ECN

Knowledge Centre WMC
Wind turbine Materials and Constructions

UPWIND:
Blade Materials and Structures

R.P.L. Nijssen
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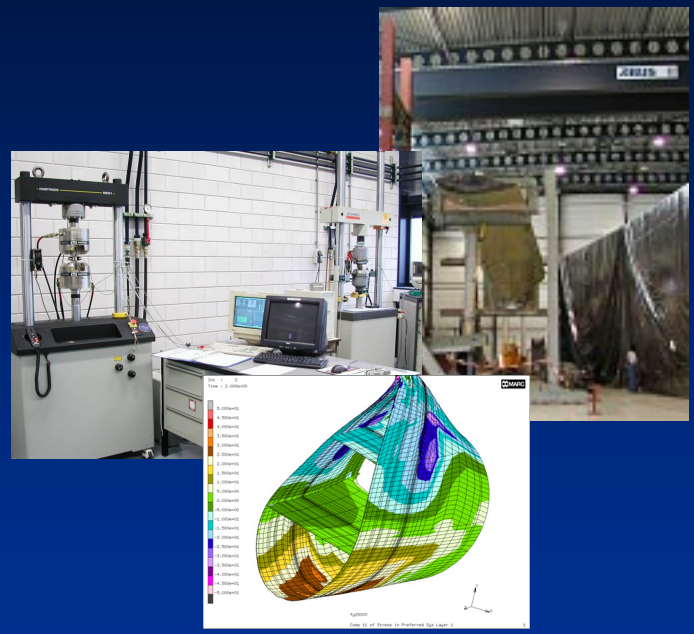
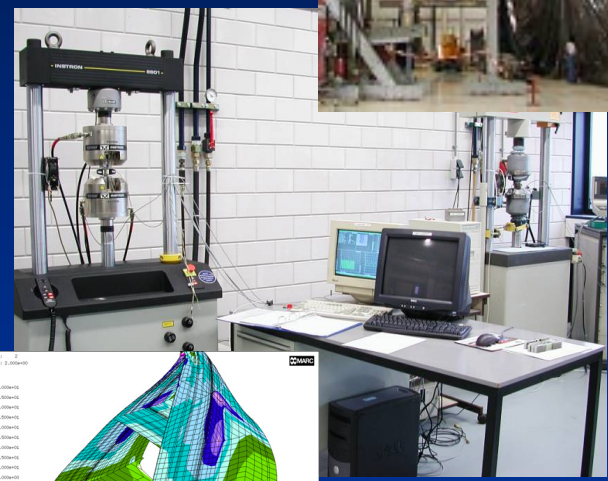


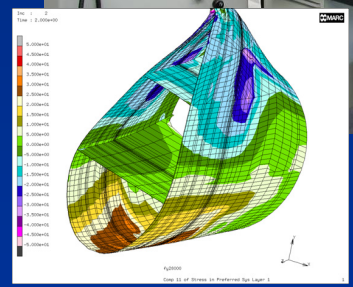
European Wind Energy Conference 2007
Session: Structural Design and Materials
Thursday, May 10th, 2007

TU Delft

Wind turbine Materials & Constructions

- History
  - Blade & Material testing for over 20 years
  - Part of Delft University of Technology until 2003
- Activities
  - Full-scale wind turbine structural testing
  - Material research
  - Software Development
- Facilities
  - Flexible full-scale test laboratory
  - Fatigue test machines
  - Workshops
  - Specimen production
- Projects (EZ/EU)
  - OPTIMAT
  - INNWIND
  - UPWIND





Full Scale Testing

Material Research
EU Project: Optimat Blades

Objectives: Reliable Optimal Use of Materials for Wind Turbine Rotor Blades

Scientific Coordinator: *WMC*

Period: 2002-2006

Financial Coordinator: ECN

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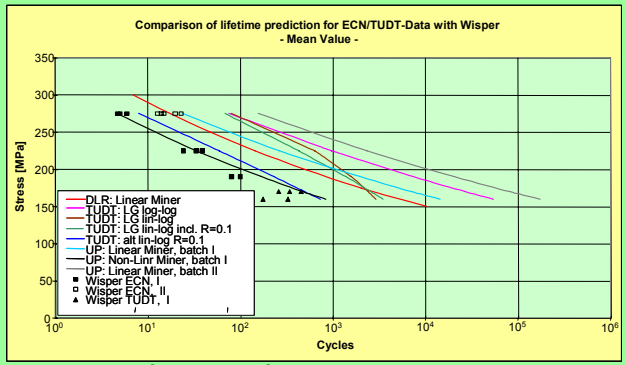
Material Research
EU Project: Optimat Blades

Variable Amplitude Loading

1

- Establishment of reference S-N curves
- Comparison between CA and VA
  - Wisper spectrum
  - Block tests
- Establishment of new Wisper spectrum
- Influence load sequence



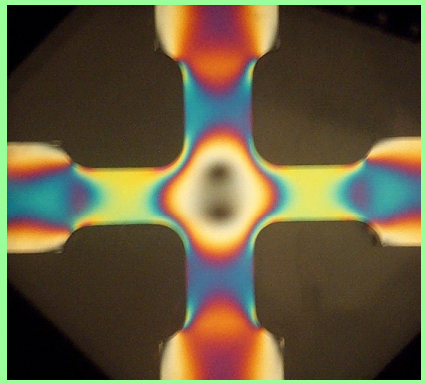
Results of various Lifetime Prediction Models

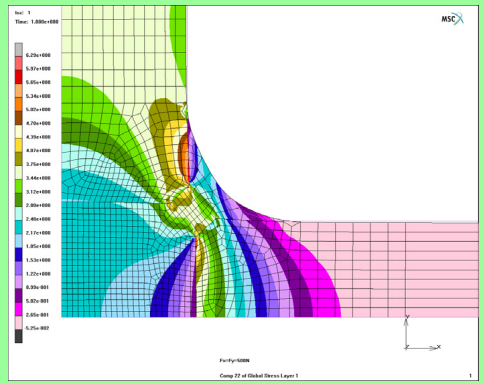
Material Research
EU Project: Optimat Blades

Complex Stress State

- Checks on uni-axial and bi-axial tests
- Investigate beam model of rotor blade vs. shell model for stress components
- Establish guidelines and safety factors for various levels of sophistication in the design

2





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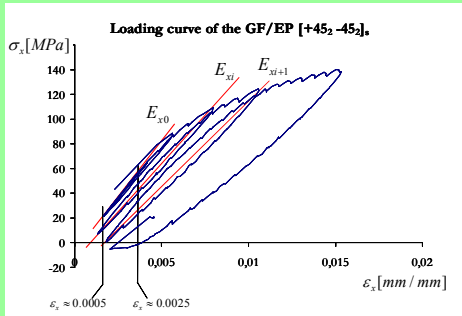
Extreme Conditions

