Automated near-net-shape preforming of Carbon Fiber Reinforced Thermoplastics

Dipl.-Ing. Michael Kühnel,
Dipl.-Phys. Alfons Schuster
Paris, 11.03.2014

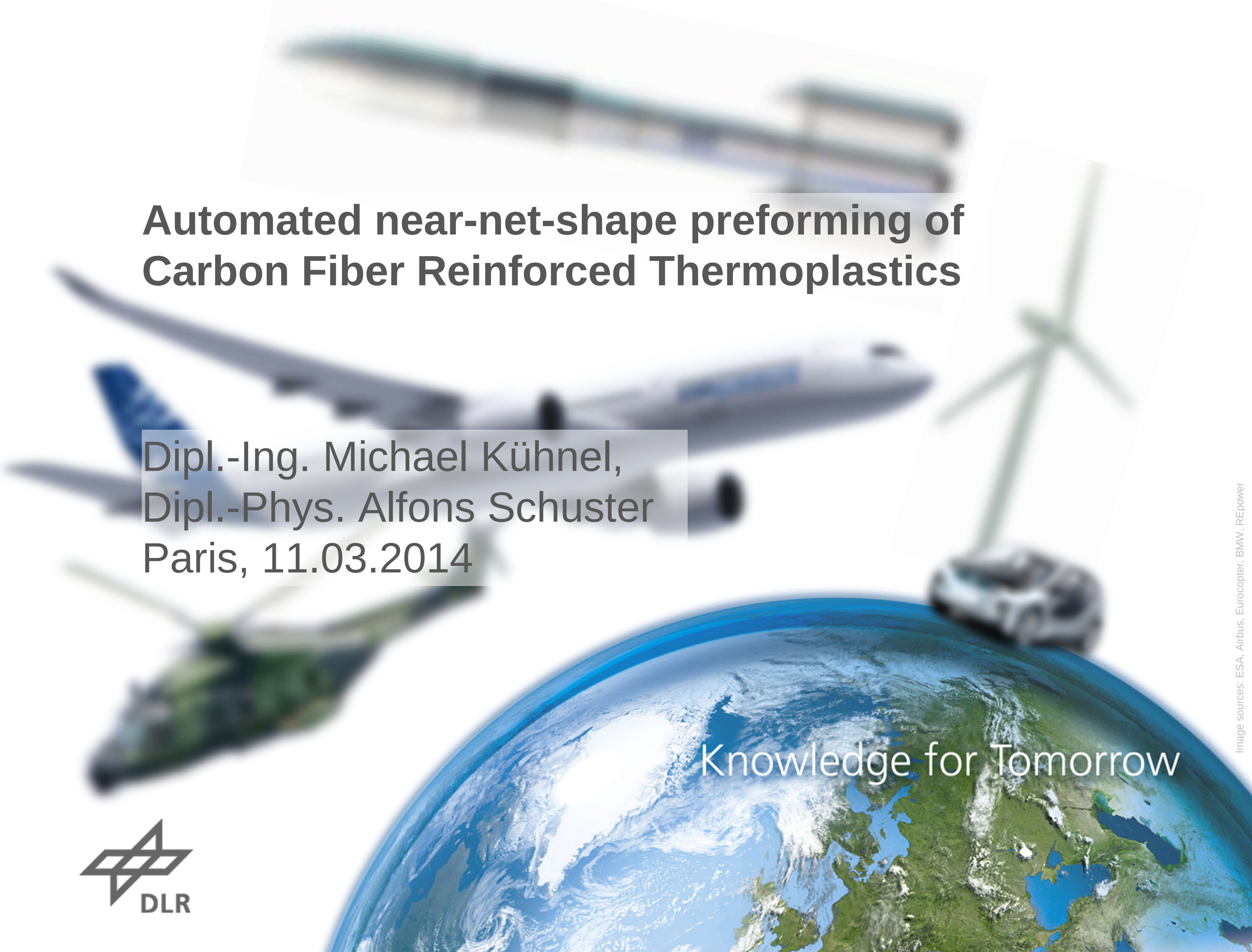

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Image sources: ESA, Airbus, Eurocopter, BMW, REpower

Content

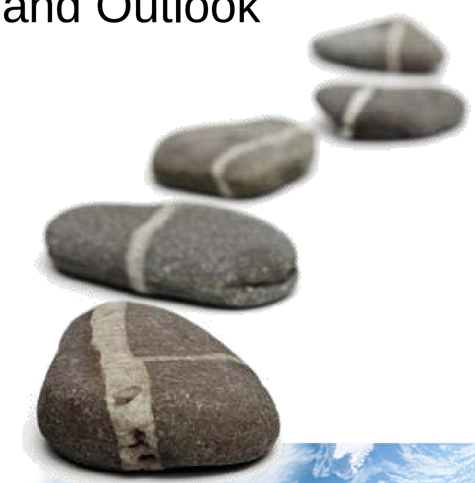
1st part (Michael Kühnel)

- The DLR-ZLP Augsburg
- Motivation
- Robotic fabric lay down
- Technology Demonstrator
- End-effector construction
- Integration in process chain

2nd part (Alfons Schuster)

- Gripping of Unique Cuts
- Cut detection system / System errors
- Template Matching
- Gripping and Laydown of Test Patterns
- Fiber Orientation for improved Detection

- Conclusion and Outlook



The DLR Center for Lightweight Production Technology (ZLP)

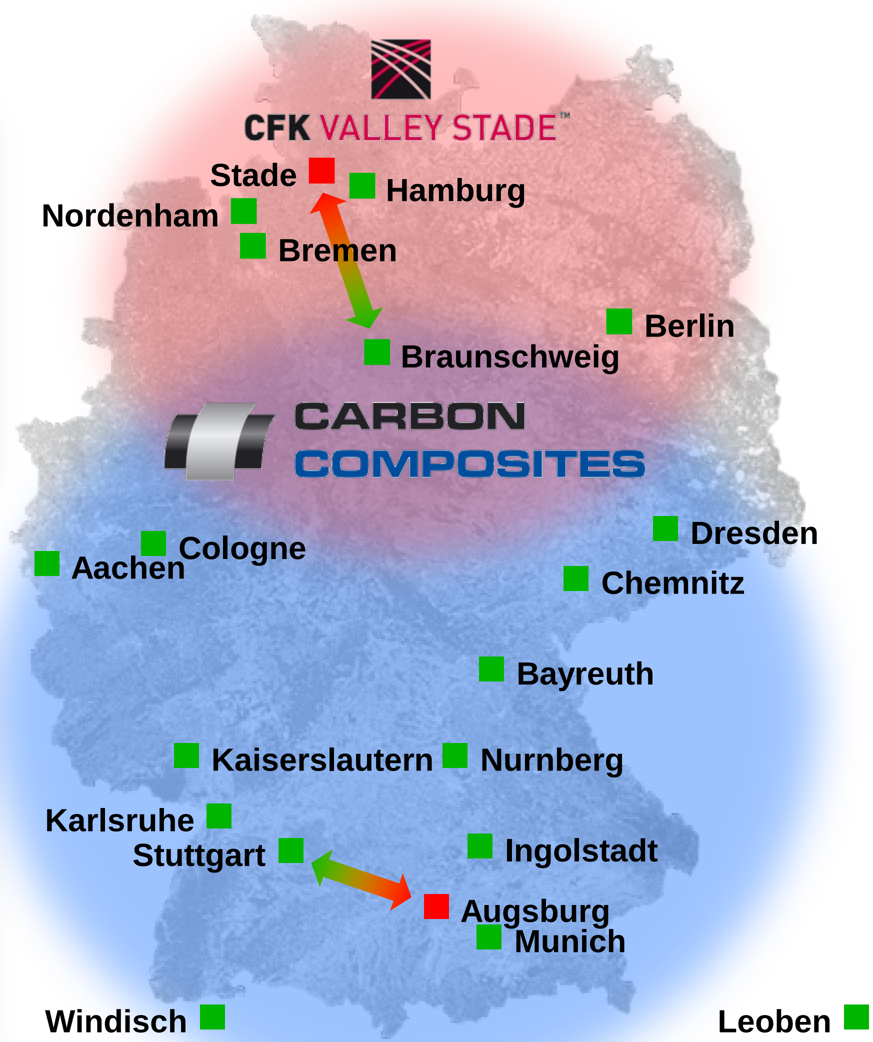
DLR-ZLP Stade

Prof. Wiedemann (Director FA), Dr. Kruse (Head ZLP)

Quelle: Airbus

DLR-ZLP Augsburg

Prof. Voggenreiter (Director BK), Prof. Kupke (Head ZLP-A)



