CFRP Upper Wing Cover for Natural Laminar Flow

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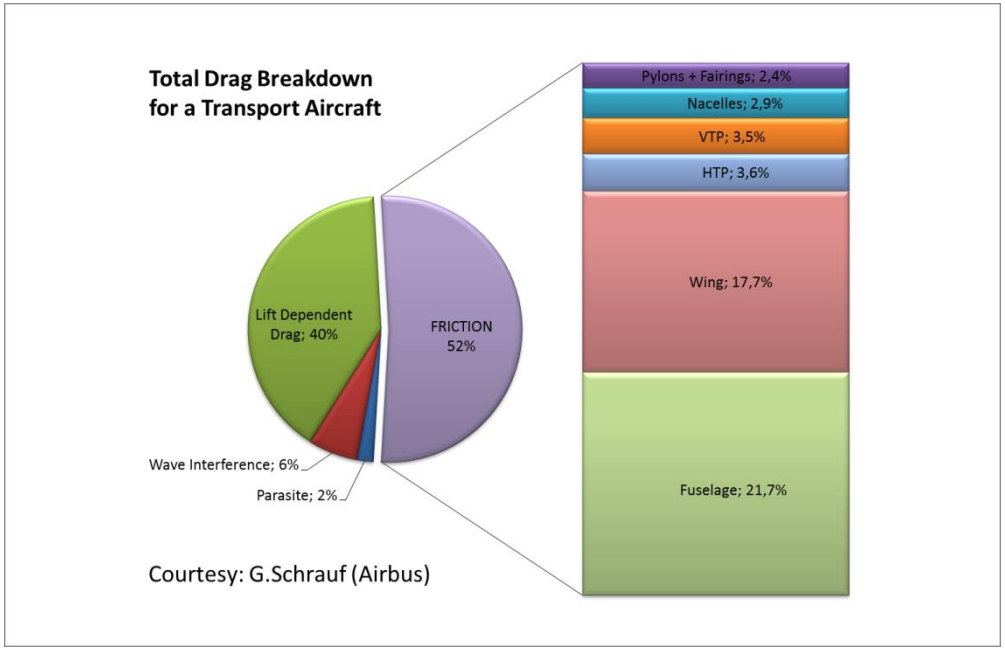
Content

- Motivation: Why natural laminar flow?
- Structural Concept for NLF Upper Wing Cover
- Manufacturing Concept
- Process induced Deformations (PID)
- Load induced Deformations (LID), Sizing Process
- Manufacturing Process of integral Wing Upper Cover
- Optical Measurement
- Resulting Waviness from PID and LID
- Summary

Why laminar flow?

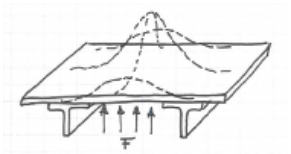
- Laminar Flow can reduce friction drag significantly!

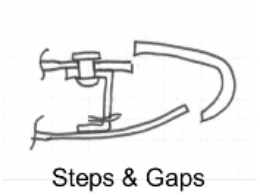
→ 5% to 8% Reduction of friction drag is possible for typical wing applications



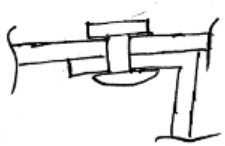
Requirements for Laminar Wing

Aerodynamic Requirements


Waviness

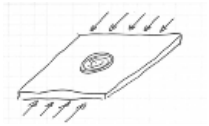

Steps & Gaps

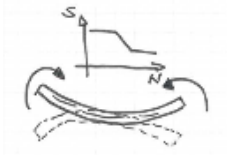

Roughness


3D disturbances
(i.e. rivets)

Structural Requirements


Stringer Debonding


Damage Tolerance


Fatigue


Maintainability


Anti-Icing


Lightning Strike

Aerodynamic requirements have to be achieved under typical production standards (high rate, low cost) to be beneficial on aircraft level!

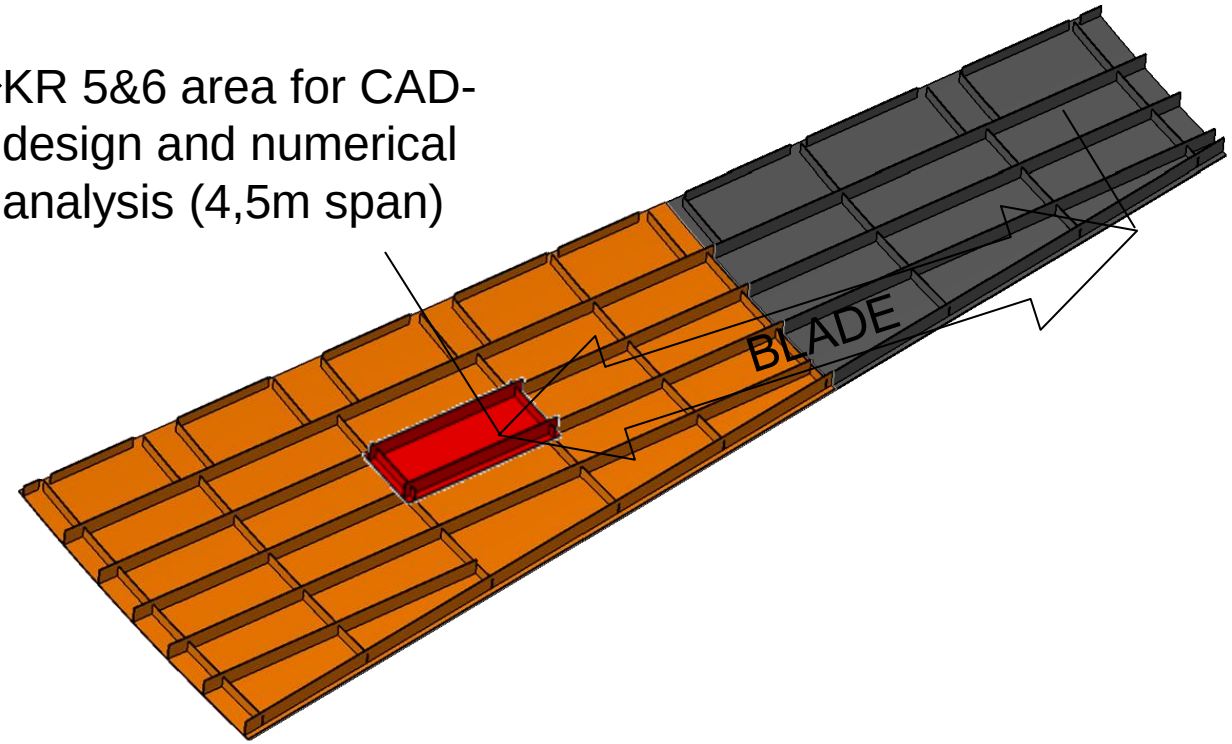
Wing geometry & manufactured parts

NLF wing research configuration NLF13

LaWiPro Panel (1,0m x 0,6m)

LaWOp Panel (2,5m x 1,5m)

KR 5&6 area for CAD-design and numerical analysis (4,5m span)



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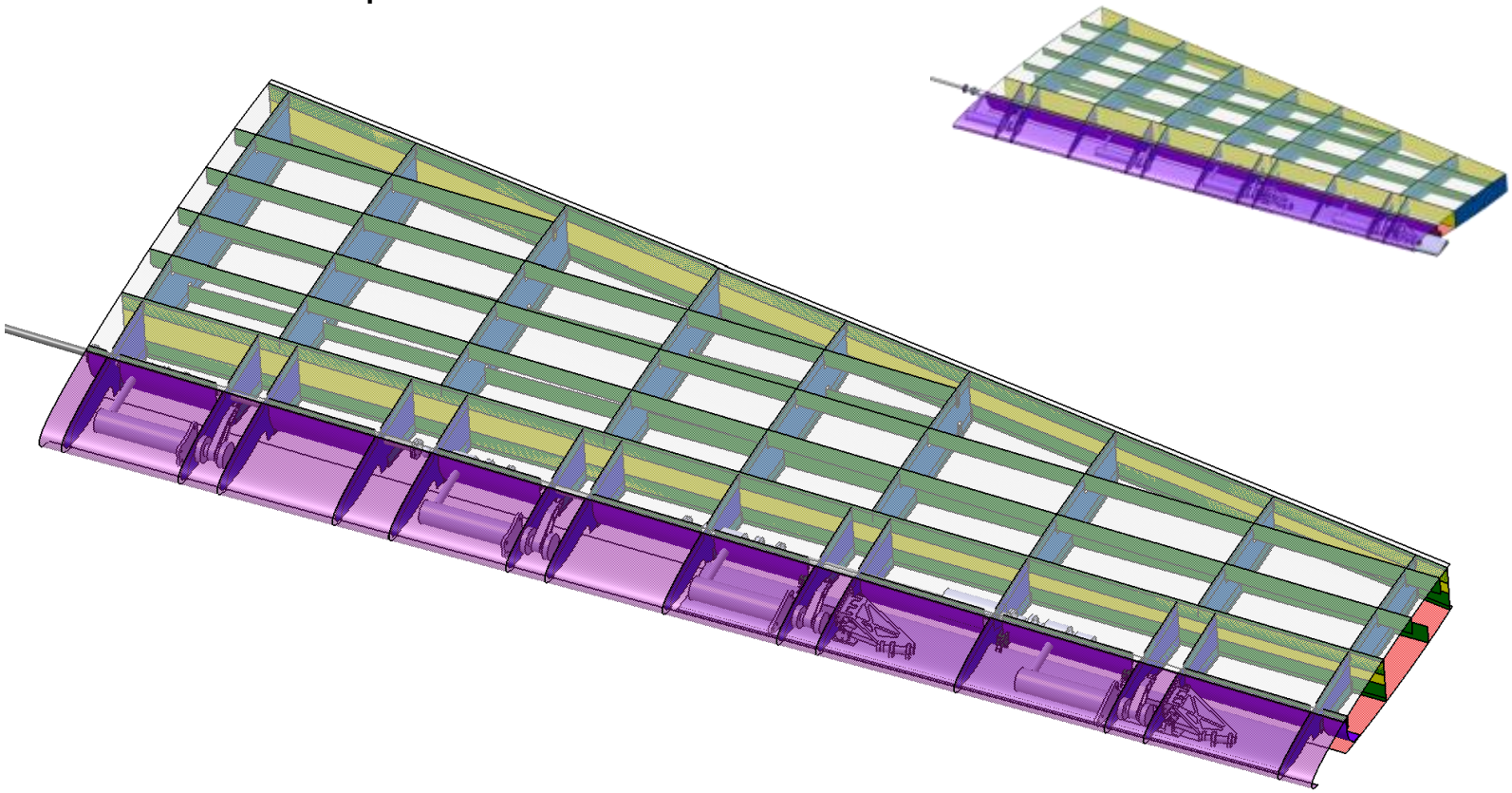
Basic Concept – DLR V6

