CFRP
Status of Application in Airframe Structures
and Future Development Process

Martin Wiedemann

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Evolution of CFRP Application

CFRP Status of Application and Future Development Process  M. Wiedemann

Institute of Composite Structures and Adaptive Systems

First Flight

CFRP Volume

0% 10% 20% 30% 40% 50% 60%


A300 A310-200 B757 B767 MD80 B737-300 B747-400 MD90 A320 A340-300 B777 A380 A350 XWB A400M
CFRP Potential in Airframe Structures

CO2-Reduction New Short Range Aircraft

Mission Zero Fuel Weight MZFW Short Range A/C

- 80% Primary Structure
- ~24.8% MZFW
- 60% potentially in CFRP
- ~15% MZFW
- 20% Weight Reduction
- - 3% MZFW
- Show Ball ~3
- up to -10% MTOW\(^1\)
- Idle\(^2\) for 500 nm mission
- ~ 20% Fuel
- CO\(_2\)-Reduction
- 0.8\times10\%=8%  

1) MTOW = Maximum Take Off Weight
2) Idle = not weight driven fuel consumption
Airframe Development Process

Feasibility > Concept > Definition > Developmt. > Production > Assembly > Series

CFRP Production Process Chain

Preparation > Forming > Infiltration > Curing > Release

Order released for Project > Top level a/c requirement > Definition of basic concept > Concept for product selected > Instruction to proceed > Authorisation to offer (ATO) > Go ahead > First metal cut > Begin final assembly > Power on > First flight > Type validation > Entry into service > End development. phase for basic aircraft
Examples of Dependencies in CFRP Structure Development

- Design appropriate to CFRP
- Materials for design
- Materials for robust and efficient production
- Production tolerant sizing
- Damage tolerant materials
- Modifiable design
- Materials for design
- Minimum tolerance design
- Sizing appropriate to quality control
- Maintainable design
- Producible design

Feasibility → Concept → Definition → Development → Production → Assembly → Series
Design appropriate for CFRP
Fiber Strength and Strain Length compared to Metal Alloys

From Fiber to Laminate

- CNT
  \( E_{\text{CNT}} / \gamma_{\text{CNT}} > 64,000 \text{ km} \)
  \( \sigma_{\text{CNT}} / \gamma_{\text{CNT}} > 3,700 \text{ km} \)

Better Resin System Required!
Design appropriate for CFRP
Laminate Strength and Strain Length compared to Metal Alloys

From Orthotropic zu Isotropic Properties

CFK-Laminate

More real composite design required
Design appropriate for CFRP

Isotropic Laminate Strength and Strain Length compared to Metal Alloys
Design appropriate to CFRP
e.g. Semimonocoque-Panel with Double Curved Stringer
Examples of Dependencies in CFRP Structure Development

- **Damage tolerant materials**
- **Production tolerant sizing**
- **Modifiable design**
- **Materials for robust and efficient production**

**Flowchart:***

- Feasibility → Concept → Definition → Development → Production → Assembly → Series

- Materials for design
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**Conceptual Flow:***

- Design appropriate to CFRP
- Materials for design
- Production tolerant sizing
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- Modifiable design

**Key Points:***

- Materials for robust and efficient production
- Production tolerant sizing
- Design appropriate to CFRP
- Minimum tolerance design
- Sizing appropriate to quality control
- Maintainable design
- Producible design
- Modifiable design
- Damage tolerant materials
Minimum Tolerance Design
e.g. „Spring-In“ in LC frame – Requirements for Production

Actual process conditions lead to cost distribution of about 2/3 for frame production and 1/3 for frame assembly.

Typical cost drivers in production
→ High failure rate due to unacceptable contour mismatch
→ High failure rate due to production problems (voids, laminate misalignment)
→ Material cost
→ Manual process, few automation

Typical cost driver in assembly
→ Fitting effort due to tolerance mismatch (Shim)

Main problem:
Proper consideration of „Spring-In“ effect in tolerance management
Minimum Tolerance Design
e.g. „Spring-In“ in LC frame – Challenge

Differences „as-designed“ versus „as-build“:

1) Change of radius in angles flange to web ($\Delta \alpha_1$, $\Delta \alpha_2$)
   → Bending load in flanges caused by assembly

2) Change of global frame radius ($r_3$)
   → Contour gaps which cannot be compensated without shim
   → No reference points for assembly possible

**As-Designed** according to tool measurement
- $\alpha_{\text{Soll}1} = 90°$
- $\alpha_{\text{Soll}2} = 90°$
- $r_{\text{Soll}3} = 1975\text{mm}$

**As-Built** (average) according to measurement final frame (COFU I²)
- $\alpha_1 = 88,75°$ ($\Delta \alpha_1 = 1,25°$)
- $\alpha_2 = 89,67°$ ($\Delta \alpha_2 = 0,325°$)
- $r_3 = 1963,5\text{mm}$ ($\Delta r_3 = 11,5\text{mm}$)
Minimum Tolerance Design
e.g. „Spring-In“ in LC frame – Theory

Influences regarding Spring-In not yet fully evaluated

Optimized process and lay-up parameters may reduce impact

\[ \Delta \theta_{ges} = \Delta \theta_{thermisch} + \Delta \theta_{chemisch} = \theta \left( \frac{(\alpha_t - \alpha_r) \cdot \Delta T}{1 + \alpha_r \cdot \Delta T} \right) + \frac{\phi_t - \phi_r}{1 + \phi_r} \]

\(\alpha_t:\) tangentialer Wärmedehnungskoeffizienten
\(\alpha_r:\) radialer Wärmedehnungskoeffizienten
\(\phi_t:\) tangentialen Laminatschwund
\(\phi_r:\) radialer Laminatschwund
\(\Delta T:}\) effektiv wirkende Temperaturdifferenz

