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Modelling of Wind Turbine Blades with ABAQUS

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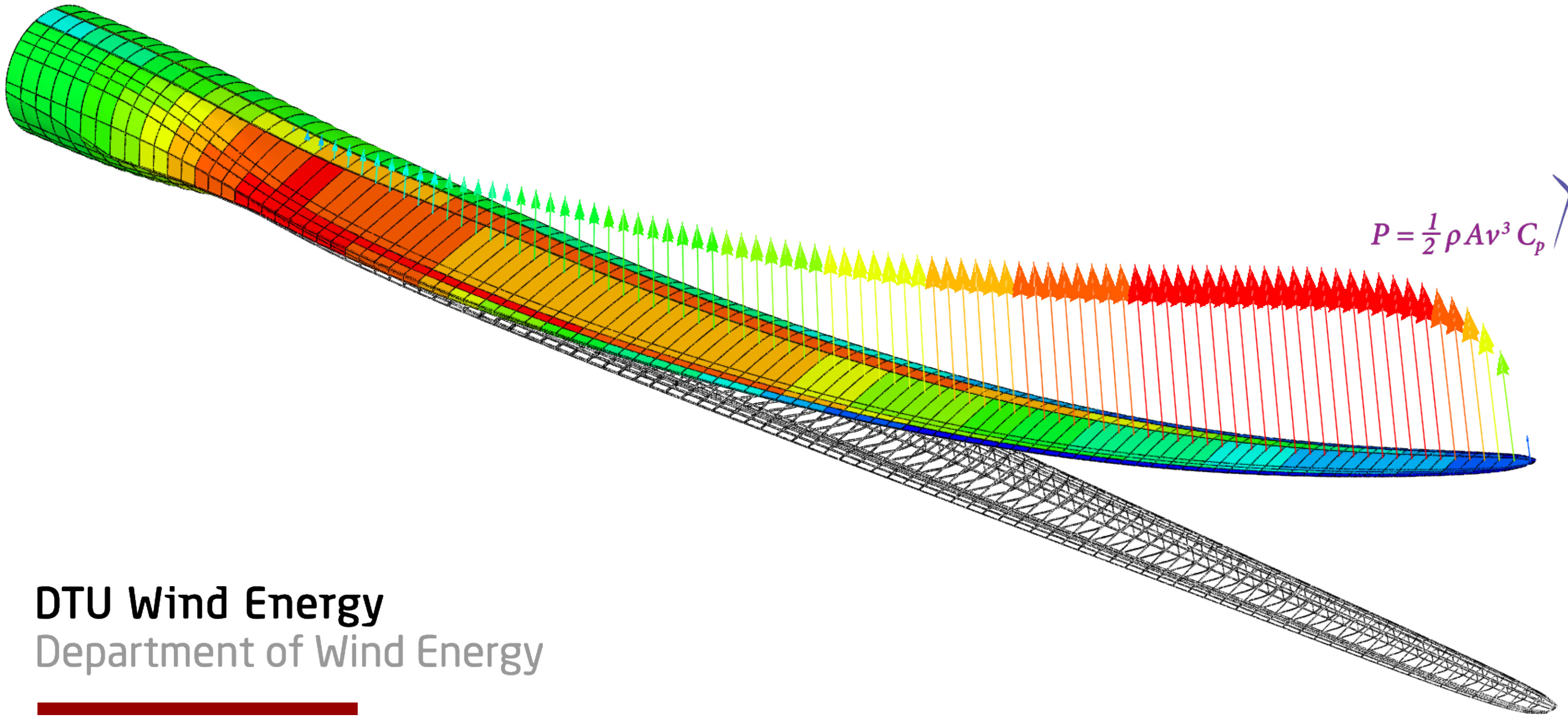
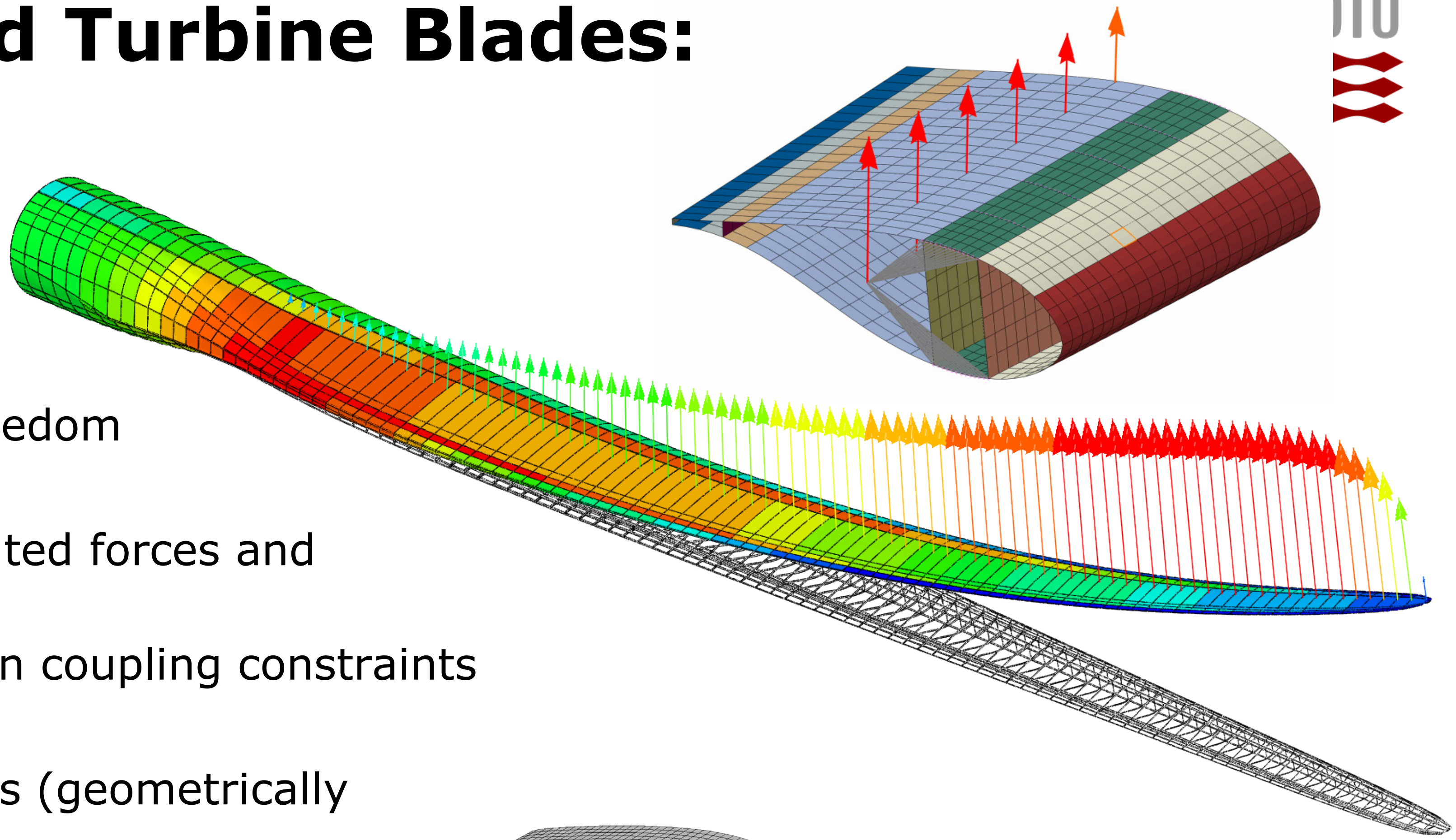
Senior Scientist

