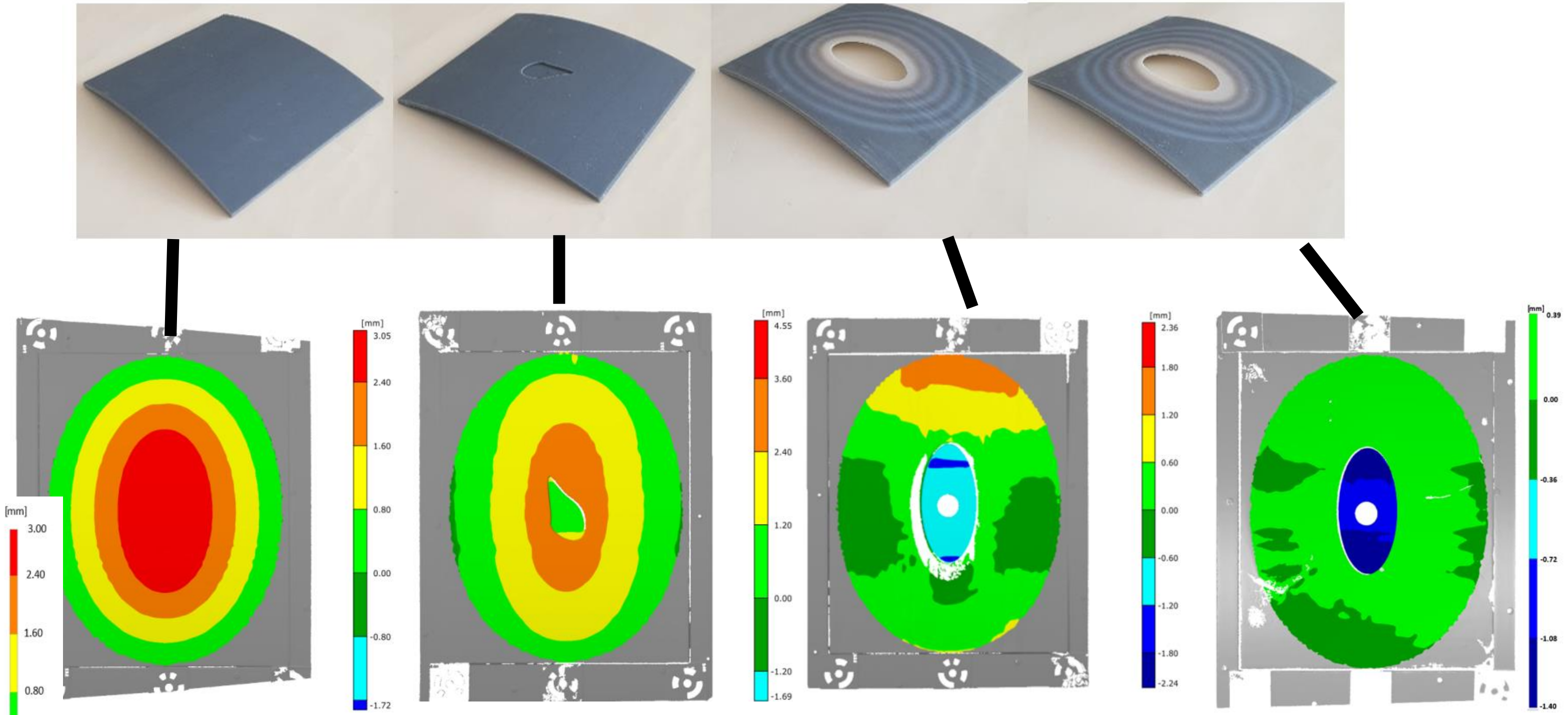
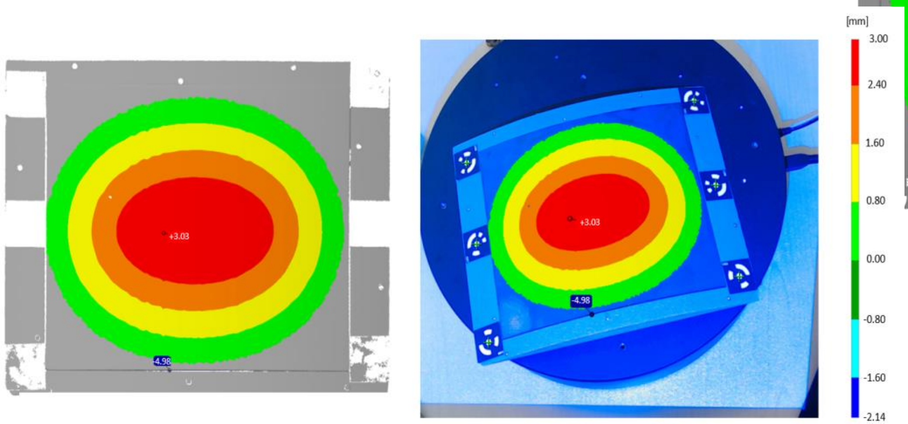
T4.1 - M24 - Lab-Scale test

- System trials and verification with predefined scarf structure
- tests with augmented reality
- curved CFRP panel for further testing in constrution





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T4.4

Smart bonded composite repair solution

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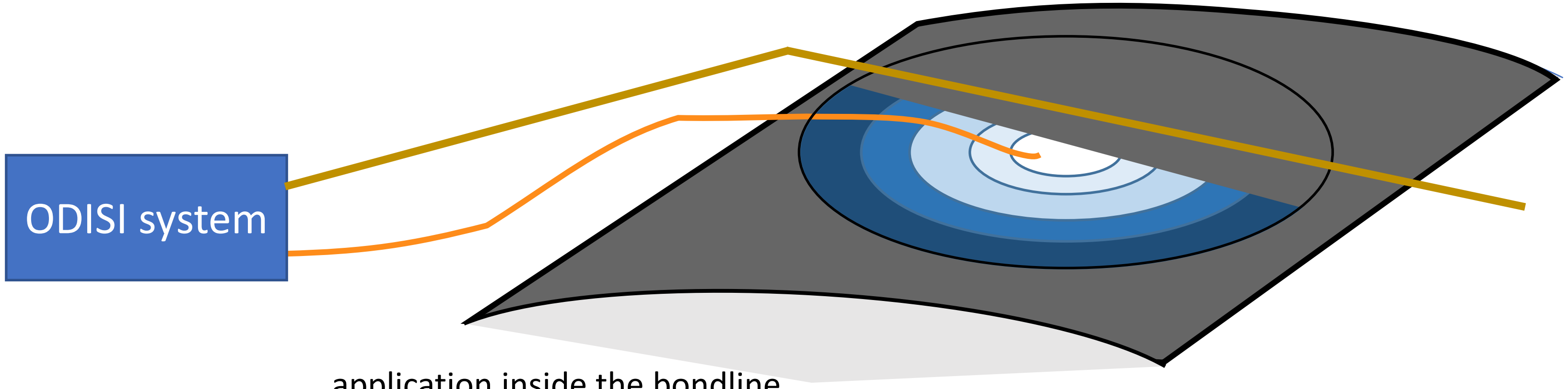
Application of FOSS to scarf-repairs

- Aim: Integrating fiberoptic sensors into a composite patch repair
  - integration on the surface through secondary bonding
  - integration directly into the bonding line between patch and workpiece



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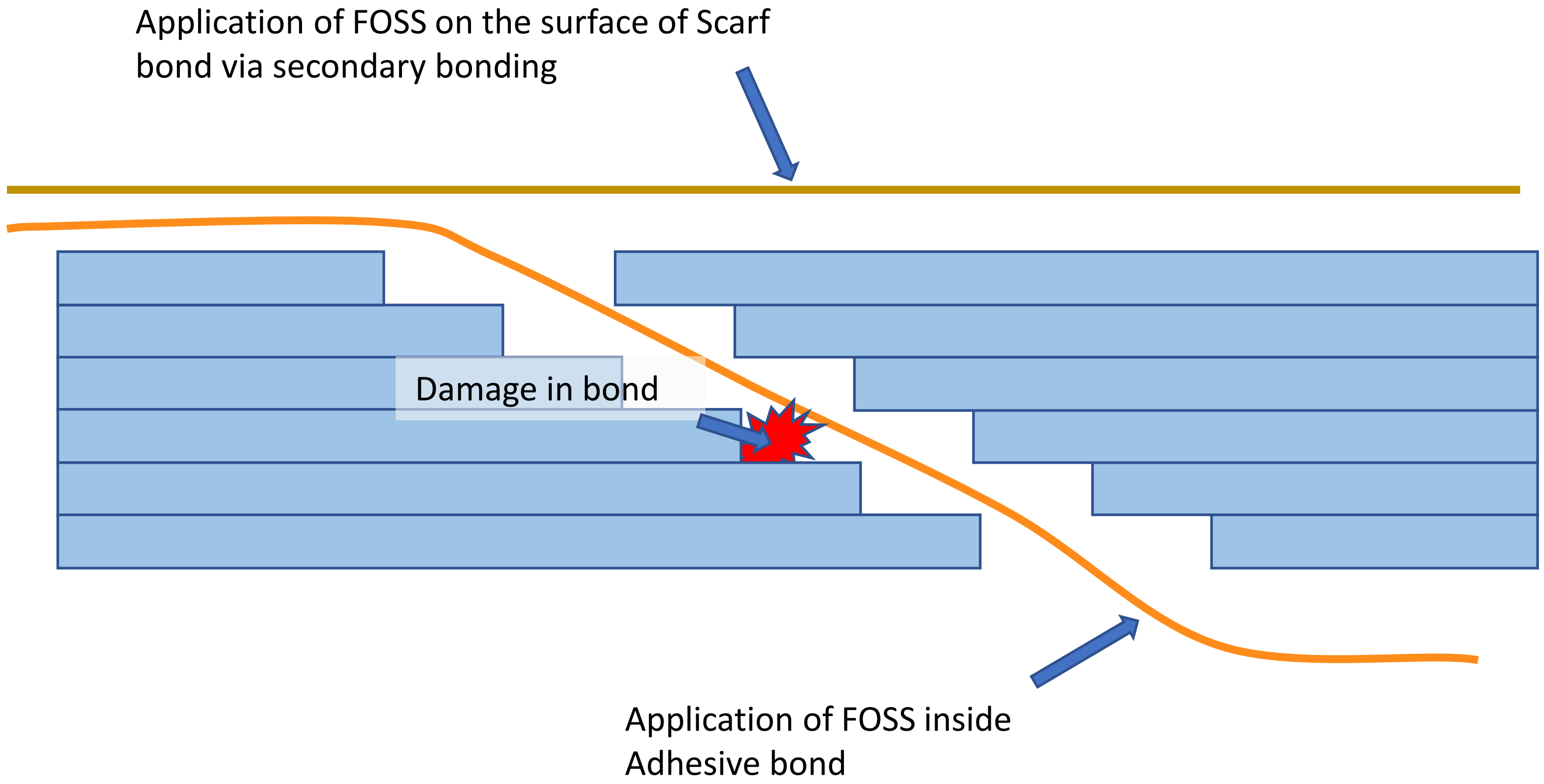

