3DEXPERIENCE®

Flexible Bodies Update

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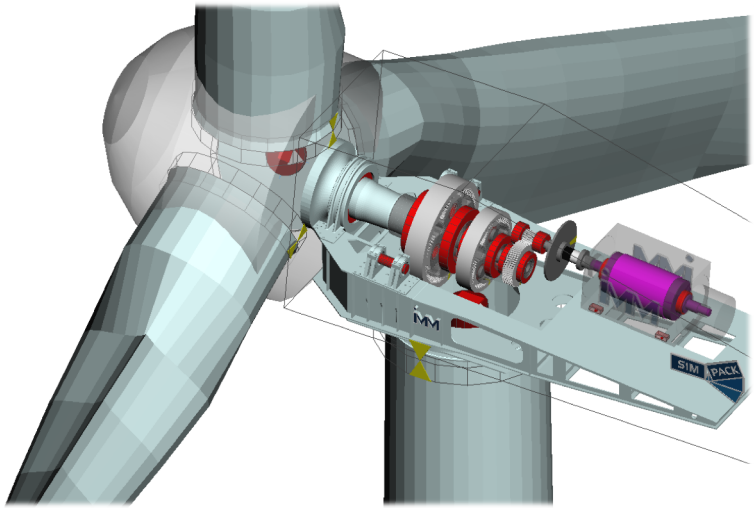
Flexible Bodies in Multibody System Models

- Reduced order model (ROM) representations of FE-models are essential for multibody simulation
- How can we retain the essential information in a straightforward way?

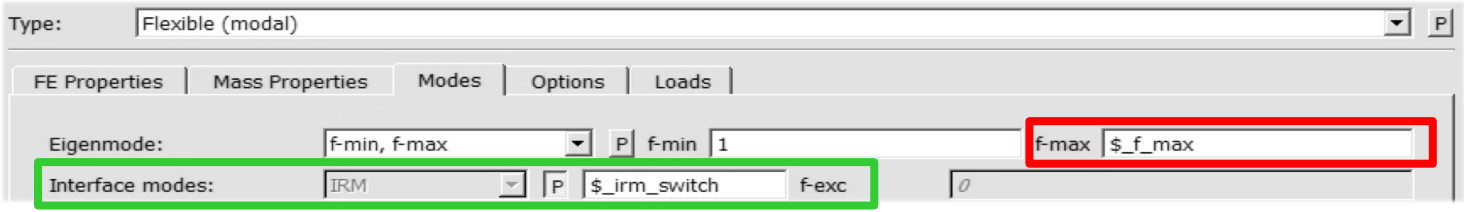
deformation $\boldsymbol{u(x,t)} = \sum$ $\boldsymbol{\Phi_i(x)}$ $\boldsymbol{q_i(t)}$ states