- Check influence of extreme conditions
  - T -40° and +60°
  - Humidity
- Identification of degradation parameters
- Phenomenological modelling and exp. determination

3



Degradation of Stiffness during Fatigue Life

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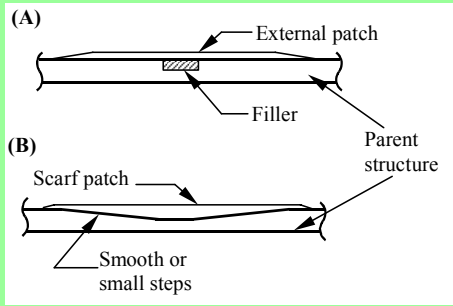
EU Project: Optimat Blades

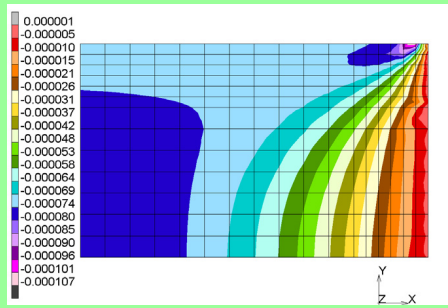
Thick Laminates & Repair

4

- Difference between thick and thin laminates studied
- Material properties in thickness direction
- Measurements using embedded optical fibres
- Repair techniques
- Influence of brick and shell FE models



Plug/Patch and scarf repair systems



FE analysis of the test specimen

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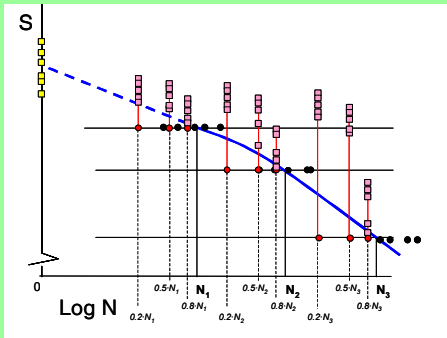
Residual Strength & Condition Assessment

- Development of predictive model for residual strength reduction
- Definition and validation of condition monitoring strategies for laminates in rotor blades

5



Stress levels for testing the residual strength after a percentage of the expected life

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RISØ
КАПЕ CRES
CCLRC Rutherford Appleton Laboratory
VTT
VUB
DEWI
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Germanischer Lloyd WindEnergie GmbH
DNV
LM Glasfiber A/S
Gamesa
Vestas
NORDEX
GE Wind Energy

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Improved Design Recommendations

6

- Task group leaders and certification bodies
- State-of-the-art analysis of results using results of the task groups 1 to 5
- Based on consistent set of tests
- Interaction effects also covered
- Basis for future design guidelines