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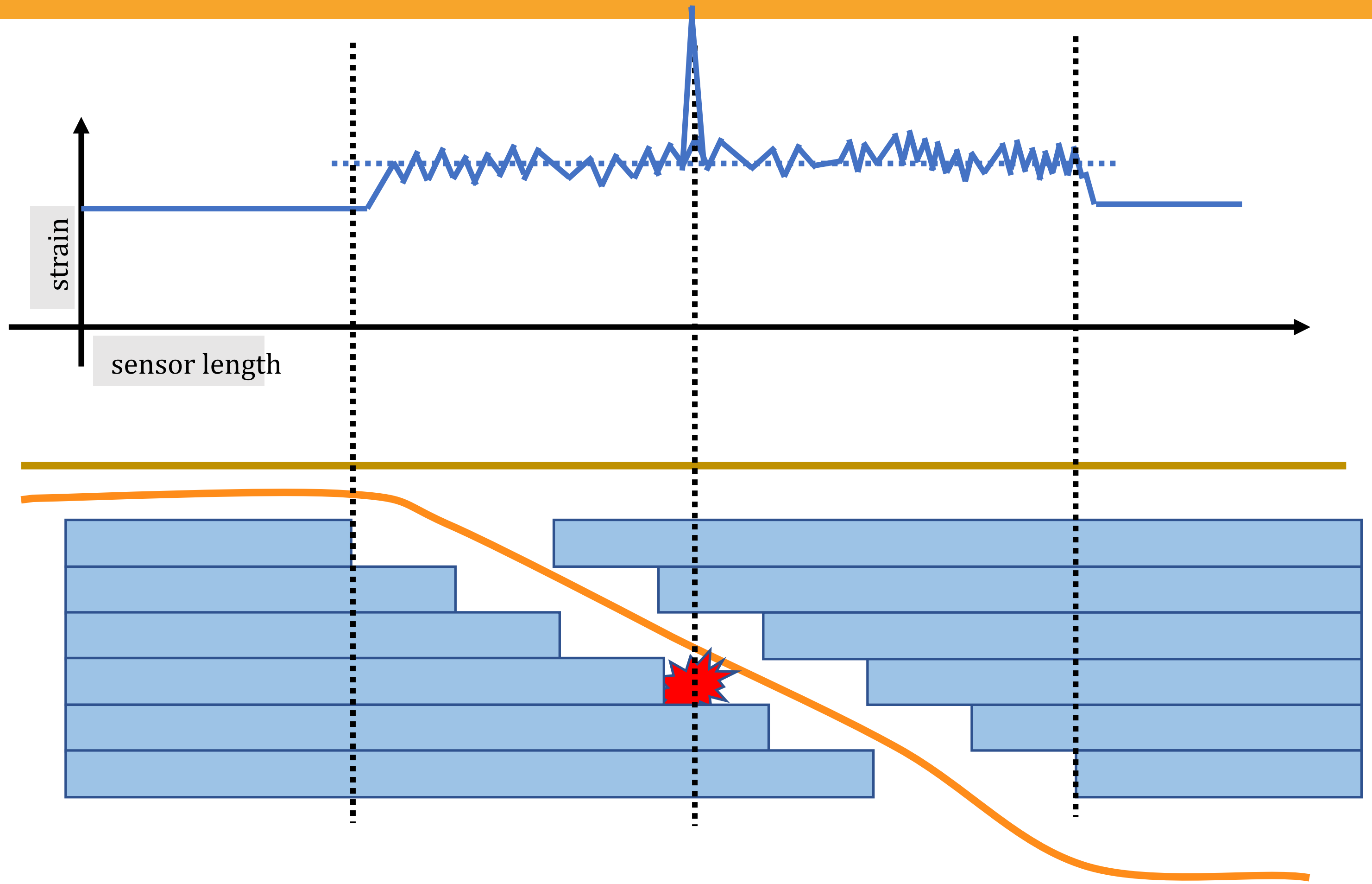
Application of FOSS to scarf-repairs

- Integrating fiberoptic sensors into a composite patch repair
- Identifying damages inside scarfed adhesive joint



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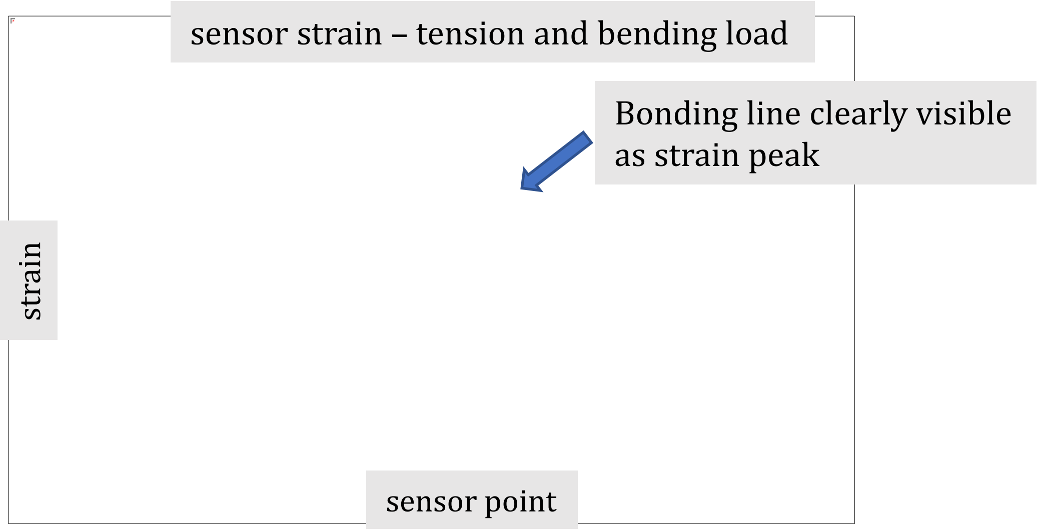
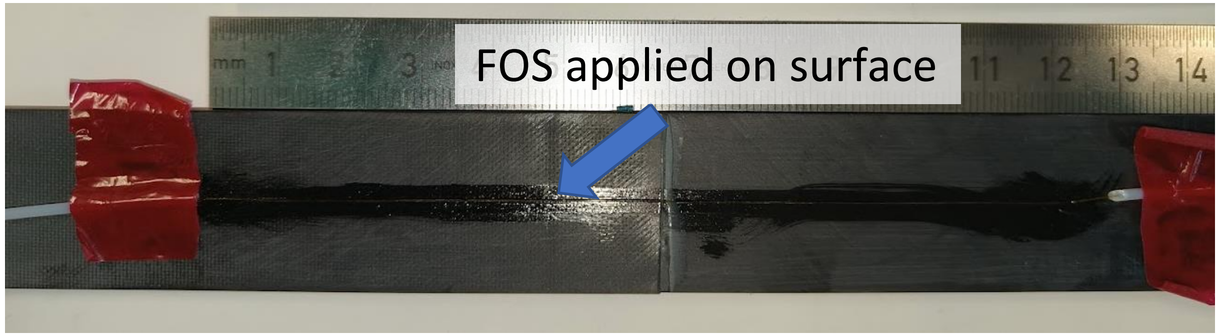
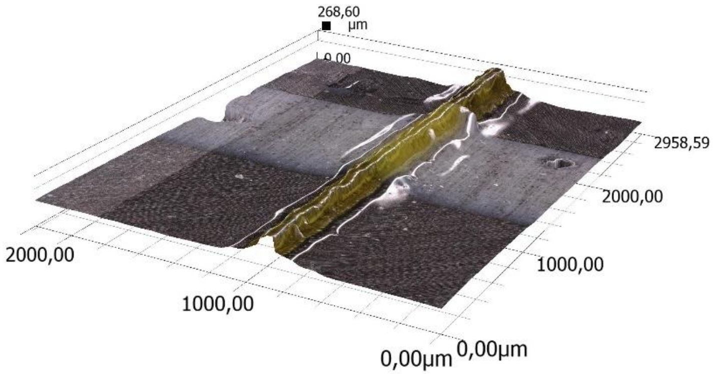
Application of FOSS to scarf-repairs

- Integrating fiberoptic sensors into a composite patch repair
- Identifying damages inside scarfed adhesive joint
  - Practical application of FOSS on top of scarfed adhesive joints







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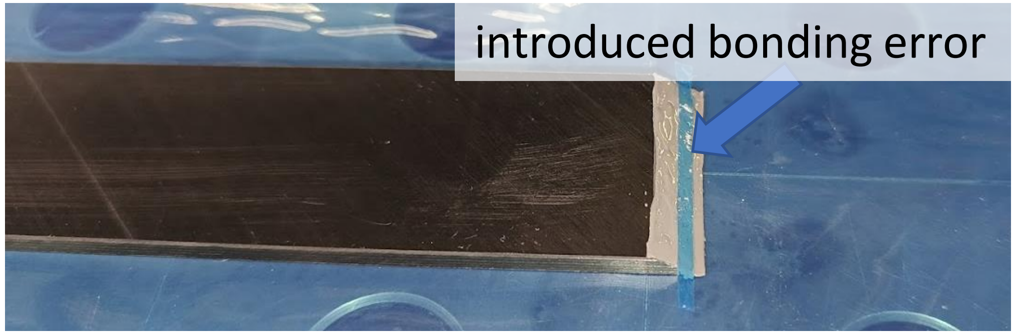
Application of FOSS to scarf-repairs

