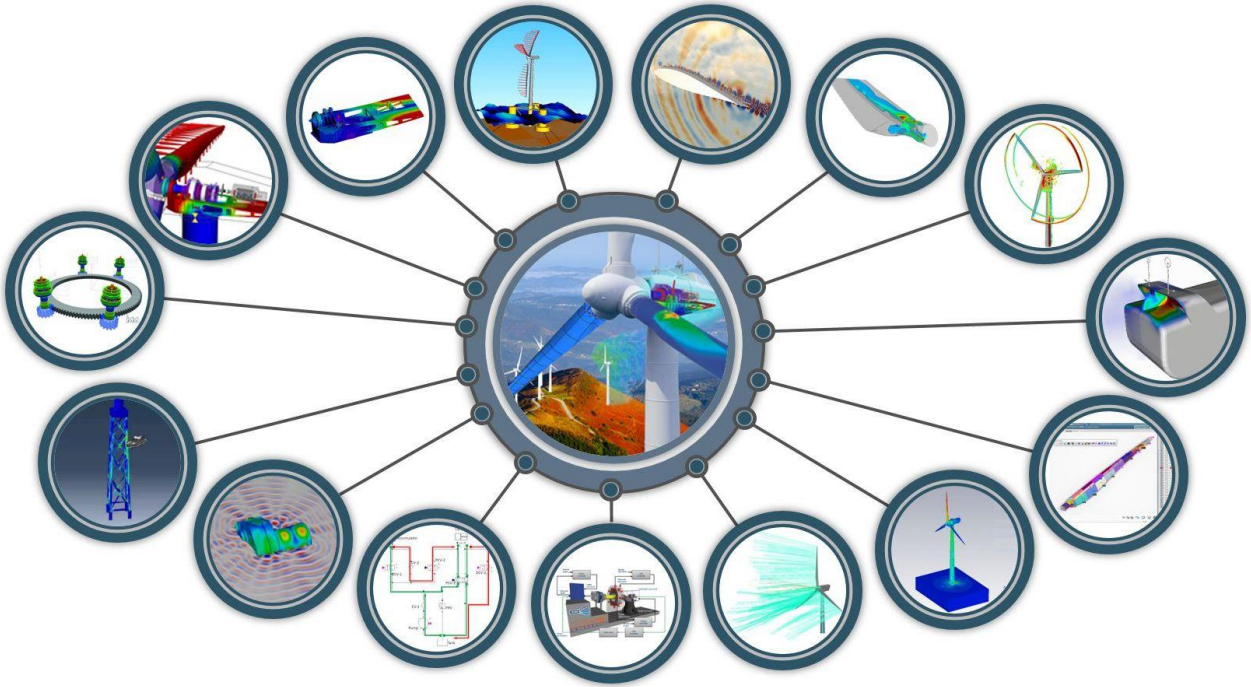
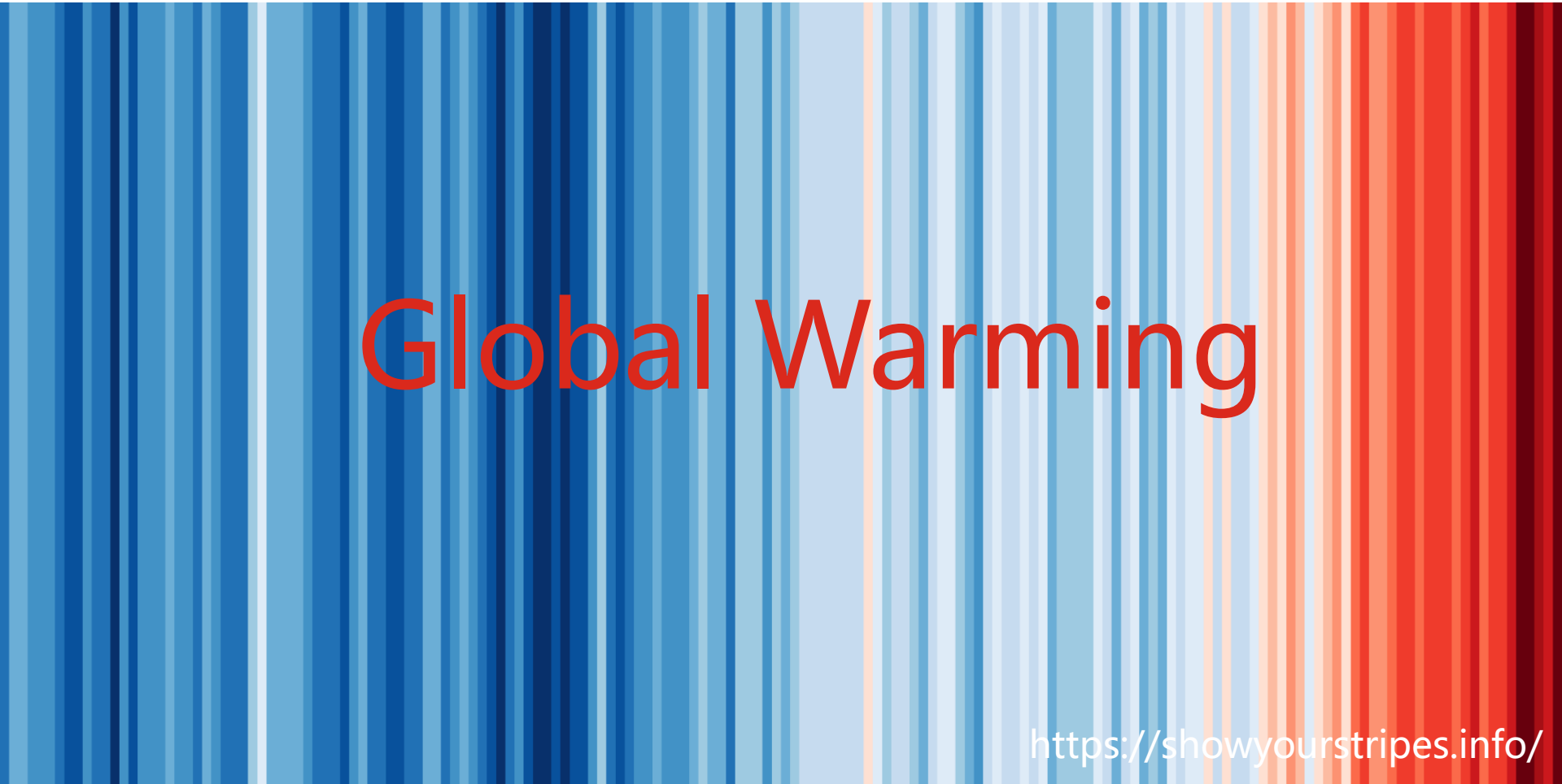
Wind Turbine Engineering



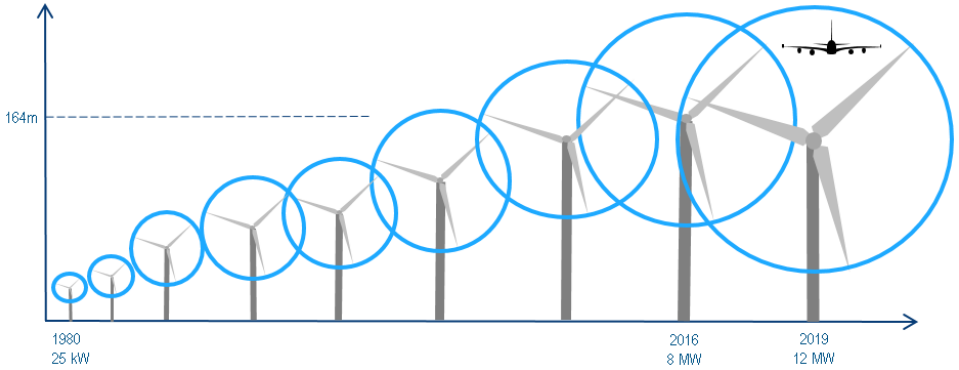
Steve MULSKI

Wouter VAN DER VELDEN

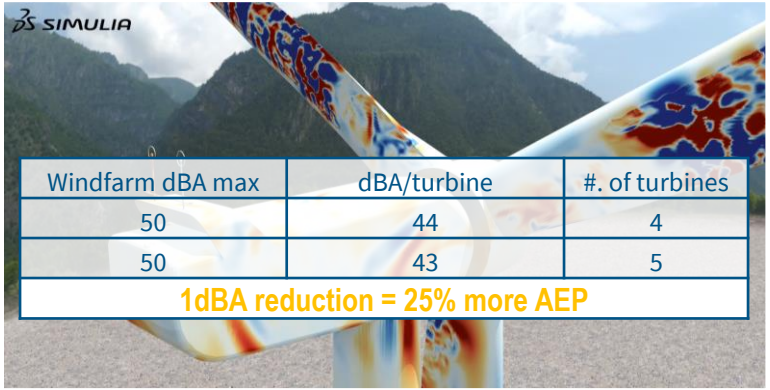

Global Warming
https://showyourstripes.info/

Wind Turbine Engineering | **Industry Tends**

Increasing Turbine Size

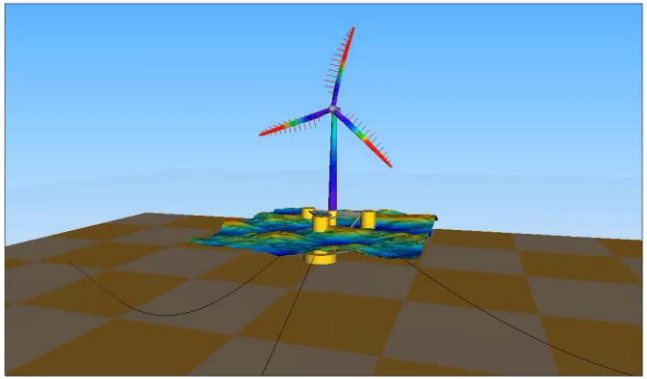


Noise

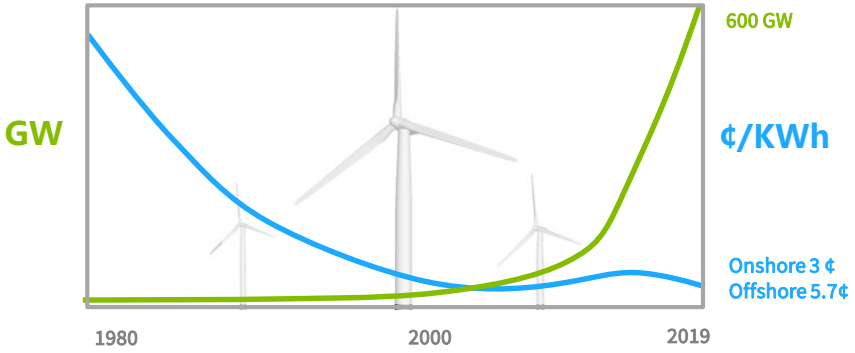


Windfarm dBA max	dBA/turbine	#. of turbines
50	44	4
50	43	5
1dBA reduction = 25% more AEP		

