Aircraft maintenance in the CFRP future

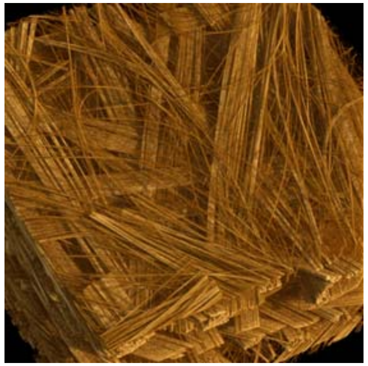
Martin Wiedemann, Heinz Voggenreiter 15th October 2009

DLR – The German National Aerospace Agency

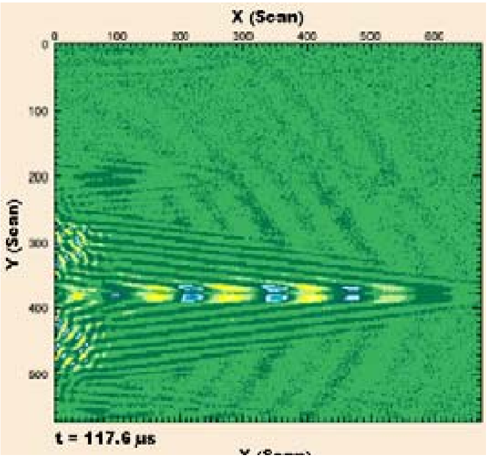
Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Maintenance for CFRP parts - The considered process chain

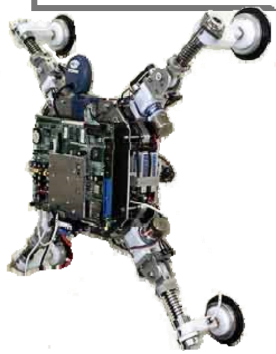
SHM
(Lamb Waves)



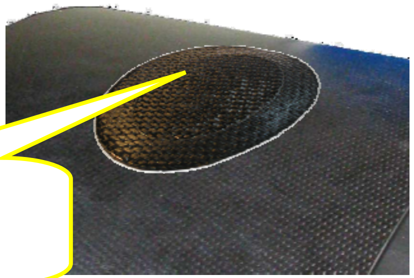
NDT
(CT improved US)



Repair
(RPR)



Bondline Control



This repair
is ok

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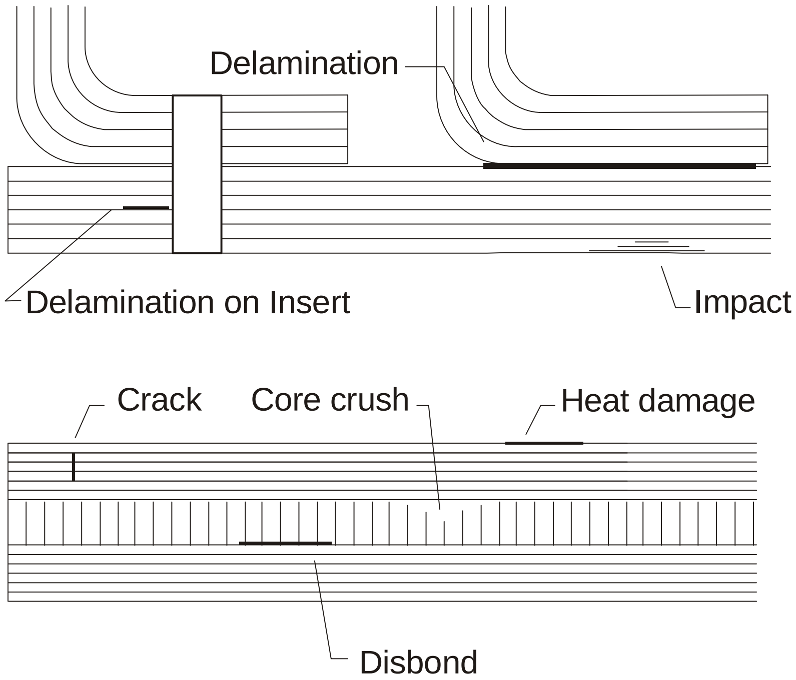
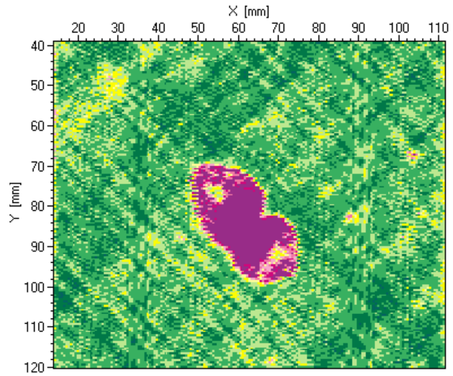
Maintenance for CFRP parts – The Challenges

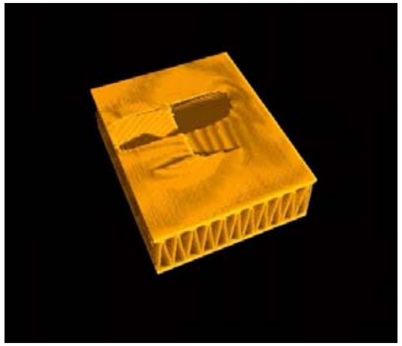
- ✈ **Barely visible damages**
- ✈ **Integral structure with hidden elements**
- ✈ **Enhanced thresholds**



Defect Types to be detected



Delamination in US

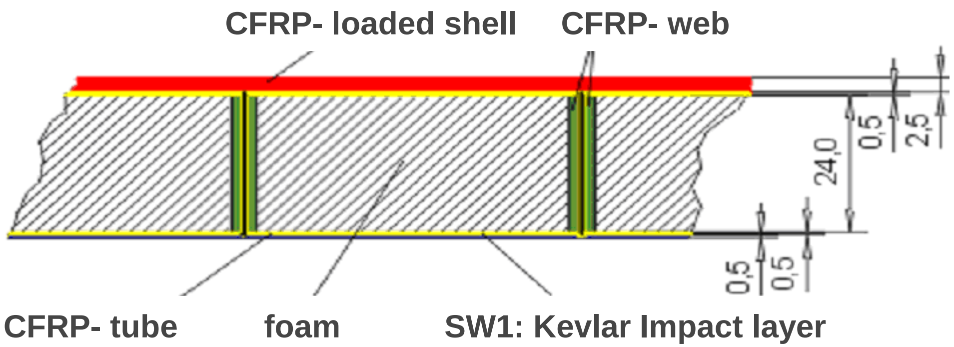


Impact with Core Crush

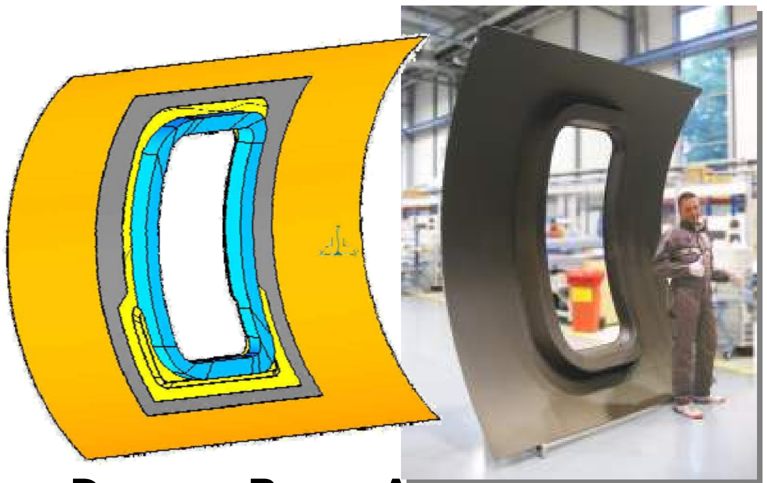
Vision: Structure with self-sensing capability

SHM with Guided Lamb Waves – The Vision

- **Fast testing of structure integrity by acoustic ultrasonic waves (lamb waves)**
- **Structure integrated observation network in damage prone areas, locations difficult to inspect, inaccessible areas**
- **Efficient off-board monitoring to localize potential deviations / defects**
- **Light and intelligent sender/receiver elements, connected by structure integrated low voltage / low power wiring**



Inaccessible Area:
Sandwich Structure



Damage Prone Area:
Door Surround Structure

SHM with Guided Lamb Waves – Technology (I)

Working Principles

Guided waves can penetrate large areas and interact with defects

Their excitation and reception is possible with piezoceramic (PZT) patches

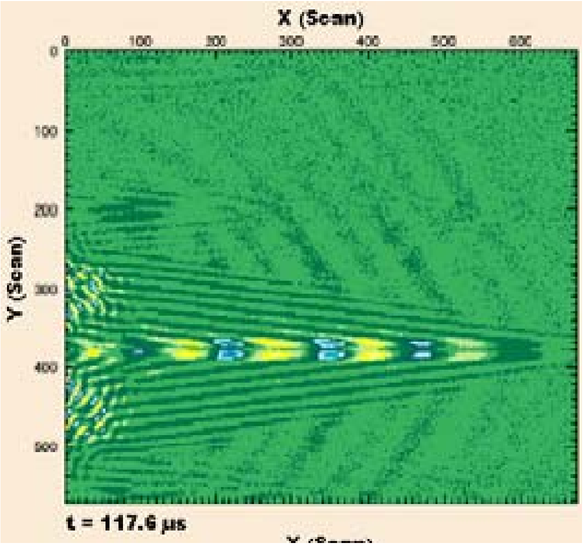
- **No time consuming scanning required**
- **Inspection of complex components**
- **Evaluation of time of flight, amplitude and wave types**