Composites Seminar,
March 12, 2015
DTU Risø Campus

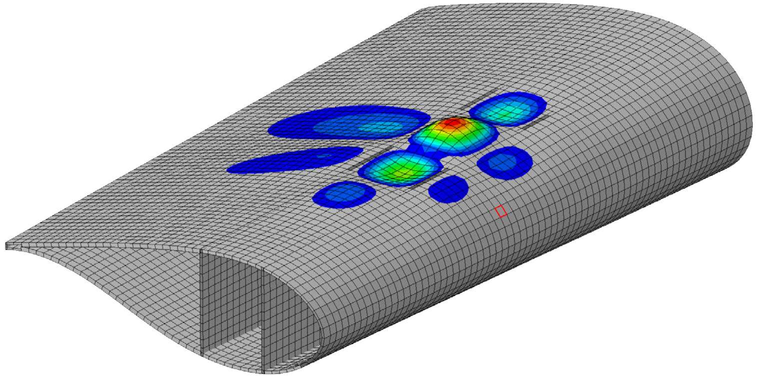


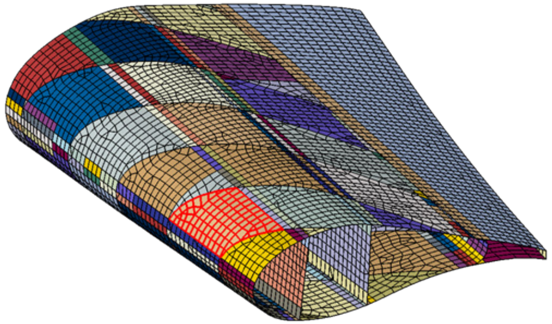
DTU Wind Energy
Department of Wind Energy

Modelling of Wind Turbine Blades: State of the Art



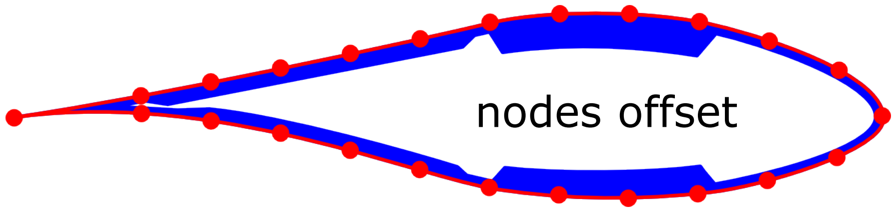
- Element types:
  - Layered shell elements
- Typical model size:
  - ca. 500.000 degrees of freedom
- Load application:
  - small number of concentrated forces and moments
  - applied through distribution coupling constraints
- Typical analysis procedures:
  - Static stress/strain analysis (geometrically linear and non-linear)
  - Natural frequency analysis
  - Eigenvalue buckling analysis



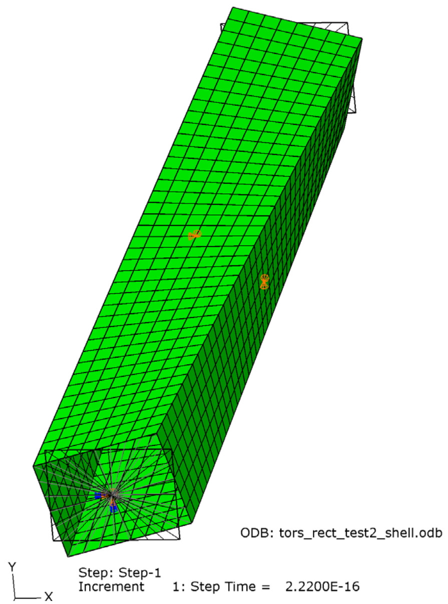


Modelling of Wind Turbine Blades: Shell Node Offset

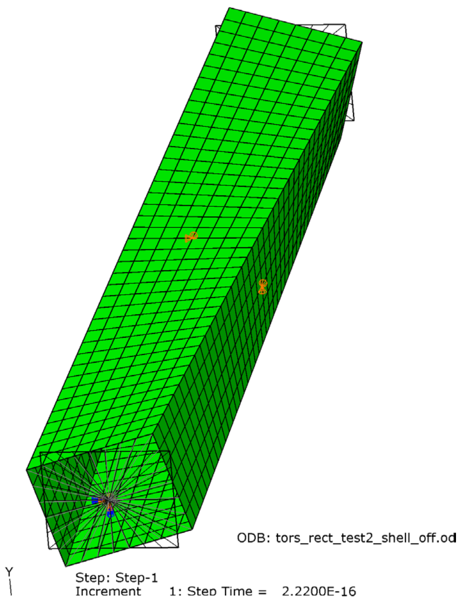
- Wind turbine blade shell models usually have the finite element nodes offset to the exterior surface.
- However, the offset creates a systematic error in the torsional stiffness of the blade.
- Benchmark example: Thin-walled beam with rectangular cross-section made from an isotropic material:



Abaqus Element Type	Mesh	Normalized angle of twist
Shell S4	28x40	0.995
Shell S4R	28x40	0.995
Shell S4, nodes offset	28x40	1.069
Shell S4R, nodes offset	28x40	1.069