- Integrating fiberoptic sensors into a composite patch repair
- Identifying damages inside scarfed adhesive joint
  - Practical application of FOSS on top of scarfed adhesive joints
  - Identifying damaged joints



sensor strain – damaged vs. undamaged

strain

Damaged bond clearly has a higher strain peak

sensor length

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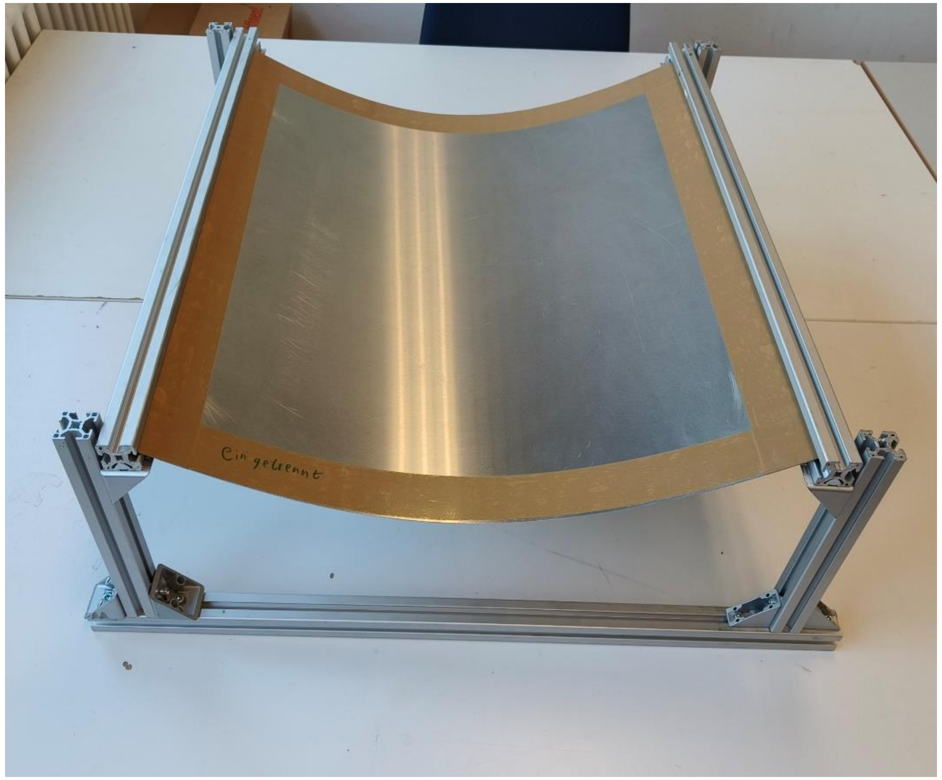
Application of FOSS to scarf-repairs

- Manufacturing of a proper patch repair



Moulding tool for manufacturing of curved carbon fiber plate

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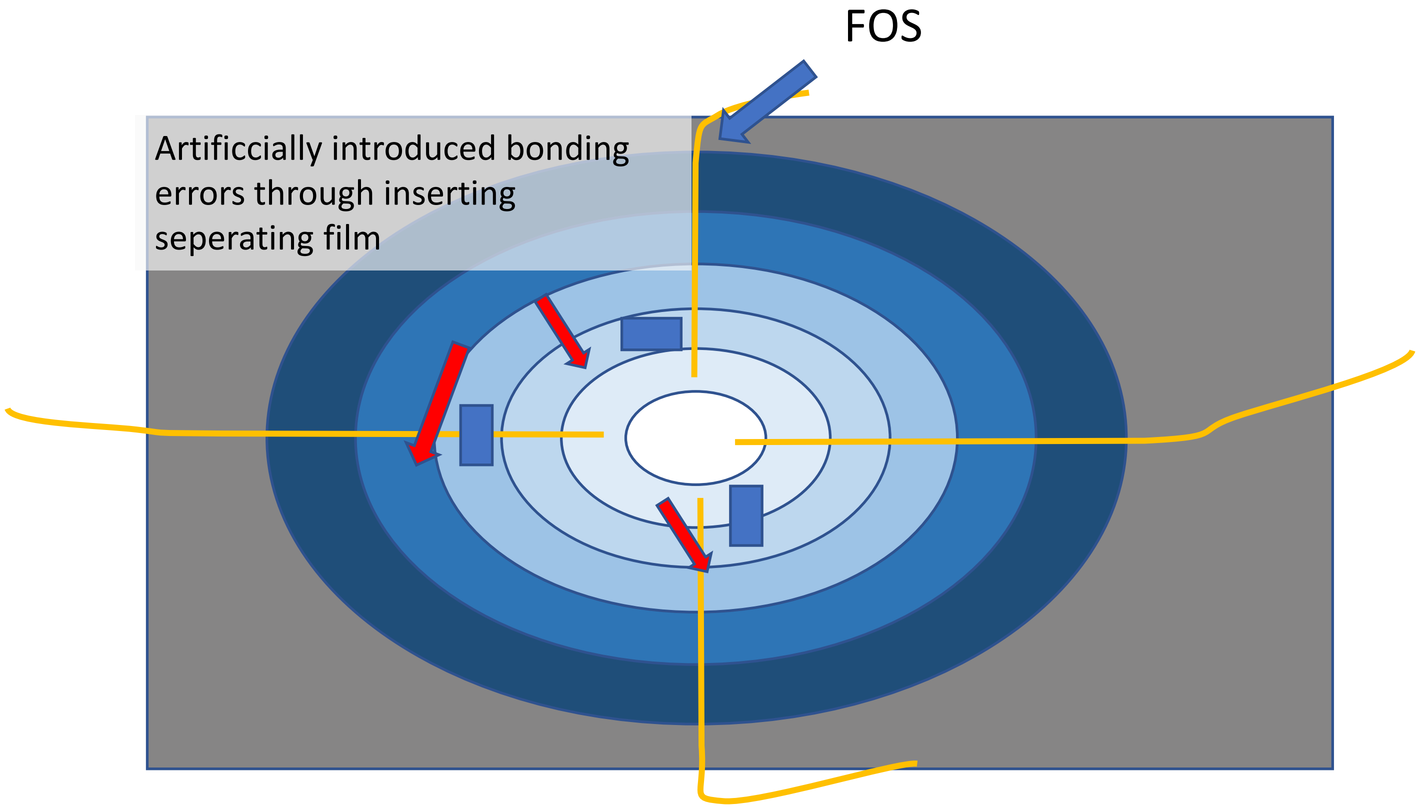
Application of FOSS to scarf-repairs

- Manufacturing of a proper patch repair
- Equipping the patch repair with fiber optic sensors
- Introducing artificial disbond into the adhesive bond



Funded by the European Union

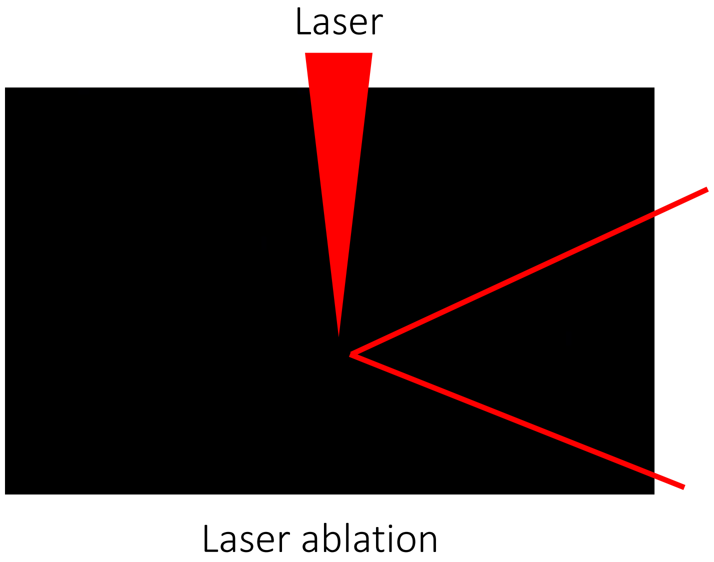
T4.2
Laser-ablation system coupled with LIBS module for surface preparation of scarf repair

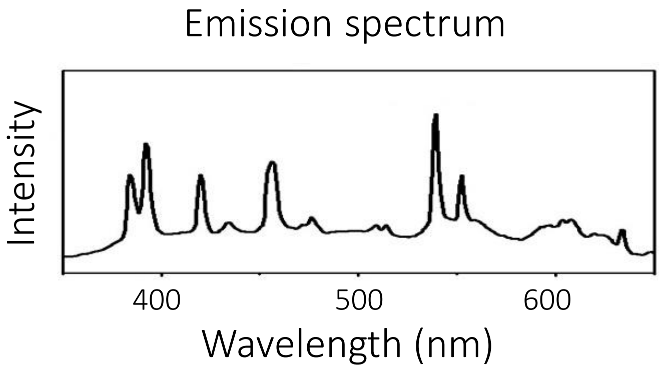
AIMEN

Funded by the European Union

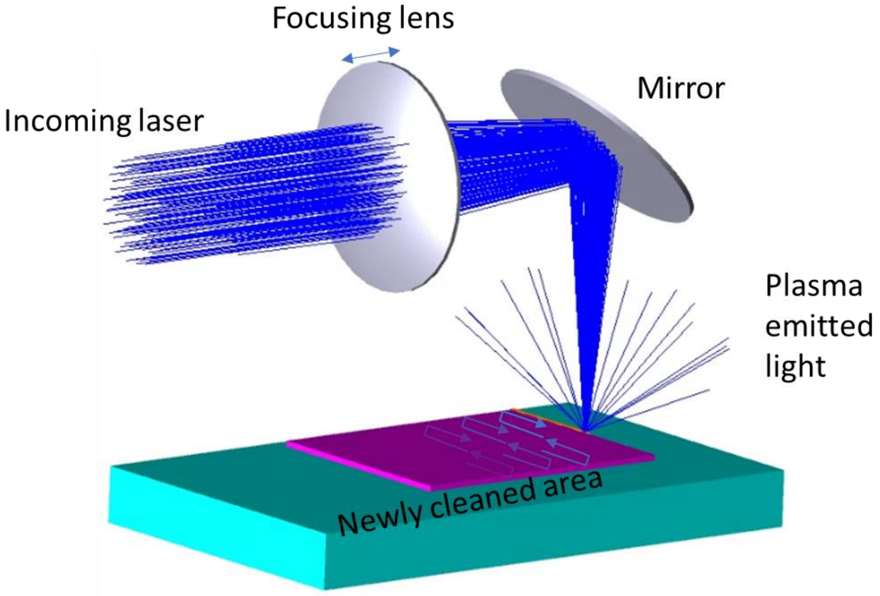
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

Laser-Induced Breakdown Spectroscopy (LIBS)





