FINITE ELEMENT SIMULATIONS IN LM WIND POWER

NAFEMS 2010 Gothenburg

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THE POWER TO DELIVER

lmwindpower.com

Results and customer portfolio

- **2006**
  - Turnover : 474 Mio. EUR
  - Employees : 3,683

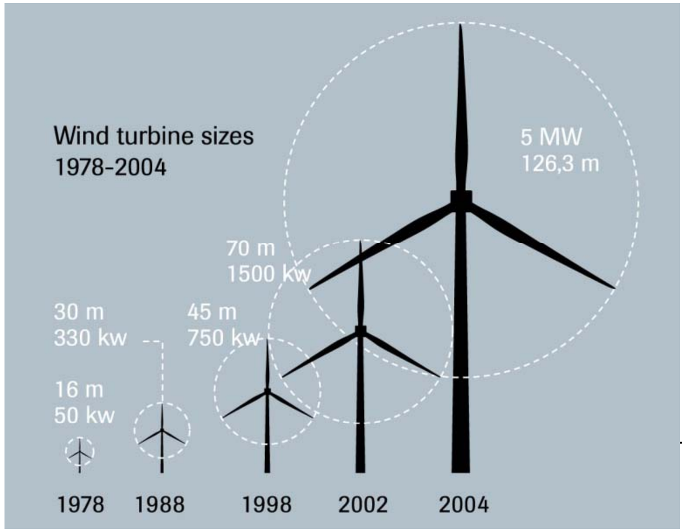
- **2007**
  - Turnover : 579 Mio. EUR
  - Employees : 5,905

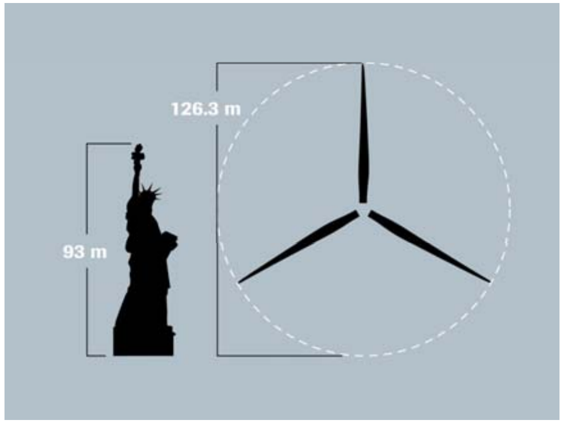
- **2008**
  - Turnover: 885 Mio. EUR
  - Employees: 7,217

- **Today**
  - Employees: ~4,500

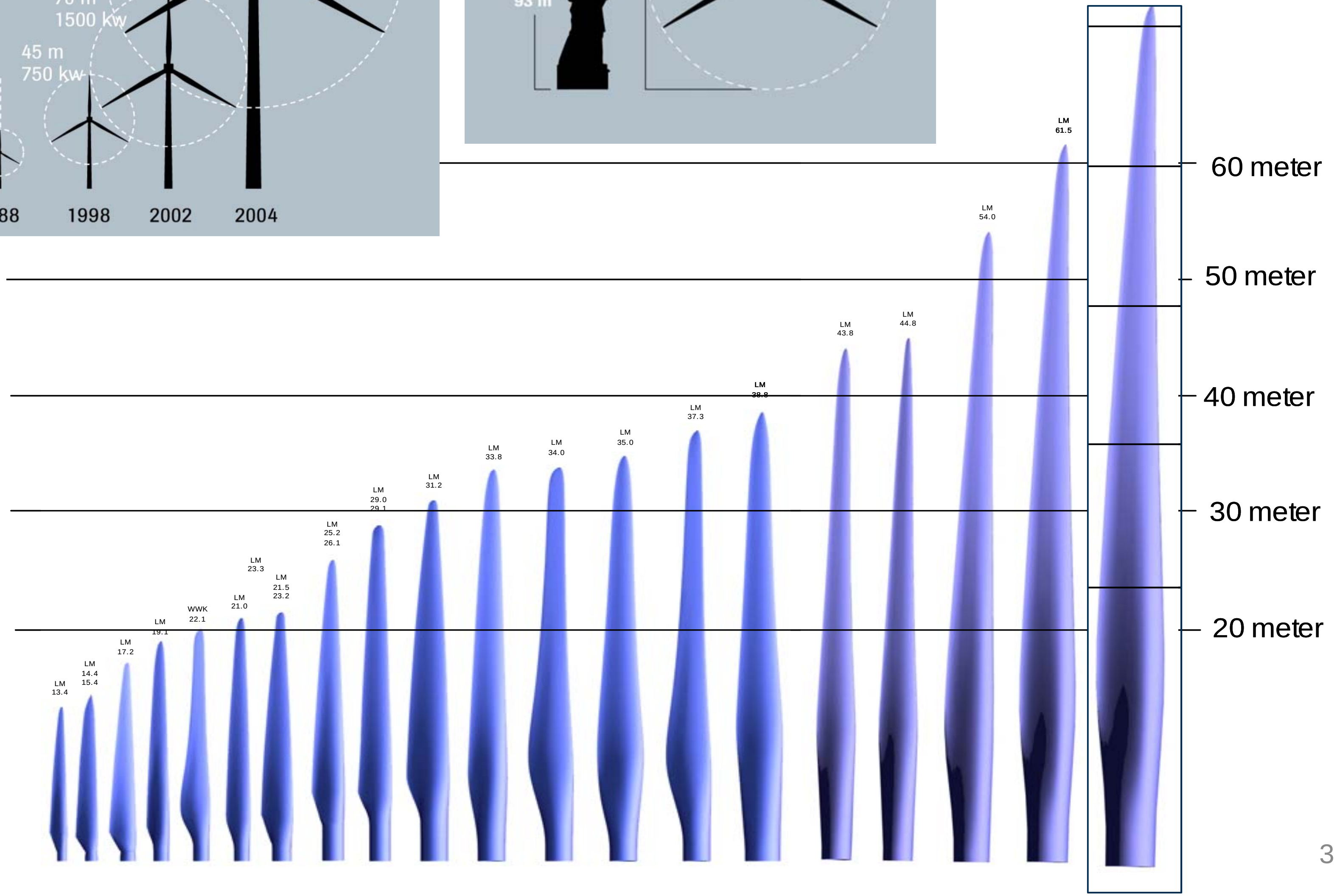
We partner up with the main wind turbine manufacturers:

Product Range





Coming up:
LM 73.5



LM Production process

1. Lay-up of glass fibre and core materials
2. Prepare for infusion
3. VARTM process
4. Impregnation with polyester
5. Curing of shells
6. Two webs placed to stabilise the shells.
7. De-moulding.
8. Finishing

Wind tunnel testing

- Development of profiles with better performance
- Testing of auxiliary details as slats, spoilers etc

Large scale testing for verification

Dynamic flap wise test

Static test

Organization

Core engineering

Aero dynamics
10 Employees:
Wind tunnel testing, CFD, Tools development

Stress enginerering
FE team:
10 Employees
FE tasks, Tools development

Materials
15 Employees:
New materials, materials characterizations, Design specifications

Total:
Approx12 with a PhD degree
Approx 30 with a Masters degree

Organisation enables us to focus on the core competences:
Do what you do best

The blade design process

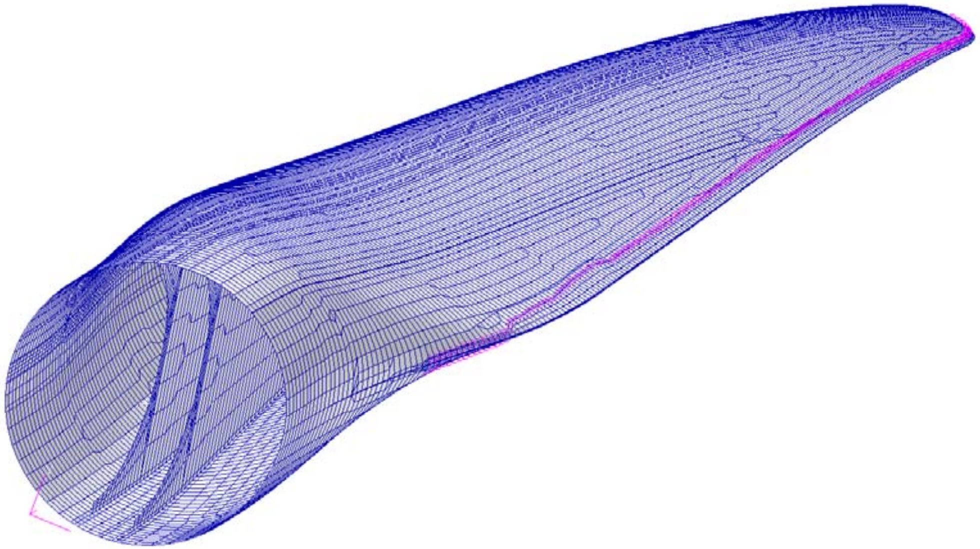
How can we …
… make a large number of new blade designs every year?
… have fast time to market and quick response to the customers?

