

Flight Testing on Ground – The Laminar Wing Leading Edge Ground Based Demonstrator

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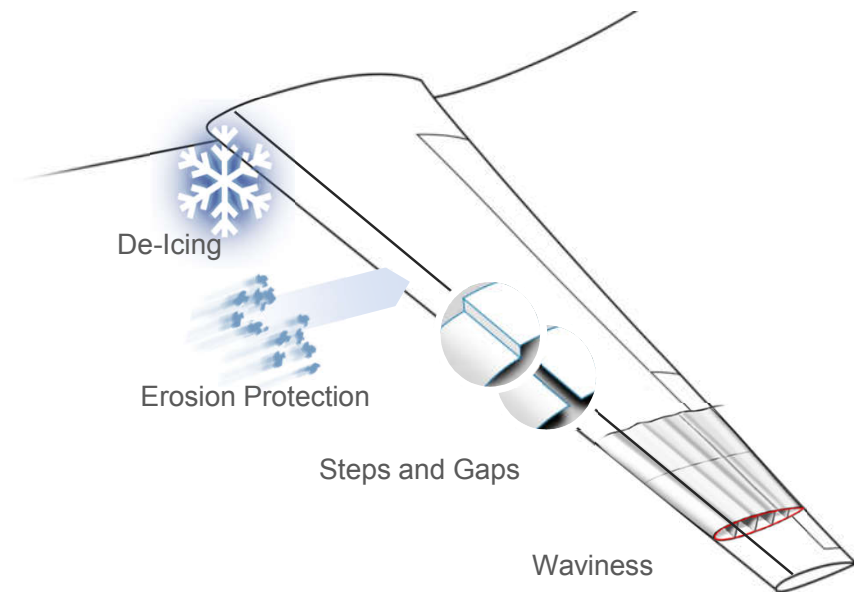
Knowledge for Tomorrow



Laminar Flow Requirements in a Nutshell

Steps, gaps and surface waviness cause transition

- Fastener heads on the surface
 - changes in stiffness...
 - and steps and gaps...
- ...are to be avoided!

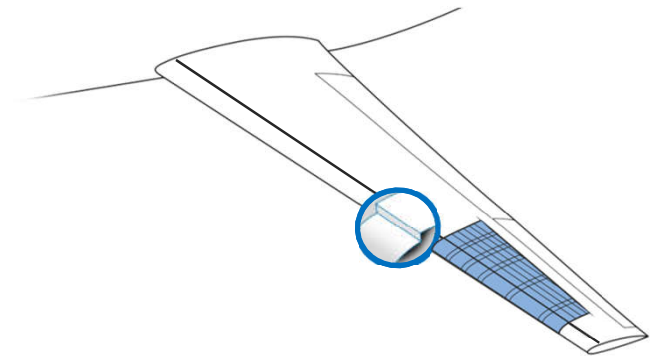
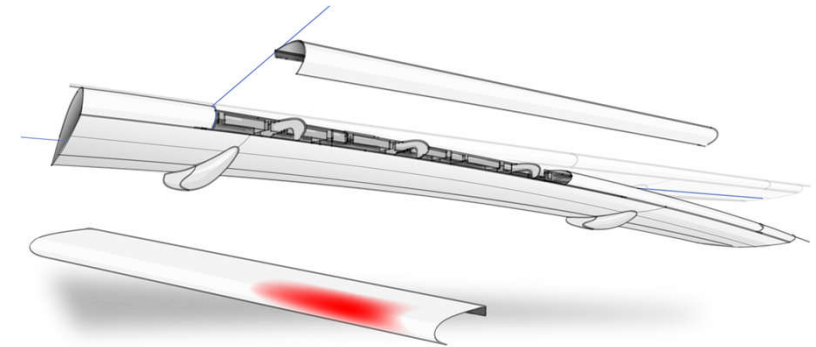


Clean Sky 2 NACOR* Goals

Demonstrate interchangeability of a full scale laminar leading edge section of a flexible wing under operational conditions

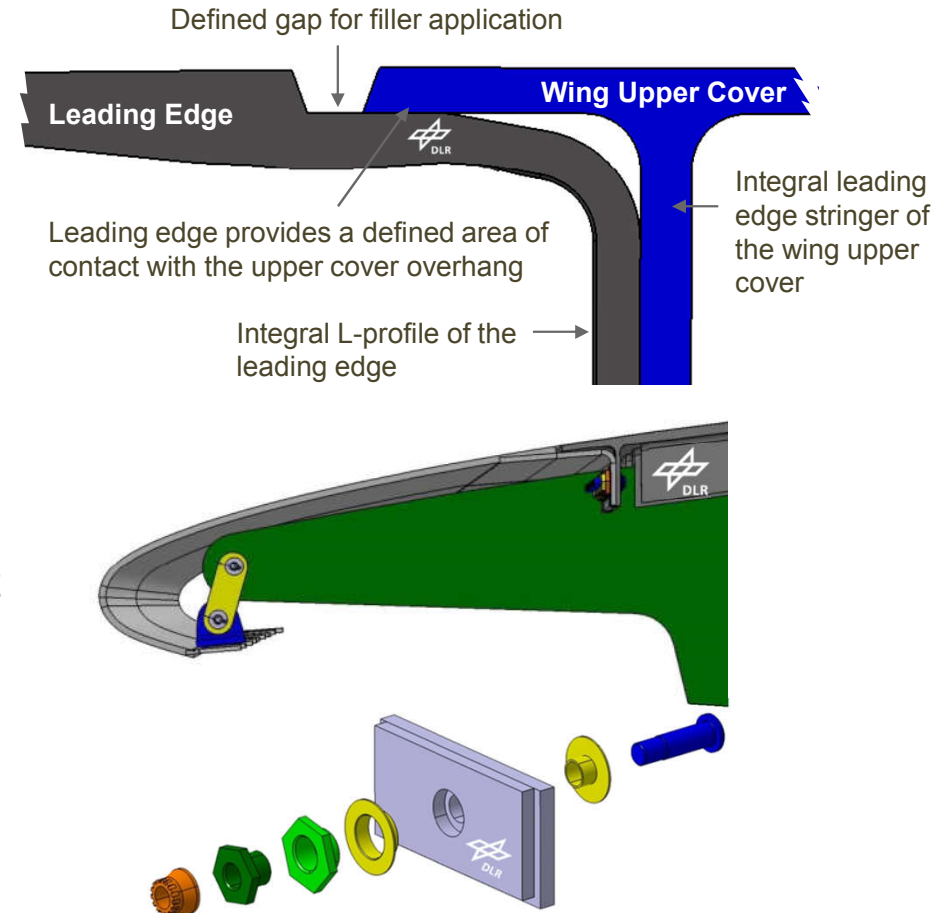
– in FAL and in service

Demonstrate compliance with the step height requirements between WUC and LE under cruise conditions



Laminar Flow Leading Edge – Design Background

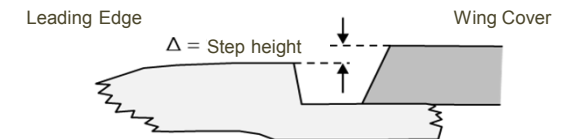
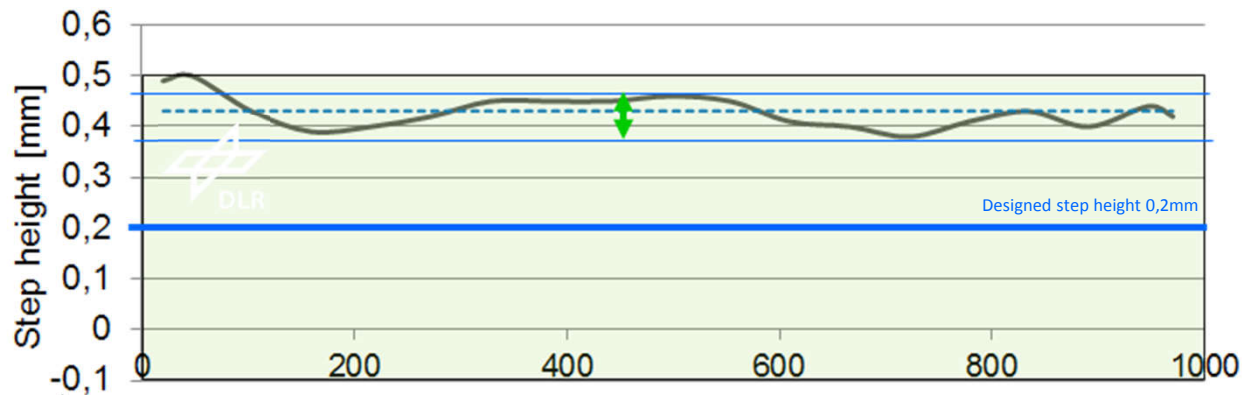
- Addressing step, gap and 3d disturbance requirements by novel joint concept
- Erosion protection through 0.12mm steel foil
- Integrated Wing Ice Protection System: CFRP layer within GFRP insulation
- Global deformation through asymmetry and thermo-elastic deformations over service life addressed by overall attachment concept: use of struts as rib connection
- Use of eccentric bushings at the connection of leading edge and upper cover to enable interchange