LIBS system scheme



- Provides information about chemical composition of sample
- Analysis of plasma generated during laser ablation
- Atomic emission spectroscopic technique for elemental analysis

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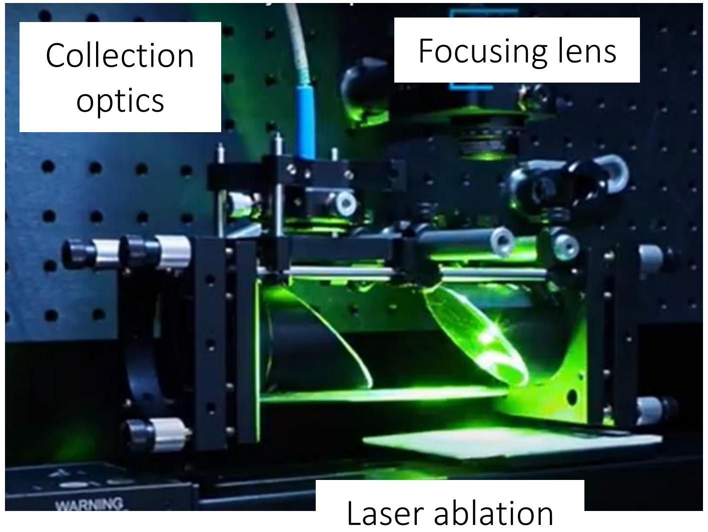
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

Development of a LIBS system for surface preparation verification

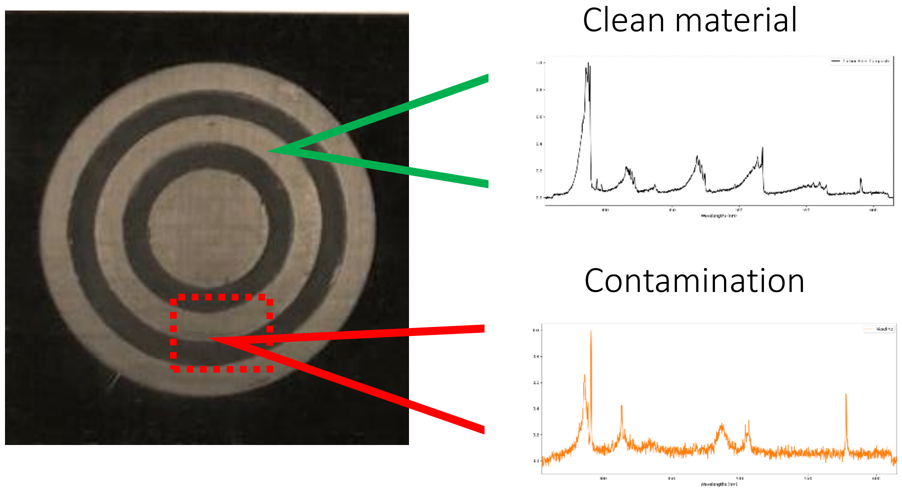
In GENEX, AIMEN will develop a system for surface preparation verification based on mapping the contaminants using LIBS-based monitoring with the aim of guaranteeing the optimal repair conditions leading to optimum bonding of the repair patch.

Surface prepared for repair

LIBS analysis



Verification of cleanliness of prepared surface



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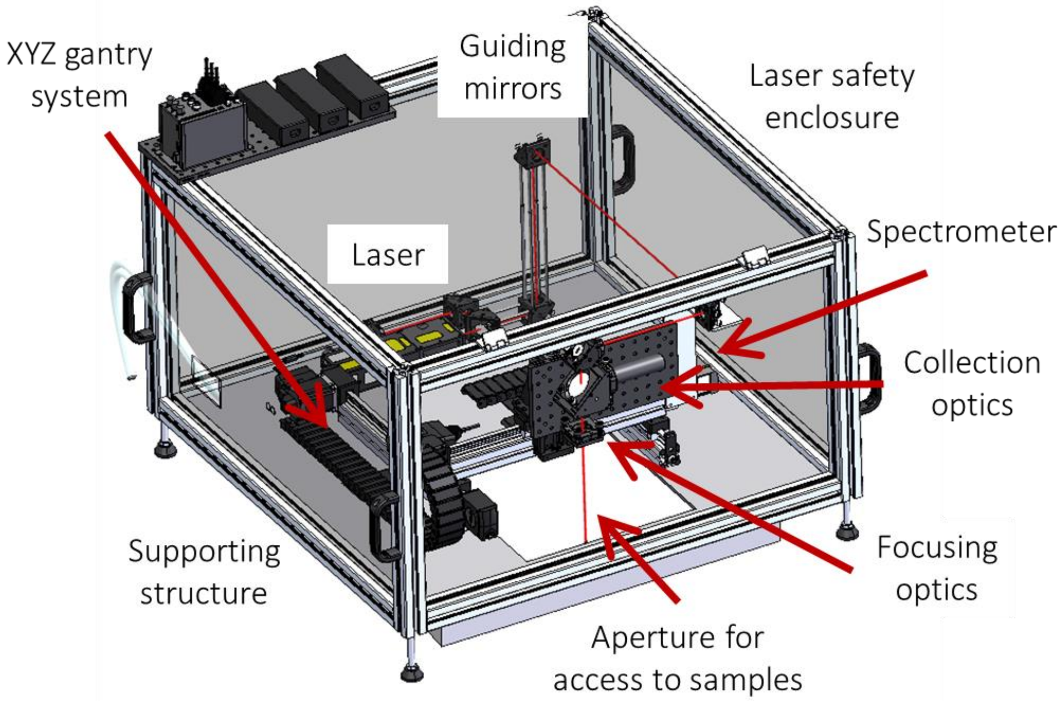
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

- Design of portable system
  - Mechanical, electrical and overall integration of components
  - Optomechanical design of laser path and collection optics
  - Accesibility and safety considerations



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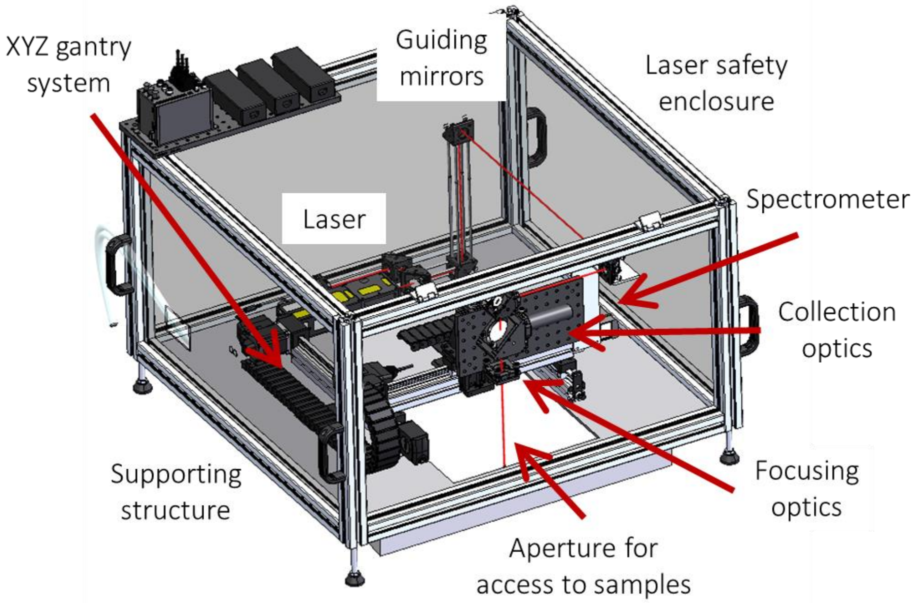
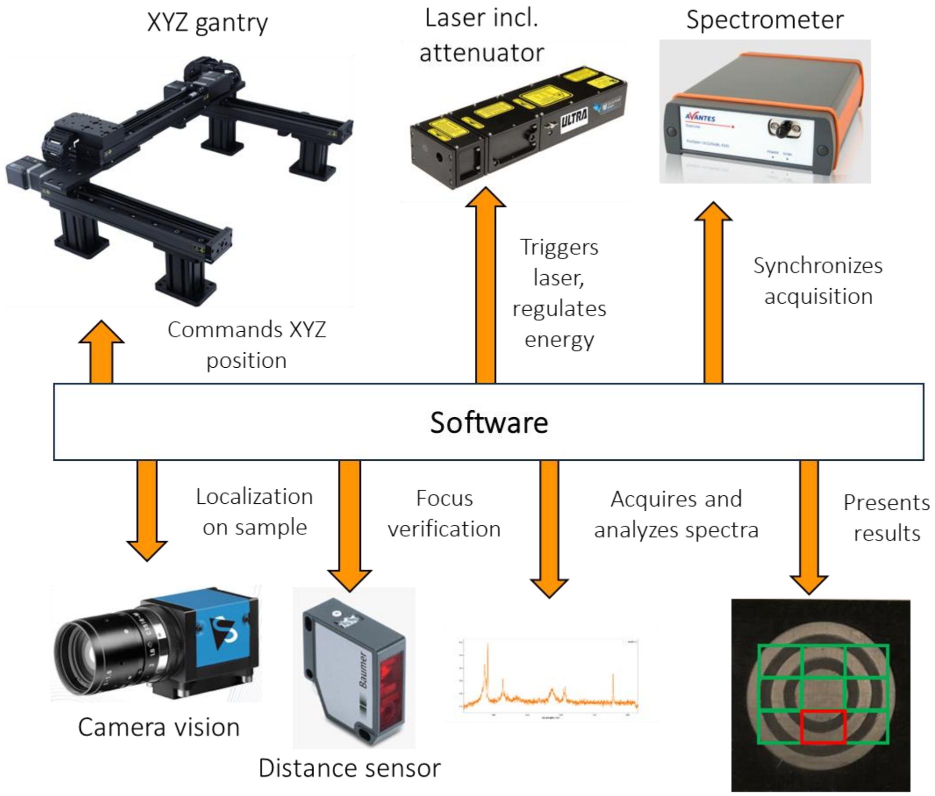
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