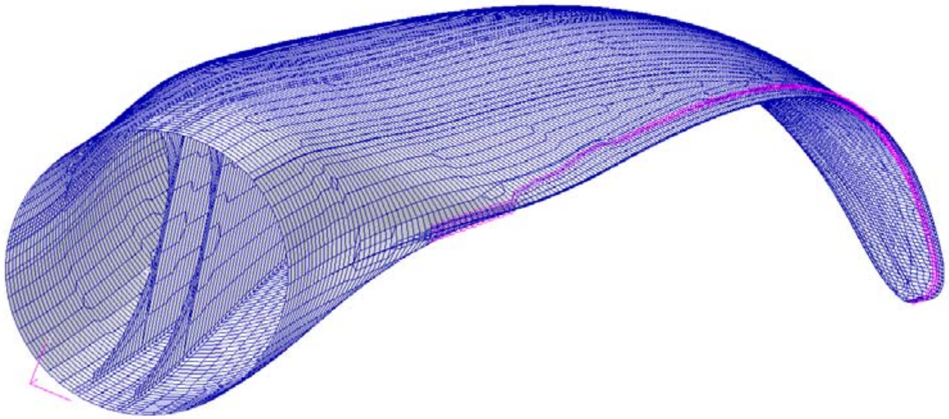
Automation and Standardization
Tools Developing/Programming
Goal: 1 button standard structural design of blade

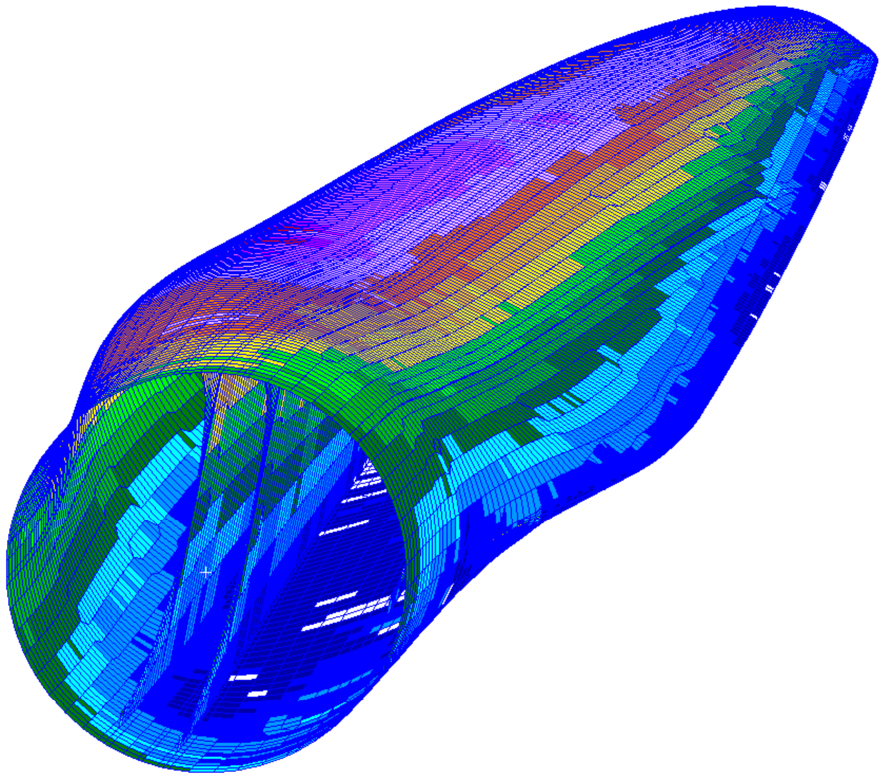
LM Blades
Standard laminate plan, layup optimization, sandwich panel optimization
AutoFEA
Automatic generation of FE model with properties, ply drops, application of loads
AutoDoc
Automatic post processing of results and report generation

Result (Spin off effect):
Routine work is minimized
Now we can focus on the fun stuff! ☺

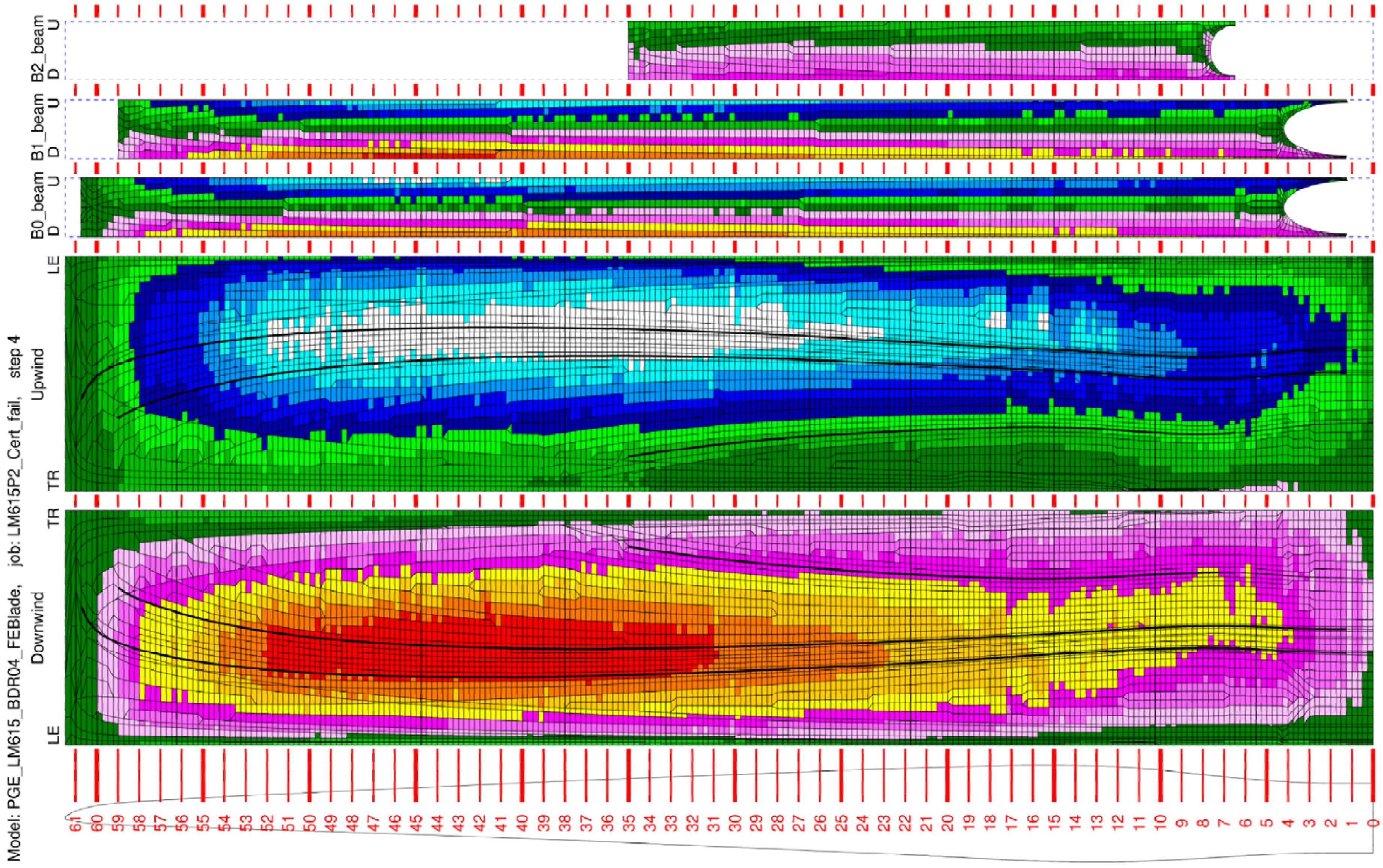
Global FE model
Undeformed, Deformed and Strains