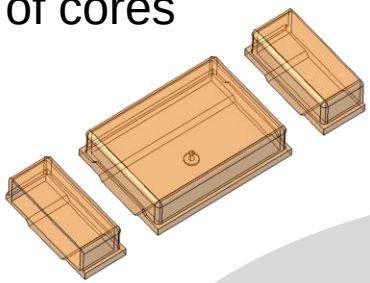
Final Basic Design: new rib positions in Leading Edge implemented

ribs perpendicular to Front Spar

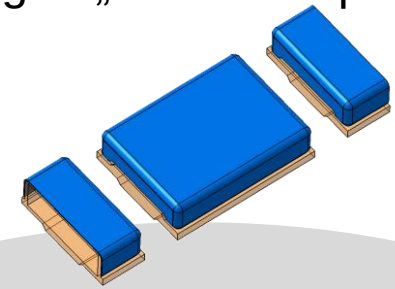


Production Concept

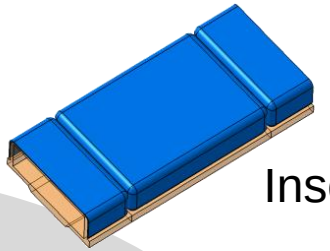
Preparation of cores



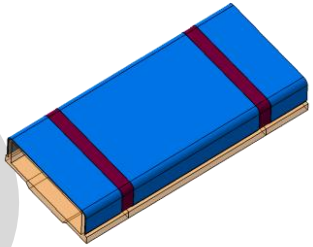
Draping of „shoe-box“ plies



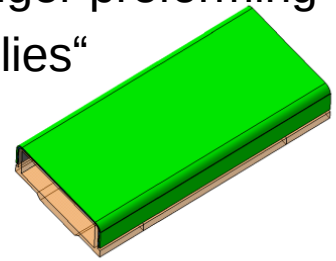
Unite cores in stringer direction



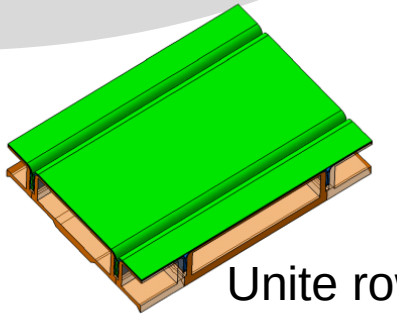
Insert gusset filler



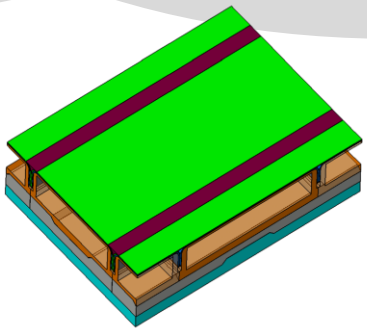
Stringer preforming „U-plies“



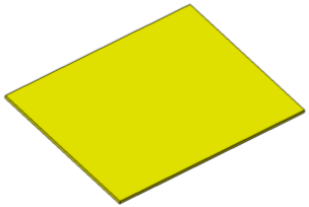
Unite rows of cores in rib direction



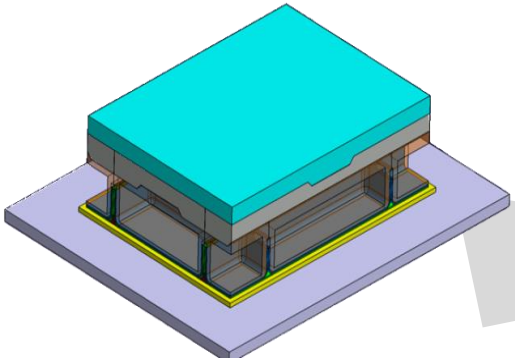
Insert gusset filler



Skin plies deposition



Unite skin & core



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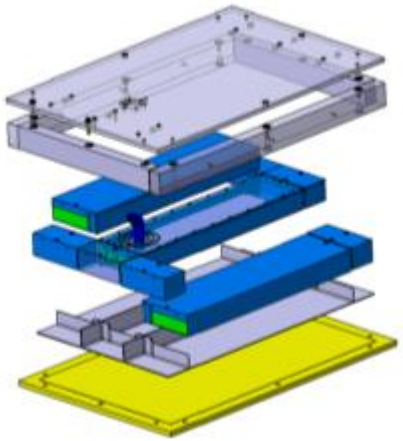
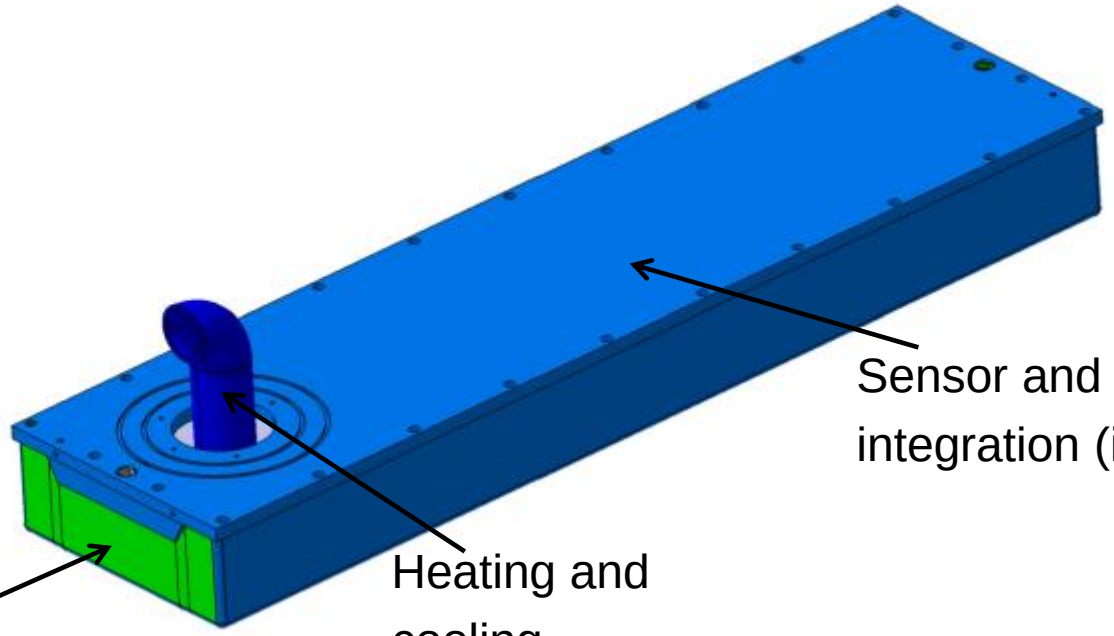
Cellular Tooling Concept



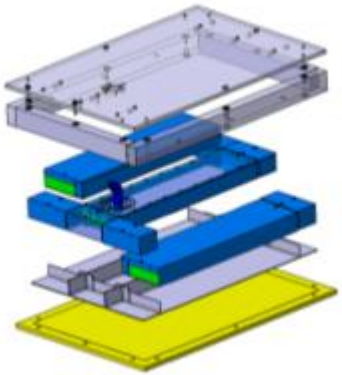
- Moulding of the stiffeners is done by many similar elements/ cells

- Adress all issues and challenges on a local/ cellular level

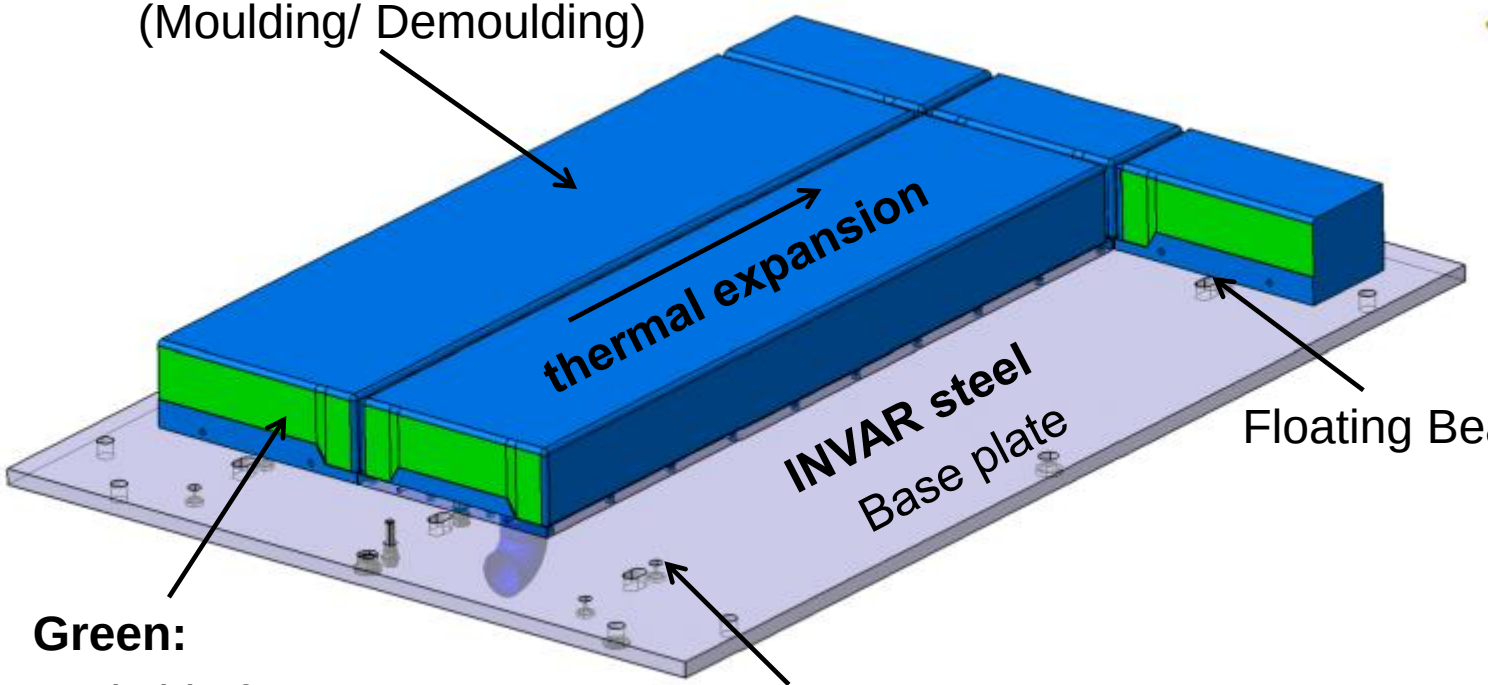
Cell features



Cellular Tooling



ALUMINIUM alloy
(Moulding/ Demoulding)