Shell elements

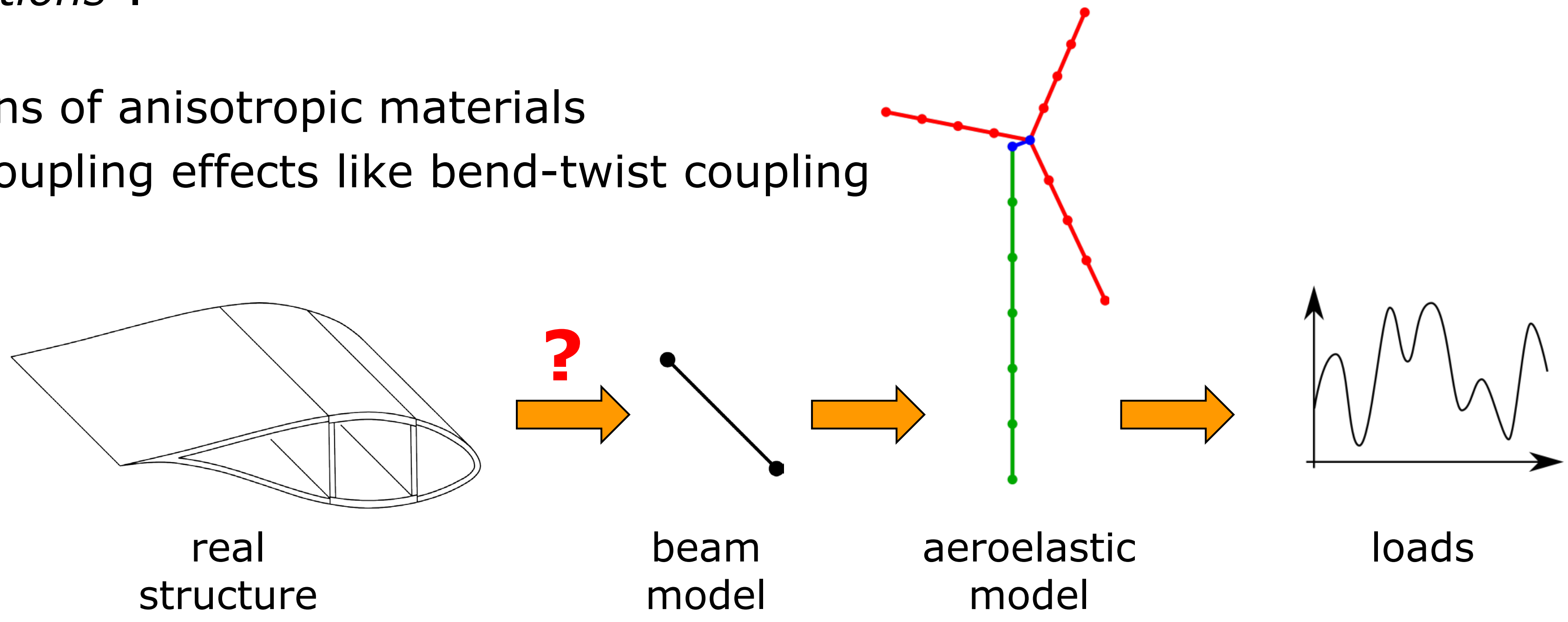


Shell elements, nodes offset

Note: Benchmark study from 2009

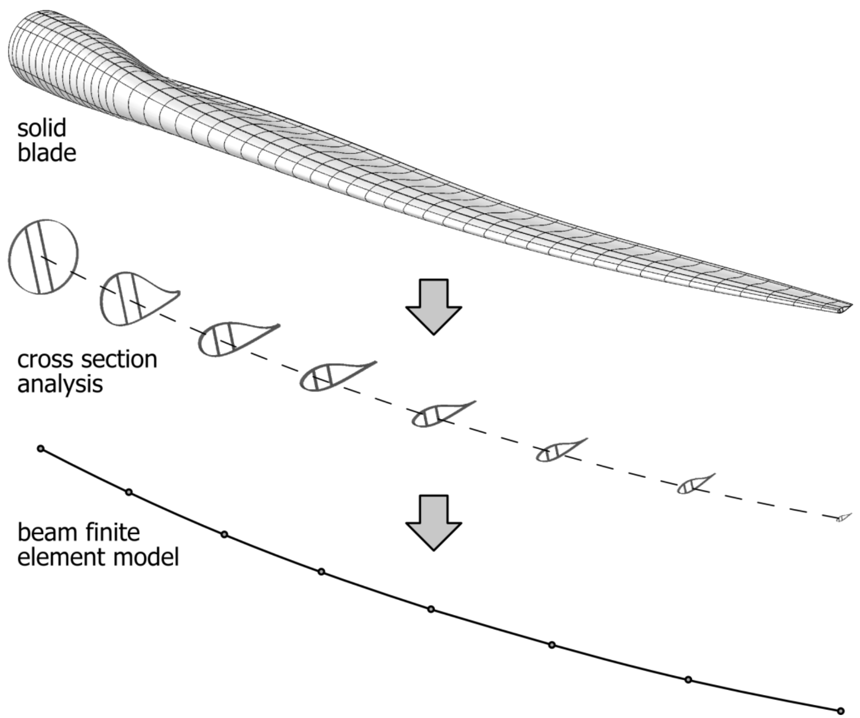
Aeroelastic Analysis

- The structural design of wind turbine blades is based on loads that are derived using an dynamic, aeroelastic model of the turbine (e.g. HAWC2).
- For efficiency reasons the aeroelastic model usually relies on beam theory to describe the structural response of the blades.
- In ABAQUS input parameters for a beam model of the blade can be computed using "*Meshed beam cross-sections*".
  Limitations are:
  - No off-axis orientations of anisotropic materials
  - No consideration of coupling effects like bend-twist coupling