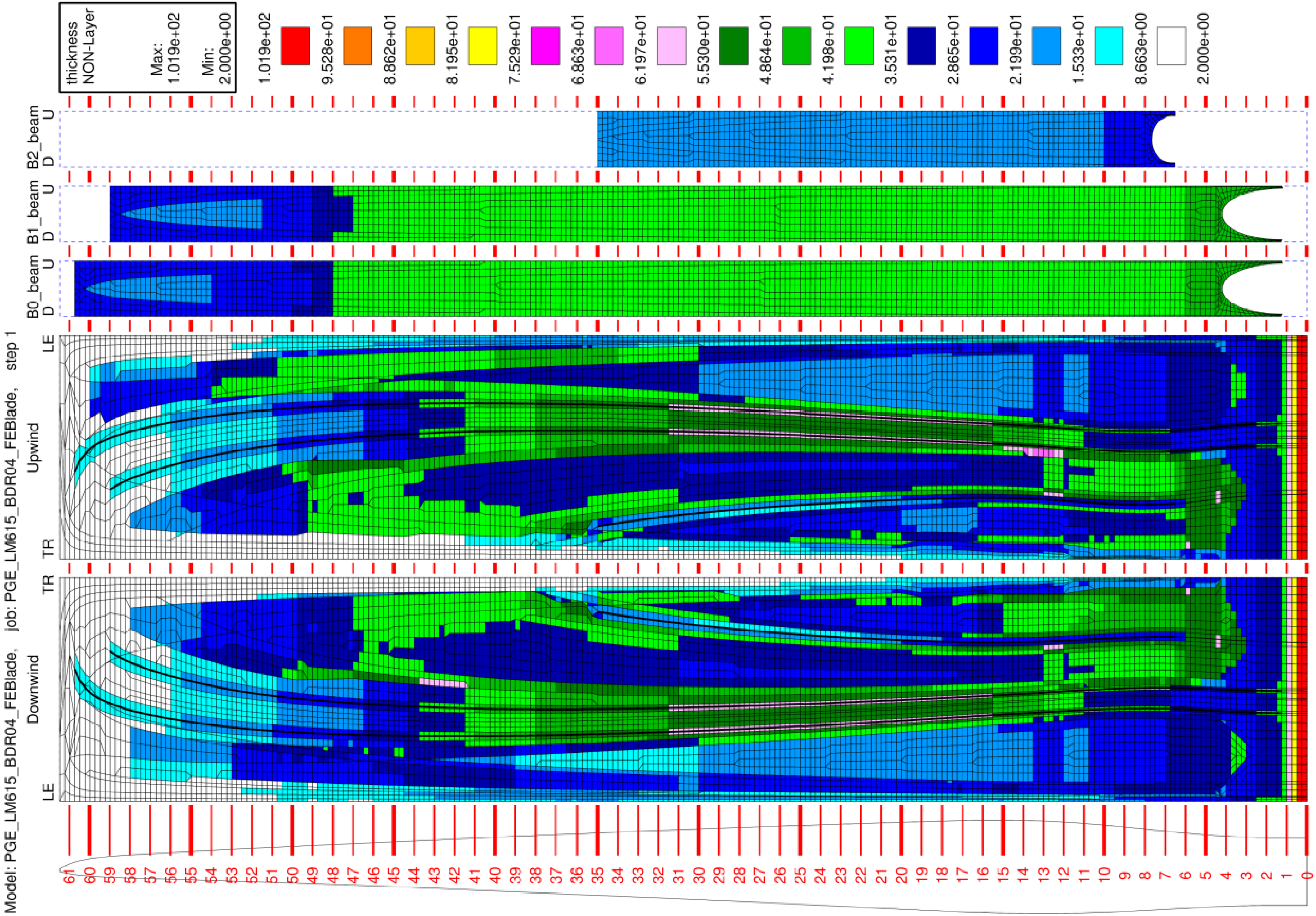




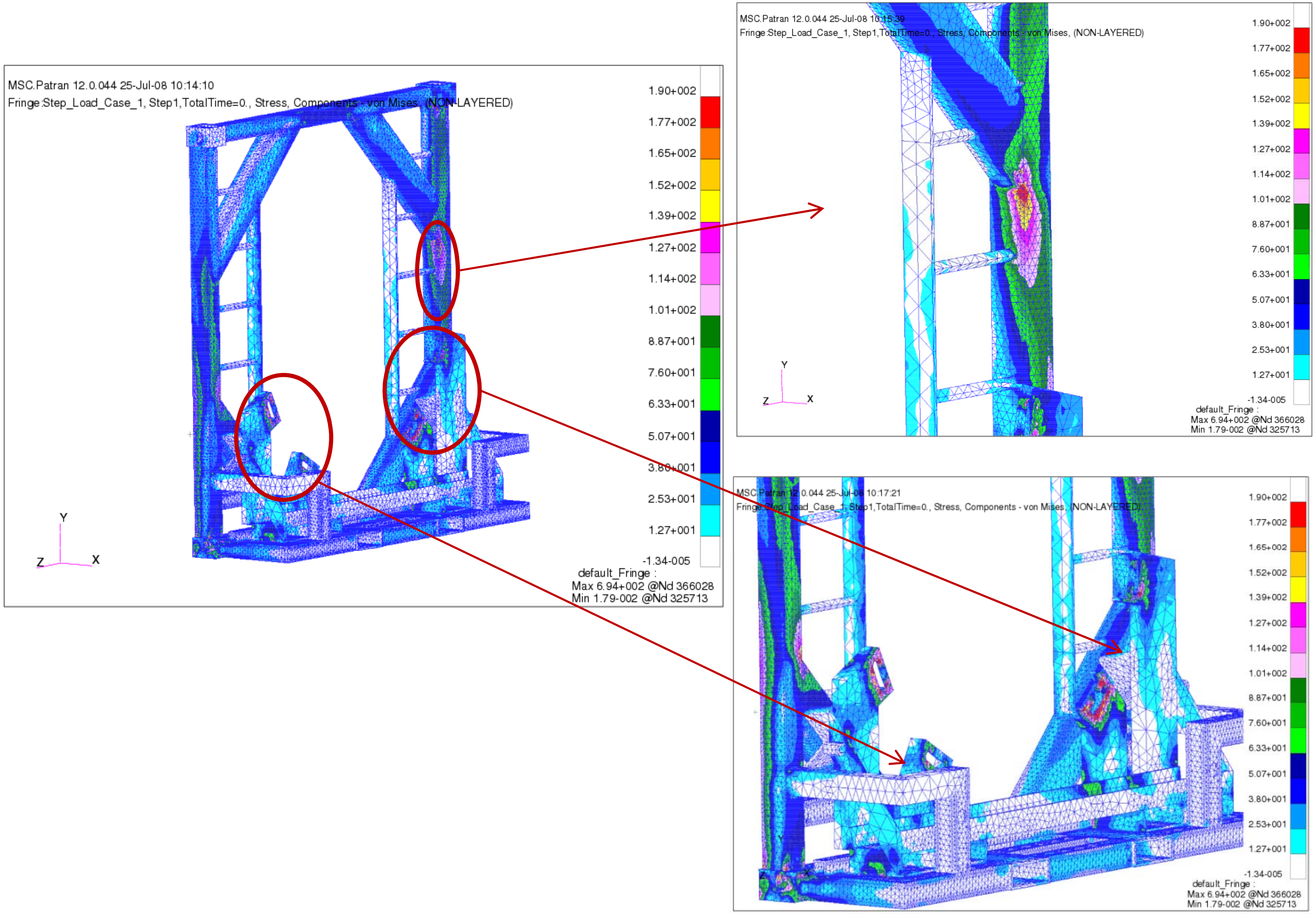
FE tasks, AutoDoc, Stretched plot, Strains



FE tasks - AutoDoc



FE tasks – Transportation rig



Full scale testing for verification

» Crash test of 40m blade

Full scale testing for verification

» Dynamic flap-wise test

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FINITE ELEMENT AND FRACTURE ANALYSIS IN WIND TURBINE BLADES

October 26th, 2010

By Anders Libak Hansen, Christian Lundsgaard-Larsen, Jesper H. Garm, Rasmus C. Østergaard

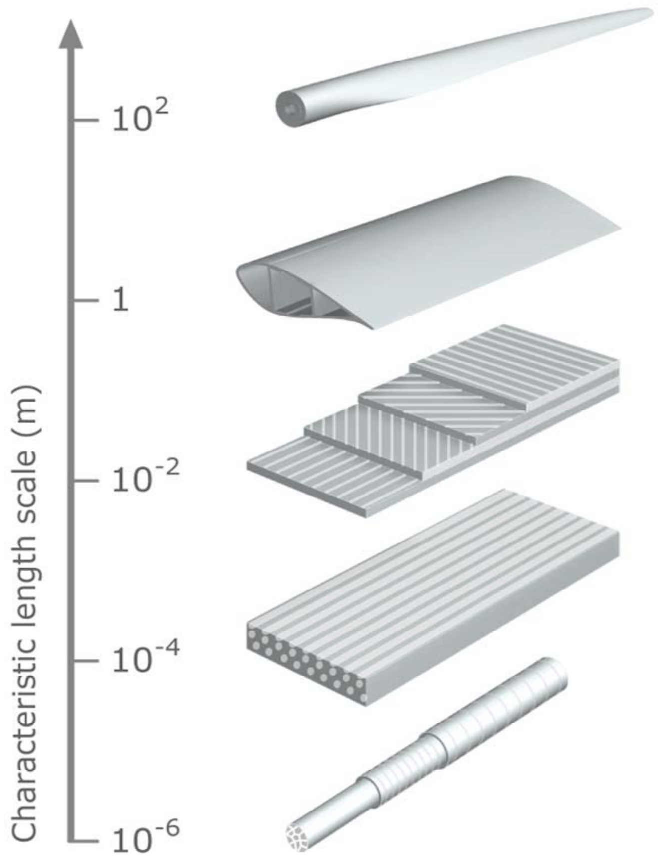
NORDIC 2010 NAFEMS CONFERENCE

LM WIND POWER

AGENDA

1. FEA and Fracture Mechanics
2. Progressive Damage Analysis
3. Fatigue Life Predictions

Reliable design requires control of different length scales



Full scale blade simulation:
- Web bond defect

Component test simulation:
- Web joint
- T- Spoiler

Material characterization:
- DCB specimen (Monotonic)
- Ply-drop in laminate (Fatigue)

