Future challenges in the design of structures made of CFRP

ICAS Workshop, 5 September 2011, Stockholm

Richard Degenhardt, Martin Wiedemann

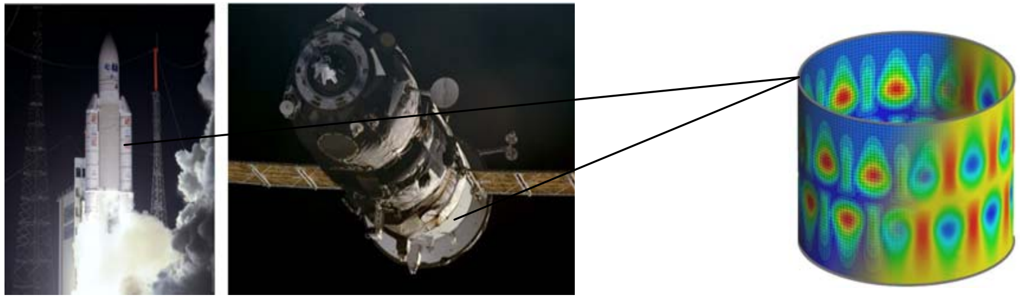
DLR, Institute of Composite Structures and Adaptive Systems, Germany

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Content

- DLR
  - Institute of Structures and Design, Institute of Materials Research
  - Institute of Composite Structures and Adaptive Systems
- Example 1 **(Space):**

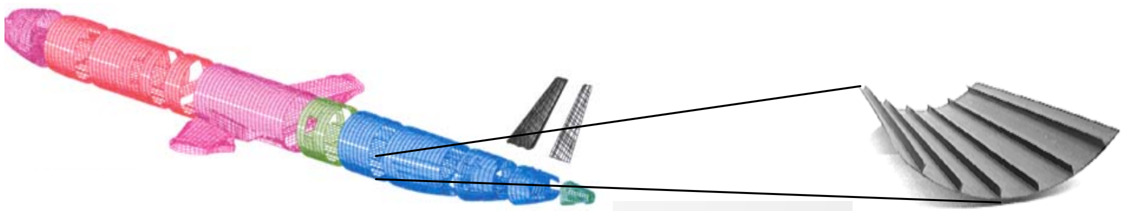
  Proposal for a new design concept of unstiffened CFRP structures



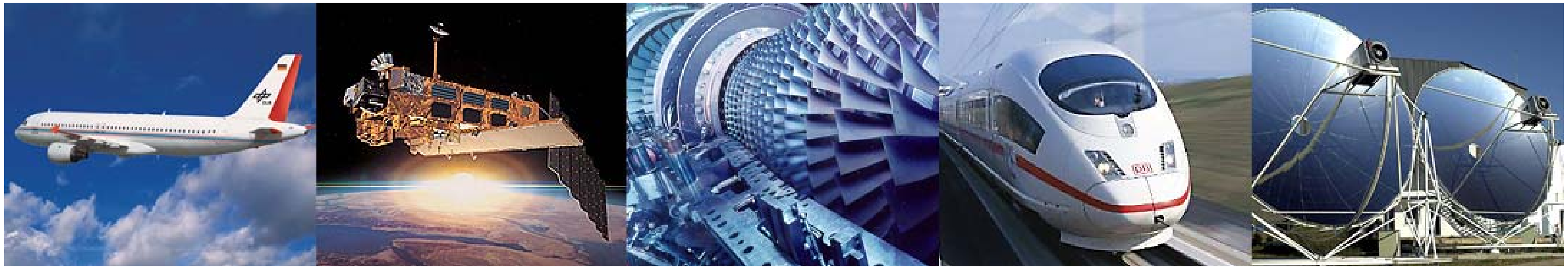
Ariane 5 Int. space station ISS

- Example 2 **(Aeronautics):**

  Exploitation of reserve capacities of stiffened CFRP in the postbuckling area



DLR
German Aerospace Center



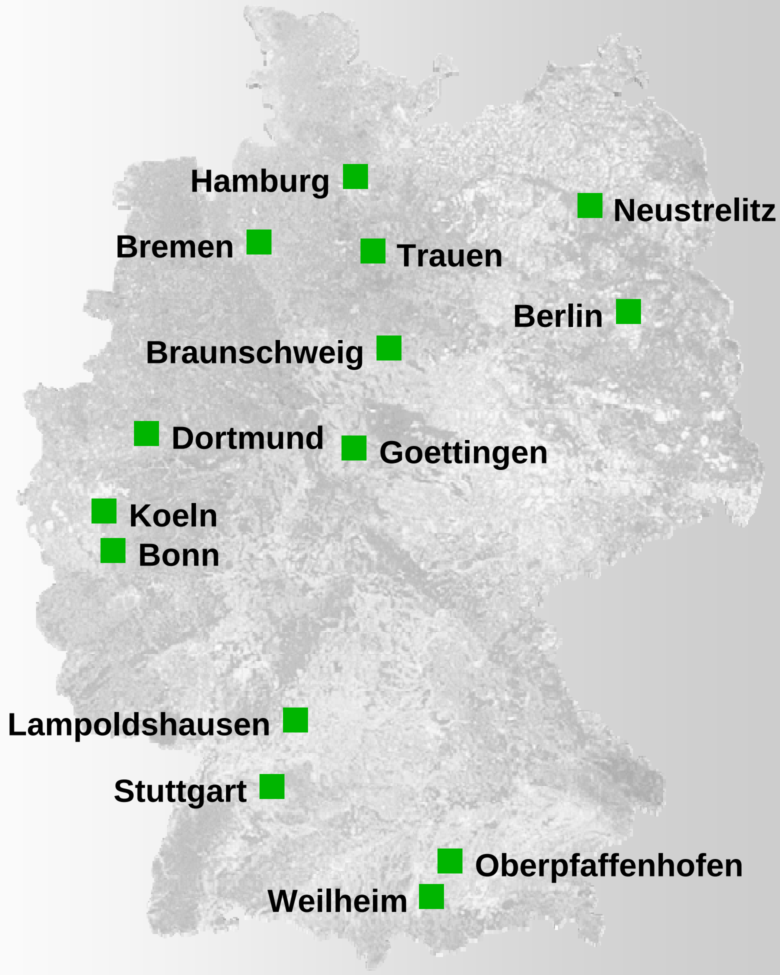
- Research Institution
- Space Agency
- Project Management Agency

Locations and employees

7000 employees across 31 research institutes and facilities at

- 15 sites.

Offices in Brussels, Paris, Singapore and Washington.



Aeronautical Research at the DLR

Materials, Structures,
Simulation and
Validiation

Aerodynamic Systems and
Flight Guidance, Virtual Aircraft
and new Configurations
Flexible Aircraft

Low emission
Noise impact,
Wake vortex
Efficient airport traffic

Virtual Engines
Propulsion Techniques
Turbines, Fans,
Combustion Technology,
Validation

Air Transport Management
Human Factors
Airport Security

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

Light Weight Alloy Structures

- Al-, Ti- and inter-metallic alloys
- Material behavior
- Friction Stir Welding
- Multi material design concepts

Fiber Reinforced Polymer Structures

- Thermoplastics
- Autoclave-less Processing
- Hybrid concepts Joining technology
- Design concepts
- Numeric simulation

Ceramics

- Fiber reinforced oxide and non-oxide ceramics
- Thermoelectric materials
- Design principles
- Ballistic protection

Hybrid Structures

- Hybrid materials de-velopment
- Hybrid design concepts
- Joining technology
- Numeric Modeling

Structural Integrity

- Numerical simulation of crash and impact behavior
- Materials models
- Crash & HVI testing
- Modeling of aircraft structures

Non destructive testing

- Computer tomography
- Ultra-Sonic-Technology
- Thermography
- Effects of defects

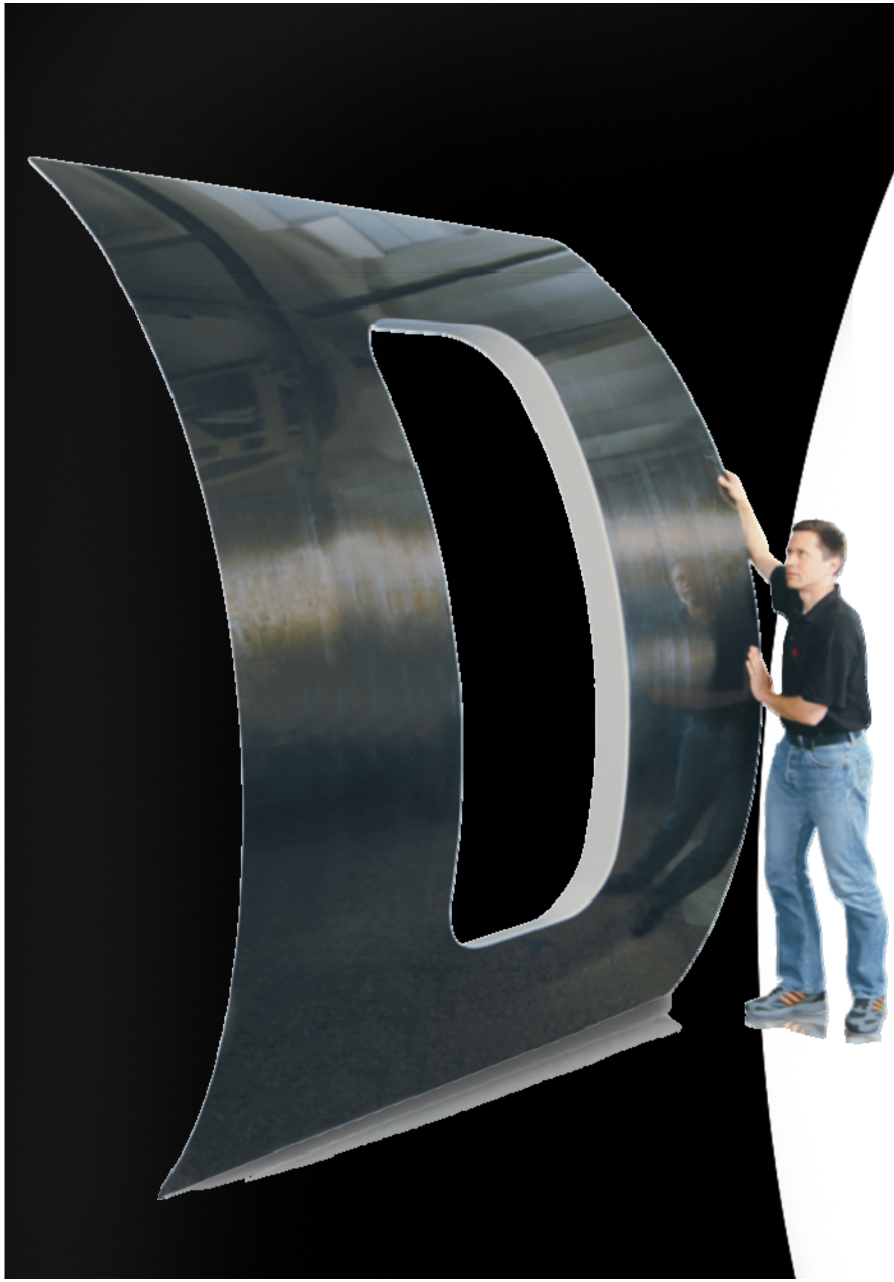
Coating Technology

- EB-PVD, Gas-Flow-Sputtering, Multi-Target-Sputtering
- Thermal and Environmental barrier coatings
- Lifing