First proof of concept: LuFo IV-4 LaWO_p

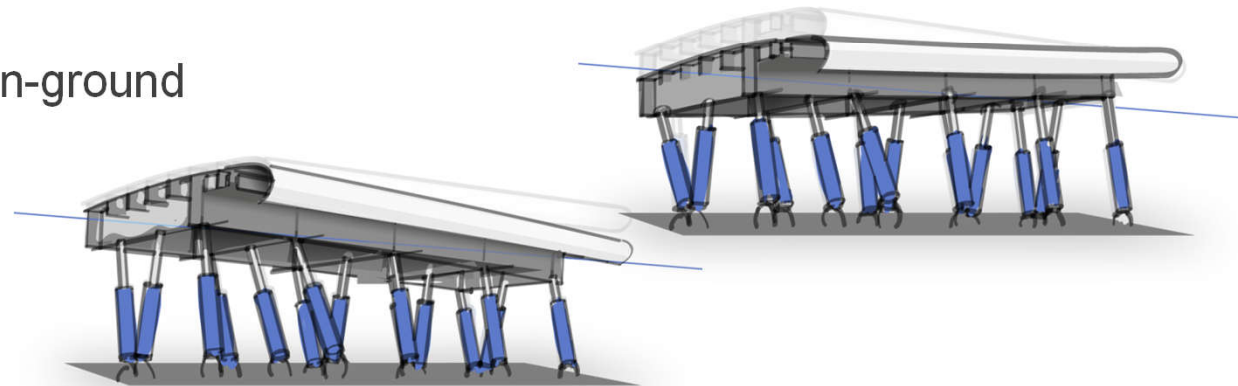
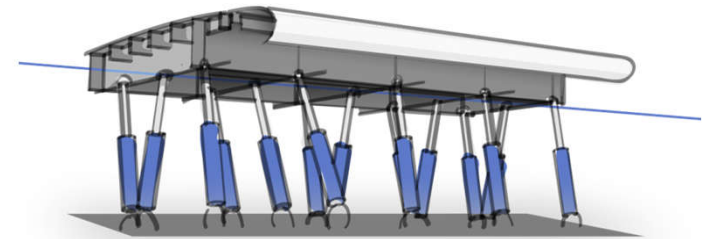
- Planar demobox, 1m span
- 2d extruded profile „leading edge“ without undercuts
- Focus on the interface between upper cover and leading edge

Successful interchange trials with steps within laminar flow requirements!



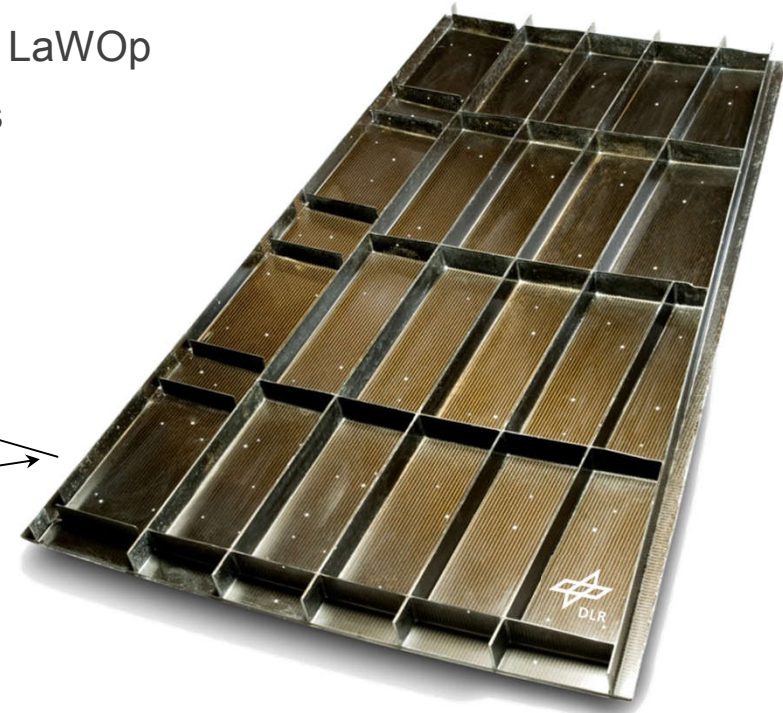
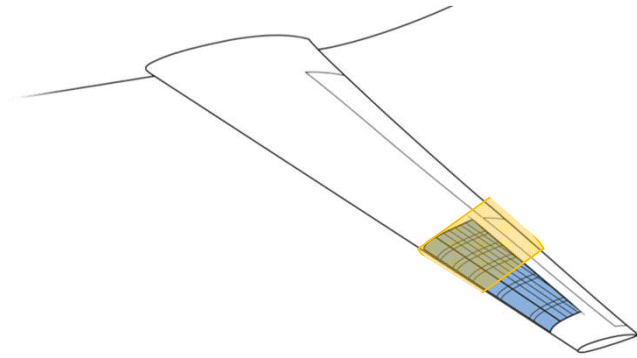
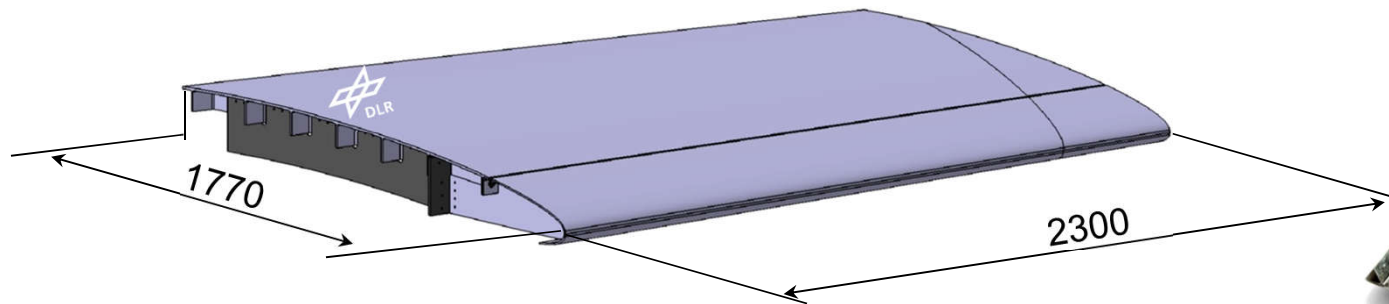
Approach in NACOR – „Flight Testing on Ground“

- Build a Ground Based Demonstrator of a wing section in a relevant scale
- Develop a test stand to create real wing operational deformations in a laboratory environment
- Recreate surface deformations of a wing on-ground and in cruise flight