FEA and Fracture Mechanics

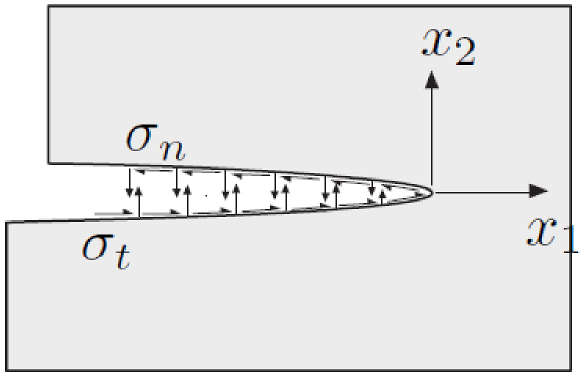
- **Linear Elastic Fracture Mechanics (LEFM)**
  - Stress intensity factors
  - Contour integrals (Less mesh sensitive)
  - Requires a pre-crack
- **Progressive Crack Growth**
  - Virtual Crack Closure Technique
  - Cohesive zone modeling (CZM)
- **CZM**
  - Fracture/damage process zone => Length scale effects
  - Load re-distribution => Non-linear fracture mechanics
  - Does not require pre-crack(s)

Cohesive Zone Modeling

» **Work of separation per unit crack area**

$$J_{cz} = \int_{\Gamma_{cz}} w dx_2 - \sigma_{ij} n_j \frac{\partial u_i}{\partial x_1} ds$$

$$w = \int \sigma_{ij} d\varepsilon_{ij}$$



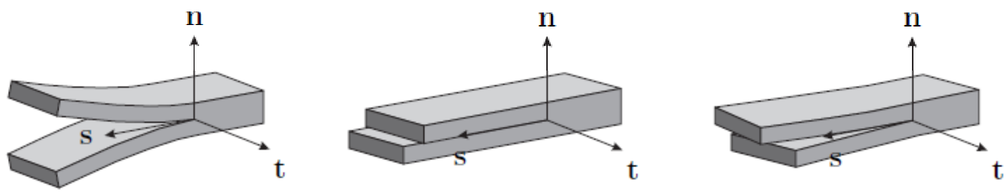
» **Traction-separation laws**

$$\boldsymbol{\sigma}(\delta_n, \delta_t) = \sigma_n(\delta_n, \delta_t)\mathbf{n} + \sigma_t(\delta_n, \delta_t)\mathbf{t}$$

$$J_{cz}(\delta_n^*, \delta_t^*) = \int_0^{\delta_n^*} \sigma_n d\delta_n + \int_0^{\delta_t^*} \sigma_t d\delta_t$$

$$\sigma_n(\delta_n, \delta_t) = \frac{\partial J_R(\delta_n, \delta_t)}{\partial \delta_n}$$

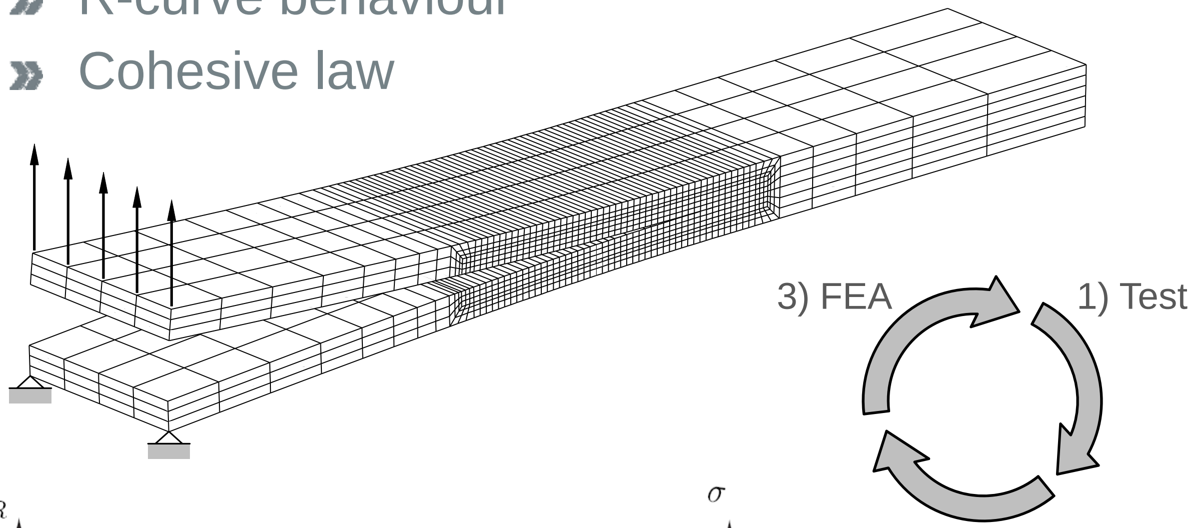
$$\sigma_t(\delta_n, \delta_t) = \frac{\partial J_R(\delta_n, \delta_t)}{\partial \delta_t}$$

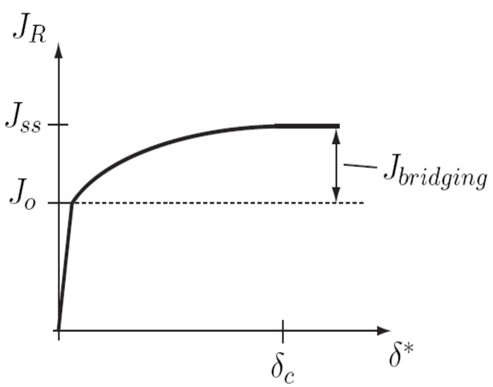


Progressive Damage Analysis

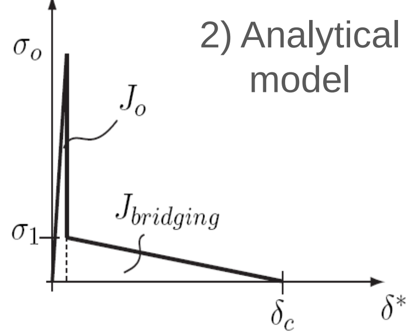
Double Cantilever Beam

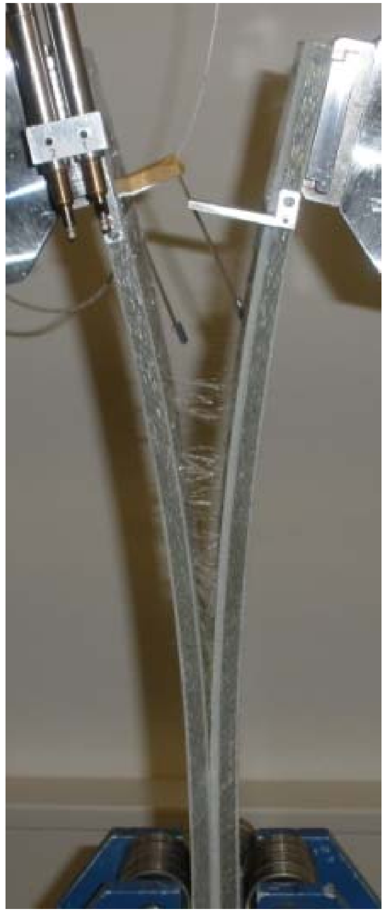
- Material interface characterization
- R-curve behaviour
- Cohesive law





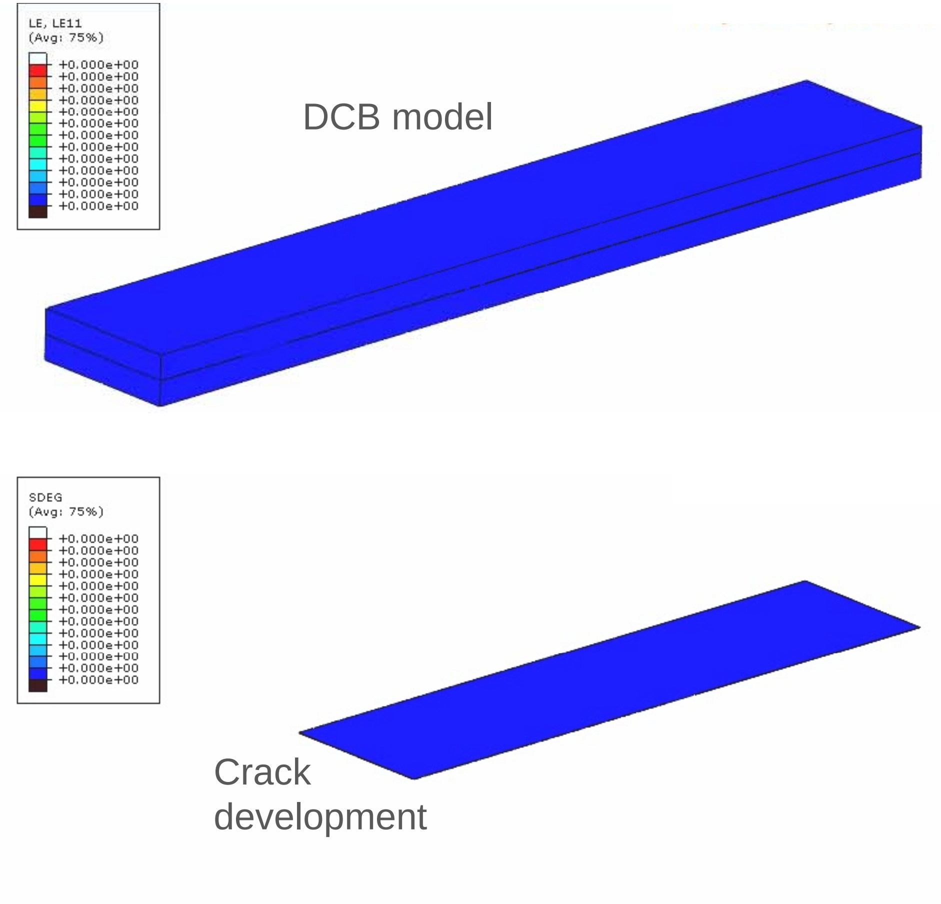
$$\sigma = \frac{\partial J_R}{\partial \delta^*}$$