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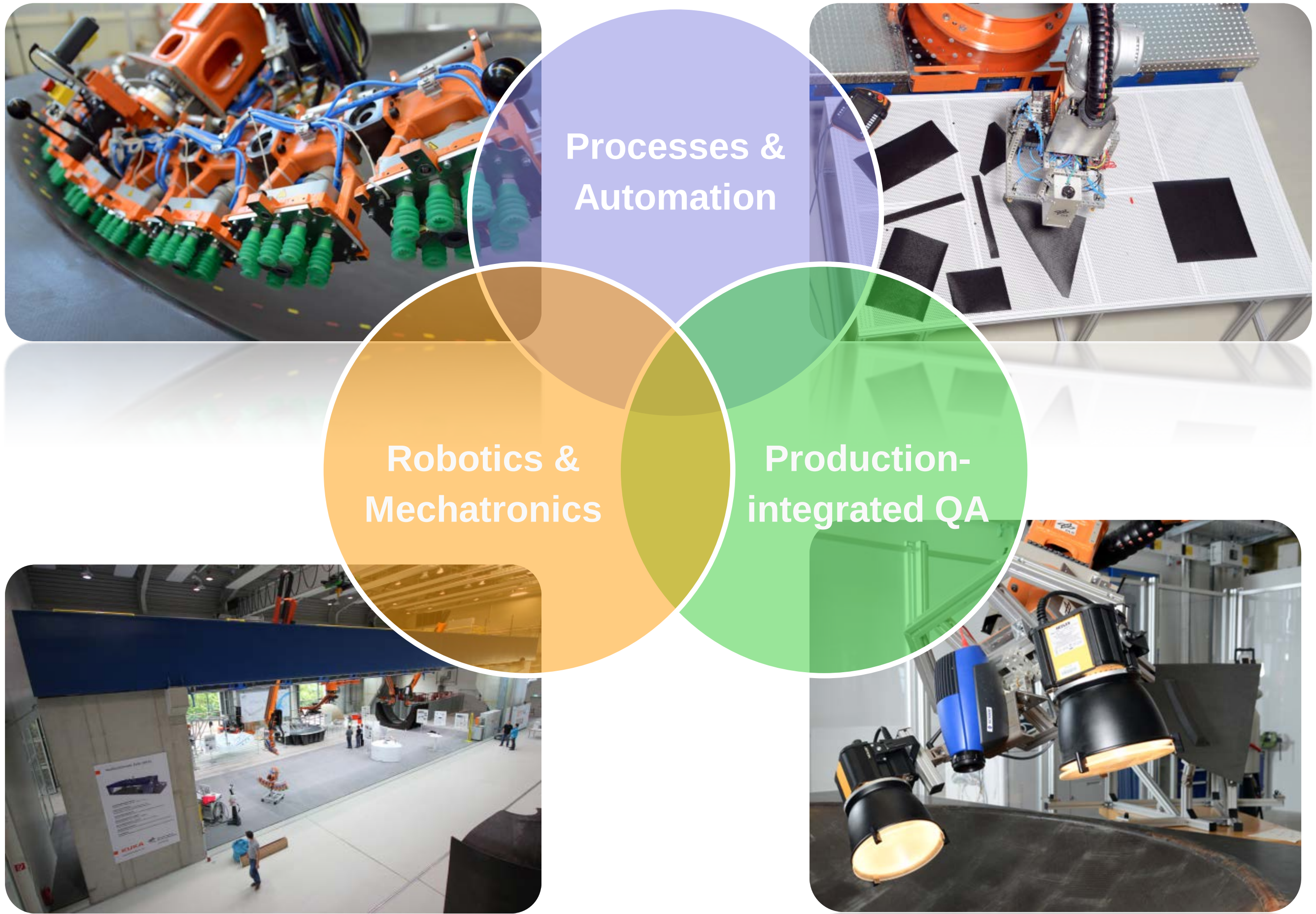
The DLR-ZLP Augsburg –
Research focus & fields of competence



Motivation: Growing demand of CFRTP parts

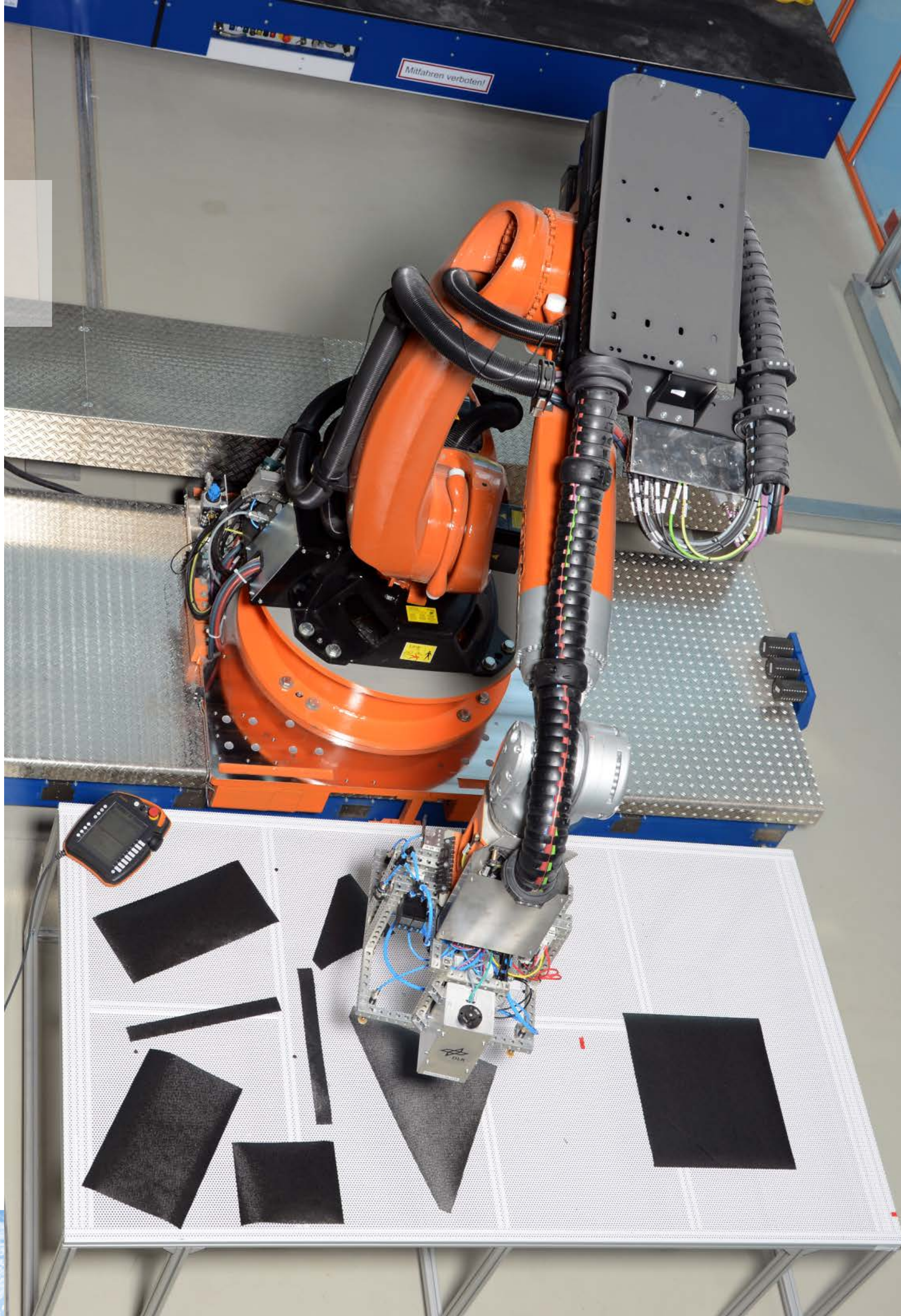
But: With which production technology achieving this?

Source: composites world [1]

Possible solution:
Robotic fabric lay down

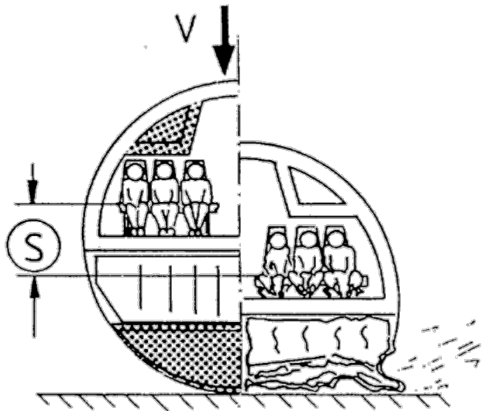
<u>Main advantage:</u>
Implementation of a highly flexible automated production process for almost every production challenge when using (and adapting) suitable end-effectors

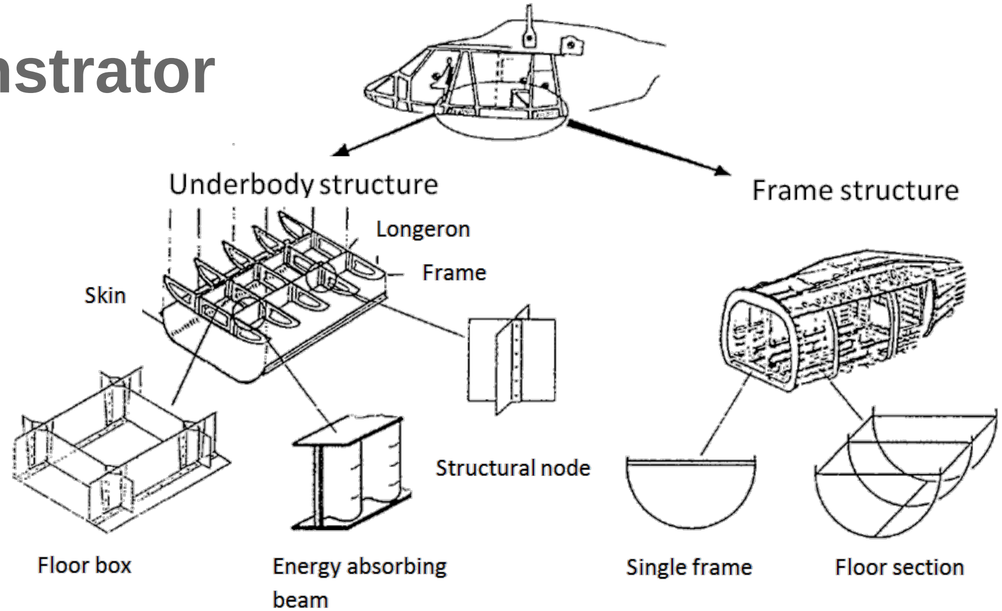
<u>Main disadvantage:</u>
Some work to implement ;-)
(you build and program your own production machine)