Experimental & Numerical methods

- Validation methods
- Analysis of special materials properties
- Numeric materials models
- Multi-scale modeling

Start-up phase



Institute of Composite Structures and Adaptive Systems

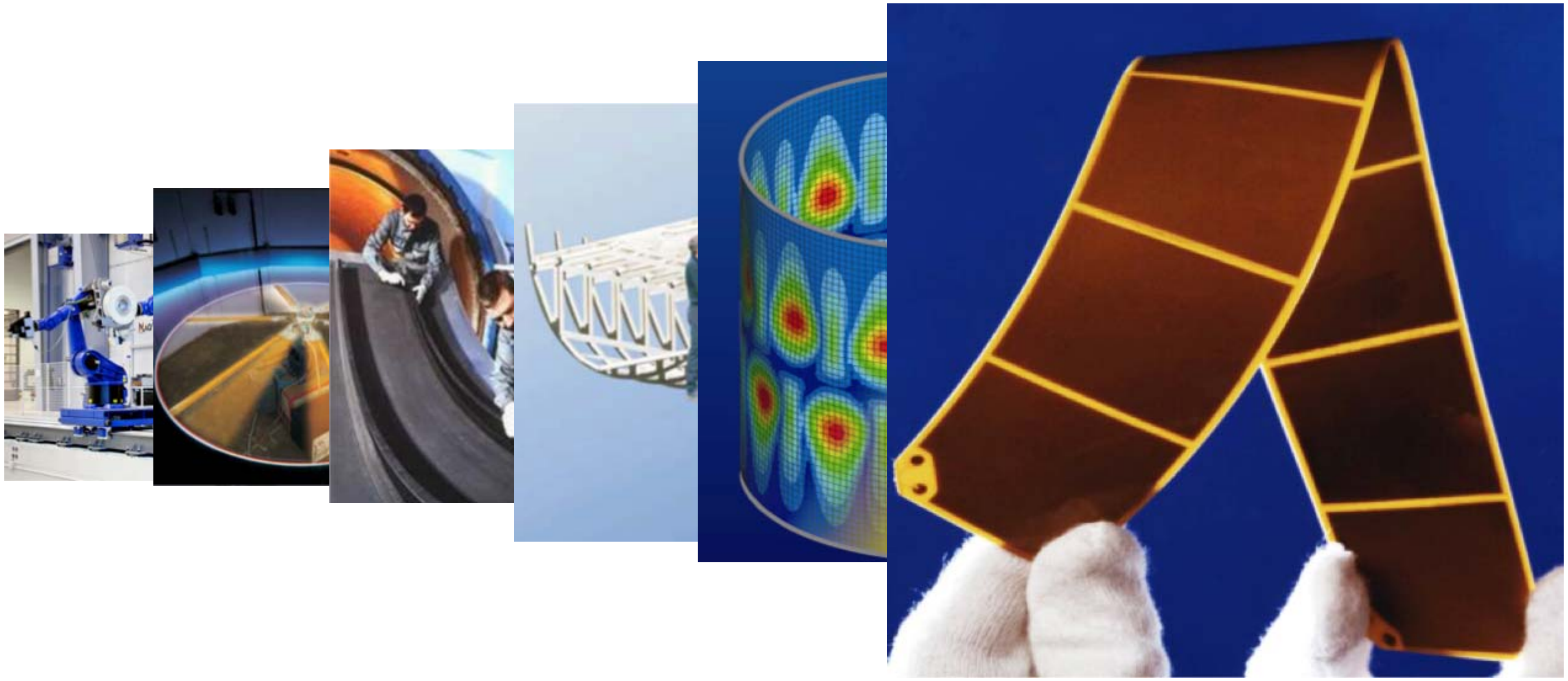
Director: Prof. Dr.-Ing. M. Wiedemann

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**

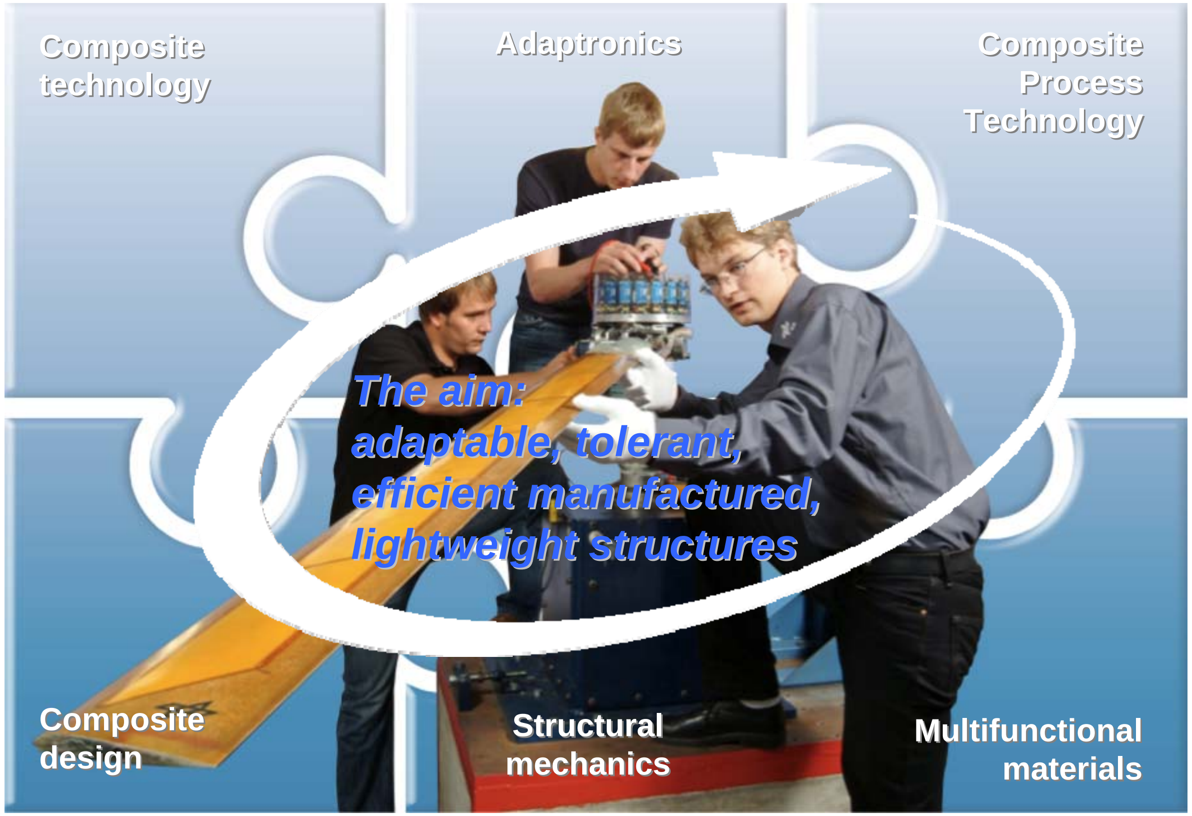


Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

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.

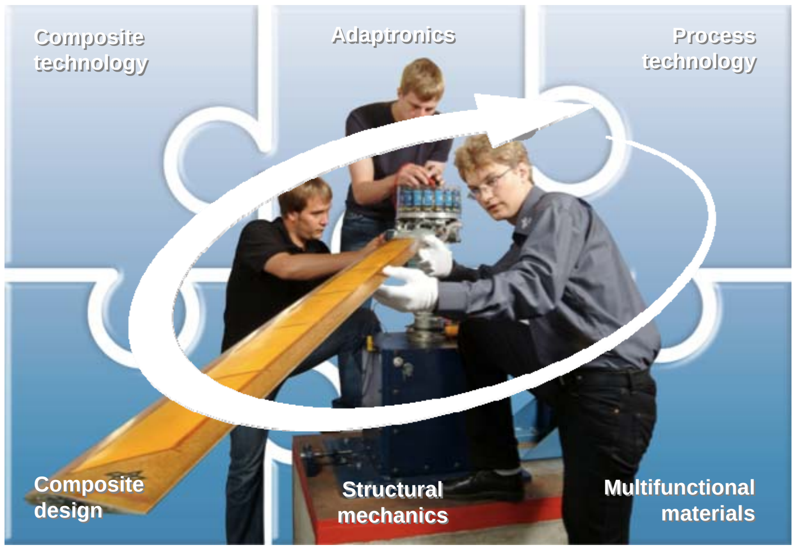


Our Fields of Research

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

Upstream Research

Basic resarch



High Performance Light Weight Structures

Downstream Research

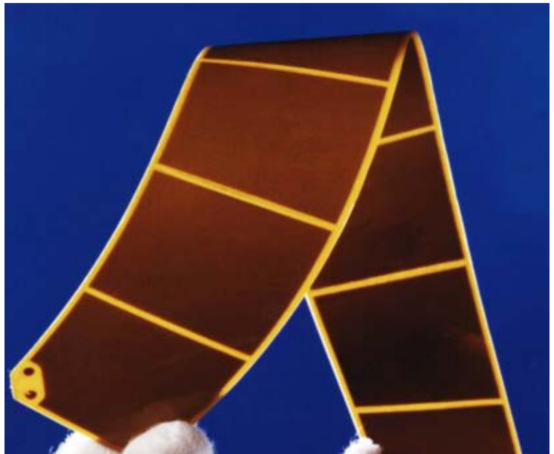
Application related research

Aeronautics	Space
Transport	Energy

Multifunctional Materials

Dr. P. Wierach

We increase the ability of the materials!



