Webinar – Wind Turbine Dynamics

3DEXPERIENCE®

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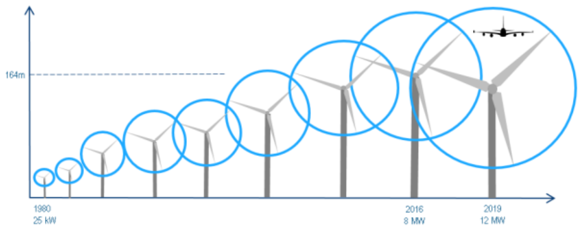
Wind Energy Executive

Wind Turbine Engineering | **Agenda**

- Industry Trends
- Technical Challenges
- IPE Wind Turbine Engineering Workflows
- Simpack History
- Fundamentals Multibody System (MBS) simulation
- Wind turbine Analysis
- Flexible Bodies
- Components
- 3DEXPERIENCE Platform
- Summary

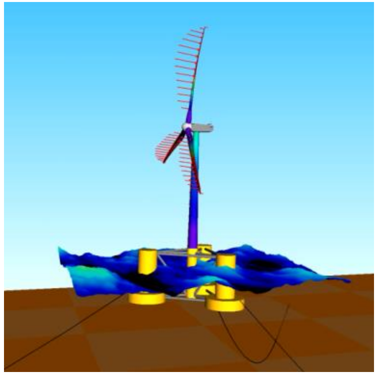
Wind Turbine Dynamics | **Trends**

Increasing Size



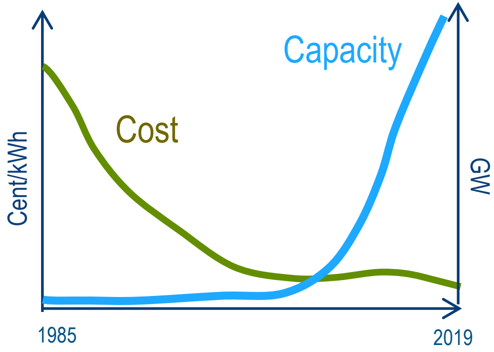
- Deformation
- Loading
- Dynamic Behavior

Offshore



- Hydrodynamics
- Control
- Maintenance

Cost of Energy

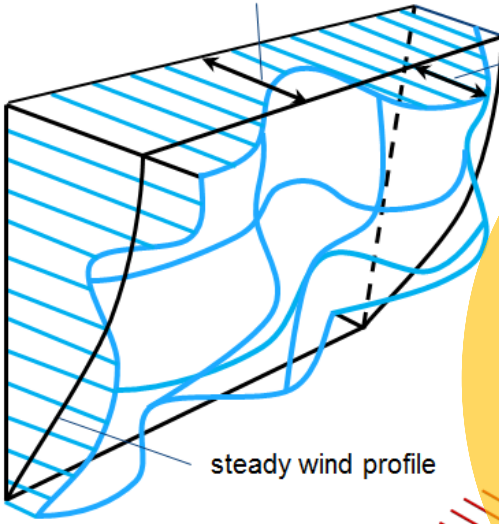


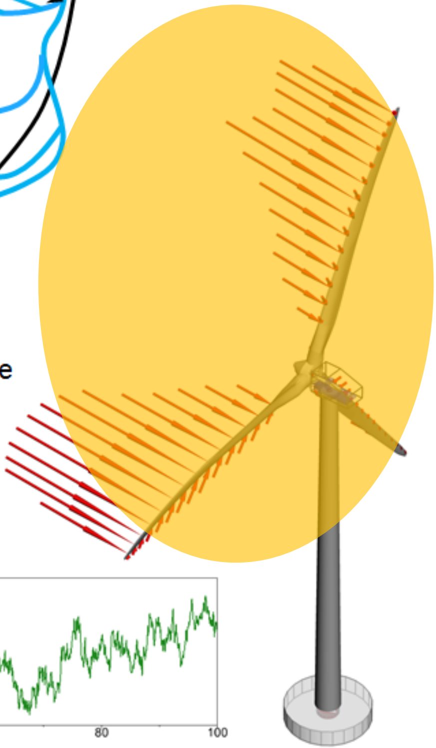
- Minimize CAPEX and OPEX (Capital Expenditure and Operational Expenditure)

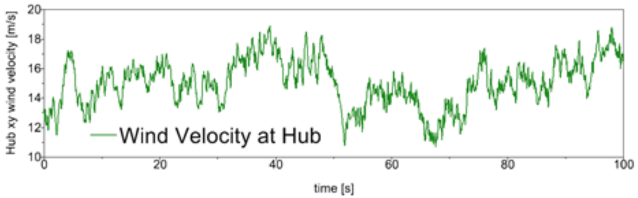
Wind Turbine Dynamics | **Technical Challenges**

Converting turbulent wind to stable electricity

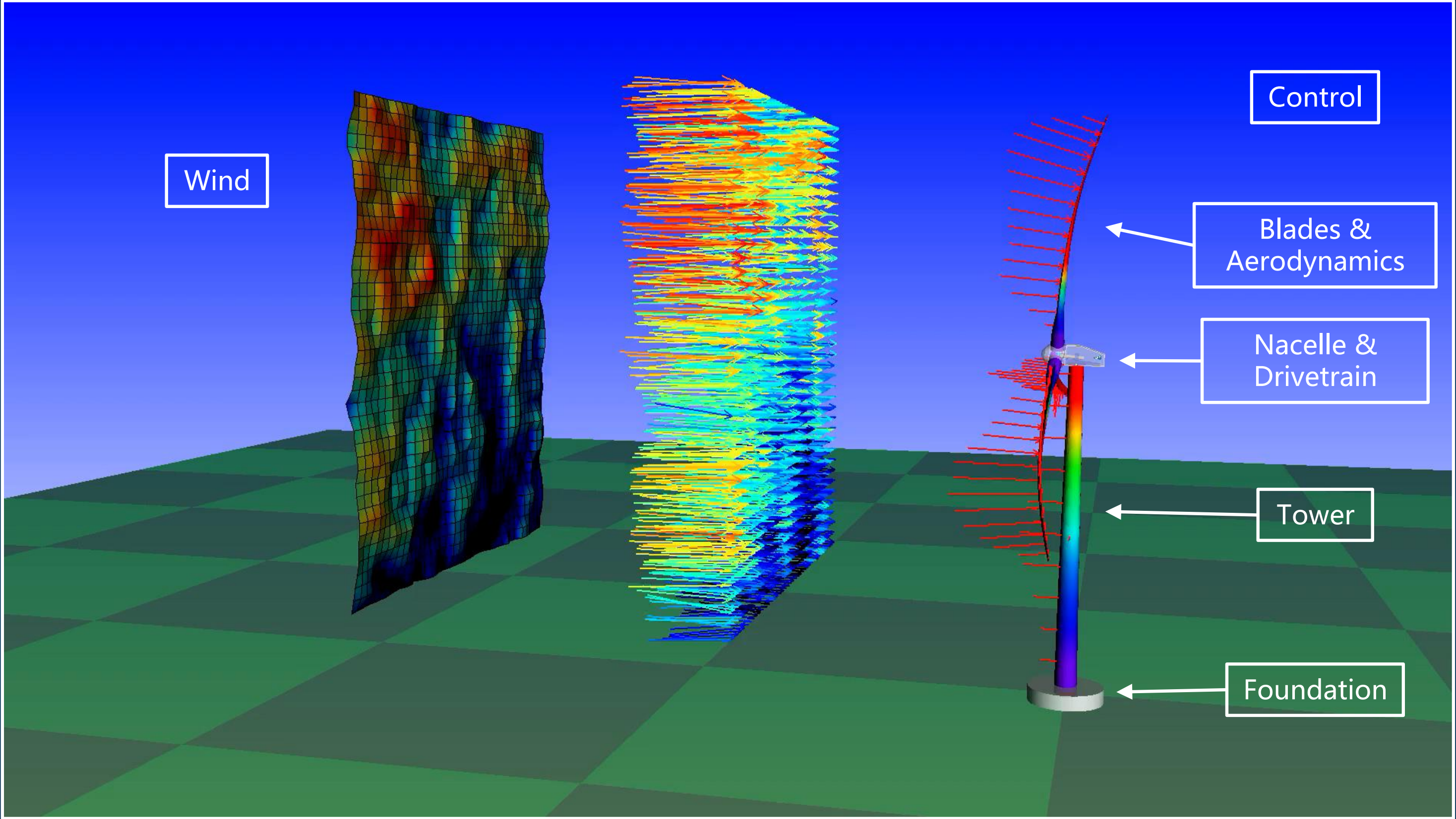
- Large transient forces (wind and waves)
- Connected to ground and grid
- Large flexible bodies
- Acoustics, hydraulics, electronics (high frequencies)
- Multi-disciplinary engineering
- Holistic simulation required



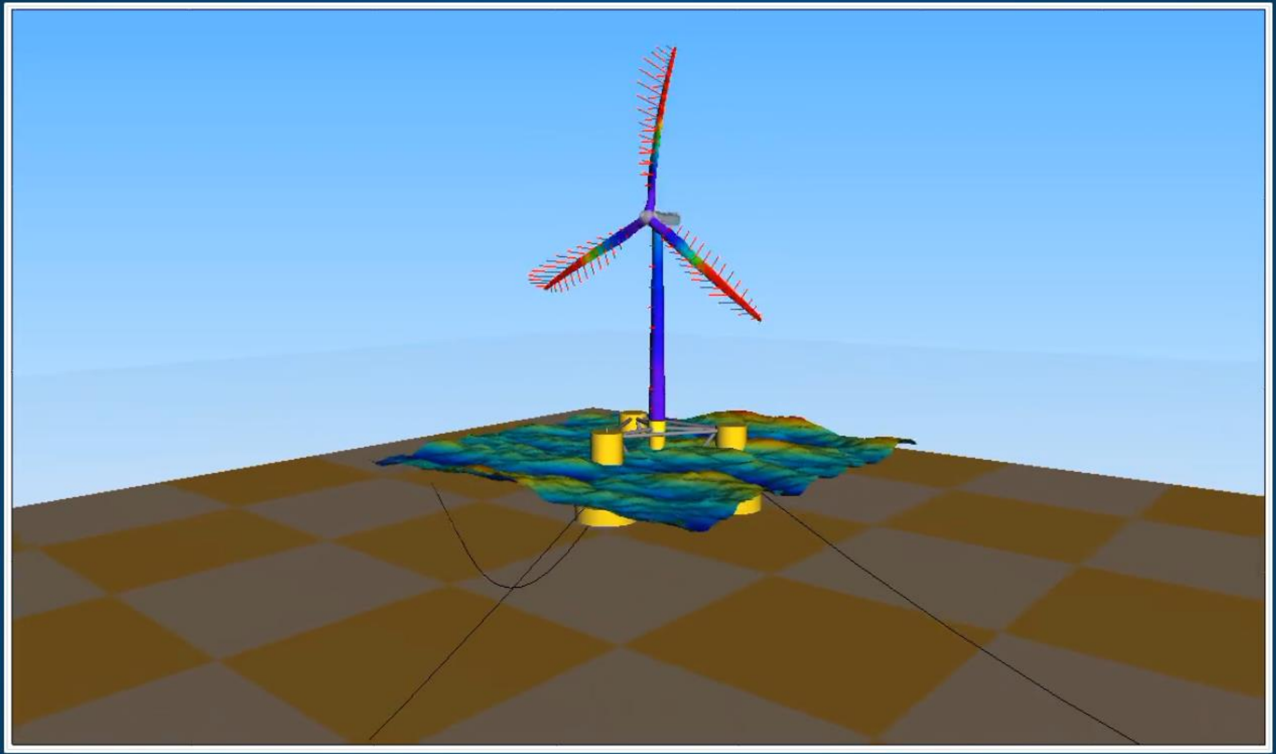




Wind Turbine Dynamics | **Onshore**



Wind Turbine Dynamics | **Offshore**

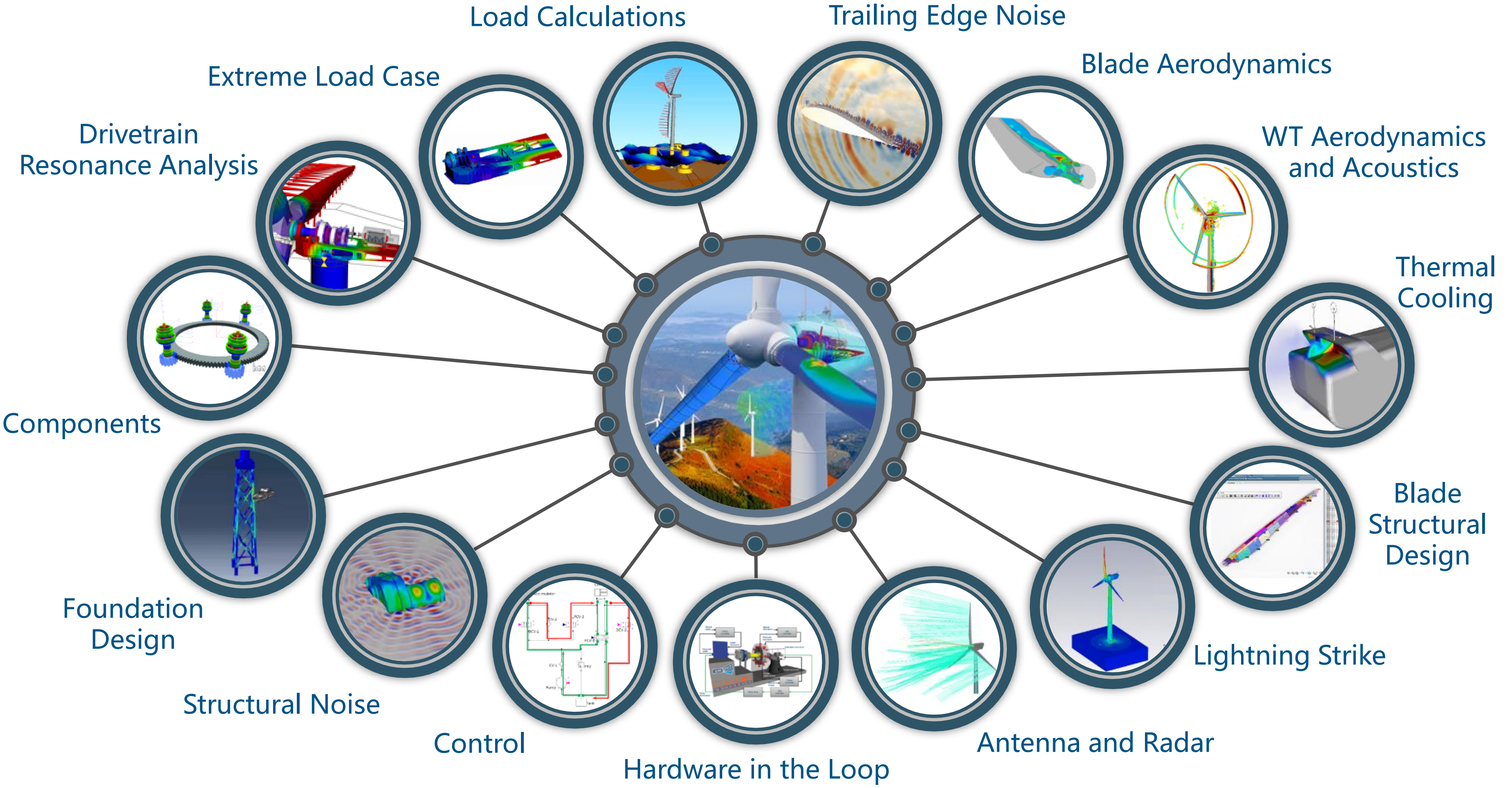


Ocean

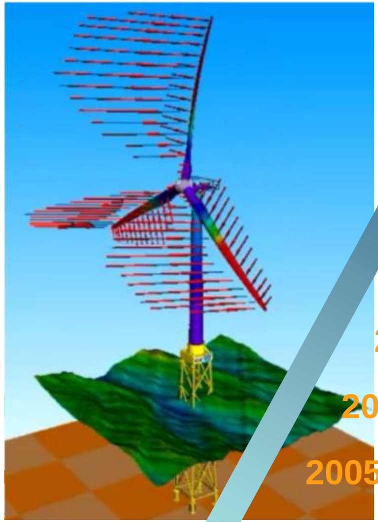
Platform

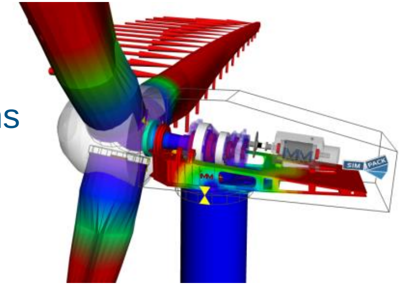
Mooring lines

Wind Turbine Engineering | **Workflows**



Wind Turbine Dynamics | **Simpack History**





2017 Two OEMs implement Simpack for Load Calculations

2016 High Fidelity Public Database

2014 SIMPACK acquired by Dassault

2013 Load Calculations template scripts in Simpack Documentation

2012 Universities and OEM create in-house Load Calculations process

2007 Commercial wind turbine OEMs and suppliers

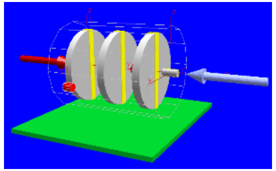
2005 First commercial Simpack Wind customer, certification body

