CFRP Upper Wing Cover for Natural Laminar Flow

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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
Laminar Flow can reduce friction drag significantly!

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

Unite skin & core

Skin plies deposition

Insert gusset filler
Cellular Tooling Concept

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

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

Cell features

- Heating and cooling
- Tolerance compliance
- Sensor and actuator integration (inside)
Cellular Tooling

ALUMINIUM alloy
(Moulding/ Demoulding)

Green:
Tool side for mating surfaces

Fixed Bearing

thermal expansion

INVAR steel
Base plate

Floating Bearing
Proof of Manufacturing Concept
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 criteria 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

\[ \Delta \varphi_2 \]

\[ \frac{\Delta \varphi}{2} \]

\[ \frac{\Delta \varphi}{2} \]

\[ M \]

\[ M \]

\[ \Delta CTE \]

\[ \Delta CTE = CTE_1 - CTE_2 \]

\[ \left\{ \begin{array}{c} \varepsilon_0^x \\ \varepsilon_0^y \\ \varepsilon_0^z \\ \varepsilon_0^z \\ \end{array} \right\} = \left\{ \begin{array}{c} A \\ B \\ C \\ D \\ \end{array} \right\} \]

\[ M^{*} \left[ \begin{array}{c} M_x^* \\ M_y^* \\ M_z^* \\ M_{xy}^* \\ \end{array} \right] = \bar{Q} \cdot \Delta T \cdot \left\{ \begin{array}{c} \alpha_x^* \\ \alpha_y^* \\ \alpha_z^* \\ \alpha_{xy}^* \\ \end{array} \right\} \cdot \frac{1}{2} (h_1^2 - h_0^2) \]
Simulation of Process induced deformations

Compensated tool

"Inversion" of deformation

Compensated part

FE model

Deformed geometry

\[ \alpha_{\text{angle}} = \frac{1}{6R_0 \Delta T} \frac{h^3}{(z_i^2 - z_0^2)} \frac{\varphi_{\text{mes}}}{\varphi_{\text{area}}} \]
Manufacturing of Wing Upper Cover

”CFK-Nord“ – Research Facility
Stade, Germany
Cellular Tooling- Validator
(36 cores including 10 hollow cores)
Skin Plies Layup
Skin Plies Layup
Skin Plies Consolidation
Draping Core Plies
Positioning of Stringer-Rows
Positioning of Stringer-Rows
Integral stiffening Structure
Unite Skin and Core
Closing the Tool
Autoclave Preparation
Wing Upper Cover
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
- Analysis of cross-sections
- Small waves below stringers due to unsufficient gusset filler geometry
- 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
- Ribs are NOT oriented in flight direction, but perpendicular 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
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Tack så mycket!

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