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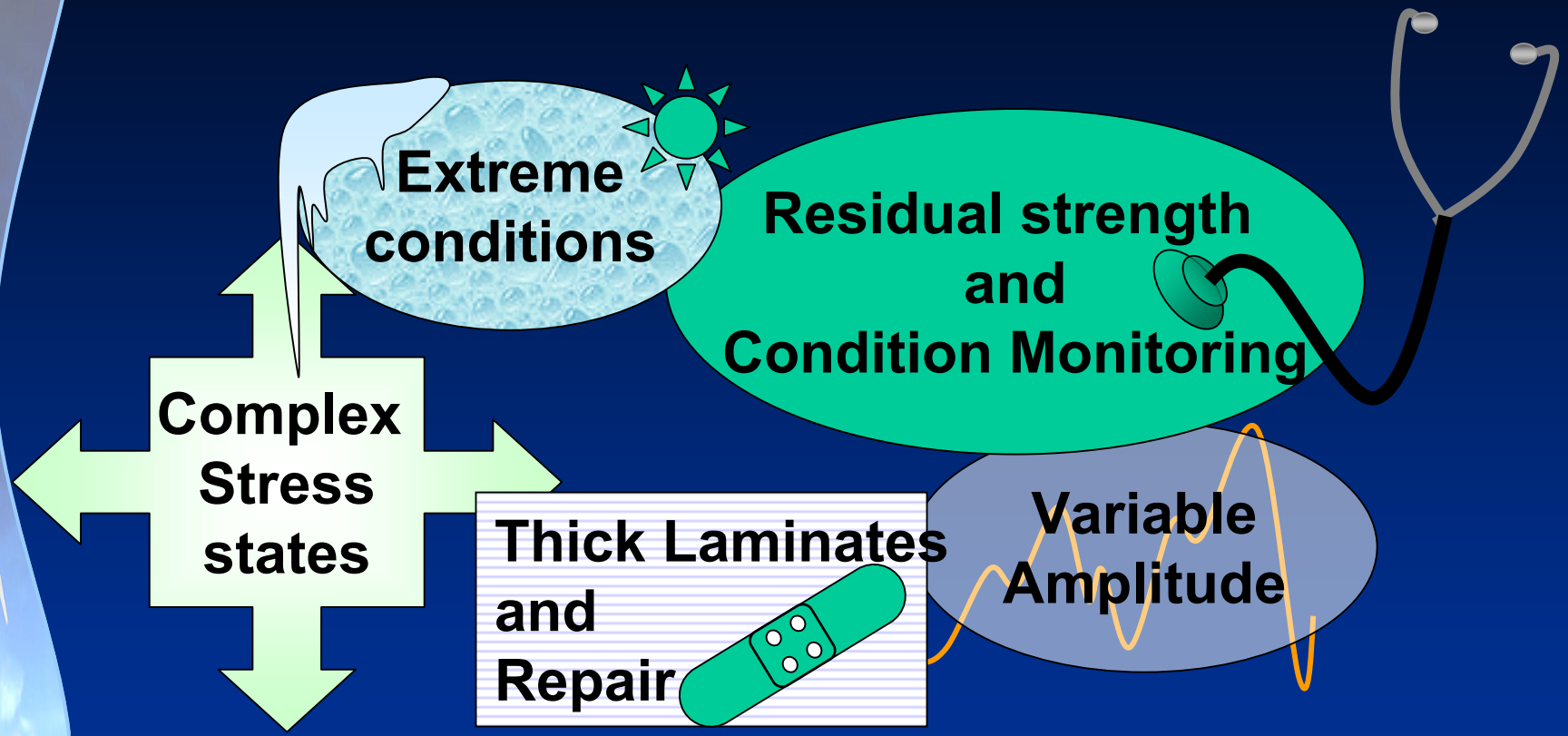
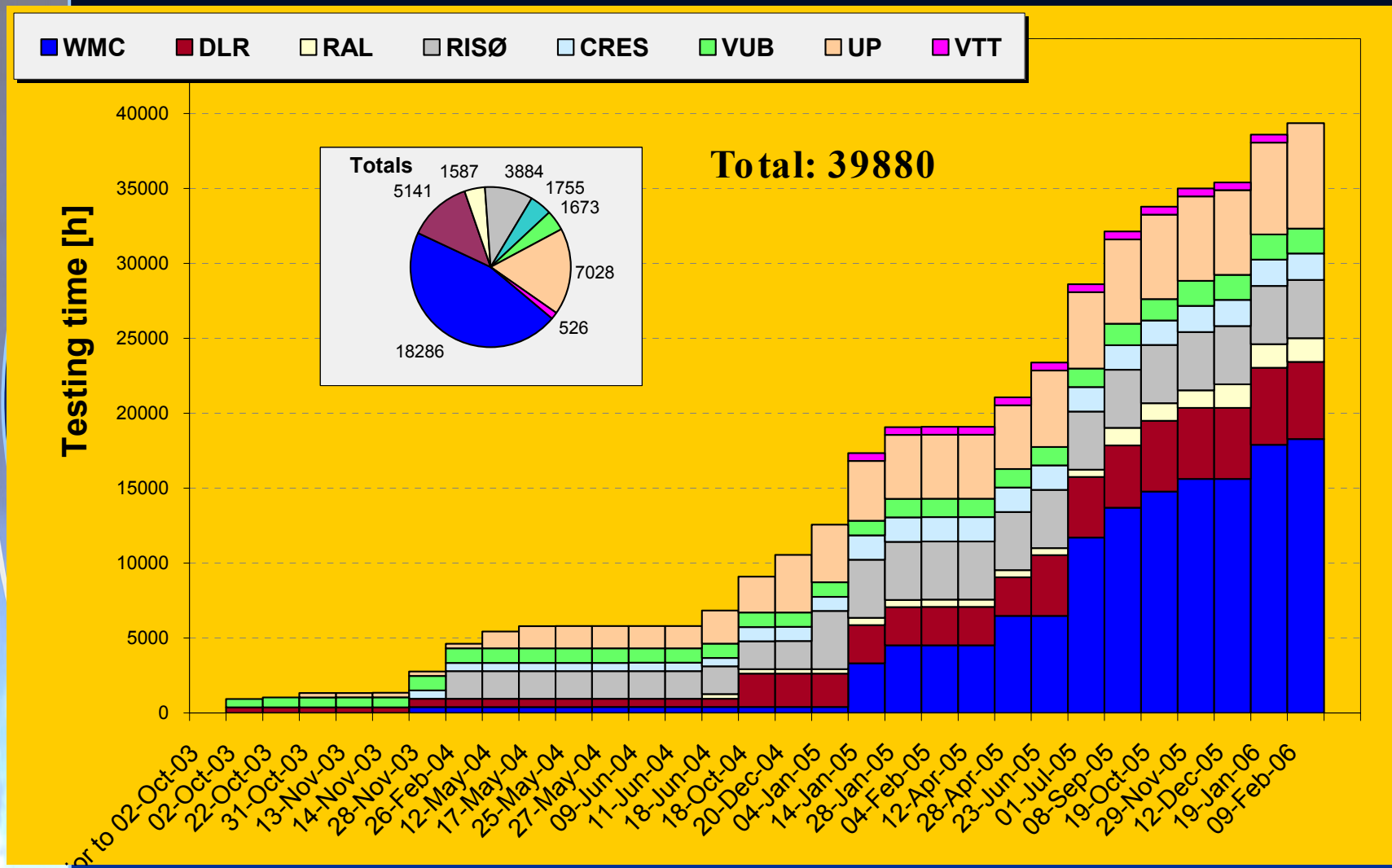
EU Project: Optimat Blades



OPTIDAT



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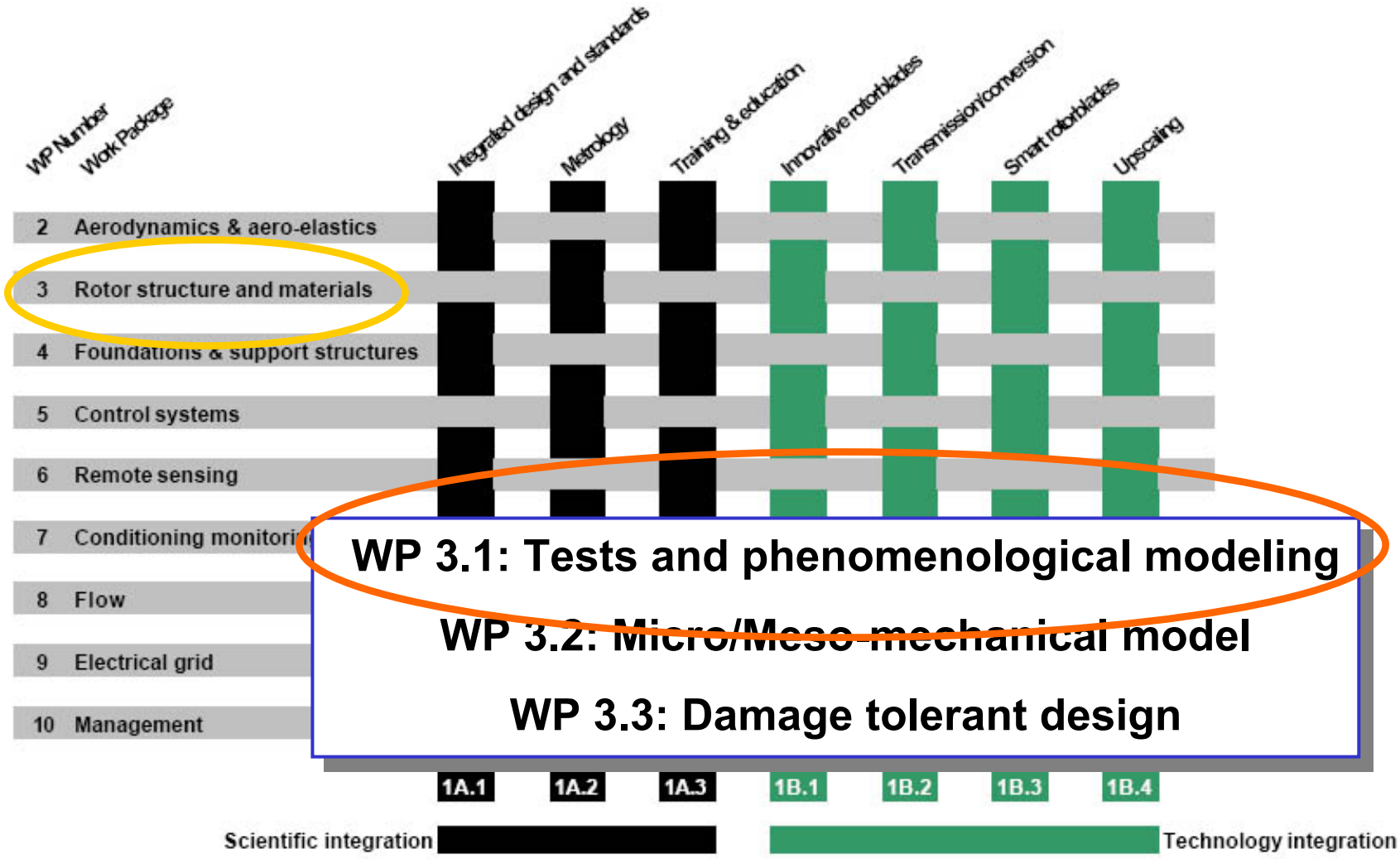
Wind turbine Materials and Constructions