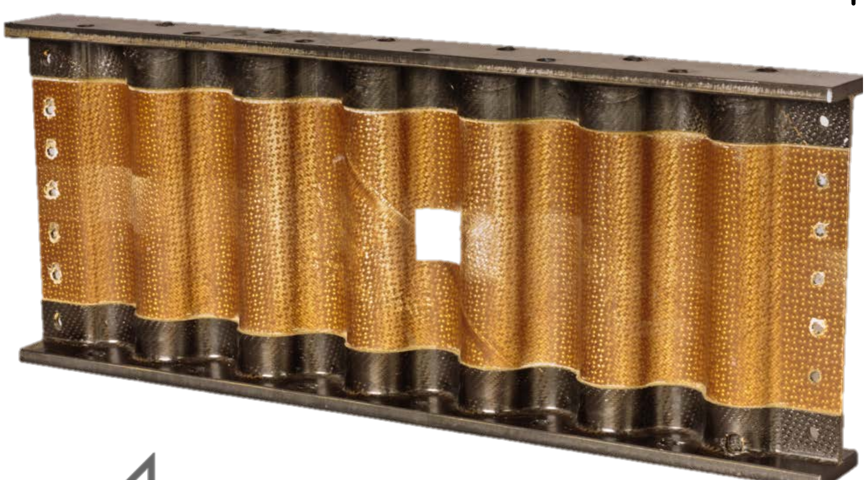


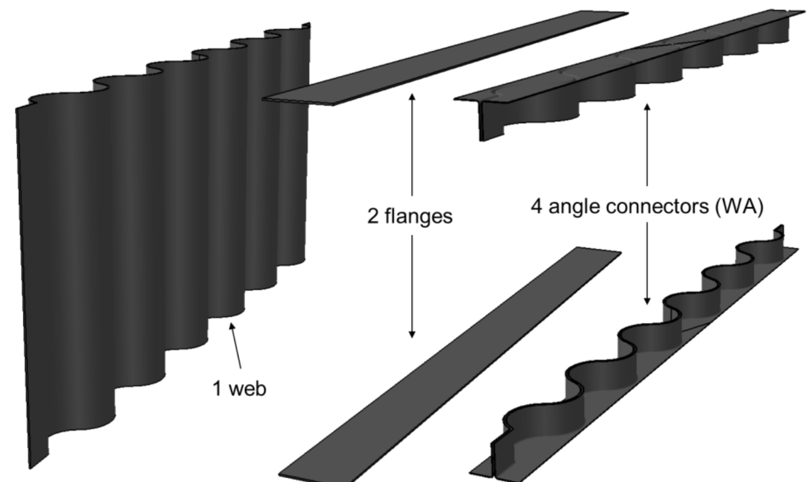
Source: DLR, Wattendorf [2]

Technology Demonstrator
Sinus wave beam









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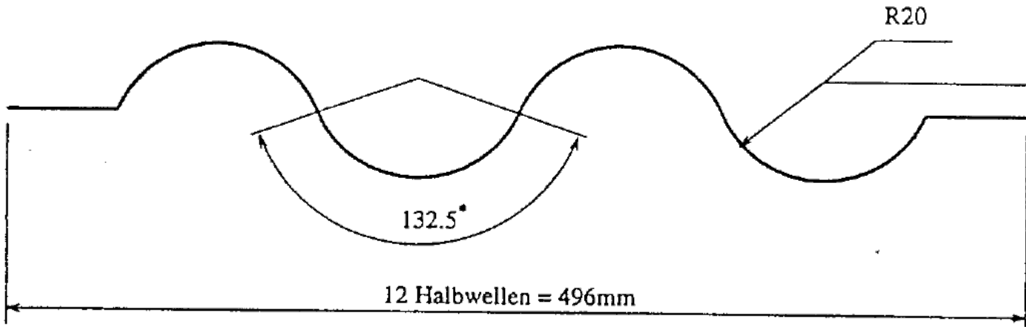
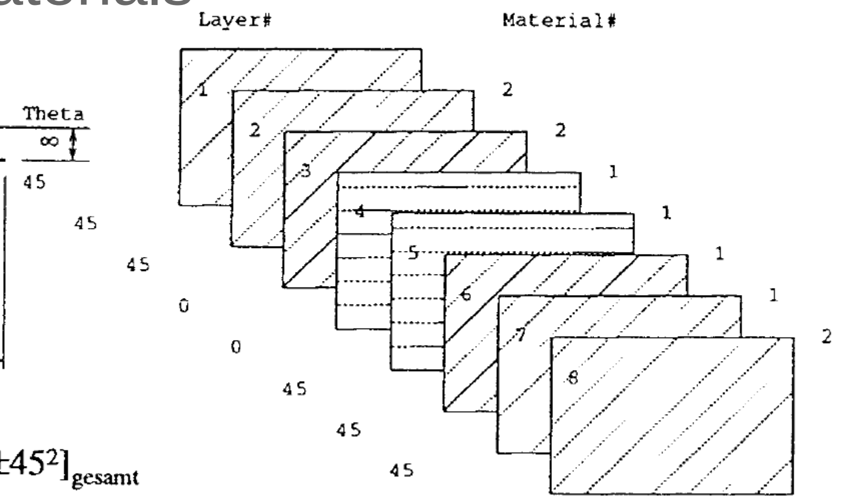
Technology Demonstrator
Geometry and considered materials



Source: MBB, DLR (Wattendorf) [2]

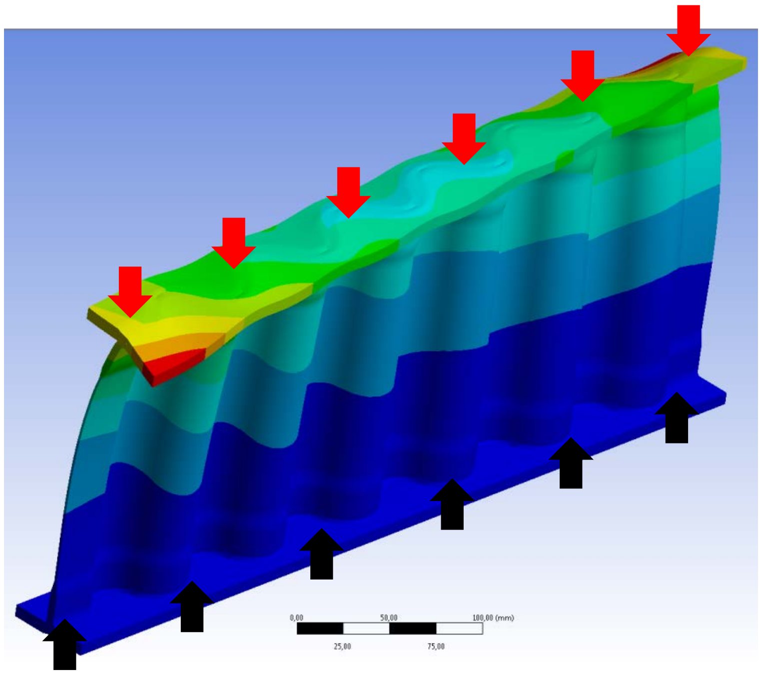


$$[\pm45^2 \quad \pm45^2 \quad \pm45^1 \quad 0/90^1 \quad 0/90^1 \quad \pm45^1 \quad \pm45^2 \quad \pm45^2]_{gesamt}$$

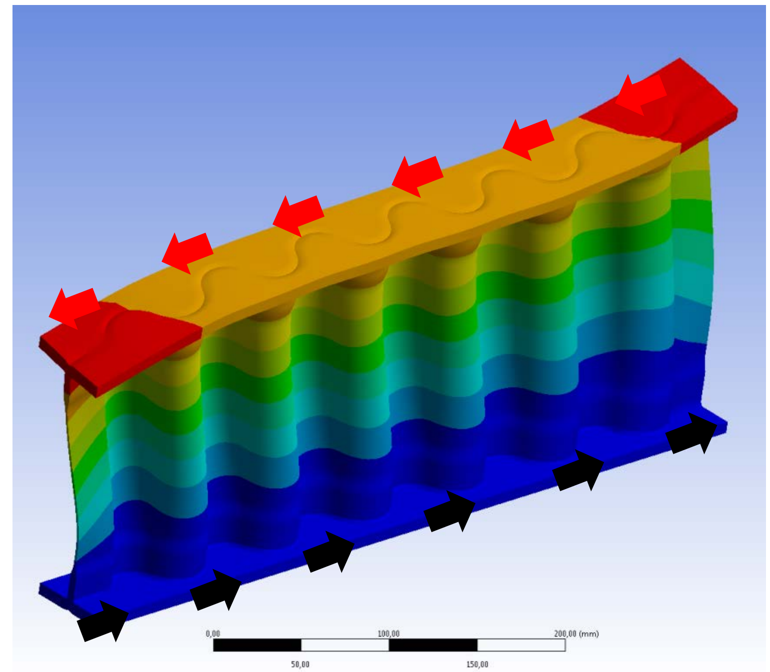
CF/PEEK woven fabric
(powder impregnated and foil stack)

CF/PEEK UD tape

Technology Demonstrator
Re-Design – FEA shell and solid model (ANSYS 14.5)