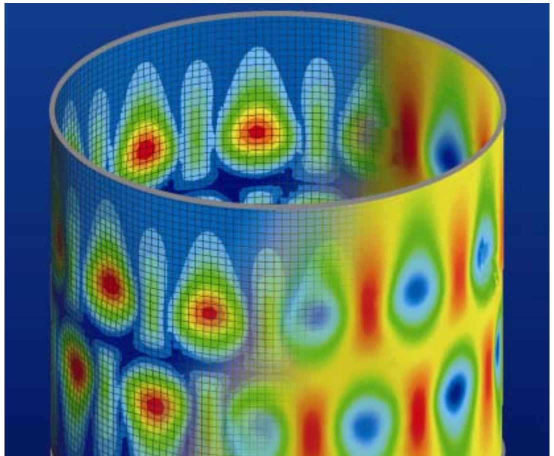
From materials to intelligent composites

- 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!



From the phenomenon via modeling to simulation

- 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!

From requirements via concepts to multi-functional structures

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

Composite Technology
Dr. M. Kleineberg

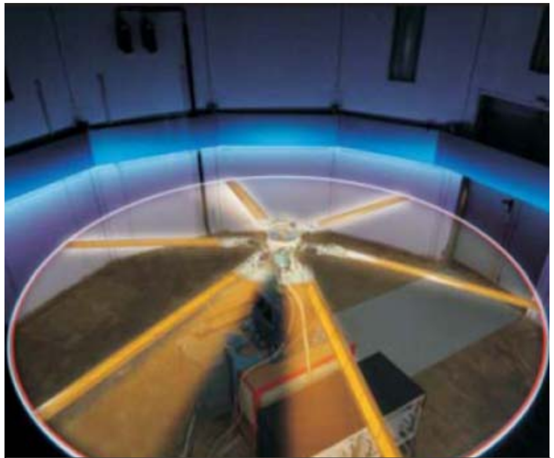
Tailored Manufacturing Concepts

From the idea via processes to prototypes

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

Adaptronics
Dr. H. P. Monner

The adaptronics pioneers in Europe!



From functional composites to adaptive systems

- 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

For sustainable processes

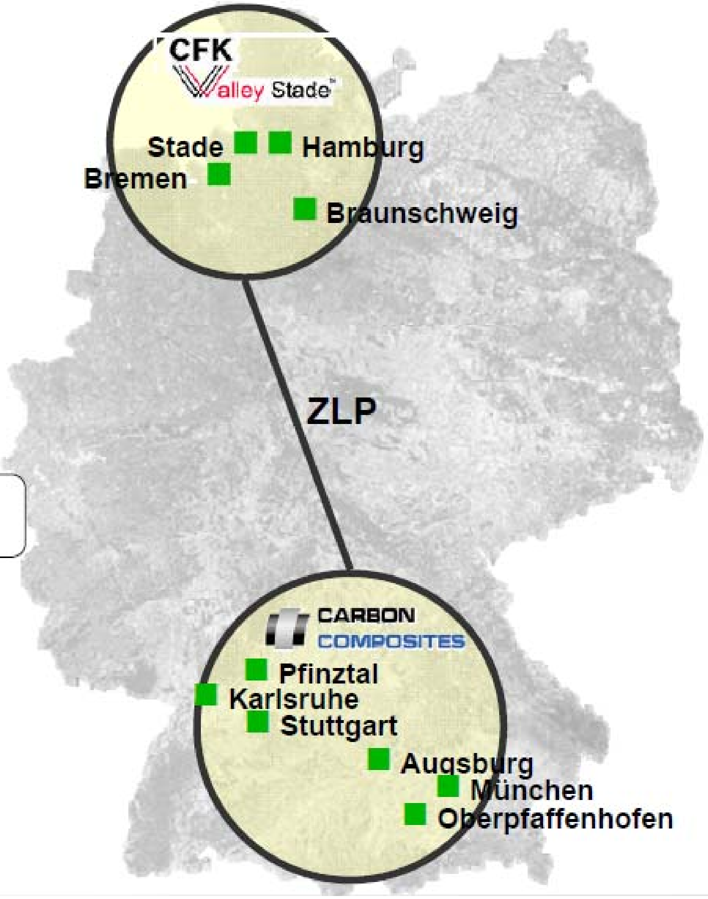
- Automated FP und TL
- Online QA within Autoclaves
- Automated Manufacturing for mass-production
- Simulation methods for maximum process reliability und process assessment

DLR Center for Lightweight Production Technology (ZLP)

ZLP Site Stade
Prof. Wiedemann, Dr. Meyer

Leader ZLP
Dr. Meyer

ZLP Site Augsburg
Prof. Voggenreiter, Dr. Dudenhausen



DLR Center for Lightweight Production Technology (ZLP) Site Stade

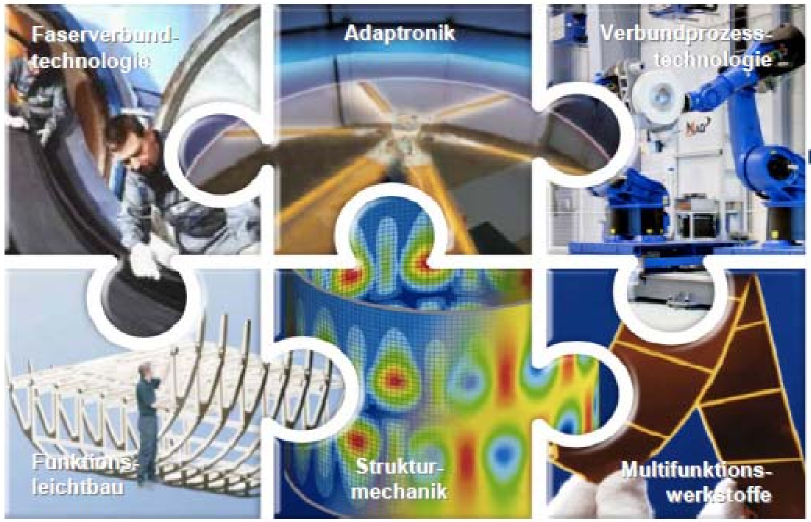
Research Topics

- 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

DLR Center for Lightweight Production Technology (ZLP)
Site Stade



Large Components

High production rates

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**

Standort Augsburg

Key Figures (Target 2013)

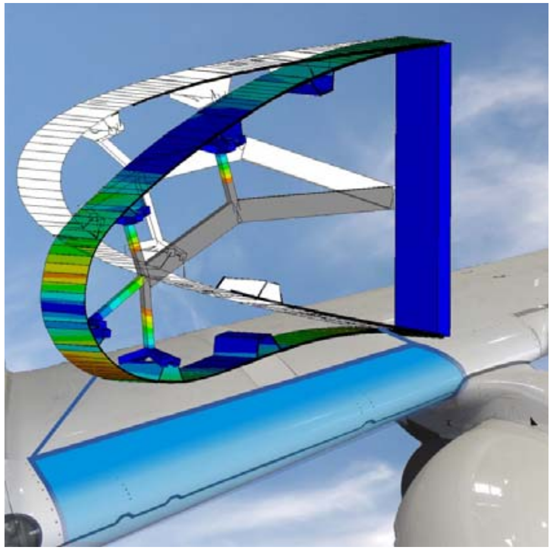
- **Staff:** **40**
- **Total investment:** **50 M€**
  Infrastructure & Machinery

Applied Research | Our Foci of Product Oriented Research

Focus
Fuselage Technologies | T. Ströhlein

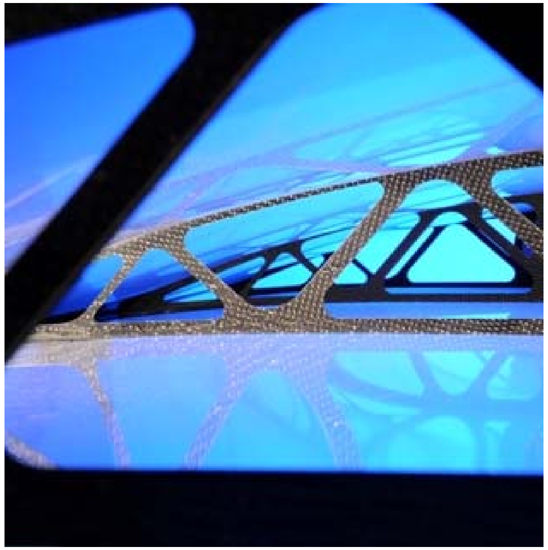
- Fuselage design
- Large cut-outs
- Manufacturing technologies

Focus
High Lift | M. Kintscher



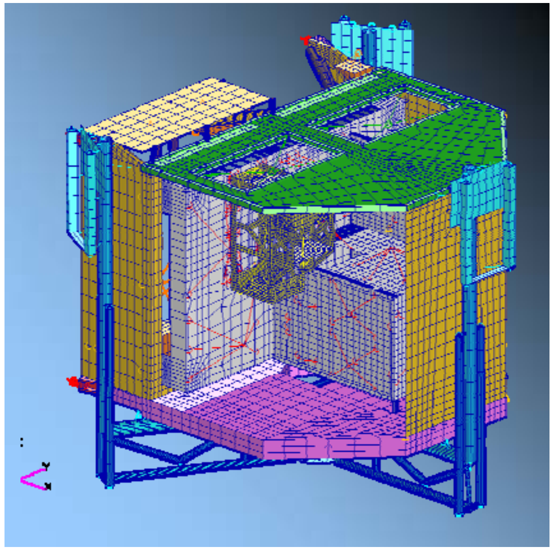
- Flexible leading edge
- Morphing of high lift systems
- Structural integration of active flow control

Focus
Special structures | M. Hanke



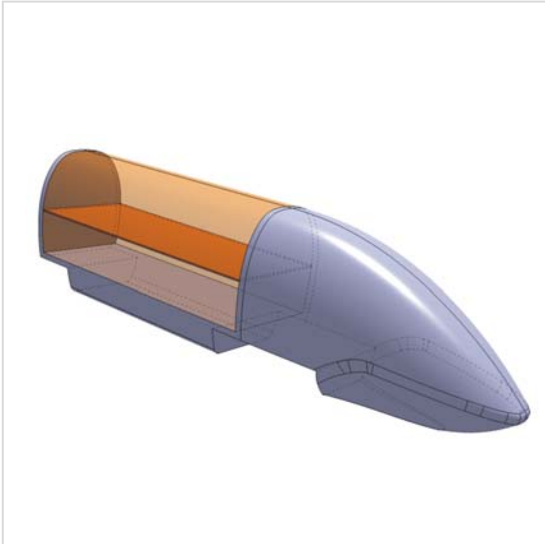
- Savety relevant aeronautic structures and UAVs
- Multifunctional composite structures
- Demonstration of design and technology

Focus
Space | Ch. Arlt



- Lander structures
- Deployable space structures
- Upper stage

Focus
Transport | J. Nickel



- Next generation train
- Novel vehicle structures

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 und 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.