- Portable LIBS system – machine concept





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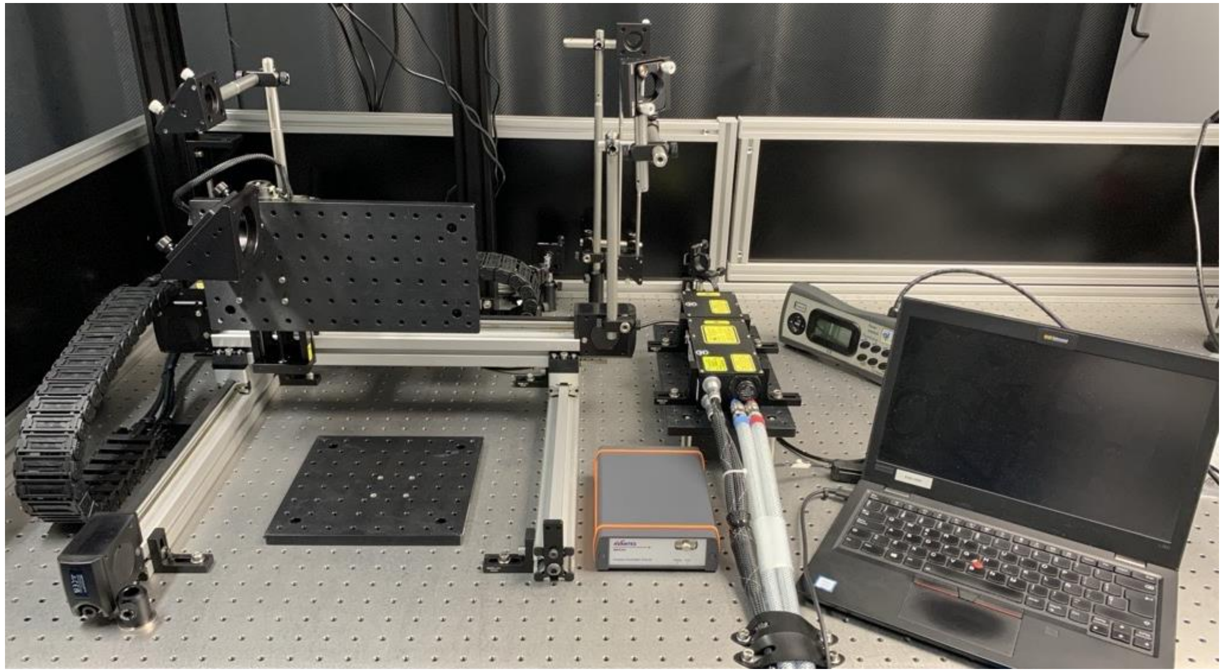
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

- Assembly and testing of the LIBS system: lab setup prior system integration

    - Testing individual components
    - Design and testing of optical path and alignment procedure for process and acquisition
    - Integration of gantry system, laser, spectrometer and measurement devices (distance sensor and camera)
    - LIBS testing using dedicated GENEX equipment



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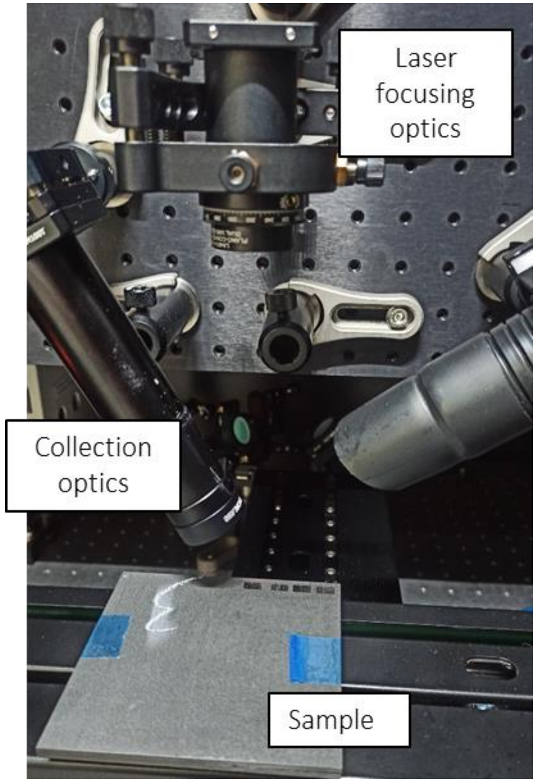
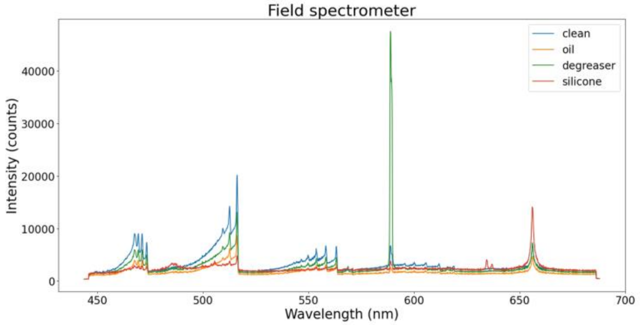
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

- Tests at lab LIBS system



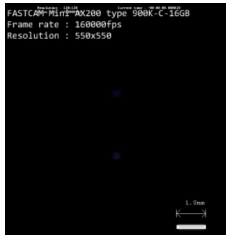
Field spectrometers tests



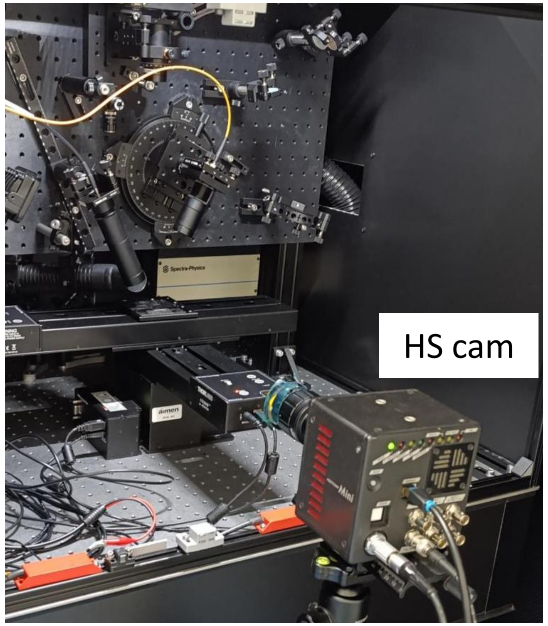
Fundamental plasma studies

Clean sample

Contaminated sample



Comparative tests of different collection systems



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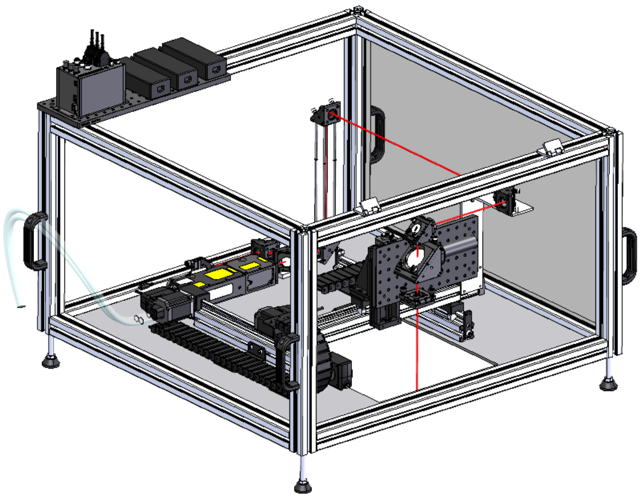
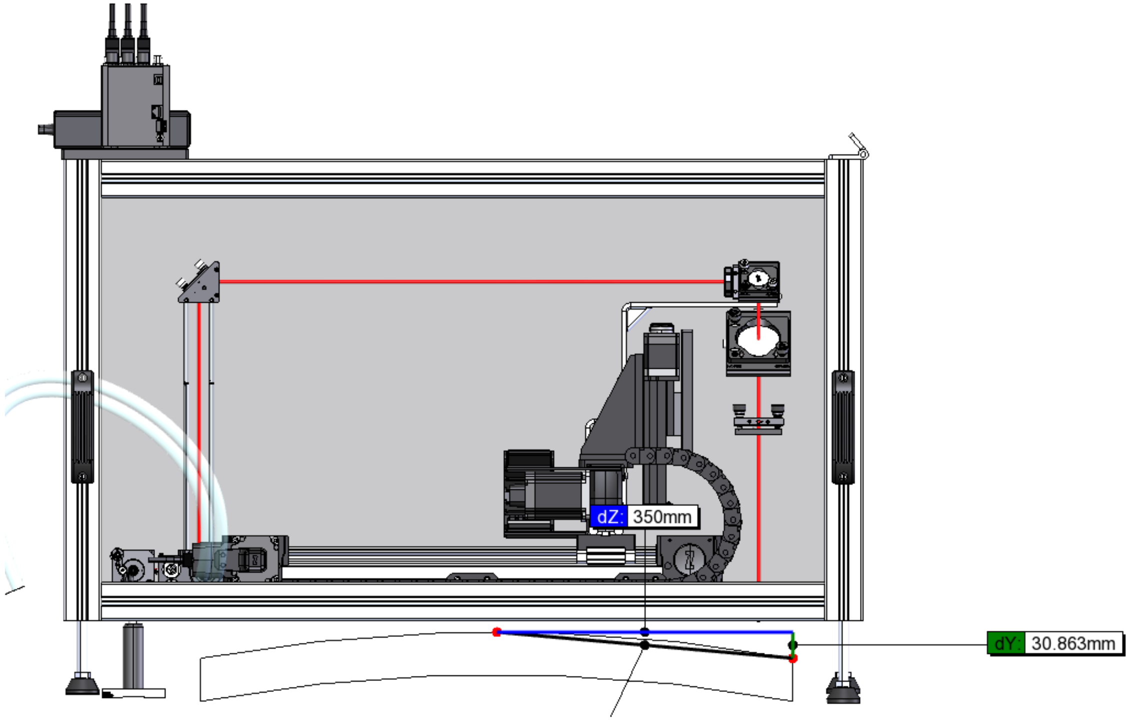
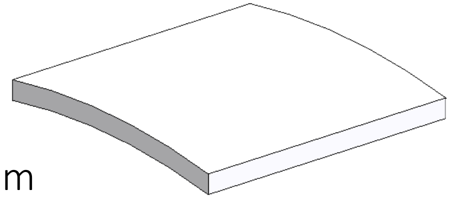
T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