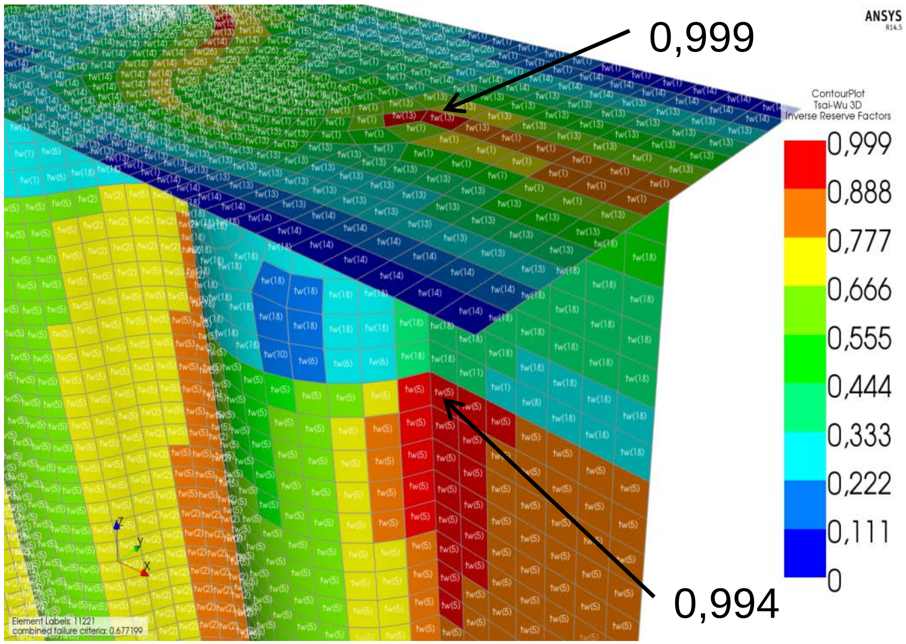


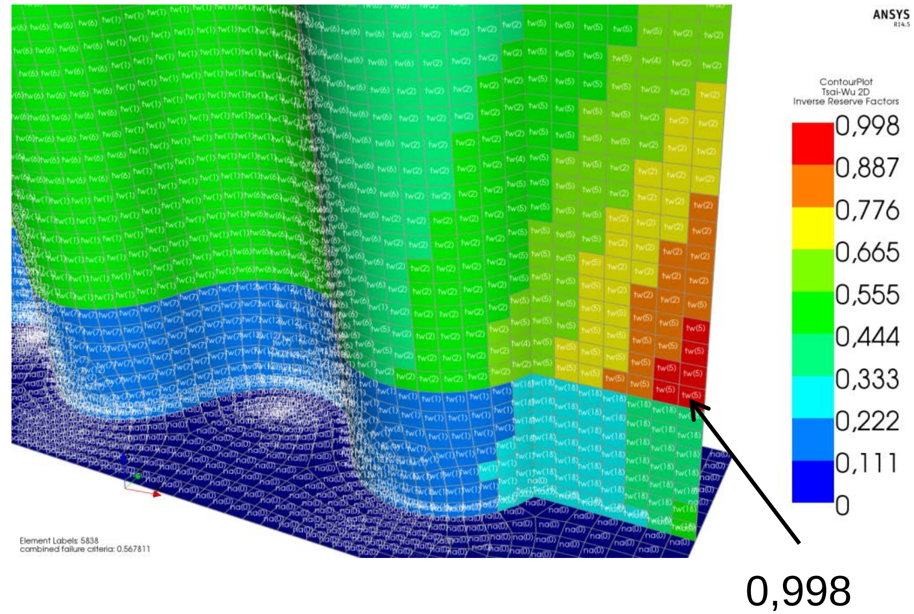
Load case 1:
Compression load



Load case 2:
Shear load

Technology Demonstrator
Re-Design – Failure (Tsai-Wu) at shell modell



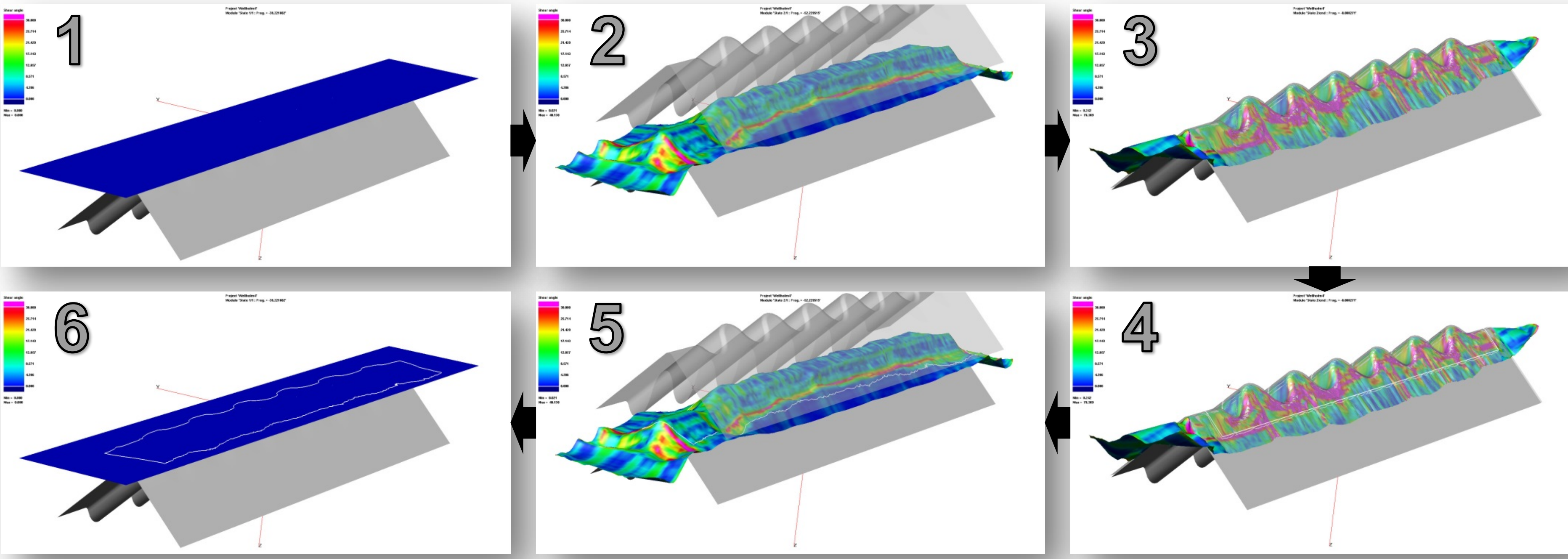


Load case 1:
Compression load
F_{max} = 223 kN

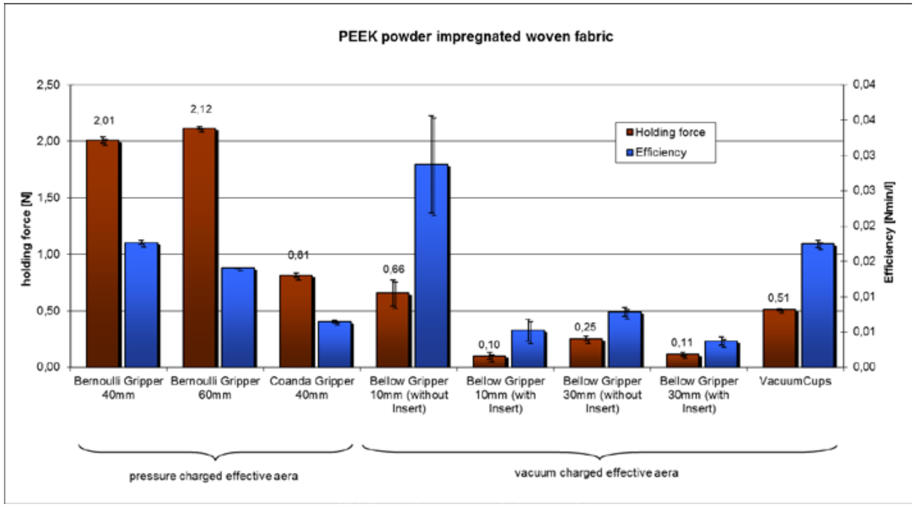
Load case 2:
Shear load
F_{max} = 77 kN

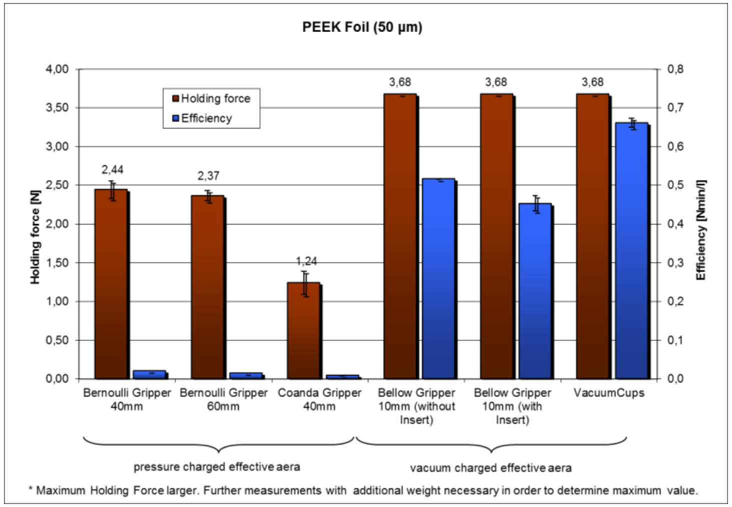
Technology Demonstrator

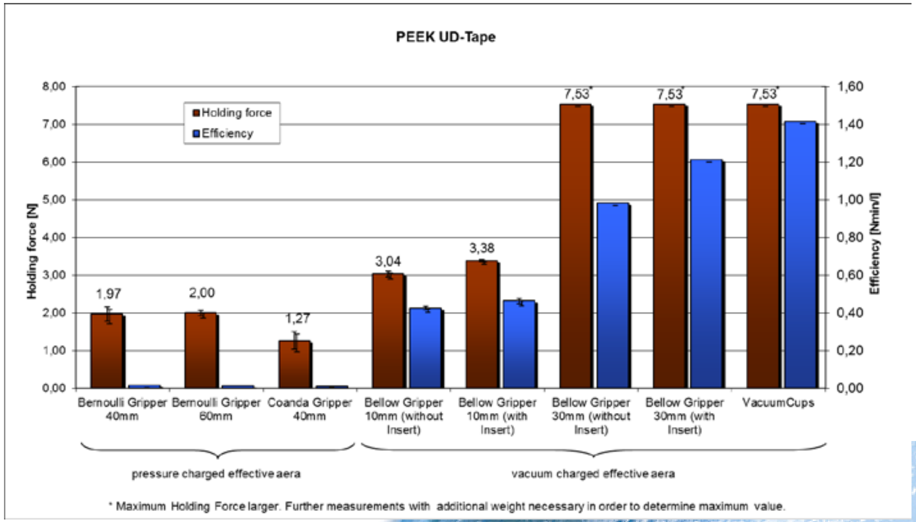
Near-net-shape cut-pieces via forming simulation (PAM-Form 2013)