Floating Bearing

Green:
Tool side for
mating surfaces

Fixed Bearing

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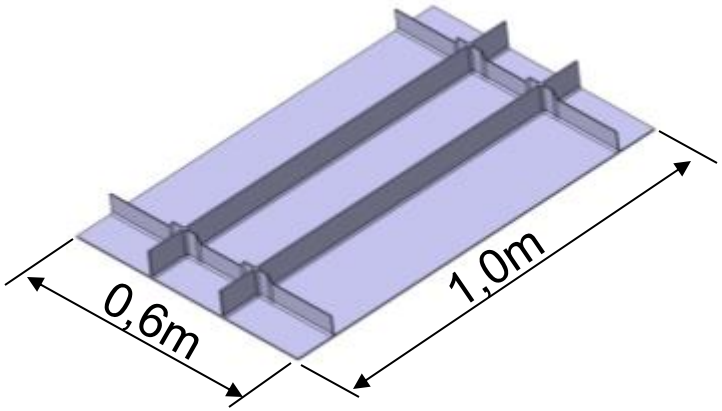
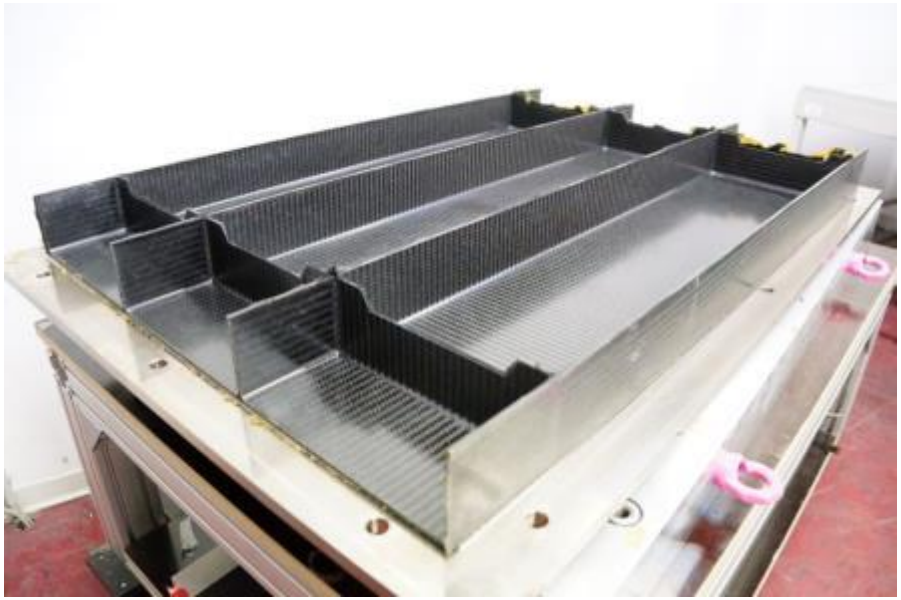
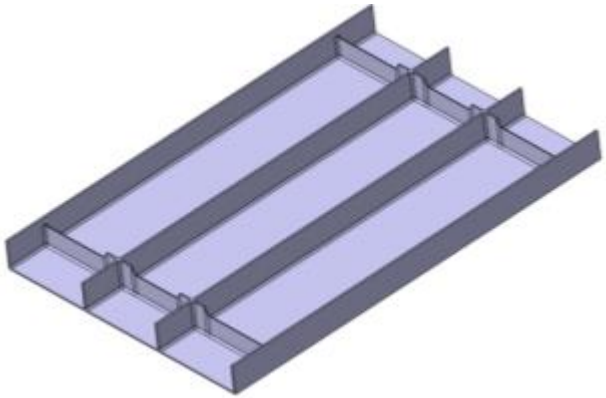
Proof of Manufacturing Concept







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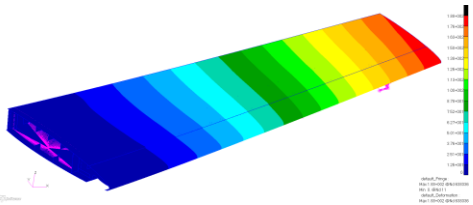
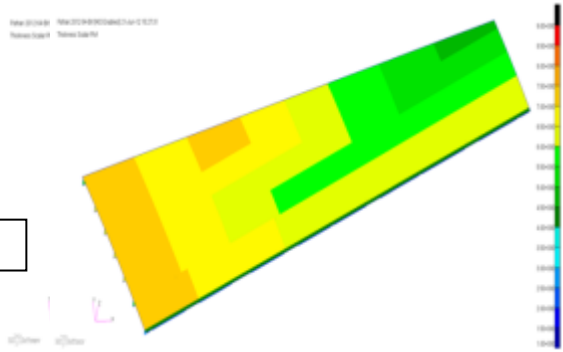
Sizing of Wing Upper Cover



FEM-Calculation of initial structure with all loadcases

Identification of critical loadcase and sizing criteria

Structural sizing for critical loadcase and criteria

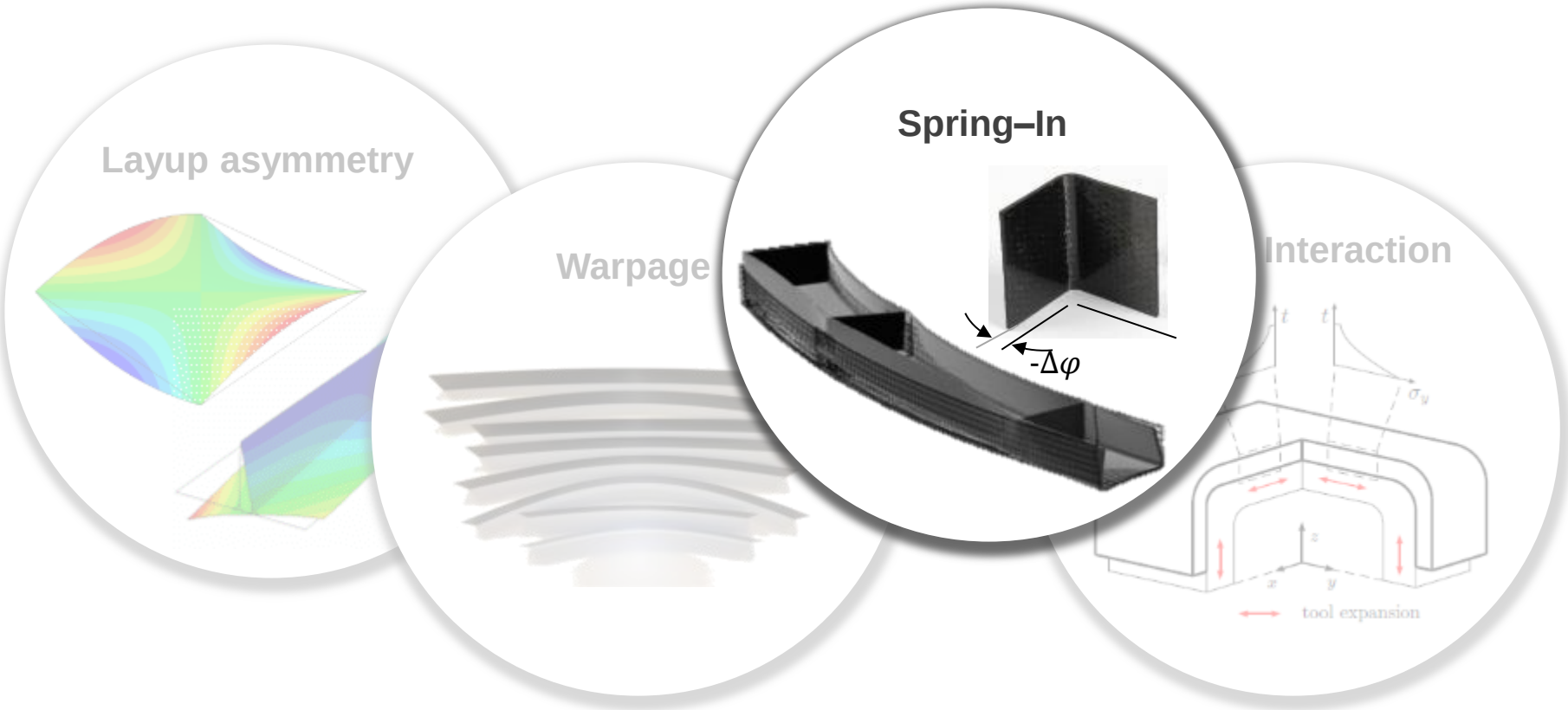


Checking dimensioning criterias up to convergence: Strength / Buckling / Damage Tolerance / Rivet Failure / Waviness

Layup sequence for wing upper cover and internal substructure

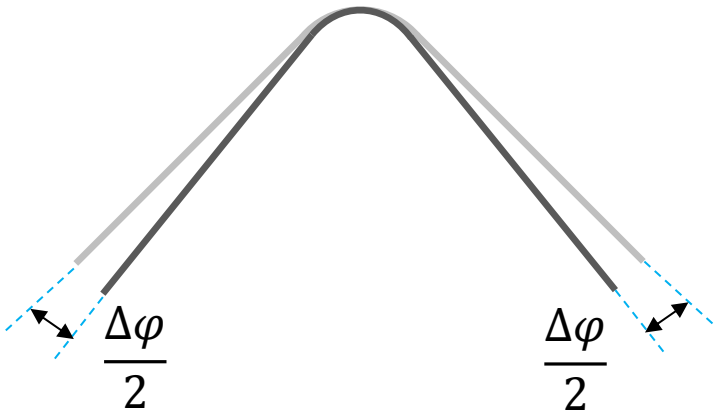
Process induced Deformations (PID)

- **Process distortions are driven by residual stresses**
- **Different inducing phenomena**