Available via: www.wmc.eu

Lessons learnt from Optimat Blades

- **Plate-to-plate and lab-to-lab variations are important in a project of this size**
  - Minor T_g and V_f variations→significant performance variations?
  - Some plates worse in static strength, better in fatigue
  - Machine-to-machine
  - Environmental conditions
  - Sometimes larger than investigated influences
  - More realistic assessment of scatter
  - Preferably: production of all specimens first, then mix and send out (not possible in practice)
- **Establishing an alternative test geometry is difficult**
  - People perceive standards automatically as “better” even when no background info is provided
  - Universal geometry is compromise…OK for consistency(?)

Topics for UPWIND WP 3.1



WP 3.1: Tests and phenomenological modeling

WP 3.2: Micro/Meso-mechanical model

WP 3.3: Damage tolerant design

Topics for UPWIND WP 3.1

- Static strength, especially compression
- Constant Life Diagram, especially concentrating on higher number of cycles
- Bi-axial stress states
- Extreme (climatic) conditions as well as influence of the frequency on fatigue test results
- Behaviour of thick and repaired laminates
- Damping
- Life cycle analysis
- Extension with new materials of the public material database OPTIDAT
  - www.wmc.eu

Partners WP 3.1

- RISØ
- ECN
- WMC
- CRES
- UP
- GE
- FIBERBLADE
- VTT
- CCLRC
- VUB

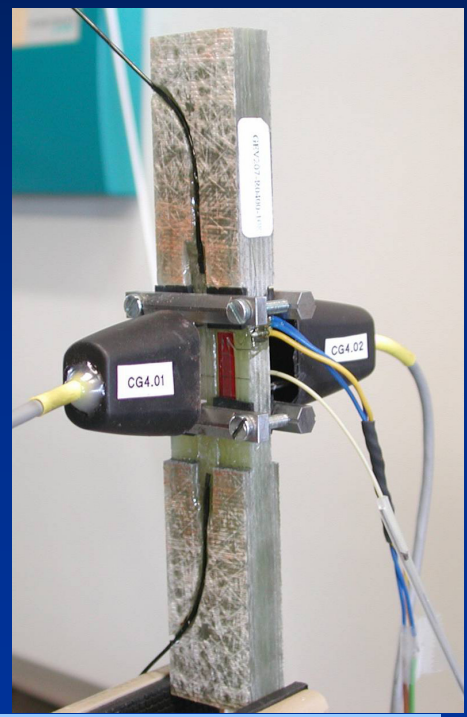
Universal test geometry

Advantages

- Fits measurement equipment
- Eliminate geometry effects
- Flexibility (progressing insights during long-term project…)
- Combined tests, e.g. residual strength

Disadvantages

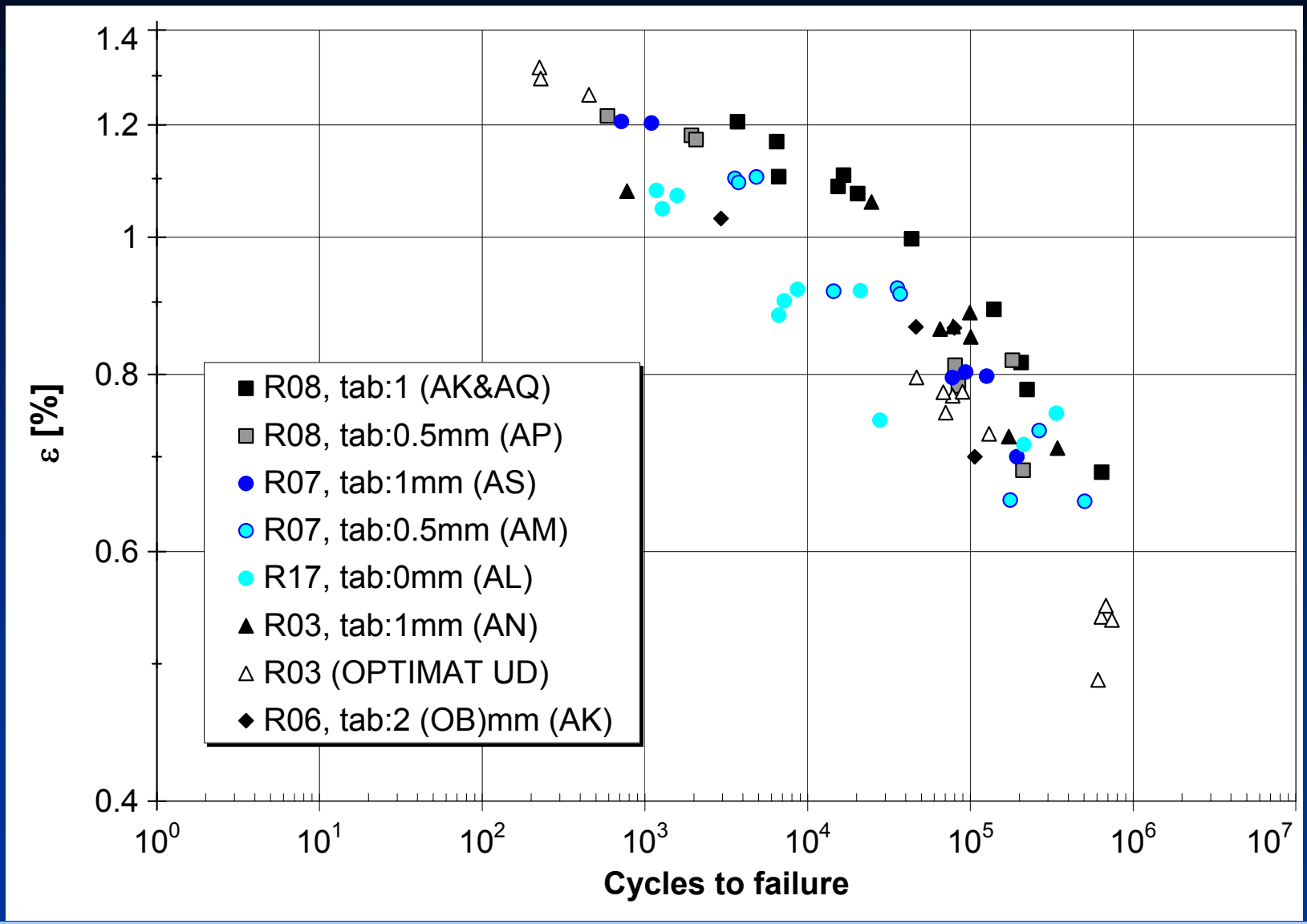
- Poorer compression characteristics than ISO/ASTM
  - Static
  - Compression-compression fatigue tests
  - Buckling (test machine dependent, elevated temperatures, after fatigue damage)