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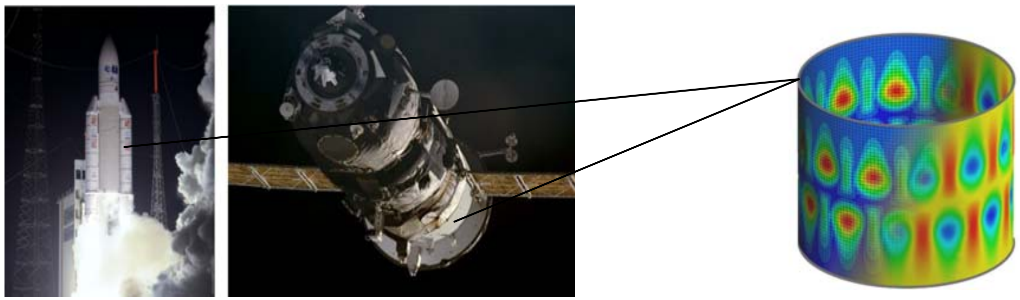

Ariane 5 Int. space station ISS

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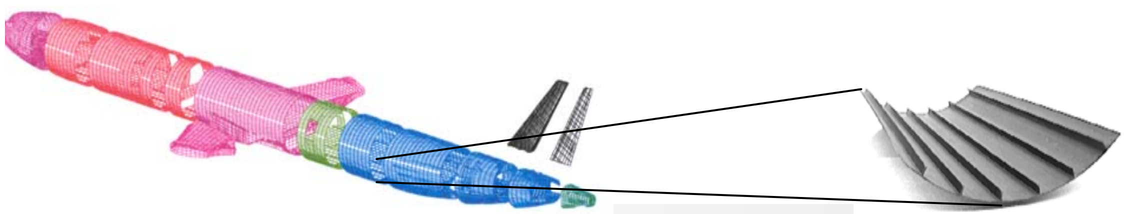
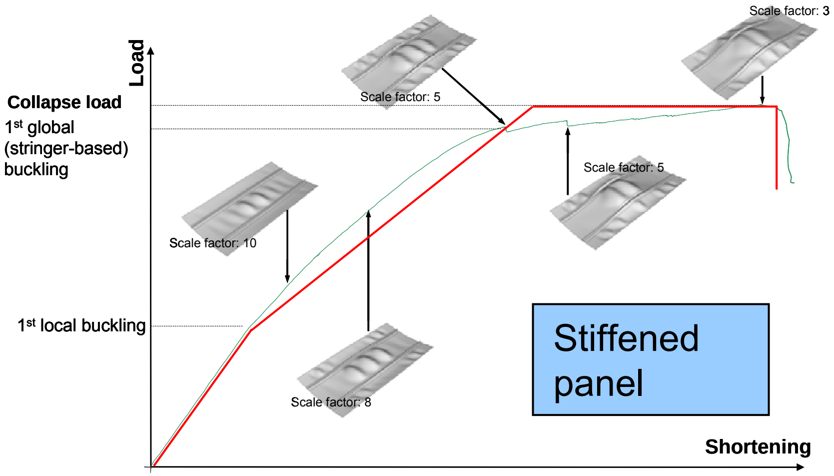


Comparison: Stiffened and unstiffened structures

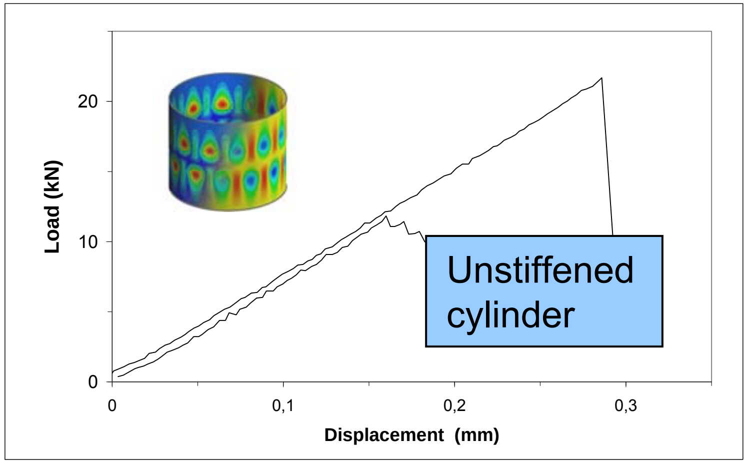
Light weight structures endangered by buckling can be divided into the following two groups:

Imperfection tolerant structures:



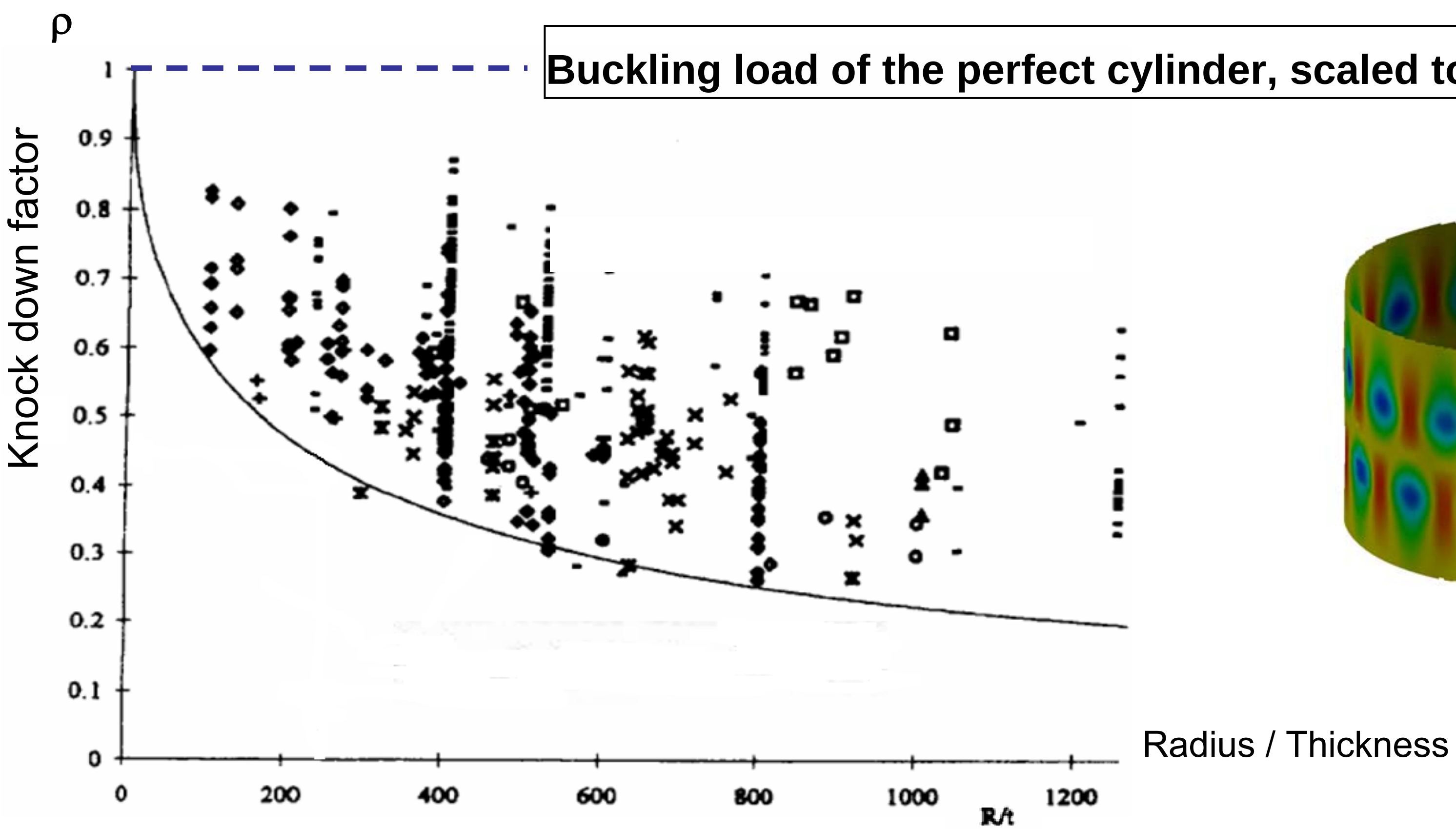
- Maximum load > first buckling load
- Postbuckling area is exploited for design
- Design load independent of imperfections

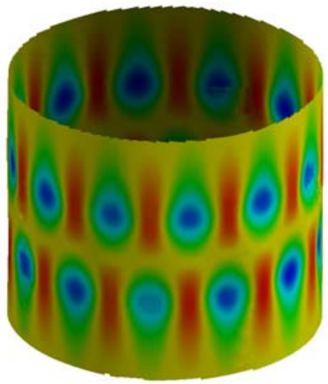
Imperfection sensitive structures:



- Maximum load = first buckling load
- No exploitable postbuckling area
- Design load highly dependent of imperfections