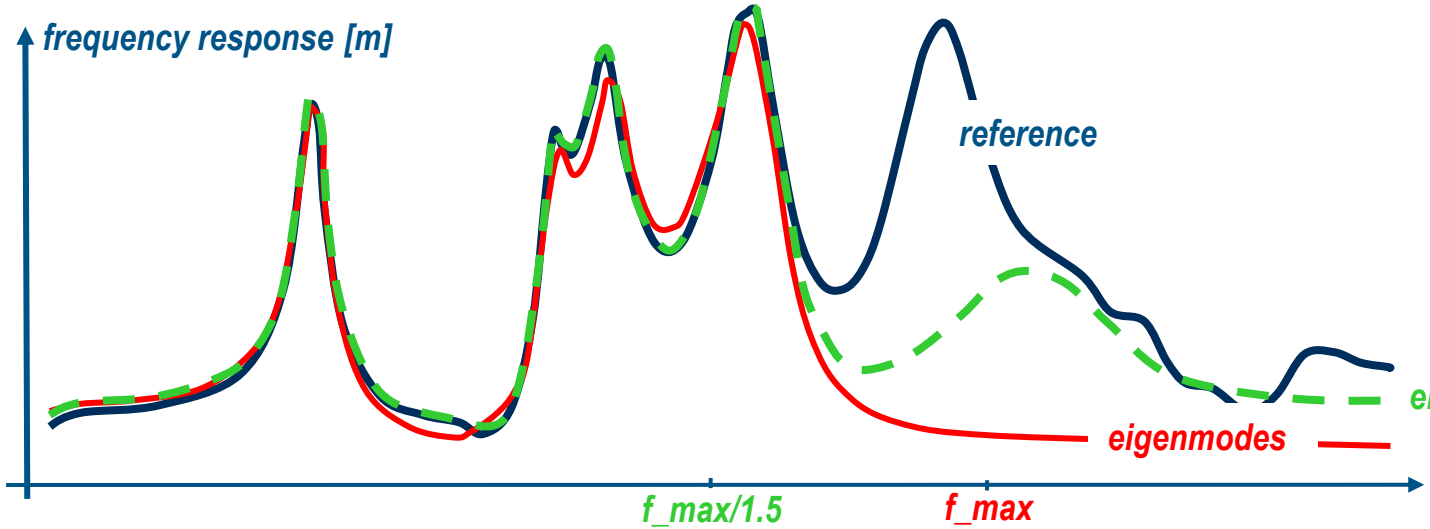


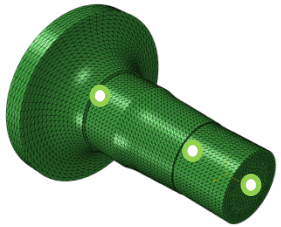
courtesy of TU Dresden

- Selecting modes means to setup the ROM‘s deformation space

How Do We Setup the ROM‘s Deformation Space?







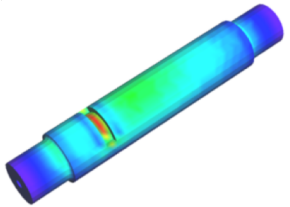
3 coupling points * 6 directions at each point = 18 interface modes

Stress Recovery From ROM‘s – Input to Durability

- Comparison of Different Methods

	Craigh Bampton …				SIMPACK …
number of modes	10	15	20	25	5
max Frequency [kHz]	65.2	105.3	232.9	257.1	14.8
Normal Stress X	14.508	18.602	0.082	0.056	0.045
Y	70.674	78.889	1.327	1.029	0.015
Z	346.708	320.970	2.250	1.612	0.071
Shear Stress XY	80.358	29.283	4.678	3.315	0.056
YZ	571.447	484.255	9.623	7.150	0.201
XZ	80.250	29.205	4.592	3.232	0.161

error in % at the critical spot

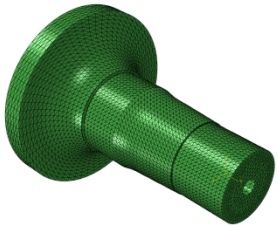


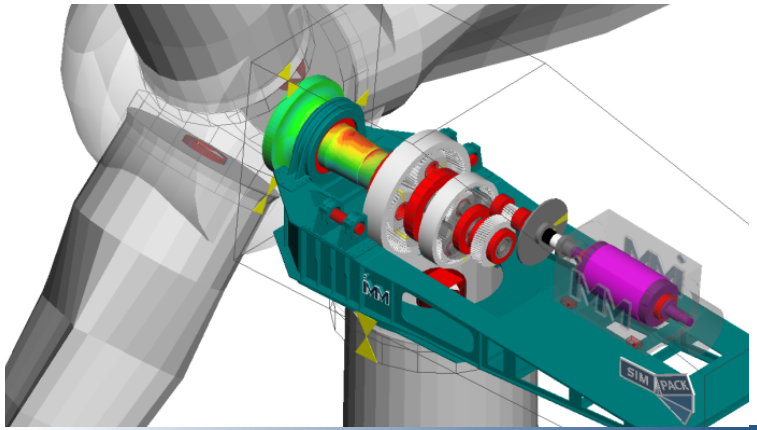
- Simpack‘s combination of eigenmodes and interface modes yields accurate stress with the least number of modes

Stress Recovery & Durability

- Interface mode+eigenmode based Substructuring in Abaqus
- All data (including strain + stress recovery matrices) is transferred through the FBI file
  - Greatly simplifies the entire workflow
- FBI file directly generated by Abaqus