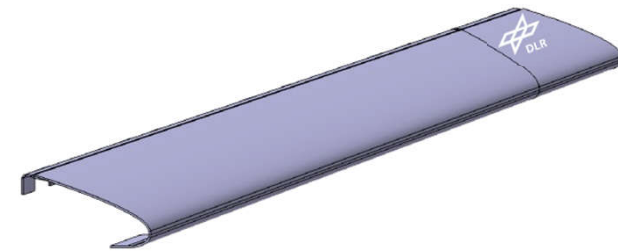
Ground Based Demonstrator Geometry

- Left hand wing, outer krueger segment, inner half
- No lower cover included, no relevance for NLF and disadvantageous for testing
- Use of existing highly integrated NLF wing upper cover form LuFo IV-4 LaWOp
 - Full wing complexity: curvature, taper, decreasing profile thickness
 - Design elements for leading edge attachment concept are present

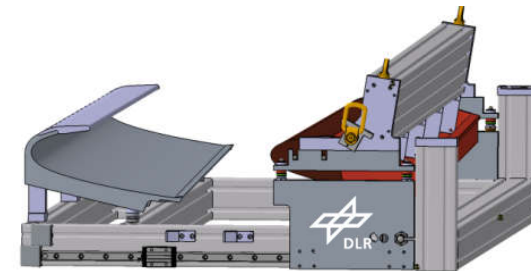


Three Areas of Focus in the Development

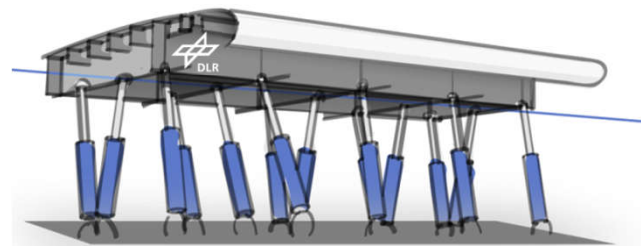
1) Design of the Multi-material Multi-functional Laminar Leading Edge



2) Leading Edge Production Process Development

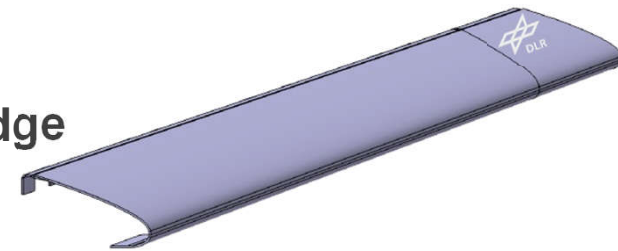


3) Test Stand Design

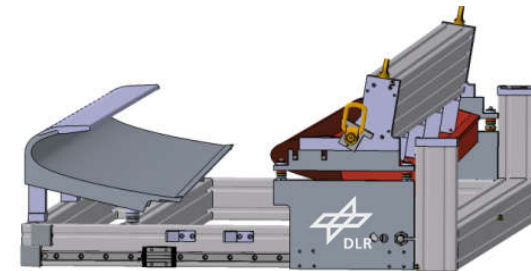


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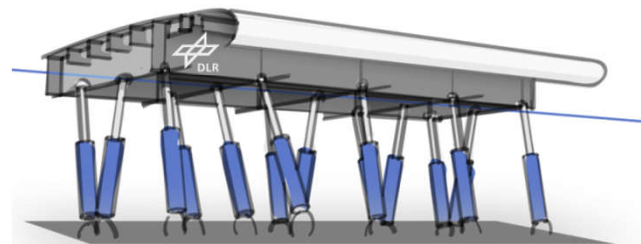
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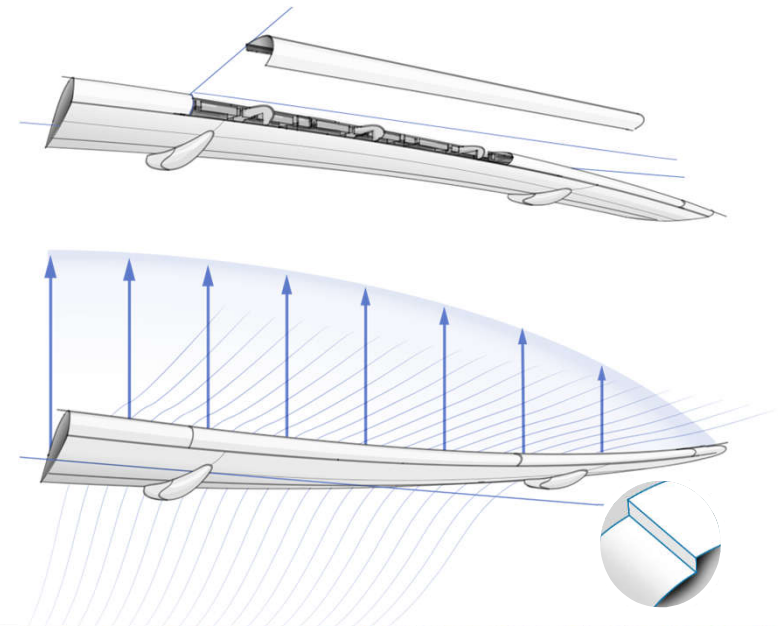
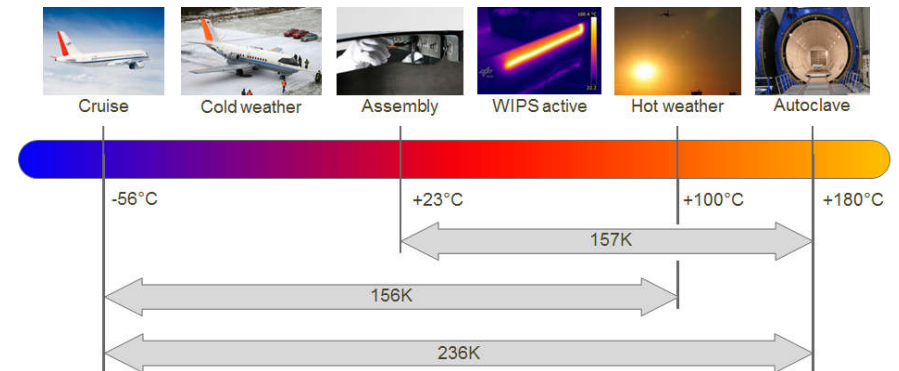


3) Test Stand Design



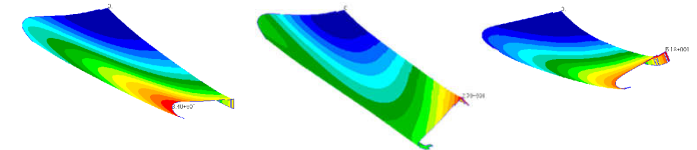
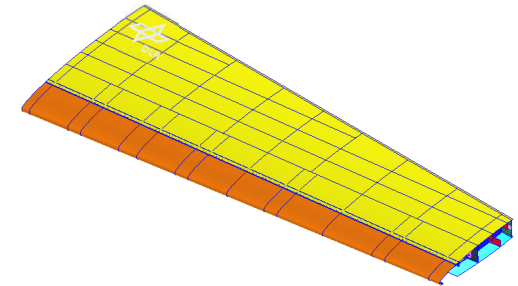
Preliminary Design – Aim and Challenges

- A composite airframe structure experiences a vast temperature range in its lifecycle
- The leading edge's multi material conception is asymmetric, thermo-elastic behaviour has to be considered
- The leading edge has to be interchangeable to be fit for operation
- Interchange has to be possible worldwide without specialised equipment
- The leading edge has to be flexible enough in spanwise direction to be mountable to a free cantilevered wing on-ground
- Step requirements between leading edge and wing upper cover have to be met at cruise conditions

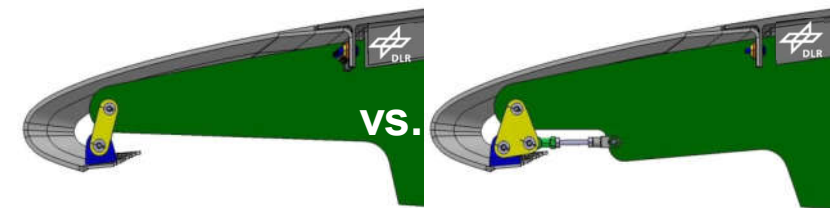


Leading Edge Design Decision Making Process

- Simulation of a wing section of a full ~4.5m leading edge segment
- Layup selection from nine different layups
 - LaWOp layup as reference, 8 UD layups of equal thickness
 - All layups investigated w.r.t.:
 - Static strength and stability in critical load cases
 - Aerodynamic NLF limits (step height, gap width, filler strains) in cruise
 - Fastener forces in all load cases
 - Assembly forces
 - Thermal deformation of free leading edge on ground
 - (Leading edge mass)
- Rib attachment selection
- Verification of layup and attachment for adverse assembly temperature conditions



a) Variante v00 b) Variante v01 d) Variante v03
Deformation at $T = -70\text{ °C}$ (5-times real deformation)