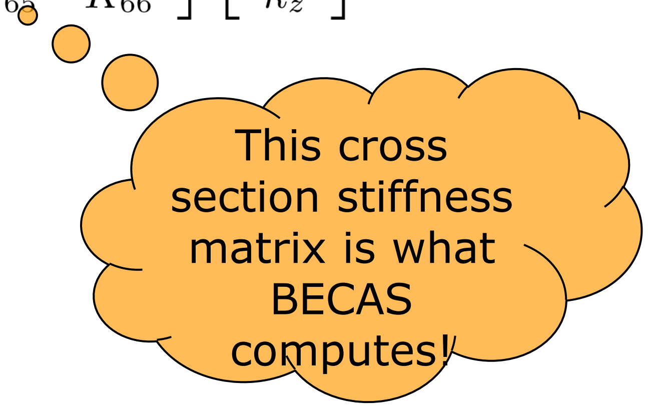


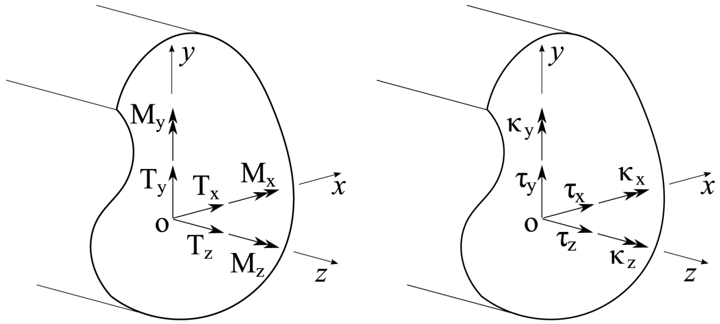
Aeroelastic Analysis: BECAS

- BECAS is DTU Wind Energy's cross section analysis software.
- It is similar to the "meshed beam cross-sections" in Abaqus, but allows for any material orientation and computes the full 6x6 cross section stiffness matrix of a beam cross section.
- More information: http://www.becas.dtu.dk



$$\begin{bmatrix} T_x \\ T_y \\ T_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} & K_{15} & K_{16} \\ K_{21} & K_{22} & K_{23} & K_{24} & K_{25} & K_{26} \\ K_{31} & K_{32} & K_{33} & K_{34} & K_{35} & K_{36} \\ K_{41} & K_{42} & K_{43} & K_{44} & K_{45} & K_{46} \\ K_{51} & K_{52} & K_{53} & K_{54} & K_{55} & K_{56} \\ K_{61} & K_{62} & K_{63} & K_{64} & K_{65} & K_{66} \end{bmatrix} \begin{bmatrix} \tau_x \\ \tau_y \\ \tau_z \\ \kappa_x \\ \kappa_y \\ \kappa_z \end{bmatrix}$$



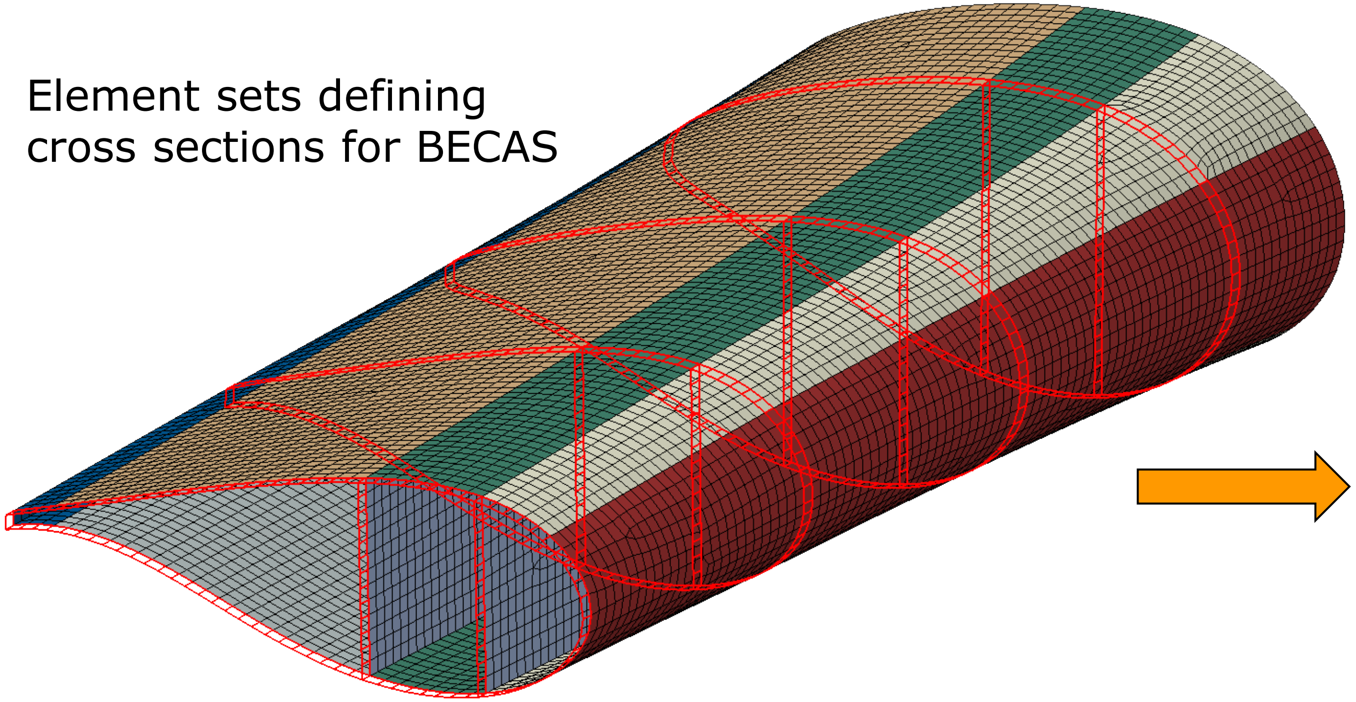


(a) Forces and moments (b) Strains and curvatures

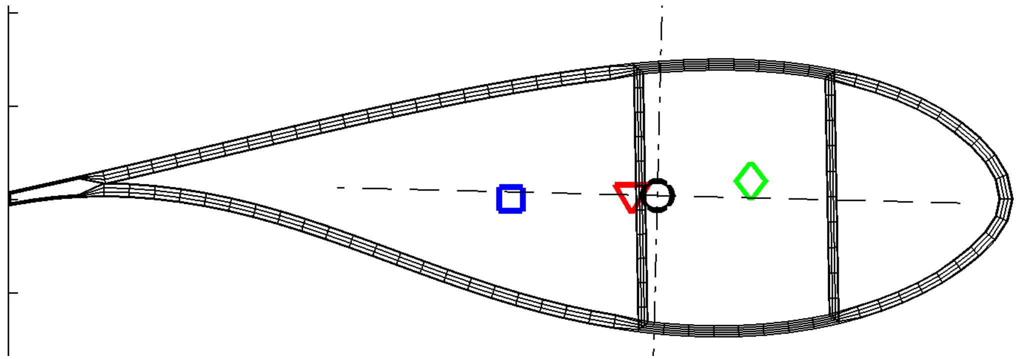
BECAS and ABAQUS

- BECAS is integrated with ABAQUS.
- “Shellexpander” automatically generates BECAS input files (2D cross section meshes) based on the information contained in an ABAQUS finite element shell model.