Offshore



Decreasing Margins, Increasing Capacity



Wind Turbine Engineering | **Challenges**

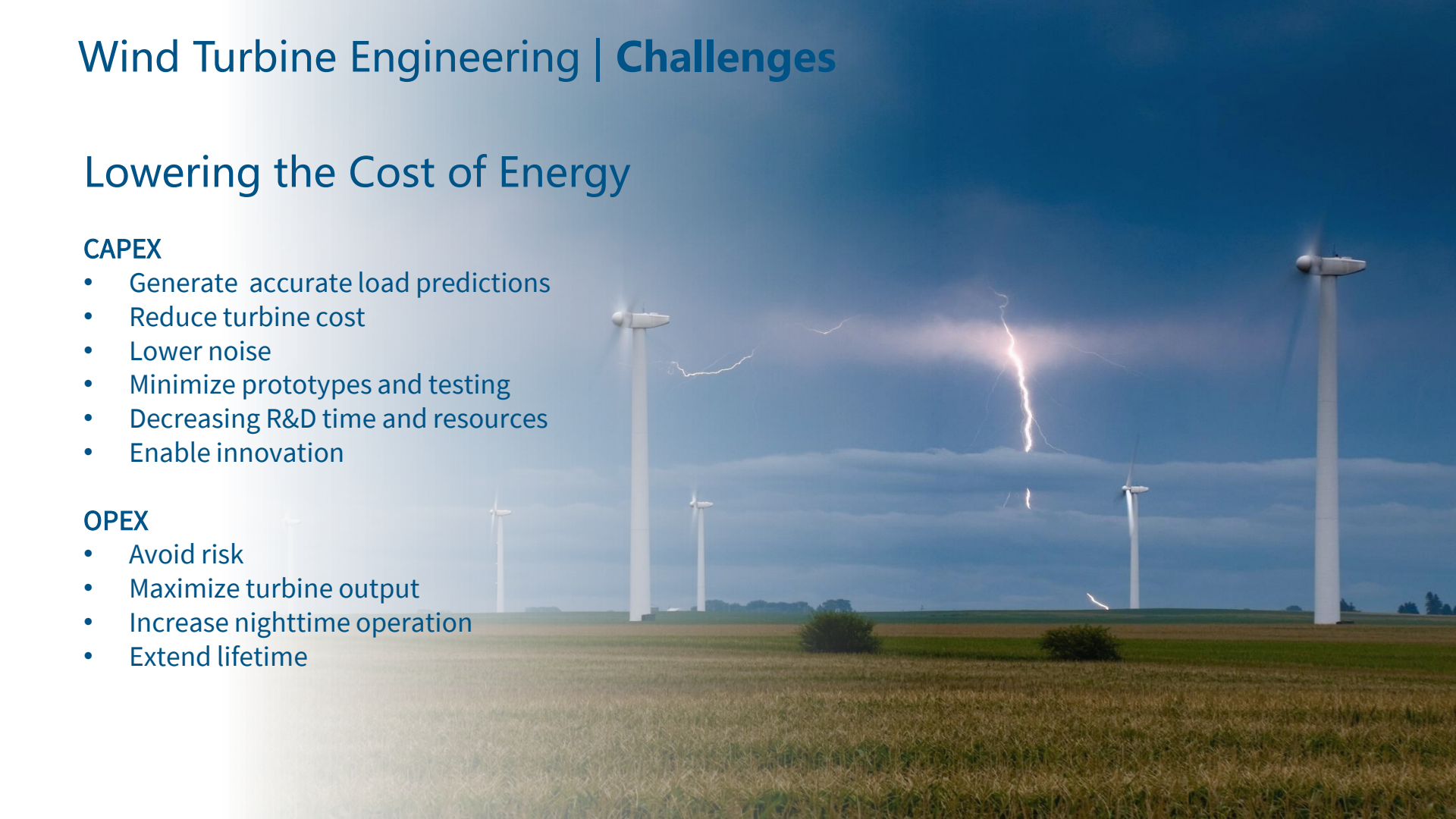
Lowering the Cost of Energy

CAPEX

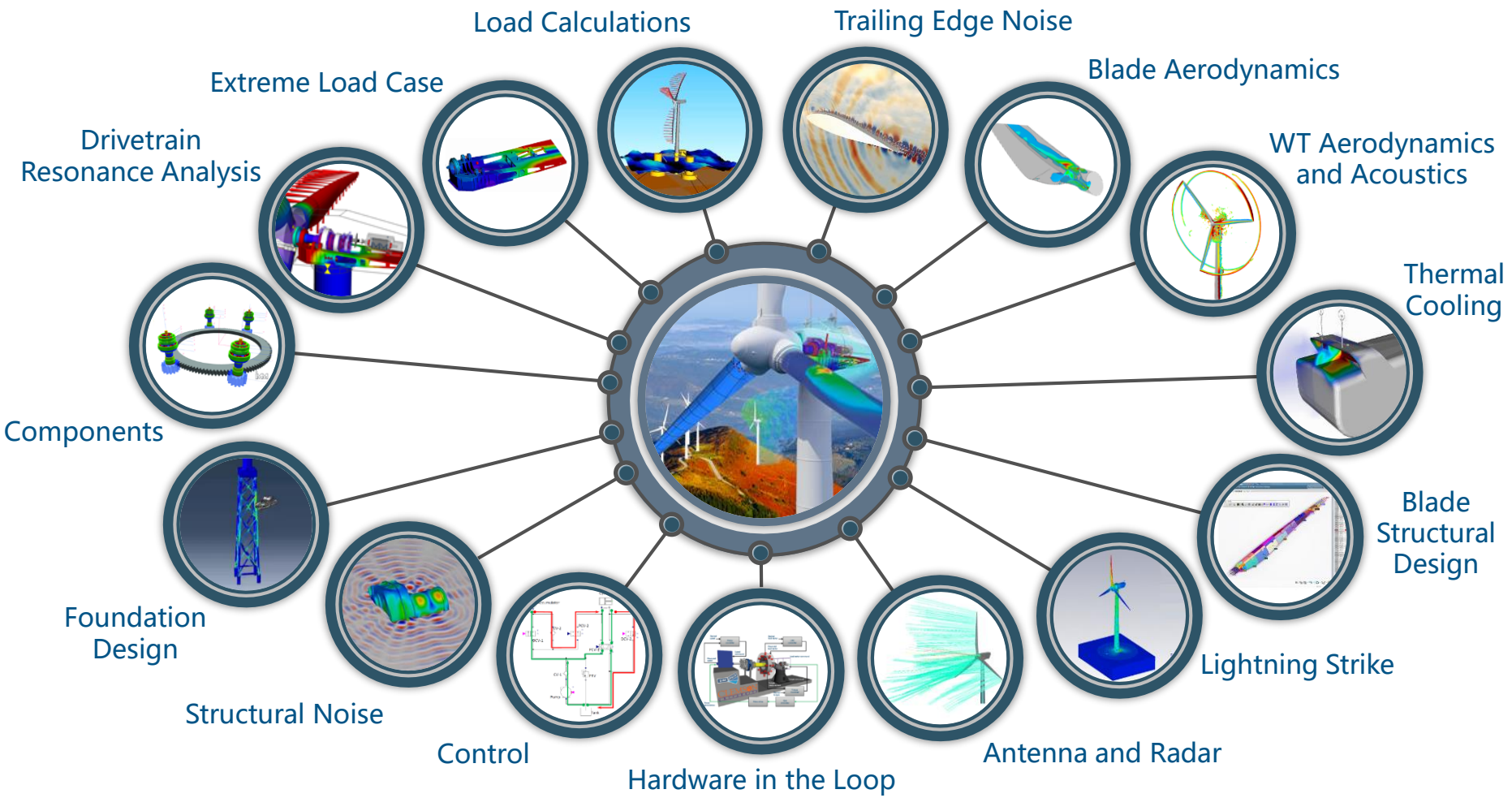
- Generate accurate load predictions
- Reduce turbine cost
- Lower noise
- Minimize prototypes and testing
- Decreasing R&D time and resources
- Enable innovation

OPEX

- Avoid risk
- Maximize turbine output
- Increase nighttime operation
- Extend lifetime



Wind Turbine Engineering


Load Calculations
Trailing Edge Noise
Extreme Load Case
Blade Aerodynamics
Drivetrain
Resonance Analysis
WT Aerodynamics
and Acoustics
Thermal
Cooling
Components
Blade
Structural
Design
Foundation
Design
Lightning Strike
Structural Noise
Control
Hardware in the Loop
Antenna and Radar

Wind Turbine Engineering | **Benefits**

- Cost Savings
- Optimize Products
- Power Increase
- Avoid Risk
- First-to-Market

Wind Turbine Engineering | **Cost Savings**

With accurate high fidelity modelling, significant cost savings can be achieved

CAPEX reduction using MBS simulation for a single multi-megawatt turbine:

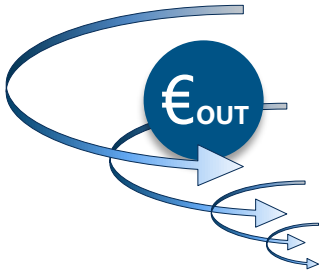
Accurate simulation enables a CYCLE of:

→ decreased loads

→ reduced mass

→ lower dimensions

= **Downward Spiraling Costs**



Component	Cost Reduction
Tower	12%
Rotor	10%
Nacelle	13%
Drivetrain	9%

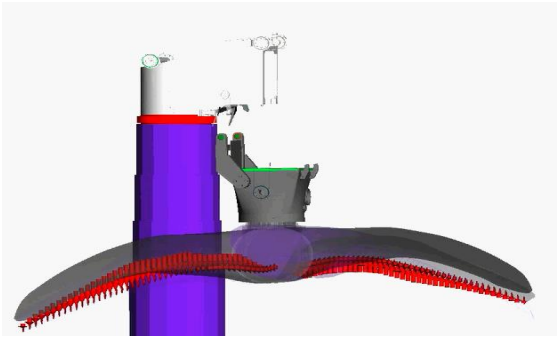
Savings = 340 k€ / turbine

Based on a 5MW Turbine

Wind Turbine Engineering | **Cost Savings**

Substantial cost savings can also be achieved through innovation

Courtesy SkyWind



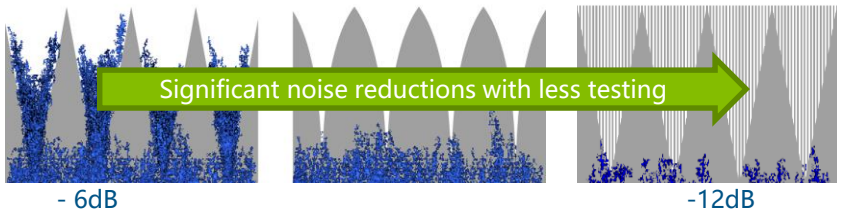
- Ability to simulate all aspects of all designs, in any level of fidelity
- Anything that can be imagined can be simulated.