Cold weather



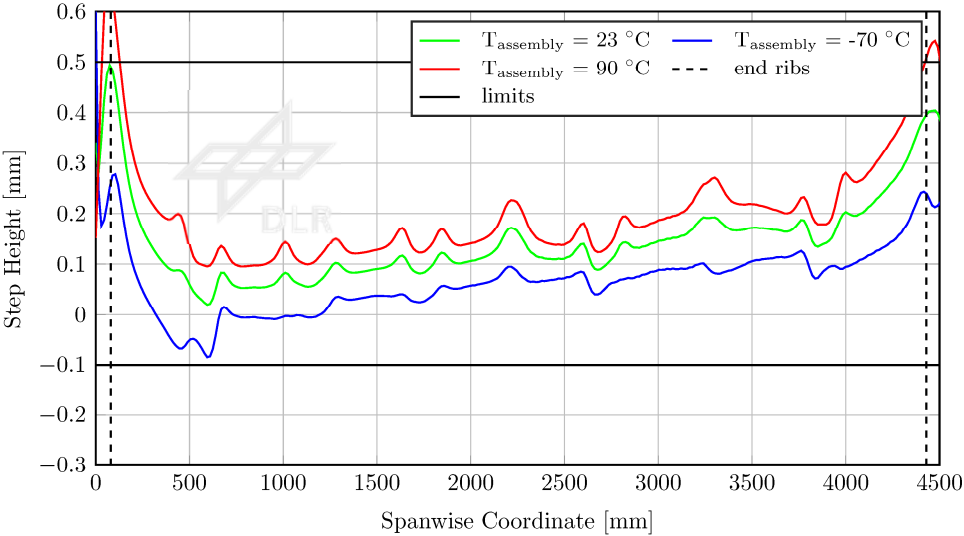
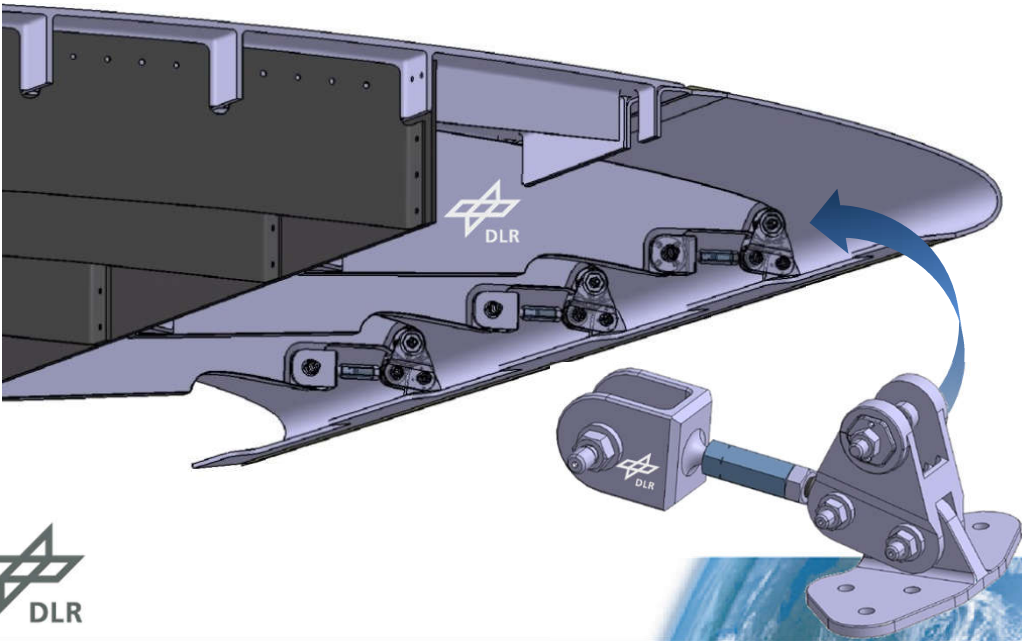
Hot weather



Selection and Verification Results

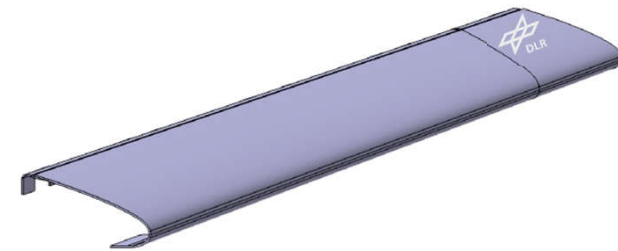
- Shear-type layup selected
- Focus on type B rib connections with additional strut
- Step height within boundaries for all assembly conditions

| Function | Ply | Material | Angle [°] | Ply Thickness [mm] |
|--------------------|-----|---------------------|-----------|--------------------|
| Erosion Protection | 1 | Steel 1.4310 | | 0,120 |
| | 2 | Hexply M21/56%/1080 | +/-45 | 0,066 |
| WIPS | 3 | Hexply M21/56%/1080 | +/-45 | 0,066 |
| | 4 | Hexply M21/56%/1080 | +/-45 | 0,066 |
| | 5 | Hexply M21 46280 | +/-45 | 0,310 |
| | 6 | Hexply M21/56%/1080 | +/-45 | 0,066 |
| | 7 | Hexply M21/56%/1080 | +/-45 | 0,066 |
| | 8 | Hexply M21/56%/1080 | +/-45 | 0,066 |
| Structure | 9 | Hexply M21 T800S | 45 | 0,262 |
| | 10 | Hexply M21 T800S | -45 | 0,262 |
| | 11 | Hexply M21 T800S | 90 | 0,262 |
| | 12 | Hexply M21 T800S | -45 | 0,262 |
| | 13 | Hexply M21 T800S | 45 | 0,262 |
| | 14 | Hexply M21 T800S | -45 | 0,262 |
| | 15 | Hexply M21 T800S | 45 | 0,262 |
| | 16 | Hexply M21 T800S | 0 | 0,262 |
| | 17 | Hexply M21 T800S | 0 | 0,262 |
| | 18 | Hexply M21 T800S | 45 | 0,262 |
| | 19 | Hexply M21 T800S | -45 | 0,262 |
| | 20 | Hexply M21 T800S | 45 | 0,262 |
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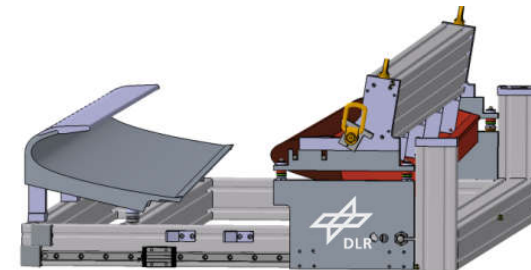