Element sets defining cross sections for BECAS

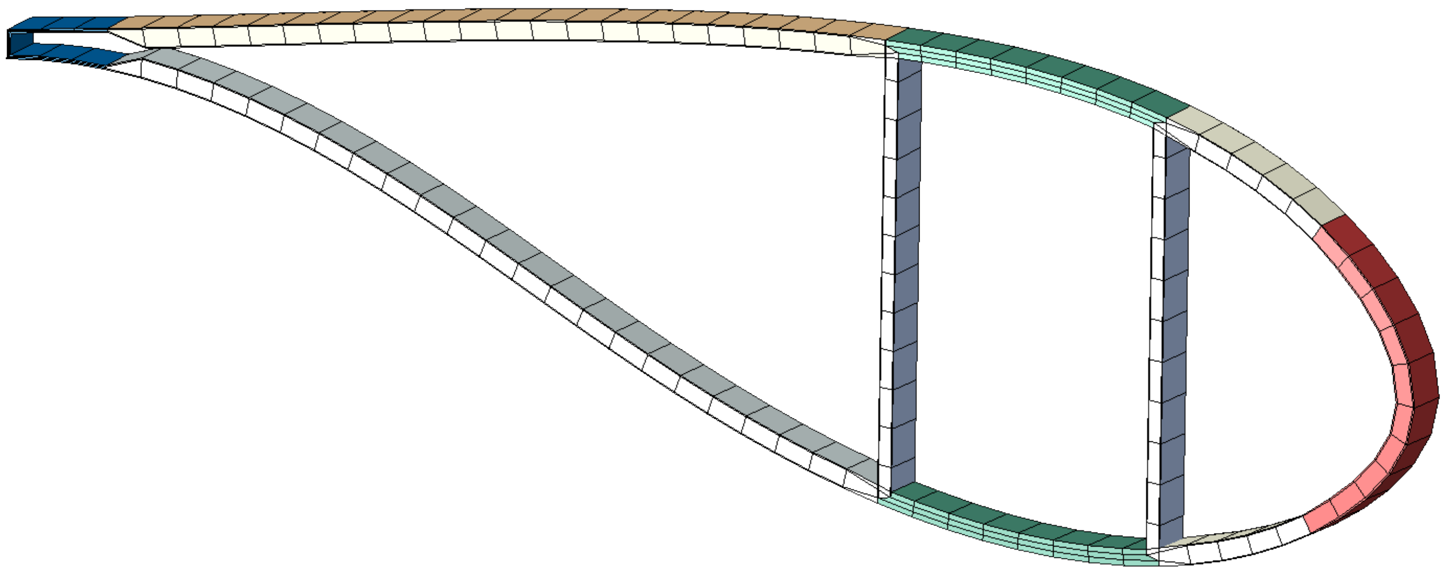


Shellexpander generated 2D mesh



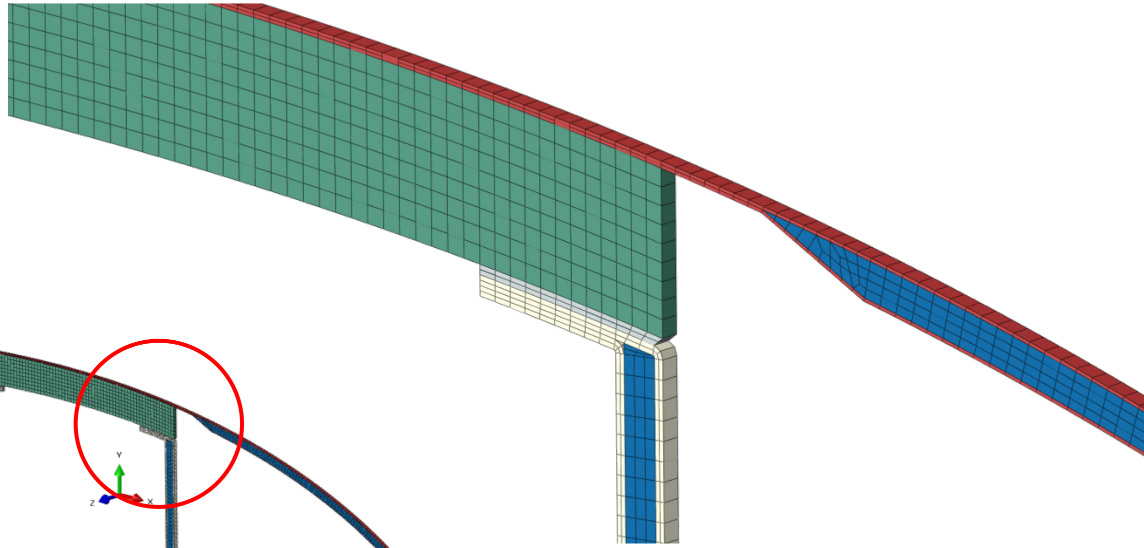
BECAS and ABAQUS

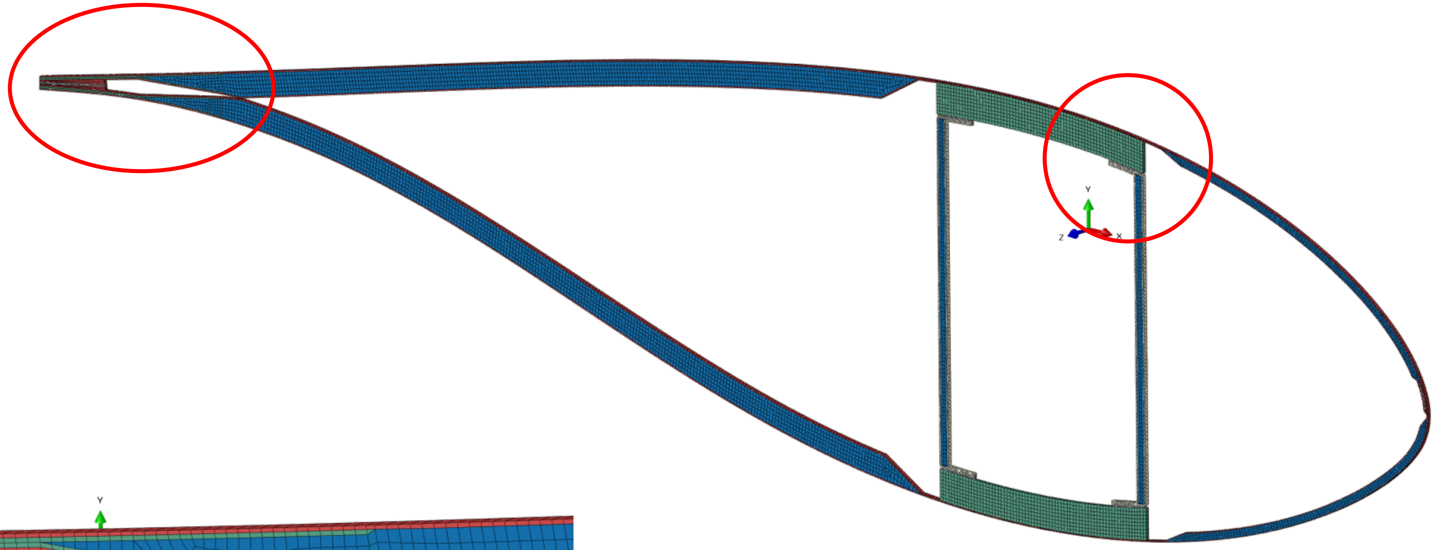
- Use a slice of an ABAQUS 3D solid finite element model and pass the FE stiffness matrix of the slice to BECAS.
- The command *SUBSTRUCTURE MATRIX OUTPUT can be used for that purpose.
- Limitation: Elements may only have translational degrees of freedom (Continuum elements or continuum shell elements).

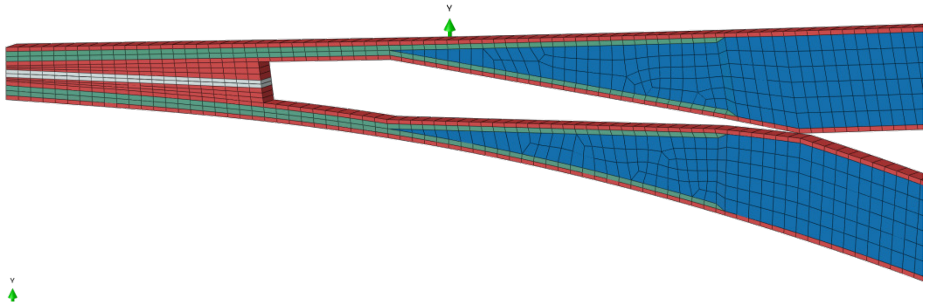


High Resolution Non-Linear Analysis