*(Nelson, 1989 S. 2410)
entspricht bei 90° Winkel
0,45°
0,18° bis 0,63°
0° bis 0,81°
Minimum Tolerance Design

e.g. „Spring-In“ in LC frame – Simulation

Analysis of „Spring-In“ deformation in the corner radii frame to web after introduction of the modified thermal expansion coefficients:

“As-Designed” in frame outer flange $\alpha_{Soll1}=90^\circ$, measured “As-Built” $\alpha_1=88,75^\circ$

<table>
<thead>
<tr>
<th></th>
<th>V2</th>
<th>V7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{gel}$</td>
<td>180$^\circ$C</td>
<td>110$^\circ$C</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>$88,75^\circ$</td>
<td>$89,39^\circ$</td>
</tr>
<tr>
<td>2D + 3D</td>
<td>simulation of the radii</td>
<td>simulation of the radii</td>
</tr>
</tbody>
</table>

Minimum Tolerance Design

e.g. „Spring-In“ in LC frame – Simulation
Examples of Dependencies in CFRP Structure Development

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Sizing appropriate to Quality Control Techniques

e.g. consideration of undetectable imperfections in sizing

Old Squirter-Tool 4 Channels

Better Impuls-Echo Tool with 192 Channels
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Feasibility ➔ Concept ➔ Definition ➔ Development ➔ Production ➔ Assembly ➔ Series
Sizing appropriate for Production Tooling
e.g. mechanism to produce manufacturing driven imperfections

a) Autoclav Process

Resin border at rib tie web (end of modules)

b) Deforming Process

Resin border at rib tie web (end of modules)

Section A-A

Resin border at rib tie web due to increased radius of modules (wear and tear)

Stringer web

c) Mechanical Impact

Forces on rib tie web due to overcoming resin border during deforming process

Section B-B

Local defect

Stringer web

Bending Moment Skin

Section B-B (enlarged)

Bending Moment Rib Web

Rib tie web

Skin

Module part
Examples of Dependencies in CFRP Structure Development

- **Damage tolerant materials**
- **Materials for robust and efficient production**
- **Production tolerant sizing**
- **Modifiable design**

**Flowchart Diagram:**

- **Feasibility** → **Concept** → **Definition** → **Developmt.** → **Production** → **Assembly** → **Series**

- **Design appropriate to CFRP**
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- **Maintainable design**
- **Minimum tolerance design**
- **Sizing appropriate to quality control**
- **Materials for design**
- **Design appropriate to CFRP**
- **Feasibility**
Producible Design

e.g. surround structure for fuselage cutout

1) Selected Design Concept:
   Cutout Frame as Ladder Structure
   + Lighter
   + Easier to assemble
   + Better for repair
   - High manufacturing cost

2) Manufacturing Concept
   Target: Lower manuf. cost
   New tooling concept developed
   Simplified demonstrator to validate the concept
Producible Design

Examples for Improvement

- New forming and air-cast concept
- Better grouping and runout of plies
- Flexible kernels

Results

- Reduction in preforming >50%
- Reliable filling concept integrated in the tooling
- Cheaper Tools
  - Plug and Play kernels
  - Number of kernels reduced
  - Demoulding simplified
  - Reusable kernels
  - Rework minimized
- Reduction in Assembly
  - Shimless concept (shape to adjacent parts given by the female tooling)
  - Spring-in pre-calculated and anticipated in tooling
  - Number of single parts and attachments significantly reduced
Develop New Aircraft (DNA) Process
and contributing disciplines…

TLRs  
Baseline  
DPs /SAM  
Drawings  
Parts  
Product

Feasibility  
Concept  
Definition  
Developmt.  
Production  
Assembly  
Series

- FPO
- Aero
- Cabin
- Stress
- Design
- Loads
- Weight
- M&P
- DMU
- Config.
- Install
- Manufact
- Manuf. Eng.
- Quality
- System Install.
- Manufacturing
- Manuf. Eng.
- Quality
- Cabin Syst.
- Systems
- Cabin Syst.
- Systems
- Cabin Syst.
- Systems
- Cabin Syst.
- Systems
- Loads
- Stress
- Systems

Basic Aircraft
Customization
Certification
Concepts of concurrent development process today

- **Feasibility**
- **Concept**
- **Definition**
- **Development**
- **Production**
- **Assembly**
- **Series**

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Too many people working concurrent on one major subcomponent
not efficient

- **Sub-structuring required**

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Substructuring by Parts?
Small team with all relevant disciplines responsible for one part.

- **Preferred Manufacturing Solution**

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Substructuring by Disciplines?
Earlier involvement of relevant disciplines and regular DPMs.

- **Preferred Engineering Solution**

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Substructuring by Components?
Component build teams for fully equipped sections for assembly.

- **Preferred FAL and Programs Solution**
Proposed CFPR Development Process: Iterative

One CFK Core Team with design responsibility and budget
(Materials&Process, Stress, Design, Cabin, System Installation, Manufact. Engineering, Quality, Design to Cost, Automation,...)
We take care for full process chain in CFRP structures

- efficient
- tolerant
- light
- adaptable

CFRP Structures

Material Development

Design Methods

Sizing Design

Manufacturing Technologies

Adaptive Systems

Production Technologies
Production Technologies for High Performance Structures

- Large Components
- High Volume Parts
- Assembly
- NDT

Adaptive Systems
Manufacturing Technologies
Sizing Design
Design Methods
Material Development
Production Technologies
DLR Center for Lightweight Production Technologies
Sites, Partners and Customer

Stade
The North Platform
Bremen
Braunschweig

Augsburg
The South Platform

Stuttgart
München
“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

Thank you for listening