Future challenges in the design of structures made of CFRP

ICAS Workshop, 5 September 2011, Stockholm

Richard Degenhardt, Martin Wiedemann

DLR, Institute of Composite Structures and Adaptive Systems, Germany
Content

- **Example 1 (Space):**
  Proposal for a new design concept of unstiffened CFRP structures

- **Example 2 (Aeronautics):**
  Exploitation of reserve capacities of stiffened CFRP in the postbuckling area
DLR
German Aerospace Center

Research Institution
Space Agency
Project Management Agency
Locations and employees

7000 employees across 31 research institutes and facilities at
- 15 sites.

Aeronautical Research at the DLR

- **Aircraft Structures**
- **Engine**
- **Air Transport Concepts**
- **Weather & Climate**
- **Systems & Cabins**
- **ATM & Airports**
- **Flight Physics**

- Materials, Structures, Simulation and Validation
- Virtual Engines, Propulsion Techniques, Turbines, Fans, Combustion Technology, Validation
- Aerodynamic Systems and Flight Guidance, Virtual Aircraft and new Configurations, Flexible Aircraft
- Low emission, Noise impact, Wake vortex, Efficient airport traffic
- Air Transport Management, Human Factors, Airport Security

Institute of Composites Structures and Adaptive Systems
Institute of Structures and Design
Stuttgart

71 Employees
Scientists: 43
Guest Scientists: 2
Doctorate Students: 2
Technicians/Admin.: 24

Institute of Materials Research
Köln/Porz

75 Employees
Scientists: 32
Guest Scientists: 2
Doctorate Students: 9
Technicians/Admin.: 25
Institute of Composite Structures and Adaptive Systems
Director: Prof. Dr.-Ing. M. Wiedemann

We are experts for the design and realization of innovative lightweight systems.
Our research serves the improvement of:

- Safety
- Cost efficiency
- Functionality
- Comfort
- Environmental protection
Our Professional Competences in the Institute of Composite Structures and Adaptive Systems
Our Professional Competences – Bricks of the Process Chain of High Performance Lightweight Structures

We orient ourselves along the entire process chain for building adaptable, efficient manufactured, lightweight structures.

For excellent results in the basic research and industrial application.

Composite technology

Adaptronics

Composite Process Technology

Composite design

Structural mechanics

Multifunctional materials

The aim: adaptable, tolerant, efficient manufactured, lightweight structures
Our Fields of Research

Our research and development on material systems and lightweight structures aims at
Safety • cost efficiency • functionality • comfort • environment protection

Upstream Research
Basic research

Composite technology
Adaptronics
Process technology
Composite design
Structural mechanics
Multifunctional materials

High Performance Light Weight Structures

Downstream Research
Application related research

Aeronautics
Space
Transport
Energy

Institute of Composites Structures and Adaptive Systems
Multifunctional Materials
Dr. P. Wierach
We increase the ability of the materials!

• Fiber- and nanocomposites
• Smart materials
• Structural health monitoring
• Material characterization

Structural Mechanics
Dr. A. Kling
With high fidelity to virtual reality for the entire life cycle!

• Global design methods
• Stability and damage tolerance
• Structural dynamics
• Thermal analysis
• Multi-scale analysis
• Process simulation

Composite Design
Dr. C. Hühne
Our design for your structures!

• Design and Sizing
• Structure concepts and assessment
• Multi-functional structures
• Shape-variable structures
• Hybrid structures

From materials to intelligent composites
From the phenomenon via modeling to simulation
From requirements via concepts to multi-functional structures

Institute of Composites Structures and Adaptive Systems
Composite Technology
Dr. M. Kleineberg

Tailored Manufacturing Concepts

- New technologies for manufacturing
- Hybrid manufacturing
- Assembly
- Repair
- Process automation

Adaptronics
Dr. H. P. Monner

The adaptronics pioneers in Europe!