- 3D slice of a wind turbine blade: 20.000 nodes!

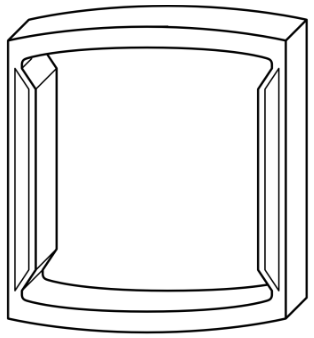




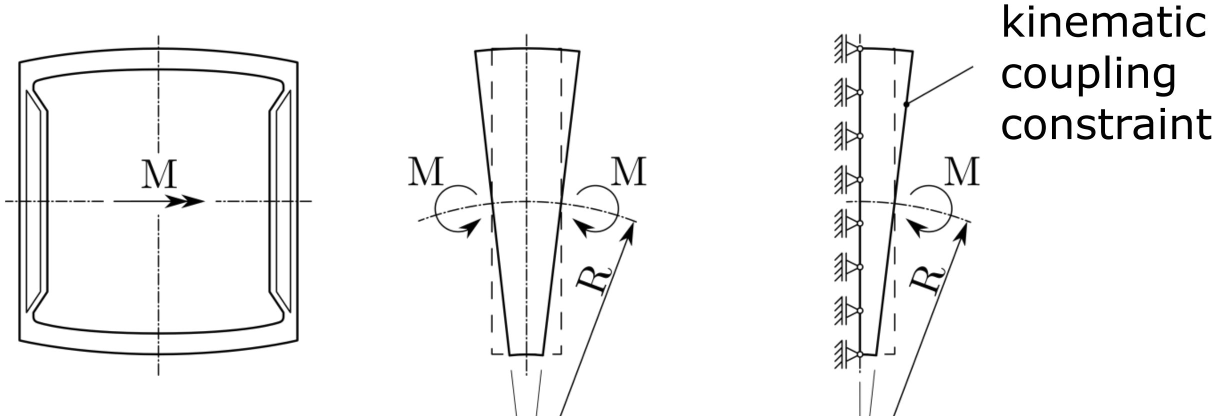


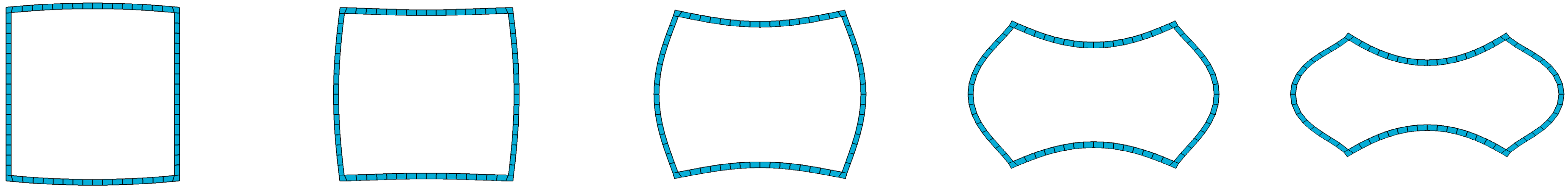
High Resolution Non-Linear Analysis

- Modelling trick:
  In pure bending a beam section exhibits no out-of-plane warping deformation, even if geometrical non-linearity is included.
- Kinematic coupling constraint applied only to the out-of-plane degree of freedom.
- If the axis of bending does not coincide with one of the principal axes of the section, further consideration are required to guarantee equilibrium.