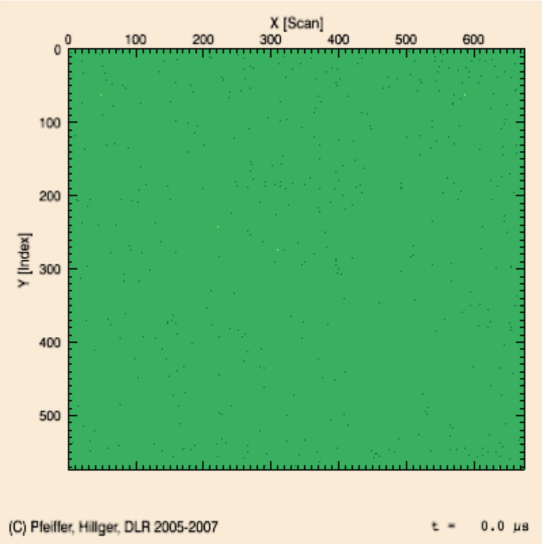
However:

- **For each frequency at least two different wave modes exist**
- **Each mode is dispersive**
- **Interaction between Lamb-waves and damage is complex and difficult to predict**
- **A practical application requires a high degree of research and development**

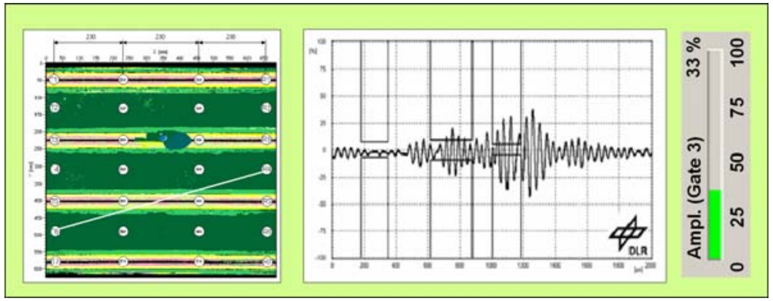
CFRP-component with PZT-patches used as actuators and sensors for Lamb-waves

Working Principles

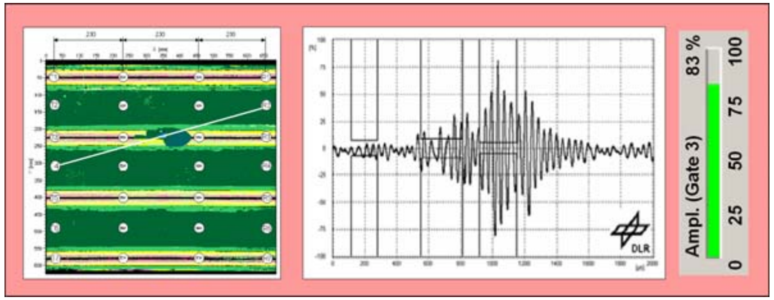




Received signal going through intact structure



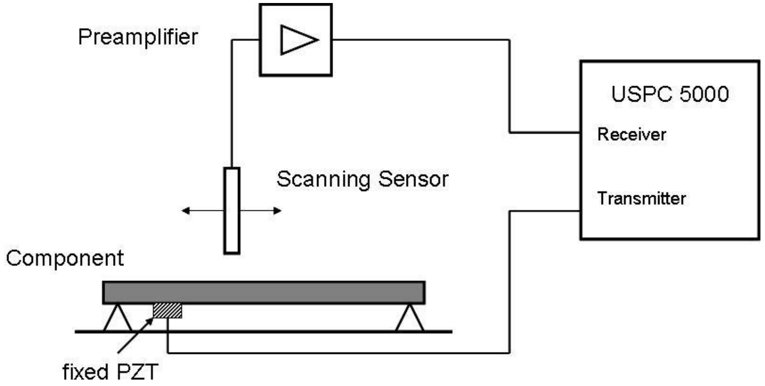
Received signal through structure with local defect

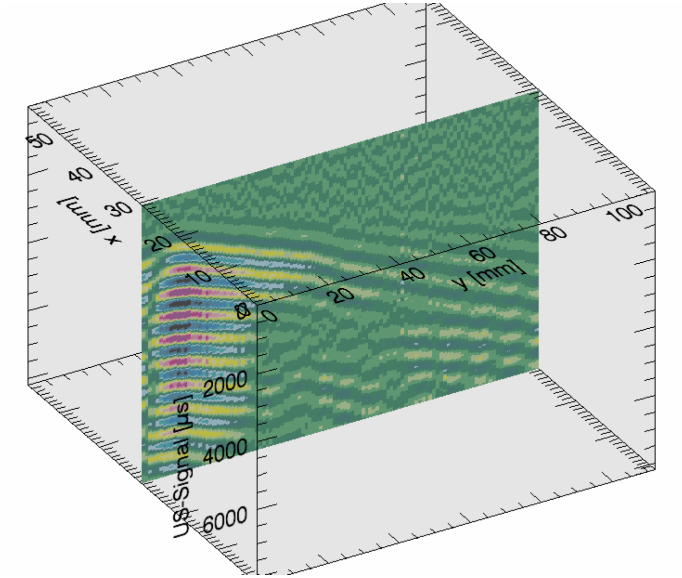


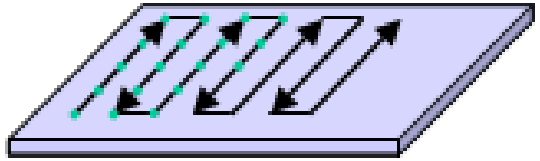
SHM with Guided Lamb Waves – Technology (III)

Capturing of 3D-Lamb Wave Data Files

- Excitation of a fixed PZT
- Meander scanning, grid 2x2 mm
- Excitation at each point of the scanning grid
- Air-coupled scanning receiver
- 3D-data file (x-y-t), file size 1-20 Gbyte
- Scanning time: for 600*800 mm:
- 40 min.(240.000 points)
- Comparison: scanning laser doppler vibrometer (SLDV) 300 points within 20 minutes





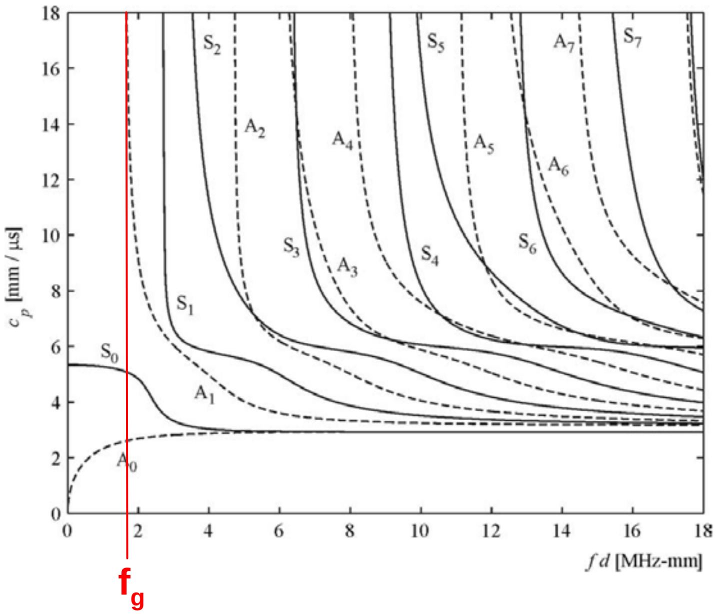


A = f(x, y, t)

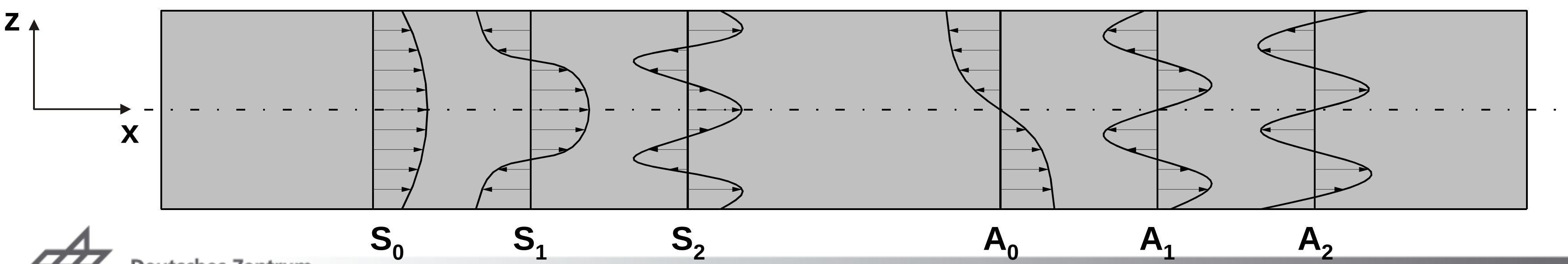
SHM with Guided Lamb Waves – Technology (IV)