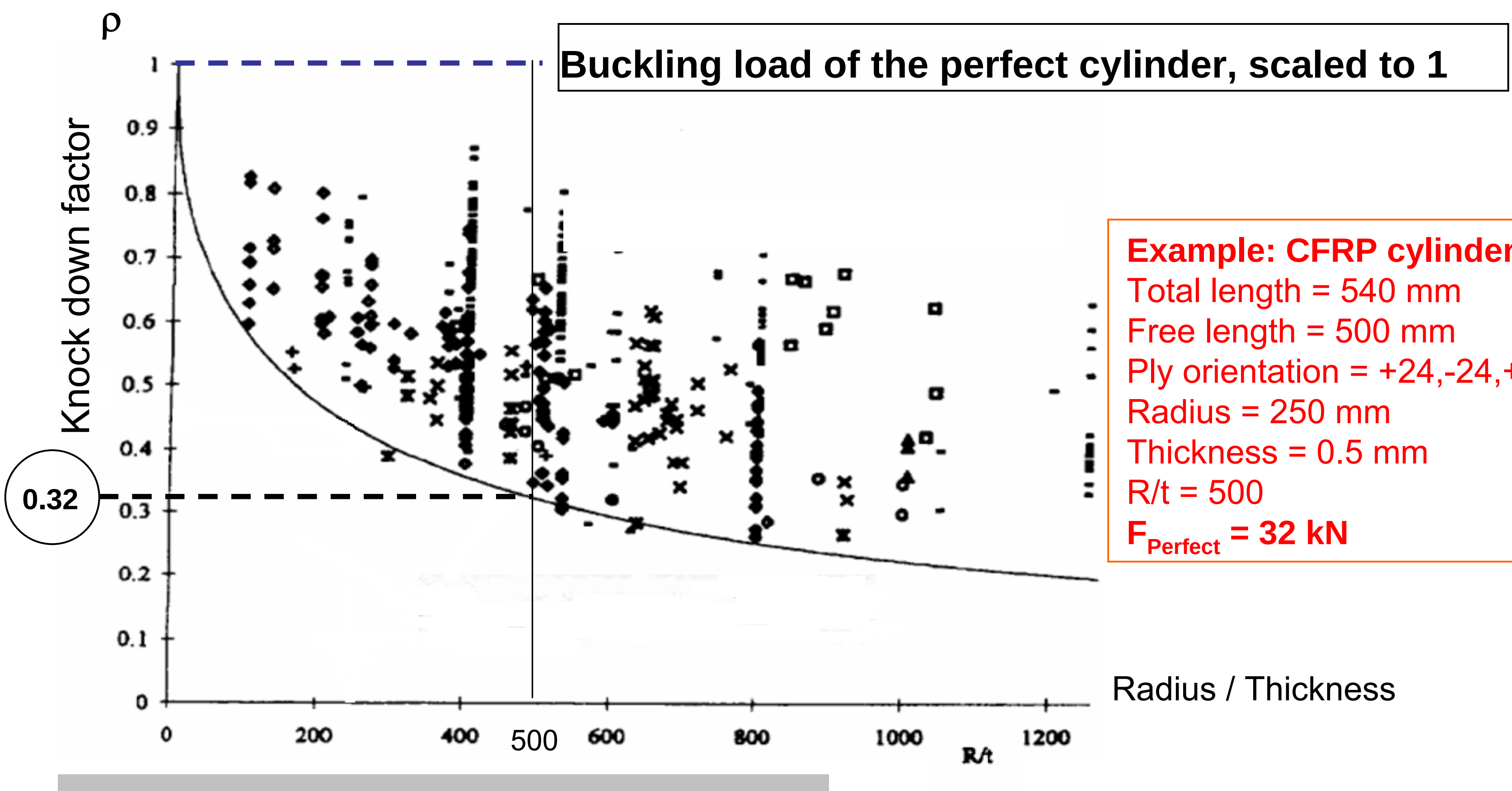
State-of-the-art - NASA-SP 8007 Design guideline





- Valid for metallic structures
- No guidelines for composites structures

NASA-SP 8007 - Example

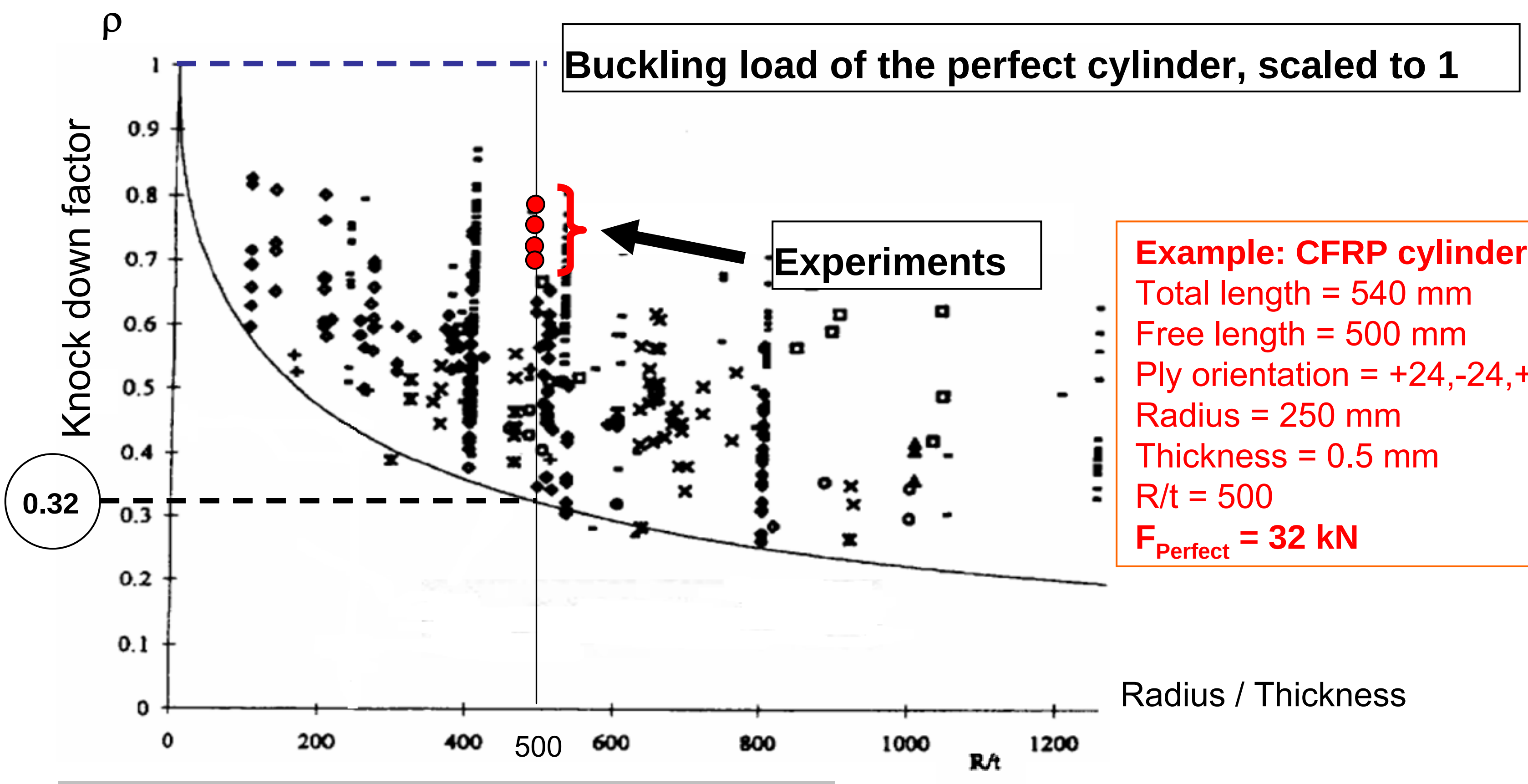


Example: CFRP cylinder
Total length = 540 mm
Free length = 500 mm
Ply orientation = +24,-24,+41,-41
Radius = 250 mm
Thickness = 0.5 mm
R/t = 500
$F_{Perfect}$ = 32 kN

$F_{Design\ load}$ = $F_{Perfect}$ * ρ_{NASA}

$F_{Design\ load}$ = 32 * 0.32 = **10.2 kN**

NASA-SP 8007 - Example



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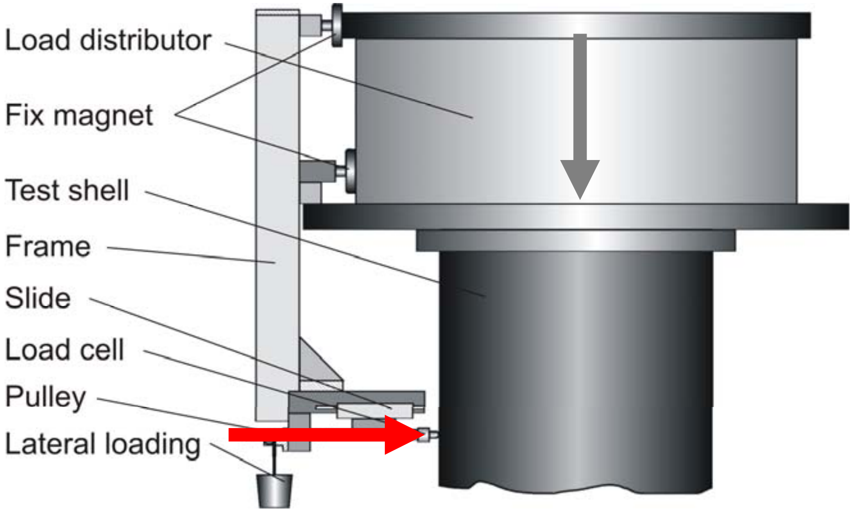
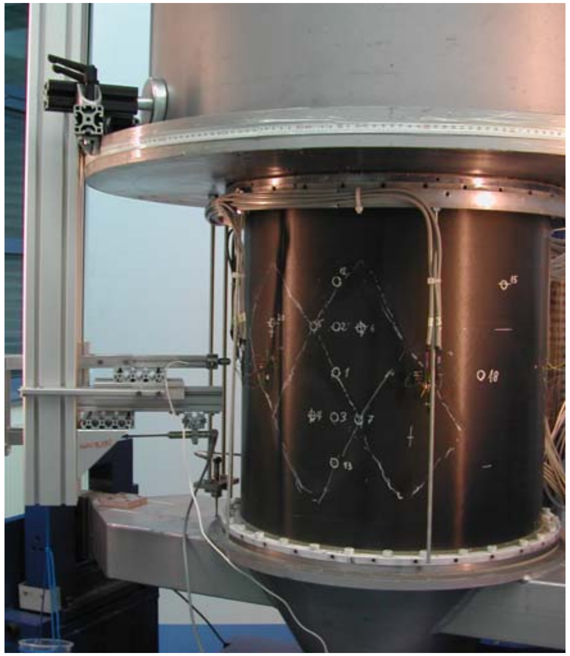
Single Perturbation Load Concept (SPLC)