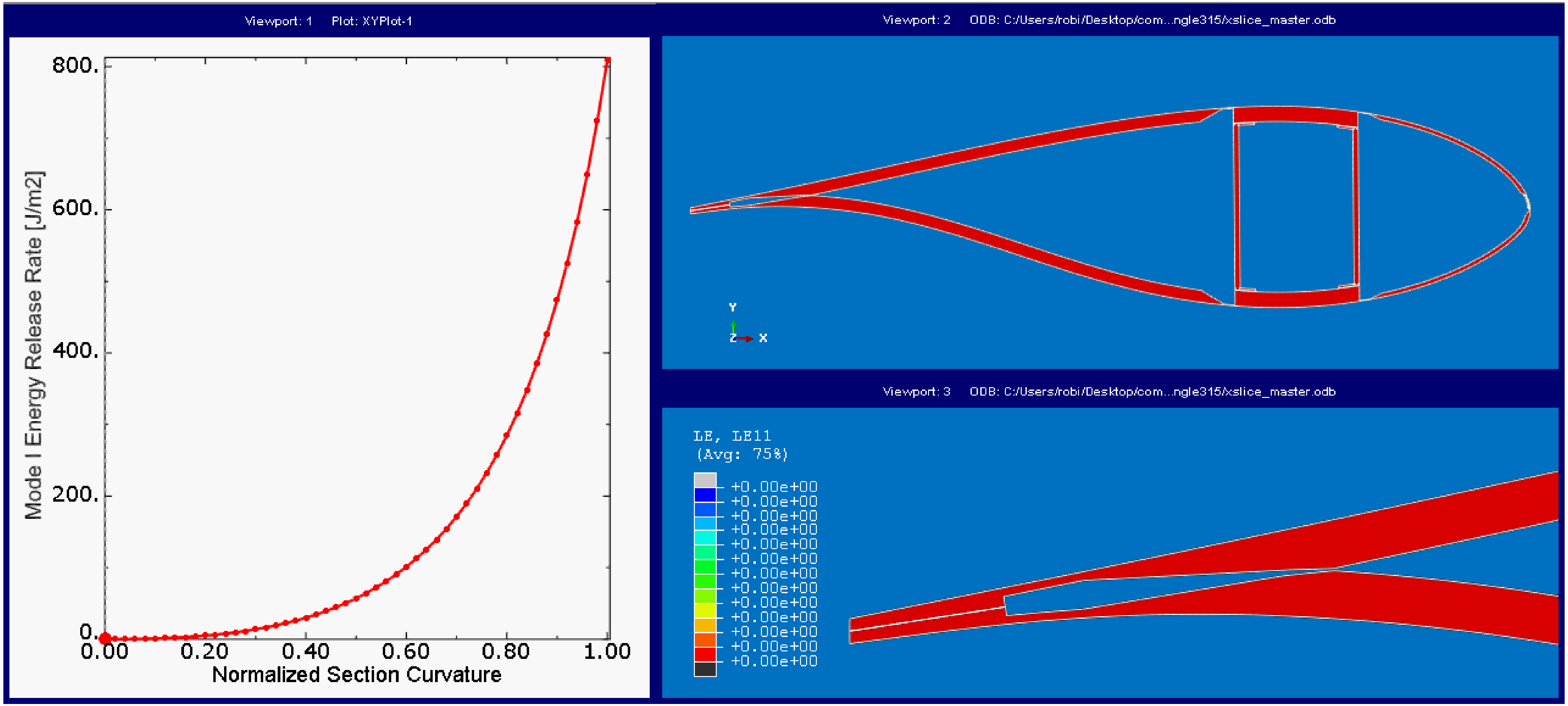


Modelling principle here sketched for a box girder section instead of a blade section.