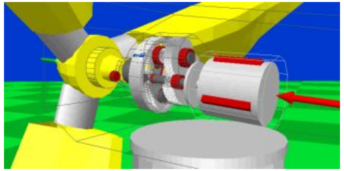
2000 Universities simulate detailed wind turbine drivetrains

1998 First commercial automotive customers

1993 First commercial rail manufactures purchase Simpack

1987 Start of development at DLR and MAN Technology





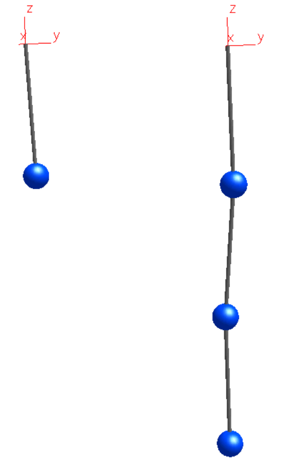
Simpack is a general purpose Multibody System (MBS) simulation software used to predict and visualize motion, coupling forces and stresses, of any mechanical system.

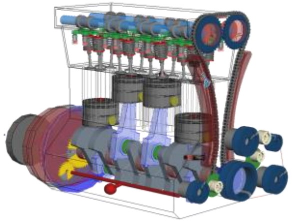
Wind Turbine Dynamics | **MBS Simulation**

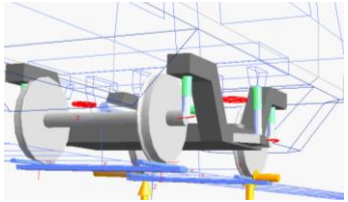
Why Multibody System (MBS) simulation?

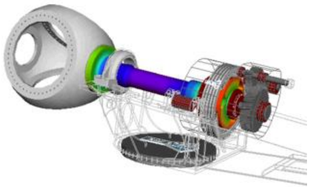
- Components behave differently depending upon their surroundings
- In order to accurately predict and minimize loading on components, system simulation is necessary

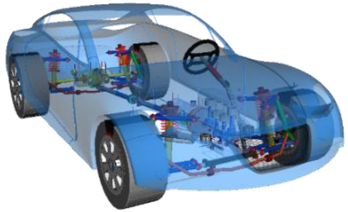
0.5 Hz 1.3 Hz

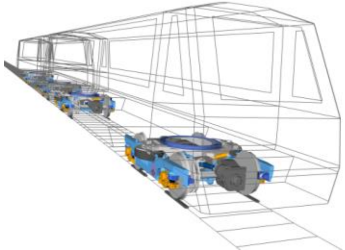








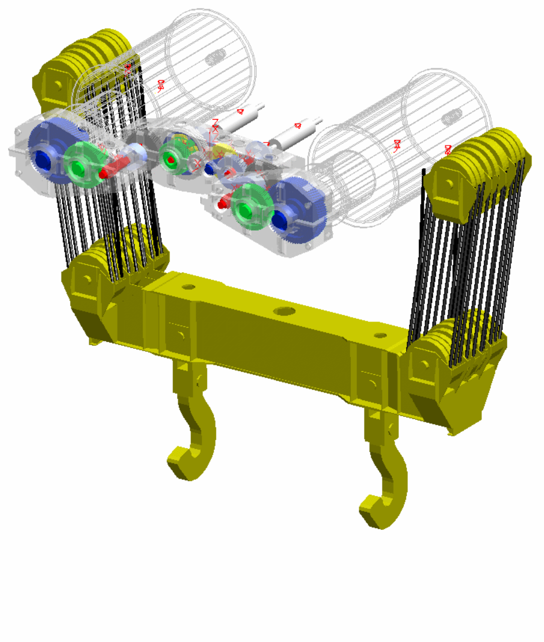


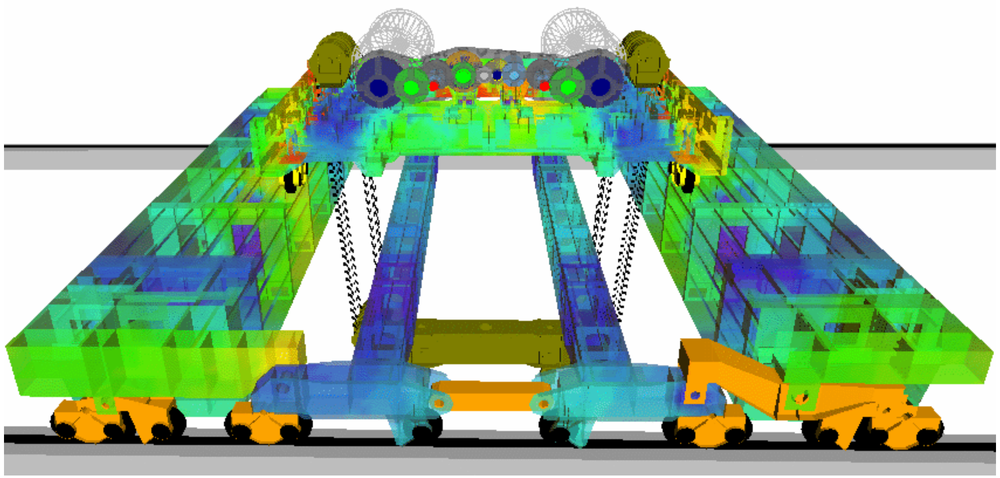


Wind Turbine Dynamics | **Ladle Crane**

IMM TU Dresden, Simpack UM 2014

- Investigation of fault scenarios
- System simulation required for accurate loads prediction

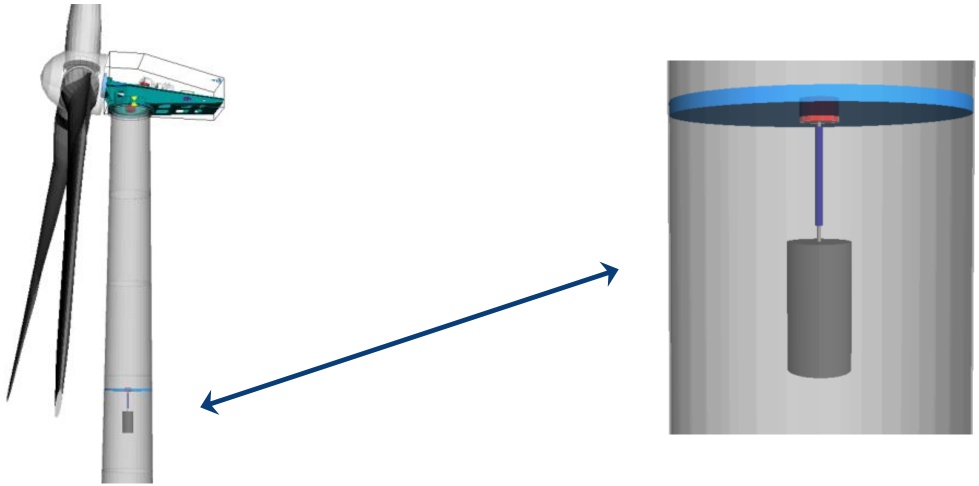




Wind Turbine Dynamics | **Optimization and Sensitivity**

Vibration Absorber Example

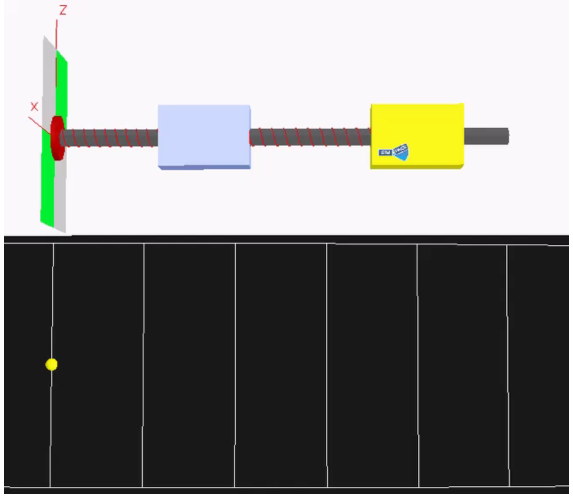
- How do different parameters influence the dynamics and loading?
- What are the optimal parameters?
- How susceptible is the design to manufacturing tolerances, or how stable is the design?

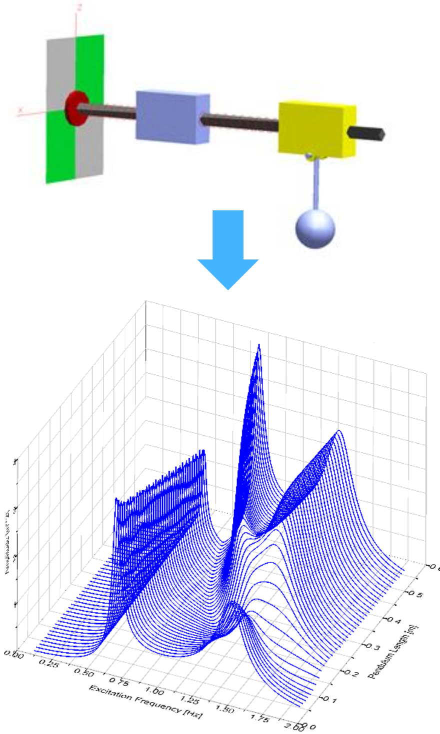


DASSAULT SYSTEMES

Wind Turbine Dynamics | **Optimization and Sensitivity**

Maximum loading and displacements occur at natural frequencies. Sensitivity studies can be carried out in the time and frequency domains.

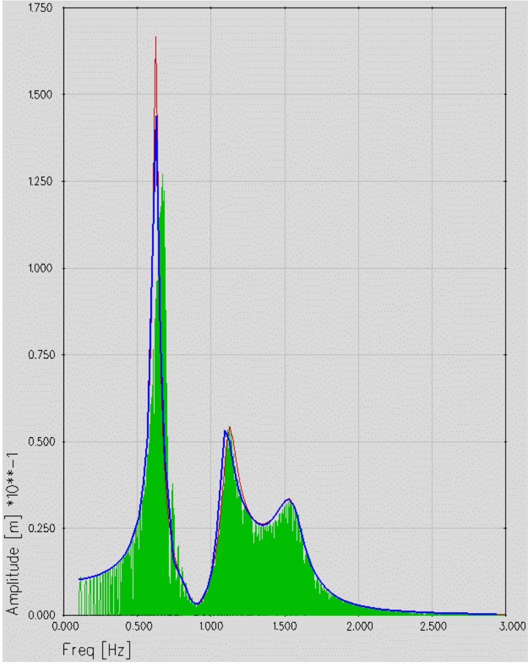




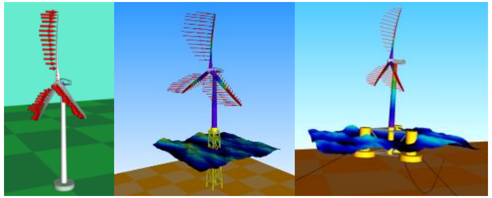
Linear System Analysis

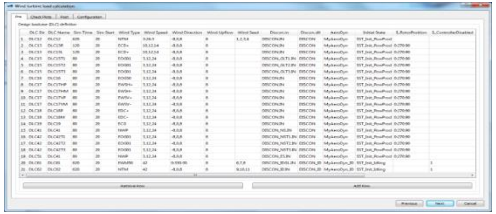
Non-linear Frequency Sweep

Non-linear Frequency Pass



Wind Turbine Dynamics | **Load Calculations**





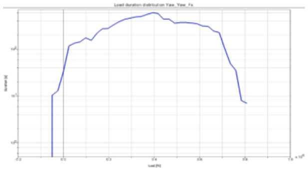
Solver Technology
- Fast, accurate and robust

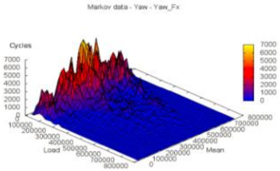
Simulation Model
- Any type of wind turbine
- Any level of fidelity

Automation
- Template Scripts for all Design Load Cases
- Result and report generation

Integration
- Easy integration into existing workflows
- Reading and writing of any data format type