Lamb Wave Mode Selection to Filter Required Information

- At a given frequency there exist a series of wave modes
  - Symmetric modes (S_n-tension-modes)
  - Antimetric modes (A_n-bending-modes)
- Each mode has its specific speed and wavelength
- Below a material specific frequency (f_g) only A_0- and S_0-mode are generated



Quelle: G. Mengelkamp, Entwicklung einer Intelligenten Struktur – Eine Kombination Globaler und Lokaler Verfahren zur Schadensdiagnose, Dissertation, Universität Siegen, 2006



SHM with Guided Lamb Waves – Technology (V)

Wave Reflection Due to Distortion Leads to Mode Conversion

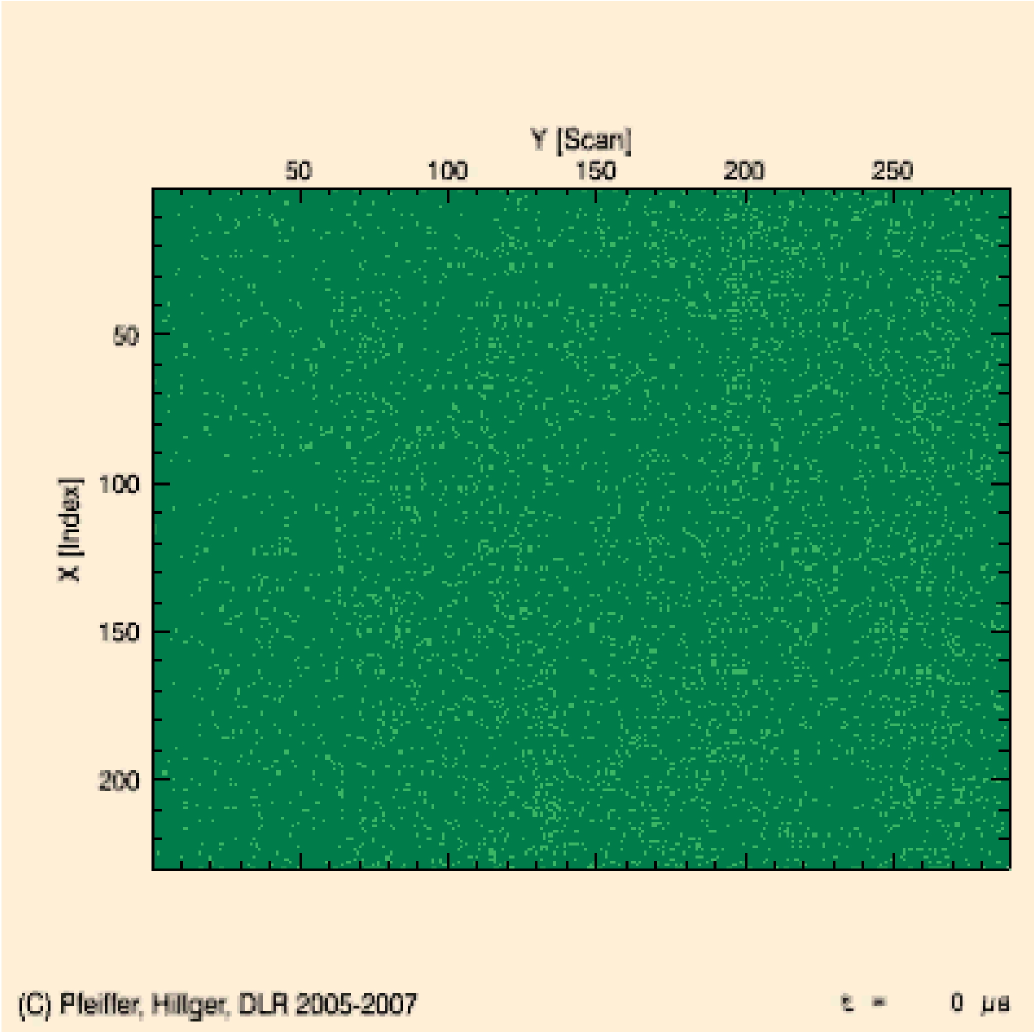
Example:
Local area on a tailboom has been analyzed with stiffness change on skin due to bonded additional sensor.

Actuator sends a single mode.

The reflected mode shows a different wavelength.

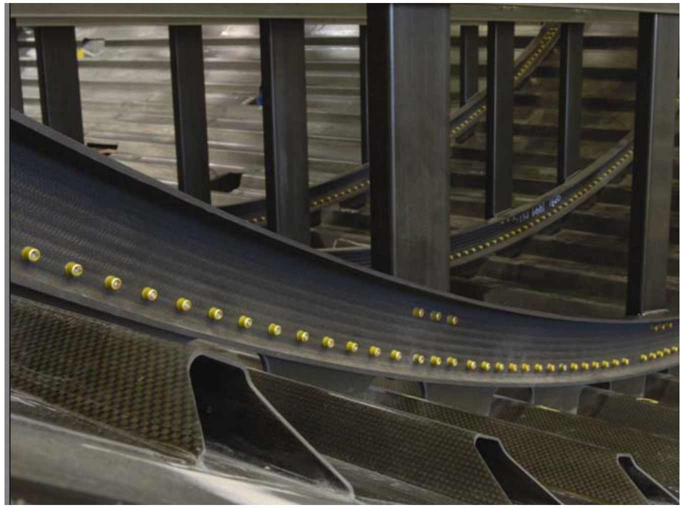
The distortion (stiffness) leads to mode conversion.

EC135 Tailboom (AISHA II Project)



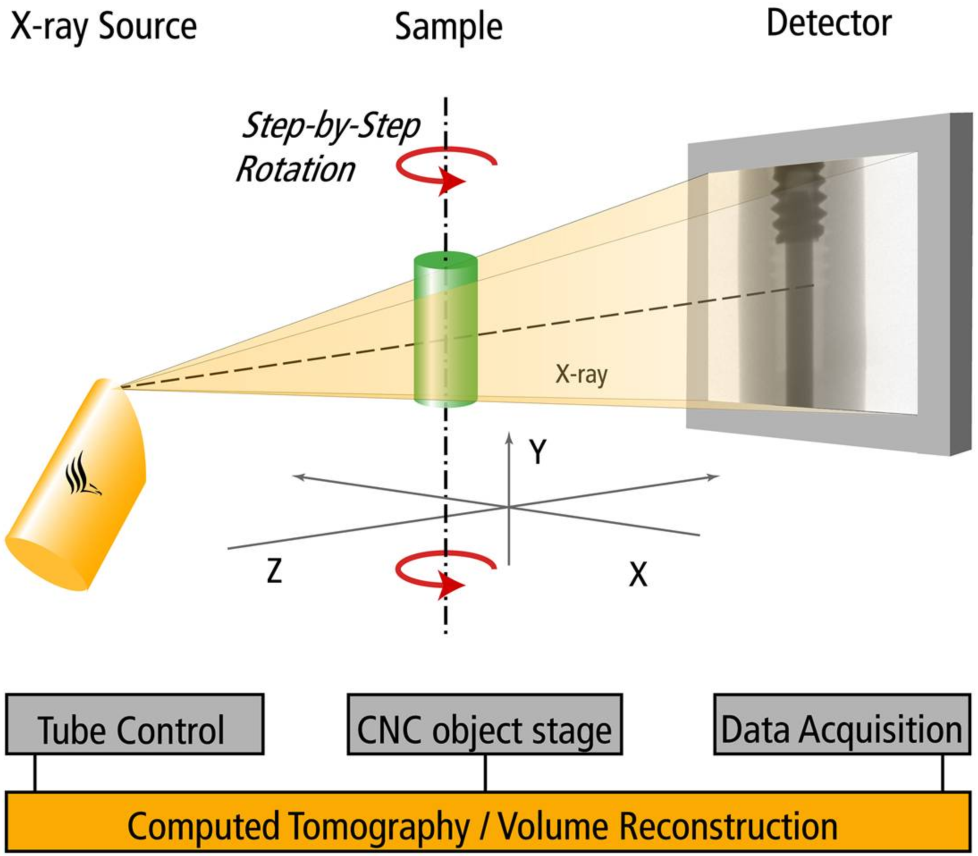
SHM with Guided Lamb Waves – Remaining To Do’s

- Algorithms for signal analysis to localize deviations
- Correlation between signal analysis and size of defect
- Range of applicability to be evaluated
- Technology required to assess optimal actuator/sensor placement for specific structures
- Self diagnosis capability
- Proof of reliability / durability in operational tests
- Technology Certification