Over 50x reduction in hoisting costs

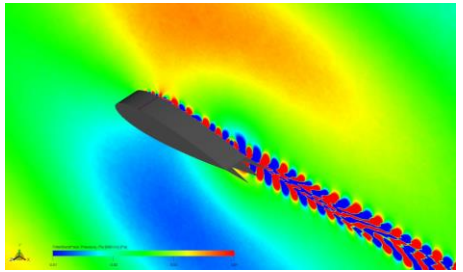
Wind Turbine Engineering | **Optimize Products**

Achieving early design benefits with Lattice Boltzmann CFD

Wind Tunnel Campaign	Simulation Campaign
Poor repeatability	100% repeatable
Limited data and insight	Understanding of physics
Only 2-4 add-ons / test	10x more design iterations



- Aeroacoustics: transient and realistic flow
- Short turnaround time (10x faster than competition & automated volume meshing)
- Extensive user and validation base for noise-suppression add-ons



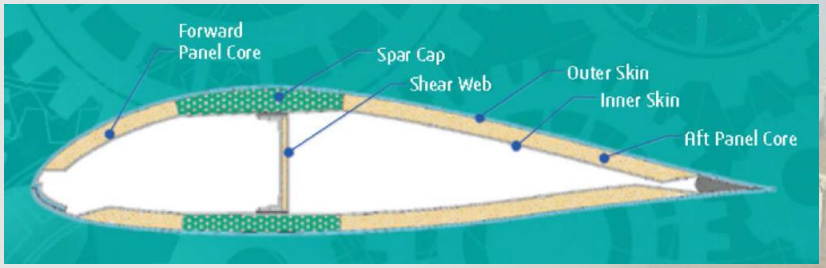
DASSAULT SYSTEMES

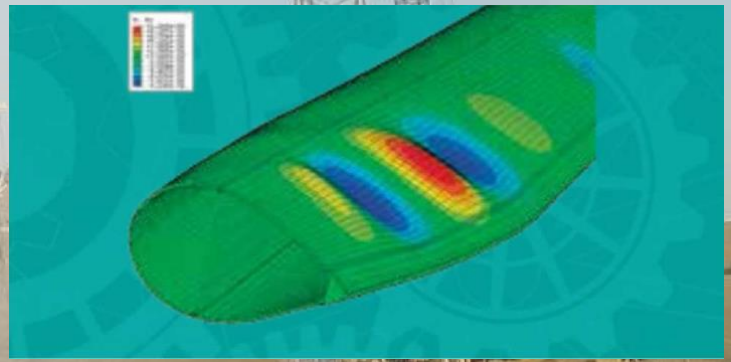
Wind Turbine Engineering | **Power Increase**

High fidelity FE analysis enables innovative wind turbine blade design with significant savings and energy gains

Investigate composite properties
Automate workflows
Compare variants within design space
Shorter development time
Reduced testing

12 percent power increase

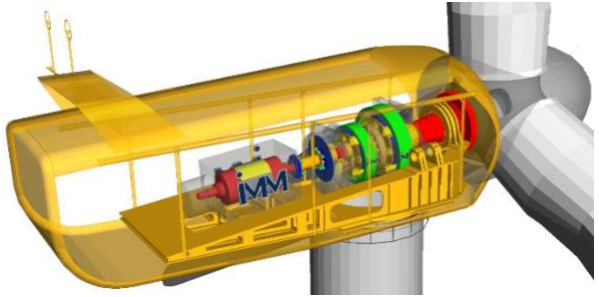


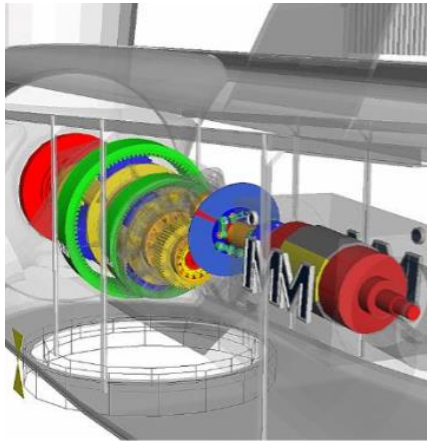


Courtesy NSE Composites, https://www.3ds.com/fileadmin/PRODUCTS/SIMULIA/PDF/case-study/simulia-nse-comp.pdf

Wind Turbine Engineering | **Avoid Risk**

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

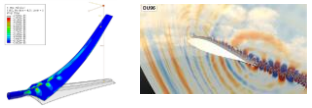
Courtesy IMM TU Dresden

Higher fidelity = risk reduction, optimization and cost savings

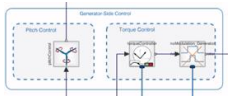
DASSAULT SYSTEMES

Wind Turbine Engineering | **Avoid Risk**

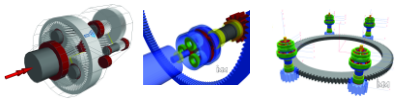
Concurrent Engineering



Blades & Aerodynamics

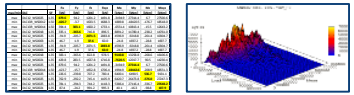


Control



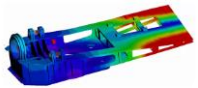
Components

- gearbox,
- pitch system,
- yaw system,
- ….



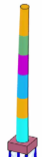
Load Calculations

Certification



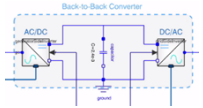
Structural parts

- hub,
- bedplate,
- ….



Tower

Foundation

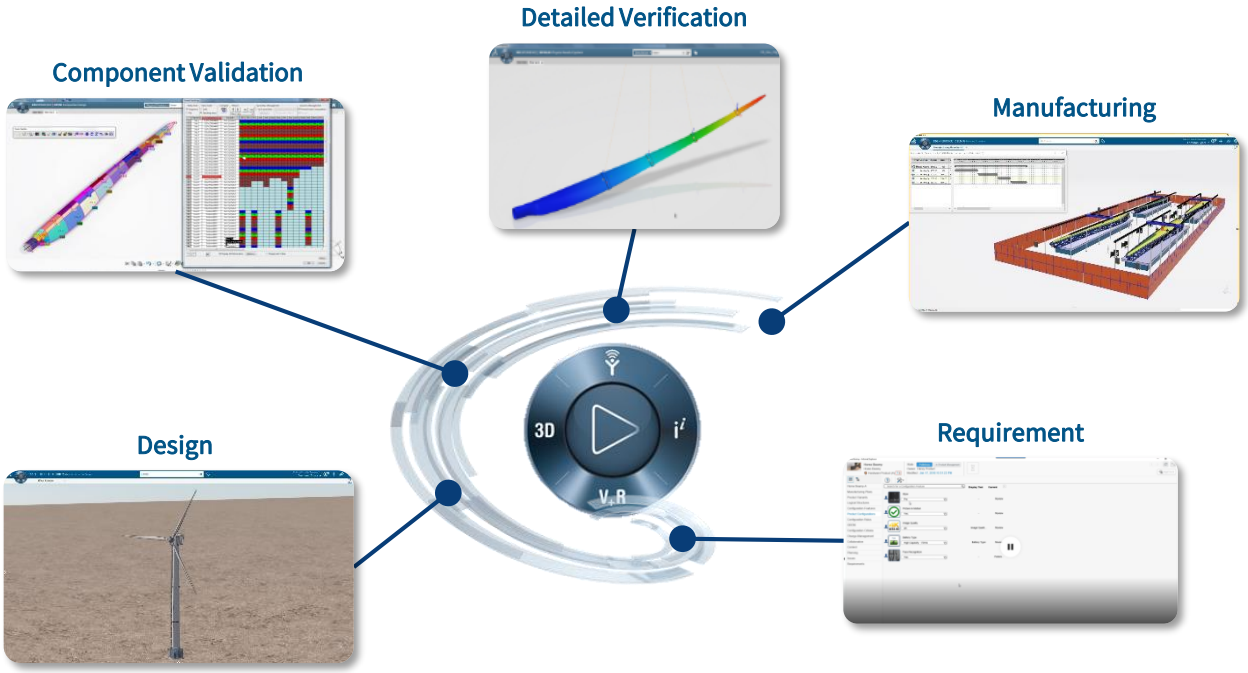


Electrical System

Wind Turbine Engineering | **Avoid Risk**

3DEXPERIENCE **Platform** - The Digital Thread

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

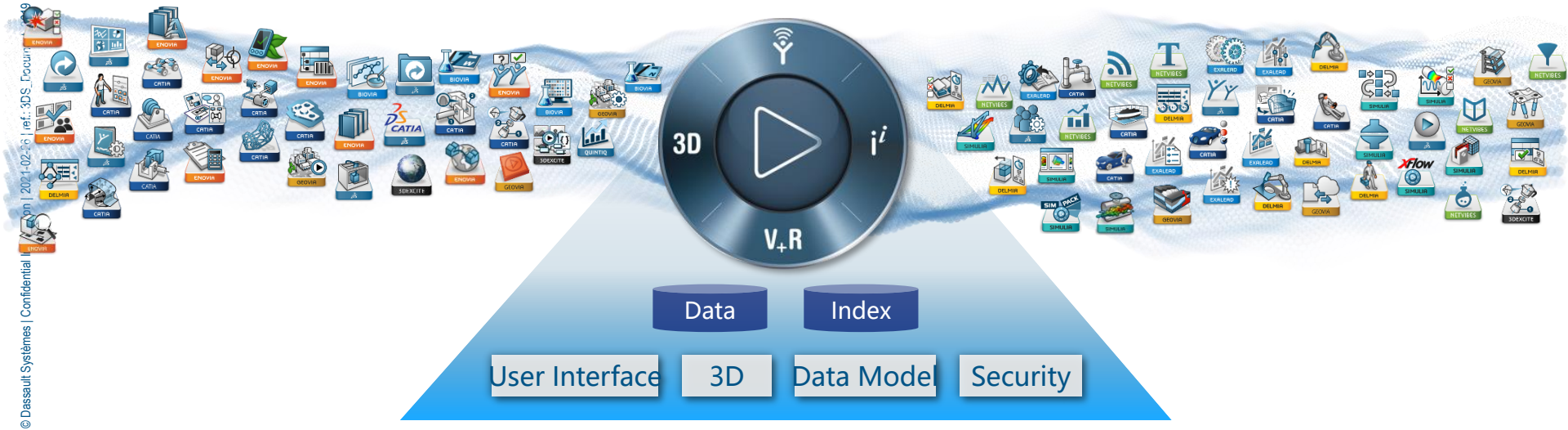


- Single Source of Truth
- Traceability
- Versioning
- Collaboration
- Configuration
- Automated Workflows