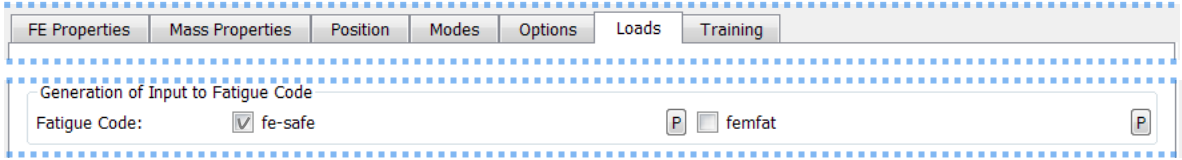
Abaqus → Simpack





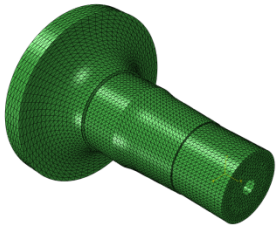
Stress Recovery & Durability

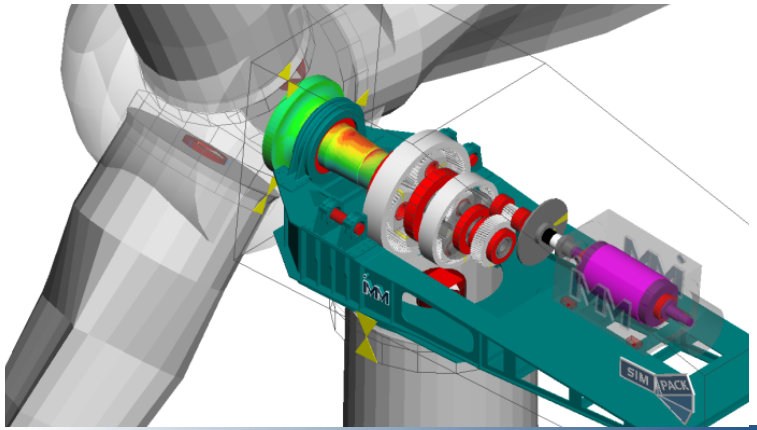
- Input to fe-safe can be generated during the measurement run

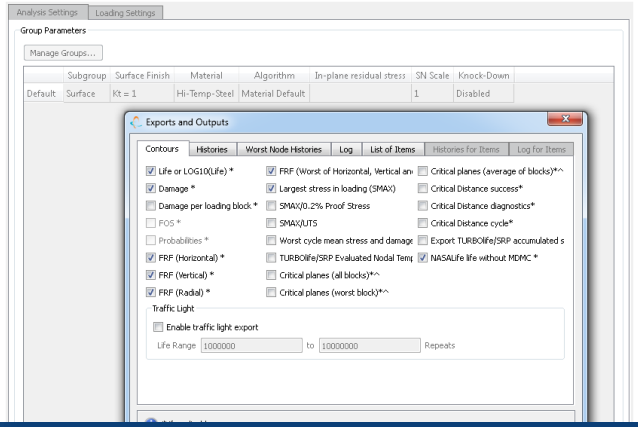


- fe-safe reads modal stress from Abaqus via Simpack and time signals from Simpack generated “history”

Abaqus → Simpack → fe-safe







How Does Simpack Help Users to Integrate Flexible Bodies?

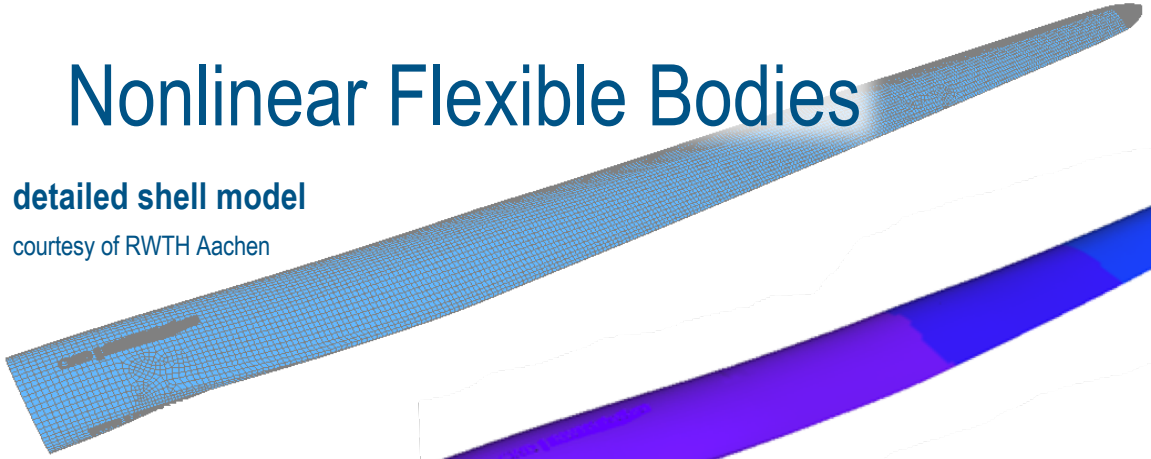
- Straightforward reduction process based on interface modes and eigenmodes
  - Interface modes are setup through modeling
  - Eigenmodes are selected by frequency range
- Accurate dynamic response of flexible structures on the system level
  - Deformation and Stress in Simpack shouldn‘t differ more than 0.5 % when compared with the FE-model
- Efficient multibody simulation with the least number of modes