Composite

Structure

NDT with Computer Tomographie – Method

Basics



NDT with Computer Tomographie – Method

Devices

Mikrofocus

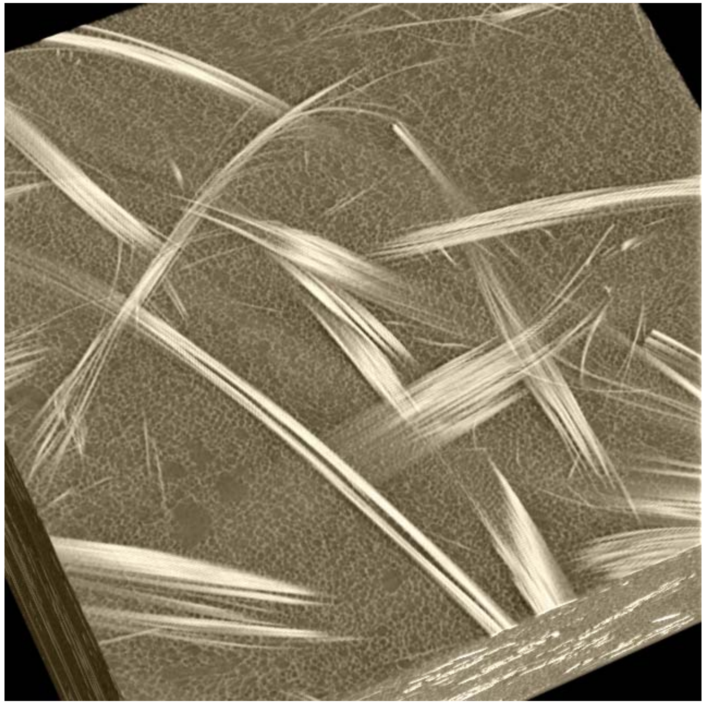
Resolution 5 µm (240 KV)

Nanofocus

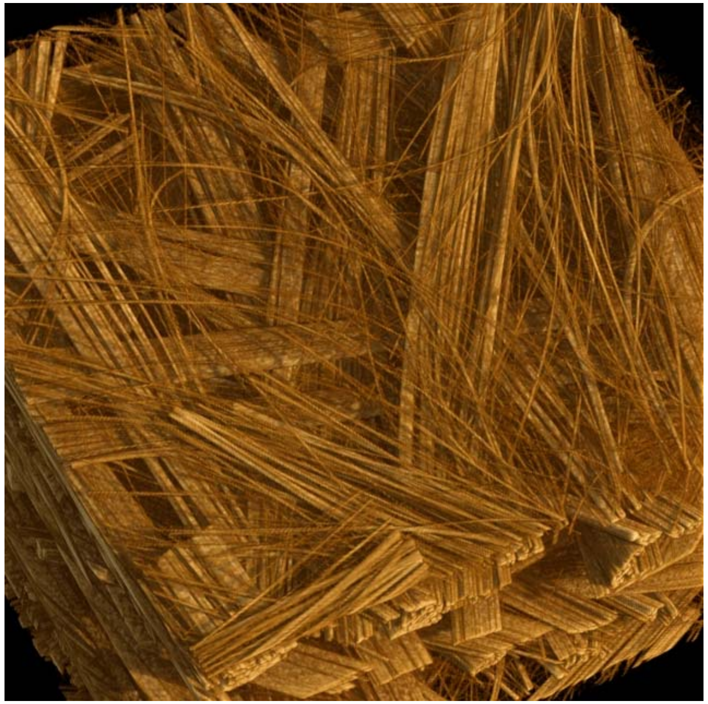
Resolution 2 µm (160 KV)

NDT with Computer Tomographie – **Process**

The Potentials



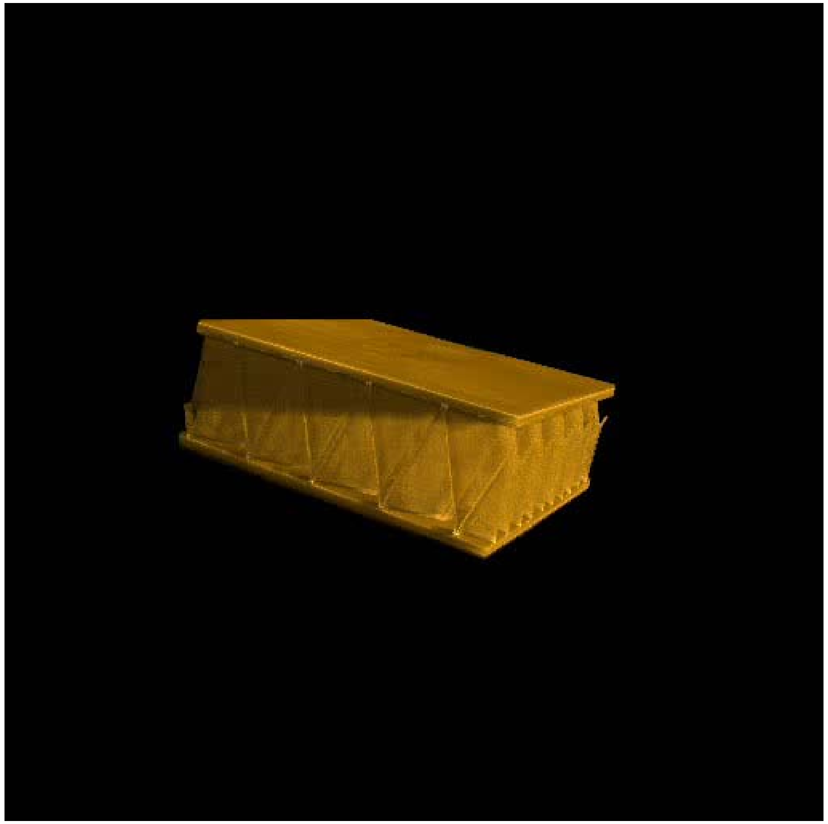
Resin and embedded glas fibers



Digital extraction of glas fibers

NDT with Computer Tomographie – Method

Analysis of Complex Structures



Double-wall structures (CFRP)

Advantages

- **3D-image of damage area**
- **Digital separation of impactor without influencing the impact area**
- **Quantitative analysis of defects**

Limits

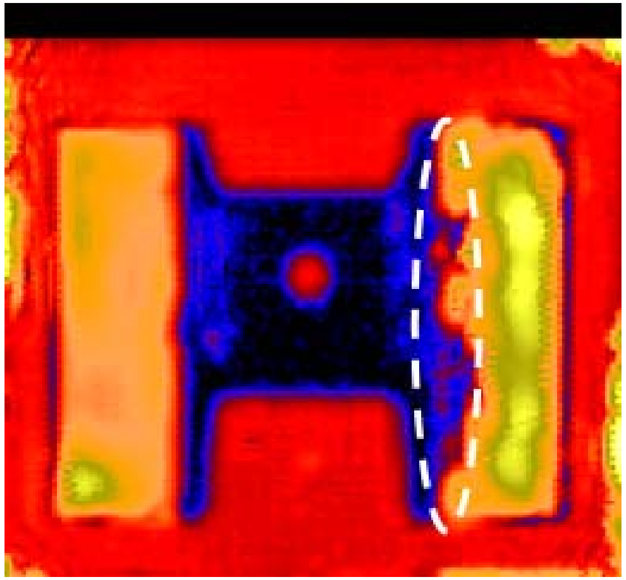
- **Limited size of inspectable parts depending on resolution**