Preliminary programme

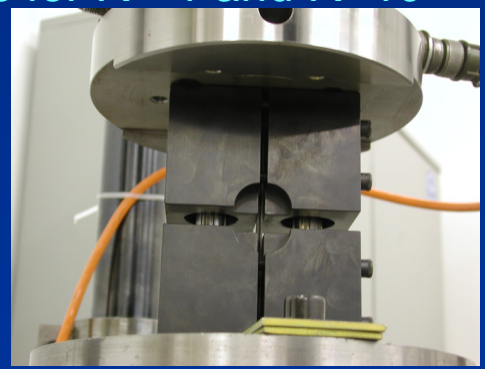
- **Reference material**
  - Glass Epoxy, delivered by GE
  - WMC can also make their own plates
    - Layouts
    - Embedded sensors
- **Study of several rectangular geometries for 4 and 6 layer lay-ups tested in preliminary programme**
  - Free length
  - Width
  - Tab thickness: from 0 to 2 mm
  - Static and zero-mean stress (R= -1) fatigue

First test results (R=-1 fatigue)



Compression

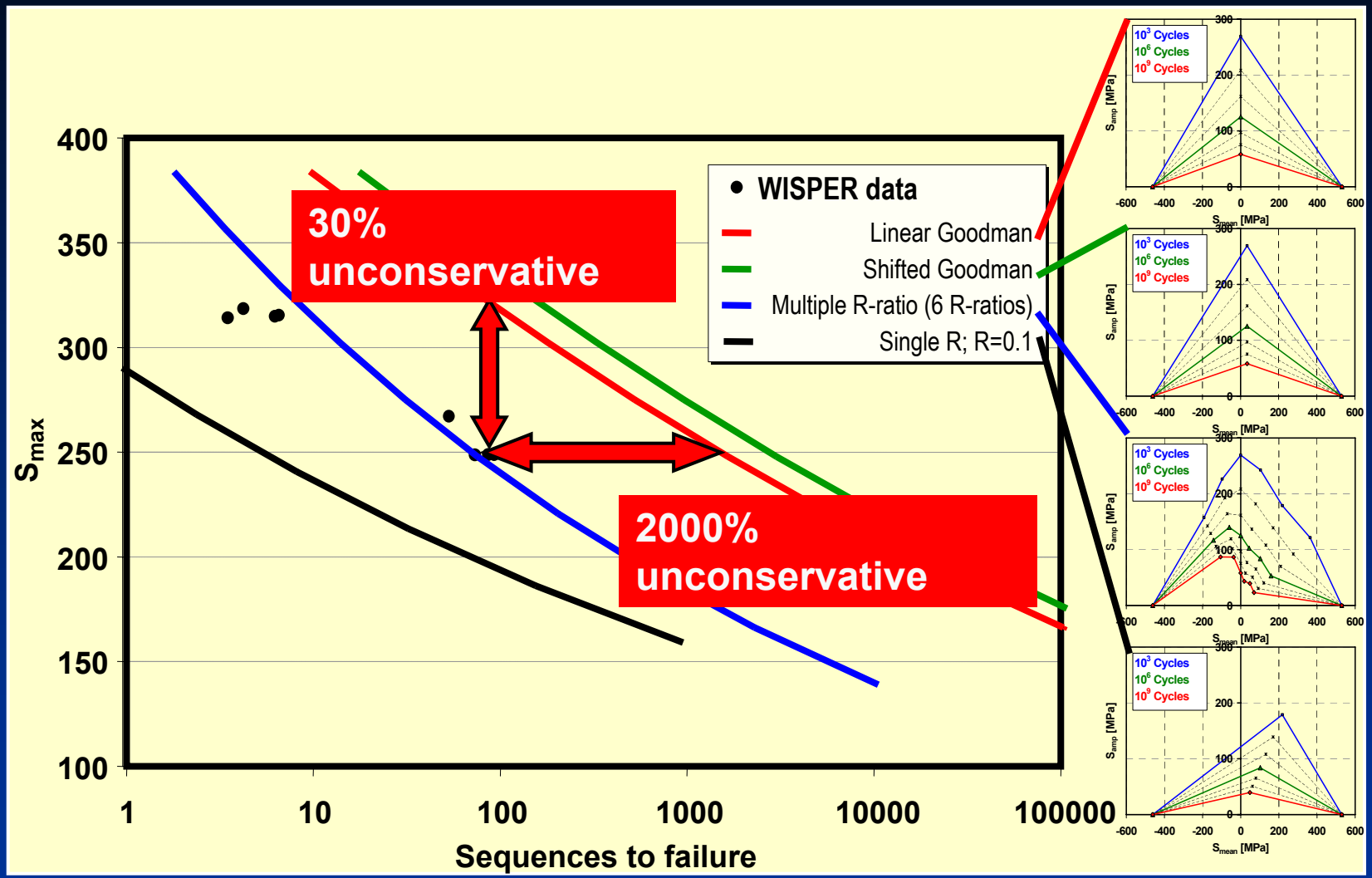
- **Approach Compression**
  - Risø set-up *(RISØ)*
  - ISO *(WMC)*
  - Combined loading *(WMC)*
  - Test short OPTIMAT *(WMC/UP/CRES)*
  - Standard OPTIMAT as reference *(WMC/UP/CRES)*
  - Compression test University of Dresden *(GE)*
  - VUB will look at the full optical field for compression
- **Objectives**
  - New geometry for static compression
  - Fatigue geometries for R=-1 and R=10