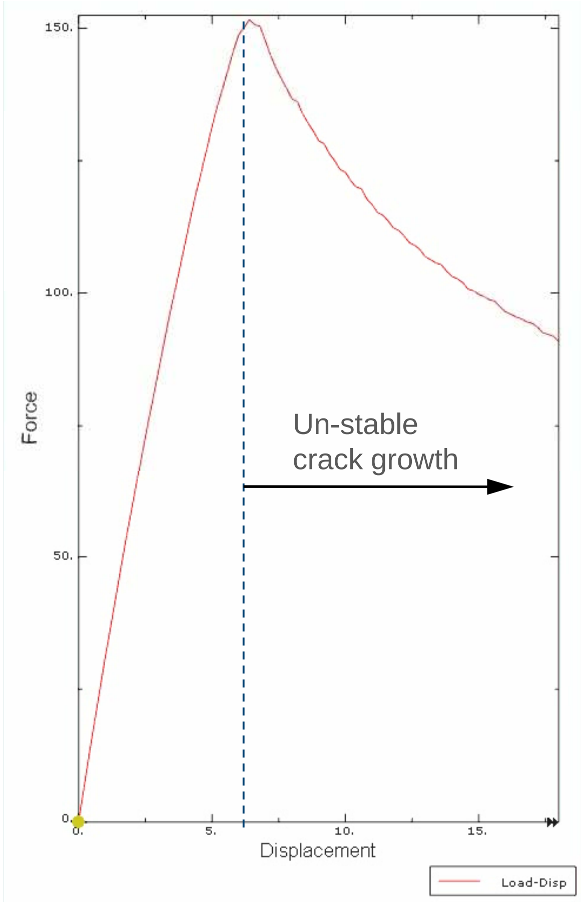




Progressive Damage Analysis

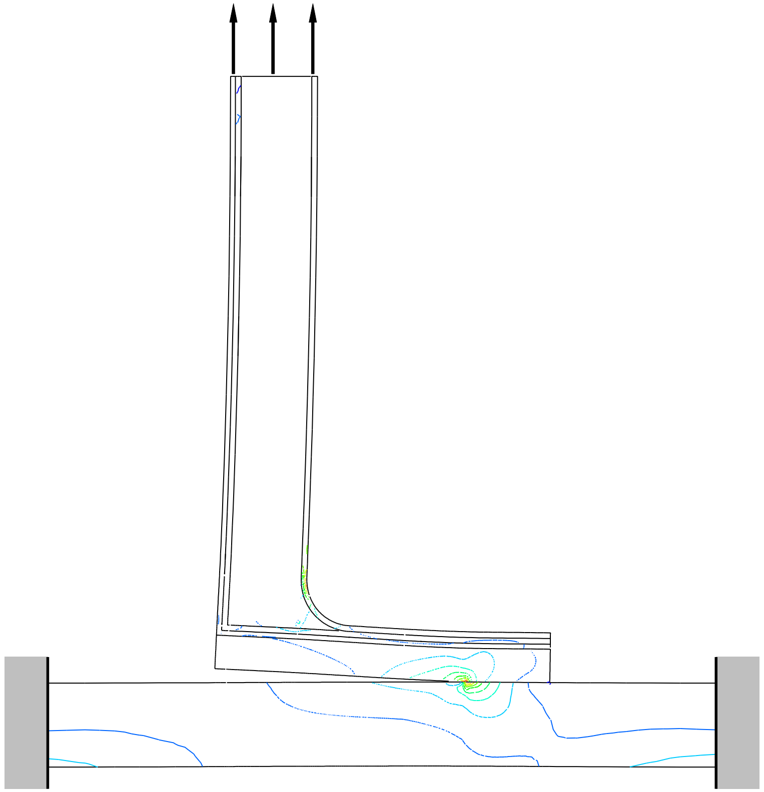
» Double Cantilever Beam





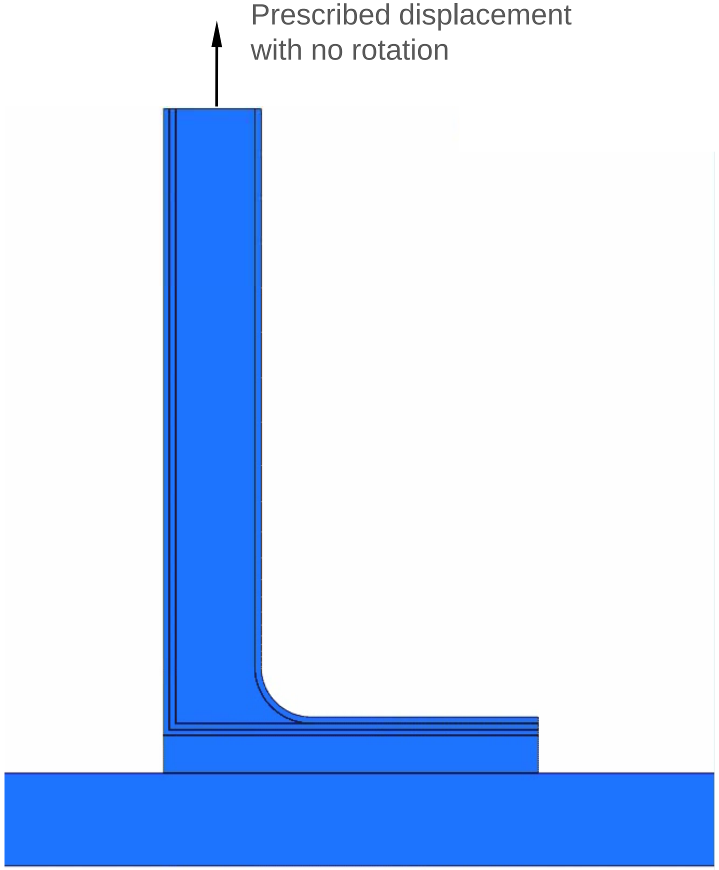
Progressive Damage Analysis

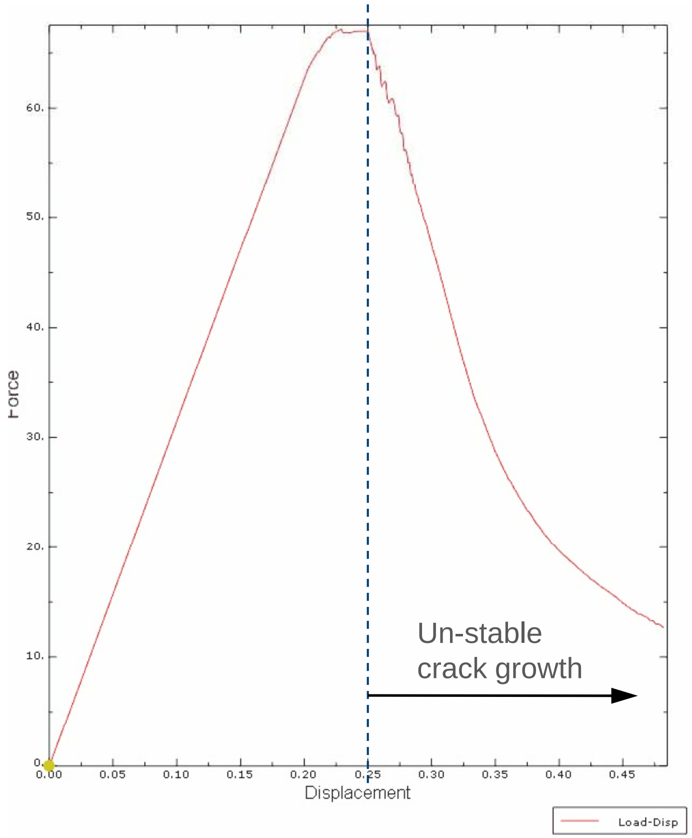
- **Web joint component test**
  - Virtual test bench
    - Design – Materials – Process
  - Strength envelope
    - Axial and bending loads