- Simulation and demonstration of adaptive systems
- Active vibration control
- Active noise control
- Active shape control
- Autarkic Systems

Composite Process Technology
Dr. M. Meyer

Research with industrial dimension

- Automated FP und TL
- Online QA within Autoclaves
- Automated Manufacturing for mass-production
- Simulation methods for maximum process reliability und process assessment

Institute of Composites Structures and Adaptive Systems
Our Professional Competences

**DLR Center for Lightweight Production Technology (ZLP)**

**ZLP Site Stade**  
Prof. Wiedemann, Dr. Meyer

**ZLP Site Augsburg**  
Prof. Voggenreiter, Dr. Dudenhauen

Leader ZLP  
Dr. Meyer
DLR Center for Lightweight Production Technology (ZLP) Site Stade

Research Topics
- Robot based AFP
- High production rates
- Online-QS for Autoclave
- Thermoset & Prepreg
- Tooling Technologies
- Process simulation

Key-Figures (Target 2013)
- Staff: 40
- Total investment: ~68 M€
  Infrastructure & Machinery
Our Professional Competences

DLR Center for Lightweight Production Technology (ZLP)
Site Stade

CFK-NORD

Large Components

High production rates

Institute of Composites Structures and Adaptive Systems
Our Professional Competences

**DLR Center for Lightweight Production Technology (ZLP)**
**Site Augsburg**

*Research Topics*
- Textile- and Infusion-technologies
- Robotics, mechantronics
- Thermoset & Thermoplast
- Integrated quality control technologies
- Joining and assembly technologies

*Key Figures (Target 2013)*
- Staff: 40
- Total investment: 50 M€
  Infrastructure & Machinery
**Applied Research** | Our Foci of Product Oriented Research

**Focus**  
**Fuselage Technologies** | T. Ströhlein

- Fuselage design
- Large cut-outs
- Manufacturing technologies

**Focus**  
**High Lift** | M. Kintscher

- Flexible leading edge
- Morphing of high lift systems
- Structural integration of active flow control

**Focus**  
**Special structures** | M. Hanke

- Safety relevant aeronautic structures and UAVs
- Multifunctional composite structures
- Demonstration of design and technology
In order to deal with strength, stability and thermo-mechanical problems we operate unique experimental facilities like thermo-mechanical test facilities, buckling facilities with the special feature of dynamic loading. Manufacturing facilities like preforming, filament winding, liquid composite moulding or microwave curing enable us to develop novel manufacturing techniques and the realization of innovative composite structures.

We transfer our scientific and technical expertise in the field of design and manufacture of lightweight composite structures and adaptronics as partners in an international network of research and industry.
Content

⇒ DLR
  ⇒ Institute of Structures and Design, Institute of Materials Research
  ⇒ Institute of Composite Structures and Adaptive Systems

⇒ Example 1 (Space):
  Proposal for a new design concept of unstiffened CFRP structures

⇒ Example 2 (Aeronautics):
  Exploitation of reserve capacities of stiffened CFRP in the postbuckling area
Comparison: Stiffened and unstiffened structures

Light weight structures endangered by buckling can be divided into the following two groups:

**Imperfection tolerant structures:**
- Maximum load > first buckling load
- Postbuckling area is exploited for design
- Design load independent of imperfections

**Imperfection sensitive structures:**
- Maximum load = first buckling load
- No exploitable postbuckling area
- Design load highly dependent of imperfections
State-of-the-art - NASA-SP 8007 Design guideline

Valid for metallic structures

No guidelines for composites structures
**Example: CFRP cylinder**
- Total length = 540 mm
- Free length = 500 mm
- Ply orientation = +24,-24,+41,-41
- Radius = 250 mm
- Thickness = 0.5 mm
- \( R/t = 500 \)
- \( F_{\text{Perfect}} = 32 \text{ kN} \)

Buckling load of the perfect cylinder, scaled to 1

**Design load**

\[
F_{\text{Design load}} = F_{\text{Perfect}} \times \rho \quad \text{NASA}
\]

\[
F_{\text{Design load}} = 32 \times 0.32 = 10.2 \text{ kN}
\]
**Example: CFRP cylinder**
- Total length = 540 mm
- Free length = 500 mm
- Ply orientation = +24, -24, +41, -41
- Radius = 250 mm
- Thickness = 0.5 mm
- R/t = 500
- \( F_{\text{Perfect}} = 32 \text{ kN} \)

\[
F_{\text{Design load}} = F_{\text{Perfect}} \cdot \rho_{\text{NASA}}
\]

\[
F_{\text{Design load}} = 32 \cdot 0.32 = 10.2 \text{ kN}
\]
Single Perturbation Load Concept (SPLC)