NDT with Computer Tomographie – Method

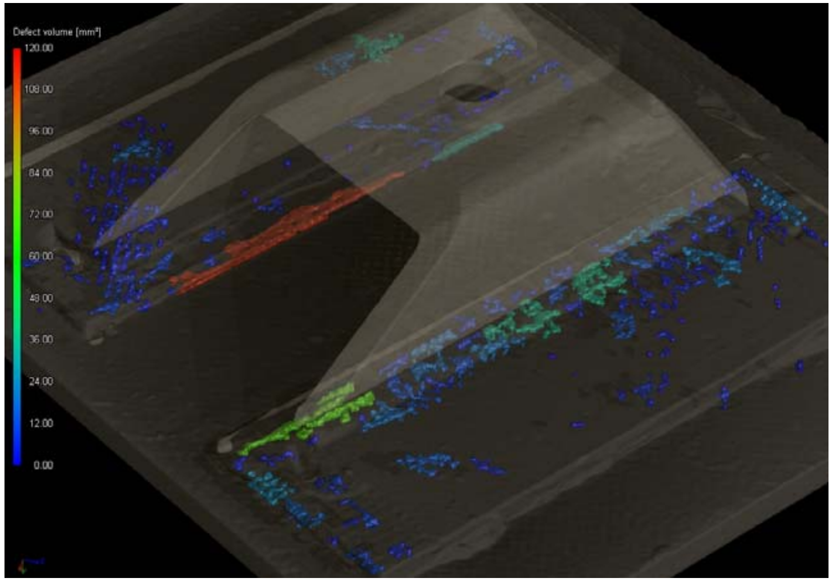
Bridging the mobile NDT methods

From 2D-Information to 3D-Information

Air-coupled ultrasonic



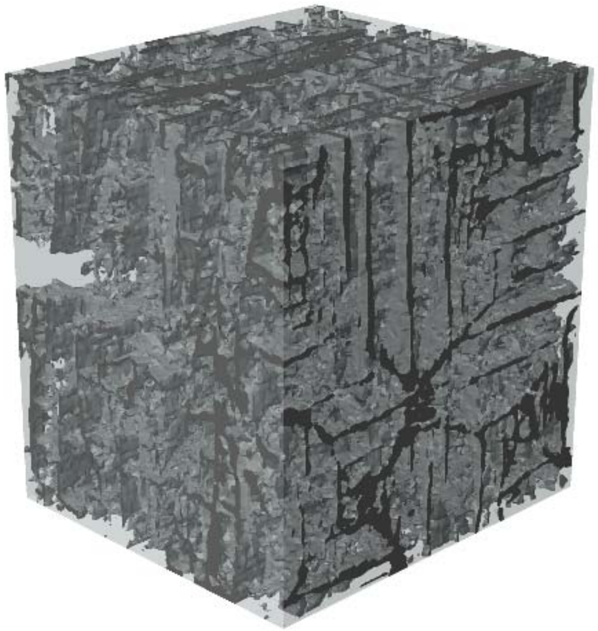
Computer-tomography

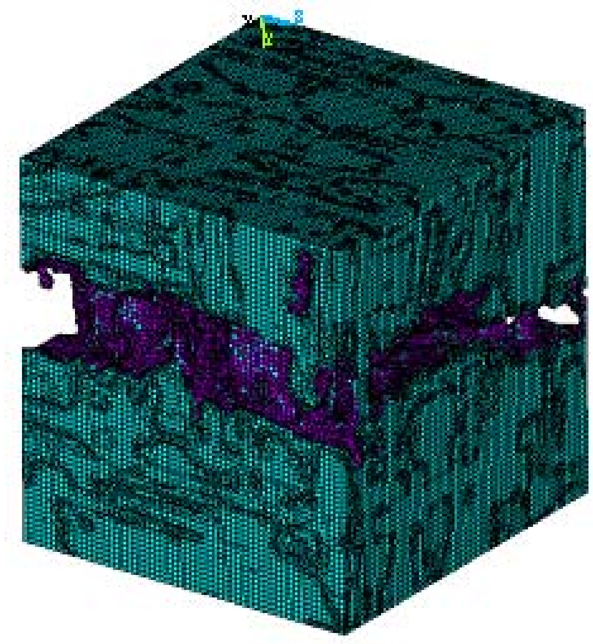


Improved interpretation of effects of defects

NDT with Computer Tomographie – Method

Bridging analysis and FEM

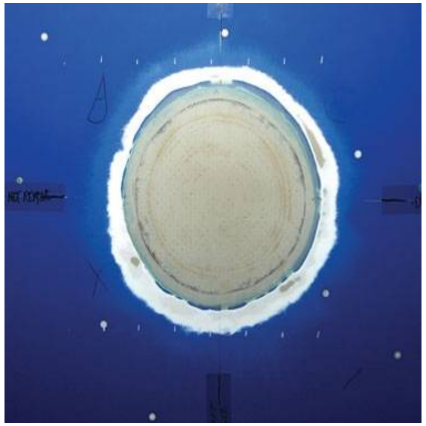




- CT-Analysis of defects

- Meshing of defect area
- FEM based calculation of remaining mechanical performance

CFRP Repair – **Major Challenges**

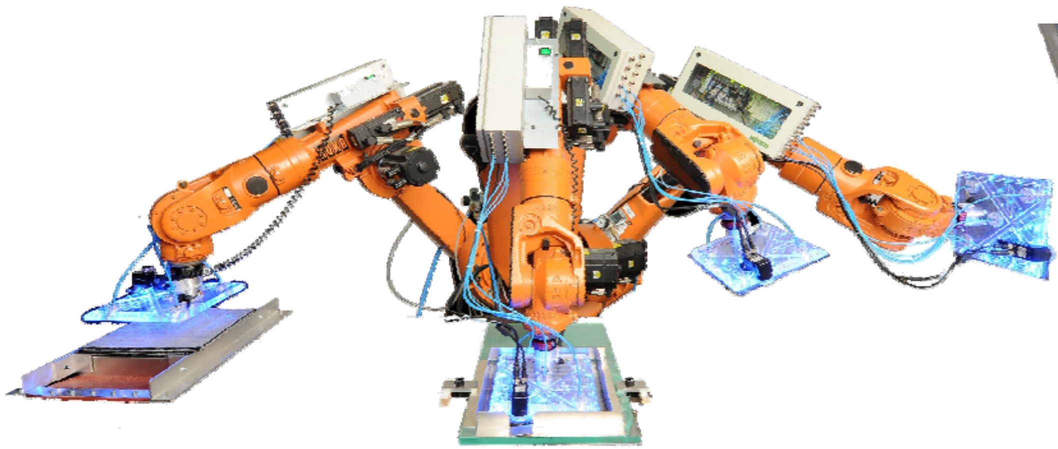


Repairs done tomorrow
Demonstration of B787 Repair

Challenges

- ✈ **Reduction of Maintenance Time**
- ✈ **Reduction of Maintenance Costs**
- ✈ **Quality**
- ✈ **Reproducibility / Human Factor**
- ✈ **Performance**

Solution



- ✈ **Automation of Repair Process**

CFRP Repair – Integrated Process Chain

Phases

Identification and Localization of Damage

↓

Scanning of real Geometry

↓

Choice of suitable Repair (Geoemtry / Layup / Material)

↓

Automated Milling / Grinding of Taper and Repairhole

↓

Scanning of Repair Position and Patch (As-Is versus To-Be)

↓

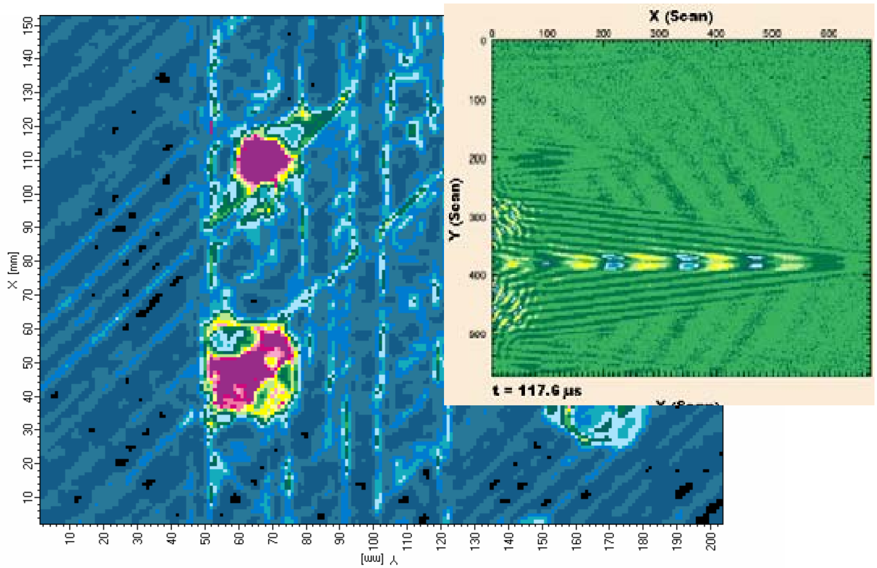
Manufacturing of suitable Tooling via Rapid-Prototyping

↓

Manufacturing of suitable Patches

↓

Automated Positioning and Bonding of Patches



CFRP Repair – Integrated Process Chain

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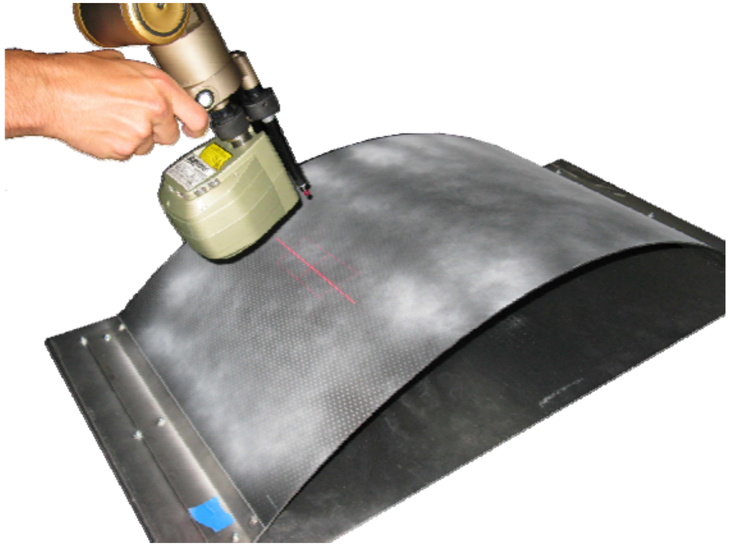
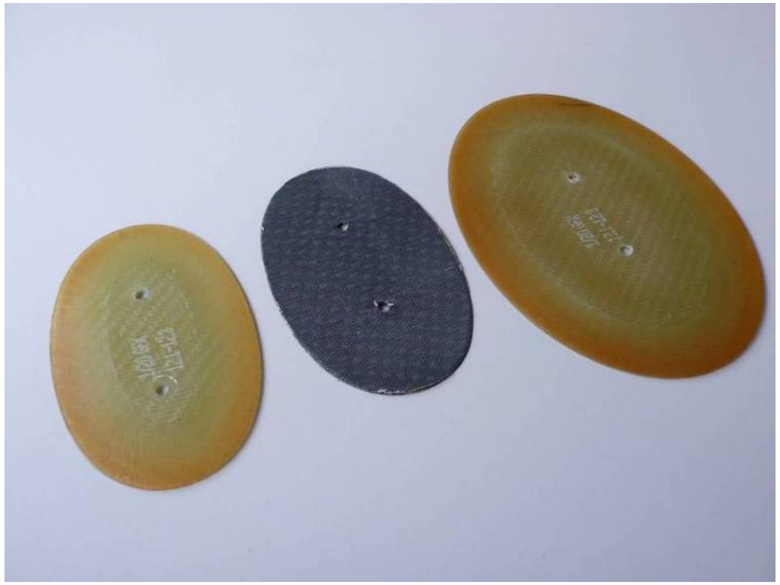