Radial perturbation load

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



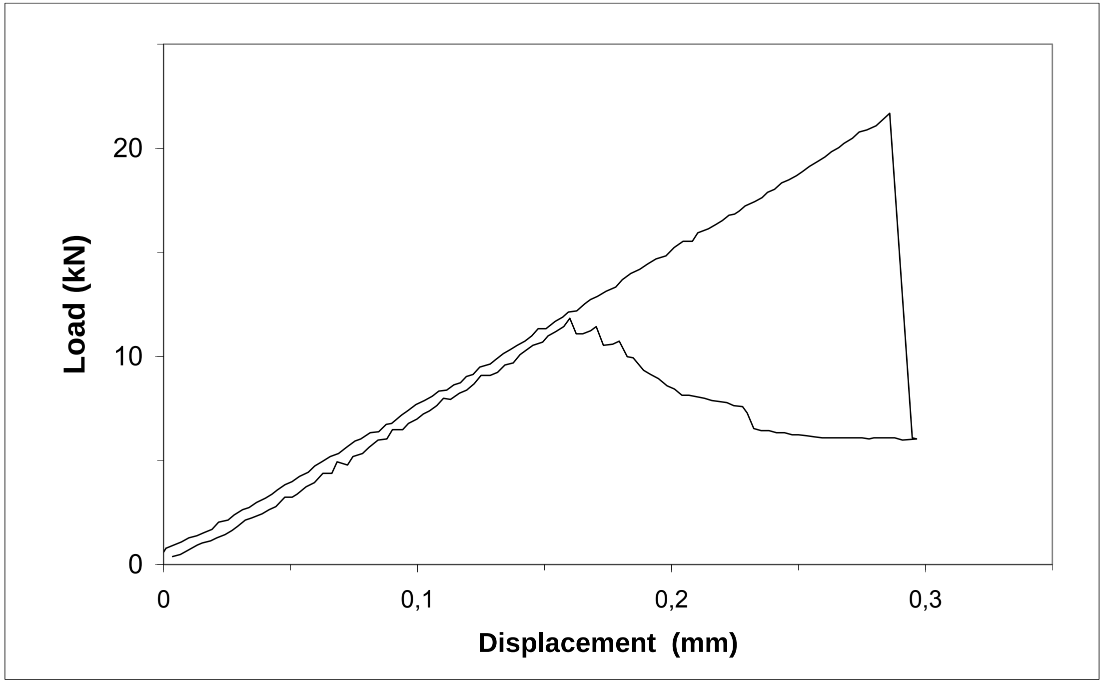


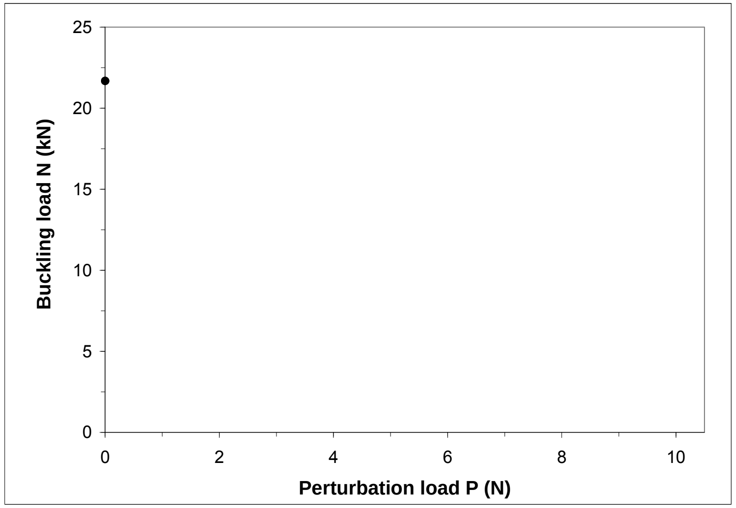
- **Test procedure:**

  1. radial perturbation load

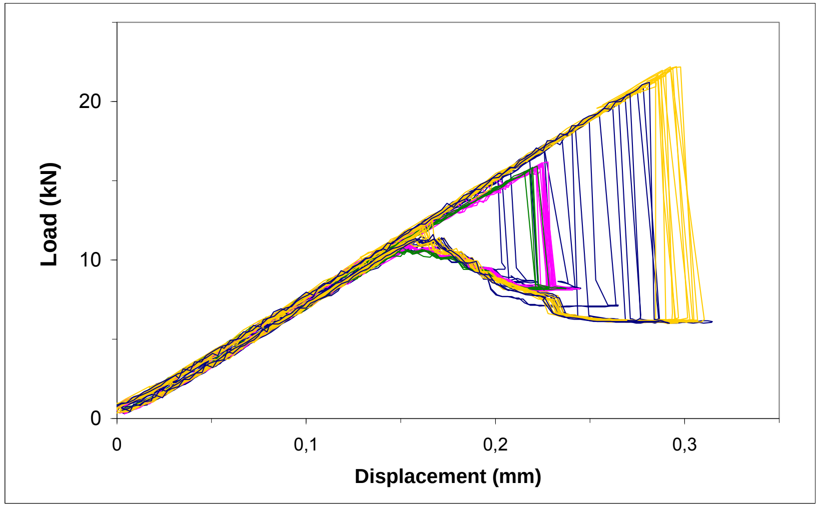
  2. axial compression

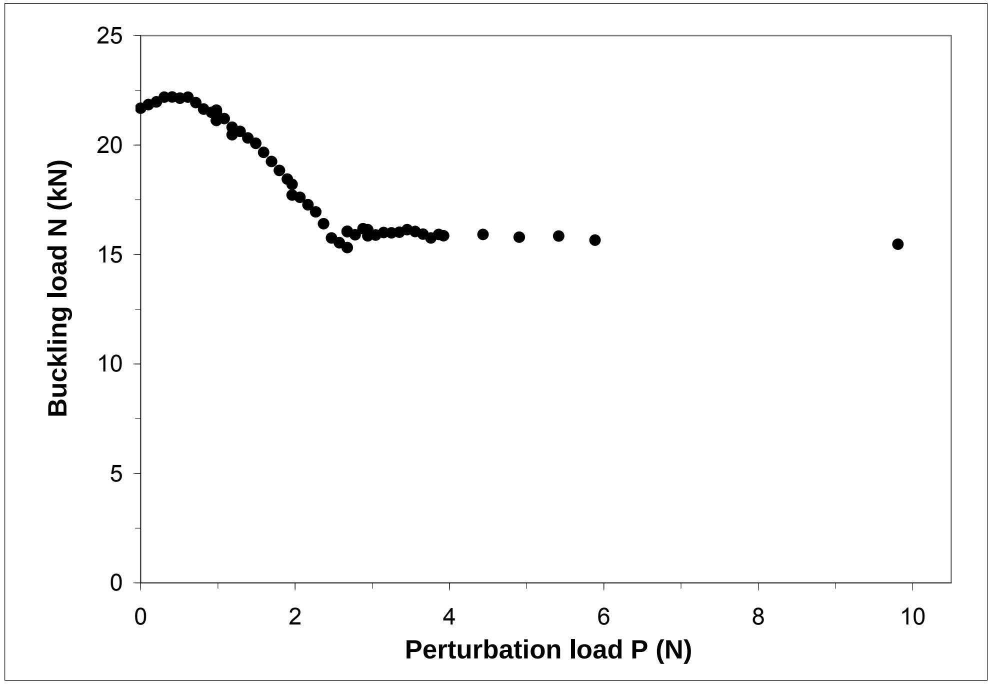
Single Perturbation Load Concept (SPLC)





Single Perturbation Load Concept (SPLC)

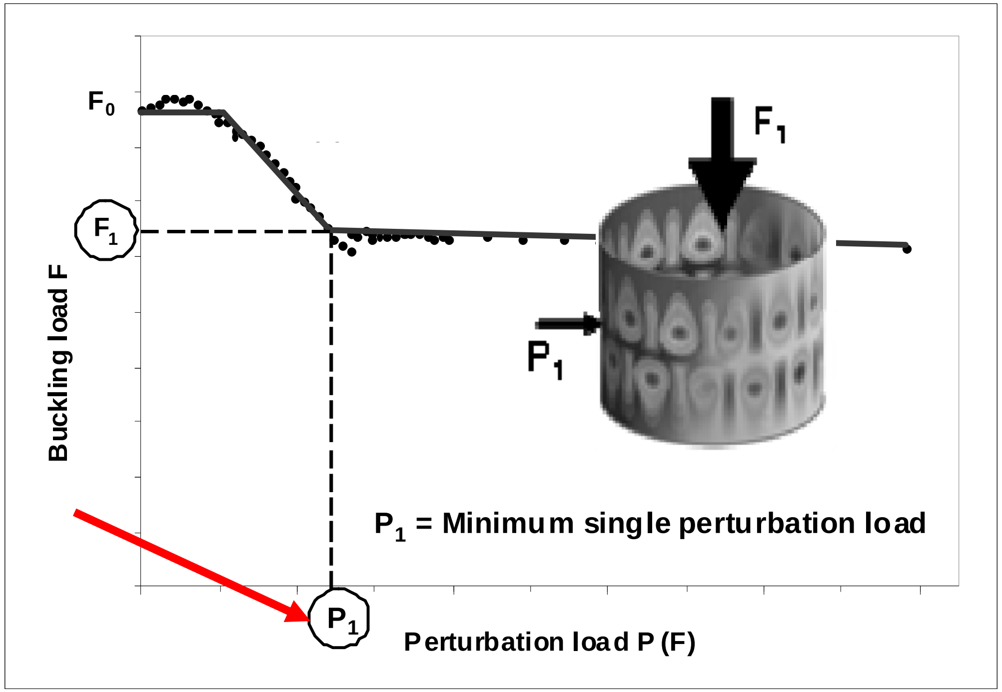




- Each dot marks one test
- Unexpected horizontal curve progression

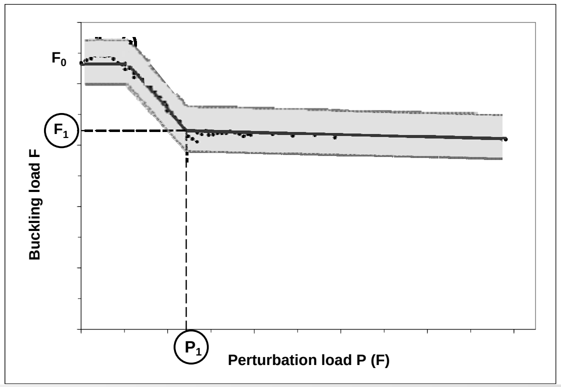
Single Perturbation Load Concept (SPLC)