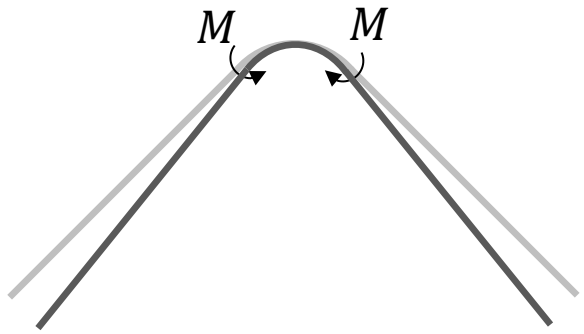


Semi-numerical model approach

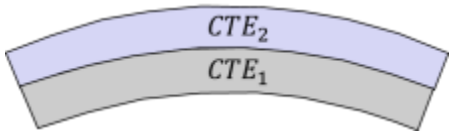
Specimen deformation



Corresponding model



$$\Delta\varphi \xrightarrow{CLT} \mathrm{M} \xrightarrow{CLT} \Delta CTE$$



$$\Delta CTE = CTE_1 - CTE_2$$

$$\begin{Bmatrix} \underline{\varepsilon^0} \\ \underline{\varkappa} \end{Bmatrix} = \begin{Bmatrix} \underline{\underline{A}} & \underline{\underline{B}} \\ \underline{\underline{B}} & \underline{\underline{D}} \end{Bmatrix}^{-1} \cdot \begin{Bmatrix} \underline{N} \\ \underline{M} \end{Bmatrix} \begin{Bmatrix} M_x^* \\ M_y^* \\ M_{xy}^* \end{Bmatrix} = \underline{\underline{\bar{Q}}}_1 \cdot \Delta T \cdot \begin{Bmatrix} \alpha_x^* \\ \alpha_y^* \\ \alpha_{xy}^* \end{Bmatrix}_1 \cdot \frac{1}{2}\left({h_1}^2 - {h_0}^2\right)$$

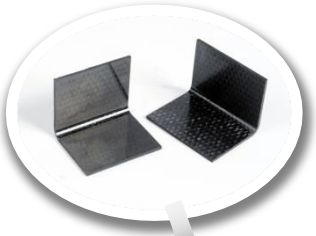
Simulation of Process induced deformations

Compensated part

Nominal part

Compensated tool

FE model



$$\alpha^{*}_{angle} = \frac{1}{6R_0\Delta T} \cdot \frac{h^3}{\left(z_1^2 - z_0^2\right)} \cdot \frac{\varphi_{mes}}{\varphi_{area}}$$

“Inversion” of deformation

Deformed geometry

Manufacturing of Wing Upper Cover

„CFK-Nord“ – Research Facility
Stade, Germany

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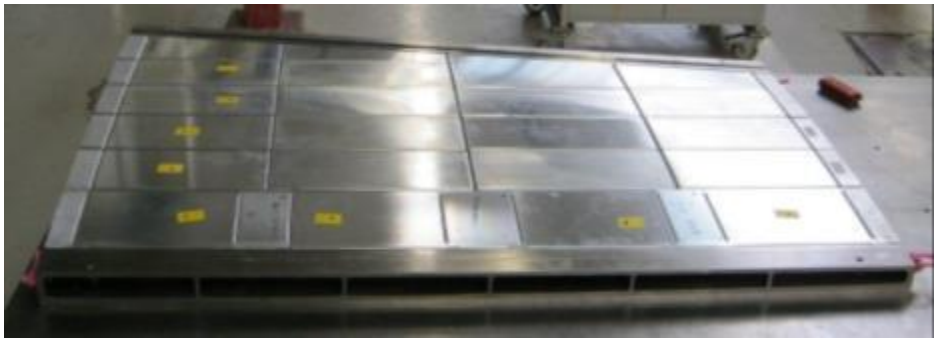
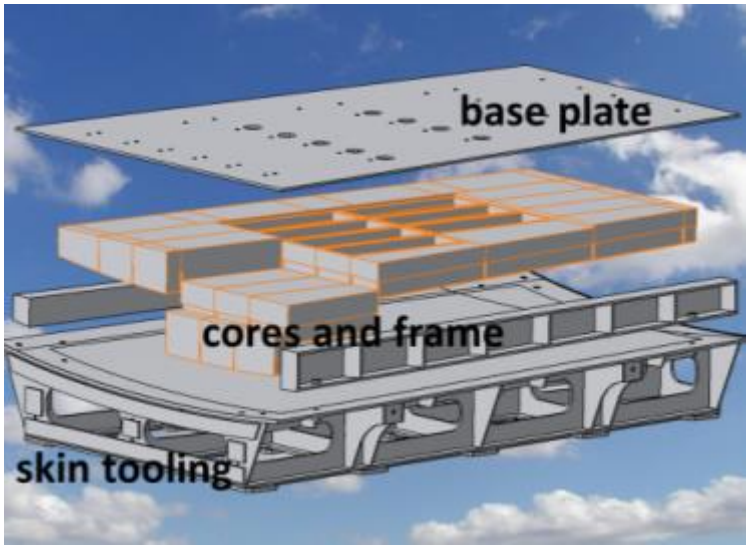
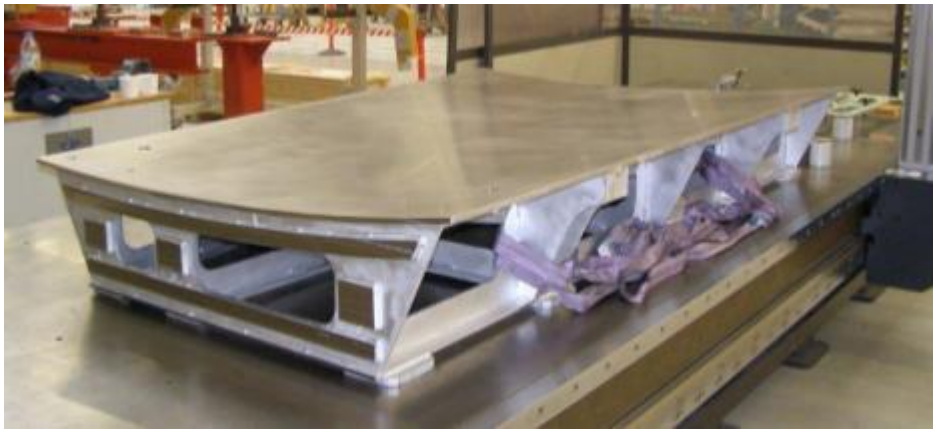
Cellular Tooling- Validator
(36 cores including 10 hollow cores)







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Skin Plies Layup

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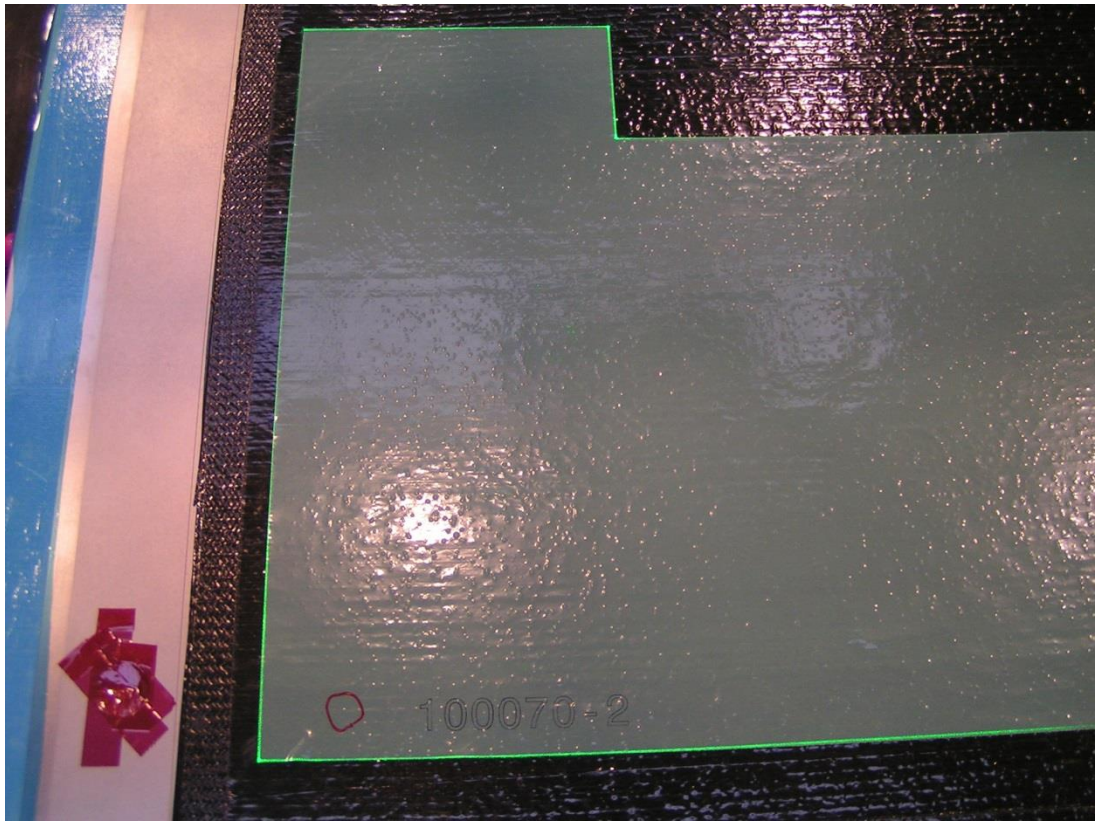
Skin Plies Layup