Three Areas of Focus in the Development

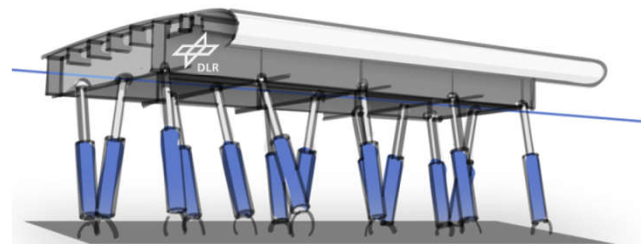
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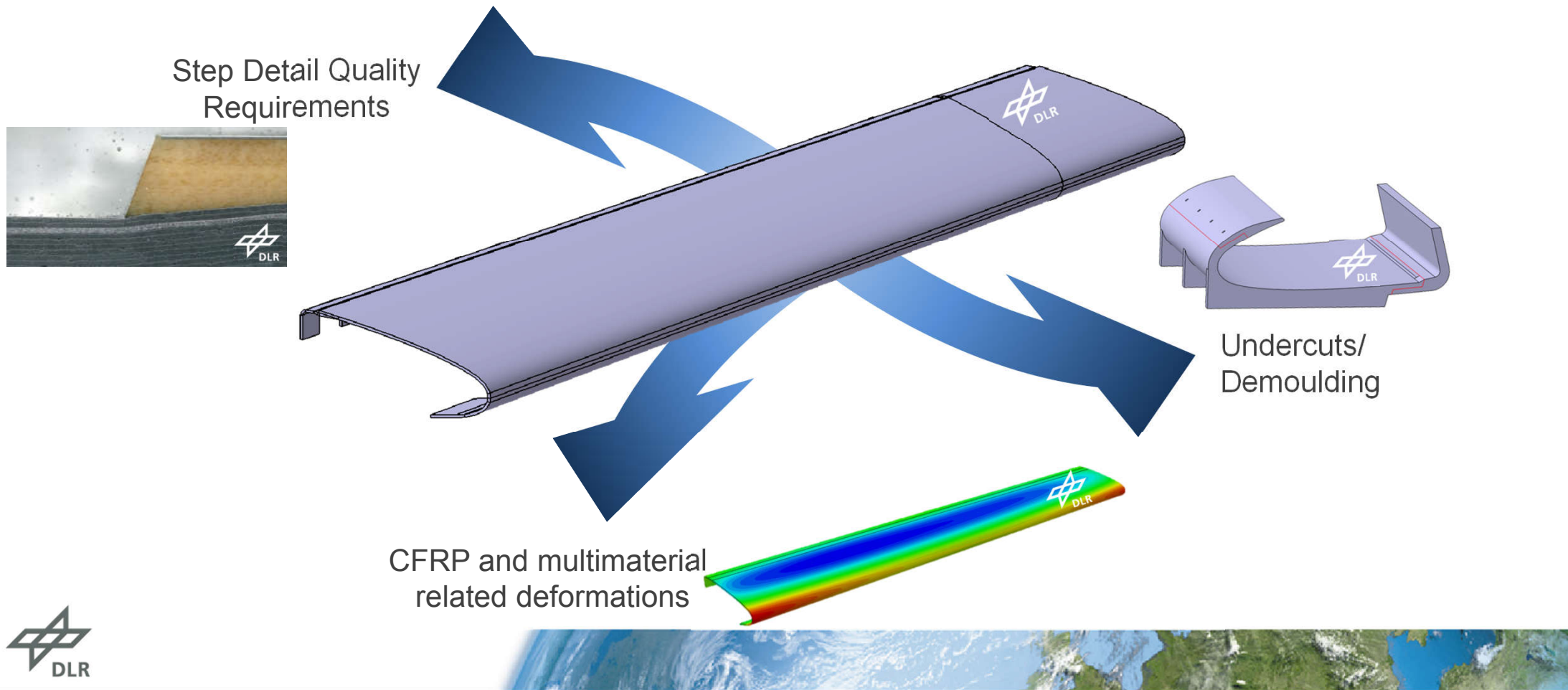
2) Leading Edge Production Process Development



3) Test Stand Design

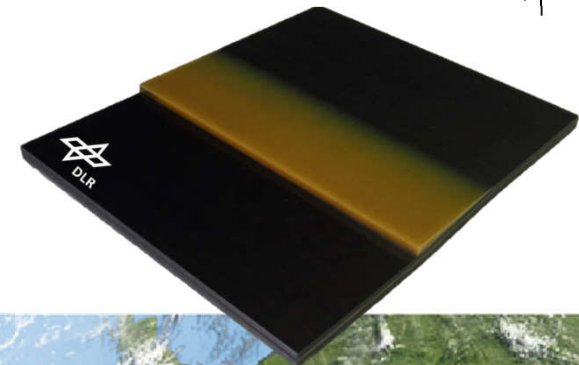
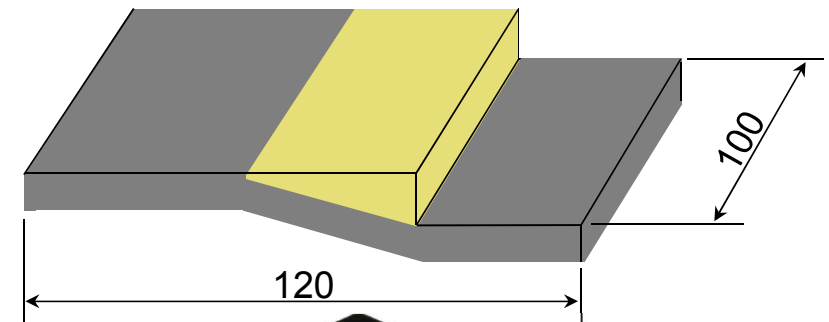
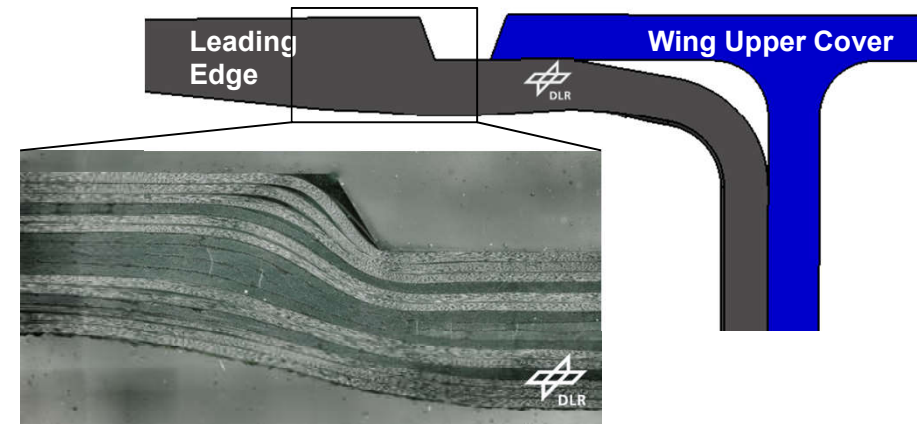