- The durability of any component can be analysed at high fidelity
  - Main shaft
  - Bed plate
  - Tower
  - Transition piece
  - Jacket structures
  - …

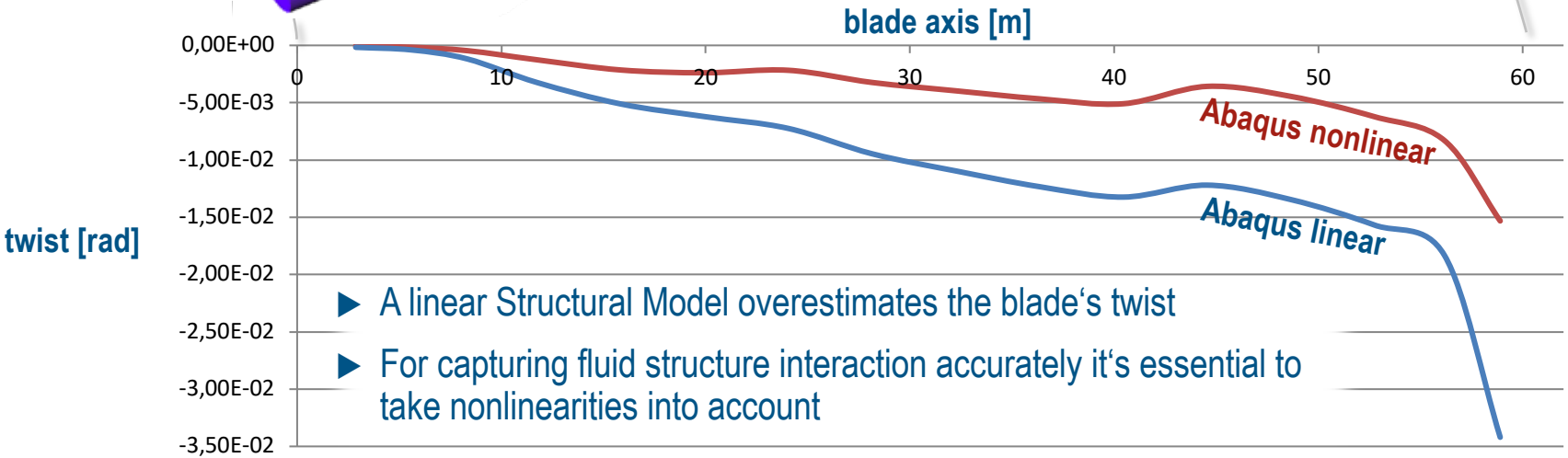
Nonlinear Flexible Bodies

detailed shell model

courtesy of RWTH Aachen



lift force distribution causes 7 m bending at tip

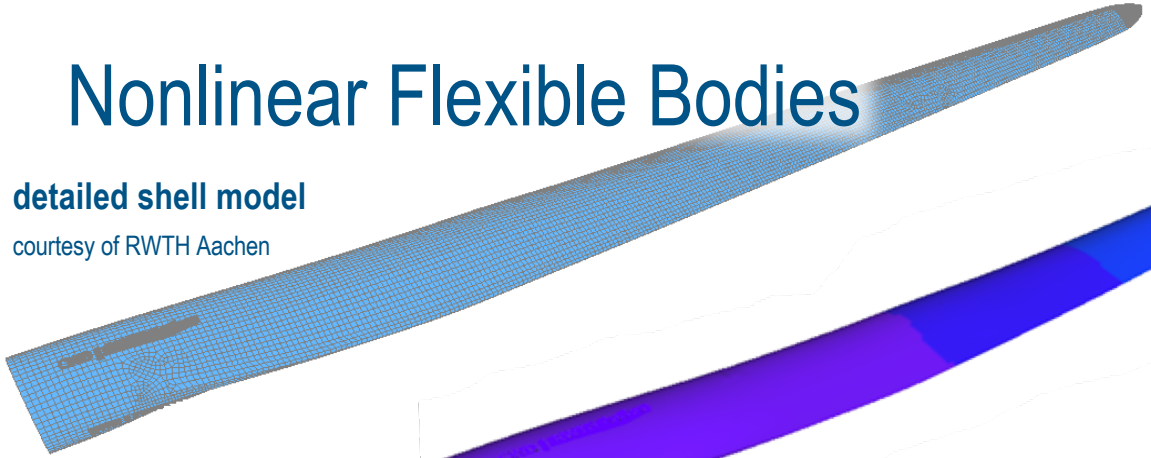


- A linear Structural Model overestimates the blade‘s twist
- For capturing fluid structure interaction accurately it‘s essential to take nonlinearities into account

Nonlinear Flexible Bodies

