Composite structures
Potentials for improved performance and function integration

Martin Wiedemann
32nd Risø International Symposium on Materials Science
09-06-11
Overview

- Some words about the DLR – The German Aerospace Center
- Core competencies at the DLR-Institute
  Composite Structures and Adaptive Systems
- Potential contributions to further performance improvements
  - Material
  - Simulation
  - Design
  - Manufacturing Technologies
  - Function Integration
  - Composite Process Technologies
- Conclusion and Perspectives
The DLR

German Aerospace Research Center
Space Agency of the Federal Republic of Germany
DLR Sites and employees

6900 employees working in 33 research institutes and facilities
- at 8 sites
- and in 7 field offices.

DLR Mission

To open up new dimensions for exploring the earth and the universe, for protecting the environment and for promoting mobility, communication and security:

- Research portfolio ranging from basic research to innovative applications and the products of tomorrow
- Operating large-scale research facilities for DLR’s own projects and as a service provider for its clients and partners
- Promoting the next generation of scientists
- Advisory services to government
DLR Research Fields

- Aeronautics
- Transportation
- Energy
- Space
### DLR Executive Board

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Dr.-Ing. Johann-Dietrich Wörner, Chairman</td>
<td>Overall strategy and development, External relations, Corporate Communication, ESA Council</td>
</tr>
<tr>
<td>Klaus Hamacher, Vice Chairman</td>
<td>Human Resources, Finance, Corporate Organisation, Quality Assurance and Infrastructure, Technology Marketing, Information technology, Project Management Agency</td>
</tr>
<tr>
<td>Gerd Gruppe</td>
<td>Space Agency, National/ESA program</td>
</tr>
<tr>
<td>Prof. Dr.-Ing. Rolf Henke (temporarily)</td>
<td>Space: research, programs, projects, technology transfer</td>
</tr>
<tr>
<td>Prof. Dr.-Ing. Rolf Henke</td>
<td>Aeronautics: research, programs, projects, technology transfer, Approved Design Organisation</td>
</tr>
<tr>
<td>Prof. Dr.-Ing. Ulrich Wagner</td>
<td>Transport and Energy: research, programs, projects, technology transfer</td>
</tr>
</tbody>
</table>
DLR Program Management

Program Directorates

- Aeronautics
- Space
- Energy
- Transport

Institutes and Facilities

Know-how, Research facilities

Service and resource agreements

Projects Programs

Resources
DLR Total income 2010 – Research, operations and management tasks (excluding trustee funding from the Space Agency/ DLR Project Management Agency): **751 Mio.€**

![Pie chart showing income distribution](chart.png)
DLR Large-scale facilities (1)

- Research aircraft
- Research helicopters
- Compressor and turbine test rigs
- German Space Operations Center (GSOC)
- German Remote Sensing Data Center (DFD)
DLR Large-scale facilities (2)

- Space propulsion test rigs
- Wind tunnels
- Solar furnace
- Solar fields
- Autoclaves
- Traffic tower
Institute of Composite Structures and Adaptive Systems

We are experts for the design and realization of innovative lightweight systems.

Our research serves to improvement:

- 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 align our research along the entire process chain for building adaptable, tolerant, efficiently manufactured light weight structures.

For excellent results in the basic research and industrial application.

The aim: adaptable, tolerant, efficiently manufactured, lightweight structures
Evolution in wind turbine size

Mass growth for commercial MW-scale blade designs (primarily fiberglass)

DLR-FA Competencies and potentials for wind energy

Adaptronics

Composite process technologies

Morphing
Vibration Control

Production technologies for large parts / high volume

Manufacturing technologies

Multifunctional materials

Efficient manufacturing and tooling concepts

Cost efficient materials SHM

Composite design

Structural mechanics

Performance and production optimized lightweight design

Sizing Methods, Effects of Defects, Testing

Source: Gurit
Multifunctional materials

The aim: adaptable, tolerant, efficiently manufactured, lightweight structures

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

We increase the ability of the materials!
Multifunction materials

Specific Strength and Strain of Lightweight Metals and Composite Laminates

- Wood
- TiAl (NiCr 20)
- UD Flax & Phenol (50% FVG)
- UD GFK (60% FVG)
- UD AFK (Kevlar); 60% FVG
- UD CFK (60% FVG) HM
- UD CFK (60% FVG) HT
- UD CFK (60% FVG) UMS
- UD AlMgZn
- Steel (12% Cr)

Specific Stiffness (Strain Length) $E/\gamma$ [km]
Specific Strength (Strength Length) $\sigma/\gamma$ [km]
Structure health monitoring by lamb waves

Working principle

- Generation and reception of lamb-waves with piezo transducers to identify damages
- Visualization of wave propagation to allow an interpretation of the complex signals received by the piezo sensor
- Below a certain frequency $f_g$ only two modes are excited:
  - Symmetric mode ($S_0$ - longitudinal mode)
  - Anti-symmetric mode ($A_0$ - bending mode)
Structure health monitoring by lamb waves

Example of structure wave propagation with and without defect (visualized by ultrasonic measurement of surface displacements)

Received signal with intact stringer bonding

Received signal with defect in stringer bonding
**Structural mechanics**

The aim:
- adaptable, tolerant, efficiently manufactured, lightweight structures

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

With high fidelity to virtual reality for the entire life cycle!
Structural mechanics - goals

Experimental

- Phenomena
- Properties
- Validation

Method development

- Sizing methods
- Effects of defects
- Virtual Structures

Virtual testing
Structural mechanics – effects of defects

Develop validated and reliable methods to predict the strength of composite structures with manufacturing defects for assessment of defect criticality and need for repair.