- Compatibility with demo





Proposed demo part



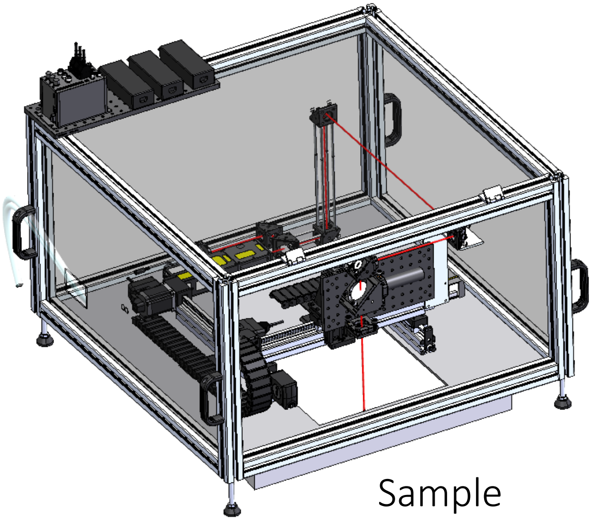
- Aprox. dimensions (GMI):
  - Area: 700 x 700 mm
  - Radius of curvature: 2-3 m

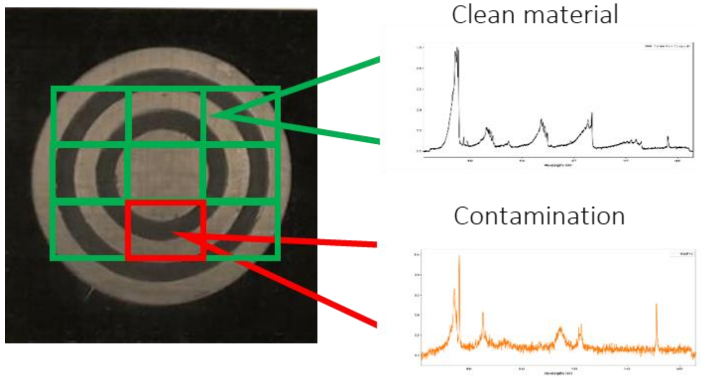
Z-axis range of gantry system = ±35 mm → height difference of demo can be compensated

T4.2 Laser-ablation system coupled with LIBS module for surface preparation of scarf repair (Lead: AIMEN; Partners: GMI, ZIEG) (M4-M30).

- Integration into the Genex IoT platform

Portable LIBS system



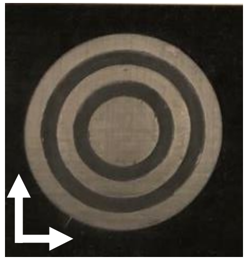


Analysis of contamination status on selected interrogation points

Matrix of results (.csv)

	X1	X2	X3
Y1	OK	OK	OK
Y2	OK	OK	OK
Y3	OK	NOK	OK

Image as reference of coordinate system (bmp?)



GENEX IoT

Funded by the European Union

T4.3
Digital transformative composite repair heating

ITAI / GMI

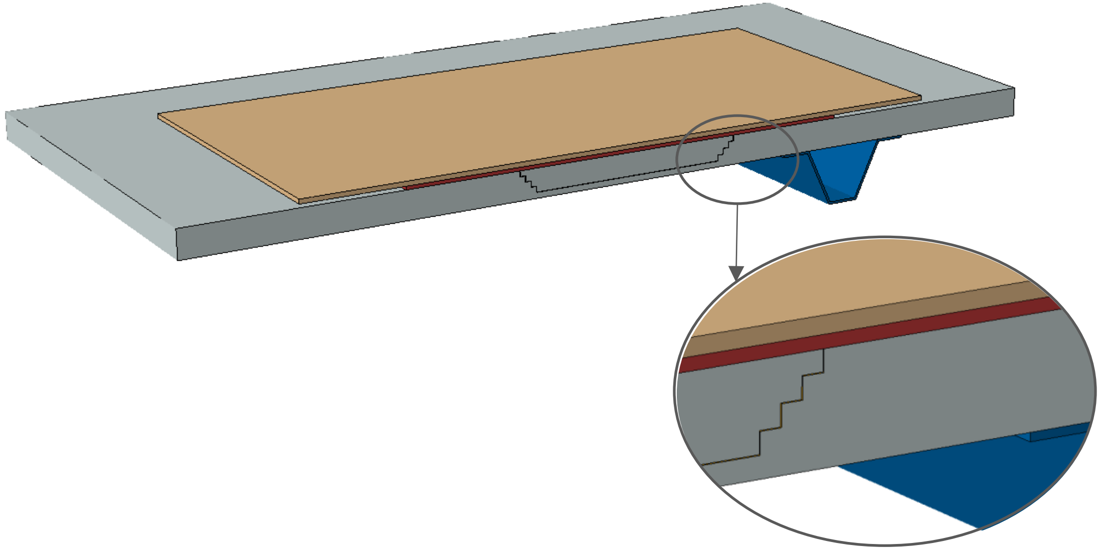
Funded by the European Union

Initial approach for scarf repair

Goal: Define a methodology to design optimal heating blanket geometries for customized repairs.

Numerical model definition:

- Geometric definition of the scarf (with layer orientation)
- Adhesive/resin curing process definition
- Material thermal properties (Conductivity, heat capacity and density with orientations)
- Heating sources properties (Heat flux)
- External conditions (Natural convection)



Simplify numerical model to reduce computational cost.

⇩

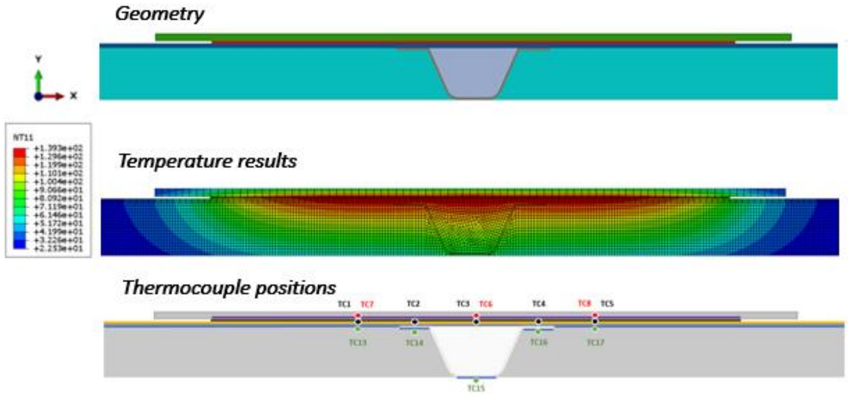
Run a large number of simulations (DoE) to cover the full range of possible repair scenarios.

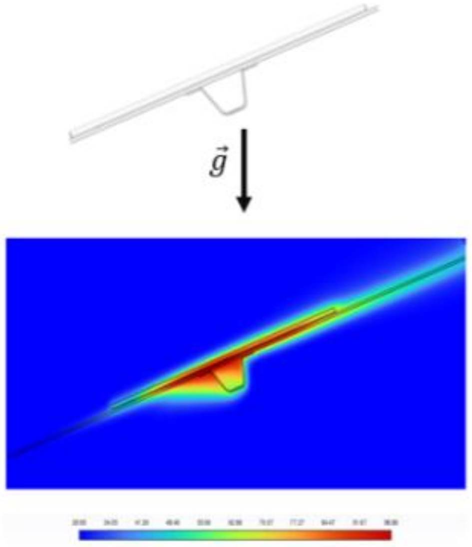
Result: A ROM (reduced order model) to compute in real time the repair model that will give the optimal blanket design for a particular repair.

Funded by the European Union

Cost efficient simulation of the repair process

- A thermal conduction FE 2D model of a cross-section of the repair area was validated with experimental data of a horizontal repair. The model was able to run in 3s.
- A DoE of 500 simulations was defined, parameterized and run.
- From the DoE results, a reduced order model (ROM) was trained to determine in real time the temperature field distribution. Poor behaviour with stringer position was detected.
- This model was not able to account for temperature gradients caused by hot air rise when the repair plane is different from the horizontal.
- A CFD model was built and run for several repair angles in order to characterize the influence of the fluid temperature in the convection coefficient.





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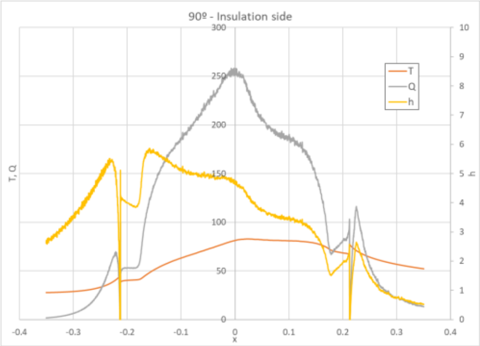
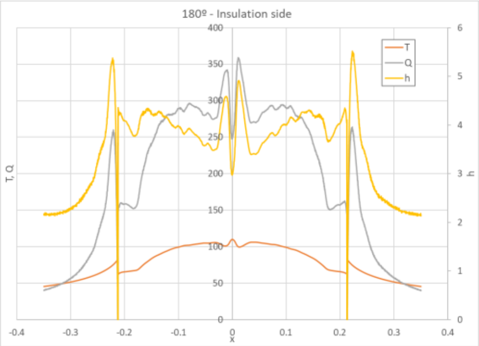
Cost efficient simulation of the repair process

- Convection coefficient are calculated from the temperatures and heat fluxes normal to the external surfaces of the solids A DoE of 500 simulations was defined, parameterized and run.

$$q = h(T - T_{ref})$$

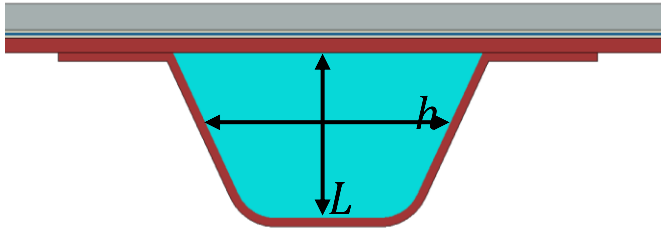




- Multi linear adjustment of the convection coefficient

- This convection behavior has been implemented in a user subroutine and included in the FEM simulation

- The behaviour of the air conductivity inside the stringer was modelled.