detailed shell model

courtesy of RWTH Aachen



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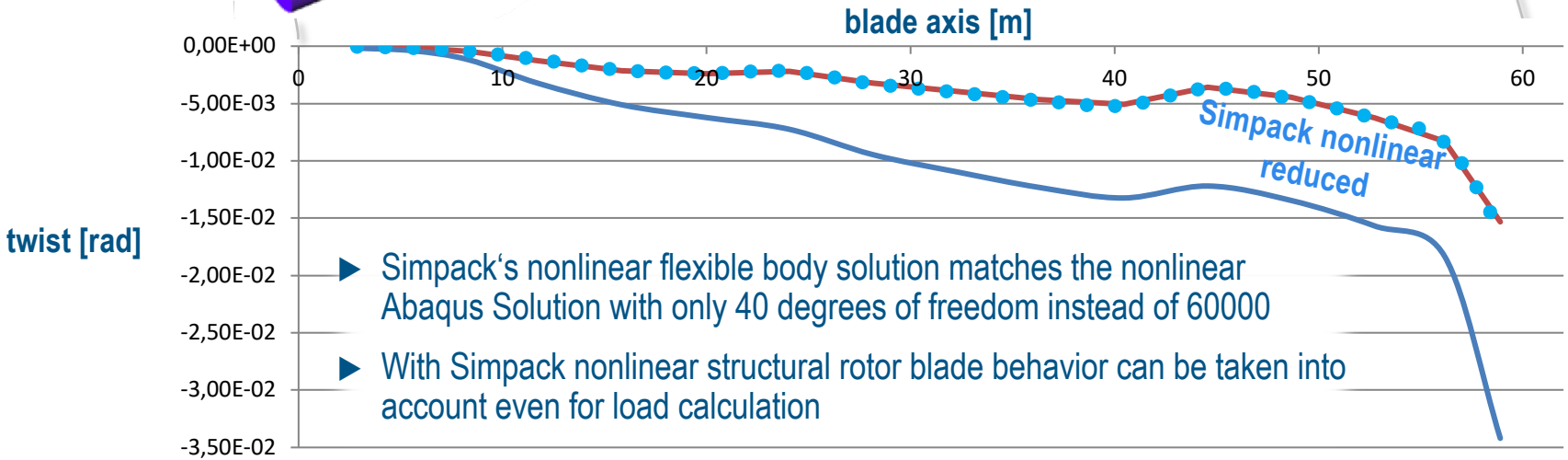

- Simpack's nonlinear flexible body solution matches the nonlinear Abaqus Solution with only 40 degrees of freedom instead of 60000
- With Simpack nonlinear structural rotor blade behavior can be taken into account even for load calculation

Composite Beam Technology

VaMeSH Project: New capabilities for rotorcraft design

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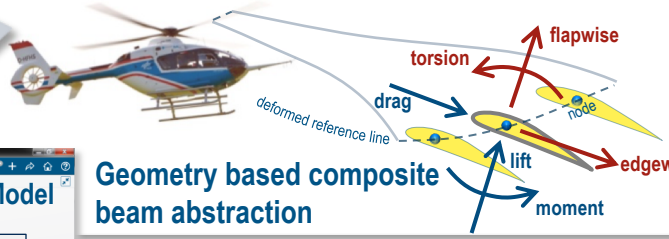
SIMULIA Simpack