Ageing & Fatigue

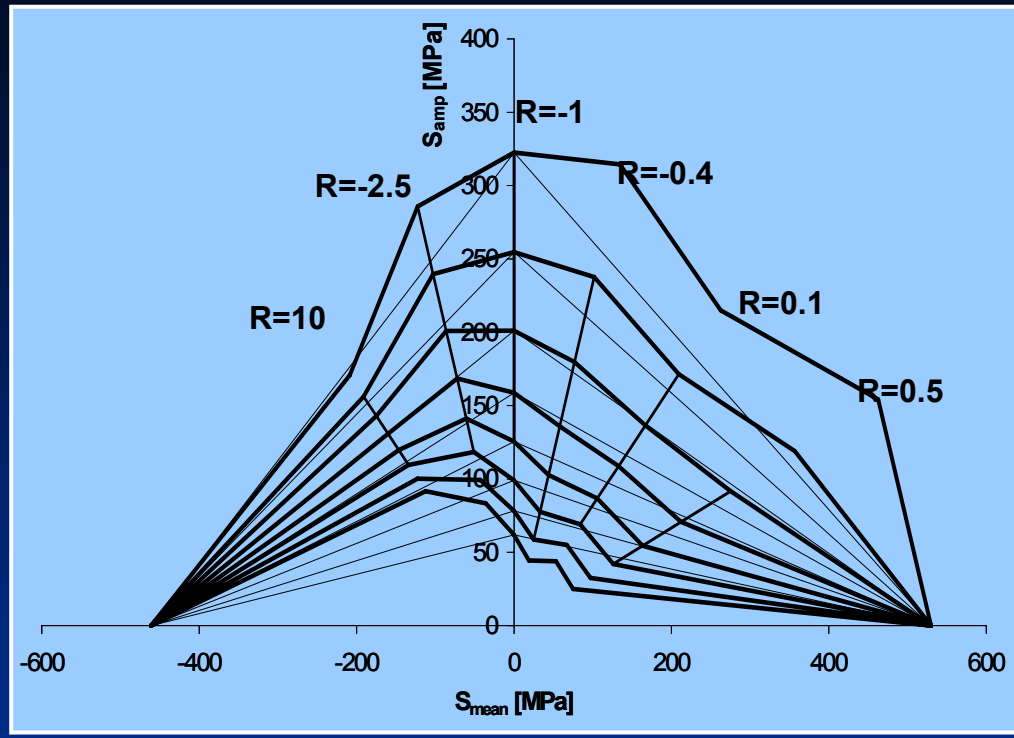
- **Problem: initial fatigue results within OPTIMAT BLADES**
  - Lower than expected
  - Required lower frequencies
- **Is it only temperature or other effects as well?**
  - Check at various frequencies and temperatures
- **Check fatigue behaviour at elevated temperatures and high humidity levels**

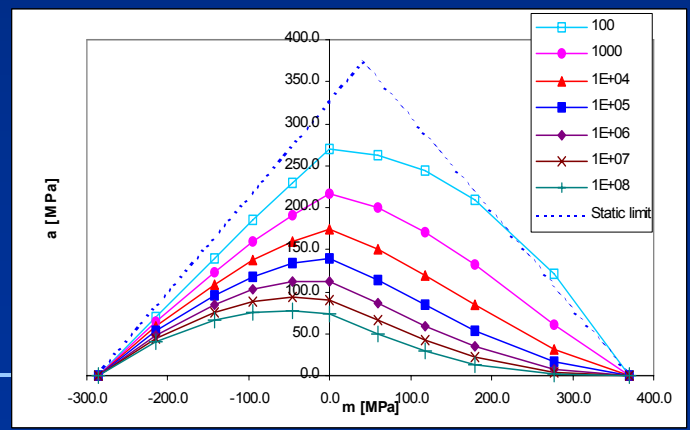
Constant Life Diagram (CLD)



CLD…modelling

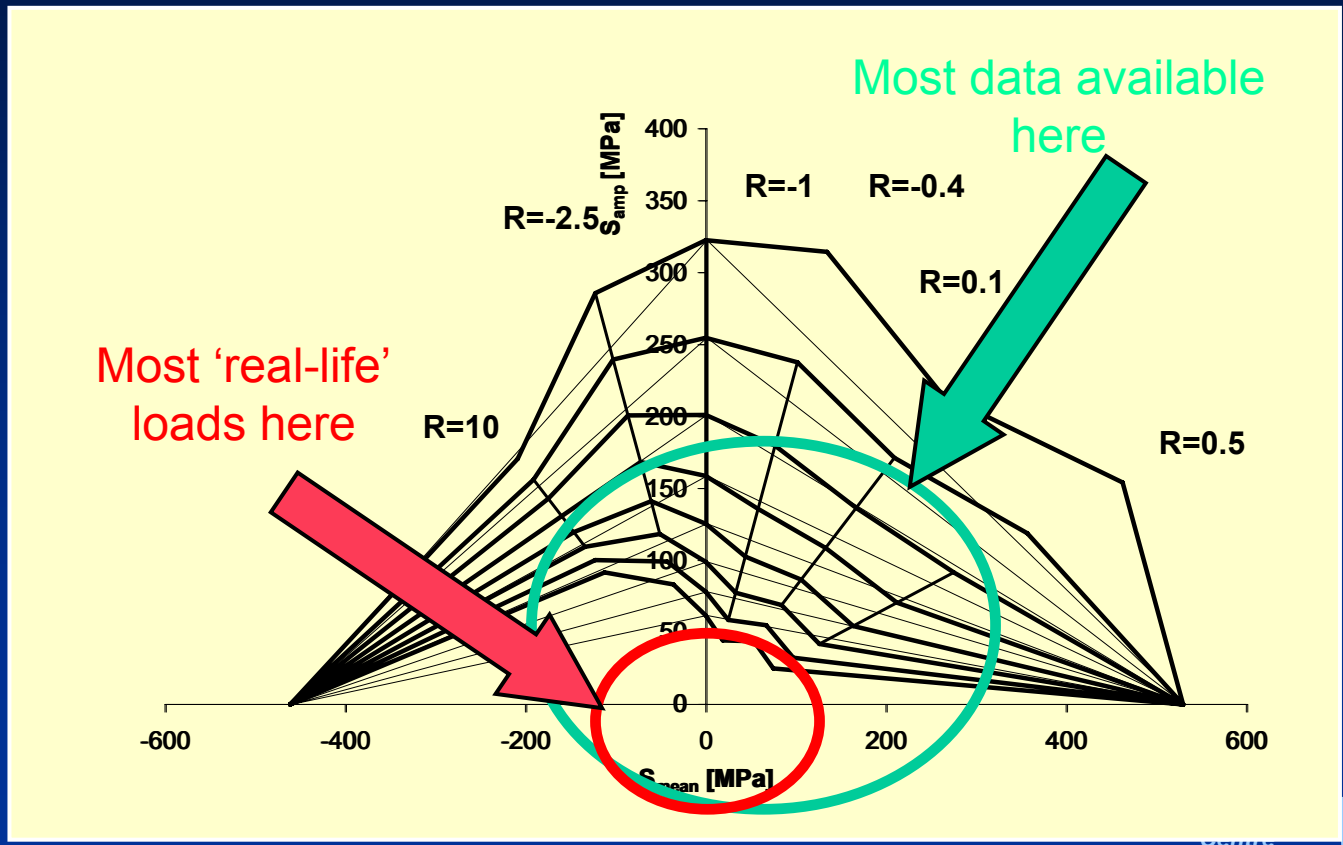
- Linear Goodman Diagram: poor performance
- Development of comprehensive CLD formulation (based on regression through multiple R-values)
- Ideally: Static strength + few tests determine fatigue behaviour