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Skin Plies Consolidation

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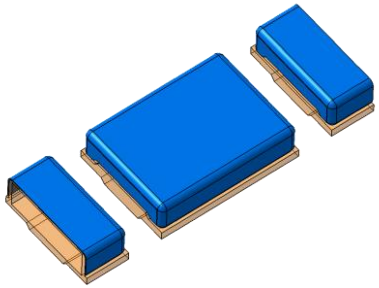
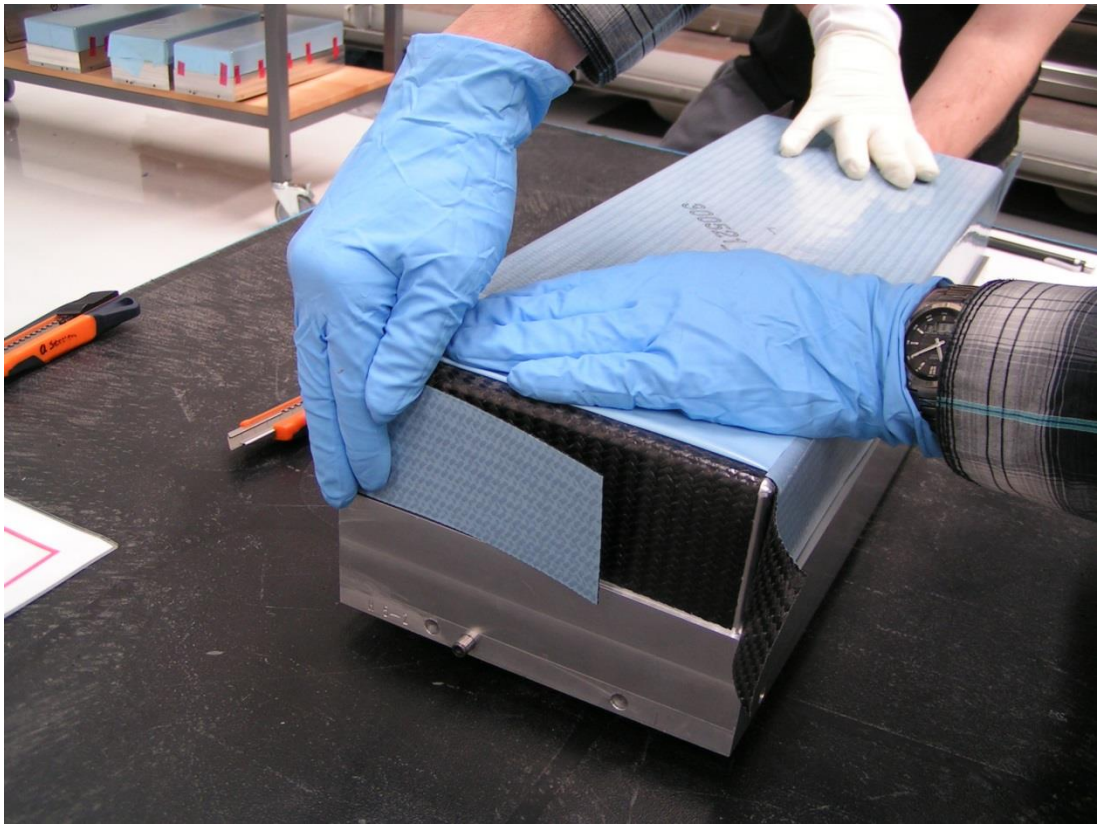
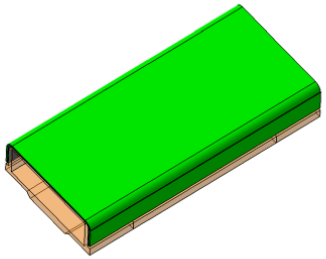
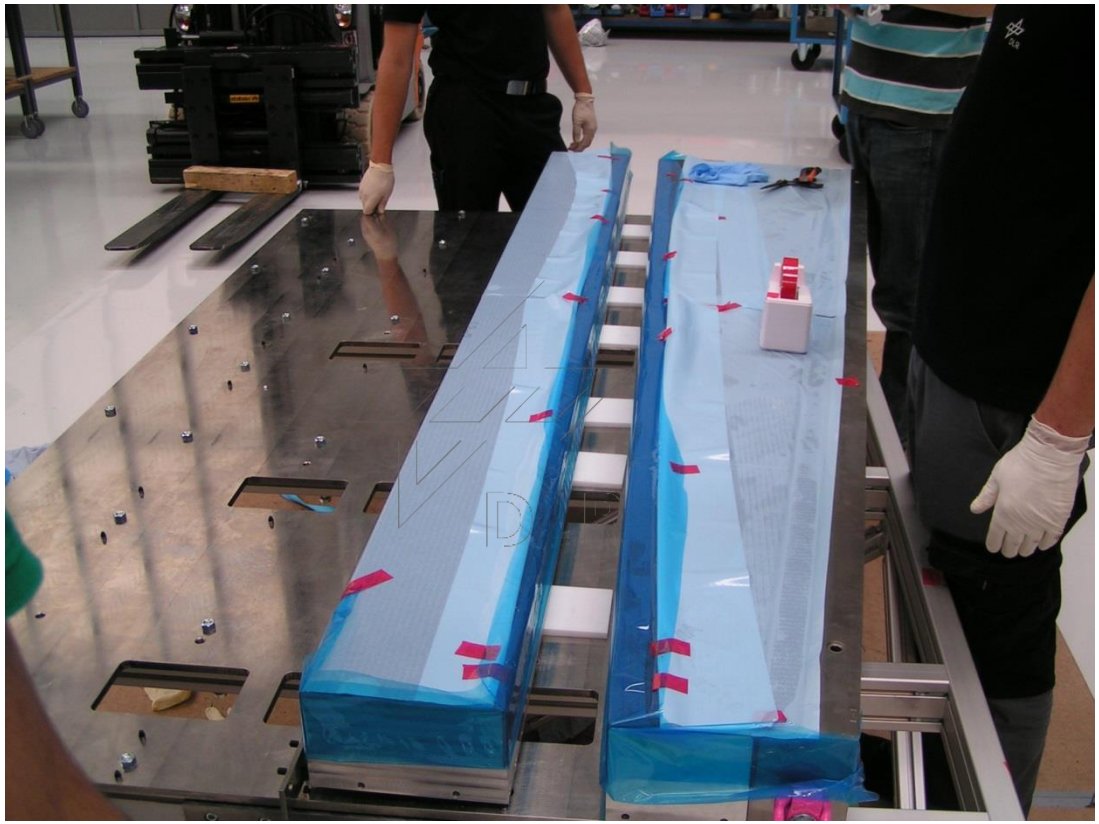
Draping Core Plies





Positioning of Stringer-Rows





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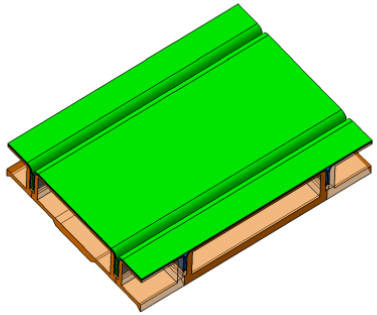
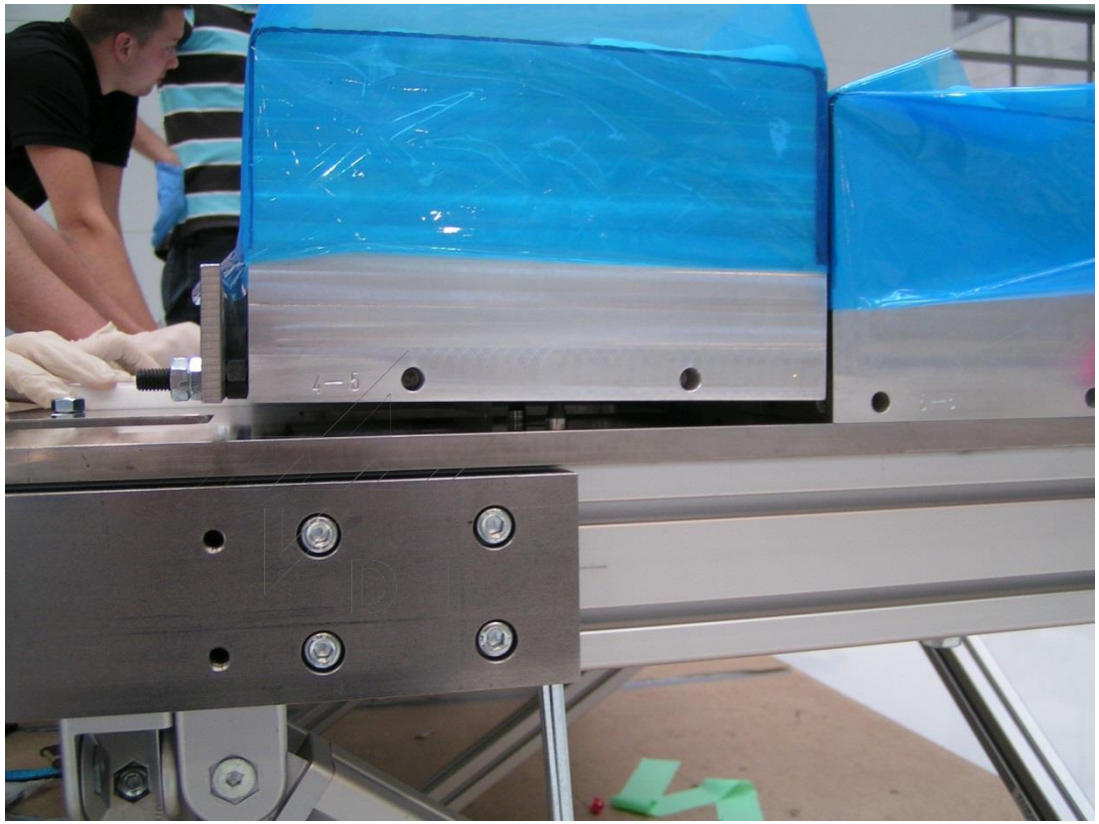
Positioning of Stringer-Rows





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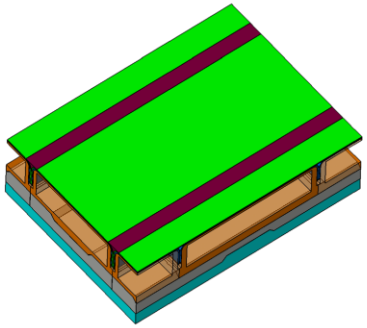
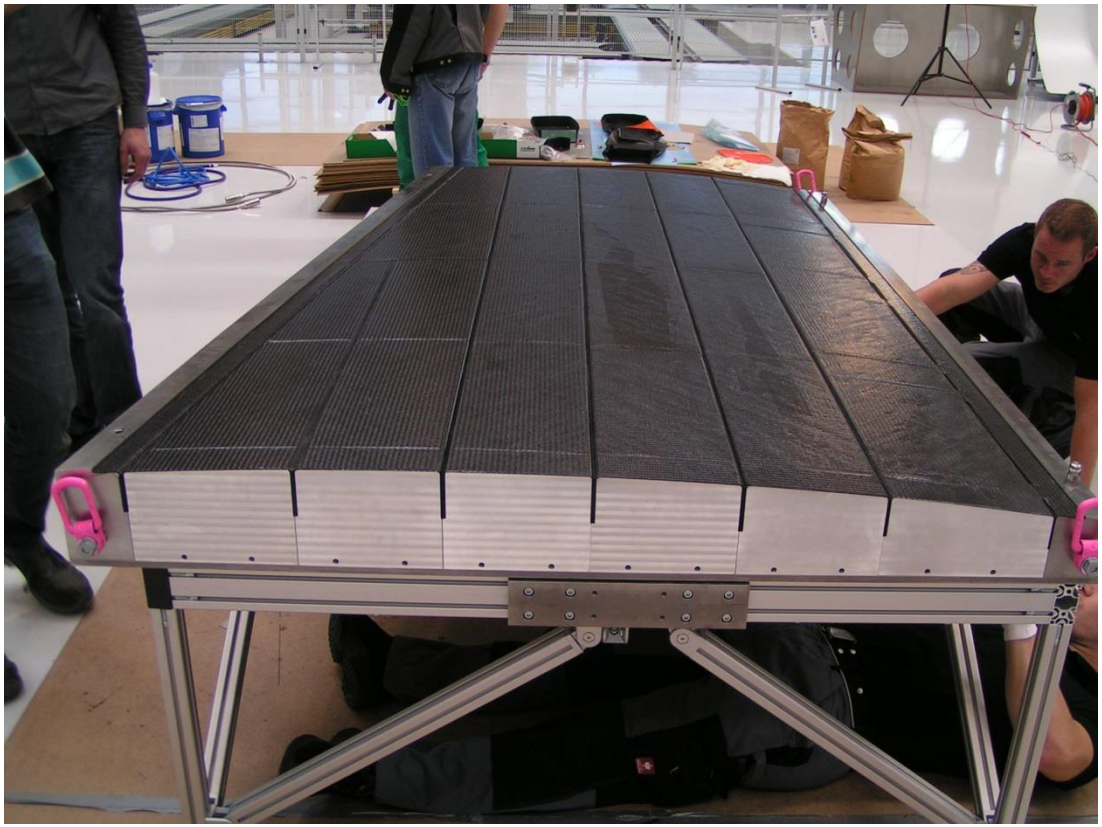
Integral stiffening Structure