End-effector construction
Gripper selection and distribution



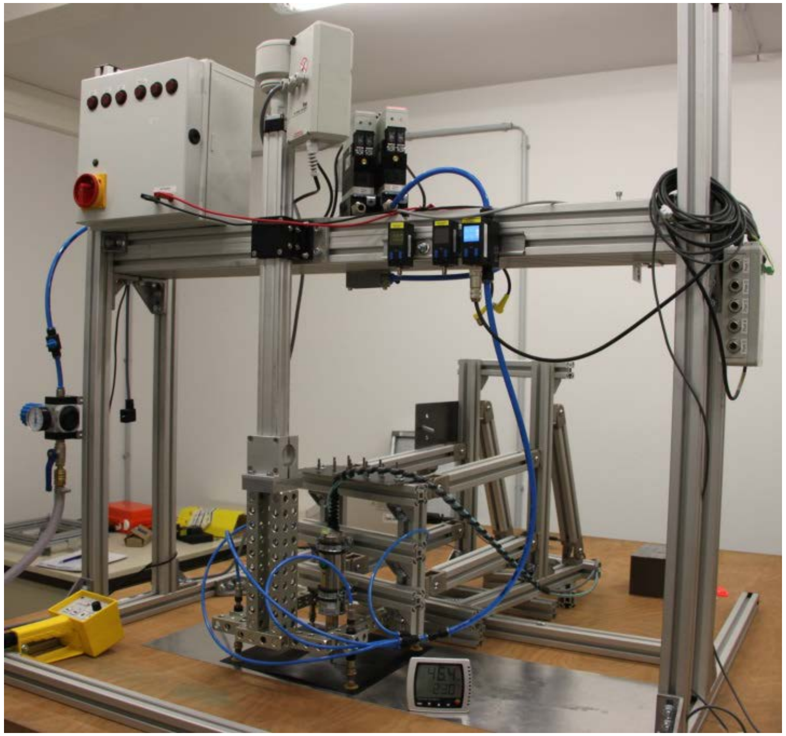


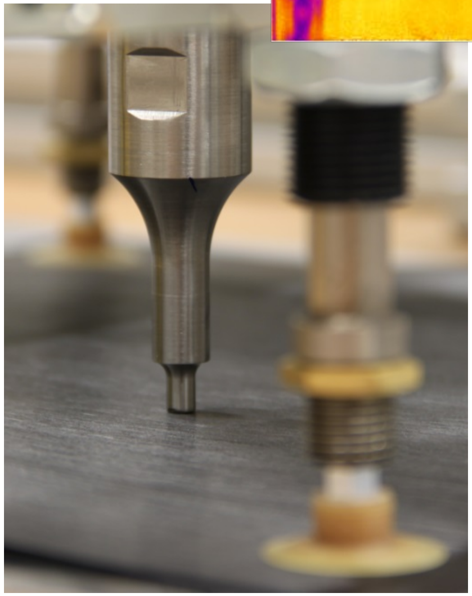


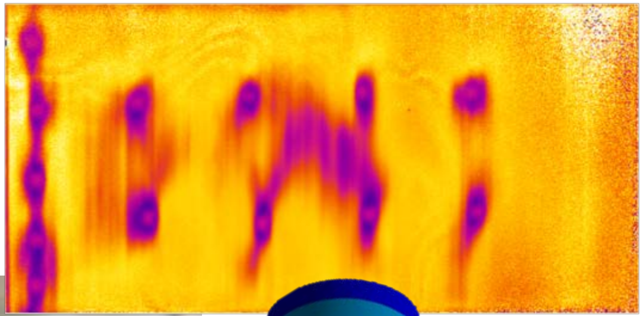

Vacuum Cup on spring follower

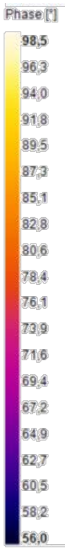

Bellow gripper

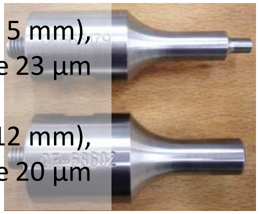
End-effector construction
Fixation of cut-pieces via Ultrasonic welding unit