Geometry based composite beam abstraction

SIMULIA Structural Model

Intersect 3D geometry
Mesh cross sections
Assign material
Generate beam stiffness matrices
and stress and deformation recovery matrices

CATIA Part Design

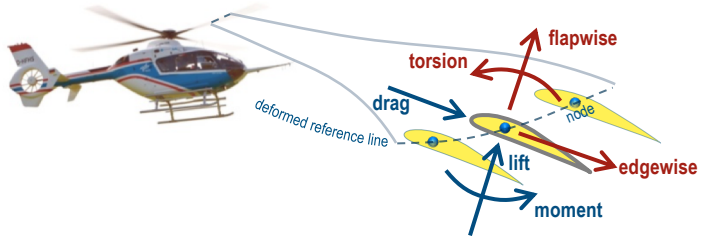
Create CAD model of the rotor blade

DLR

Federal Ministry for Economic Affairs and Energy

Composite Beam Technology

SIMULIA Simpack rotorcraft model



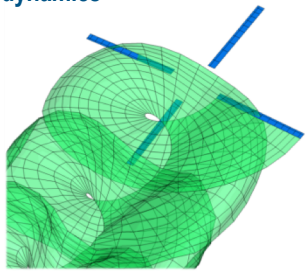
Structure Deformation

Aero Loads

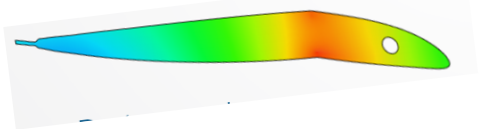
Rotorblade Aerodynamics

DLR's "S4" code for multi scale aerodynamics

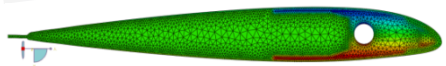
Freewake
Prescribed wake
Lookup tables



- Realistic stiffness values derived from 3D Geometry
- No difficult to acquire input data required like shear center offsets, etc…
- Deformable cross sections (3D warping)