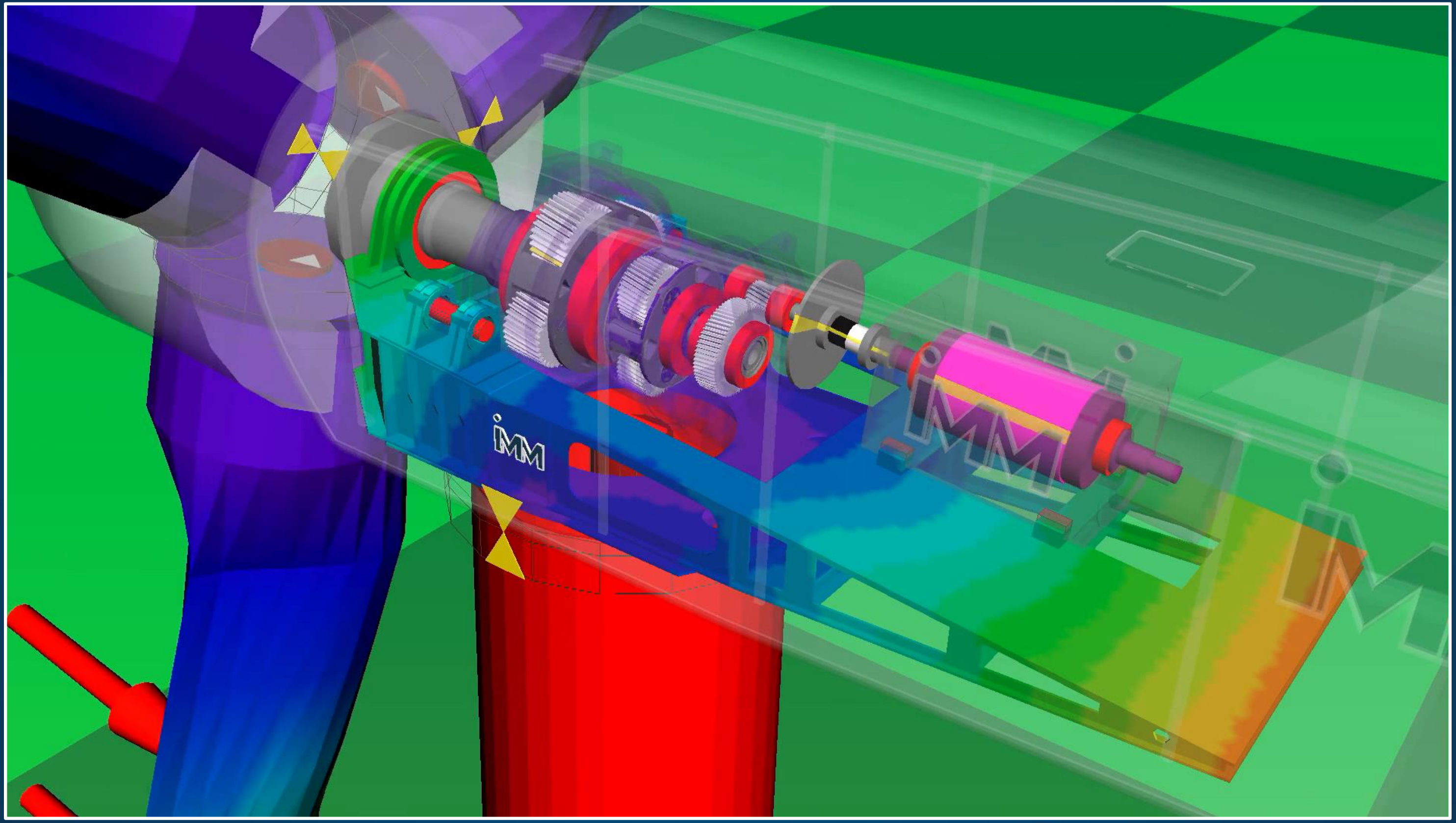
			Fx	Fy	Fz	Fxyz	Mx	My	Mz	Mxyz
max/min	DLC	SF	[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]
max	DLC12_WS0025	1.35	**879.6**	94.2	1201.2	1491.8	-3194.9	27314.4	6.7	27500.6
min	DLC13R_WS0012	1.50	**-426.7**	-3.7	1633.5	1688.3	1889.8	-18420.5	-176.7	18518.0
max	DLC13R_WS0014	1.50	394.4	**303.1**	1660.2	1733.1	-6551.4	10813.4	-15.5	12643.2
min	DLC12_WS0018	1.35	335.1	**-365.6**	746.8	896.5	8891.2	11780.4	-238.2	14761.0
max	DLC12_WS0025	1.35	-91.9	-205.7	**2071.5**	2083.8	4596.9	-9218.8	-261.4	10304.7
min	DLC12_WS0003	1.35	46.7	1.9	**37.6**	60.0	-24.8	1697.2	-28.8	1697.7
max	DLC12_WS0025	1.35	-91.9	-205.7	2071.5	**2083.8**	4596.9	-9218.8	-261.4	10304.7
min	DLC12_WS0003	1.35	46.7	1.9	37.6	**60.0**	-24.8	1697.2	-28.8	1697.7
max	DLC12_WS0018	1.35	383.1	-365.6	822.8	978.5	**9140.8**	13258.8	-268.6	16106.6
min	DLC12_WS0021	1.35	429.8	283.5	1637.8	1716.8	**-7620.5**	12017.7	90.5	14230.4
max	DLC12_WS0025	1.35	879.6	94.2	1201.2	1491.8	-3194.9	**27314.4**	6.7	27500.6
min	DLC13R_WS0014	1.50	-423.7	-15.7	1652.8	1706.4	1994.9	**-18442.6**	-208.9	18551.3
max	DLC12_WS0025	1.35	226.6	-239.8	707.2	780.4	6400.1	6490.5	**536.7**	9131.1
min	DLC12_WS0025	1.35	762.9	-292.2	745.4	1105.9	6420.7	26473.8	**-576.0**	27247.3
max	DLC12_WS0025	1.35	781.1	-294.3	744.2	1118.3	5386.4	27116.4	-336.7	**27648.2**
min	DLC12_WS0021	1.35	87.4	-24.2	991.2	995.3	40.1	-16.3	-98.8	**107.9**





On Premise   On Cloud

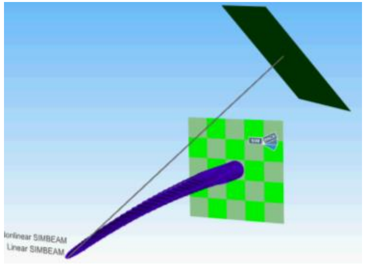
Wind Turbine Dynamics | **Emergency Stop**

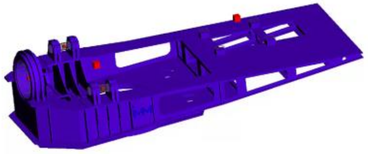


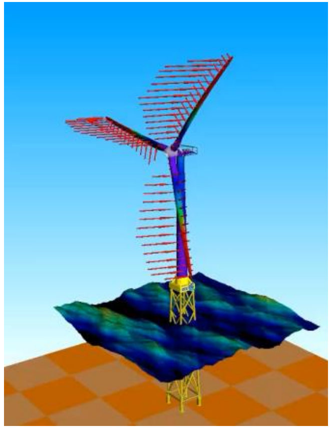
Wind Turbine Dynamics | **Extreme Load Case**

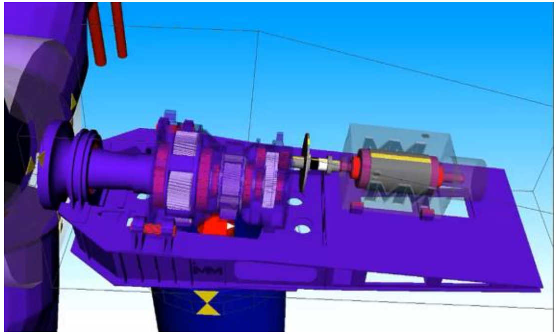
Simulations of extreme loads must often consider additional effects in order to achieve accurate results

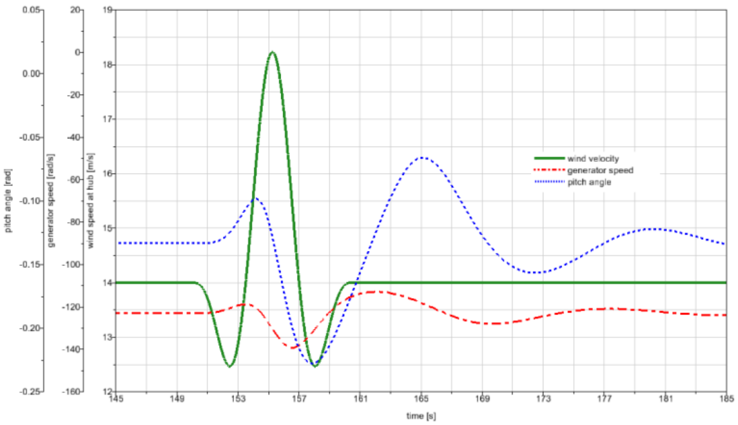
- Non-linear blade deformation
- Flexibility of major components







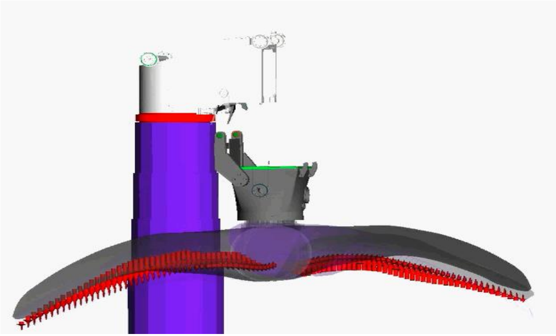




Wind Turbine Dynamics | **Assembly Load Case**

Substantial cost savings can also be achieved through innovation

Courtesy SkyWind



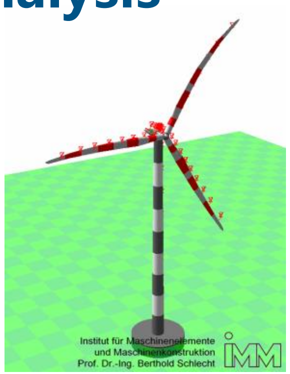
- Ability to simulate all aspects of all designs, in any level of fidelity
- Anything that can be imagined can be simulated.

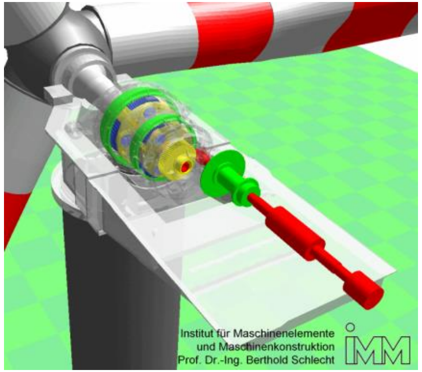
Over 50x reduction in hoisting costs

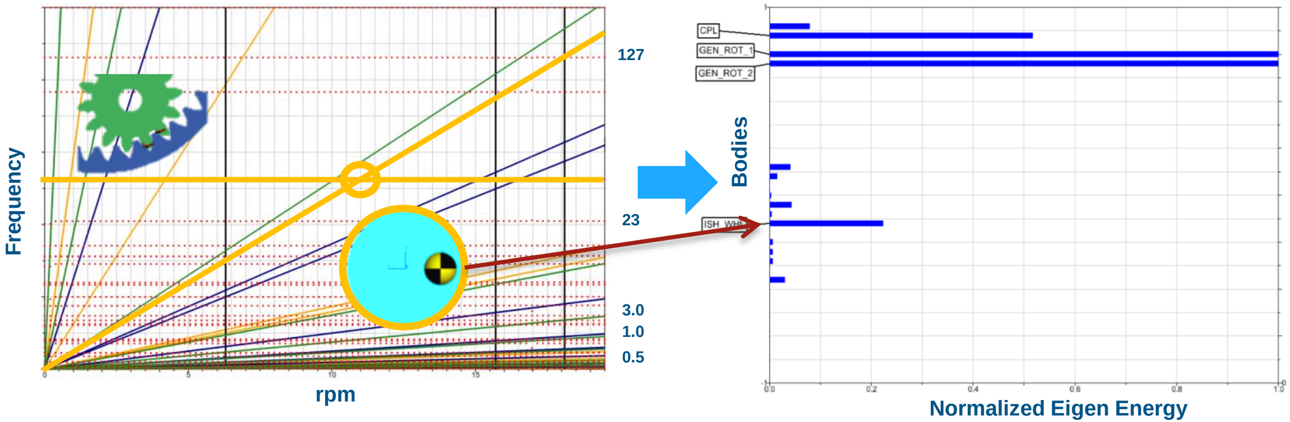
Wind Turbine Dynamics | **Resonance Analysis**

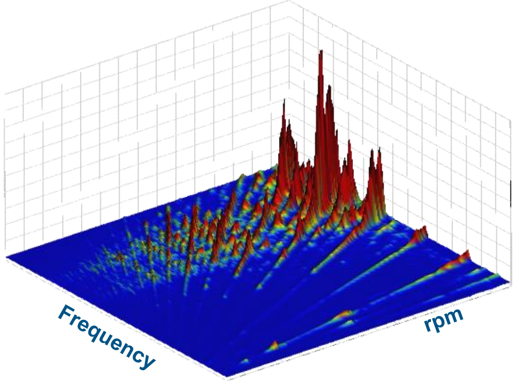
Critical Resonances

- Identification, comprehension, and elimination
- Automated run-up, resonance detection, and result generation



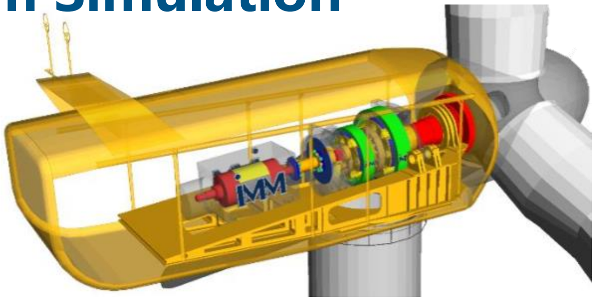




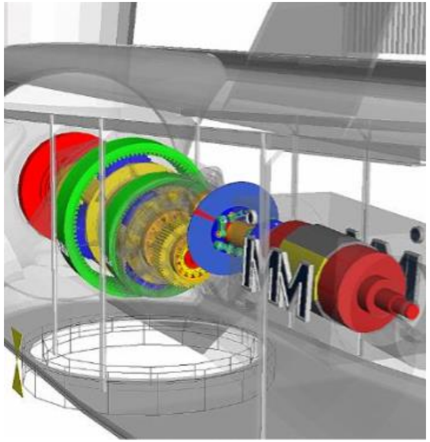


DASSAULT SYSTEMES

Wind Turbine Dynamics | **Holistic System Simulation**



Accurately calculate natural frequencies with higher fidelity models in order to avoid critical resonances that result in faults and down time. Higher accuracy also enables a larger optimization and cost savings potential.