DASSAULT SYSTEMES

Wind Turbine Engineering | **First-to-Market**

Eliminate silos with the **3D**EXPERIENCE **Platform**



Improve productivity

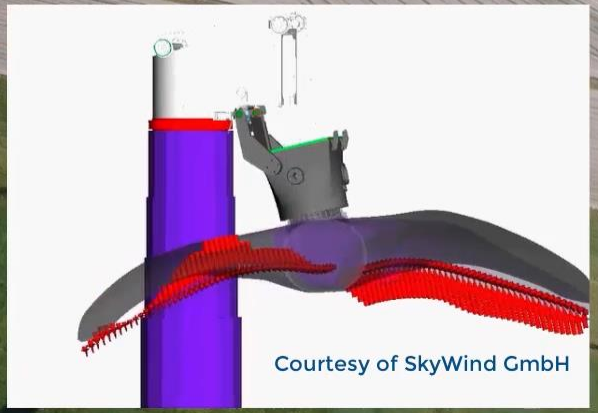
LIVE

On Premise On Cloud

DASSAULT SYSTEMES

3D V.R 3DEXPERIENCE

INNOVATE



Wind Turbine Engineering | **Workflows**

Load Calculations

Extreme Load Case

Drivetrain
Resonance Analysis

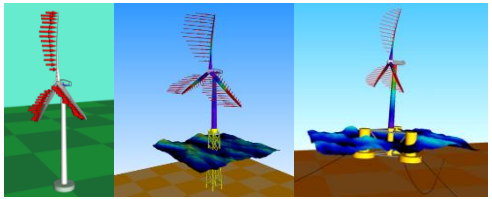
Wind Turbine Engineering | **Load Calculations**

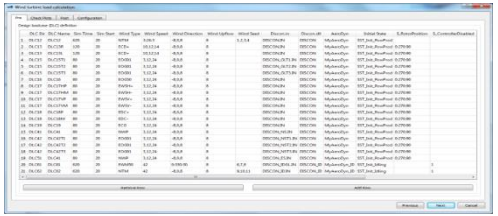
Solver Technology
- Fast, accurate and robust

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

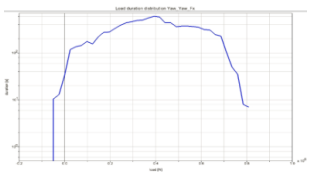
Automation
- Template Scripts for all Design Load Cases
- Result and report generation

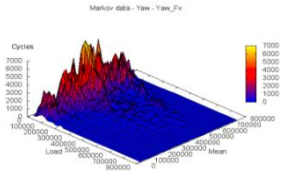
Integration
- Easy integration into existing workflows
- Reading and writing of any data format type





		Fx	Fy	Fz	Fxyz	Mx	My	Mz	Mxyz
max/min	DLC	SF	[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]
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**	-1.7	1610.5	1688.3	1889.8	-18420.5	-176.7	18518.0
max	DLC13R_WS0014	1.50	594.4	**303.1**	1660.2	1710.1	-6551.4	10813.4	-15.5	12649.2
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**	2081.6	4596.9	-9218.8	-261.4	10304.7
min	DLC12_WS0031	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	**2081.6**	4596.9	-9218.8	-261.4	10304.7
min	DLC12_WS0031	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	**9048.8**	13258.8	-268.6	16106.6
min	DLC12_WS0021	1.35	429.8	283.5	1617.8	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**	-206.9	18551.3
max	DLC12_WS0025	1.35	226.6	-230.8	707.2	780.4	6400.1	6400.5	**536.7**	9133.1
min	DLC12_WS0025	1.35	762.9	-292.2	745.4	1105.9	6420.7	26473.8	**-676.0**	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	-88.8	**107.9**





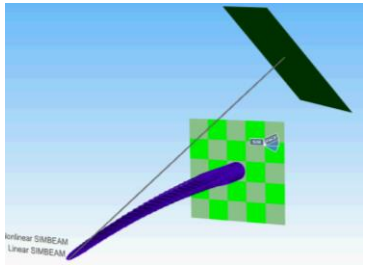
On Premise On Cloud

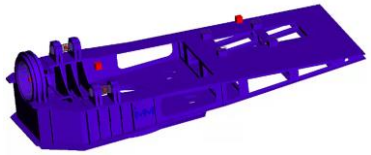
DASSAULT SYSTEMES

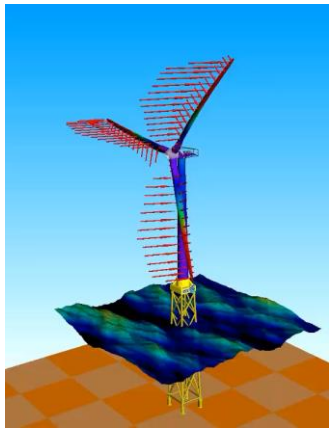
Wind Turbine Engineering | **Extreme Load Case**

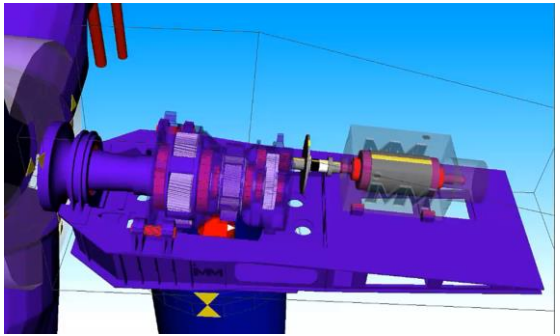
Simulations of extreme loads must often consider additional effects in order to achieve accurate results

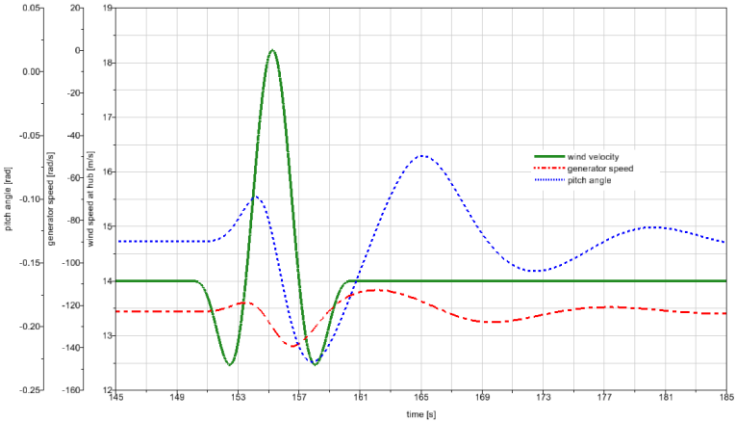
- Non-linear blade deformation
- Flexibility of major components











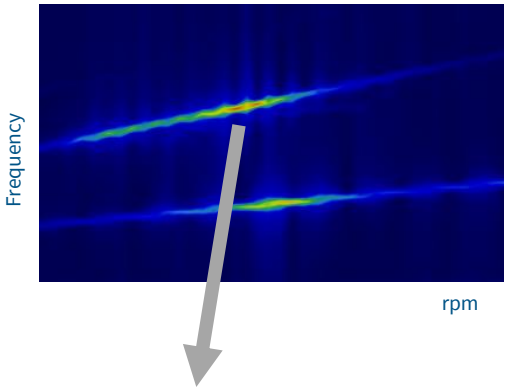
Wind Turbine Engineering | **Drivetrain Resonance Analysis**

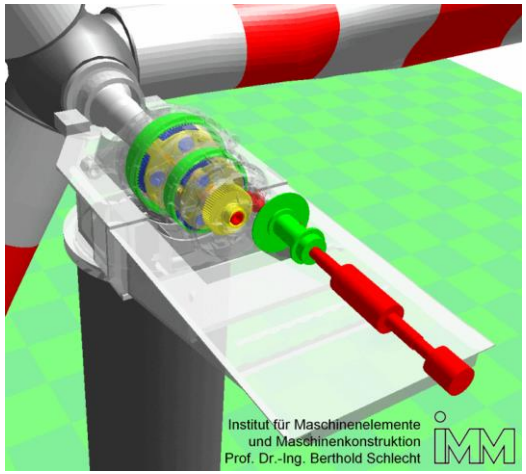
Critical Resonances.

