Challenges in the Validation of Stability Sensitive Multiaxialy Loaded CFRP Structures

DFG Workshop
Inauguration of the new Multiaxial Test Rigs at TU Braunschweig and Hamburg University of Technology
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DLR, Institute of Composite Structures and Adaptive Systems
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- Introduction
- DLR Institute of Composite Structures and Adaptive Systems
- Comparison: Stiffened and unstiffened structures
- Examples
  - Aerospace
  - Space
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1 kg less structural weight means saving of ca. 3 tons fuel in 20 operating years (A340-300)
Introduction

- The use of new materials as CFRP is one way to reduce structural weight.
- CFRP is already used in different primary structures (e.g. aerospace), however, the potential of CFRP is currently not fully exploited.
- One reason is that the material is still not fully understood and corresponding design guidelines are missing.
- Need for:
  - Improved design concepts and simulation tools
  - Validation by experimental results
- For a comprehensive validation especially experiments of multiaxial loaded structures are needed.
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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 – 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.
Structural Mechanics – Motto

Experimental Methods
- Efficient testing facilities
- Qualification of structural concepts
- Validation („Validation Experiments“)

Numerical Methods
- Fast Design Tools
- Virtual Structures
- Structural Exploitation

From the phenomenon via modelling to simulation- and testing tools
Structural Mechanics – Computational Goals

… to modify the shape of the pyramid …
- Virtual Tests
- Virtual Structures
- Virtual Certification
Experimental Testing Facilities (extract)

- Thermex (Thermo-mechanical Test Facility)
- Buckling Test facility (Compression and Shear)
- Subcomponent Tests
- Flexible Testbed (Frame bending, etc.)
Stability and Buckling – Experimental Testing

- DLR buckling test facility for stability testing under shear and axial compression
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Comparison: Stiffened and unstiffened structures

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

**Stiffened structures:**
- Maximum load > first buckling load
- Postbuckling area is exploited for design
- Design load less dependent of imperfections

**Unstiffened structures:**
- Maximum load = first buckling load
- No exploitable postbuckling area
- Design load highly dependent on imperfections
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Axially loaded CFRP panel

Deformed Shape FE-Analysis (Skin)  Measured Deformation Pattern (Optical 3D-Digitizing - Photogrammetry)

Deformed Shape FE-Analysis (Stringer)  Load-Shortening-Curve (Scaled)
Cyclic test – Load shortening curves

2000 cycles up to 92 kN
1800 cycles up to 109 kN
1 collapse test
Cyclic test – Load shortening curves

- Cycle 0001
- Cycle 0401
- Cycle 0801
- Cycle 1201
- Cycle 1601
- Cycle 2001
- Cycle 2401
- Cycle 2601
- Cycle 2801
- Cycle 3001
- Cycle 3201
- Cycle 3401
- Cycle 3601
- Cycle 3801 Collapse
Next steps

- Development of fast simulation concepts including axial compression and shear.
- Testing by combined axial compression and shear.
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State-of-the-art: NASA-SP 8007 design guideline

- Valid for metallic structures
- No guidelines for composites structures

Buckling load of the perfect cylinder, scaled to 1

Radius / Thickness
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

Buckling load of the perfect cylinder, scaled to 1

Knock down factor

Radius / Thickness

$F_{\text{Design load}} = F_{\text{Perfect}} \times \rho$ NASA

$F_{\text{Design load}} = 32 \times 0.32 = 10.2$ 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

$F_{\text{Perfect}} = 32 \text{ kN}$

$F_{\text{Design load}} = 32 \times 0.32 = 10.2 \text{ kN}$
Single Perturbation Load Concept (SPLC)
Single Perturbation Load Concept (SPLC)

- Each dot marks one test
- Unexpected horizontal curve progression
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
\( F_{\text{Perfect}} = 32 \text{ kN} \)

\[
\begin{align*}
F_{\text{Design load}} &= F_{\text{Perfect}} \times \rho \\
F_{\text{Design load}} &= 32 \times 0.32 = 10.2 \text{ kN}
\end{align*}
\]

\[
\begin{align*}
F_{\text{Design load}} &= F_{\text{Perfect}} \times \rho \\
F_{\text{Design load}} &= 32 \times 0.58 = 18.5 \text{ kN}
\end{align*}
\]
Next steps

- Development of new design concept (DESICOS)
- Testing by combined axial compression and internal pressure.
Conclusions

- Future activities are going to exploit the reserve capacities of new materials more and more.
- New design concepts are developed.
- For a comprehensive validation especially experiments of multiaxially loaded structures are needed.
Stability and Buckling – Experimental Testing

DLR Buckling Test Facility - Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>max. panel radius (extendable)</td>
<td>2300 mm</td>
</tr>
<tr>
<td>min. panel radius</td>
<td>1550 mm</td>
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<tr>
<td>max. panel length</td>
<td>1400 mm</td>
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<tr>
<td>max. panel width</td>
<td>1200 mm</td>
</tr>
<tr>
<td>max. axial force, (extendable)</td>
<td>380 kN, (1 MN)</td>
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<tr>
<td>max. shear force, (extendable)</td>
<td>210 kN, (500 kN)</td>
</tr>
<tr>
<td>max. shear stroke</td>
<td>100 mm</td>
</tr>
<tr>
<td>max. axial stroke</td>
<td>40 mm</td>
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</tbody>
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