Model Fidelity Variant	1	2	3	4	5	6	7	8	9	10
Tower flexible										✓
Main frame flexible									✓	✓
Gearing flexible								✓	✓	✓
Gearbox housing flexible							✓	✓	✓	✓
Planet carrier flexible						✓	✓	✓	✓	✓
Gearbox housing, 6 DoF					✓	✓	✓	✓	✓	✓
Shafts flexible				✓	✓	✓	✓	✓	✓	✓
Drivetrain parts, 6 DoF			✓	✓	✓	✓	✓	✓	✓	✓
Rotorblades flexible		✓	✓	✓	✓	✓	✓	✓	✓	✓
Model Natural Freq [Hz]										
1st torsional	11.9	1.9	1.9	1.9	1.5	1.5	1.5	1.5	1.5	1.5
2nd torsional	179.3	5.2	5.0	3.4	2.7	2.7	2.7	2.7	2.7	2.7
3rd torsional	424.3	22.9	15.4	8.4	7.8	7.7	7.7	7.7	7.7	7.7
4th torsional	488.0	180.8	55.2	47.0	32.3	30.9	30.7	30.6	30.2	30.0
5th torsional	536.4	424.6	150.7	93.6	97.5	96.3	93.7	93.9	92.7	92.1

Courtesy IMM TU Dresden

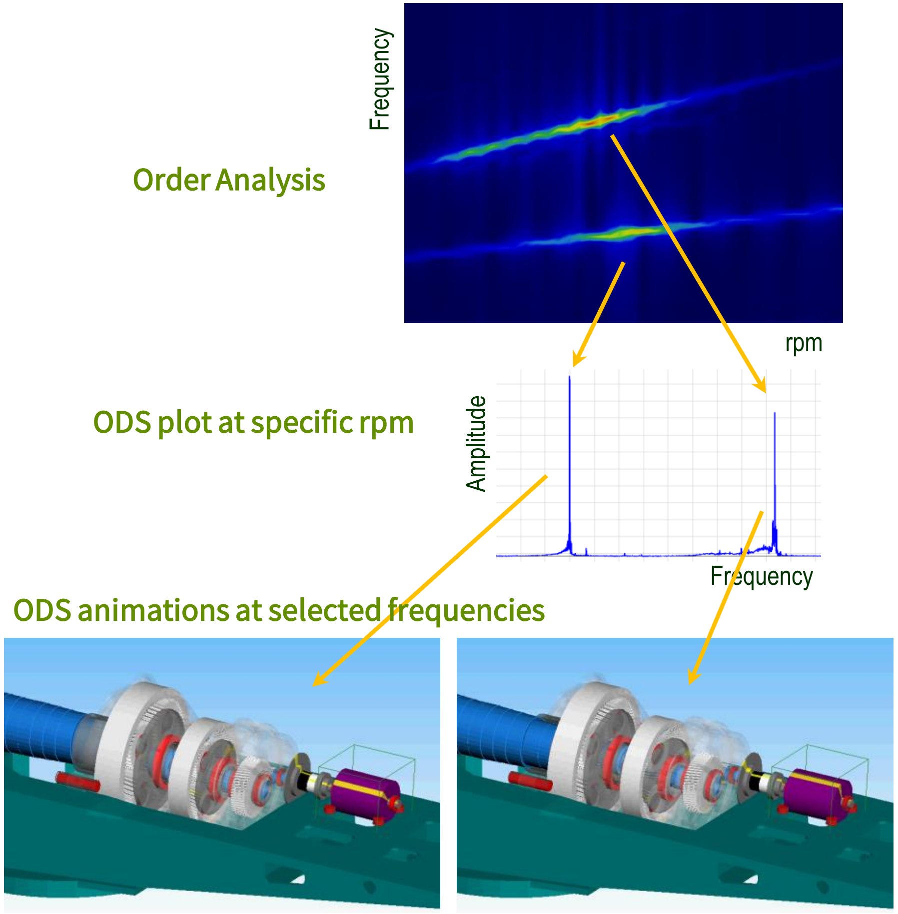
Higher fidelity = risk reduction, optimization and cost savings

Wind Turbine Dynamics | **ODS**

Operating Deflection Shapes (ODS)
Visualizing of nonlinear model behavior at discrete frequencies

ODS Process

- Input = result of a time domain simulation
- FFT analysis is performed for all states of the model
- Results
    - Amplitudes, phases and kinetic energy of each body
- Viewable animation in Post

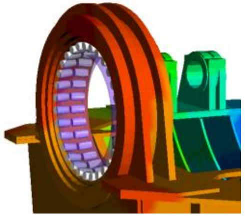


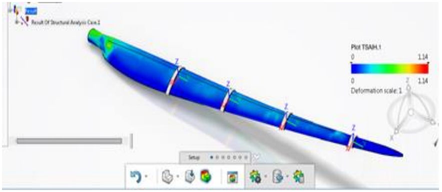
Wind Turbine Dynamics | **Component Optimization**

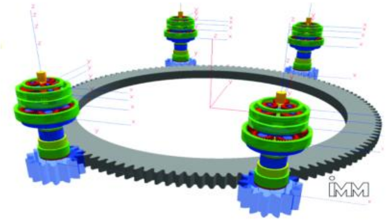
Analysis and optimization of all mechanical components

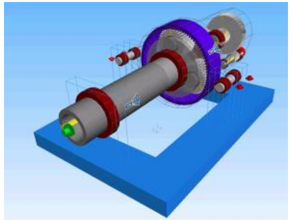
Holistic component simulation

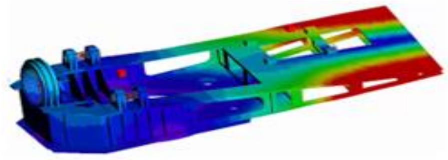
- Standalone for plausibility checks
- within test-rig for component validation
- within complete turbine for correct loads

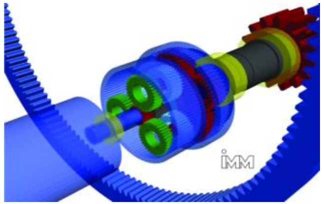


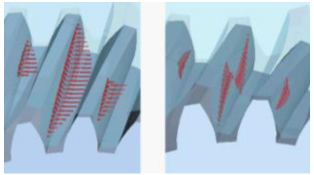


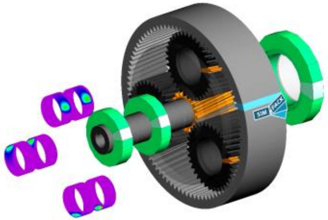








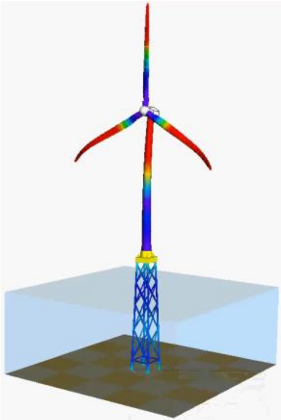


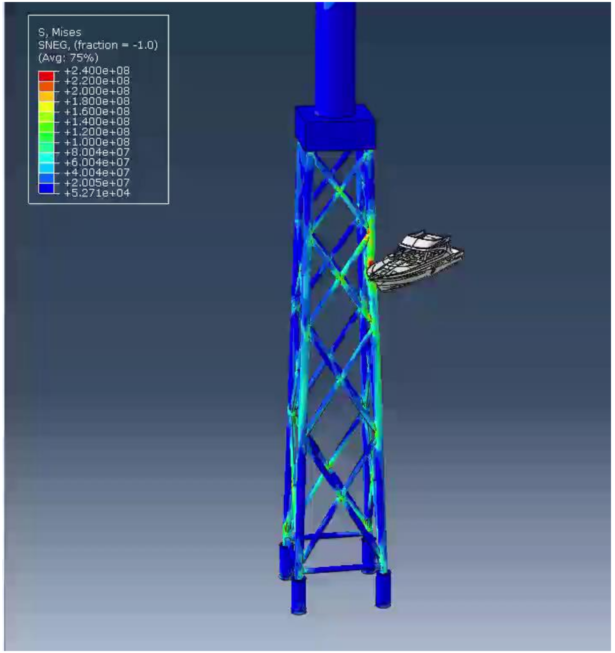


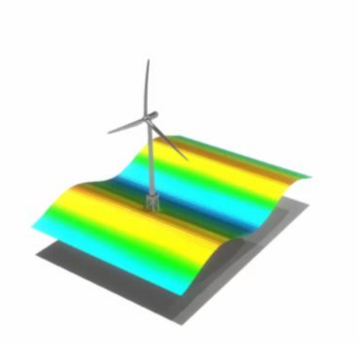
Wind Turbine Dynamics | **Foundation Design**

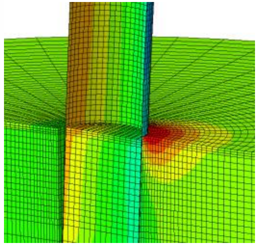
Design, investigation, optimization, and risk reduction

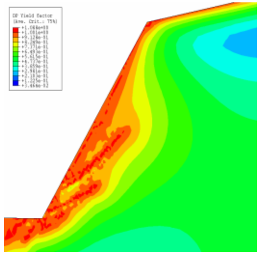
- Complete system optimization
- Damage and failure analysis
- Extreme waves
- Soil interaction
- Bolt connections

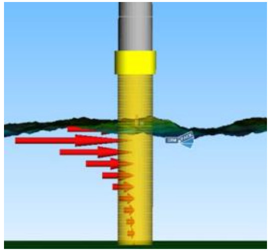












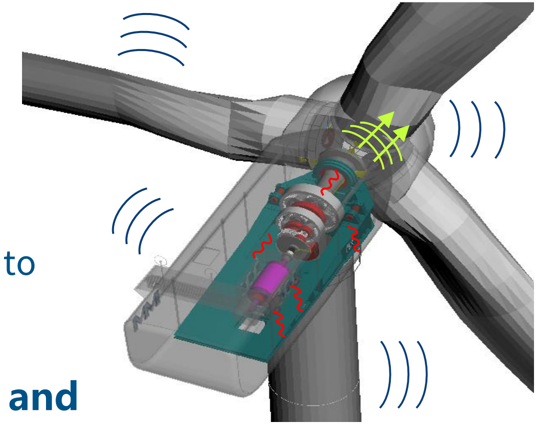
Wind Turbine Dynamics | **Structural Noise**

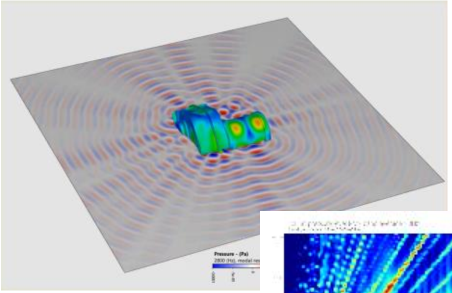
Noise reduction is a primary design driver

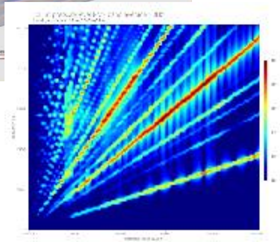
Noise vibration sources
- Gear wheel meshing
- Pumps
- Motors

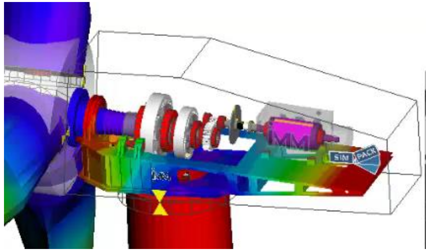
From the source the vibration is transferred to emitting surfaces.

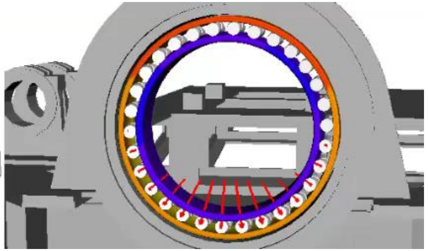
High fidelity models within accurate and capable FEA, MBS and SEA software enable structural noise reduction.





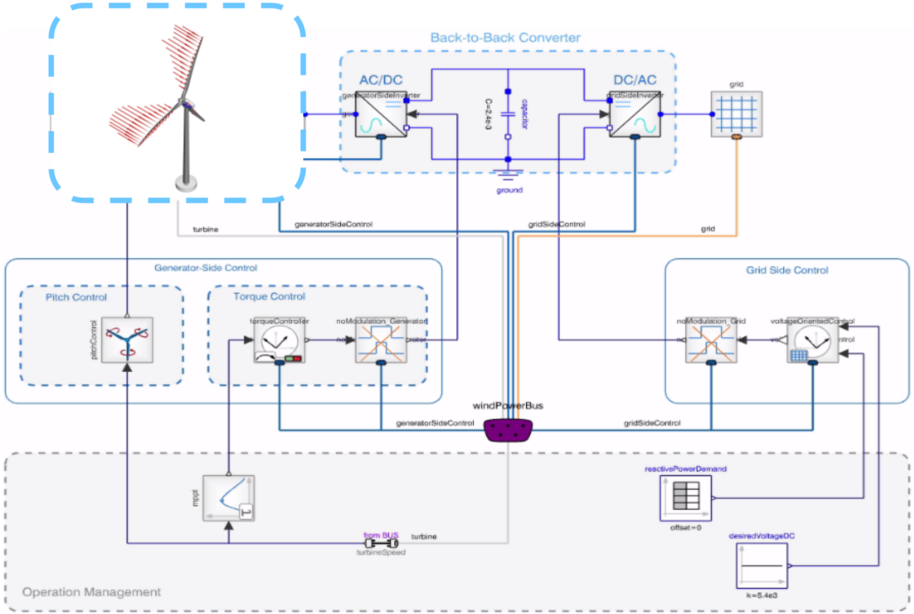




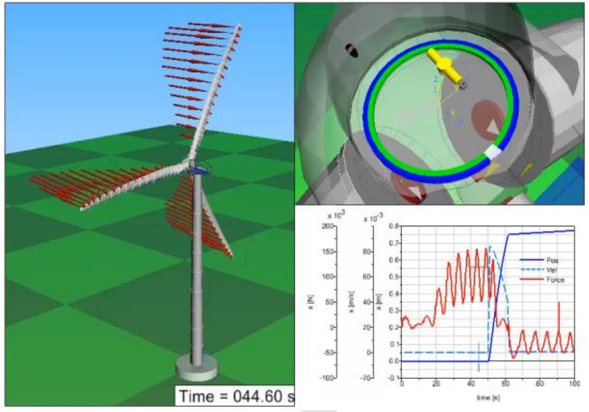


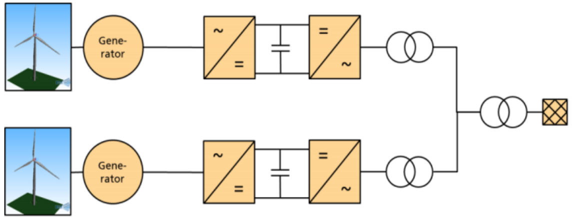
Wind Turbine Dynamics | **Control**

Optimization of fully coupled system, including control, power electronics, hydraulics, grid, etc.



Hydraulic Pitch System



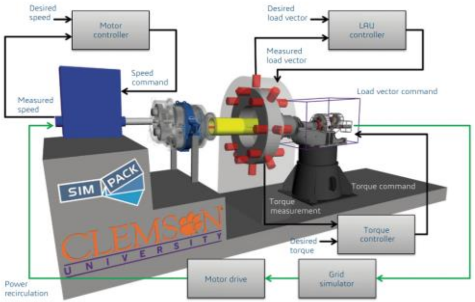


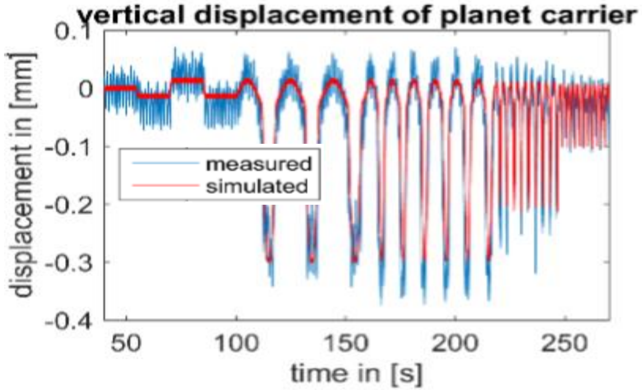
Courtesy MESH Engineering

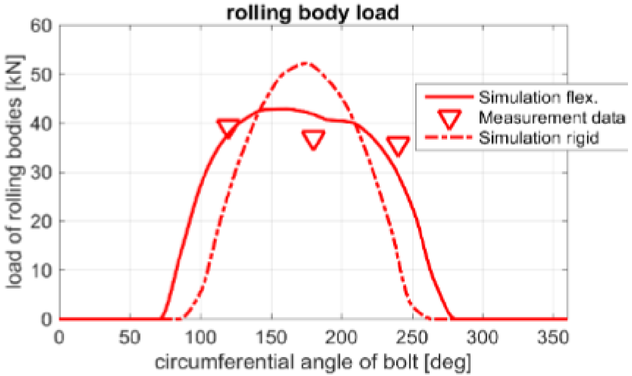
Wind Turbine Dynamics | **Hardware in the Loop**

Coupling of virtual and real world for optimal test campaigns.