- Identification, comprehension, elimination

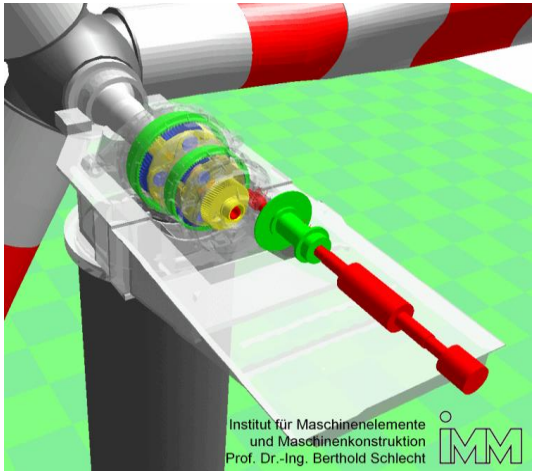
Automated

- run-up, resonance detection, result generation

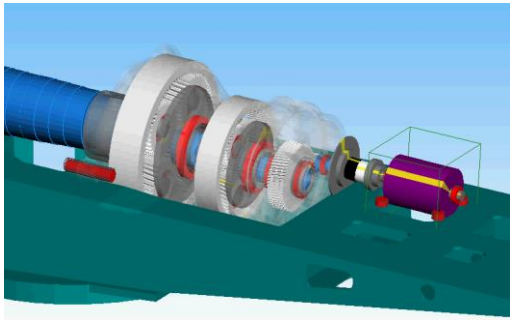




Natural frequency 23 Hz

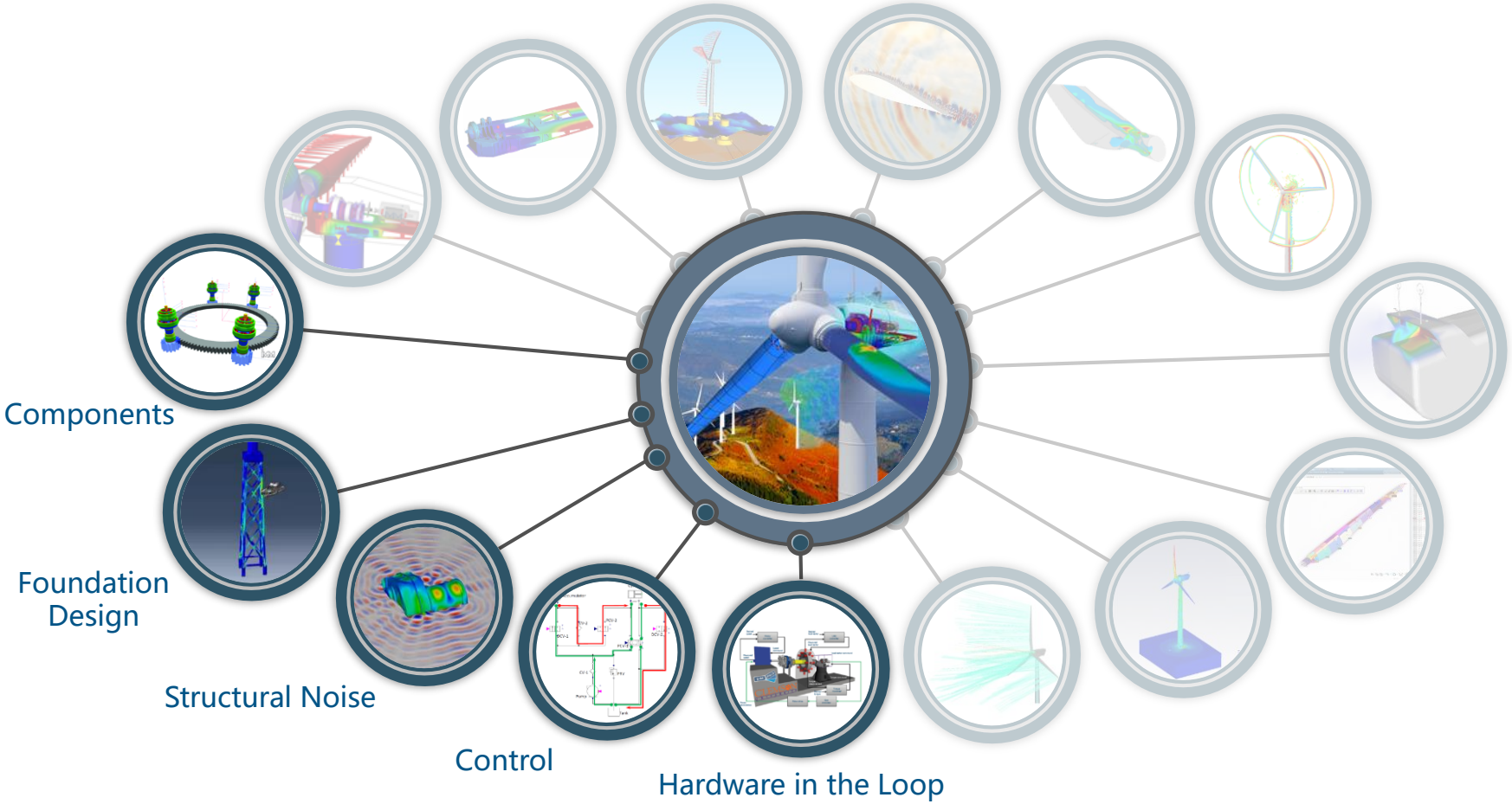


Natural frequency 127 Hz



Operating Deflection Shape

Wind Turbine Engineering | **IPE Workflows**

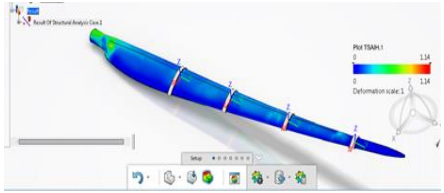


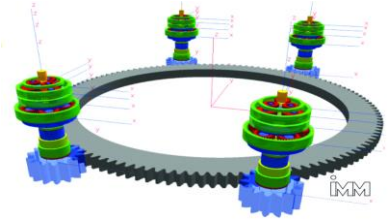
Wind Turbine Engineering | **Component Optimization**

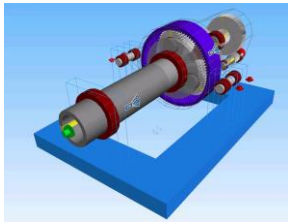
Analysis and optimization of all mechanical components

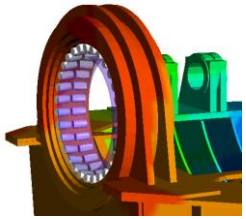
Holistic component simulation

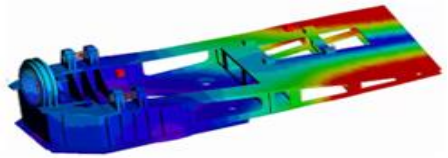
- Standalone for plausibility checks
- within test-rig for component validation
- within complete turbine for correct loads

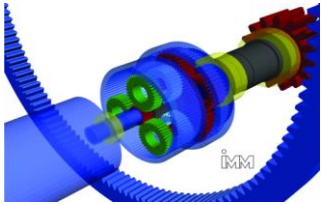


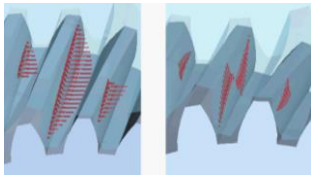


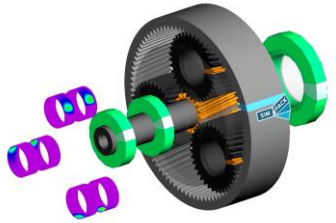










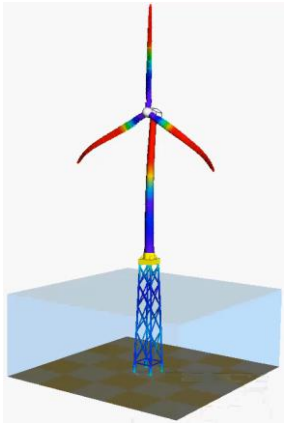


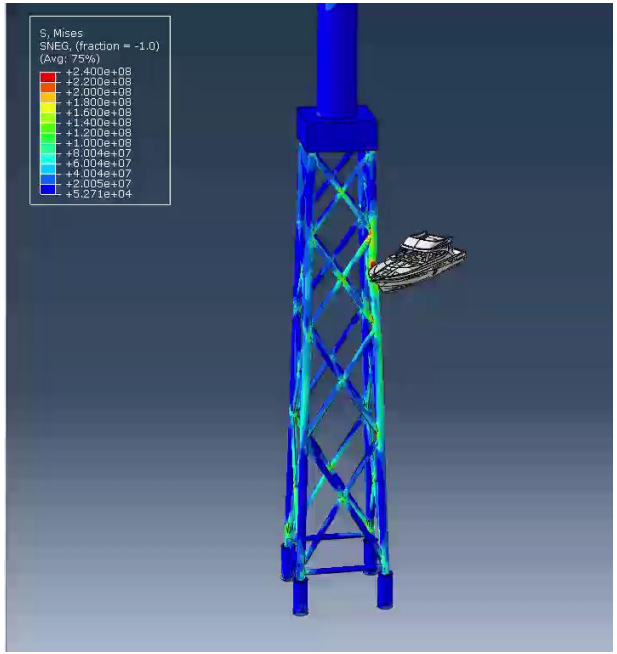
DASSAULT SYSTEMES

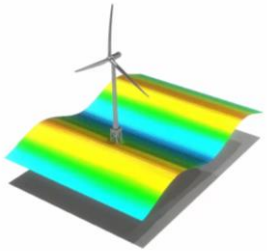
Wind Turbine Engineering | **Foundation Design**

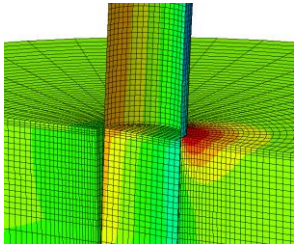
Design, investigation, optimization, and risk reduction

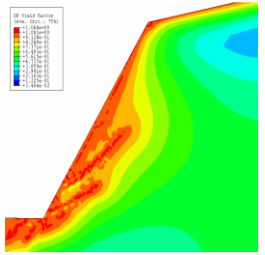
- Complete system optimization
- Damage and failure analysis
- Extreme waves
- Soil interaction
- Bolt connections

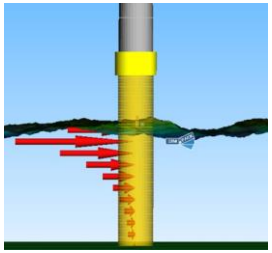


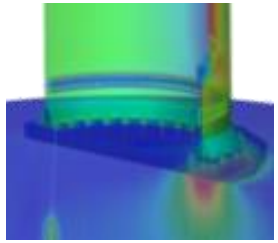












Courtesy DNV

DASSAULT SYSTEMES

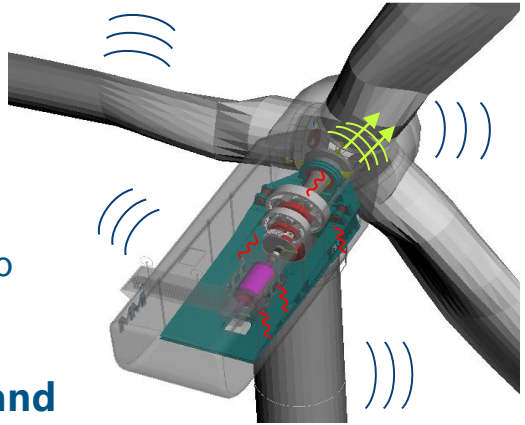
Wind Turbine Engineering | **Structural Noise**

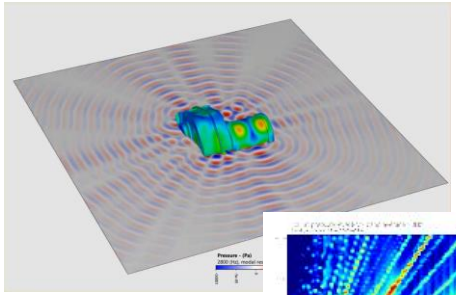
Noise reduction is a primary design driver

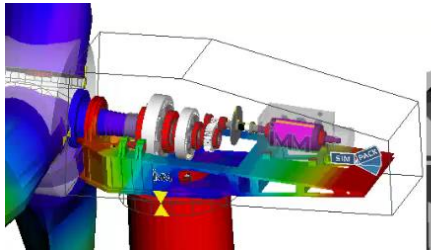
Noise vibration sources
- Gear wheel meshing
- Pumps
- Motors

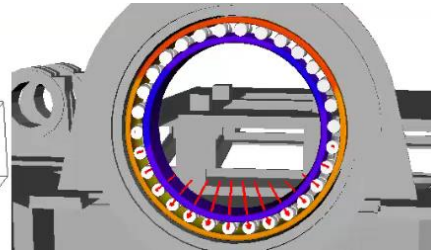
From the source the vibration is transferred to emitting surfaces.