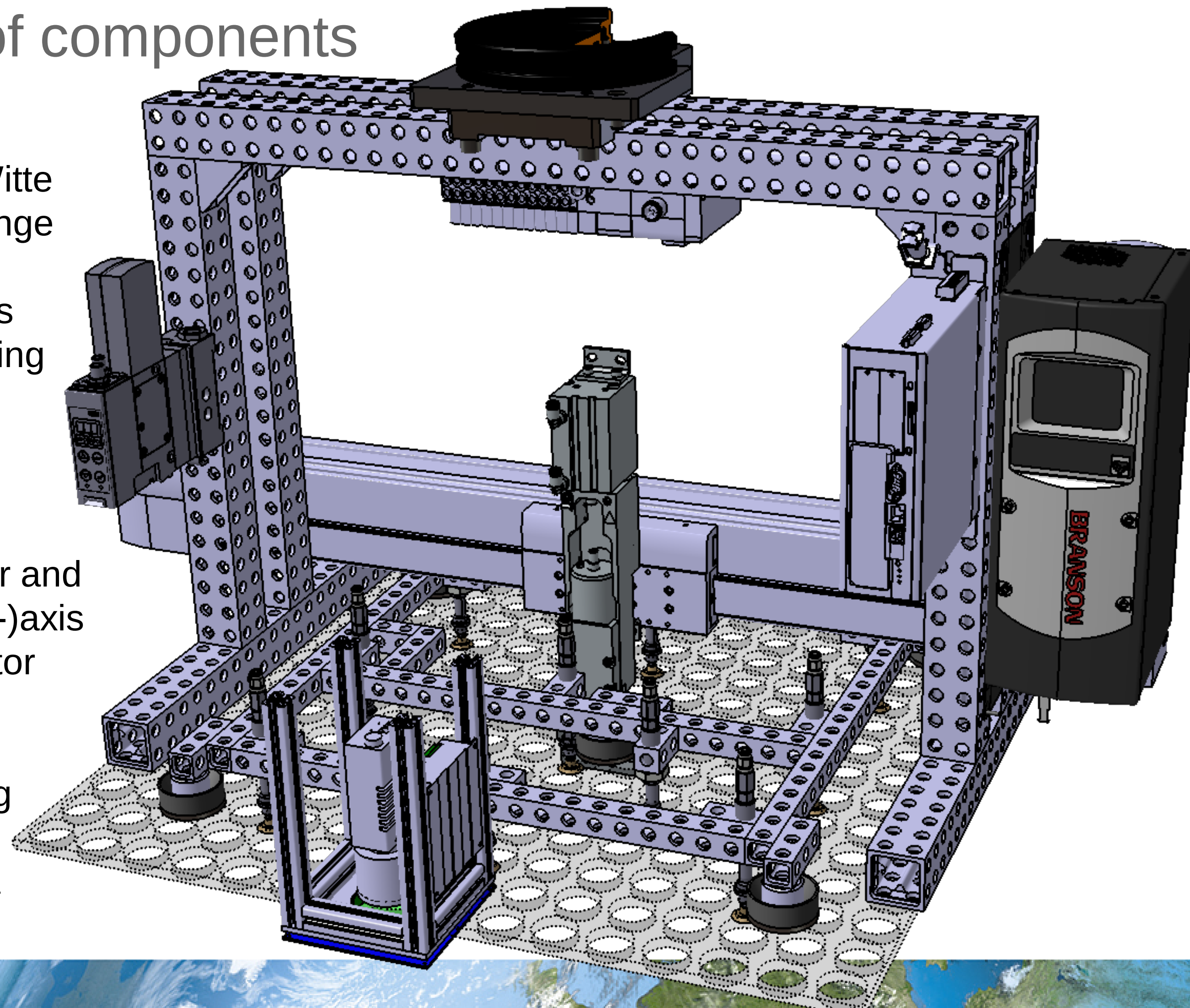




Horn 5 (Ø 5 mm), Amplitude 23 µm

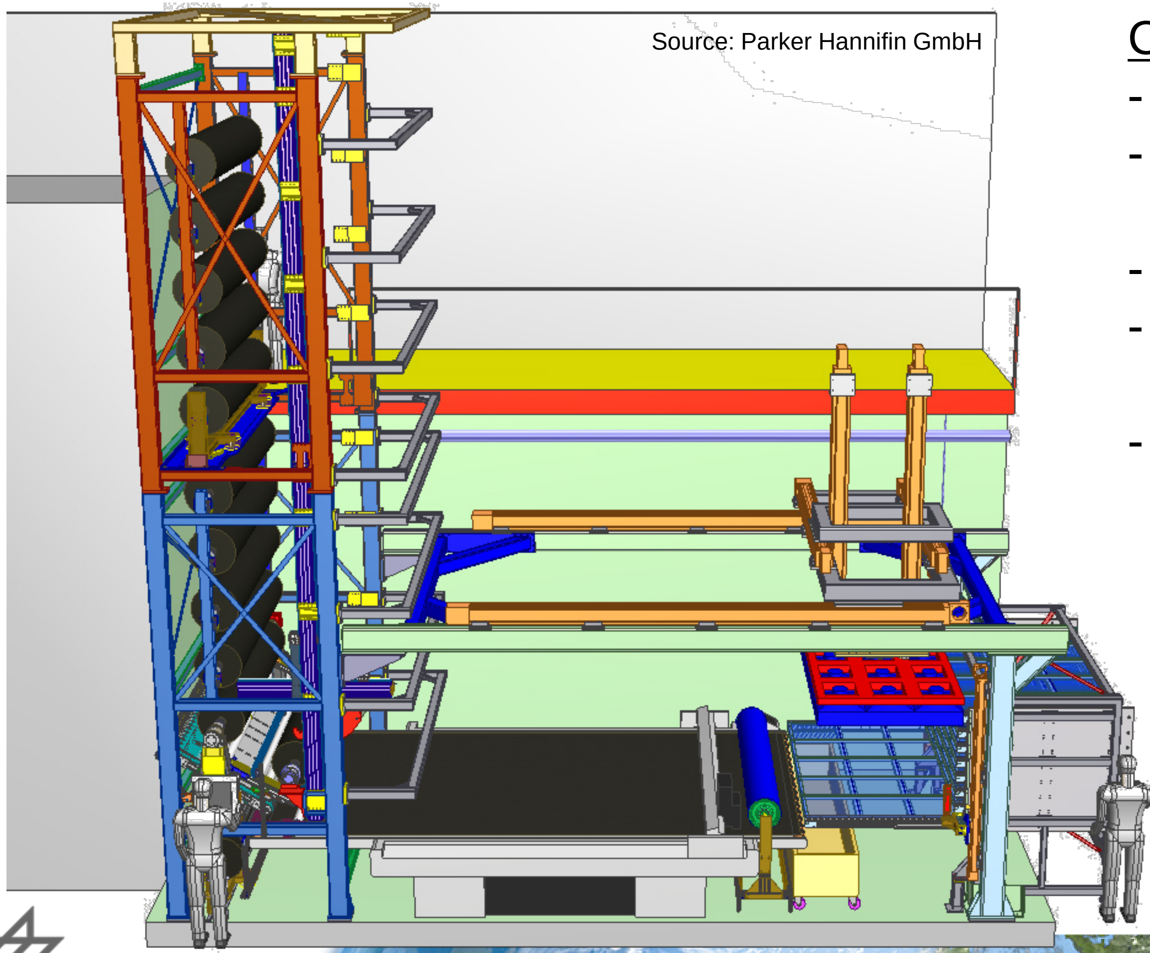
Horn 12 (Ø 12 mm), Amplitude 20 µm

End-effector construction
Integration of components



<u>Consisting of:</u>
- End-effector frame (Witte profiles) with robot flange
- Gripper frame (Witte) equipped with grippers (Vacuum Cups on spring follower)
- Vacuum Generator
- Valve cluster
- US Generator
- US Converter, Booster and Horn on pneumatic (z-)axis
- Linear axis, servo motor and controller unit
- Downholder system + dropping and grabbing device
- Cut detection Camera

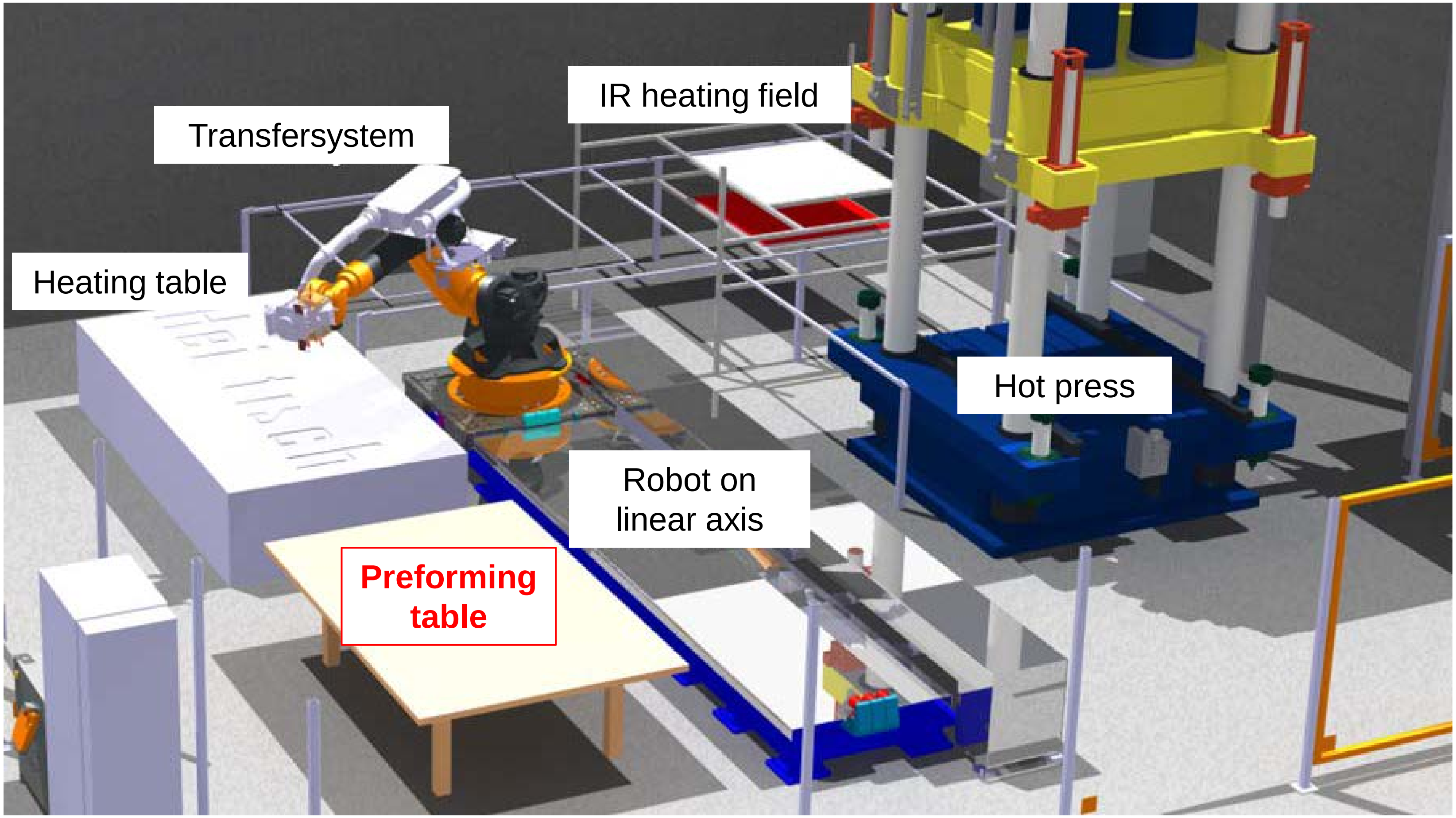
Integration in process chain
Before: Cutting center



Consisting of:

- Fabric roll storage
- Automated fabric supply
- Cutter
- Automated pick up system
- Palletizing system for
  - small (< 2,5x1,5m)
  - and large (< 16x2m) Cut-pieces

Integration in process chain
After: Consolidation processes (press/vacuum)



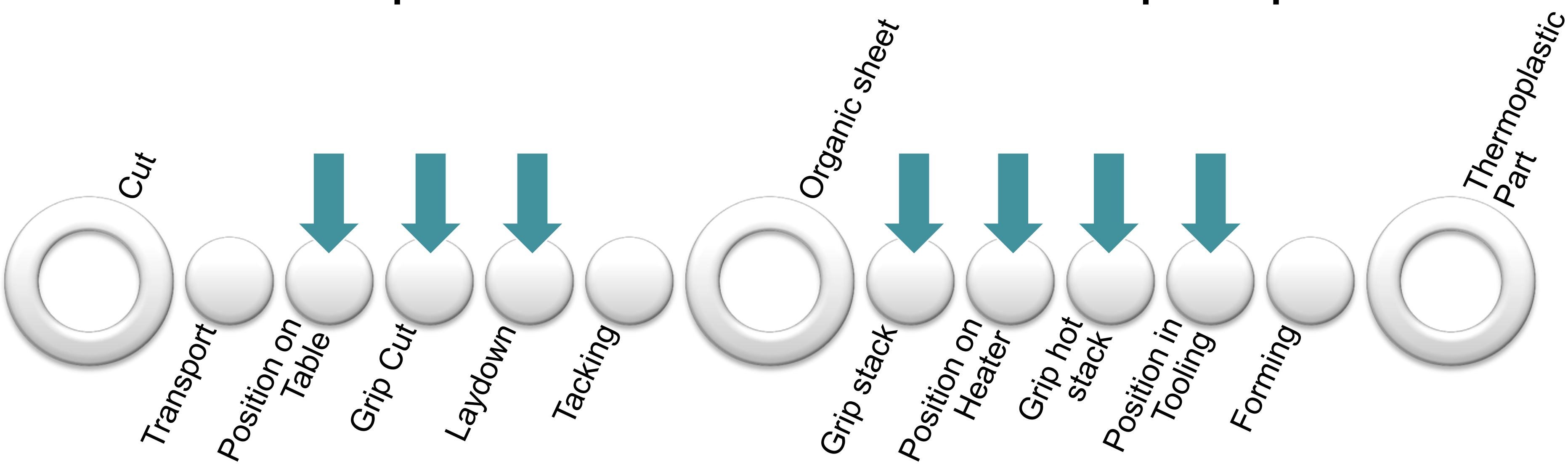
Source: DLR, Rucks

Cut detection system
Computer Vision aided Gripping of Unique Cuts

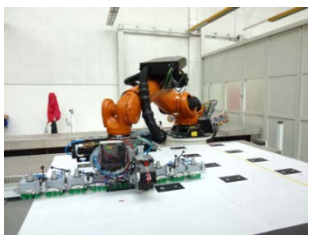
- In aerospace industry compared to automotive lower production rate but bigger part size, Complex layups with hundreds of similar, but not equal cuts