- Voids
- Folds
- Waves
Composite design

Our design for your structures!

From requirements via concepts to multi-functional structures

- Design and Sizing
- Structure concepts and assessment
- Multi-functional structures
- Shape-variable structures
- Hybrid structures
Composite design - Hybrid in couplings

High Performance Material Combination

- Alternative coupling concepts for root-hub joint and blade segments
- Hybrid structures for local reinforcement of highly loaded areas
- Minimum tolerance design

Bearing strength (LB) against the metal content for different hybrid material configurations.
Source: Axel Fink, DLR-FA
Composite design – function integration

Function integration
- Coupled aero-structure design
- Force flow optimized design
- Integration of actuators, sensors, wiring, antennas...

Source: www.rotortechnik.at
Source: Gurit
Composite design – CFRP nacelle

Casted rotor nacelle Nordex N-80 (weight 15 t)

Concept Study
- Differential design
- Fiber-, force flow and load bearing optimized
- CFRP root joints
- Metal Hub
- Shear load carrying joints made from metal
- Load transfer from CFRP to metal via hybrid material combination

Source: Internet - VDE
Manufacturing technologies

The aim: adaptable, tolerant, efficiently manufactured, lightweight structures

Tailored Manufacturing Concepts

- New technologies for manufacturing
- Hybrid manufacturing
- Assembly
- Repair
- Process automation
Manufacturing technologies - units and tooling

Concepts
- Continuous preforming
- Draping and infusion/injection technologies
- Resin flow simulation and concepts
- Smart and flexible tooling
- Tolerance management and high fidelity production
Manufacturing technologies – dielectric heating

- Glasfiber composites have good dielectric properties
- Microwaves can heat resin in glasfiber laminates effectively
- The heating is contactless, selective in the resin zone and minimal since nothing else is heated
- Large parts like rotor blades can be heated by microwaves up to full polymerization
- The microwave can be used with flexible portal units for heating locally and with flexible timing
Manufacturing technologies – process control

Process control
• Tolerance management
• Thickness control
• Reproducibility
• Adjustability
• Correctability
Adaptronics

The aim:
- adaptable, tolerant
- efficiently manufactured, lightweight structures

From functional composites to adaptive systems

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

The adaptronics pioneers in Europe!
**Adaptronics - Active Vibration Control**

**Challenge:**
Decoupling of the blade-born vibration from transmitting into the gear box or tower

**Solution:**
Use of active lightweight struts with integrated piezoelectric ceramic stack actuators

In combination with robust control algorithms a significant reduction of the vibration levels can be achieved
Challenge:
Individual twist actuation (+/-2°) of a helicopter rotor blade for noise and vibration reduction and performance improvement

Solution:
Integration of anisotropic actuation in the rotor blade skin
Development, manufacturing and test of a model rotor blade in a centrifugal and wind tunnel test (proof of concept, validation)
Adaptronics - morphing

Hinged Struts
Interface elements
Omega shaped stiffeners
Drive shaft and bearing at front spar
Front Spar
Omega shaped stiffeners

Fiber reinforced skin

FE undeformed
FE deformed
Measured deformed

x-axis in mm
z-axis in mm

0
100
200
300
400
500
600

-250
-200
-150
-100
-50
0
50
100
150
200

0
100
200
300
400
500
600

-250
-200
-150
-100
-50
0
50
100
150
200
Composite process technologies

The aim: adaptable, tolerant, efficiently manufactured, lightweight structures

Manufacturing technologies
Adaptronics
Composite process technologies
Composite design
Structural mechanics
Multifunctional materials

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

Research with industrial dimension
Composites Process Technologies
Cooperating robots working on large parts

Grofi Anlage im ZLP Stade (DLR)

Winding with robots
Conclusion on potentials for future improvements and function integration

- Hybrids and CFRP materials allow more lightweight and efficient design
- Structural health monitoring by lamb waves with integrated networks help to ease maintenance
- Better methods for simulation may replace full scale testing partially
- Intensive simulation of defects allow better assessment of criticalities
- Weight and material saving potentials in design of blades and nacelle
- Further function integration into the structure can be used
- Faster and less energy consuming manufacturing technologies are available
- Flexible toolings allow savings in manufacturing
- Process control for better quality is in development
- Active vibration control can be integrated into the structure
- Active morphing of structure profiles with integrated functional materials is possible, for example for gust loads alleviation
- Process technologies for fast fiber layup in large structures are in development