Progressive Damage Analysis

» Web joint component test

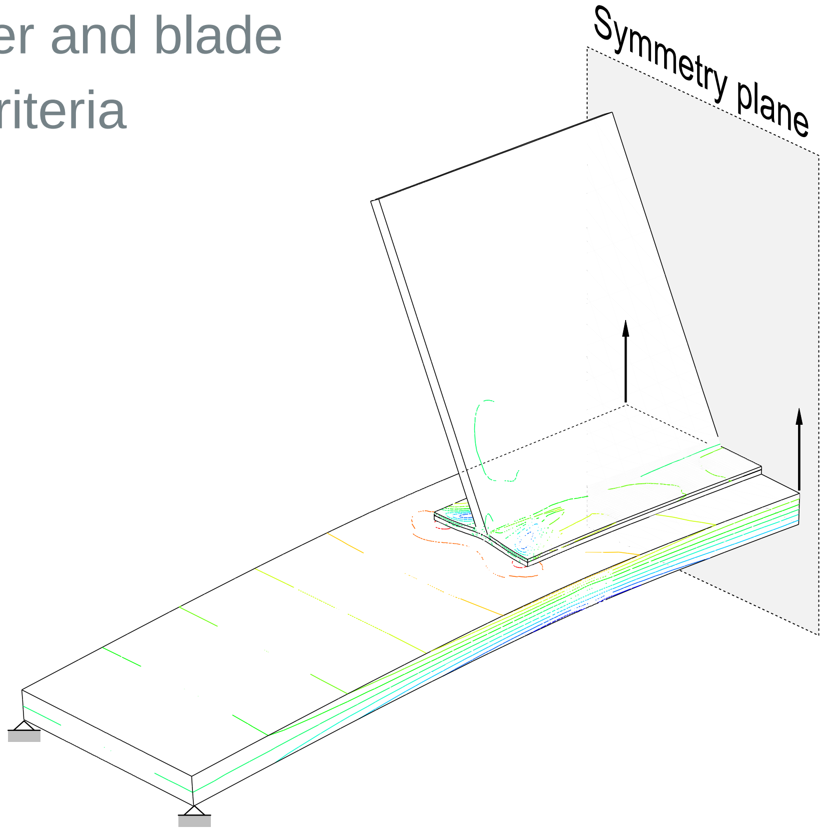




Progressive Damage Analysis

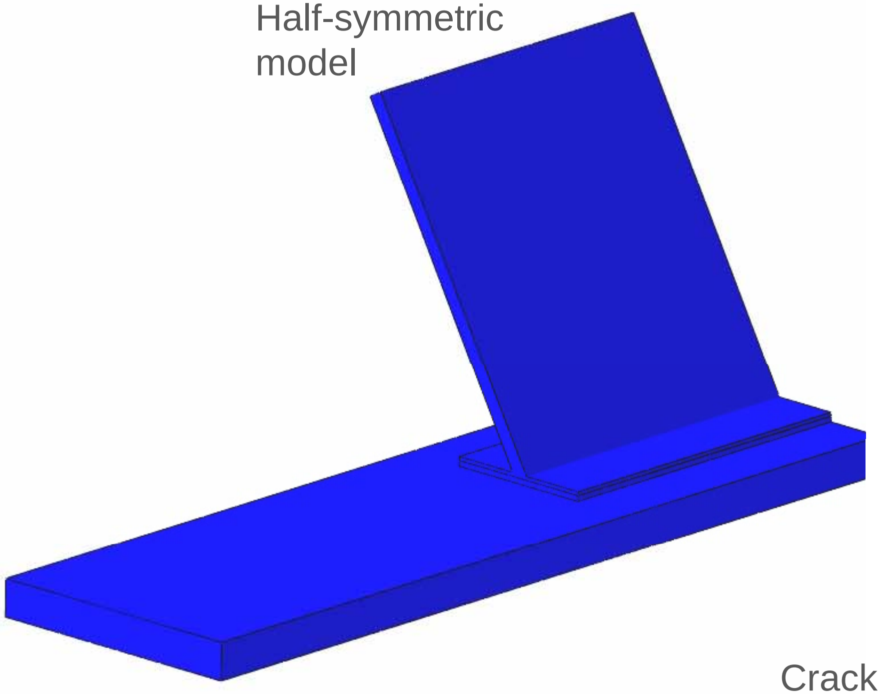
» T-spoiler component test

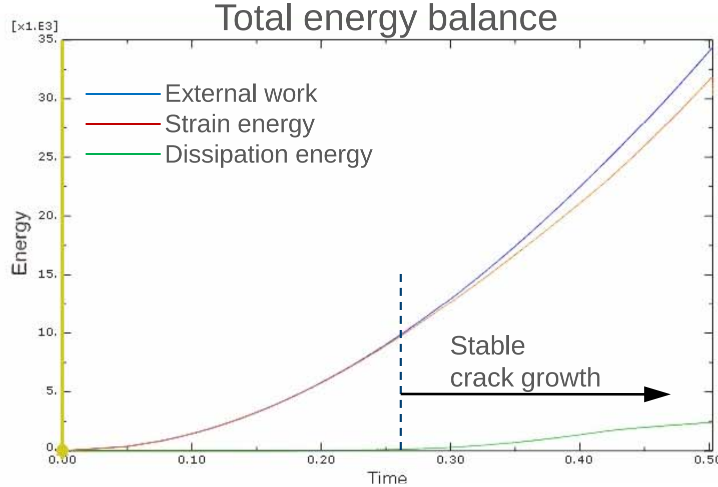
- » Combined loading from spoiler and blade
- » Fracture mechanics design criteria
- » Damage tolerence

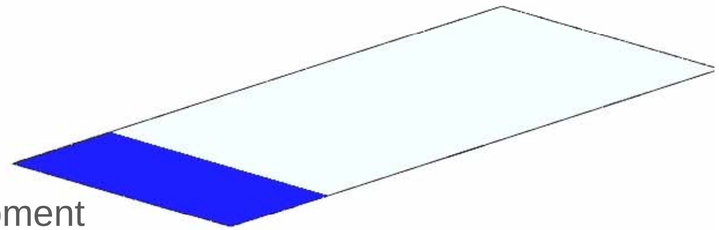


Progressive Damage Analysis

» **T-spoiler component test**

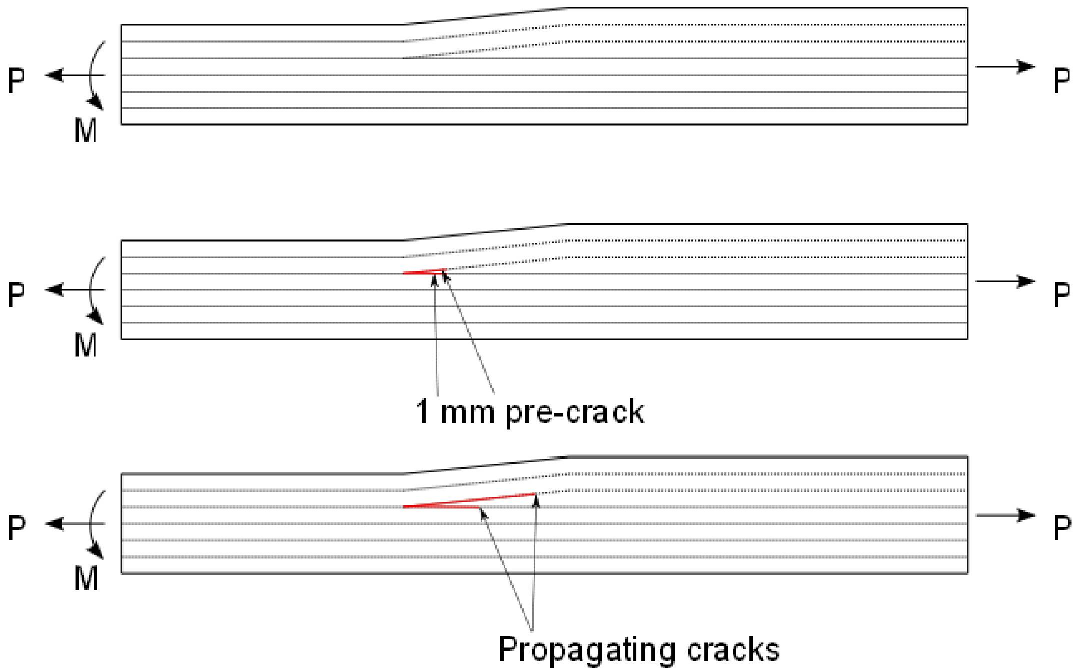


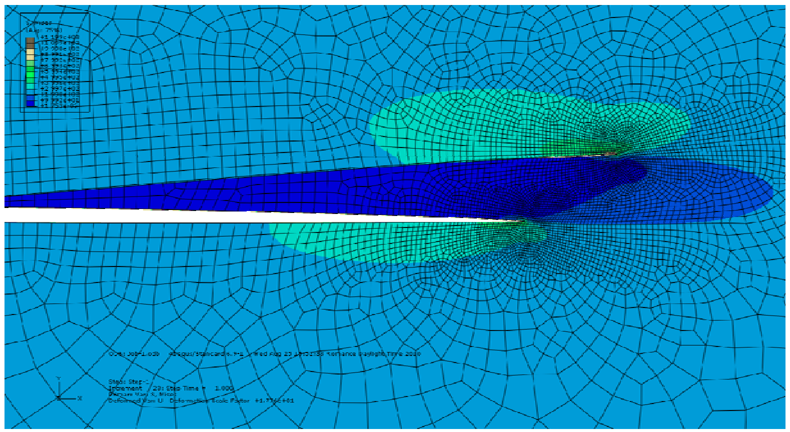




LEFM: Fatigue loading of ply-drops

- Ply-drops are used in transitions between thick and thin laminate
- Ply-drops may lead to stress concentrations, which reduces fatigue life-time
- Prediction of the life-time is made using FE and fracture mechanics