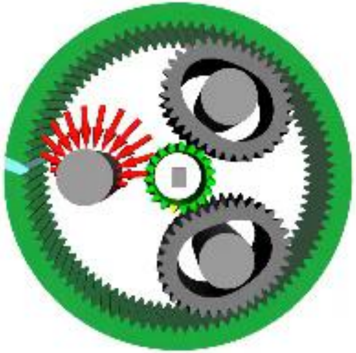
Real-time capable MBS, including flexible bodies and high fidelity components is required for realistic conditions.







Courtesy CWD RWTH Aachen



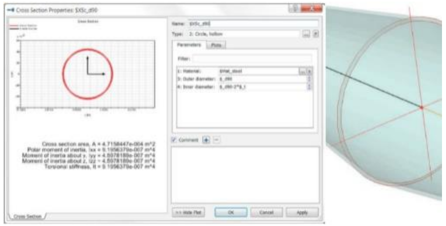
DASSAULT SYSTEMES

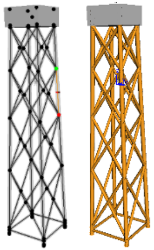
Wind Turbine Dynamics | **Flexible Bodies**

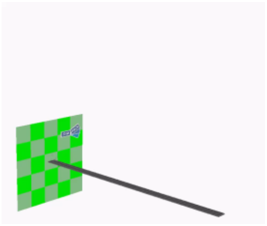
Different methods for including flexible bodies.

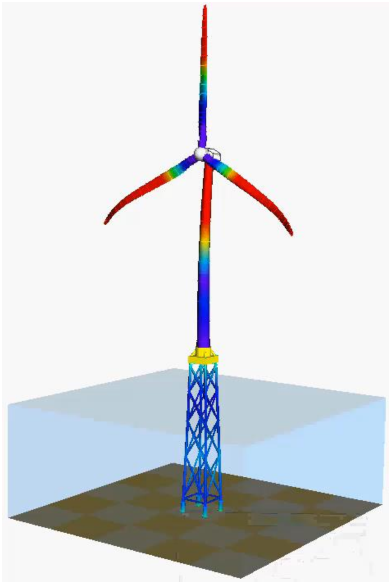
Simpack SIMBEAM
- Full parameterization
- Euler-Bernoullli and Timoshenko beams
- Linear and large deformation bending

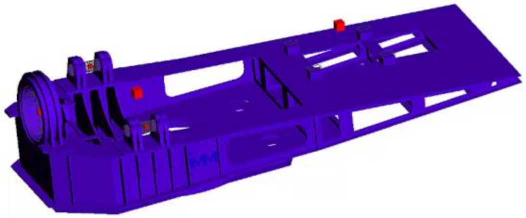
FE model import
- Linear substructure, including stress
- Durability analysis with fe-safe
- Non-linear reduction for large deformation for rotor blades

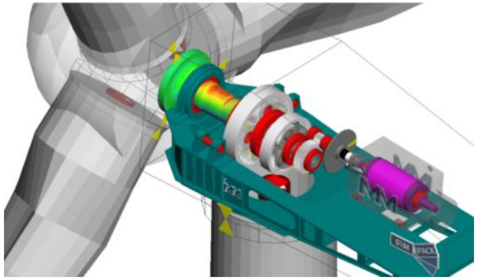


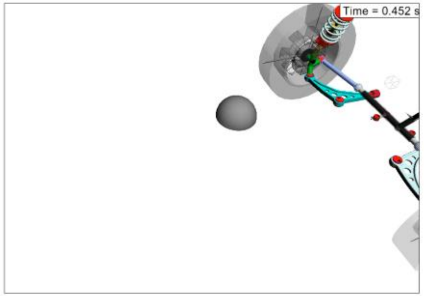








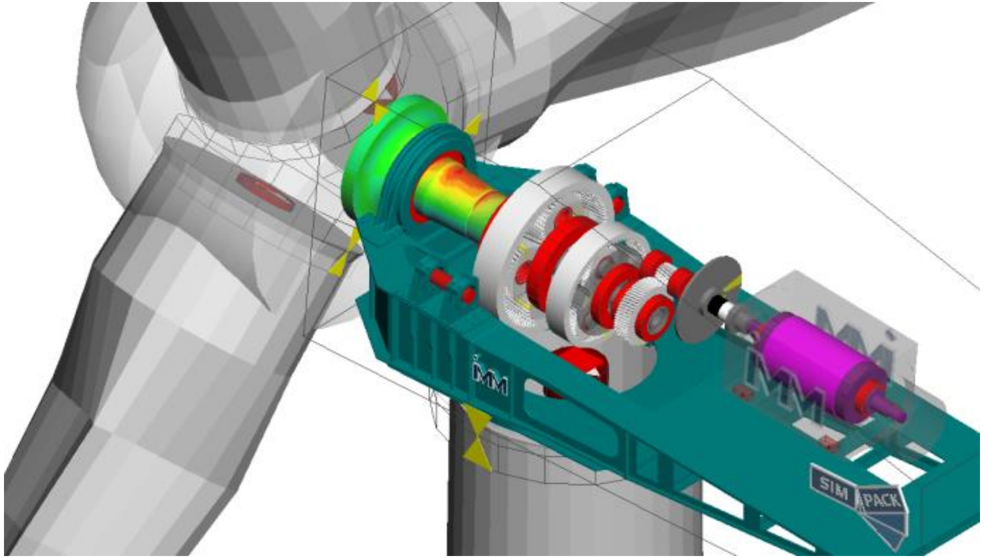




Wind Turbine Dynamics | **Flexible Bodies**

Frequency Content and Interface Modes

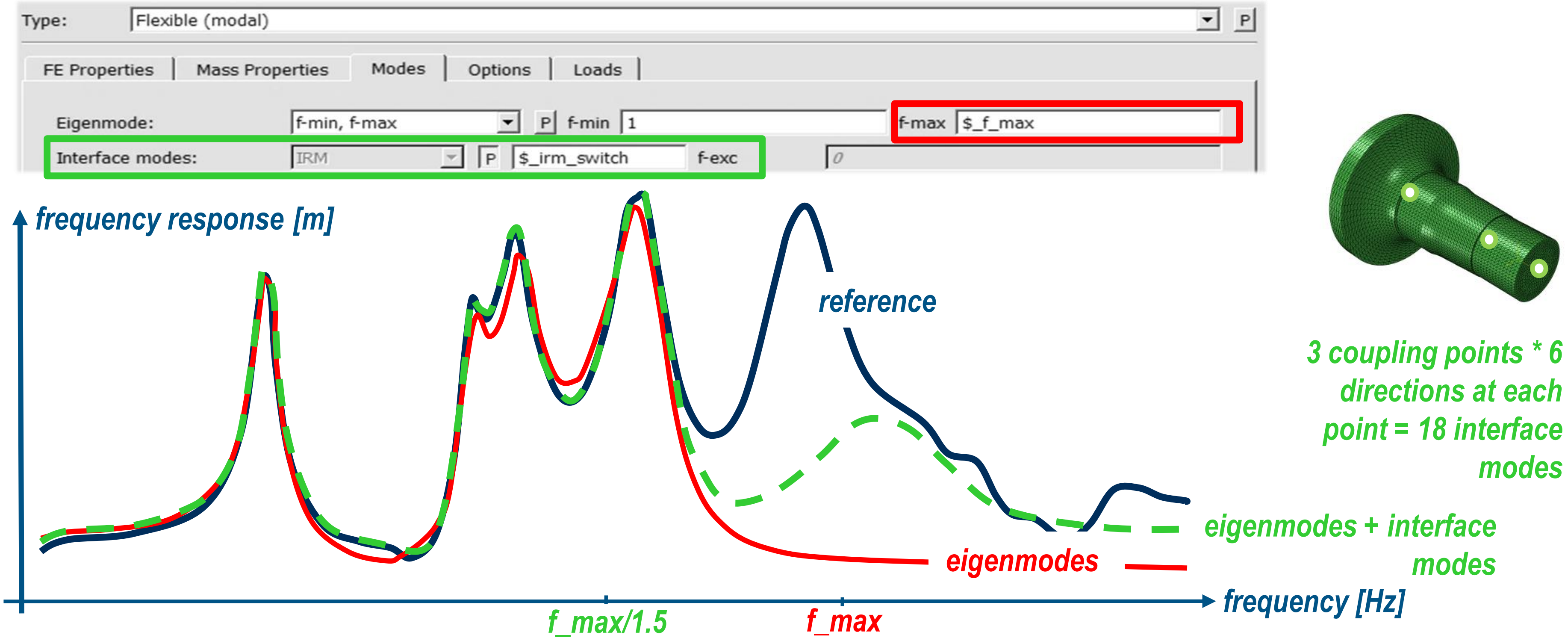
FEA



MBS

Wind Turbine Dynamics | **Flexible Bodies**

Frequency Content and Interface Modes



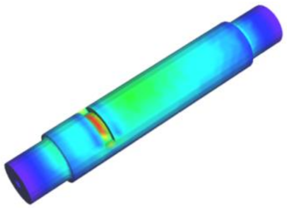
Wind Turbine Dynamics | **Flexible Bodies**

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

Wind Turbine Dynamics | **Flexible Bodies**

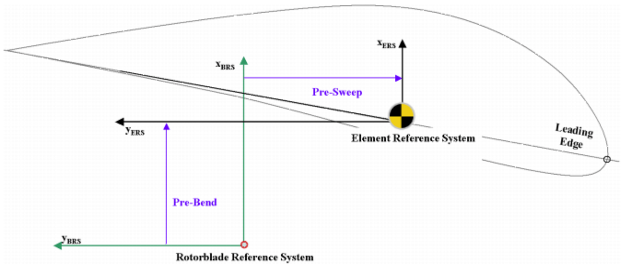
Simpack Rotor Blade Generator

- ASCII input deck
- Based on Flex5 input Parameters
- Uses SIMBEAM
- Input
  - Basic- bend only
  - Advanced - torsion-bend coupling
- Linear and large deformations

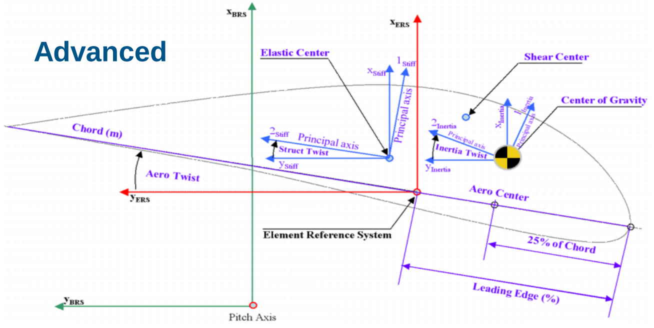
```
! ****************************************************************
! ***   Blade Structural Details (Basic only)                  ***
! ****************************************************************

param.station.begin
!                                         stiff     stiff               3D                  3D
! station   root     pre-    pre-    mass/l    edge      flap      struct    airfoil  chord     thick-   leading    (structure )
! ID        dist     bend    sweep             EI1       EI2       twist                       ness     edge       (center t25)
!           [m]      [m]     [m]     [kg/m]    [Nm^2]    [Nm^2]    [deg]     [-]       [m]     [%]      [%]        ([%]       )
   1         0.00    0.00    0.00    1445.7    7.00E+09  7.00E+09  13.00     1         2.70    100.00   50.00      50.00
   2         1.50    0.00    0.00     615.3    6.50E+09  6.38E+09  13.00     1         2.86     98.70   48.50      43.78
   ...
param.station.end
```

Basic



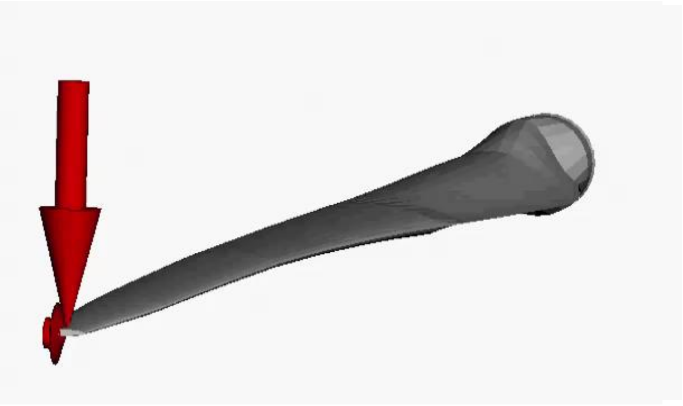
Advanced

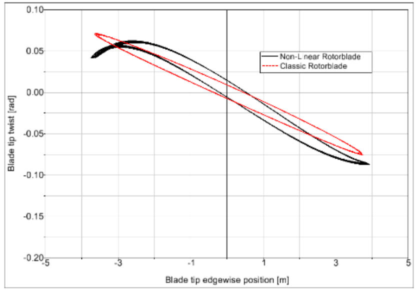


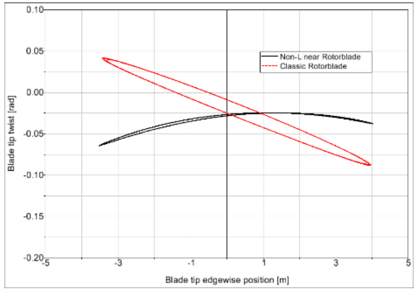
Wind Turbine Dynamics | **Flexible Bodies**

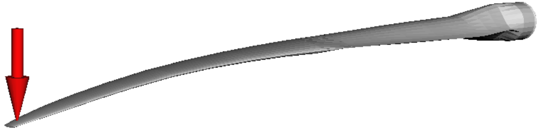
Non-linear deformation of rotorblades

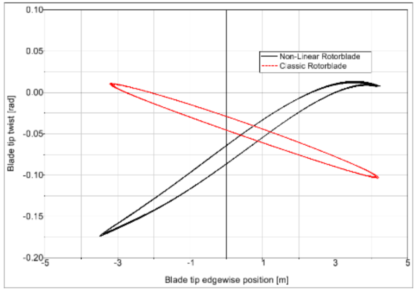
- Rotorblades size is increasing
- Twist-bend coupling now very significant
- Highly non-linear deformation