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





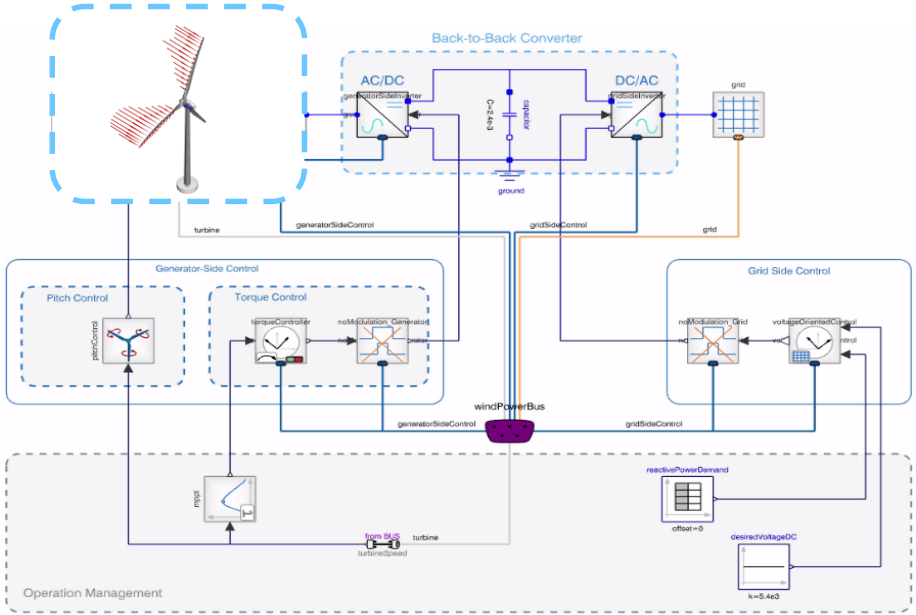


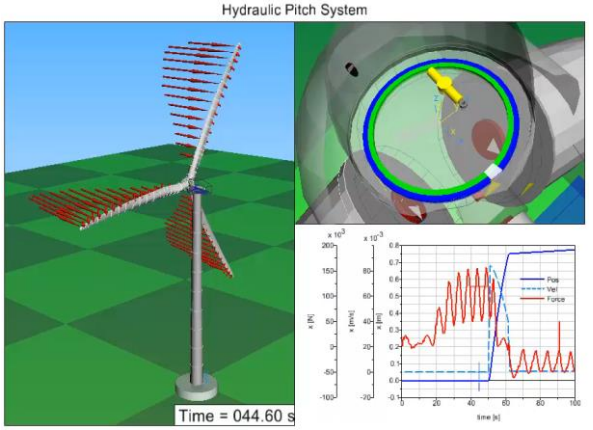


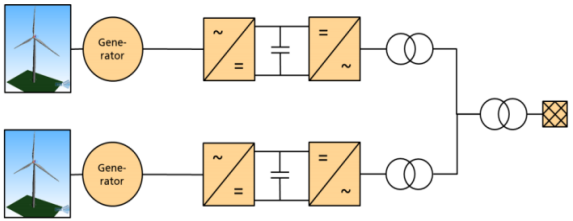
DASSAULT SYSTEMES

Wind Turbine Engineering | **Control**

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





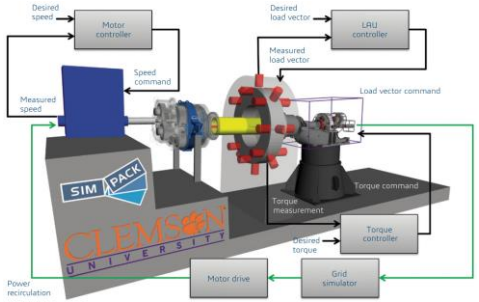


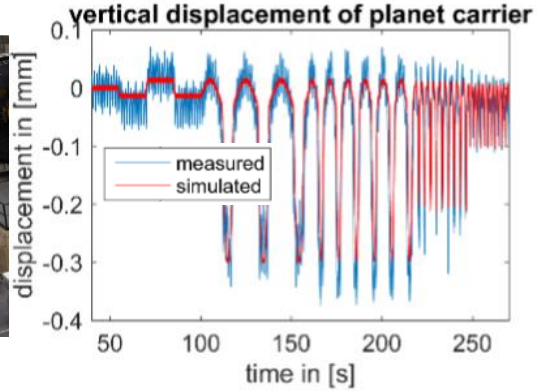
Courtesy MESH Engineering

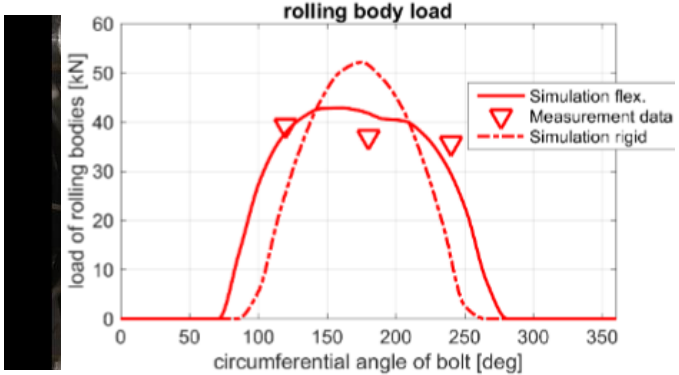
Wind Turbine Engineering | **Hardware in the Loop**

Coupling of virtual and real world for optimal test campaigns.

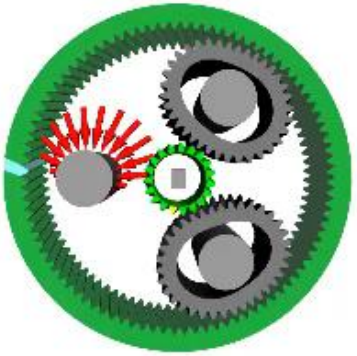
Real-time capable MBS, including flexible bodies and high fidelity components is required for realistic conditions.





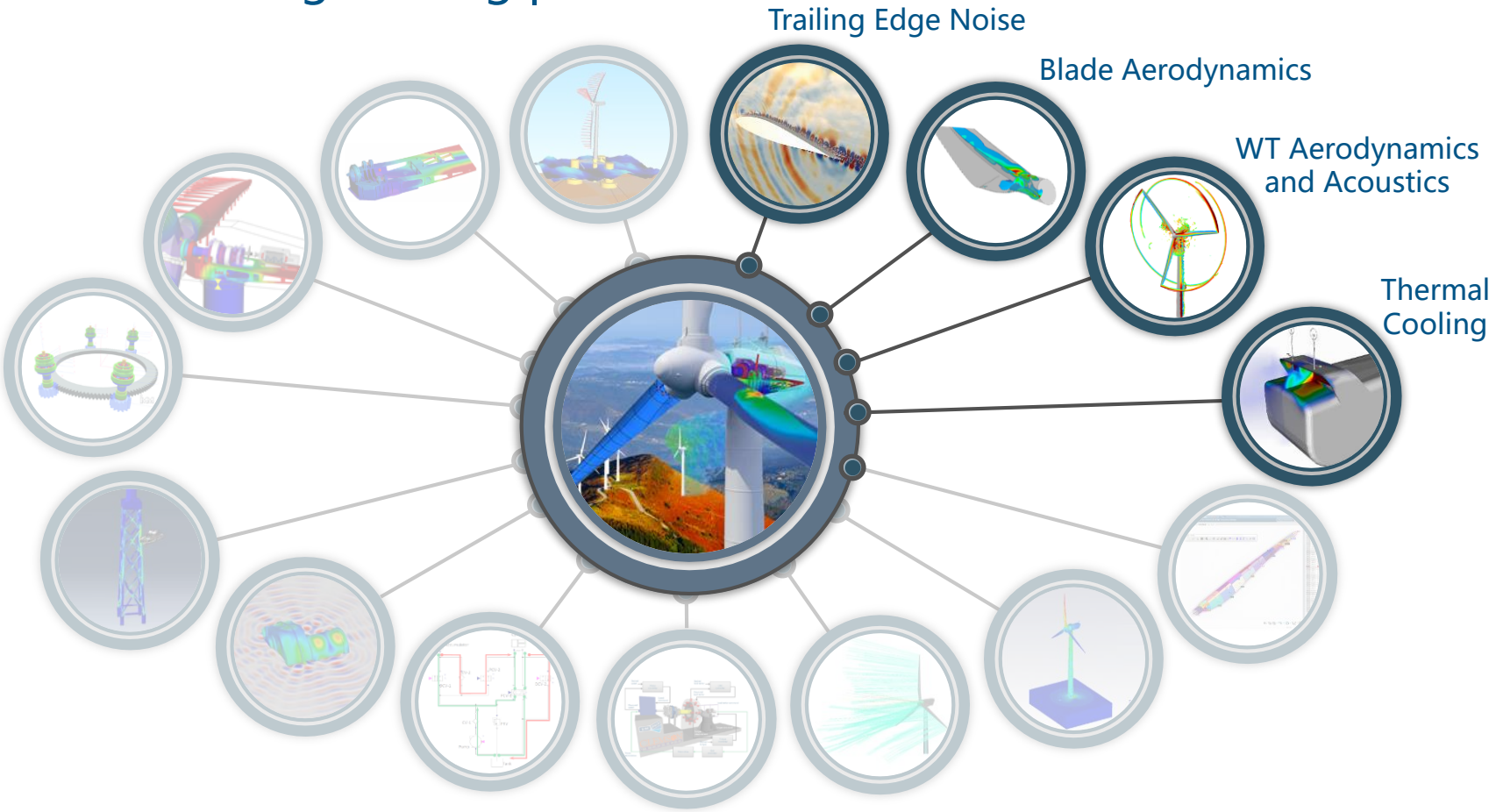


Courtesy CWD RWTH Aachen



DASSAULT SYSTEMES

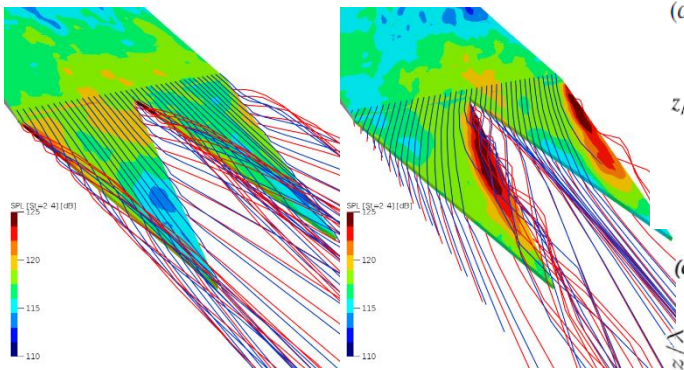
Wind turbine Engineering | **Workflows**