- Accurate stress recovery possible

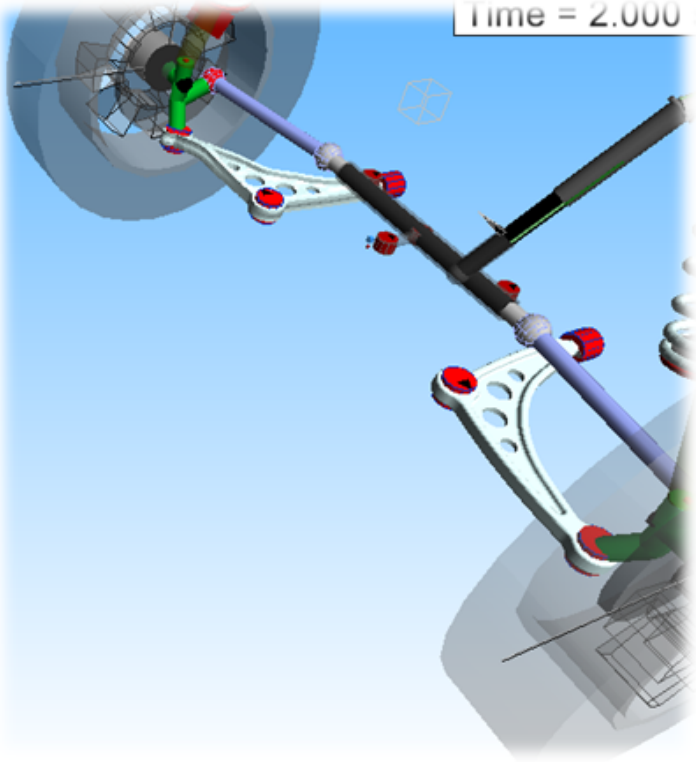


DLR

Federal Ministry for Economic Affairs and Energy

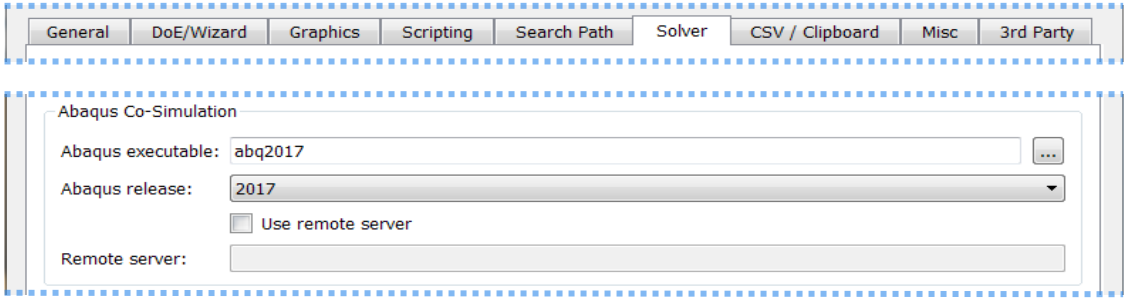
Abaqus & Simpack Cosimulation

- Study arbitrary non-linear effects on Body deformation (geometrical, elasticity, plasticity, contact, friction, etc.)
- Relies on robust and accurate co-simulation schemes
- Deformation visualized in Simpack Post
- FE specific results accessible via Abaqus Viewer
- Requires Simpack FlexModal but no other extra license



Abaqus & Simpack Cosimulation

- Abaqus release configuration in Simpack > Extras > Options

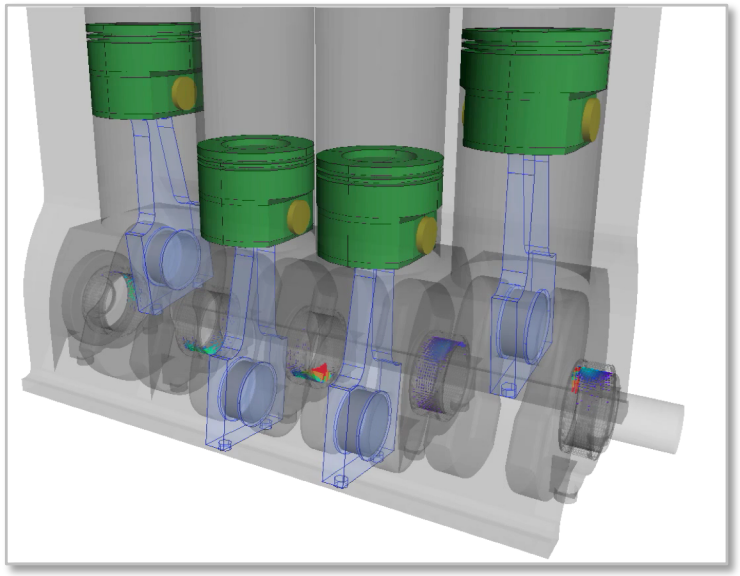


- All processes (Abaqus, Cosimulation Services, Simpack) started from Simpack
- Entire Simpack joint library (i.e. relative coordinates) supported for Cosimulation with Abaqus/Standard
- For cosimulation with Abaqus/standard FE-Model preparation on the 3DEXPERIENCE now possible
- Availability

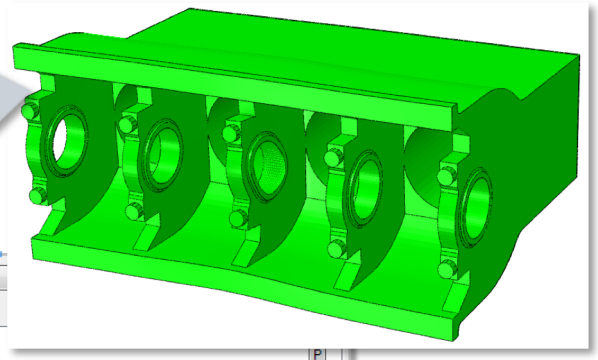
Abaqus/Explicit >= 6.14.1	Simpack >= 9.10
Abaqus/Standard >= 2017 HF3	Simpack >= 2017.1