CFRP Repair – Integrated Process Chain

Phases

1. Identification and Localization of Damage
2. Scanning of real Geometry
3. Choice of suitable Repair (Geoemtry / Layup / Material)
4. Automated Milling / Grinding of Taper and Repairhole
5. Scanning of Repair Position and Patch (As-Is versus To-Be)
6. Manufacturing of suitable Tooling via Rapid-Prototyping
7. Manufacturing of suitable Patches
8. Automated Positioning and Bonding of Patches



CFRP Repair – Integrated Process Chain

Phases

- Identification and Localization of Damage
- Scanning of real Geometry
- Choice of suitable Repair (Geoemtry / Layup / Material)
- **Automated Cleaning / Milling / Grinding of Taper and Repairhole**
- Scanning of Repair Position and Patch (As-Is versus To-Be)
- Manufacturing of suitable Tooling via Rapid-Prototyping
- Manufacturing of suitable Patches
- Automated Positioning and Bonding of Patches

Source: IFS TU Braunschweig

CFRP Repair – Integrated Process Chain

Phases

- Identification and Localization of Damage
- Scanning of real Geometry
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- Automated Milling / Grinding of Taper and Repairhole
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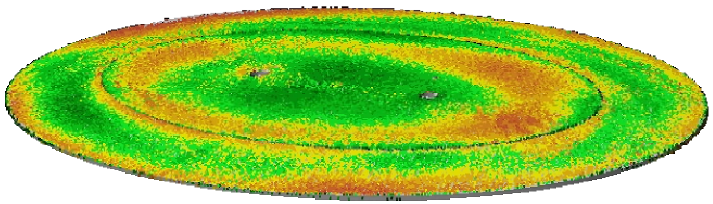

CFRP Repair – Integrated Process Chain

Phases

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- Scanning of real Geometry
- Choice of suitable Repair (Geoemtry / Layup / Material)
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- **Manufacturing of suitable Tooling via Rapid-Prototyping**
- Manufacturing of suitable Patches
- Automated Positioning and Bonding of Patches

Quelle: Fa. EOS

CFRP Repair – Integrated Process Chain

Phases

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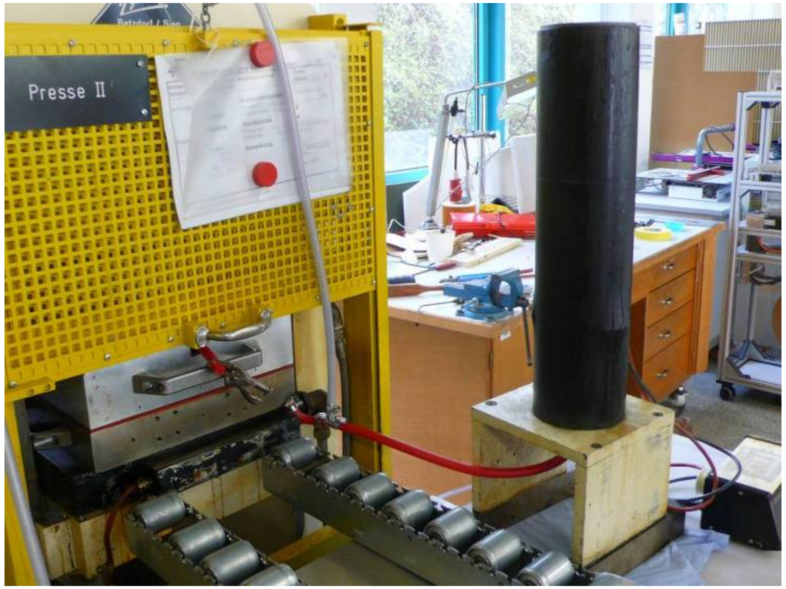


CFRP Repair – Integrated Process Chain

Phases

Identification and Localization of Damage

↓

Scanning of real Geometry

↓

Choice of suitable Repair
(Geoemtry / Layup / Material)

↓

Automated Milling / Grinding
of Taper and Repairhole

↓

Scanning of Repair Position and Patch
(As-Is versus To-Be)