Radial perturbation load

- Position and magnitude are variable
- Several tests with different imperfections

Test procedure:
1. radial perturbation load
2. axial compression
Single Perturbation Load Concept (SPLC)
Single Perturbation Load Concept (SPLC)

- Each dot marks one test
- Unexpected horizontal curve progression
New approach:
Idealization of curve
Lower boundary limit of buckling load for imperfect shells: „Load carrying capability $F_1$“

$P_1 = \text{Minimum single perturbation load}$
Questions

- What are the limits of the single perturbation concept? Especially with respect to different kinds of structures.
- What is the minimum required single perturbation load $P_1$ which is needed for the calculation?
- Are there any cases the single perturbation load is not leading to the worst imperfection?
- Applicable to stiffened structures?
- What kind of influence damages or holes will have on the buckling load?
- How does one model the structure in order to achieve reliable results?
- How broad is the bandwidth determined by stochastic approach?
Institute of Composites Structures and Adaptive Systems

Buckling load of the perfect cylinder, scaled to 1

Experiments

Example: CFRP cylinder
Total length = 540 mm
Free length = 500 mm
Ply orientation = +24,-24,+41,-41
Radius = 250 mm
Thickness = 0.5 mm
R/t = 500
F_{Perfect} = 32 kN

\[ F_{Design load} = F_{Perfect} \times \rho \]

\[ F_{Design load} = 32 \times 0.32 = 10.2 \text{ kN} \]

\[ F_{Design load} = 32 \times 0.58 = 18.5 \text{ kN} \]
Example: CFRP cylinder
Total length = 540 mm
Free length = 500 mm
Ply orientation = +24,-24,+41,-41
Radius = 250 mm
Thickness = 0.5 mm
R/t = 500
$F_{\text{Perfect}} = 32$ kN

Conclusion: The SPLC allows in this example to increase the load carrying capacity by 82%.
Next step:

EU project DESICOS (2012 - 2014)
Summary and Conclusions

- The NASA SP 8007 guideline is very conservative if composite structures shall be designed.
- The Single-Perturbation load approach is a promising alternative.
- However, a lot of new questions are not answered (e.g. minimum perturbation load).
- First steps were performed (e.g. a new empirical formula for the critical perturbation load $P_1$ for metallics).
Content

- **Example 1 (Space):**
  Proposal for a new design concept of unstiffened CFRP structures

- **Example 2 (Aeronautics):**
  Exploitation of reserve capacities of stiffened CFRP in the postbuckling area
EU projects

More Affordable Aircraft Structure through eXtended, Integrated, & Mature nUmerical Sizing

MAAXIMUS (FP 7, Level 2)

COCOMAT (FP 6, STREP) \rightarrow DAEDALOS (FP 7, Level 1)


Improved MATerial Exploitation at Safe Design of COMposite Airframe Structures by Accurate Simulation of COLLapse

Dynamics in Aircraft Engineering Design and Analysis for Light Optimized Structures

Institute of Composites Structures and Adaptive Systems
COCOMAT: Designs on panel level

**Current Design Scenario**

- Load
- Shortening
- Not allowed (III)
- Safety Region (II)
- Allowed under operating flight conditions (I)

- Ultimate Load (UL)
- Limit Load (LL)
- First Buckling Load (FBL)
- Onset of Degradation (OD)
- Collapse

**Future Design Scenario**

- Load
- Shortening
- Collaps
- Ultimate Load (UL)
- OD
- LL
- FBL
MAAXIMUS project – Strategy

Fast Development & Right-First Time Validation of a highly-optimized New Generation Composite Fuselage by a huge step in Simulation-based design

Development of two platforms

Virtual Platform
Innovative & Integrated Simulation-Based Design

Physical Platform
Full-scale Composite Fuselage Manufacturing, Assembly & Test of 2 one-shot sections

Institute of Composites Structures and Adaptive Systems
Conclusions and perspective

- Future work should facilitate full applicability of analysis methods in preliminary design.

- Speed of postbuckling analysis of stiffened panels needs to be increased.

- For collapse simulation degradation must be taken into account.
Thank you for your attention