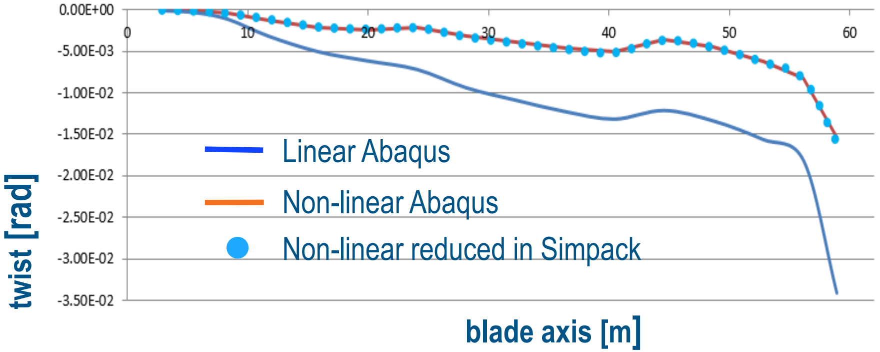


Wind Turbine Dynamics | **Flexible Bodies**

Rotorblade generation in Simpack

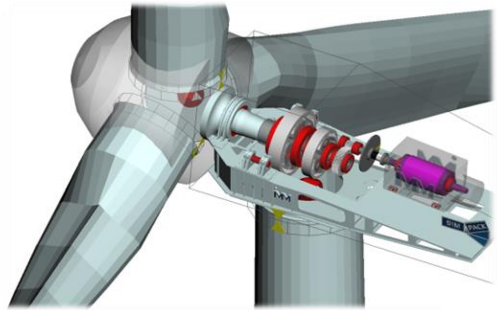
Different Levels of Fidelity

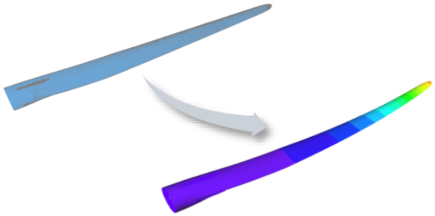
- Standard Input Data
    - Linear Beam Theory
    - Non-linear Beam Theory
        - Twist-bend coupling
        - Accuracy within 1% of Abaqus
- Non-linear Reduction (deployment phase)
    - Direct use of reduced FE model (from 60,000 to 40 DoF)

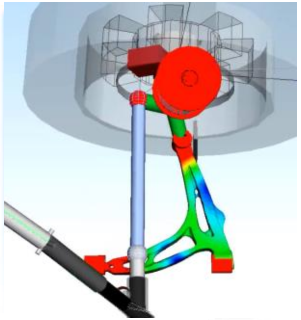


Wind Turbine Dynamics | **Flexible Bodies**

A Variety of Choices







Linear Flexible Bodies

- Accurate dynamic behavior
- Stress & fatigue
- Noise
- Detailed fluid structure interaction

Nonlinear flexible Bodies

- Large deformation
- Reduced Order Formulation

General Physics

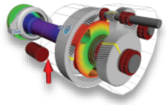
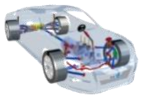
- collision analyses
- contact
- friction
- plastic deformation

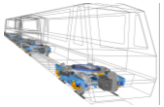
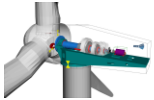
Reduced order models **Co simulation**

logical scale **physical scale**

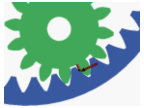
Wind Turbine Dynamics | **Components**

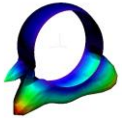
- Large library of Elements
- Cross-industry usage

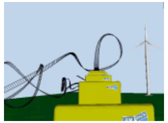
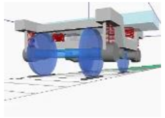
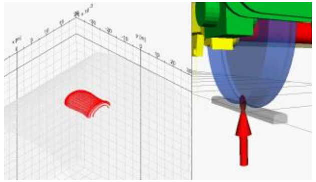
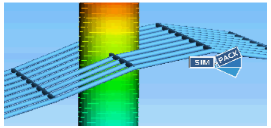
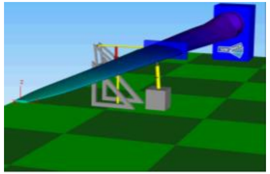



- ▶ **General**
  - ▷ Contact
  - ▷ Gear pair
  - ▷ EHD
  - ▷ Rolling bearing
  - ▷ Dyn. Bushing
  - ▷ ....
- ▶ **Automotive**
  - ▷ Elkin. sensors
  - ▷ Tires
  - ▷ Roads
  - ▷ Driver
- ▶ **Engine**
  - ▷ Dyn. valve spring
  - ▷ HLA
  - ▷ Gas forces
  - ▷ Chain
  - ▷ Belt
- ▶ **Rail**
  - ▷ Rail-wheel contact
  - ▷ (Flex) track
  - ▷ Rail wear
- ▶ **Wind**
  - ▷ Rotorblade gen.
  - ▷ AeroDyn IF
  - ▷ HydroDyn IF
  - ▷ AeroModule IF



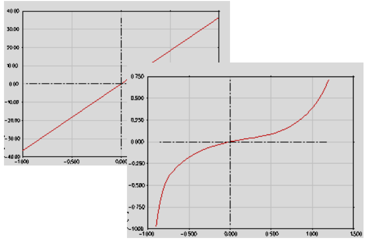







Wind Turbine Dynamics | **Components**

Rolling Bearings overview

- Linear and non-linear stiffness
- 5x5 Matrices
- Characteristic field data
    - Interface to BEARINX® Map
    - Interface to LAGER2, FVA
- Simpack Rolling Bearing Element
- Simpack general contact

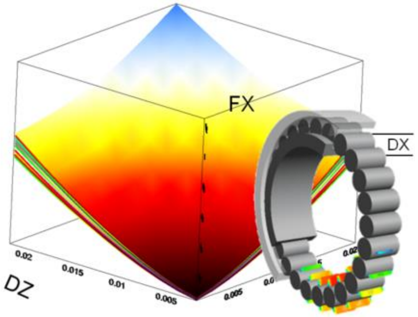
Linear and non-linear stiffness



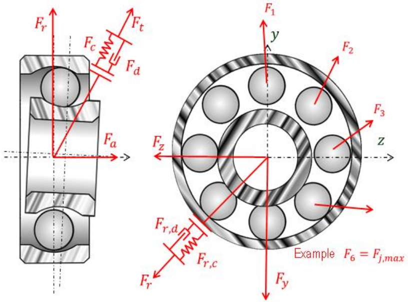
Coupled linear stiffness

$$\begin{pmatrix} c(1,1) & c(2,1) & c(3,1) & c(4,1) & c(5,1) & c(6,1) \\ c(1,2) & c(2,2) & c(3,2) & c(4,2) & c(5,2) & c(6,1) \\ c(1,3) & c(2,3) & c(3,3) & c(4,3) & c(5,3) & c(6,1) \\ c(1,4) & c(2,4) & c(3,4) & c(4,4) & c(5,4) & c(6,1) \\ c(1,5) & c(2,5) & c(3,5) & c(4,5) & c(5,5) & c(6,1) \\ c(1,6) & c(2,6) & c(3,6) & c(4,6) & c(5,6) & c(6,1) \end{pmatrix}$$

BEARINX®



Rolling Bearing Element

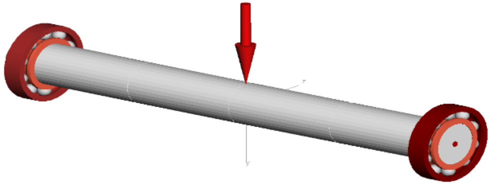


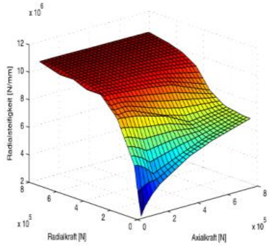
Rolling Bearing Element

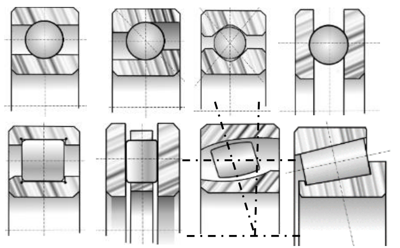
Wind Turbine Dynamics | **Components**

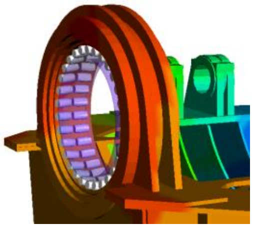
Rolling Bearings overview

- Rolling Bearing Element
  - 3D Contact Description
  - Based on inner bearing geometry
  - Analytical force description (ISO 16281)
  - Non-linear stiffness and cross-coupling
  - Flexible bearing rings
- Full Body Model
  - Full geometrical and inertial description
  - General Simpack contact Elements
  - Advanced output values (e.g. surface stress)

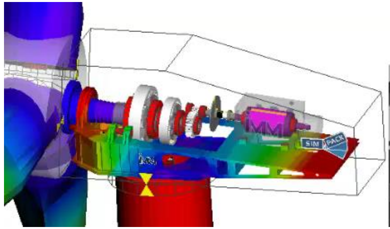


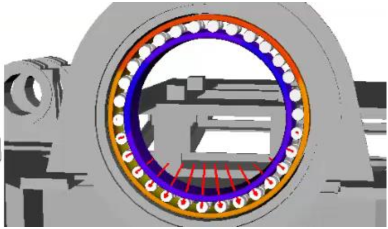


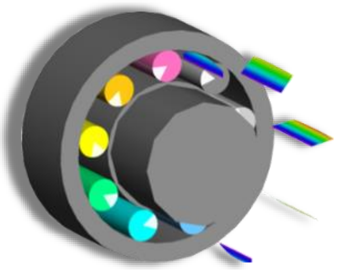


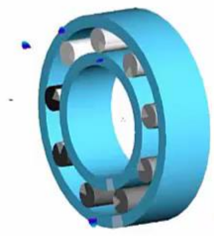


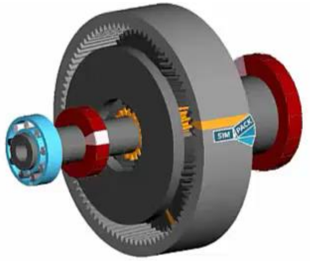
Spherical bearing



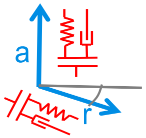
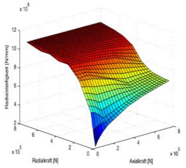
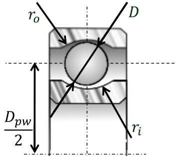








Wind Turbine Dynamics | **Rolling Bearings Overview**

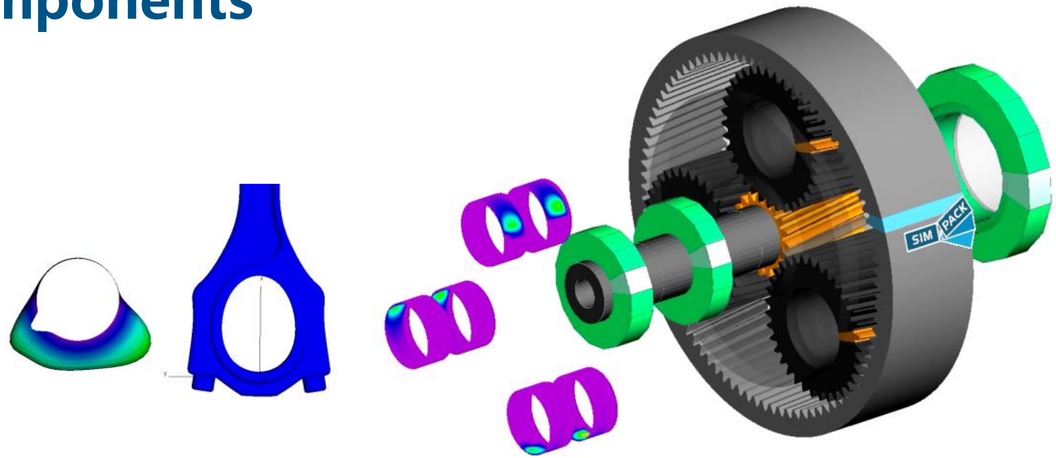
Element	Characteristics	Use	
1D Spring-Damper (FE 6, 43, 185)	• Non-linear 1D stiffness • Clearance definition	• Bearing of rigid shafts with linear angular velocity or load • Simplified NVH driveline analysis	
3D Stiffness Matrix (FE 41, Bearinx ®)	• Linear 3D stiffness • Cross-coupled forces/torques • All displacements considered	• Bearing of flexible shafts with increasing loads • NVH without bearing excitations	
3D Contact Description (FE 88)	• Non-linear 3D stiffness • Cross-coupled forces/torques • Cage rotation & flexible bearings	• Flexible bearing of flexible shafts with dynamic loads • NVH incl. bearing excitations	
Full Body Model (FE 198)	• Full description of all bearing components and contacts	• Detailed bearing analysis (e.g. normal stress and cage interaction)	

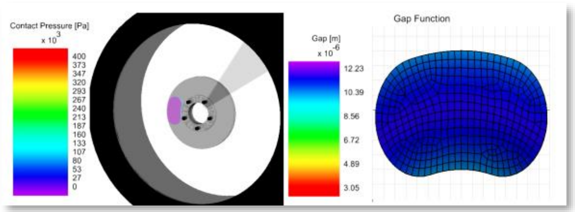
Level of Detail

Wind Turbine Dynamics | **Components**

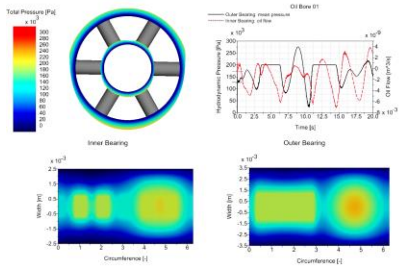
Journal Bearings overview

- Easy setup
- Cylindrical or planar bearings
- Analytical HD, online HD or one- / double-sided EHD (floating ring)
- Fluid flow coupling of bearings
- Transient oil temperature by a global thermal balancing
- Wear calculation





Brake

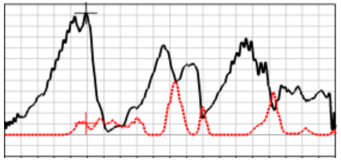


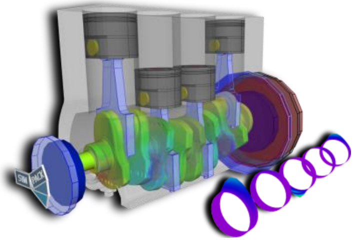
Floating bearing

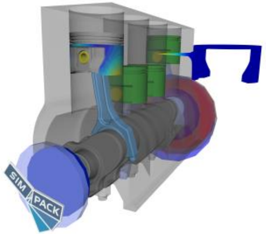
Wind Turbine Dynamics | **Journal Bearings Overview**

Element	Characteristics	Use
Approximating Hydrodynamics (FA)	• Analytical approach • All forces/torques • Mixed friction	• Fast cylindrical bearing with friction torque • Durability calculations of holistic models
Hydrodynamics (HD) or Rigid dry contact	• Online solution • All forces/torques/ friction regimes • Lokal design elements	• Geometry optimization (crowning, grooves etc.) • Oil flow analysis
Elasto-Hydrodynamics (EHD) or Rigid elastic contact	• HD / Rigid dry contact + • local deformations on one or both bodies	• Friction and wear analysis • Micro geometry optimization