↓

Manufacturing of suitable
Tooling via Rapid-Prototyping

↓

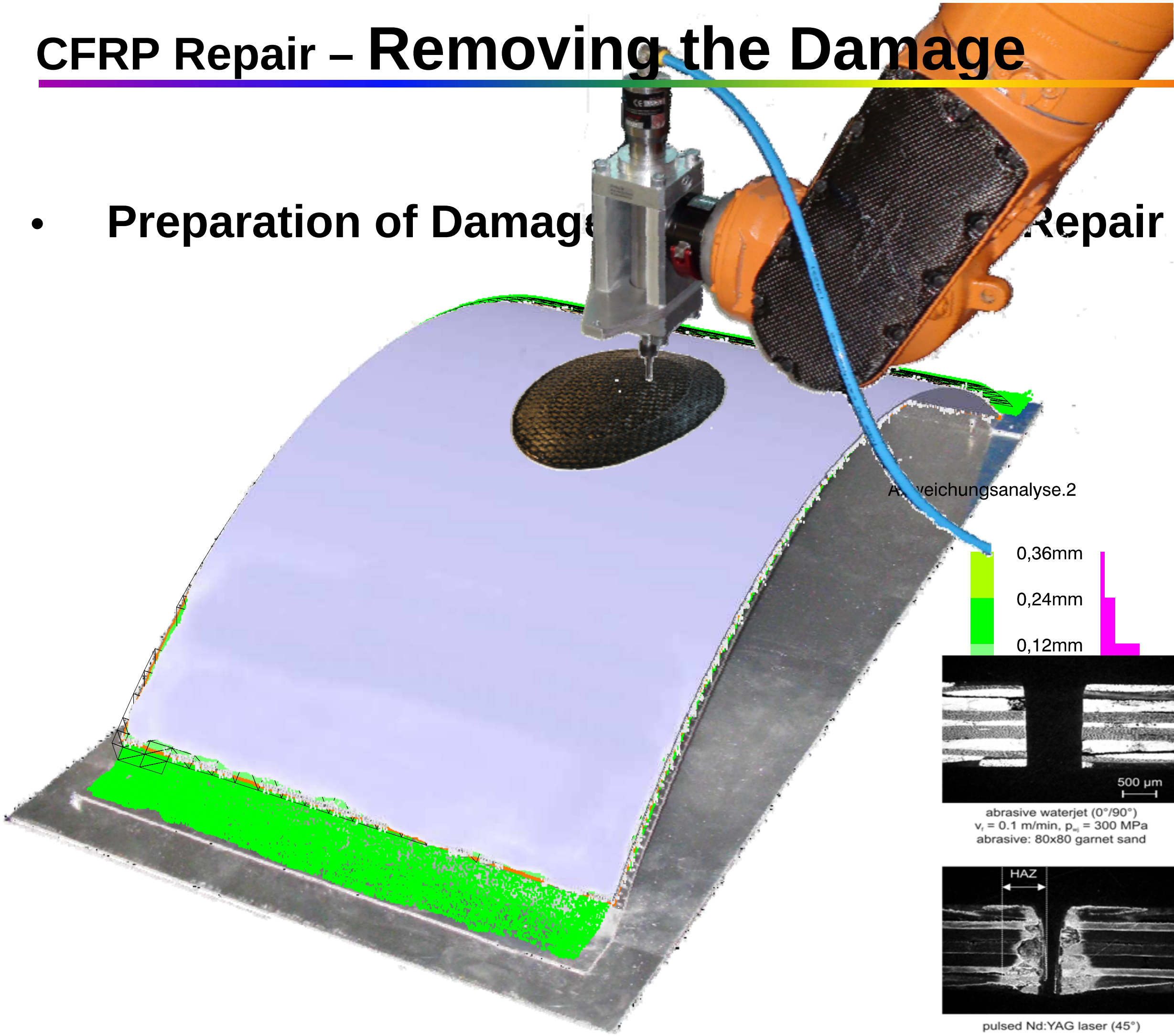
Manufacturing of suitable
Patches

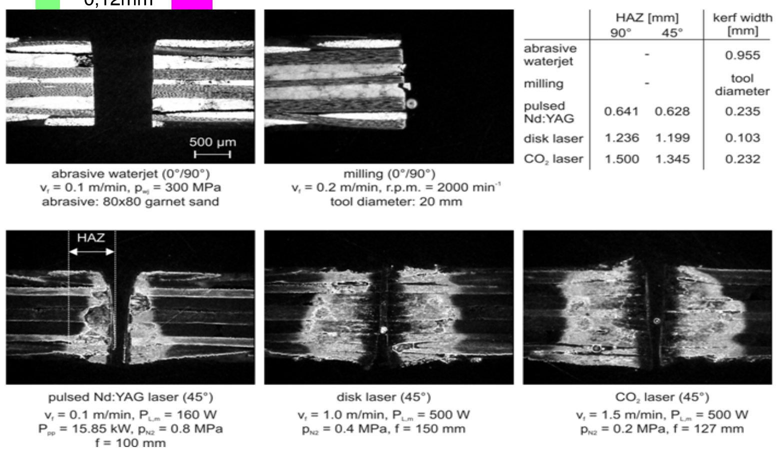
↓

**Automated Positioning and Bonding
of Patches**

CFRP Repair – Removing the Damage

- **Preparation of Damage … Repair**





	HAZ [mm] 90°	HAZ [mm] 45°	kerf width [mm]
abrasive waterjet	-		0.955
milling	-		tool diameter
pulsed Nd:YAG	0.641	0.628	0.235
disk laser	1.236	1.199	0.103
CO_2 laser	1.500	1.345	0.232

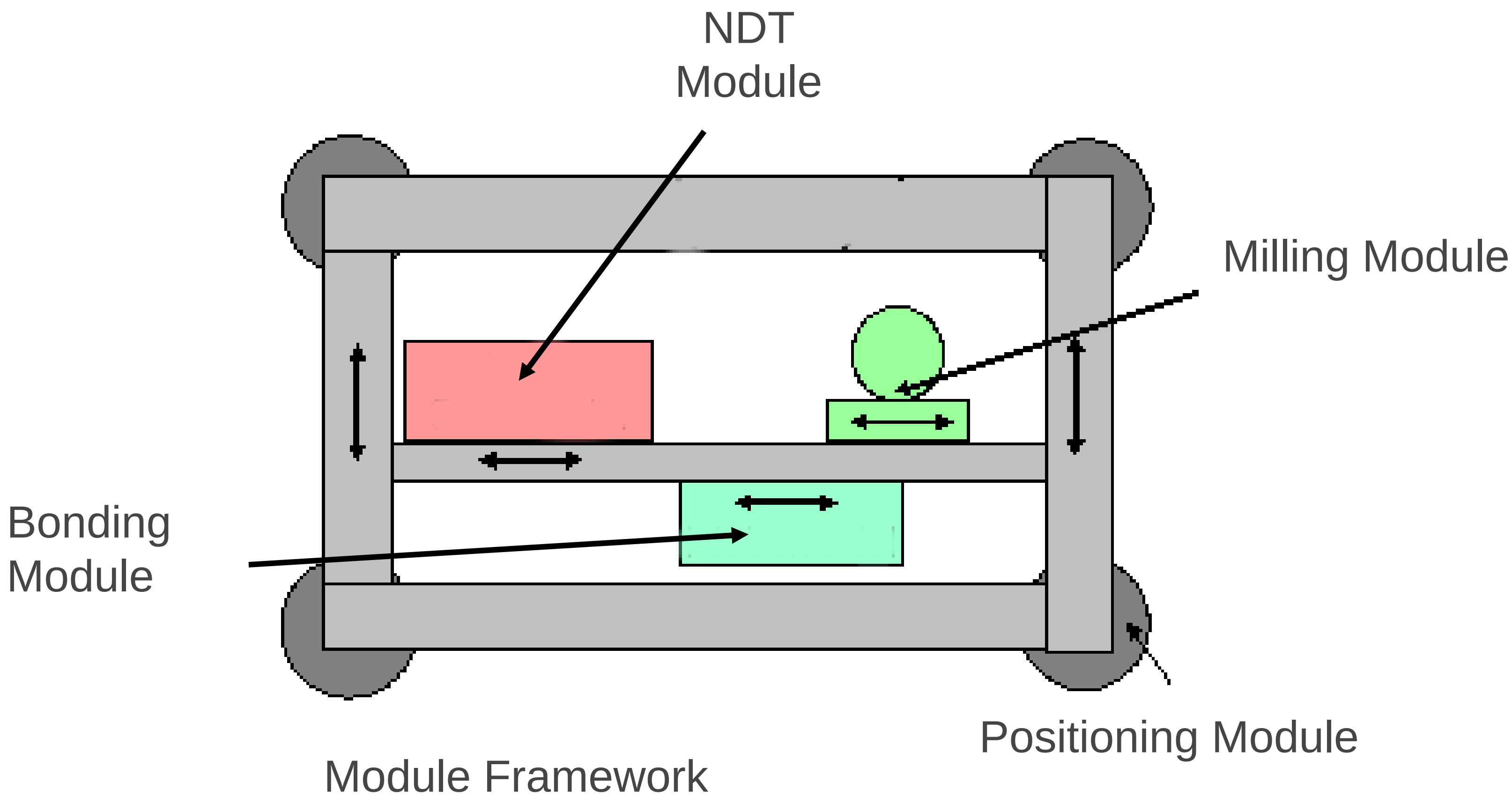
Cross section of cured prepreg, cutted with different milling methods. © **Laser Zentrum Hannover (LZH)**

Automated Positioning and Bonding of Repairpatches

Repair Region based on real 3D Shape

CFRP Repair – Repair of Tomorrow

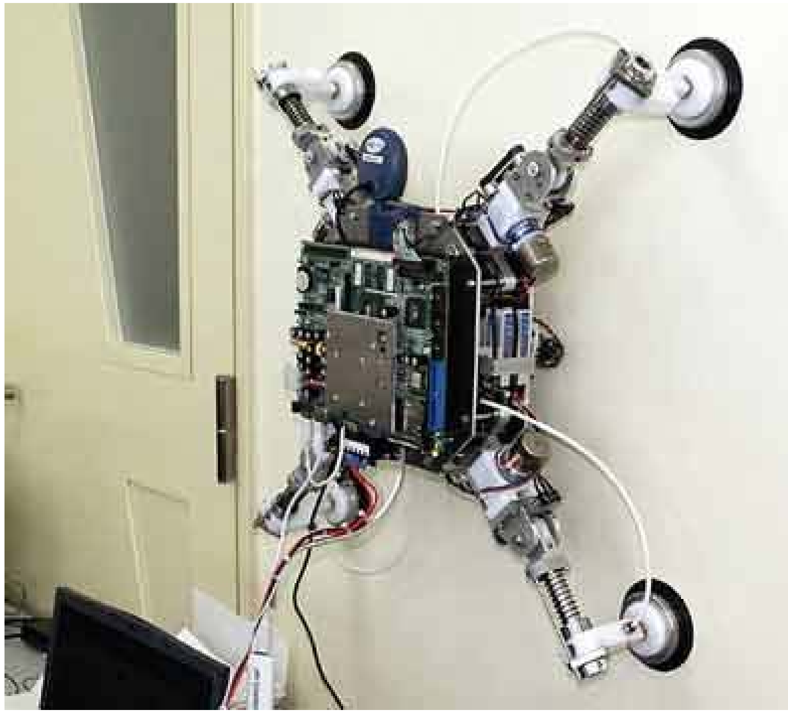
Combination of Repair Modules in one Unit for automation



CFRP Repair – Repair of Tomorrow

Combination of repair modules in one unit for automation

Tasks of today's robots



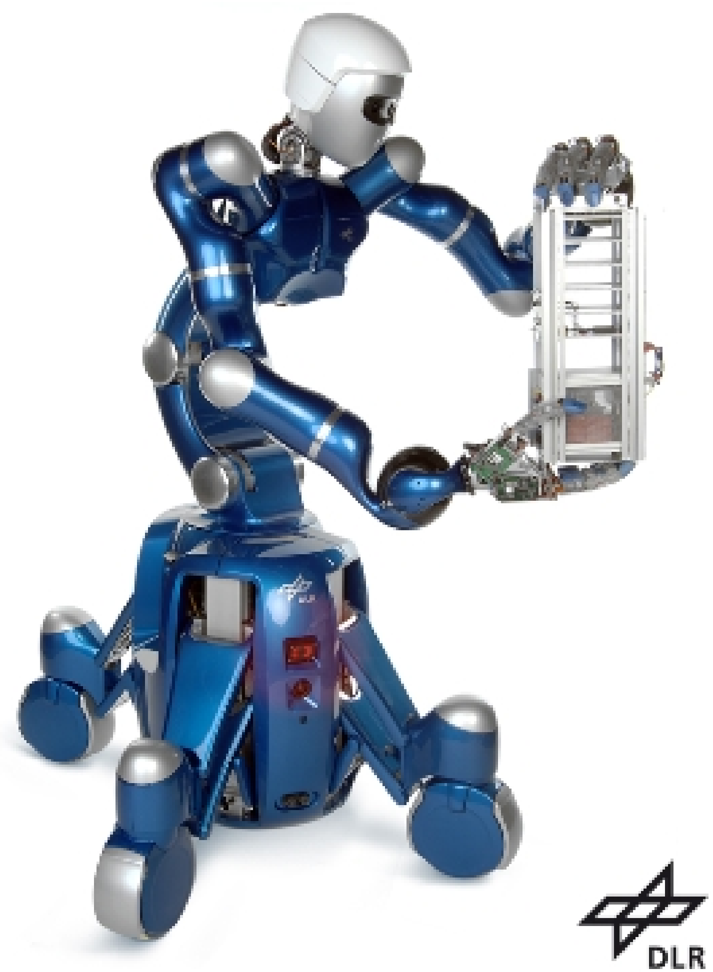
Hanging lazy beside a door…

Tasks of tomorrow's robots?