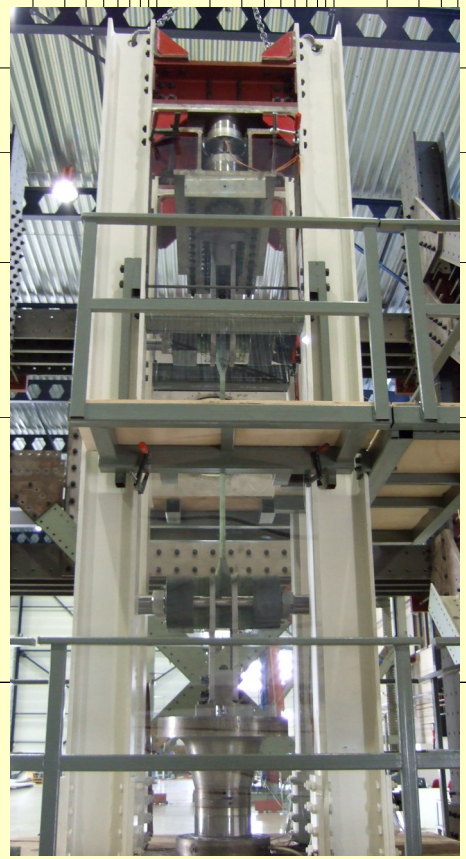


CLD…Long life tests (>10^6)

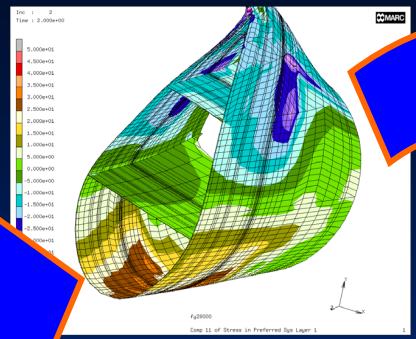
- Verify S-N curve extrapolations
- Duration typically 1 month….+ scatter!

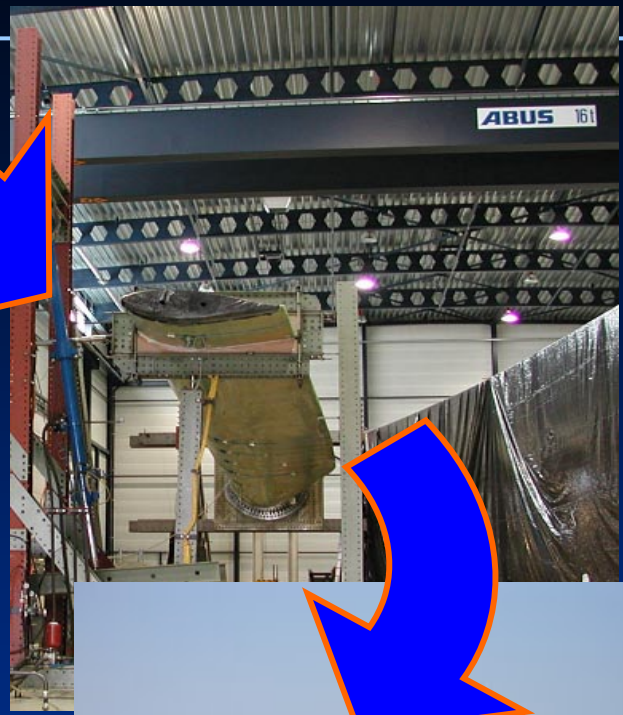


Thick Laminates



Circle of life





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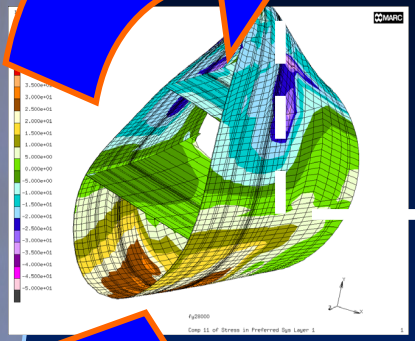
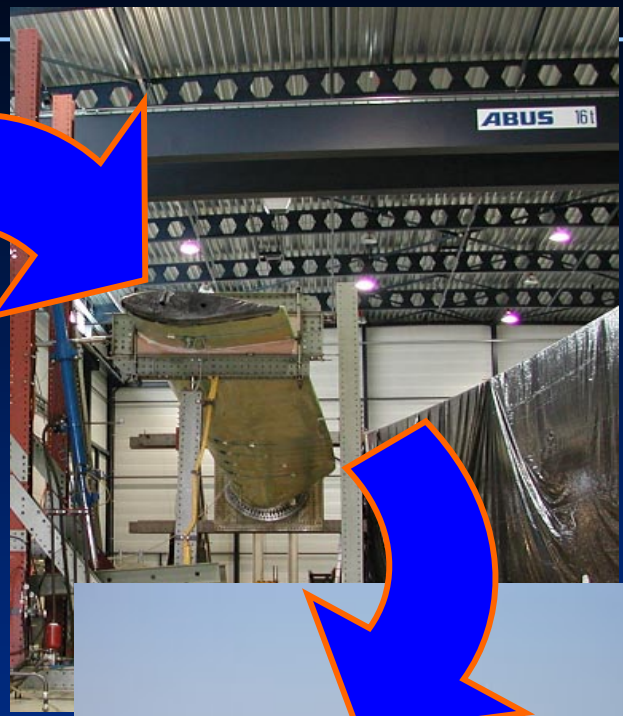
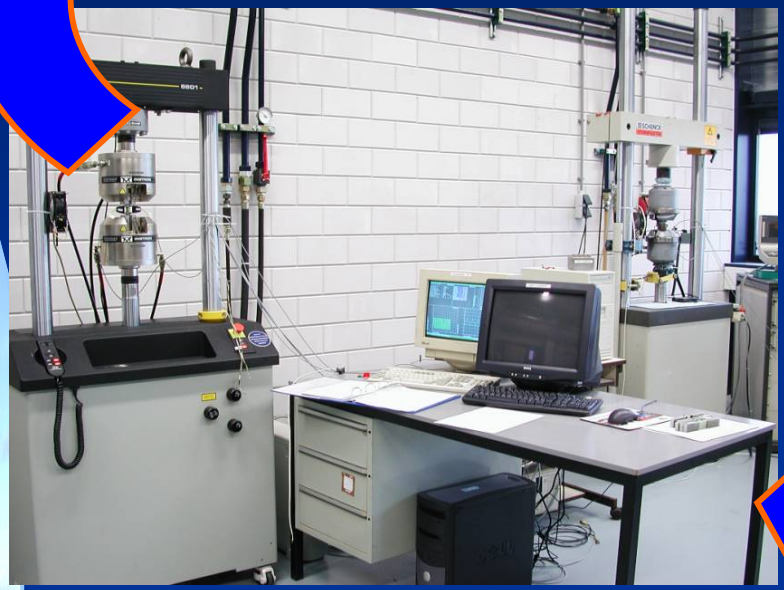
Missing link?