$$Q = \frac{kA}{L}(T_1 - T_2)$$

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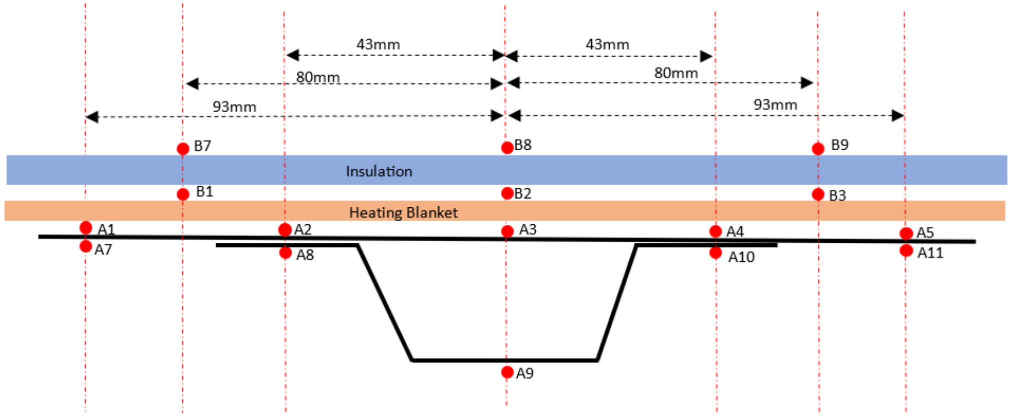
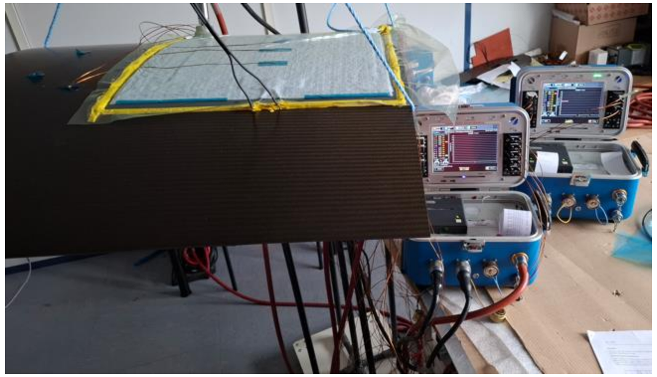
Cost efficient simulation of the repair process - Validation

- Objective: Obtain experimental results to validate the numerical results
- Tests configuration:

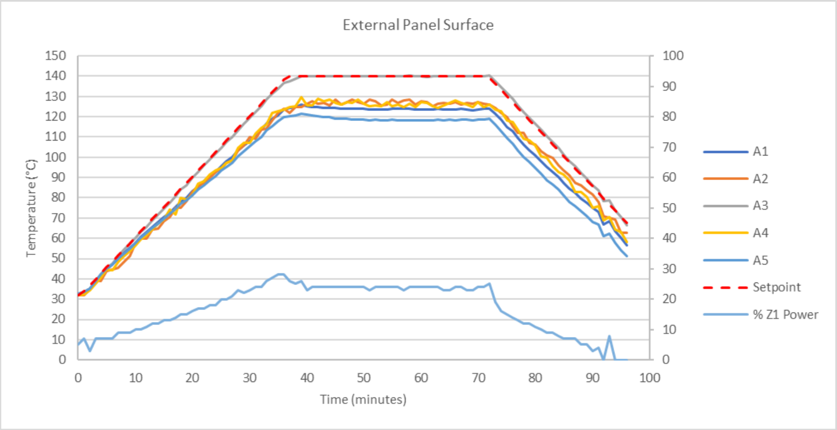
Thermocouple's locations



Horizontal configuration



Vertical configuration



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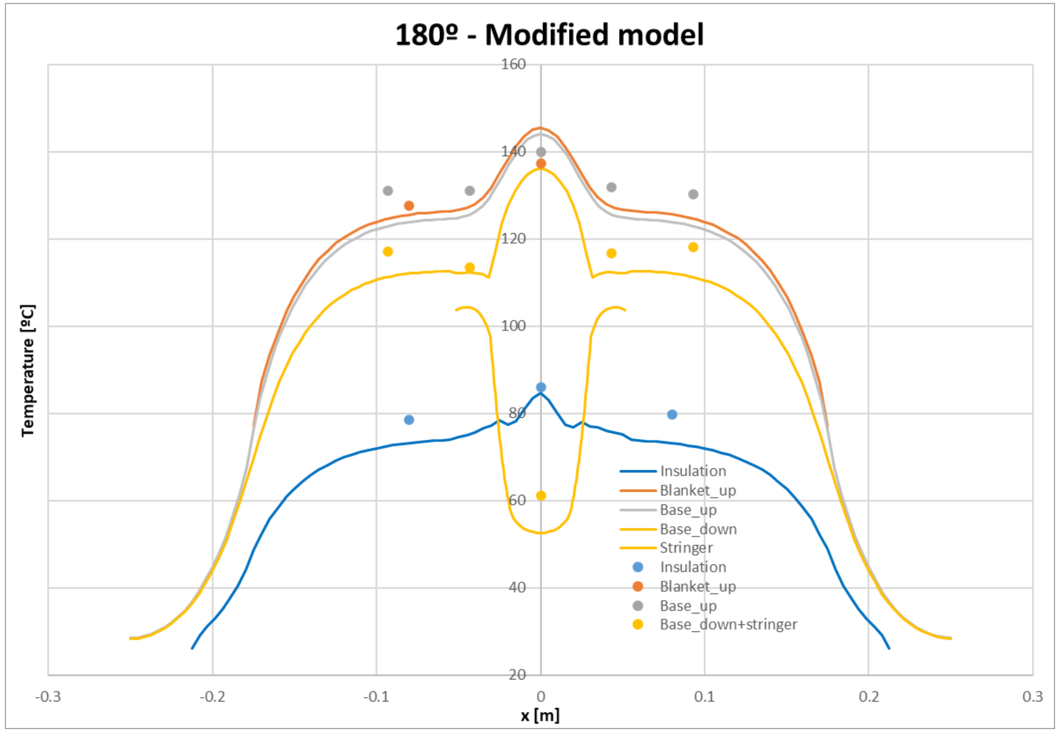
Cost efficient simulation of the repair process - Validation

- The behaviour of the hot air inferred from the CFD analysis was included in the 2D FEM simulations to account in a cost-efficient way for the repair slope



Funded by the European Union

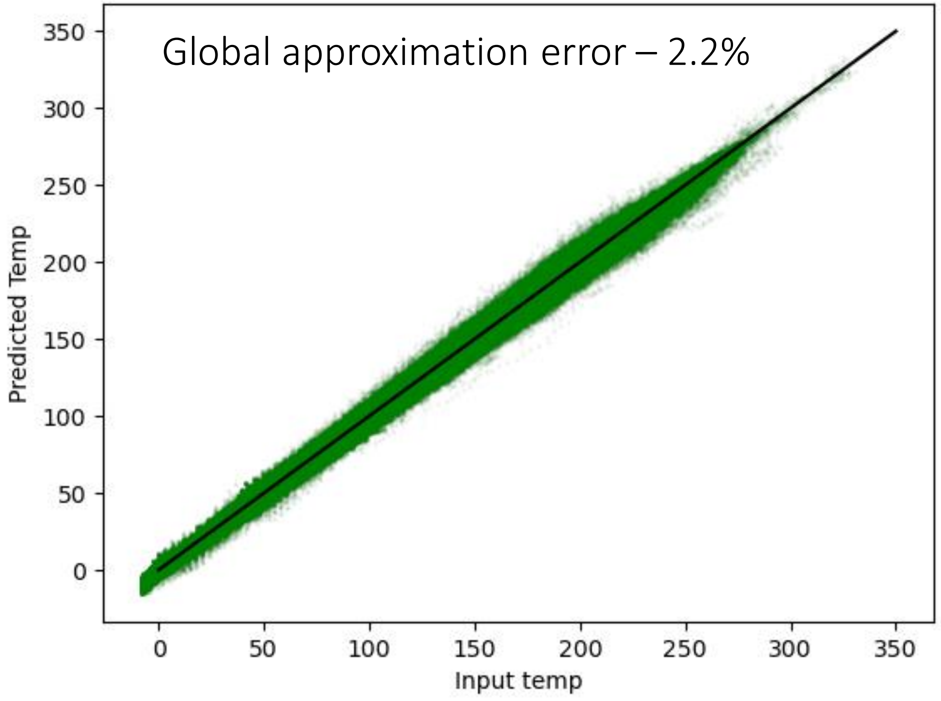
Technical progress: Digitally assisted blanket design

DoE:

From the preliminary DoE we concluded that a larger amount of data was required, specially in the data concerning the stringer position. Thus, the new DoE has been designed in the following way:

	Min	Max
External Temperature	-10	30
Surface thickness	1	5
Stringer thickness	1	3
Stringer wing length	15	40
Stringer core length	15	40
Insulation thickness	3	6
Repair Diameter	50	400
Stringer position	-1	1
Slope	0	180