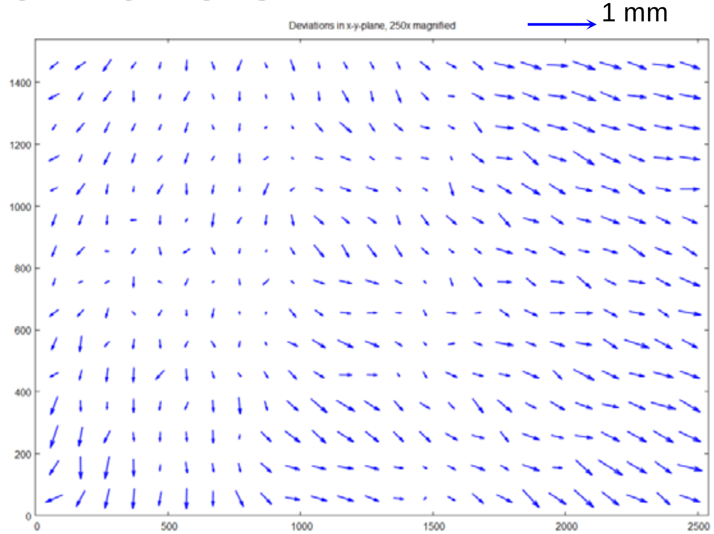
→ **“Teachless” system for complex layups of unique cuts**

→ **Reduce process errors → reduce errors of composite part**



Cut detection system
System errors

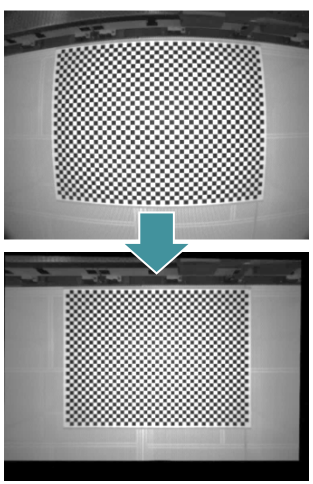


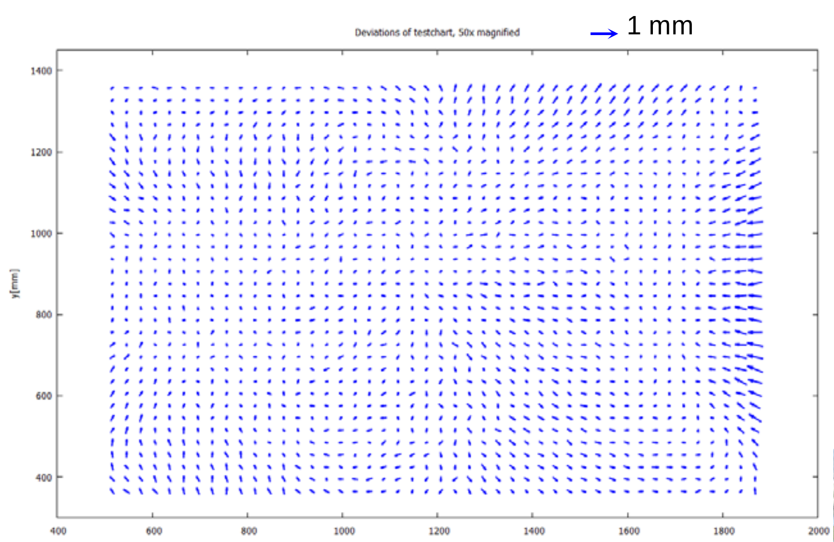


Absolut Positioning with Industrial Robots

Absolute deviation in x-y- plane:

- Min=0.006 mm, Max=0.400 mm, μ=0.165 mm, σ=0.076 mm
- very satisfactory since steady





Geometric Properties of Imaging System

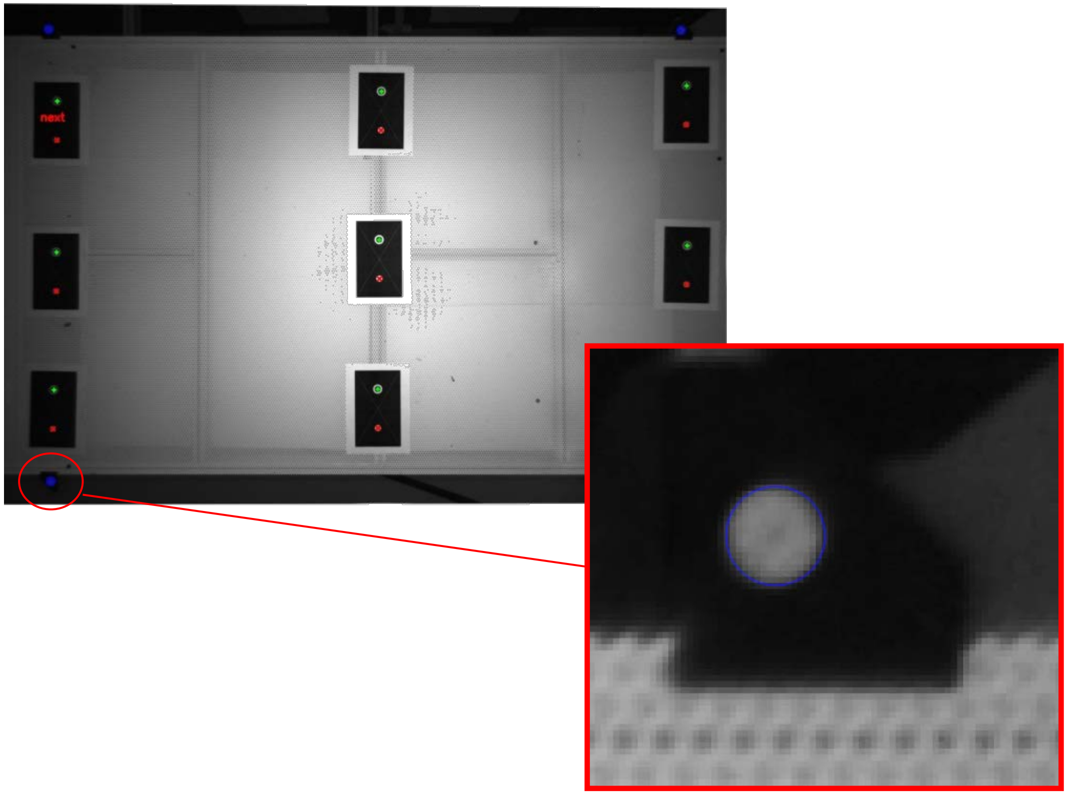
Absolute deviation in x-y- plane:

- Min=0.003 mm, Max=0.663 mm, μ=0.153 mm, σ=0.089 mm
- very satisfactory in sweet spot, fine detection necessary

Alternative Solution: Drift Correction by Markers

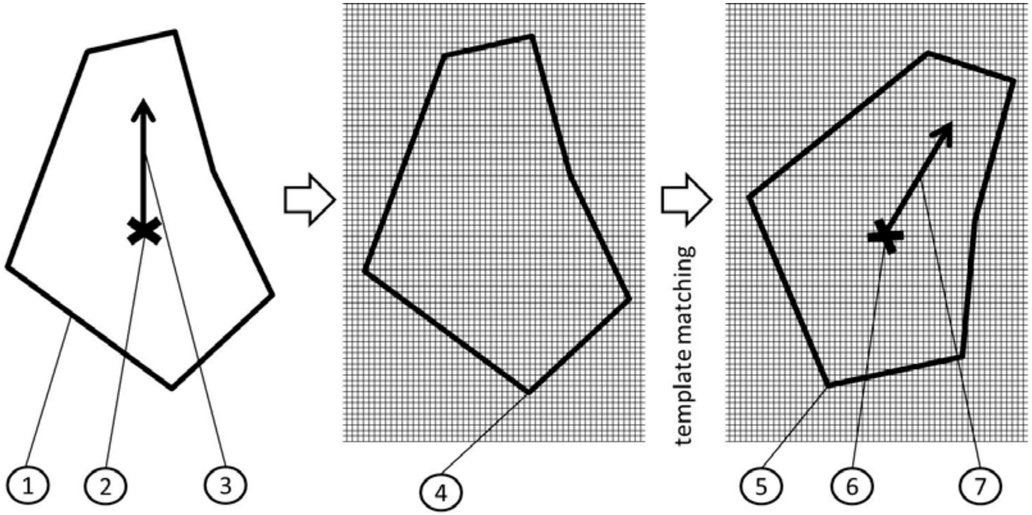
- Promising results, corrects both drift and angular displacements
- Obfuscates drift between robot and table, increases noise

→ **To be examined thoroughly**



Cut Detection by means of Computer Vision: Template Matching

- Use 2D Contour from CAD (e. g. Dassault’s CATIA-CPD Plybook)
- Generate digital representation matching the camera resolution
- Calculate normalized cross correlation for every possible orientation



1. Contour from CAD
2. Reference Point
3. Orientation

4. Digital representation matching the camera‘s resolution

5. Camera Image
6. Reference Point
7. Orientation

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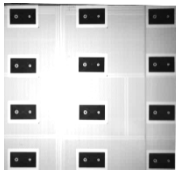
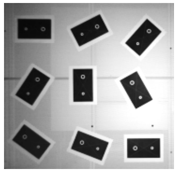
Gripping and Laydown of Test Patterns