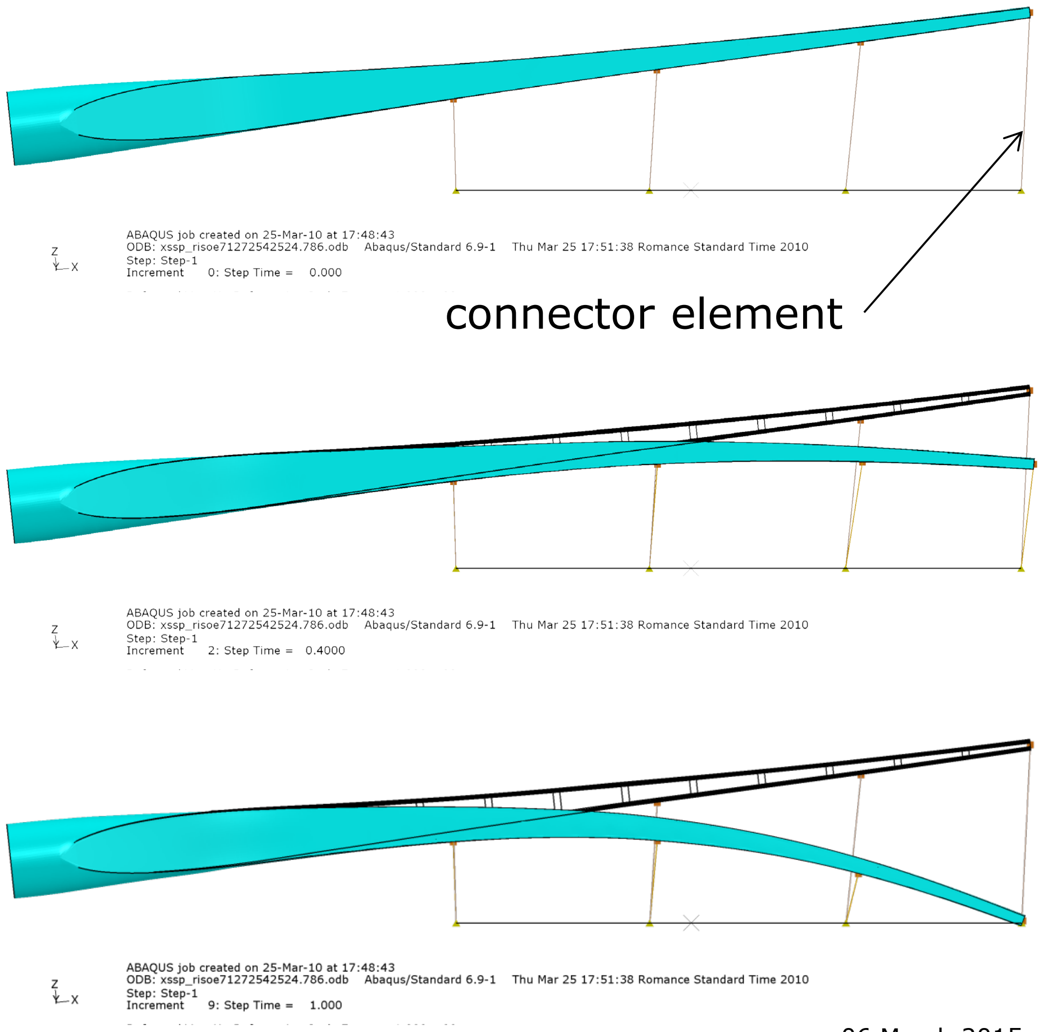


High Resolution Non-Linear Analysis: Energy Release Rate at the Trailing Edge

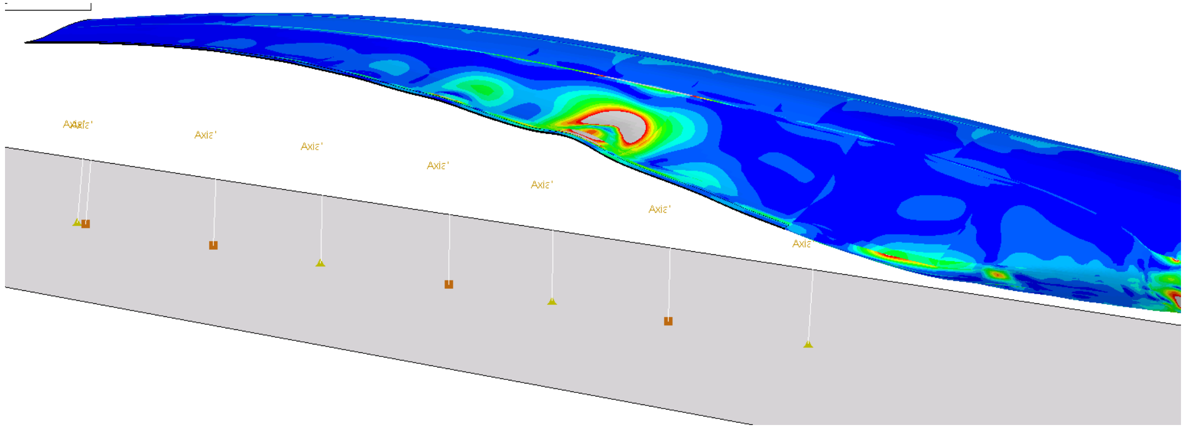


Simulation of Wind Turbine Blade Full Scale Tests

- Wind turbine blade full scale tests (fatigue and ultimate) are a part of the blade certification process.
- Movie of a full scale test in the DTU Wind Energy blade test facility (the fun is at 1:16)
- During static tests concentrated loads are applied to the blade to approximate a certain bending moment distribution.
- If loads are applied through cables, the loads application direction changes significantly due to blade deformation.
- In ABAQUS connector elements of type “AXIAL” can be used to model this effect.
- The connector element can be “actuated”, i.e. a relative motion can be prescribed or a load can be applied to the element.

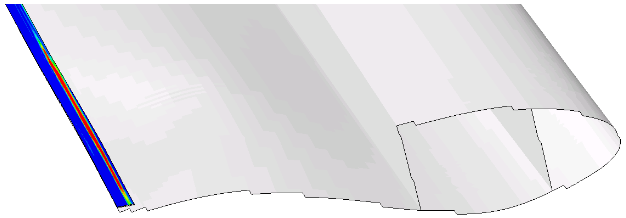


Simulation of Wind Turbine Blade Full Scale Tests



- Good match between full scale test results and numerical simulation.

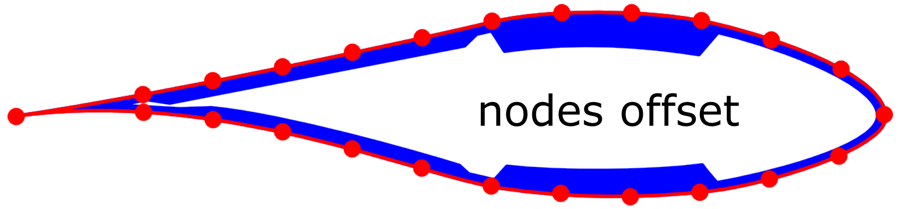
Simulation of debonding at the trailing edge using cohesive elements or VCCT

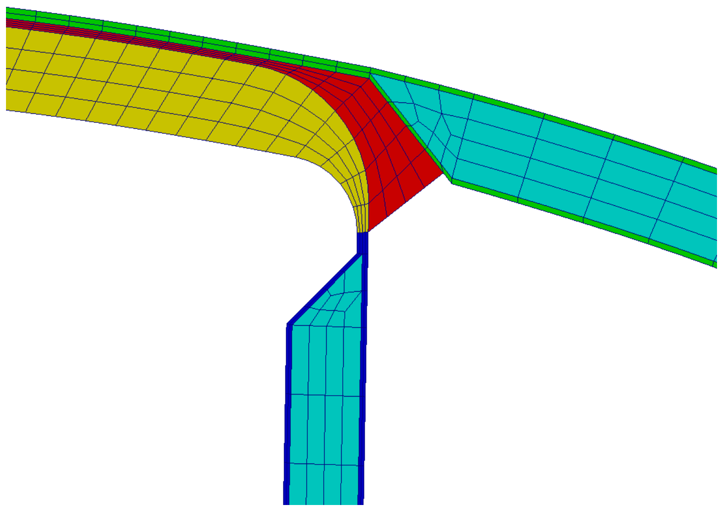


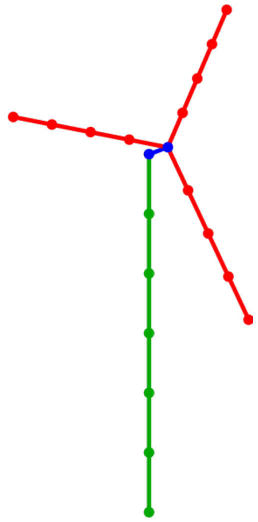
Courtesy of Philipp Haselbach
PhD Student
phih@dtu.dk

A Short ABAQUS Wish List

- A better implementation of the "node offset" option for shell elements.
- An efficient tool for creating 2D cross section finite element meshes of composite beams.
  → Composite Modeller for ABAQUS
- A beam element that accepts a fully populated 6x6 cross section stiffness matrix as input.







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Thank You.

Questions?