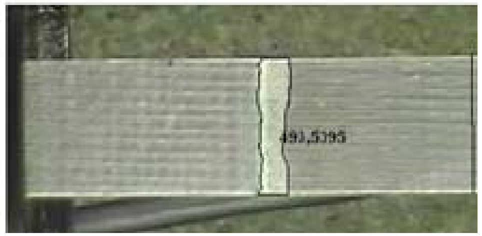
Fatigue test of ply-drop specimens

- Fatigue tests conducted on ply-drop specimens
- For considered load-level, a visible crack has initiated after 3000 cycles
- Crack continues to propagate during fatigue loading

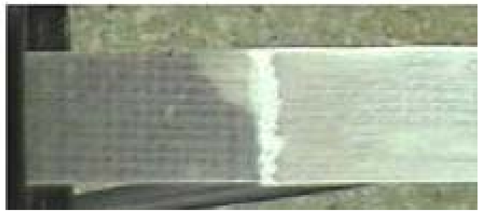
0 cycles

3,000 cycles

822,000 cycles

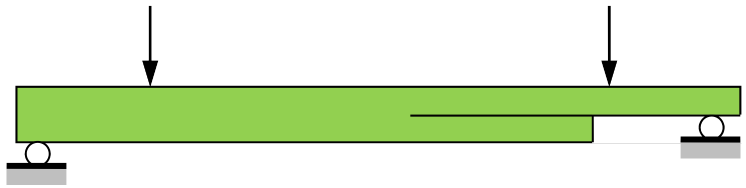


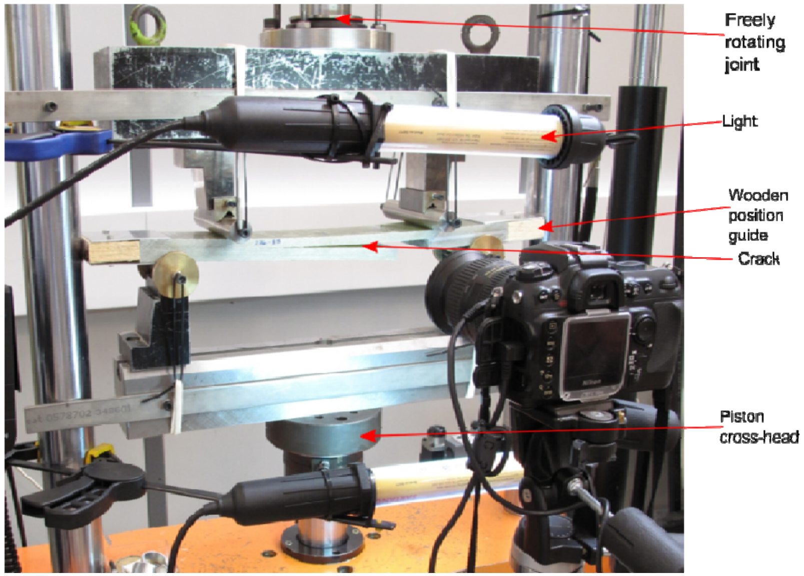
2,007,000 cycles



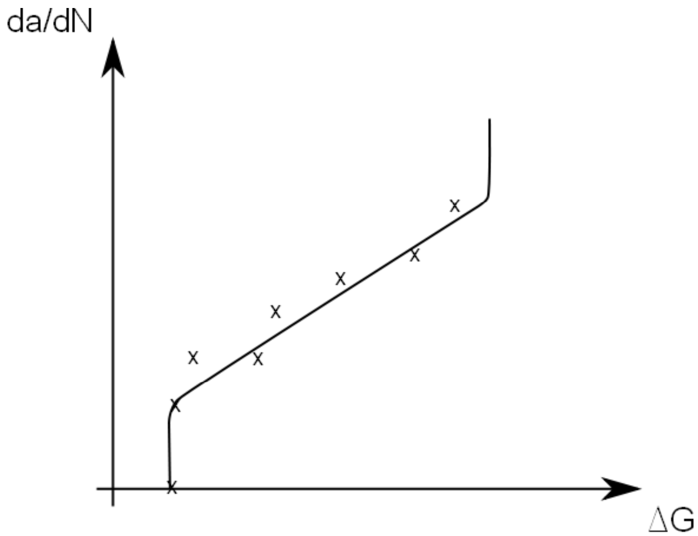
Paris law from material tests

- Four point bending fatigue test used to drive the crack





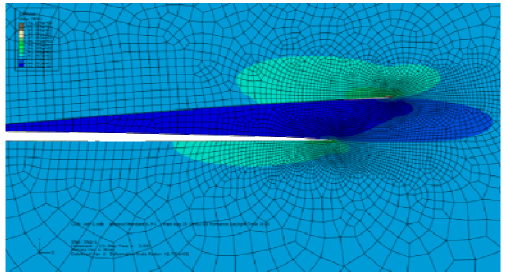
- Paris law extracted for the considered material

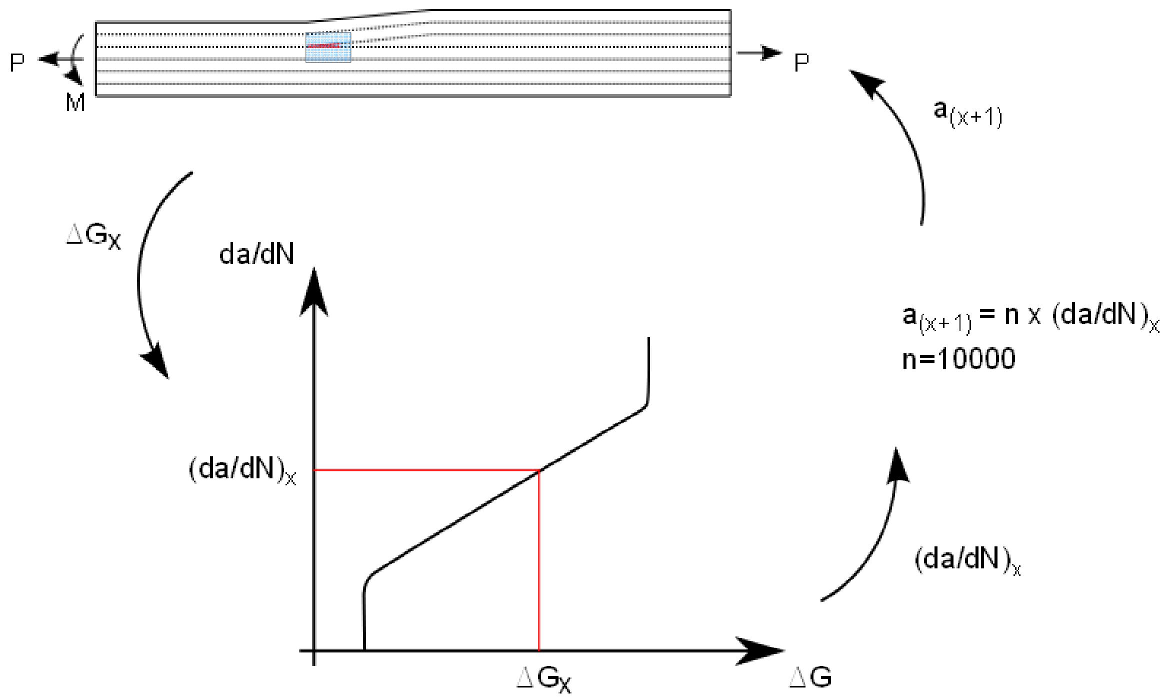


- Paris law describes crack growth rate as function of loading magnitude (energy release rate)

Procedure for predicting fatigue life-time

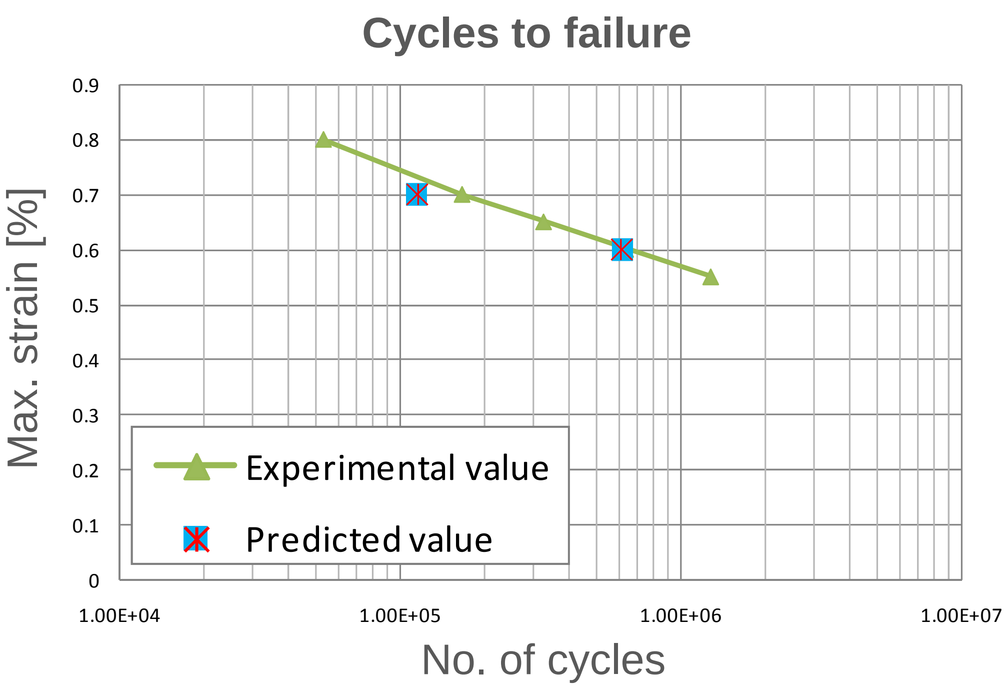
- G is calculated for present crack length (initial crack length is 1 mm)
- Corresponding crack growth rate found from Paris law diagram
- Crack propagation length at n number of cycles found and added to FE model