Main Process Design Drivers



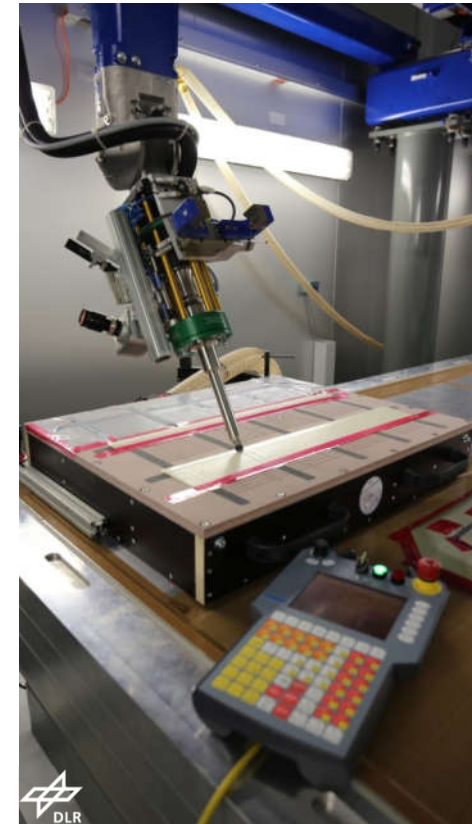
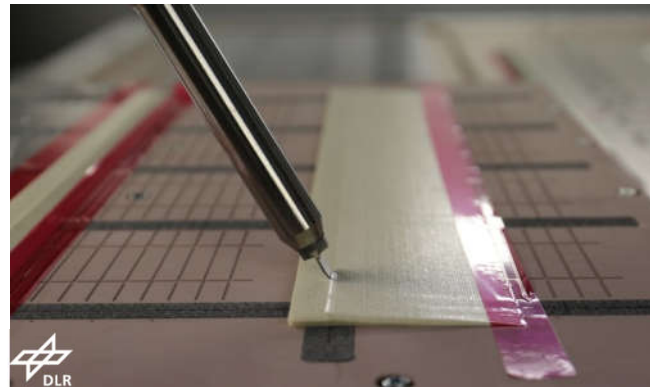
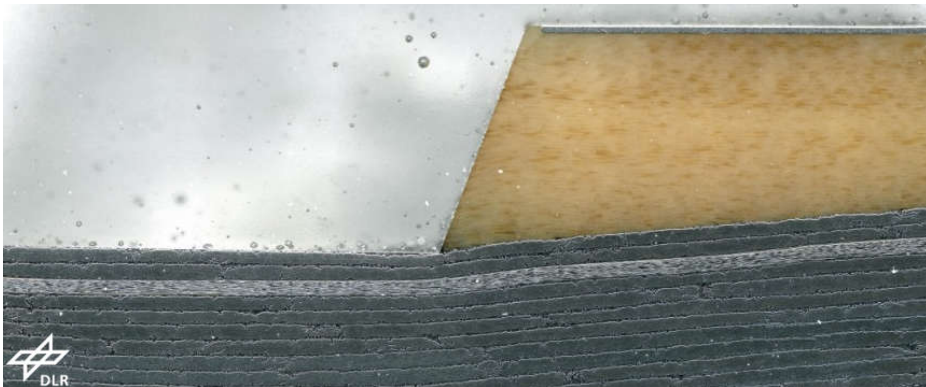
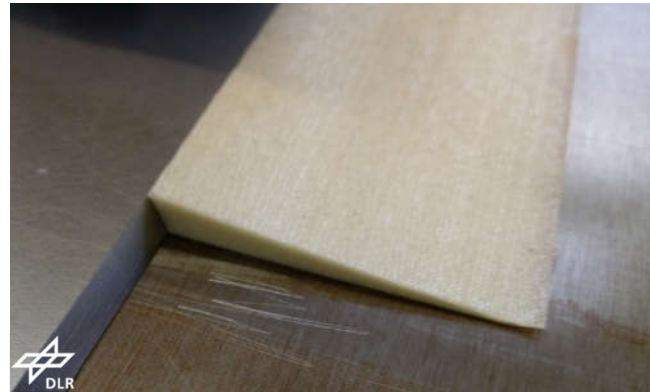
Step Detail Design and Processing (1)

- Depending on laminate and step height of the landing, resin rich zones form at the edges as well as disadvantageous fibre orientations
- Resin rich edges may tend to crack and get lost over time in aircraft service life
- Problematic when erosion shield is applied directly upon the resin
- Test campaign initiated with small scale step samples
- GFRP Wedge inlays with leading edge parent laminate manufactured with INVAR tooling sheets for the step
- Material: HexPly 56%/1080/1100mm



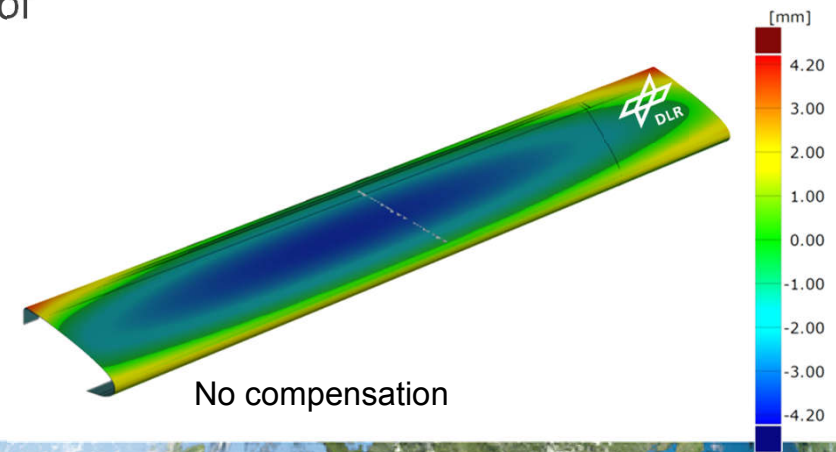
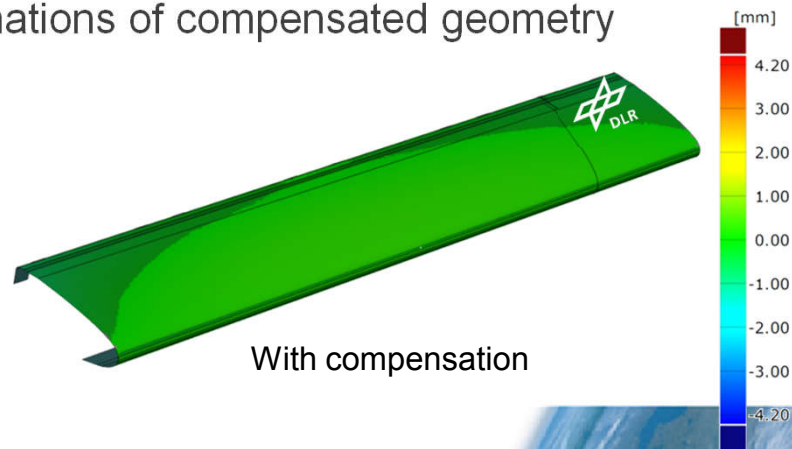
Step Detail Design and Processing (2)

- Number of plies in the wedge matches step height, considering erosion protection
- Step angle of tooling is formed using ultrasonic cutting to achieve good preform-tooling fit
- Cut sections of a test specimen show very good tool/part conformance regarding the forming of the step



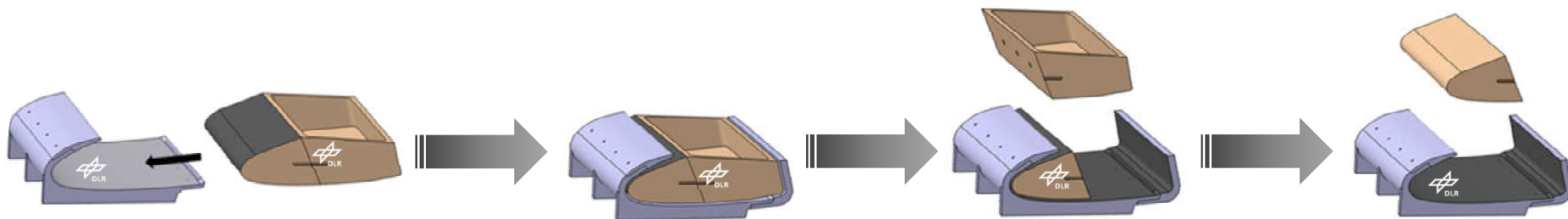
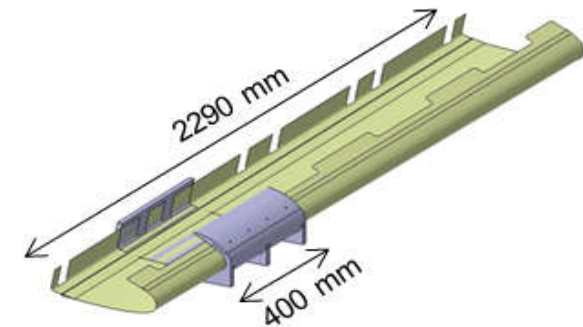
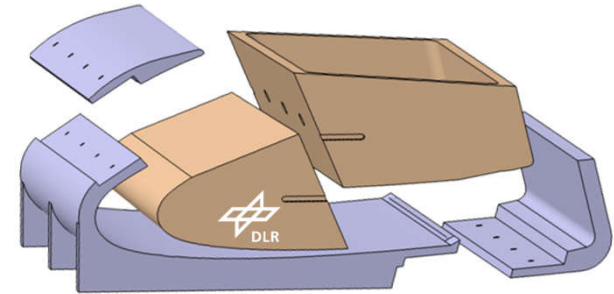
Understanding Process Induced Deformation

- A phenomenological-numerical simulation strategy (P-approach) is used to derive tool compensation measures
- Series of tests: Plane, single curved, assessment of step samples to gain information for deformation simulation of the LE (Abaqus)
- Verification of the model with subscale leading edge manufacturing trials
- Compensation of the demonstration leading edge and simulation of deformations of compensated geometry