Level of Detail



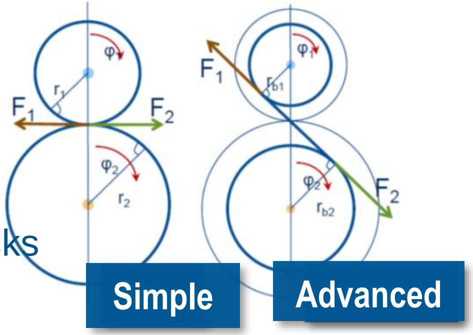


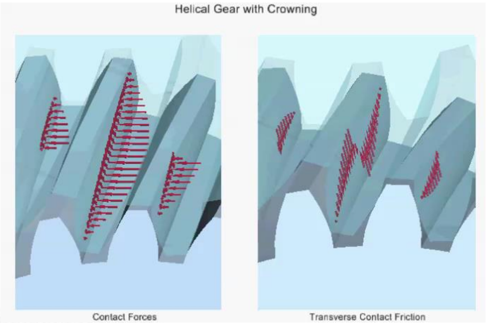


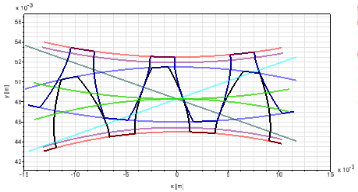
Wind Turbine Dynamics | **Components**

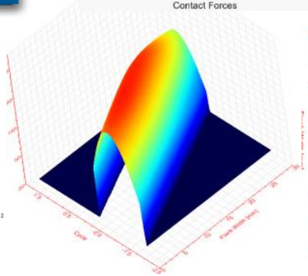
Gear Wheels

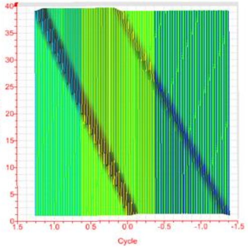
- Basic Gear Pair
  - No meshing excitations
  - Recommended for linearization tasks
- Gear Pair 225
  - Meshing excitations
  - Profile and flank micro geometry
  - Pre Plots: check plot, load intensity, mesh contouring
- Gear Pair 225 with Flexible Bodies
- Non-standard gear profiles

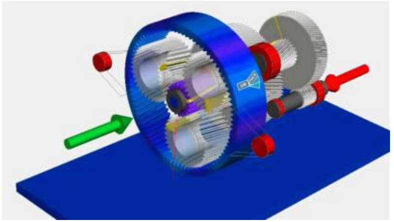


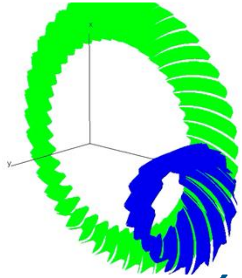








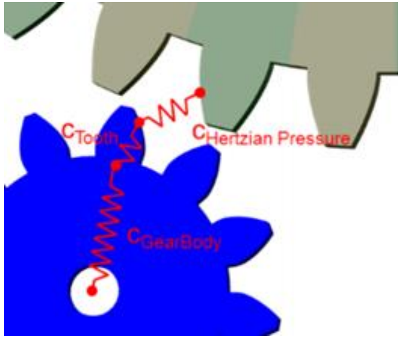


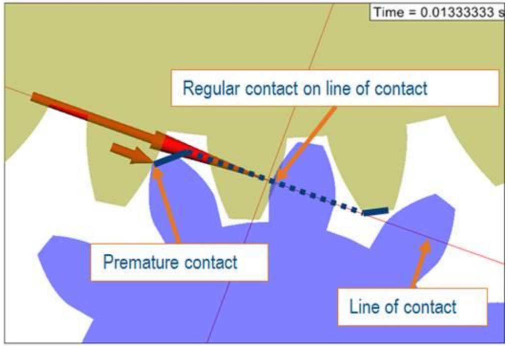


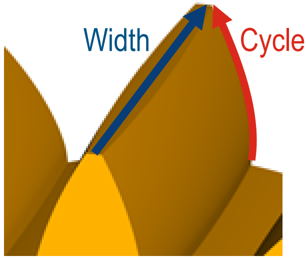
Wind Turbine Dynamics | **Components**

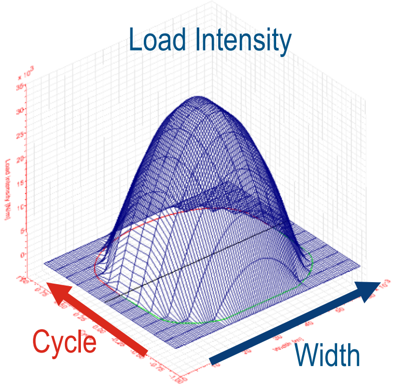
Gear Pair 225

- DIN 3990
- Weber Banaschek
  - Clear separation of stiffnesses (body, tooth and contact)
  - Recommended for use with flexible gears and ring gears
- Extended tip contact
- Contact pattern plot



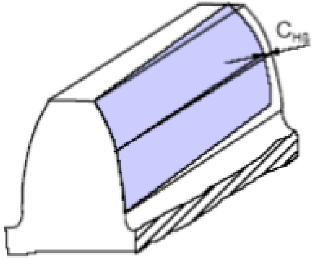




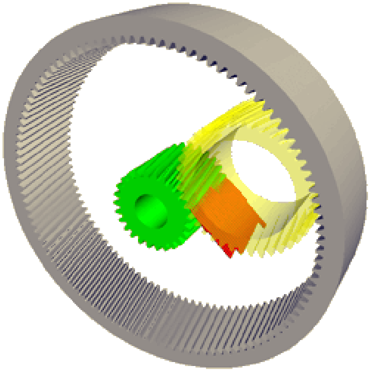


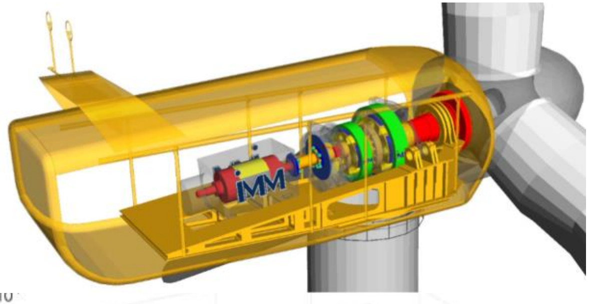
Wind Turbine Dynamics | **Components**

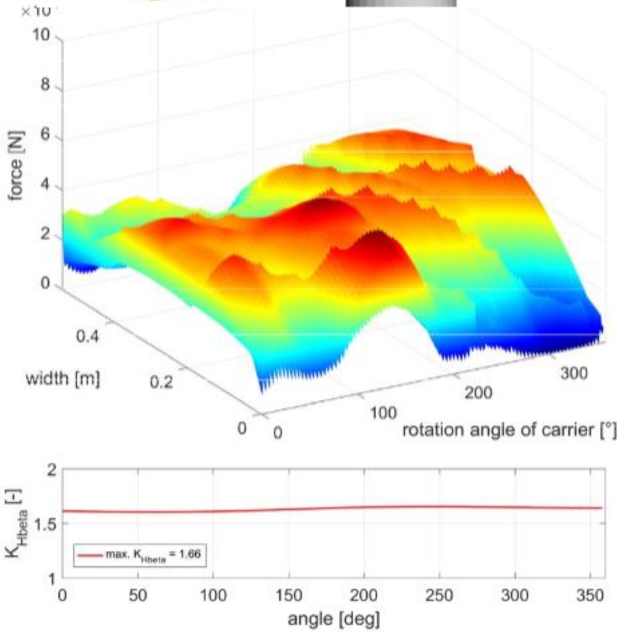
Optimization of tooth load distribution



helix angle modification
$f_{H\beta}$= 90 µm







Face load factors, $K_{H\beta}$, optimization by varying:

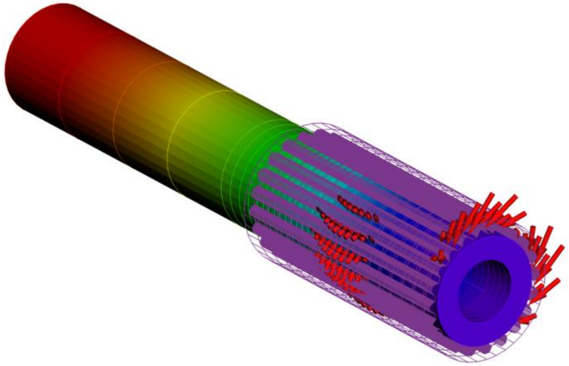
- Gear tooth modification
- Gearbox support stiffness
- Planet pin shit, tangential and radial

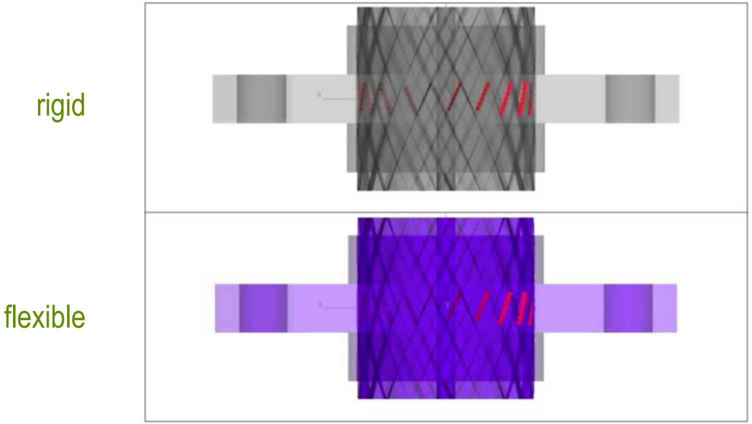
https://www.3ds.com/fileadmin/EVENTS/SIMULIA-Simpack/archive-wind-drivetrain2018/4a-2-TU-Dresden-IMM-Rosenloecher.pdf

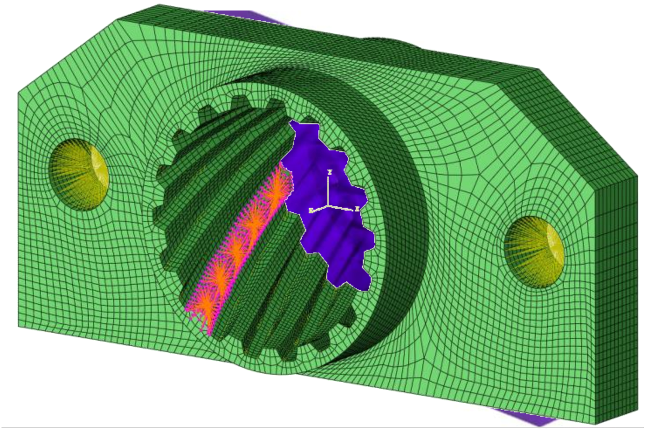
Wind Turbine Dynamics | **Components**

Flexible Spline Coupling

- Rigid
  - Detailed contact
- Flexible
  - Beam elements
  - FEA Bodies





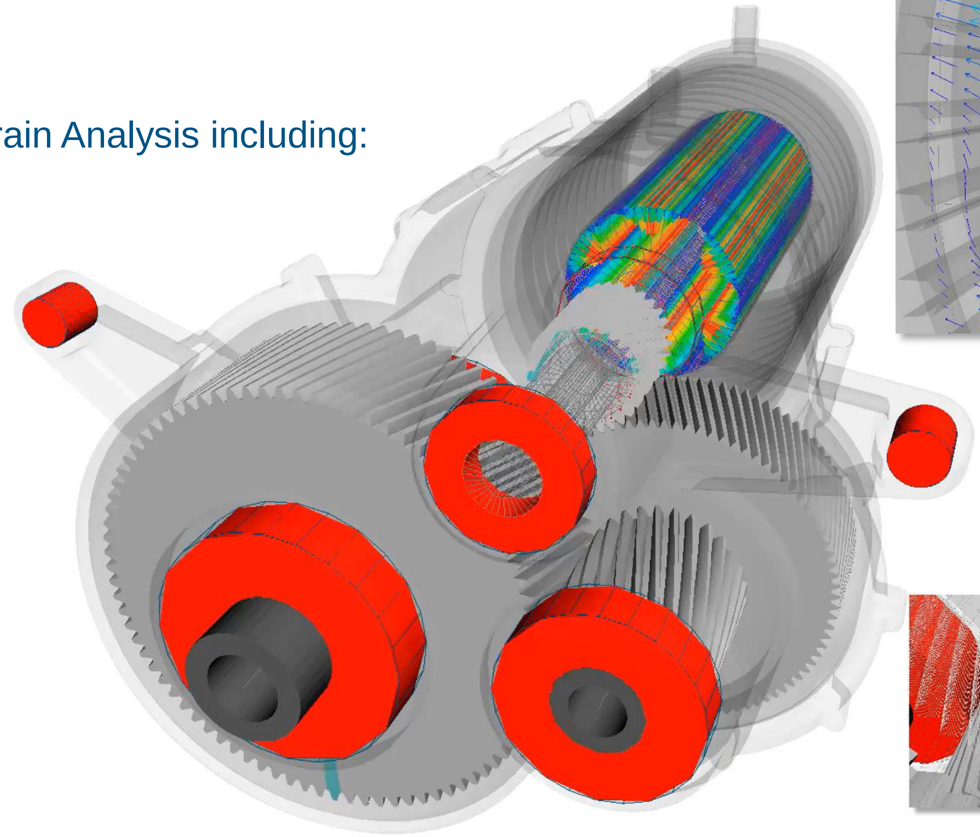


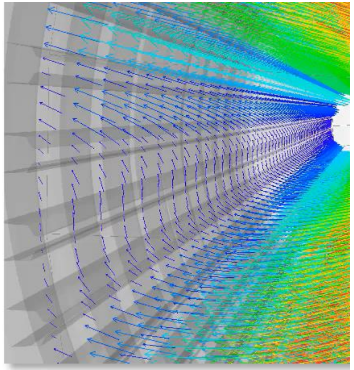
Wind Turbine Dynamics | **Components**

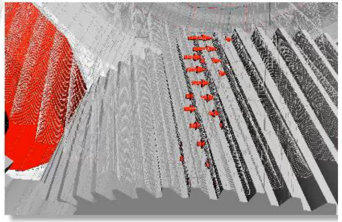
Electric Machine Interface

Allows for Full System Drivetrain Analysis including:

- Gear Meshing
- Roller Bearing
- Nonlinear Bushings
- Spatial Electric Loads







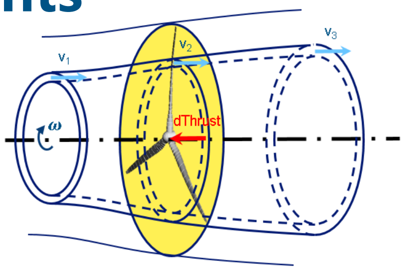
Wind Turbine Dynamics | **Components**

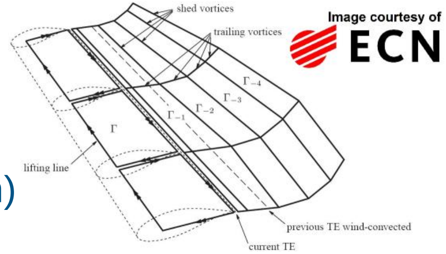
Aerodynamic Methods

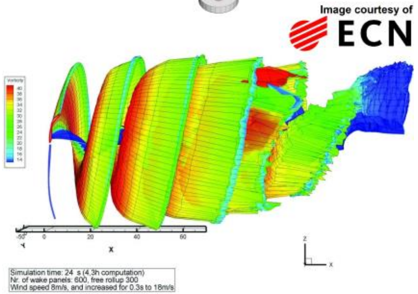
- Blade Element Momentum (BEM)
  - AeroDyn from NREL
  - AeroModule from ECN
  - Flex5 (customer implementation)