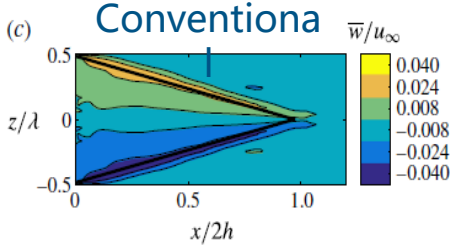


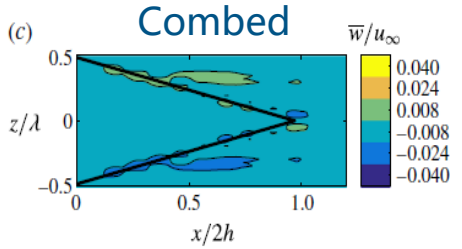
Wind Turbine Engineering | **Trailing Edge Noise**

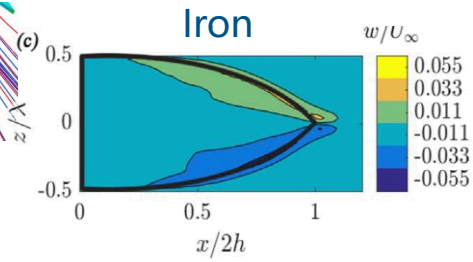
Estimate noise levels from small wind turbine blade sections while designing and optimizing noise suppression add-ons

- Design of Experiments
- Simulate real-life conditions
- Fully automated on SIMULIA Cloud







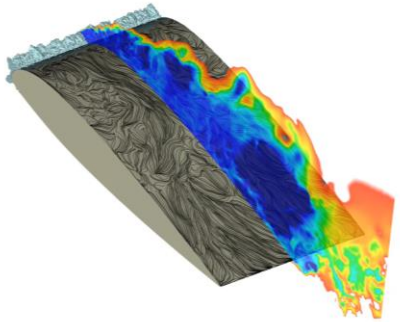


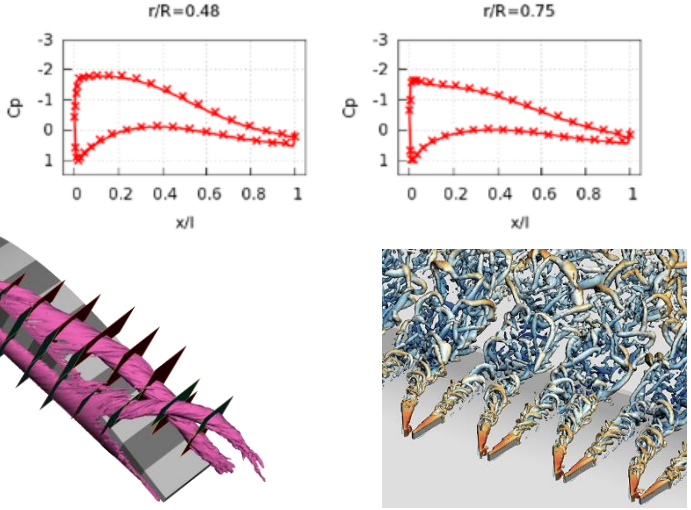
DASSAULT SYSTEMES

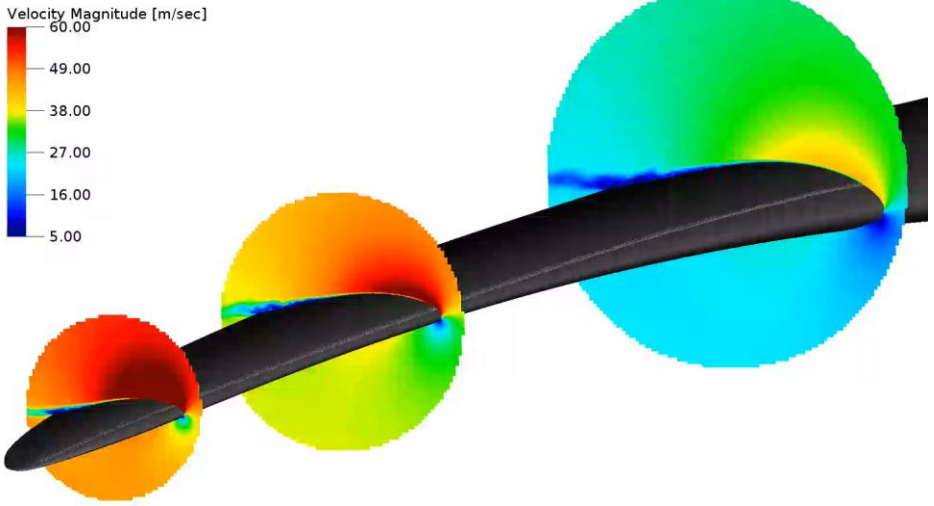
Wind Turbine Engineering | **Blade Aerodynamics**

Estimate the aerodynamic and acoustic performance of a full wind turbine blade and tip including rotational and induction effects

- Broad flow regime with complex flow behaviour
- Complex geometry modelled without any simplification



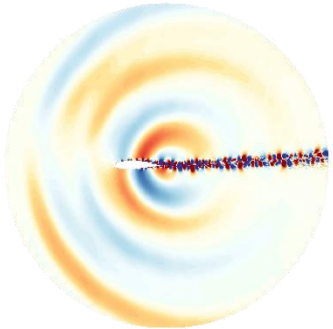


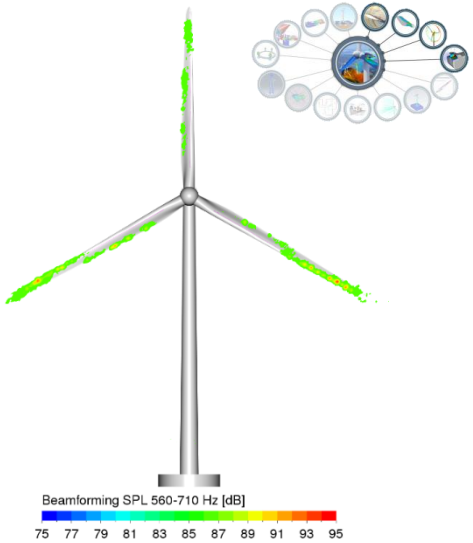


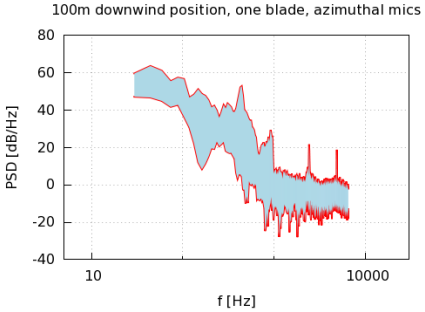
Wind Turbine Engineering | **Aero and Acoustics**

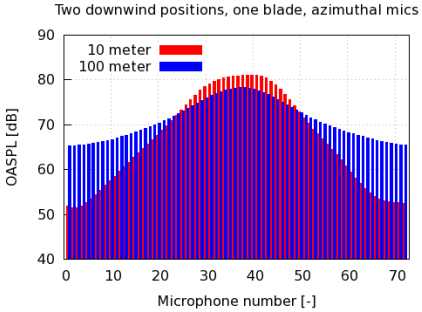
Estimate the complete assessment on full wind turbine system level for aerodynamic and aeroacoustic performances

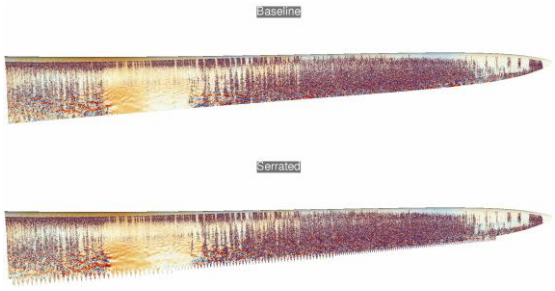
- Real life effects
- System level noise prediction









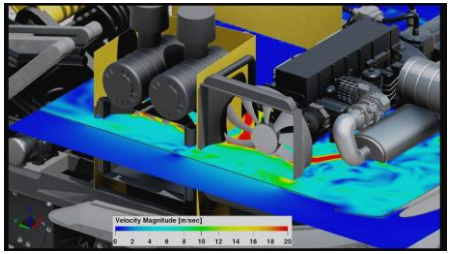


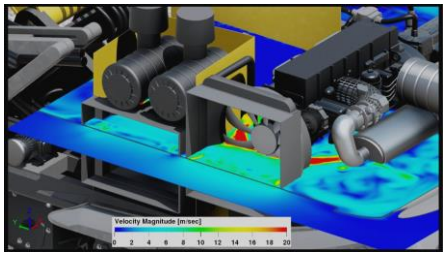
DASSAULT SYSTEMES

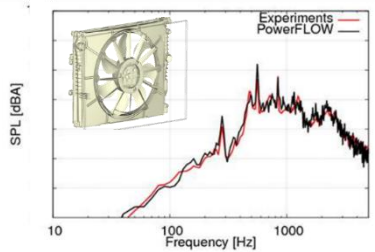
Wind Turbine Engineering | **Thermal Cooling**