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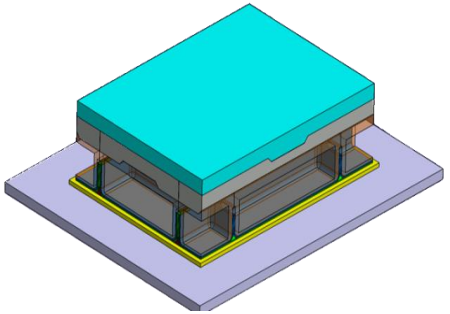
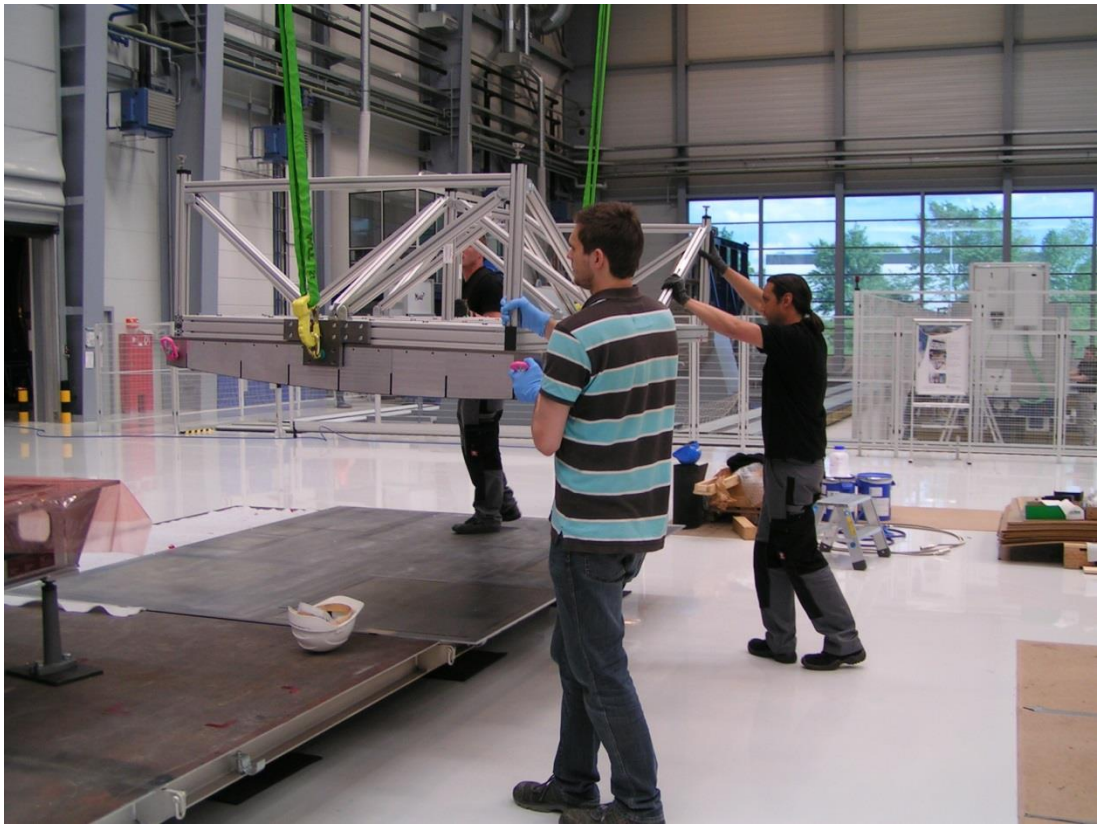
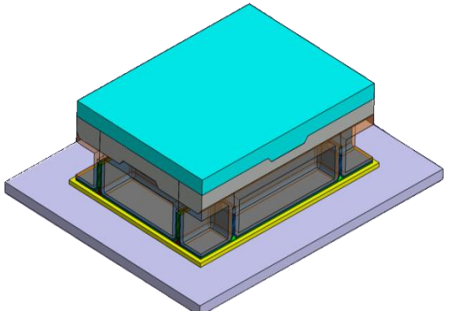
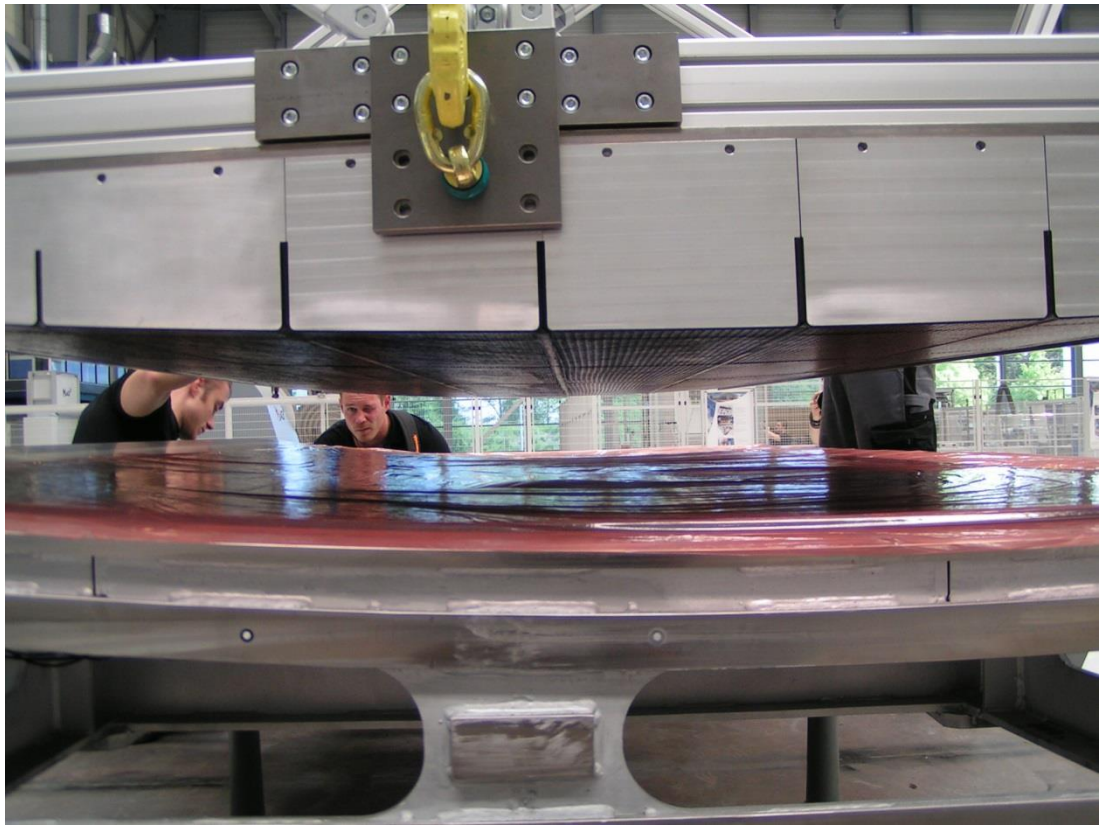
Unite Skin and Core