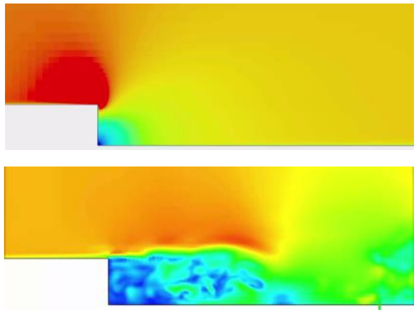
- Free Vortex Wake
  - AeroModule from ECN
  - S4 from DLR (customer implementation)

- CFD (Navier Stokes, Lattice Boltzmann)
  - 3DEXPERIENCE, PowerFLOW, XFlow
  - Customer implementations





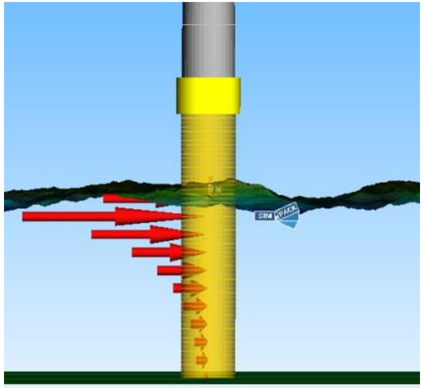


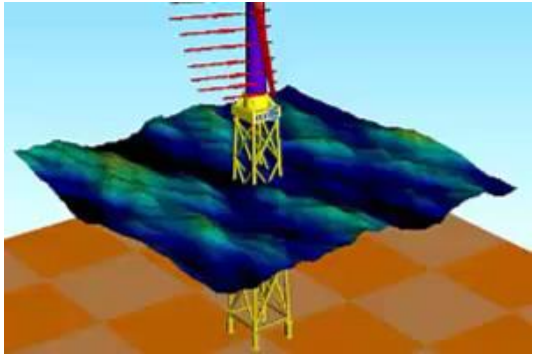


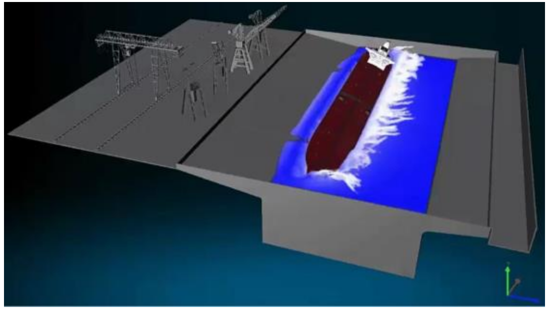
Wind Turbine Dynamics | **Components**

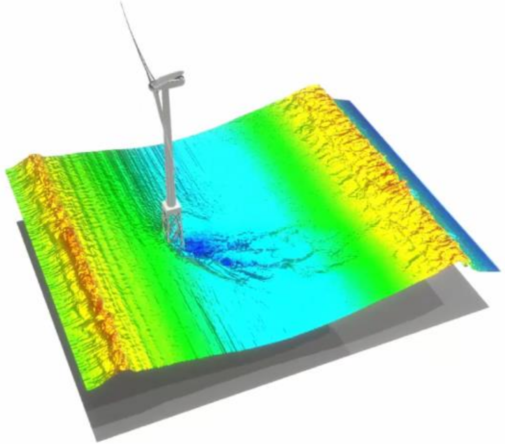
Hydrodynamic Methods

- Morrison Equations (HydroDyn)
  - Slender cylinders
  - Offshore fixed and floating structures
- Linear hydrodynamics (HydroDyn)
  - hydrostatic, waves/currents, added mass, radiation/diffraction
- CFD
  - Detailed Loading
  - Extreme events
  - Optimization









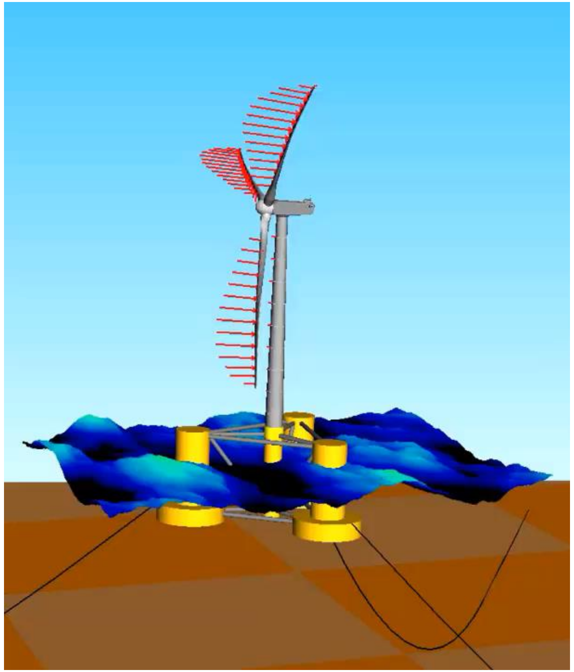
DASSAULT SYSTEMES

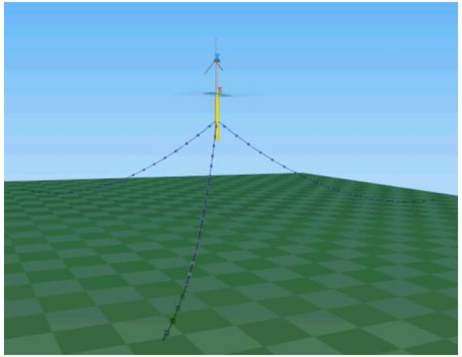
Wind Turbine Dynamics | **Components**

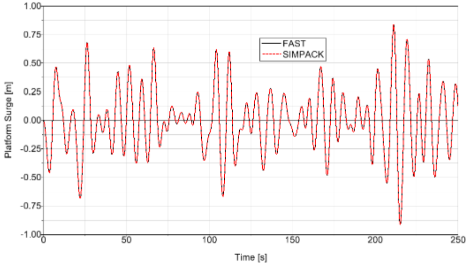
Offshore mooring lines

- Quasi-static mooring line
  - MAP (NREL)
  - Multi-Segmented
  - Seabed contact and friction

- Dynamic mooring
  - Morrison equations (HydroDyn)
  - Multi-body line
  - Contact, friction, etc.

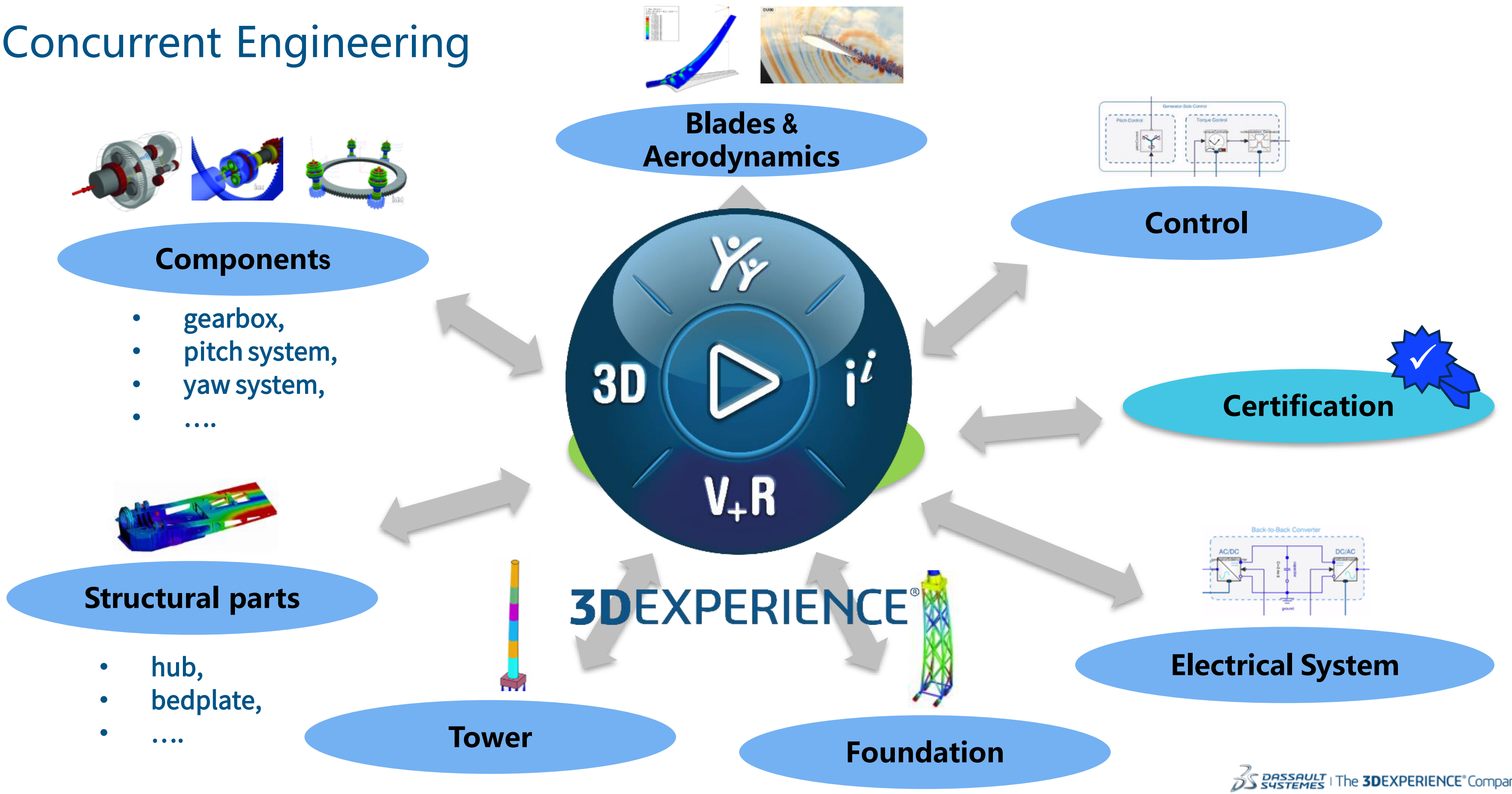






Wind Turbine Engineering | **3DEXPERIENCE Platform**

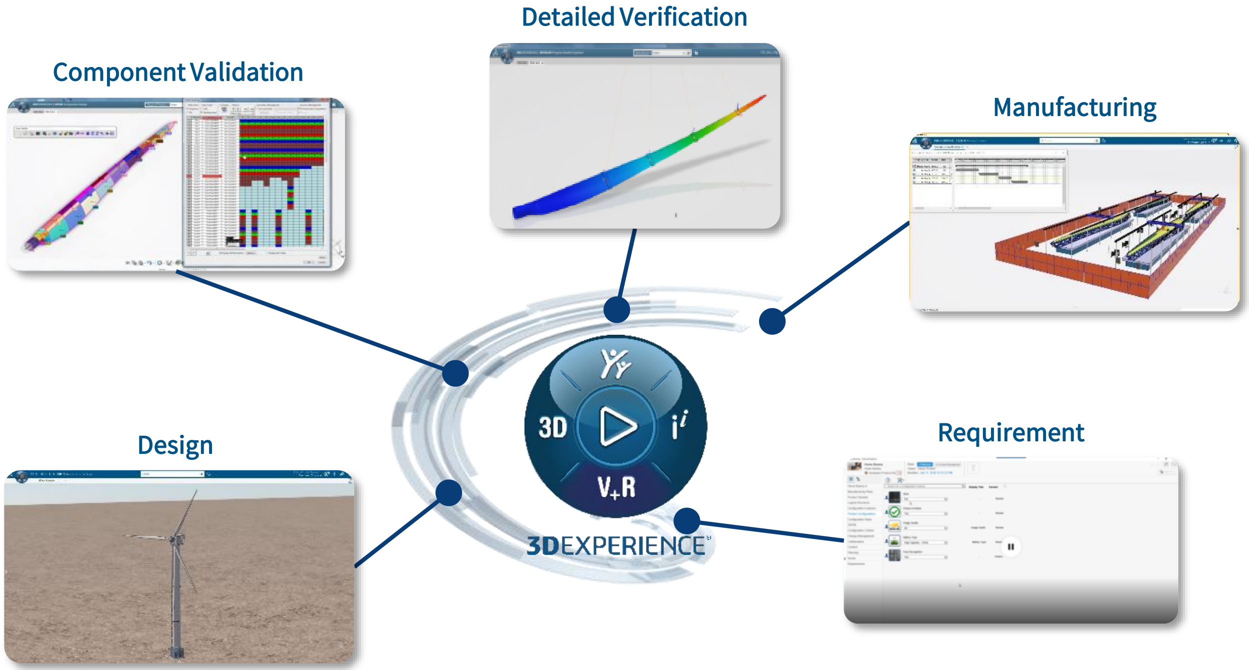
Concurrent Engineering



Wind Turbine Engineering | **3DEXPERIENCE Platform**

The Digital Thread

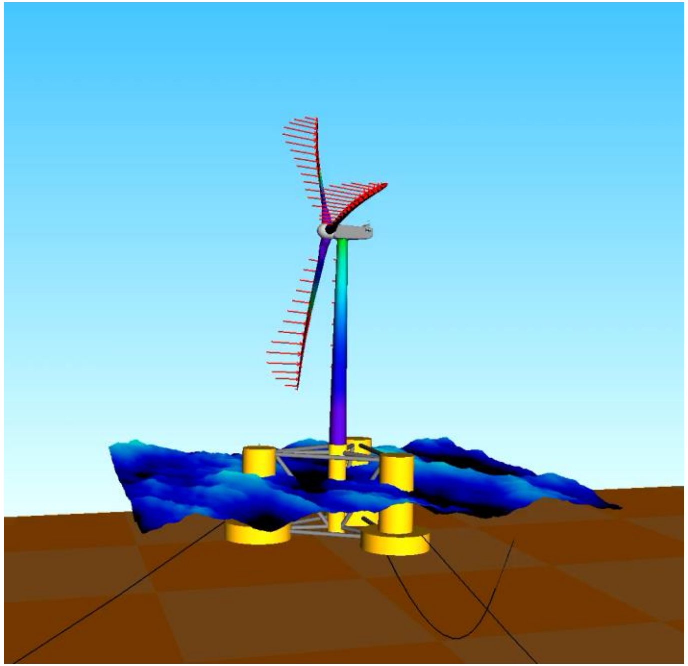
Full digital continuity from design to validation to manufacturing eliminates translations and other sources of data loss.

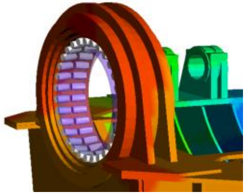


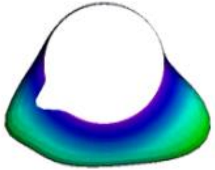
- Single Source of Truth
- Traceability
- Versioning
- Collaboration
- Configuration
- Automated Workflows

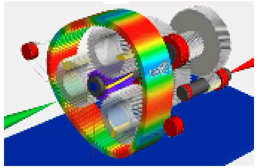
Wind turbine Dynamics | **Summary**

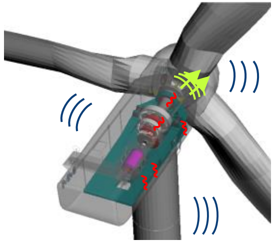
- Dynamics and load prediction of any wind turbine type, and at any level of fidelity.
- Unified solution
    - Design Load Calculations
    - Component Optimization
    - Stress, durability
    - Acoustics
    - Realtime
    - …
- Transparent simulation environment
- 3DEXPERIENCE











THANK YOU FOR YOUR ATTENTION!

IF WE™