$$2^7 3^2 + 200 \cdot 16 = 4352$$



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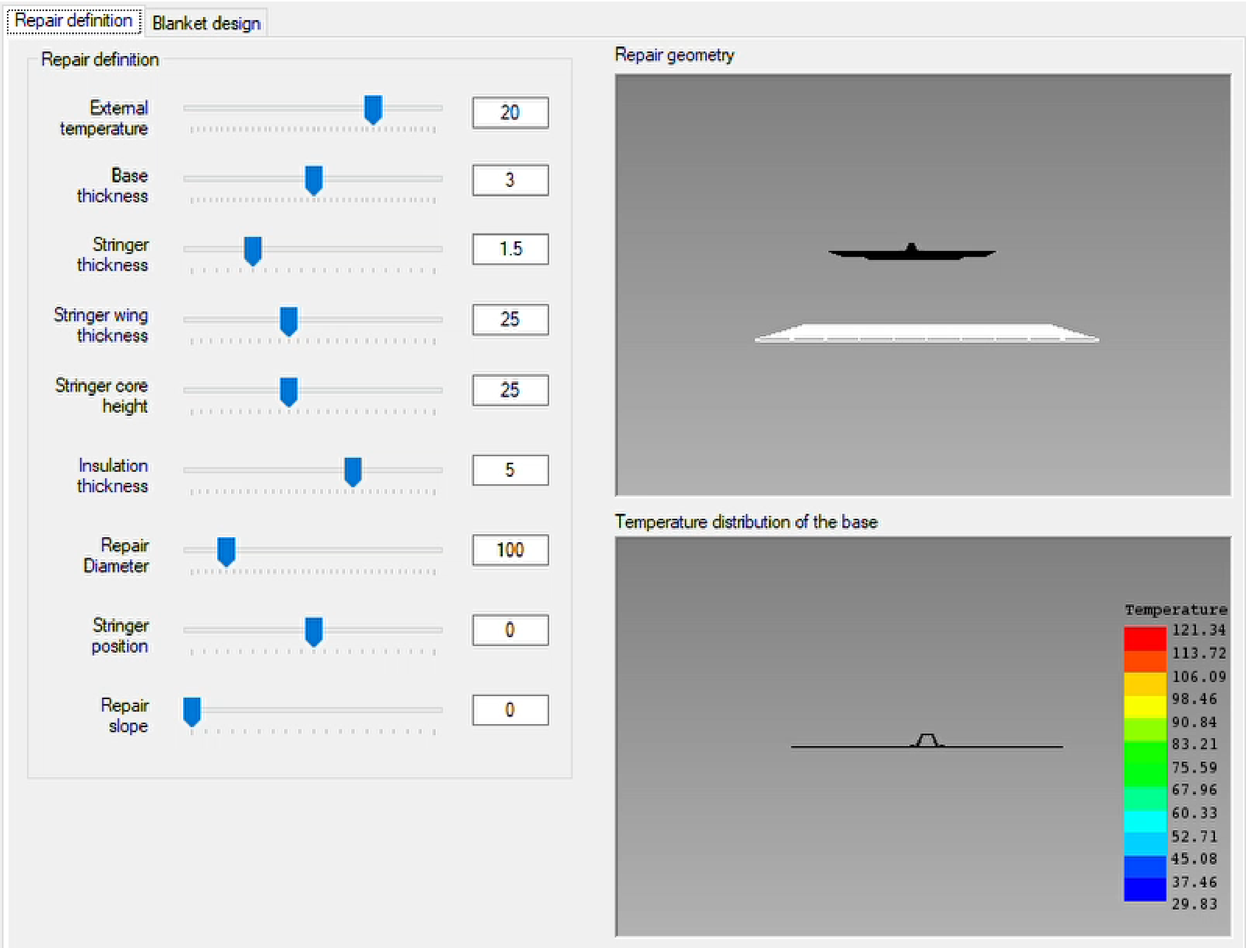
Digitally assisted blanket design



Funded by the European Union

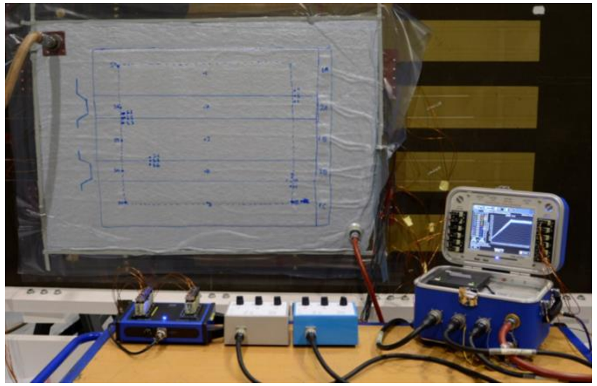
Contribution to WP5 demonstrator:

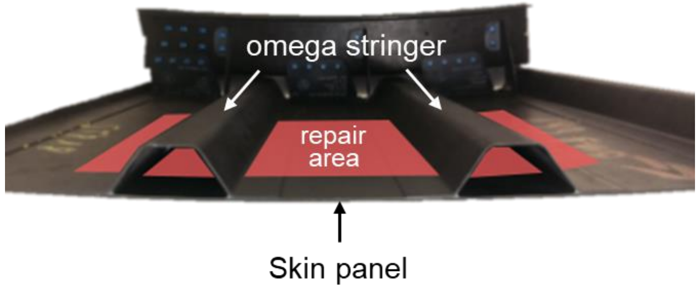
Application of the control algorithm to a real type repair scenario :

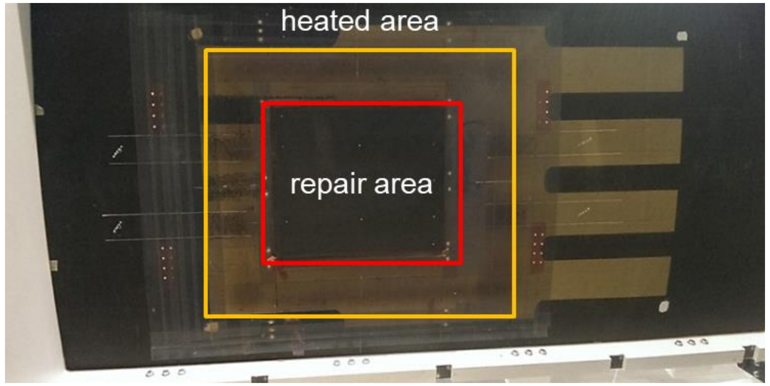
The Demonstrator component provided by **Aernnova Illescas**, will be repaired with the assistance of new digital-based solutions for automated hot bonding with customized heating blankets and on-line control of the repair bonding process.

The application of the developed algorithm will require to install specific and compatible hardware to receive all the real-time data (temperature, power) which are transmitted from the ANITA hot bonder using the IoT platform.

Alongside the algorithm will be able to calculate in real time the optimal condition parameters and use them to re-program the heat cycle of the repair process.







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On-line control of the repair bonding process

An advanced strategy for thermal control of the repair bonding process will be developed based on temperature control (ANITA89 hot bonder-GMI), to optimize the heat generation and diffusion during composite repair. An optimized Model Predictive Control (MPC) architecture, using surface mounted thermocouples as control sensors and heating blankets as heat suppliers (actuators) will be used. The thermo-kinetic model developed in T4.1. will be used to ensure the complete curing of the entire patch area by controlling heat supply based on real-time sensor's data. Constraints to avoid overheating will be set by GMI and included in the control loop. A perturbation observer based on a Kalman filter will be implemented to account for non-linear variable convection coefficients. The design, control and data transfer tools will be validated on representative prototype in WP5 using CONDUCTOR®90 cuttable blankets.

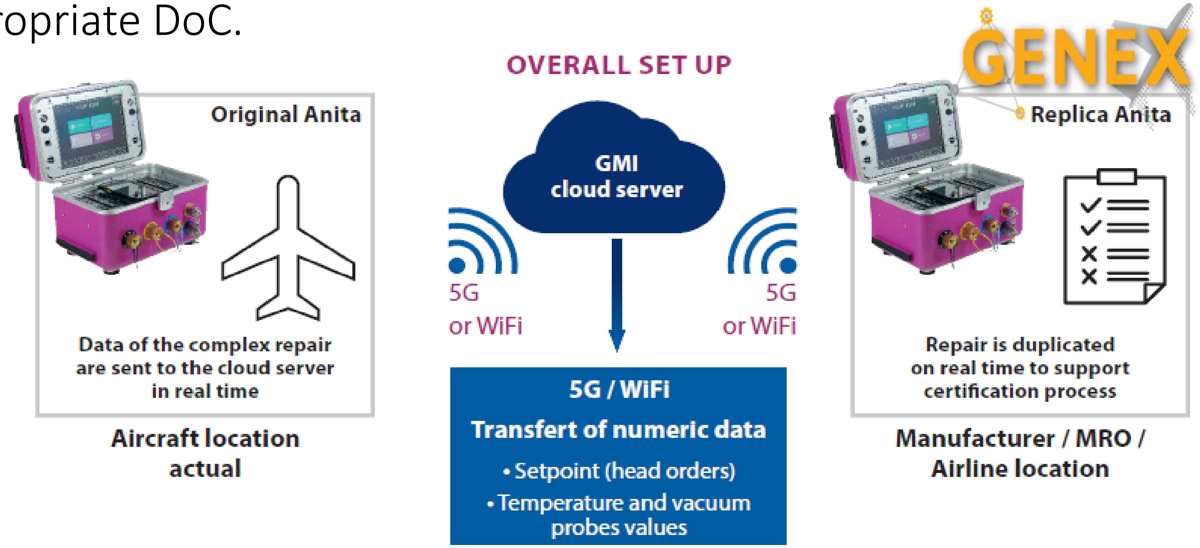
Funded by the European Union

Upcoming tasks - On-line control of the repair bonding process – Final vision

DIGITAL-PHYSICAL TWIN

Connecting ANITAs via **WiFi or 5G, to transmit in real-time data** to create **“Replica”** through:

- **A second ANITA**, identical to the **“Original” repair (Physical Twin)**
- Calculation of the **Degree of Curing (DoC)** applying corresponding material curing equations **(Digital Twin).**
- **GENEX Digital Twin Model,** which will also provide feedback for **extension of curing cycle** and / or **increase of set Temperature**, to ensure appropriate DoC.



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R&D for the Aviation Industry in the EU

4. Standards supporting the digital transformation of aviation

Specific challenges:

The fast-paced digital transformation observed in several industrial sectors is extending to aviation and air transport. The need to anticipate the changes and evolutions of aviation standards requires timely and upstream investigation, through several case studies, of the application of radically new concepts and processes for aviation products, processes and operations (such as machine-learning techniques, 'internet of things'). This includes developing capabilities such as tools and methods for design, simulation (digital twins), verification and validation and their application to aircraft certification, regulatory approval and safety monitoring processes.

Scope:

The targeted actions focus on specific safety issues, for which no new technological development will be undertaken but, building on previous research and innovation actions, the relevant changes to the aviation safety standards will be prepared and coordinated with stakeholders:

- Develop a robust safety risk assessment methodology to support the identification and consolidation of safety hazards and their mitigation using numerical tools (the 'digital twin' concept);
- Prepare the roadmap for the next evolution(s) of airworthiness and maintenance standards for new digital applications and validate the new capabilities for the associated performance and risk assessment.

Contribution to EASA activities: Roadmap for the changes to aviation standards

Impact: EU preparedness for the deployment of digital innovation in aviation and air transport

Part 8 - Page 469 of 479

Horizon Europe - Work Programme 2021-2022
Climate, Energy and Mobility

Results needed by: 2024

Legal entities:

European Union Aviation Safety Agency (EASA), Konrad-Adenauer-Ufer 3; D-50668 Köln; Germany

Form of Funding: Indirectly managed actions

Type of Action: Indirectly managed action

Indicative timetable: 1st quarter 2022

Indicative budget: EUR 2.10 million from the 2022 budget

Should we start preparing ourselves and our organizations for the coming
Digital Transformation ???

THANK YOU!

CONNECT WITH GENEX

101056822
01.09.2022
42 months

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