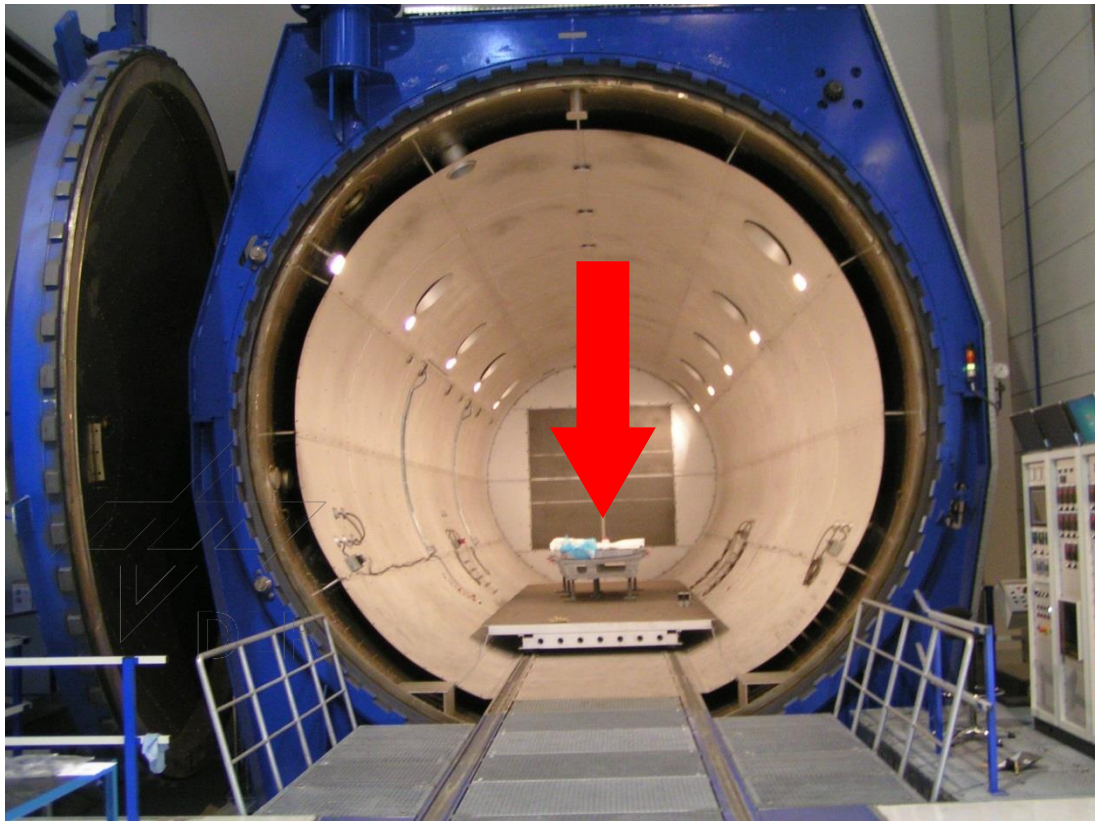


Closing the Tool





Autoclave Preparation



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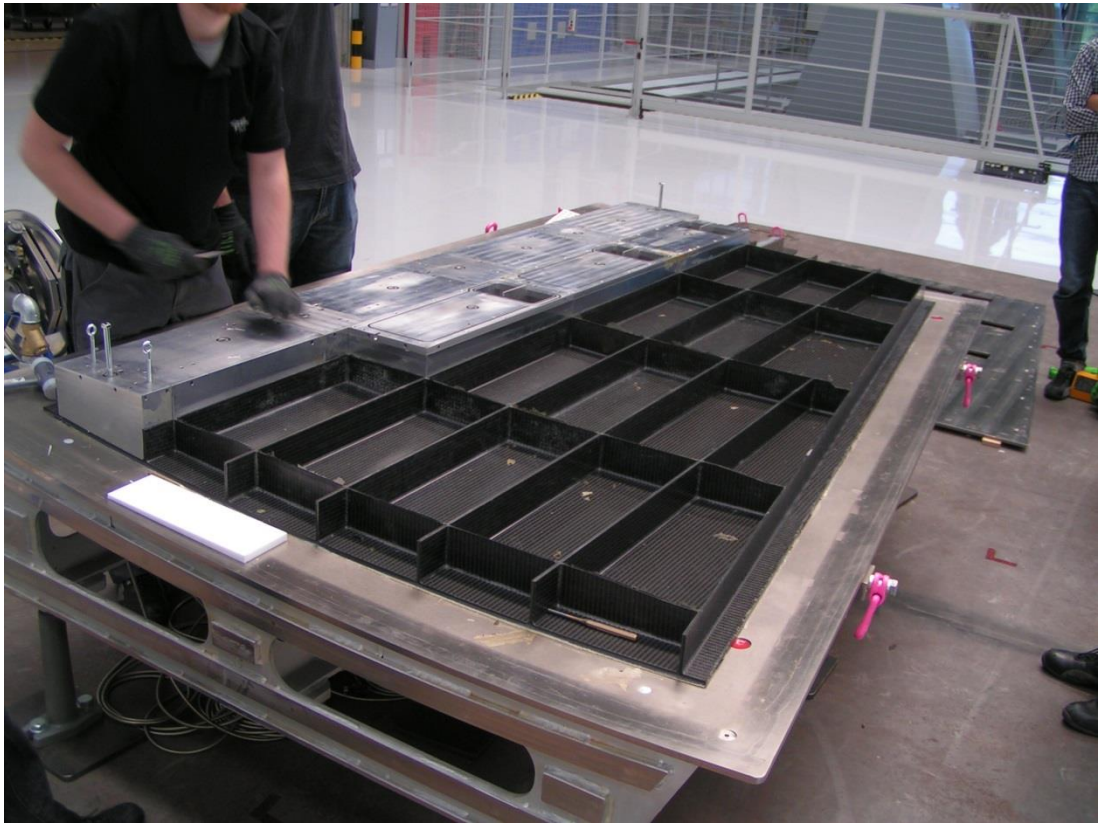
Demoulding



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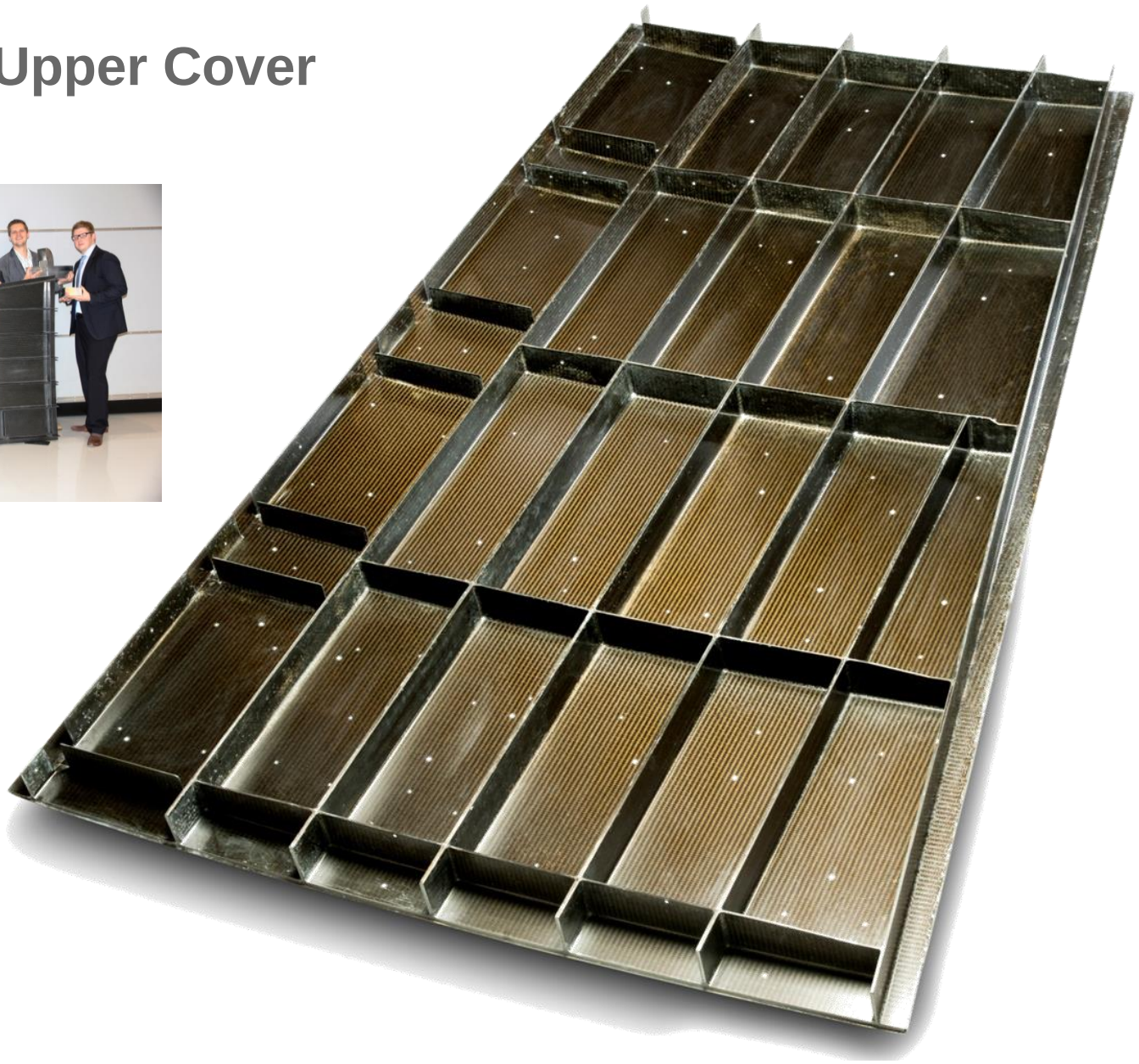
Wing Upper Cover



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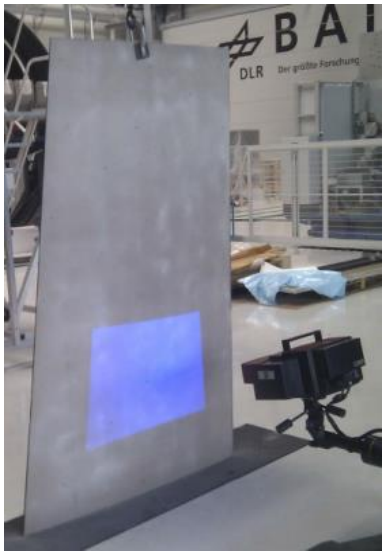
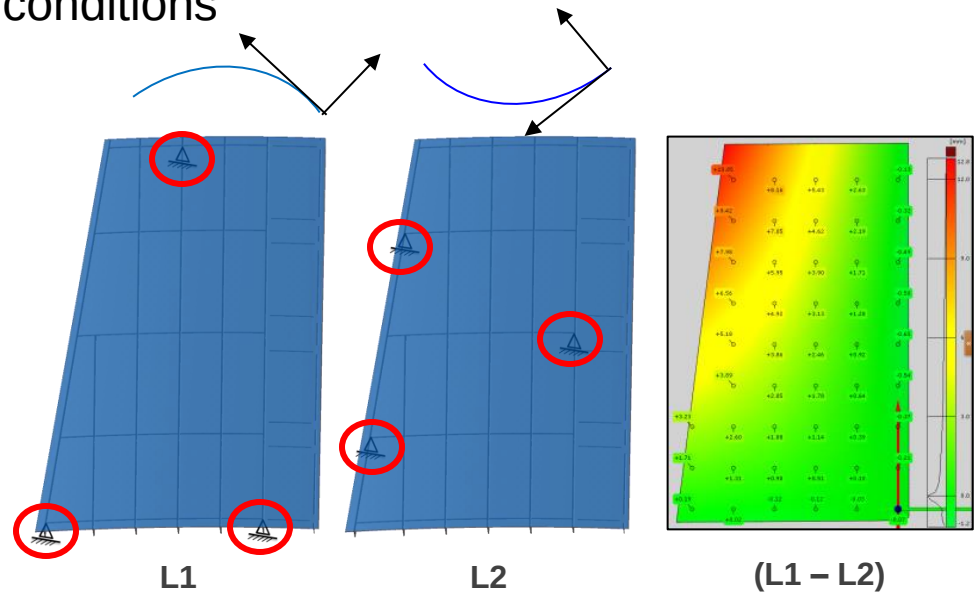
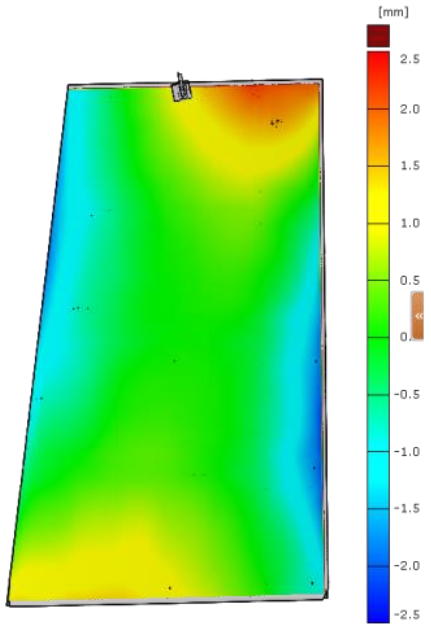
Waviness Measurement



- Optical 3D-Measurement using gom ATOS
- Best-fit with CAD-model shows global deformation
- Significant influence of gravity with different support conditions