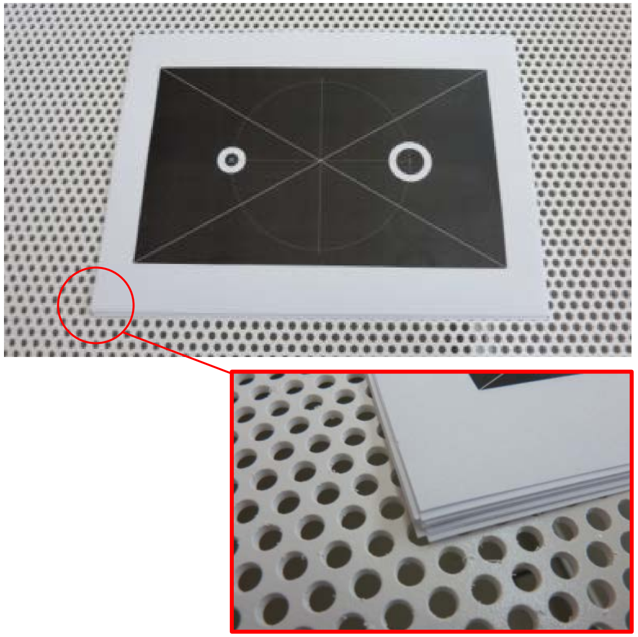
- Use test pattern to detect pickup and laydown position

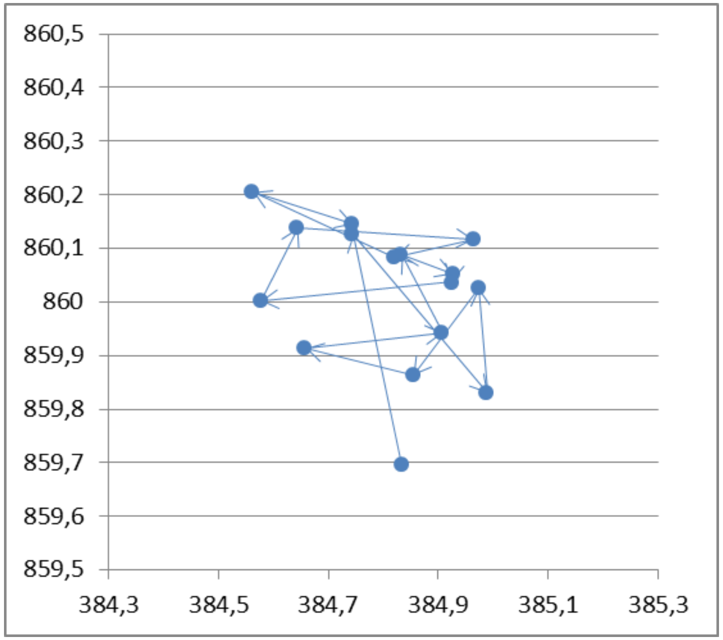
→ Overall laydown deviations achieved under optimum test conditions:

  - w/o rotation: ±0,60mm, σ_x=0,17mm, σ_y=0,16mm
  - w/ rotation ±0,71mm, σ_x=0,26mm, σ_y=0,18mm

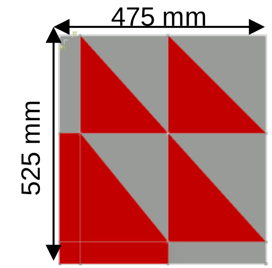






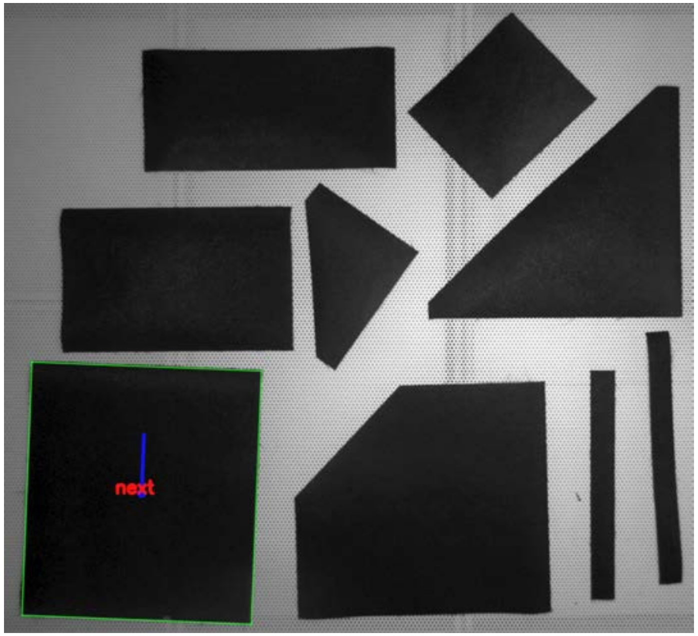


Cut Detection by means of Computer Vision: Template Matching in Practice



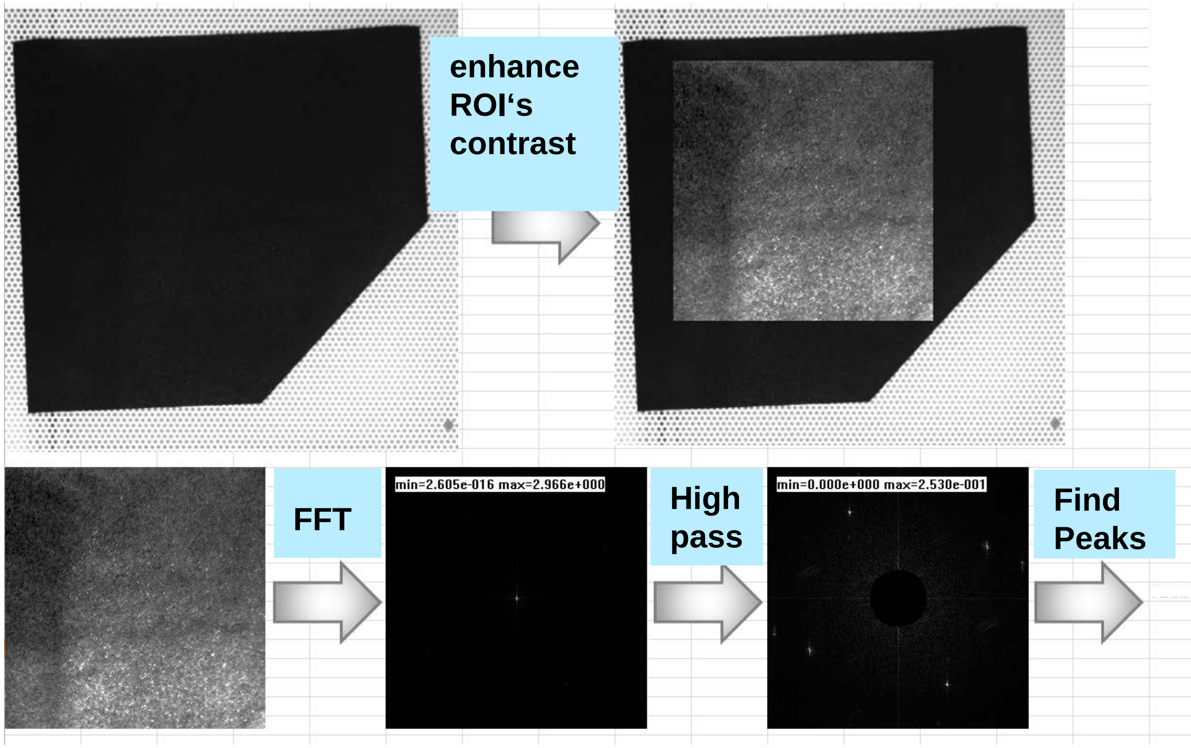
- Geometry extracted from “Dummy” Plybook
- Consider all possible rotations
- Comparison with Camera Images

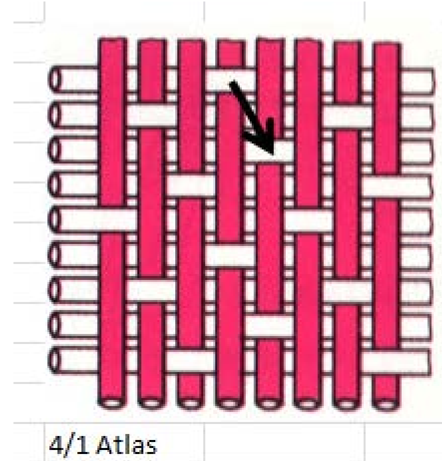
MATCH



Beyond Angle and Position: Fiber Orientation for improved Detection

- Rough estimation of overall fiber orientation by 2D-Fast Fourier Transform





→ **fiber orientation**

$\tan\varphi = \frac{2}{1} \quad \varphi \approx 27°$

$\varphi_{meas} = 30° \quad \varphi_{cut} = 3°$

Conclusion and Outlook

- Robotic fabric lay down as a possible solution for an automated and highly felxible prefoming process
- Sinus wave beam as a good component to demonstrate critical technologies on an aerospace relevant industrial level
- Forming simulation as a good method to obtain near-net-shaped cut-pieces and preforms
- Cut detection as an important technology for autonomous Gripping of various cuts

Neuschwanstein

<u>Still a lot to do:</u>

- Final end-effector construction and testing
- Advancing accuracy of Cut detection system
- Advancing speed and laydown rate of preforming process

→ The DLR-ZLP Augsburg as a perfect scientific partner for research of partly or completely automated industrial process chain solutions for the production and quality assurance of CFRTP components

View from Breitenberg towards Füssen/Tegelberg, © Kühnel

The Built-up of the DLR-ZLP Augsburg is funded by the City of Augsburg, the Free State of Bavaria as well as the German Federal Ministry for Economic Affairs and Energy.

A special thank goes to our team of the DLR-ZLP Augsburg

Federal Ministry of Economics and Technology

Stadt Augsburg

Thank you for your attention.
Are there any questions?

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