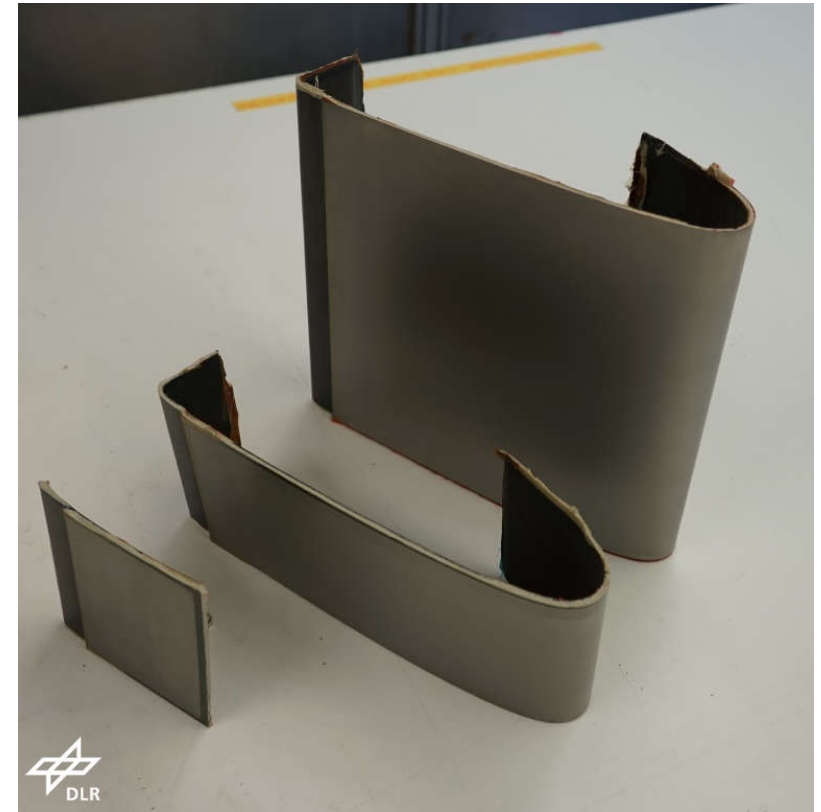
Multipart Tooling to Address Undercuts

- Multit-part tooling concept is applied to adress undercuts
- Small section of the original leading edge geometry used for validation: Subscale leading edge
- Preforming on a dedicated tool, transfer to the unassembled curing mould for easy preform insertion, closing of the mould and removal of the preforming tool



Subscale Leading Edge Trials

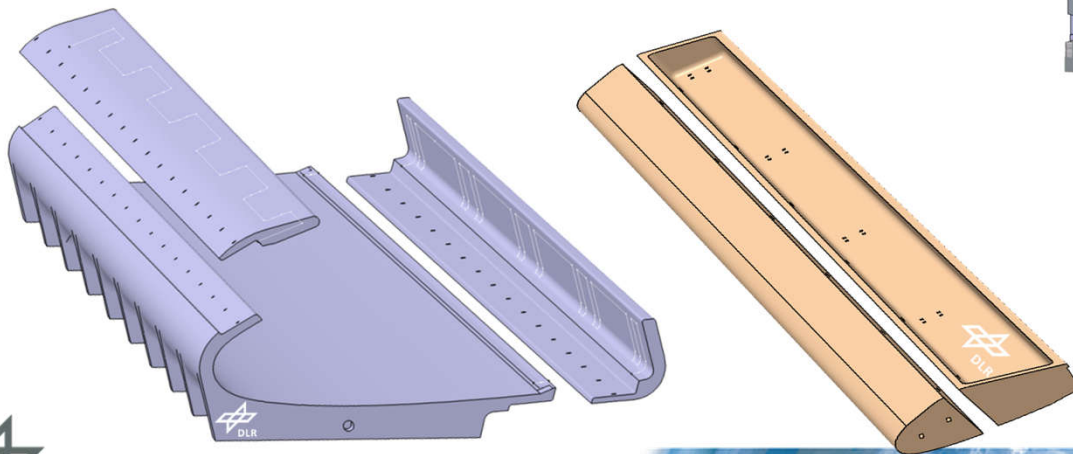
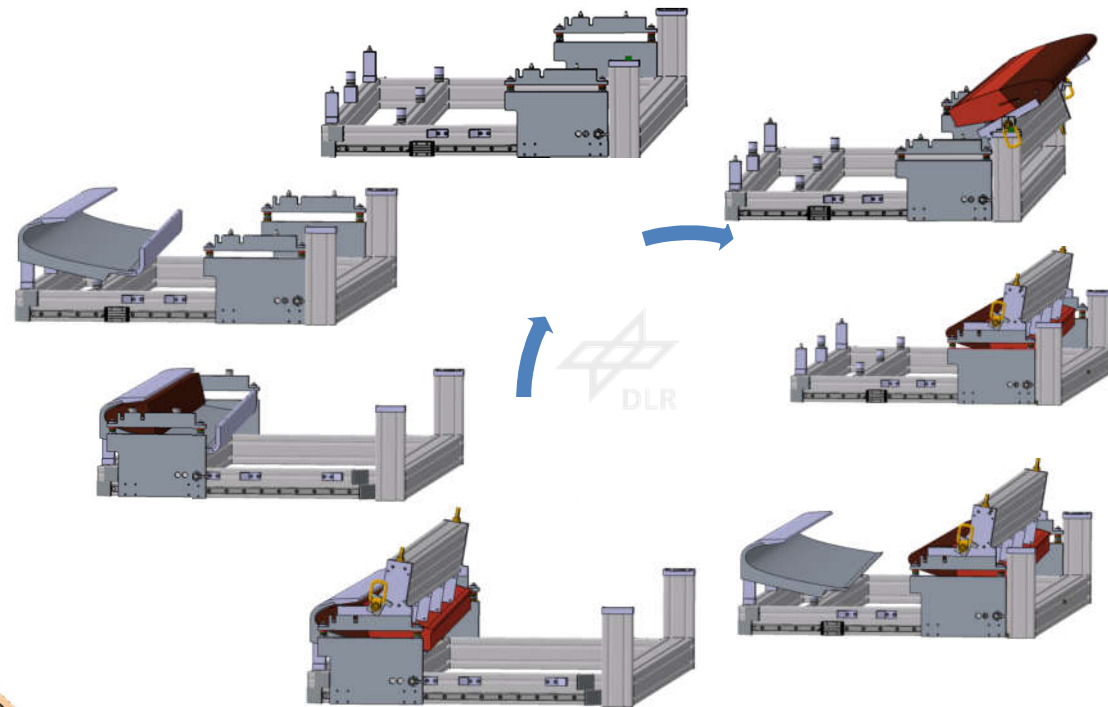
- Manufacturing tests with growing complexity performed
- From single step to section to the full subscale leading edge
 - Experience in steel foil application gained
 - Integration of GFRP wedges in the process
 - Deformation simulation verified with subscale LE



The Full Scale Process – Demonstrator Leading Edge Production Setup

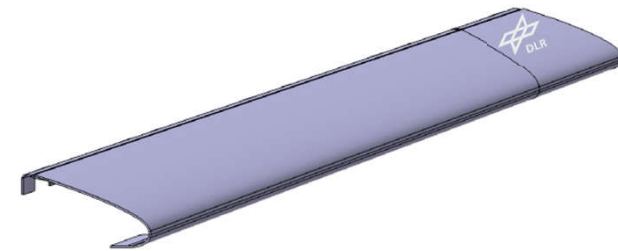
Three major components

- Curing mould – INVAR Steel
- Preforming mould – Necuron
- Handling jig ITEM frame with linear guide
 - Provide stiffness for preforming tool
 - Ensure controlled placement of preform on steel sheet without premature contact/ scraping of the sol/gel film