Actively searching defects
and repairing aircraft structures

CFRP Repair – Repair of Tomorrow

Automation will not stop tomorrow!



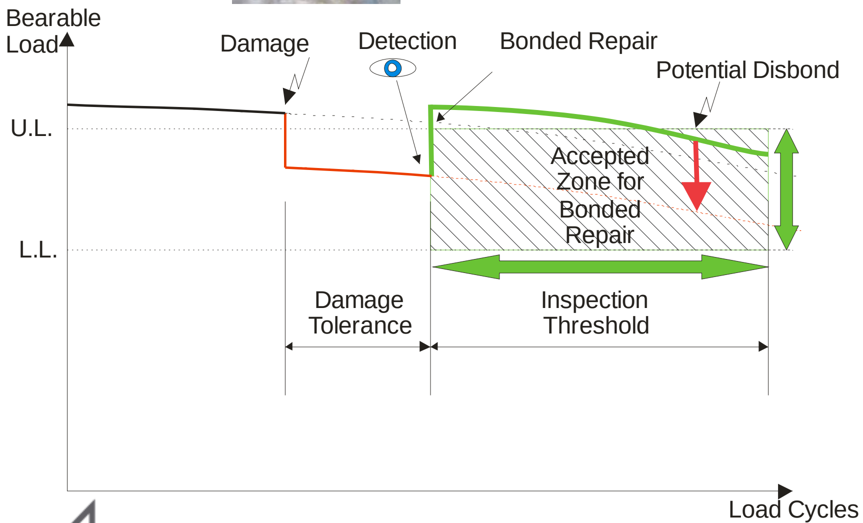
CFRP Repair – Bolted vs. Bonded

Repair scenario today

Scenario A:

Damage small and slow degradation, load carrying capability after potential disbond within inspection threshold above L.L.

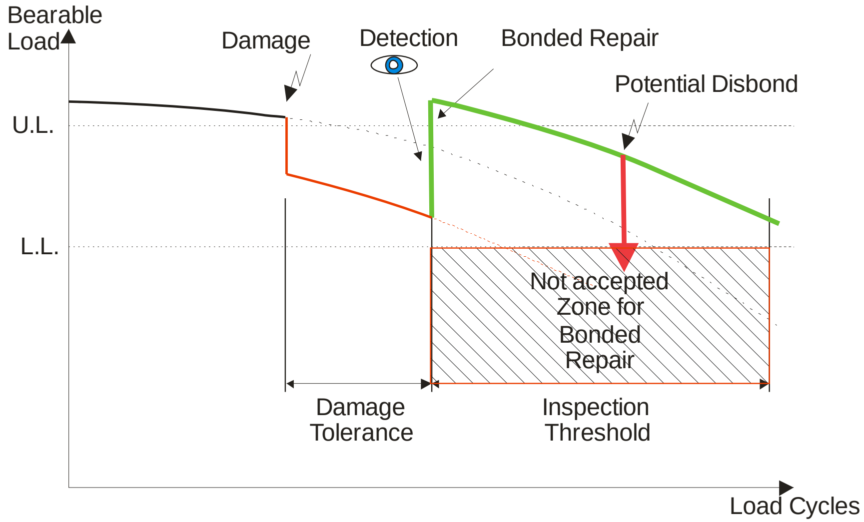
⇨ Bonded repair allowed



Scenario B:

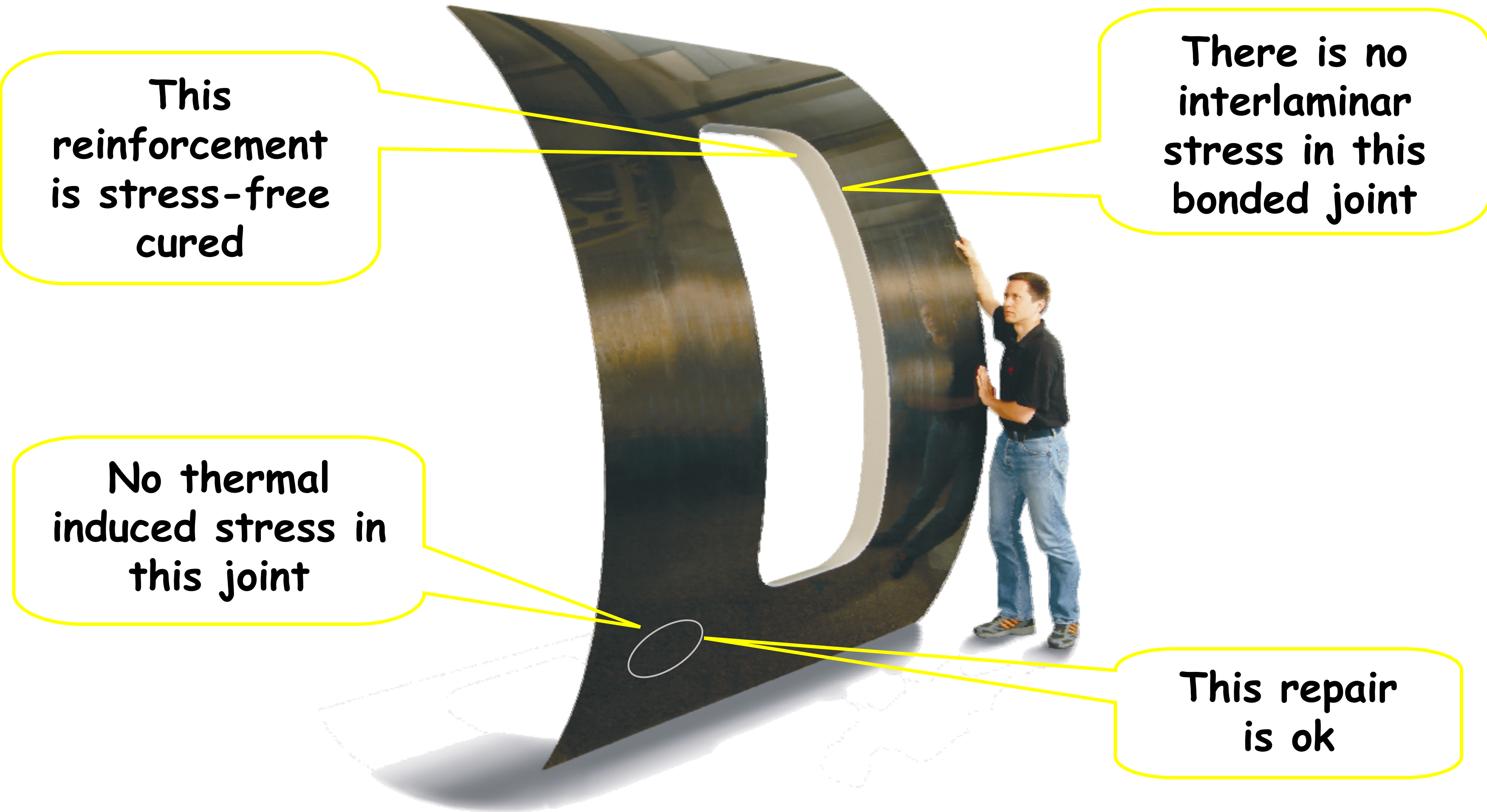
Damage medium or medium degradation, load carrying capability after potential disbond within inspection threshold below L.L.

⇨ Only bolted repair allowed



Automated Repair – Bondline Control

"Intelligent adhesives" = The speaking matrix



Aircraft Maintenance in the CFRP Future – Conclusion

- ⇨ We know the pieces, but we must build the maintenance system for the CFRP future
- ⇨ Technology Readiness Level of maitenance process elements is different
- ⇨ Some maintenance process elements are already available
- ⇨ Some elements still need to be developed – SHM, CT calibrated US, EoD, bondline quality control
- ⇨ All elements need to be standardized
- ⇨ All elements need to be qualified
- ⇨ Maintenance process for CFRP primary structure to be operational within next decade
- ⇨ DLR is working along the whole process chain to provide solutions within requested timeframe

“In light of the fact that humanity is not able to learn from past mistakes …..we can not afford to make mistakes in the future.”

Ernst Ferstl

The German National Aerospace Agency
www.dlr.de

Thank you for listening