- **New approach:**
- **Idealization of curve**
- **Lower boundary limit of buckling load for imperfect shells:** „Load carrying capability F_1"

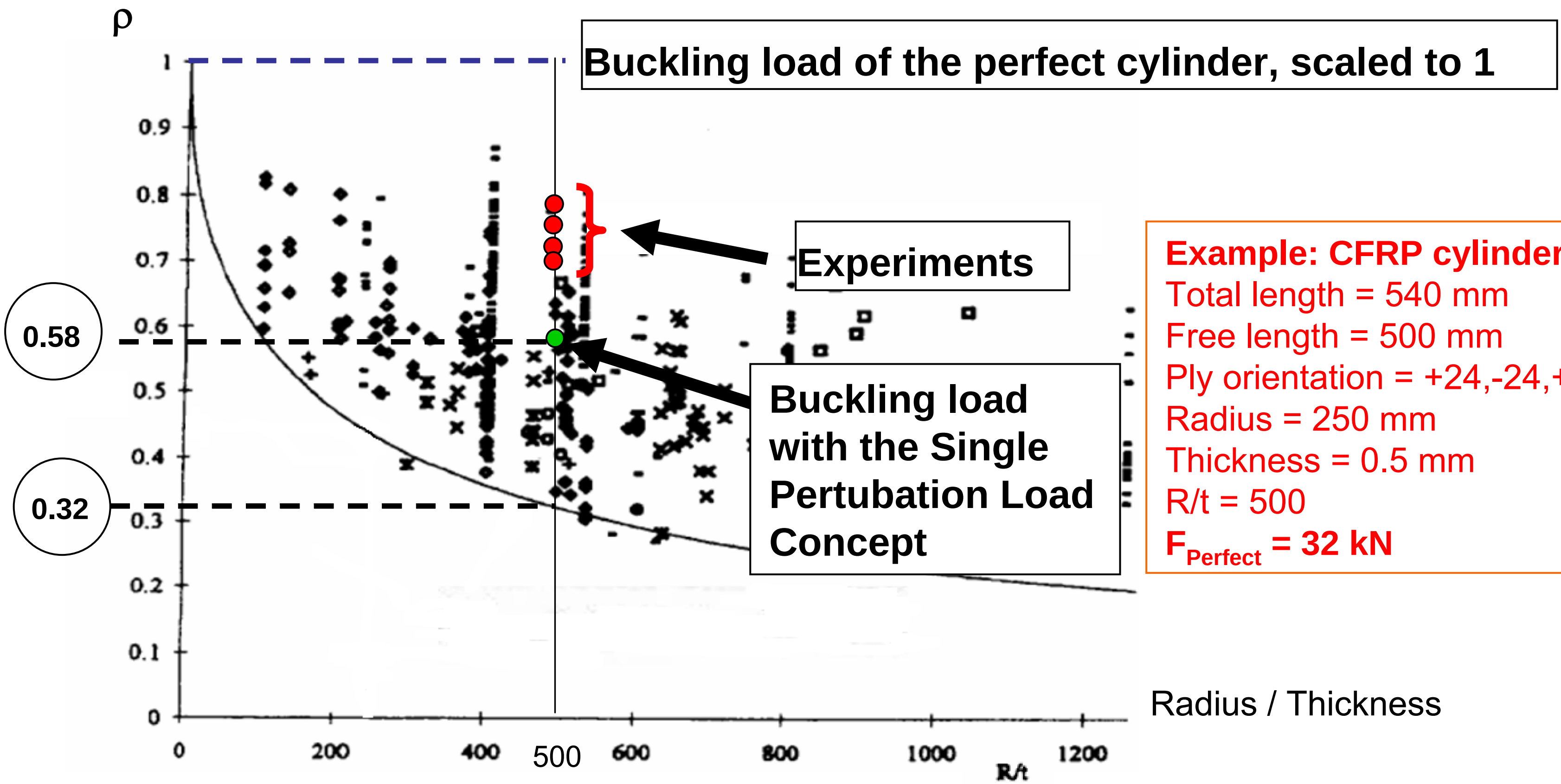


Questions

- **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**?**



NASA-SP 8007 - Example



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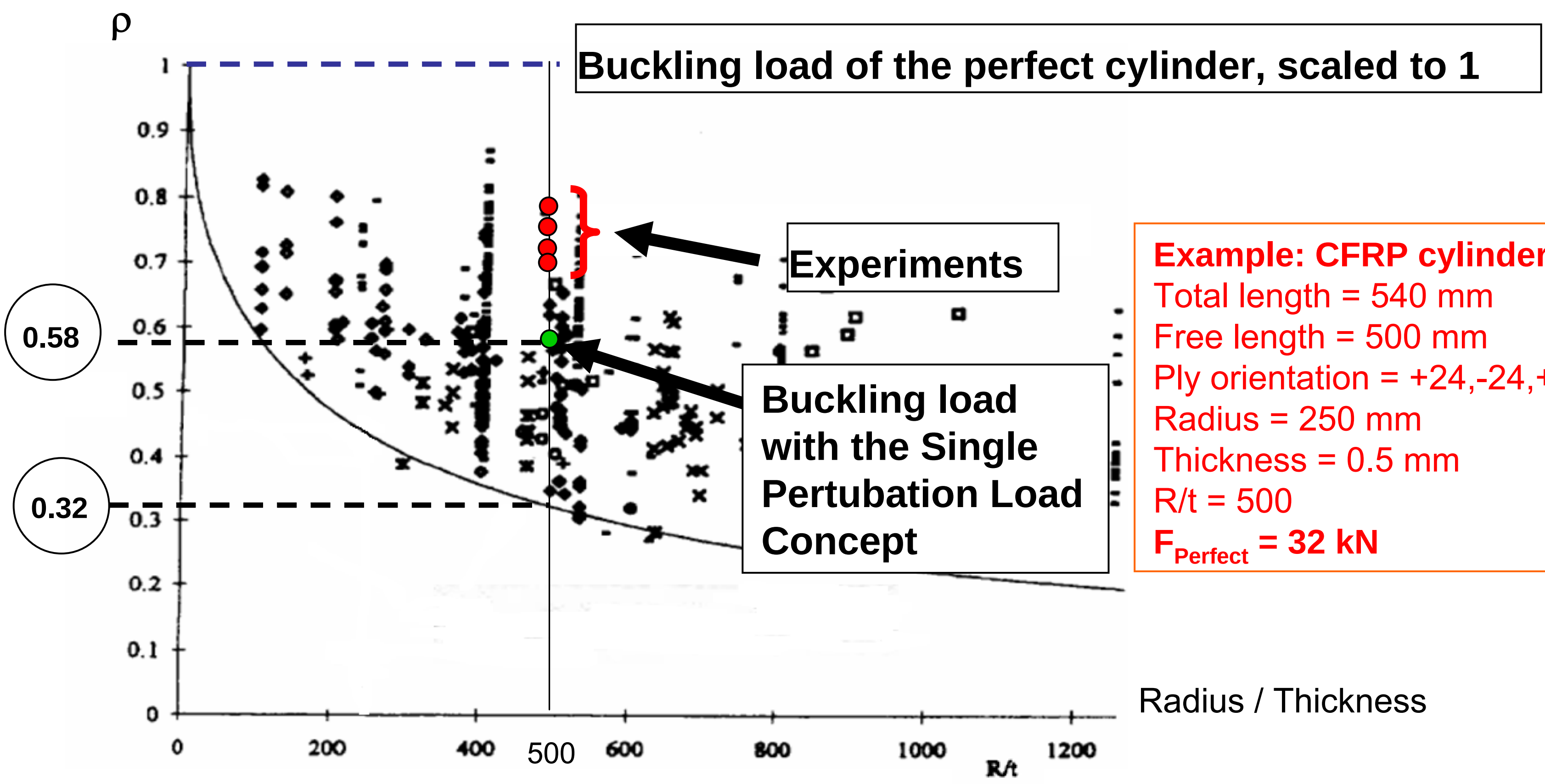
R/t = 500
$\mathbf{F_{Perfect} = 32\ kN}$

$F_{Design\ load} = F_{Perfect} * \rho_{NASA}$
$F_{Design\ load} = 32 * 0.32 = \mathbf{10.2\ kN}$

$F_{Design\ load} = F_{Perfect} * \rho_{SPLC}$
$F_{Design\ load} = 32 * 0.58 = \mathbf{18.5\ kN}$

NASA-SP 8007 - Example



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Thickness = 0.5 mm
R/t = 500
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Conclusion: The SPLC allows in this example to increase the load carrying capacity by 82 %.