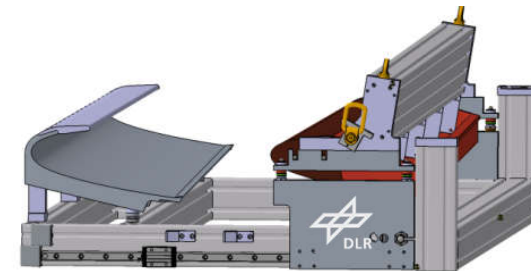


Three Areas of Focus in the Development

1) Design of the Multi-material Multi-functional Laminar Leading Edge



2) Leading Edge Production Process Development

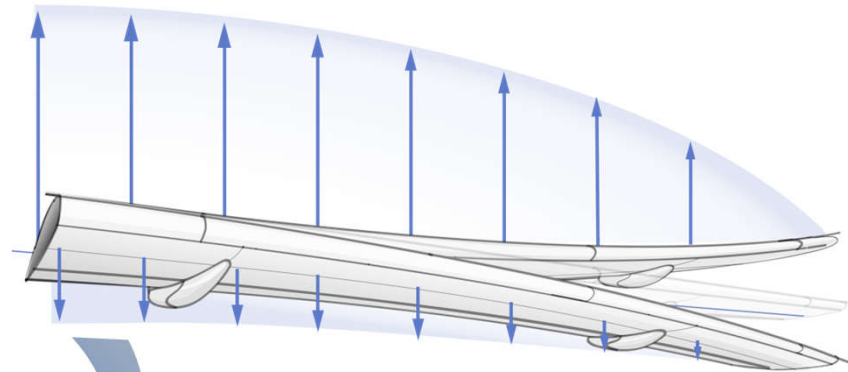


3) Test Stand Design



Test Stand Design Challenge

- Aerodynamic loads and mass of a wing on ground are continuously introduced into the structure
- Test stand loads are discrete loads
- A substructure, actuator positions and directions have to be identified, to reach wing load case surface deformations with discrete laboratory load introduction



Approach:

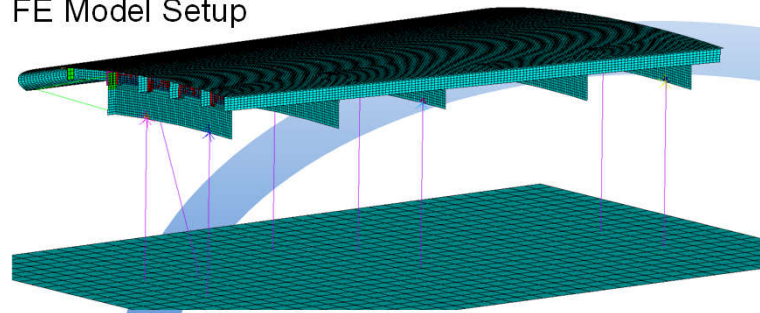
Finite Element Model + Python Framework

- Minimize deviations of target shape and ground based demonstrator geometry by modification of layup of substructure, actuator direction and elongation using the MIDACO algorithm
- Strength thresholds of composite components as additional evaluation criterion

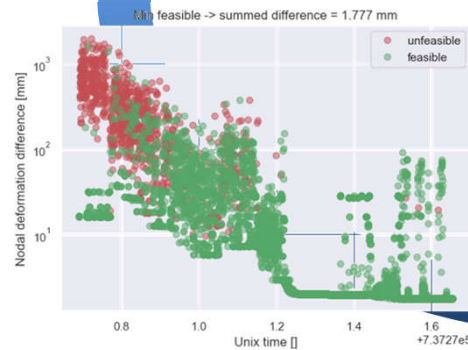
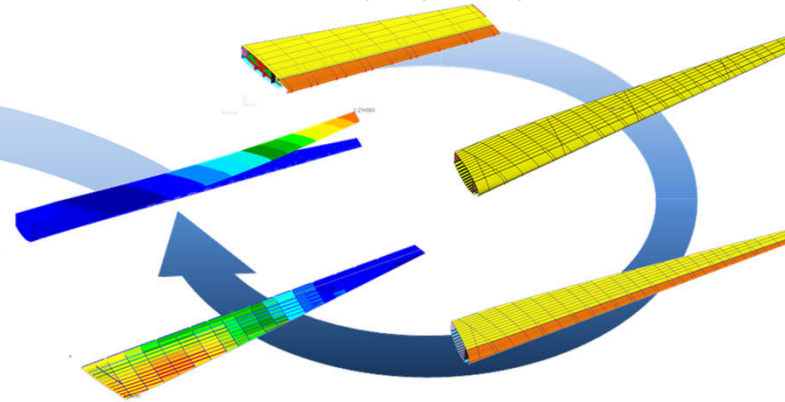


Optimization Procedure and Results

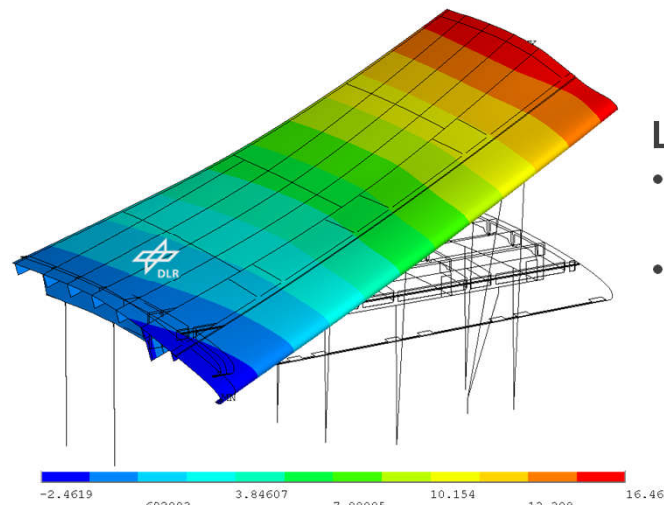
FE Model Setup



FE Target Geometry Generation from Leading Edge Design Phase



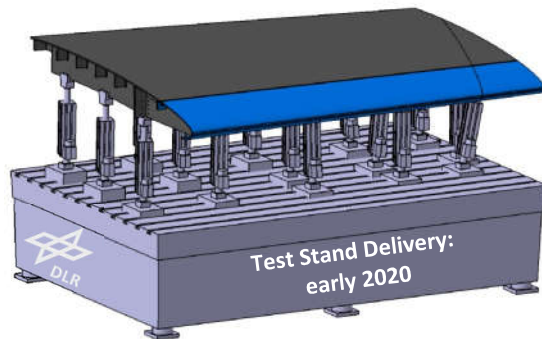
Optimization Runs: Achieved Nodal Deformation Difference



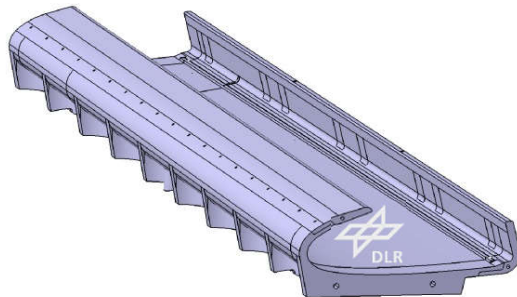
Load Case Results

- On-ground: 1.77mm deviation over all points used in the optimization
- Cruise: 14.7mm deviation over all points used in the optimization

What's the Project's Current Status?



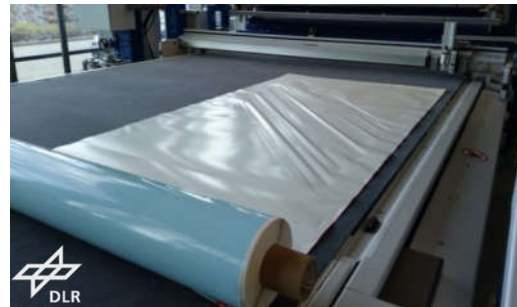
Ground Based Demonstrator overall detailed design finished



Leading edge and curing mould detailed design concluded



Ground Based Demonstrator box (front facing down) finished in May 2018



1st ply cuts for the GBD leading edge production



Leading Edge Production Toolset delivered and integrated



Contact Information



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Acknowledgements

*This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under **grant agreement No CS2-AIR- GAM- 2014-2015-01***