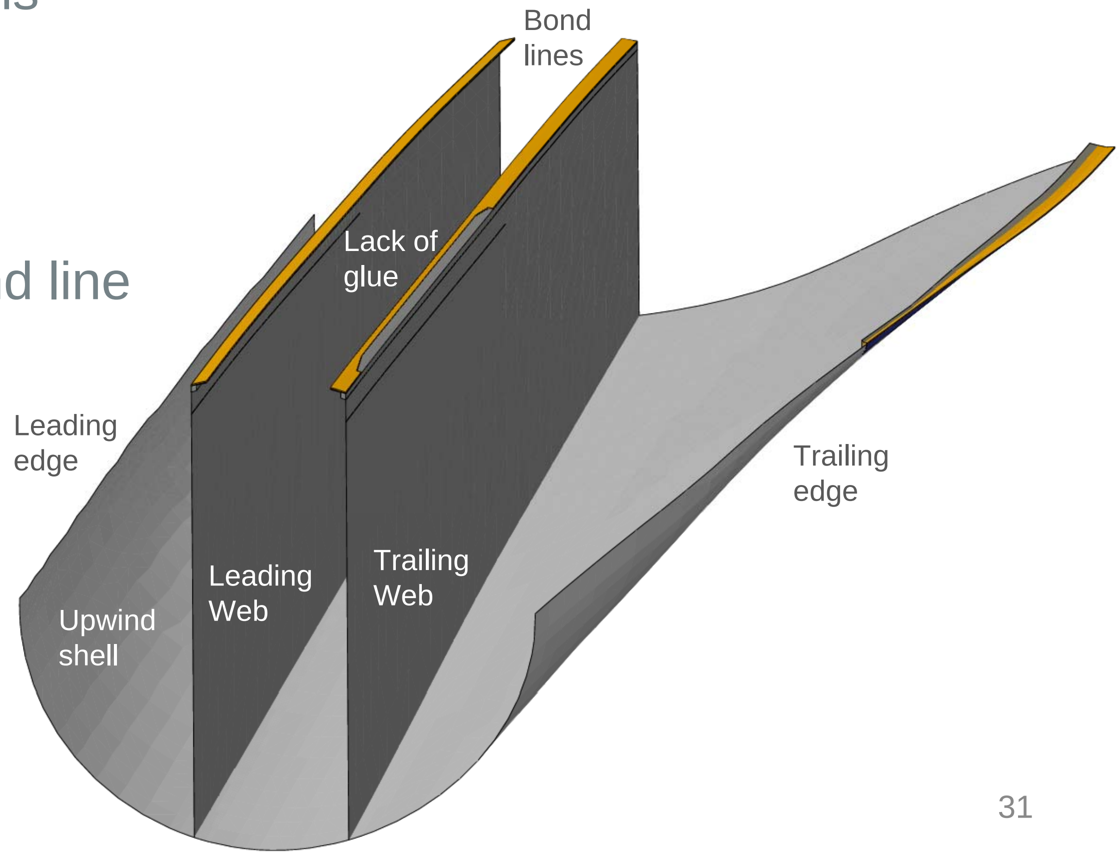
Comparison of numerical and experimental results

- Number of cycles to failure compared for experiments and simulation prediction
- Gives a rough estimate of the fatigue life-time
- FE-model is used to find the most critical position of the ply-drop in a laminate



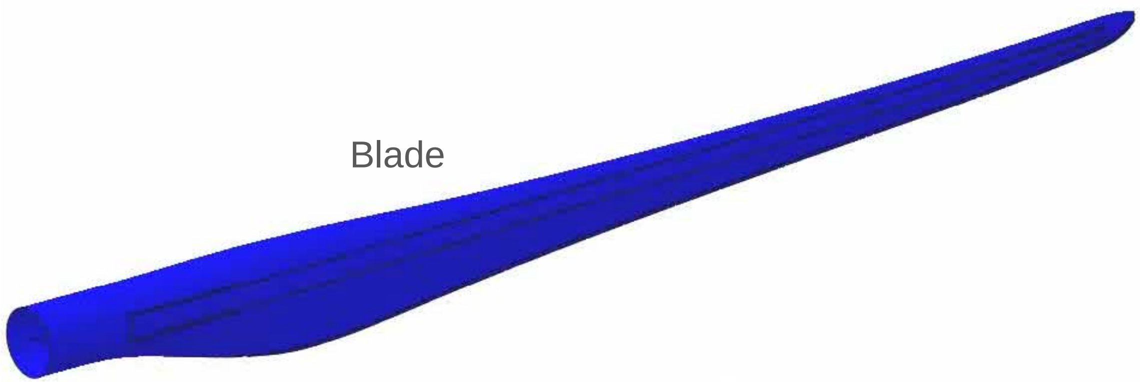
Progressive Damage Analysis

- Full-scale blade simulation
  - Interaction between non-linear deformation and fracture
  - Imperfection analysis
  - Damage tolerence
- Example
  - Lack of glue on bond line
  - Debonding
  - Buckling



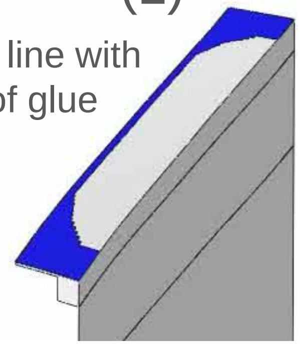
Progressive Damage Analysis

» Full-scale blade simulation



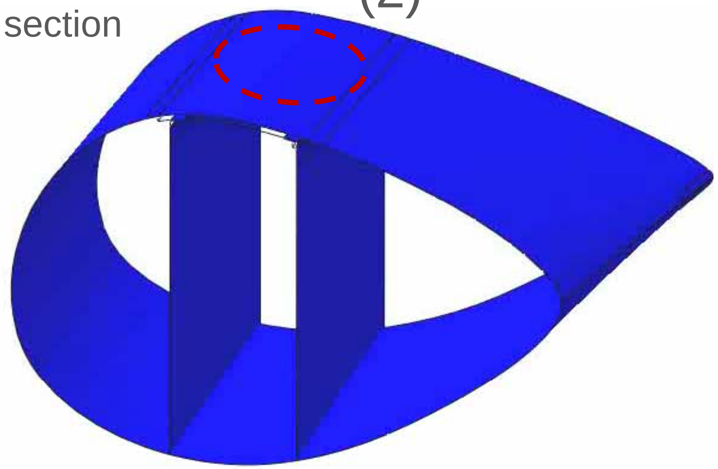
(1)

Bond line with lack of glue

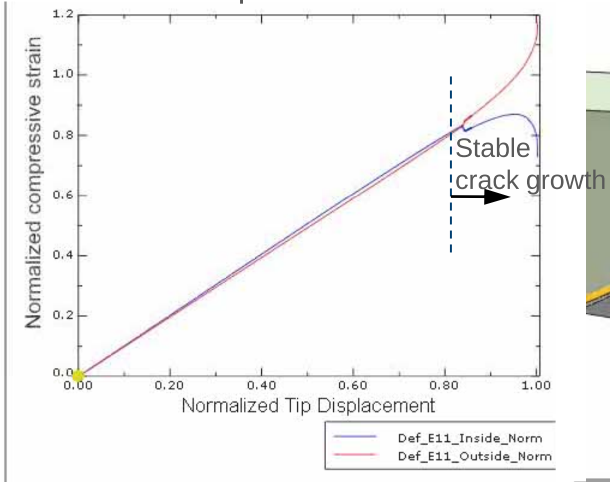


Buckling critical section

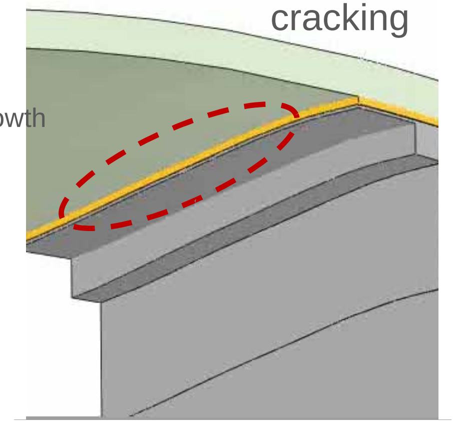
(2)



Compressive Strain



Bond line cracking



Thank you for listening!

» **Questions, comments?**

Contact:

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Virtual Wind Tunnel Tour