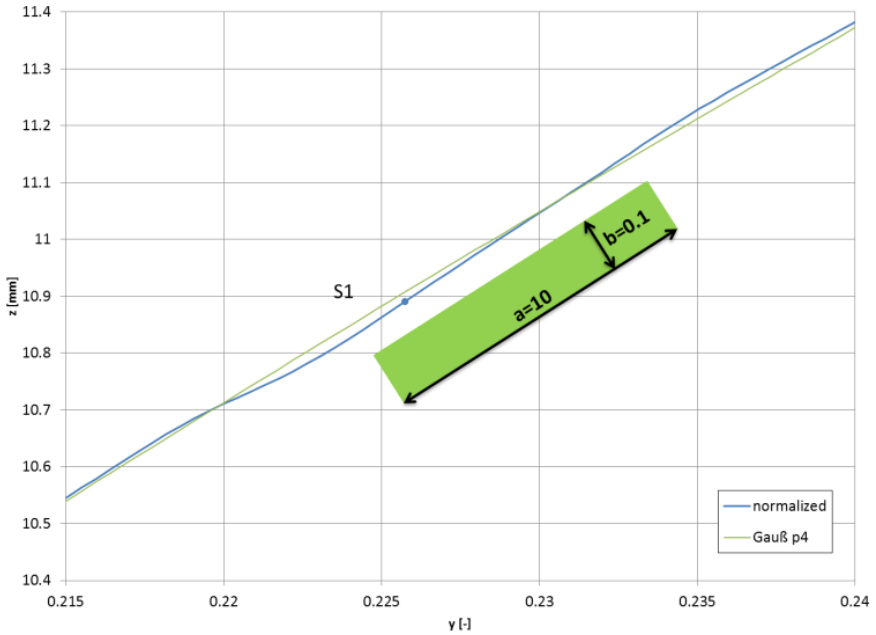


Comparison of different horizontal support conditions



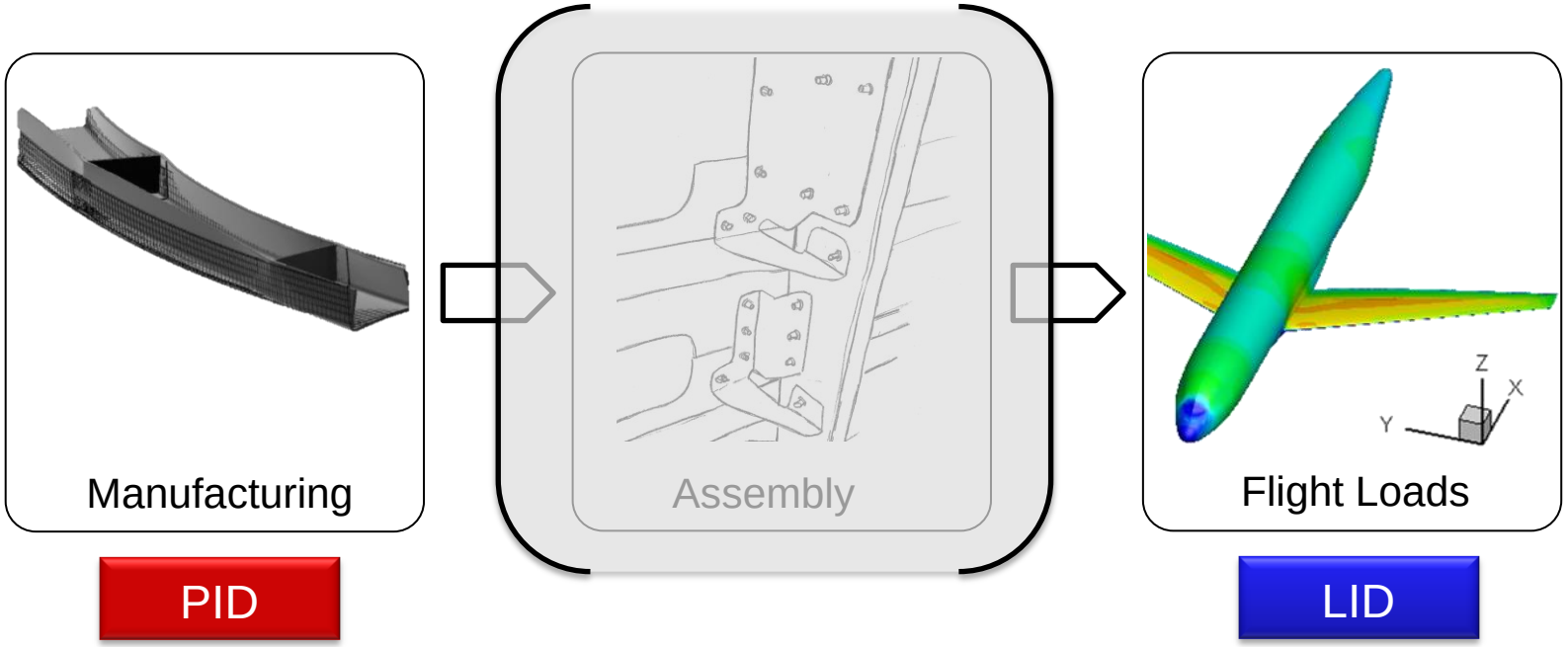
Waviness Measurement

- Analysis of cross-sections
- Small waves below stringers due to unsufficient gusset filler geometry



Gusset-filler waviness

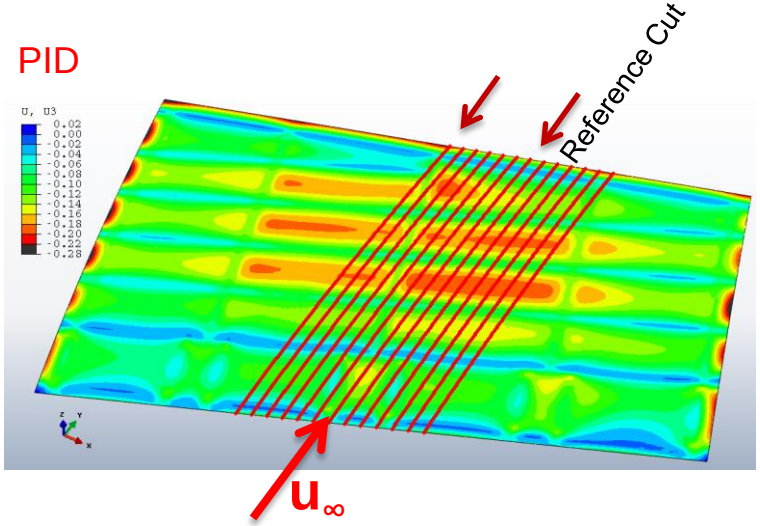
Resulting Waviness



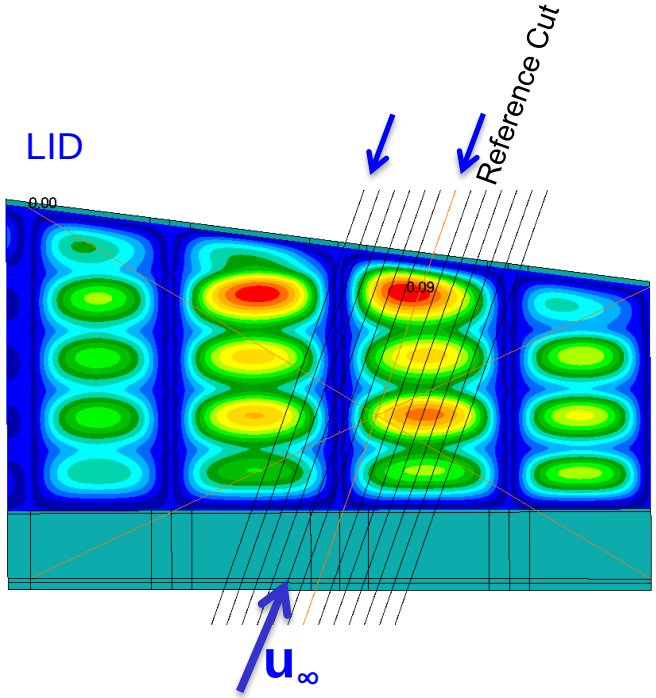
- Outer shape during cruise flight has deformations due to manufacturing, assembly and aerodynamic loads
- The real part requires an assembly rig
- Simulation substitutes it by adequate BCs

Evaluation of selected cuts

PID



LID



- Ribs are NOT oriented in flight direction, but perpedicular to front spar
- Two cuts with different characteristics have been selected for more detailed analysis
- Aerodynamic assessment with „2 ½ D“ computational fluid dynamics

Summary of main Results

Development of integral wing design
- No rivets on aerodynamic surface
- Reduced waviness

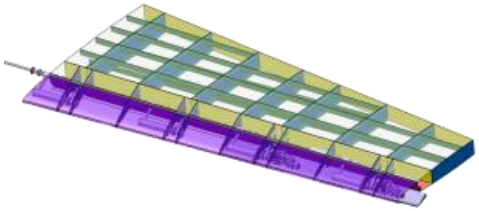
Development of cellular tooling concept
- Tolerance management
- Efficient heat-up and cooling

Method for Process induced deformations analysis
- PID-analysis capable for complex stiffened structures

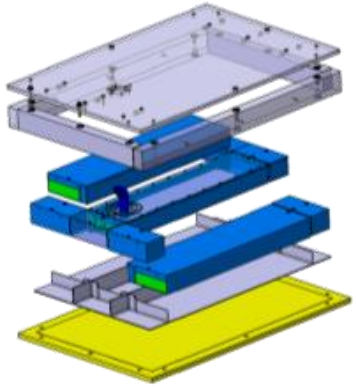
Surface Measurements on validation structures

Manufacturing of full-scale wing cover section

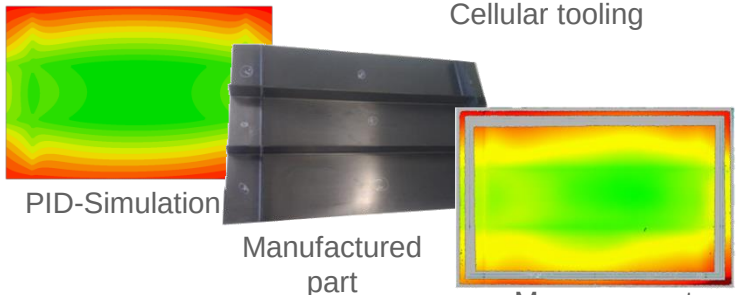
Assessment of resulting waviness from process- & load-induced deformations



Integral wing



Cellular tooling



PID-Simulation

Manufactured part

Measurement

Move.On LaWOp

Many thanks to our colleagues & partners from

- DLR Institute of Composite Structures and Adaptive Systems, Braunschweig & Stade
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DLR

Tack så mycket!

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