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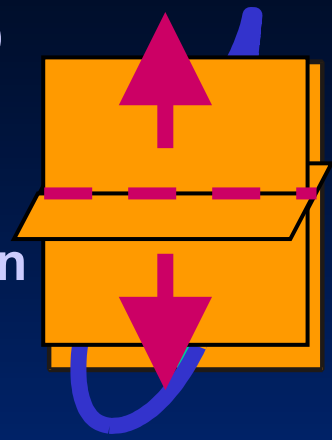
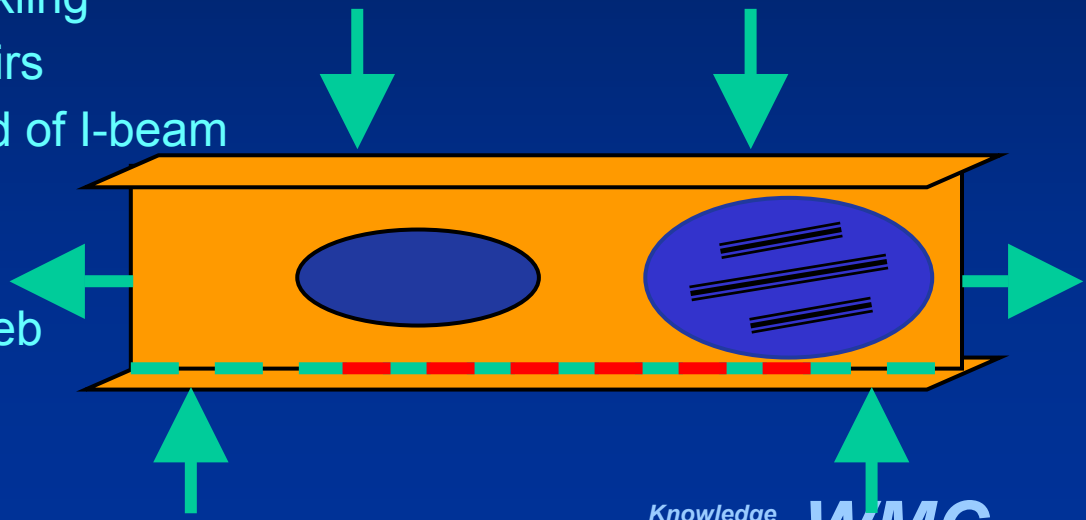
Subcomponent Testing

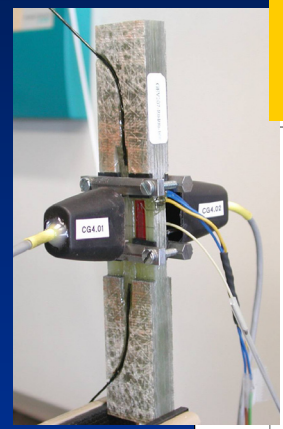
- Geometry used up to now: essentially 1D
  - No sidewise support
  - Conservative estimation
- Not actually repaired but scarf connection
  - Same quality?
- New geometry for 2D tests
  - Axial or 4-point Bending
  - Repairs and/or buckling
  - Glue and glue repairs
  - Or double C instead of I-beam
  - Or Glue connection
  - Sandwiches
  - Blade part: UD + web

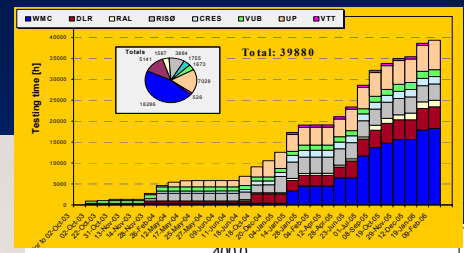


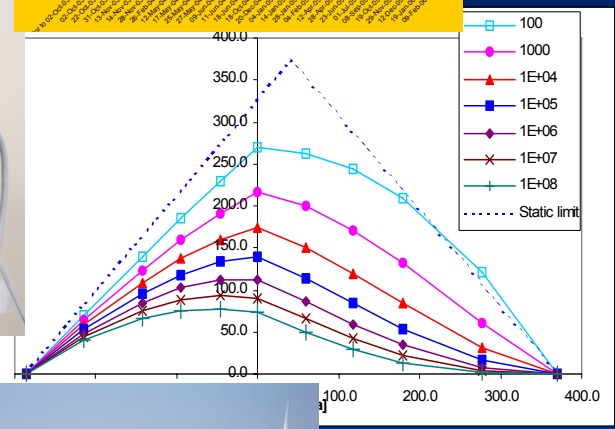


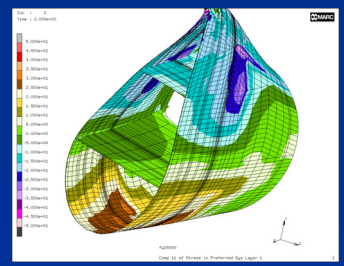
End

- Thank you!
- Questions/comments/discussion…?









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Session Questions

- What advances in methods for the design analysis of wind turbine structural components will be adopted by the industry over the next 5-10 years? What benefits will these advances bring?
- Is the full scale testing of blades and other wind turbine components likely to become more or less important in the future?
- Does the introduction of probabilistic approaches to wind turbine design calculations result in more optimised structural components, more conservatism, or more uncertainty?
- Is it likely that adaptive blades will ever replace pitch regulated blades?