Next step:

EU project DESICOS (2012 - 2014)

New Robust DESign Guideline for Imperfection Sensitive COmposite Launcher Structures

DESICOS

Collaborative Project Level 1

Call identifier: FP7-SPACE-2011-1, Theme 9: Space

Topic addressed: **Activity: 9.2.** Strengthening the foundations of Space science and technology
SPA.2011.2.2-01 Space transportation technologies

PART B

02 May 2011

Co-ordinator: Prof. Richard Degenhardt
DLR Braunschweig
E-mail: richard.degenhardt@dlr.de
Fax: +49 531 295 2232

List of participants:

No	Short name	Legal name	Country
1	DLR	Deutsches Zentrum fuer Luft- und Raumfahrt e.V.	Germany
2	ASTRIUM-F	Astrium SAS	France
3	ASTRIUM-D	Astrium GmbH	Germany
4	GRIPHUS	GRIPHUS – Aeronautical Engineering for Manufacturing LTD	Israel
5	TU-Delft	Technische Universiteit Delft	Netherlands
6	LUH	Gottfried Wilhelm Leibniz Universität Hannover	Germany
7	PFH	Private University of Applied Sciences Göttingen	Germany
8	POLIMI	Politecnico di Milano	Italy
9	RTU	Rigas Tehniska Universitate	Latvia
10	RWTH	Reinisch-Westfälische Technische Hochschule Aachen	Germany
11	TECHNION	TECHNION – Israel Institute of Technology	Israel
12	CRC-ACS	Centre for Advanced Composite Structures	Australia
13	NASA	National Aeronautics and Space Administration	USA

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).

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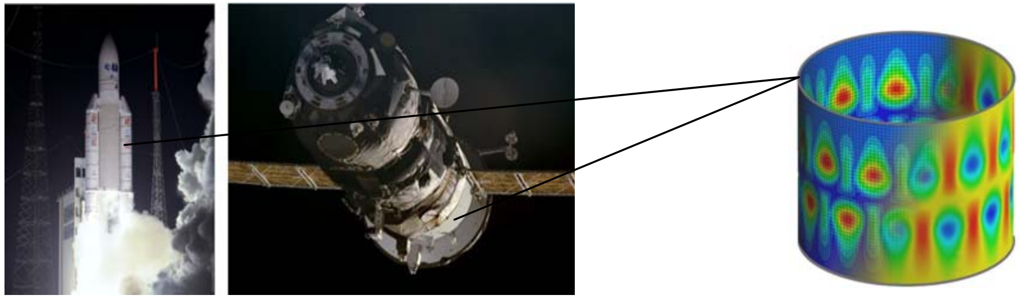

Ariane 5 Int. space station ISS

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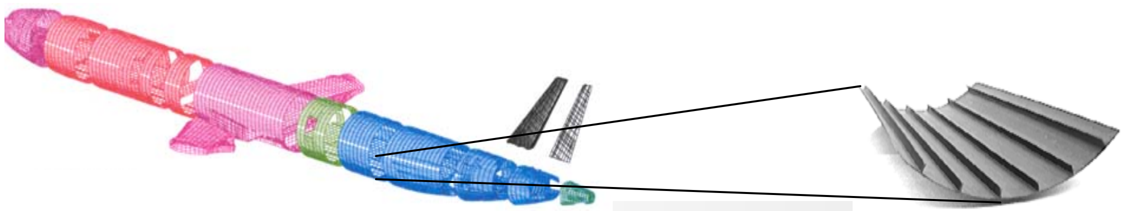
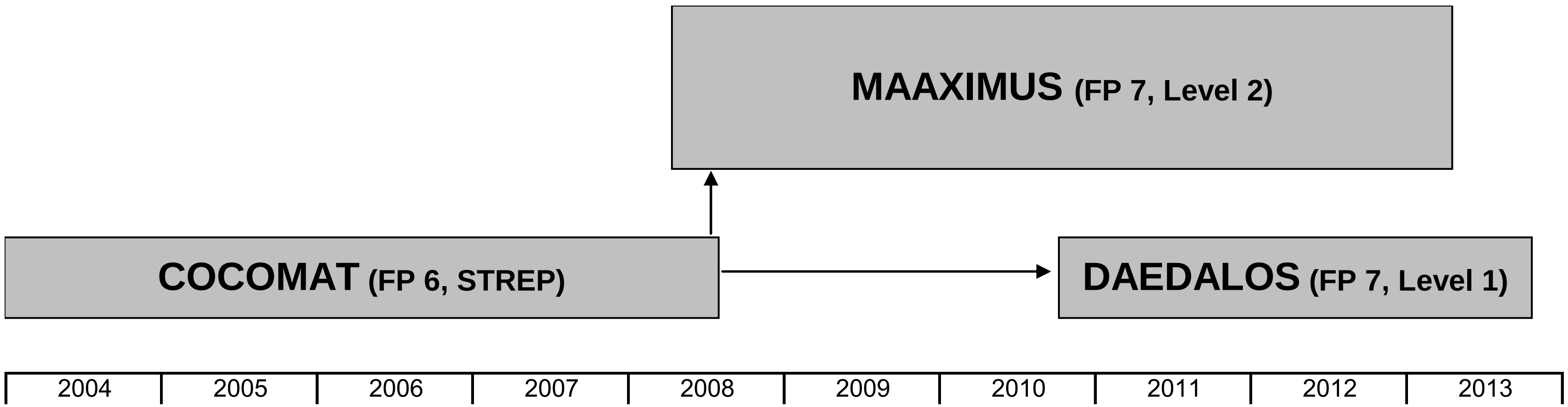


EU projects

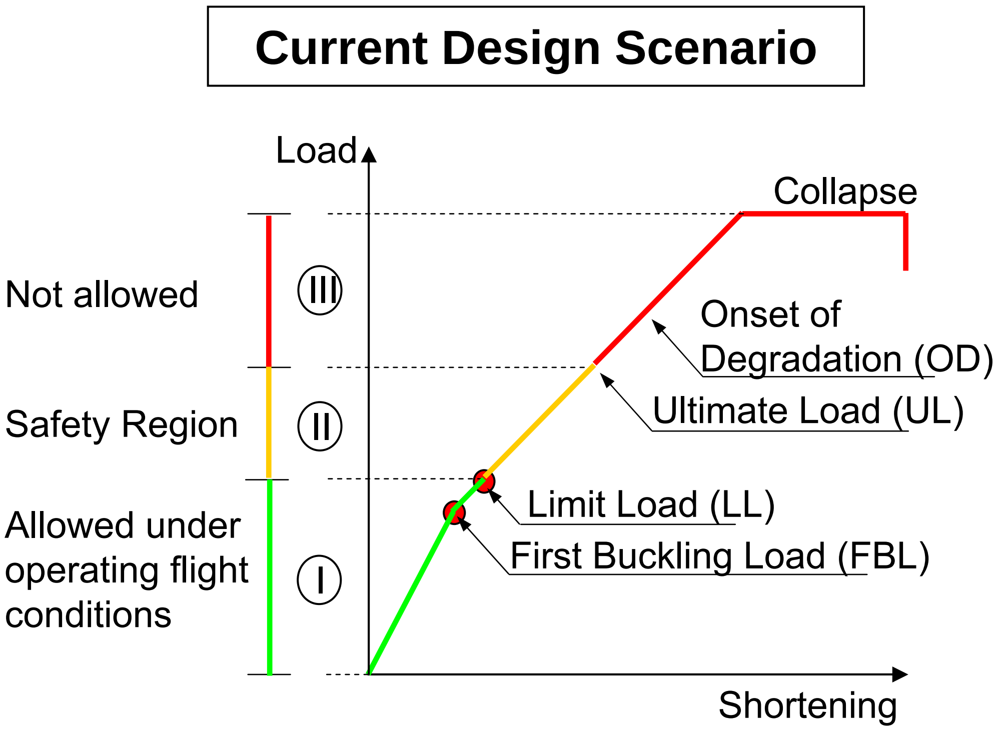
More
Affordable
Aircraft Structure through
eXtended,
Integrated, &
Mature
nUmerical
Sizing

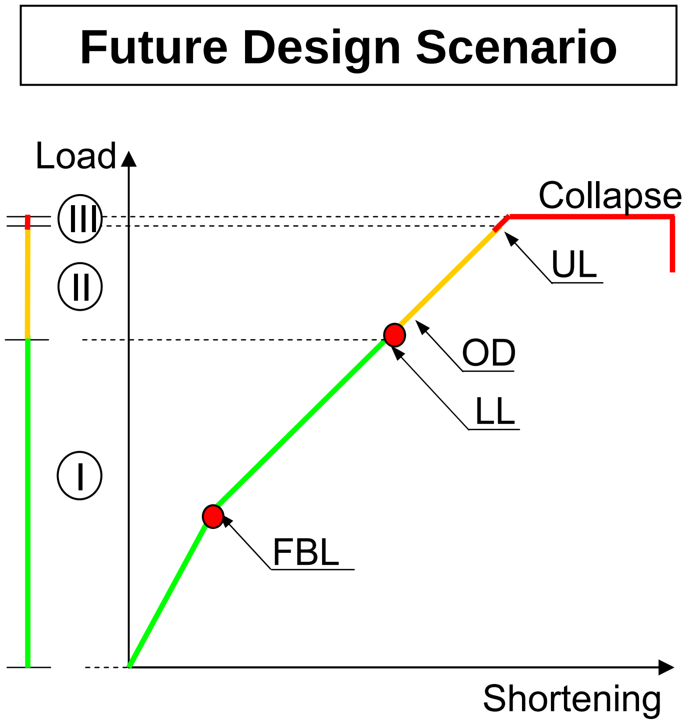


Improved MATerial Exploitation
at Safe Design of COmposite Airframe Structures
by Accurate Simulation of COllapse

Dynamics in Aircraft Engineering
Design and Analysis for
Light Optimized Structures

COCOMAT: Designs on panel level





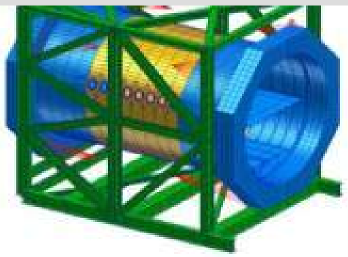
MAAXIMUS project– Strategy

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

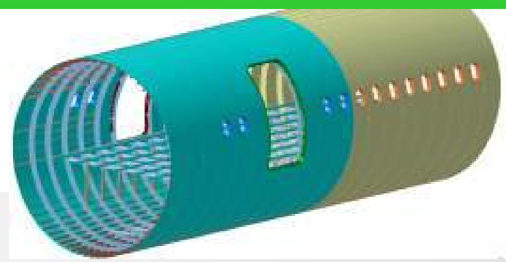
Virtual Platform

Innovative & Integrated Simulation-Based Design



Physical Platform

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



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