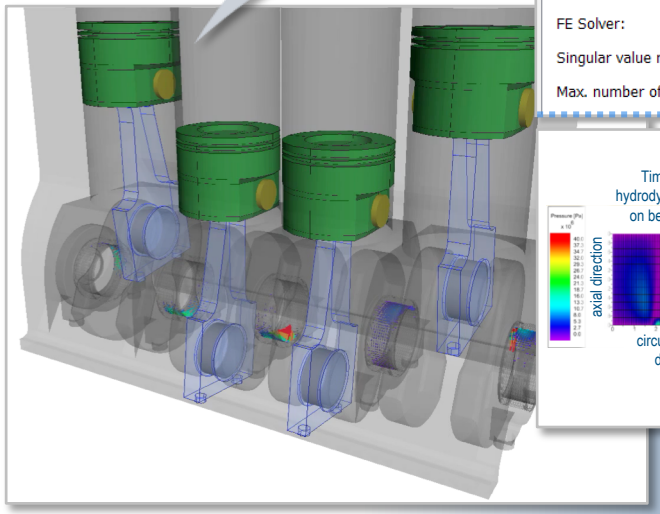
Flexible Body Interaction With Fields

- Pressure distributions in journal bearings are actually transient distributed loads
- In MBS the established abstraction level for interaction is that of point wise forces
  - Approximately 900 nodes (i.e. 1800 DOF) to be retained per bearing shell
- Simpack 2018x handles the impact of transient distributed loads on deformation and stress with the least number of degrees of freedom at very high accuracy



Flexible Body Interaction With Fields





Type: Linear flexible

FE Properties | Mass Properties | Position | Modes | Options | Loads | Training

Output nodal surface forces:	☑
Train FE structures with surface loads:	☐
FE Solver:	Auto from fbi file
Singular value ratio:	1000
Max. number of residuals per force element:	50

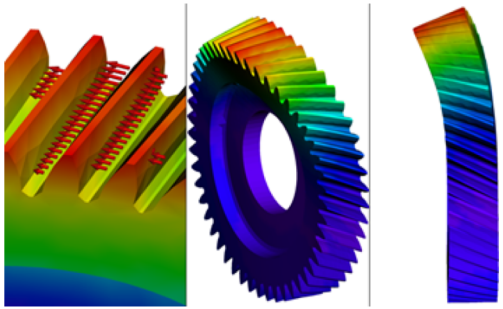
Simpack automatically decomposes time history of loads $\mathbf{p}_i(\mathbf{r},\mathrm{t})$ into unit loads $\mathbf{p}_i(\mathbf{r})$

$$\left\| \mathbf{p}(\mathbf{r},t) - \sum_i \mathbf{p}_i(\mathbf{r})\alpha_i(t) \right\|^2 \rightarrow minimum$$

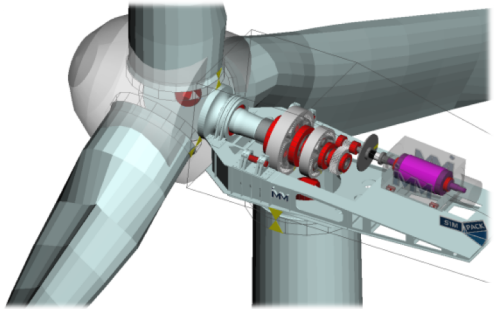
For a single journal bearing i=1,30-50 -> 5 bearings -> 150-250 unit loads for the entire engine block

Flexible Body Interaction With Fields

- Available with Simpack 2018x for EHD, PCM and user routines
- A new technology for a variety of use cases
  - Electromagnetic forces
  - Fluid pressure
  - Roller bearings
  - Gearwheels, see Govind MOHAN‘s presentation *Distributed Surface Loads Based Approach for Modeling Flexible Gears*

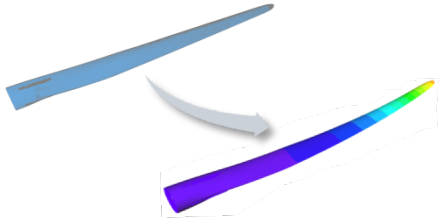


Summary - Flexible Bodies - A Variety of Choices



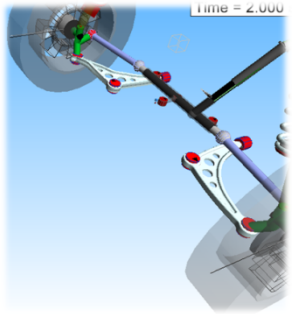
Linear Flexible Bodies

- Accurate dynamic behavior
- Stress & fatigue of wind turbine components
- Noise
- Detailed fluid structure interaction



Nonlinear flexible Bodies

- Large deformation
- Reduced Order Formulation



General Physics

- collision analyses
- contact
- friction
- plastic deformation

Reduced order models — **Co simulation**

logical scale — **physical scale**