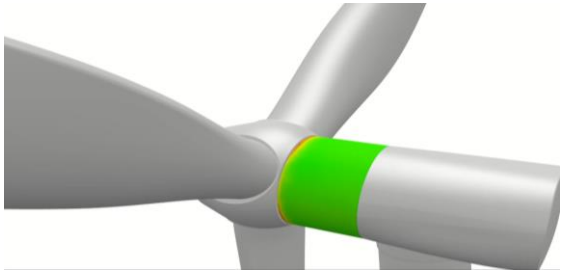
Estimate the aero, thermal and acoustic performance of all thermal components inside and outside a wind turbine

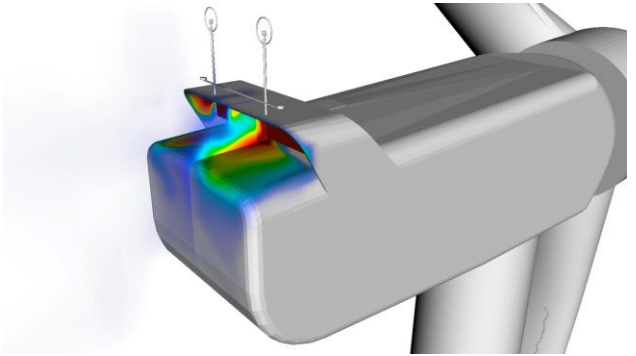
- Easy handling complex geometries
- Understanding of radiation, conduction and convection process by high-fidelity CFD/thermal coupling process

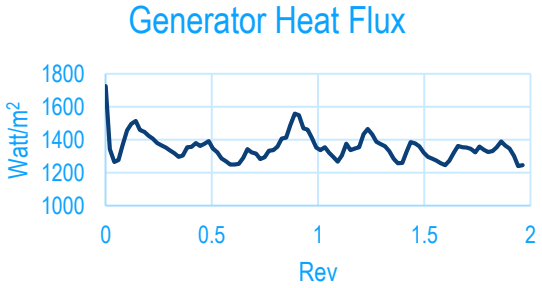




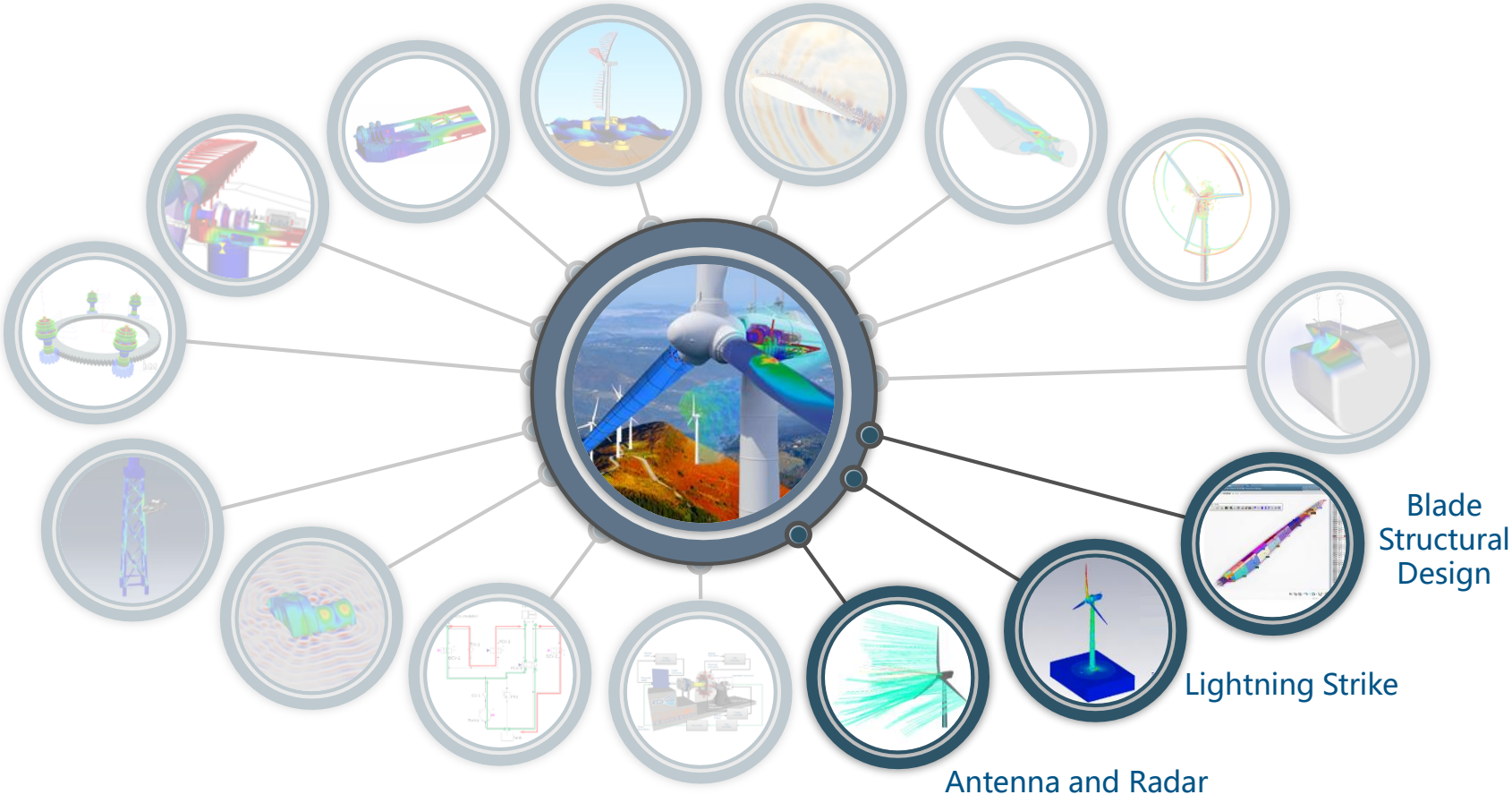








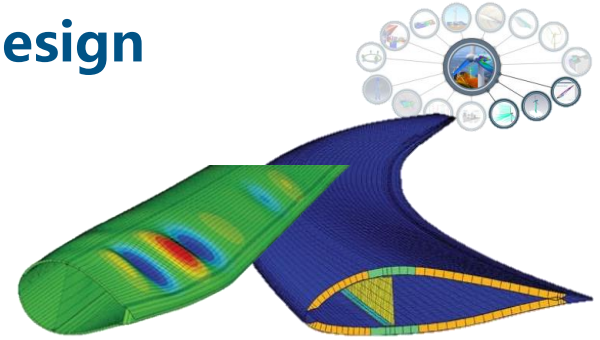
Wind Turbine Engineering | **Workflows**



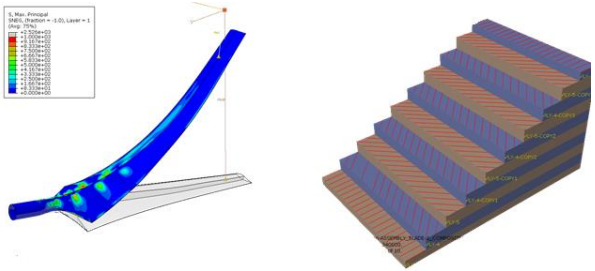
Wind Turbine Engineering | **Blade Structural Design**

Streamline the complete process for blade design and enable new and innovative designs while minimizing time-to-market and risk.

- Load Calculations
- Composite Concept Design
  - Shear section properties analysis
  - Blade flexibility analysis (static and dynamic)
- Composite Detailed Design
  - Detailed plies design, incl. drop-off
  - Stress, buckling and fatigue
  - damage and failure analysis
- Optimization and preparation for manufacturing



Courtesy NSE Composites

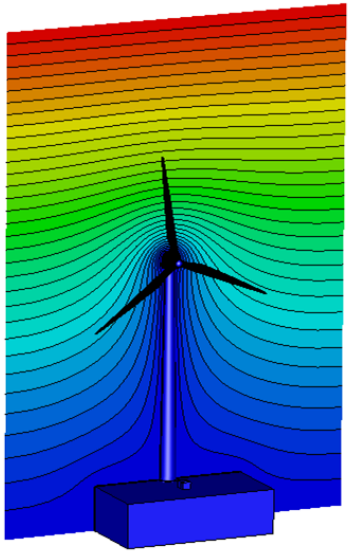


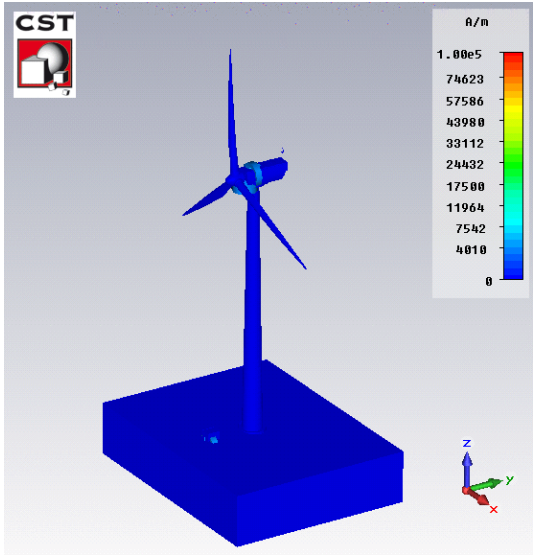
DASSAULT SYSTEMES

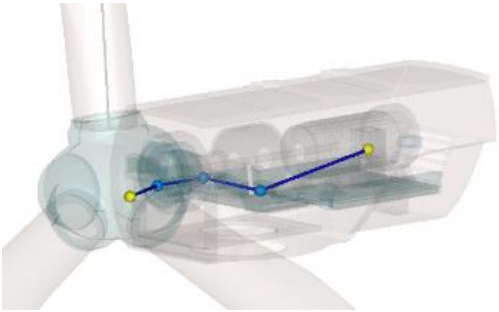
Wind Turbine Engineering | **Lightning Strike**

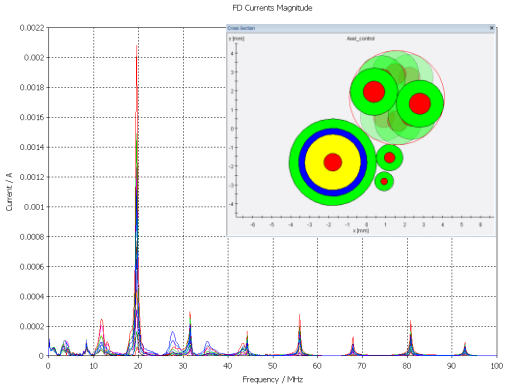
Ensure optimal lightning protection and avoid risk.

- Attachment area prediction
- Currents on wind turbine and in cabling





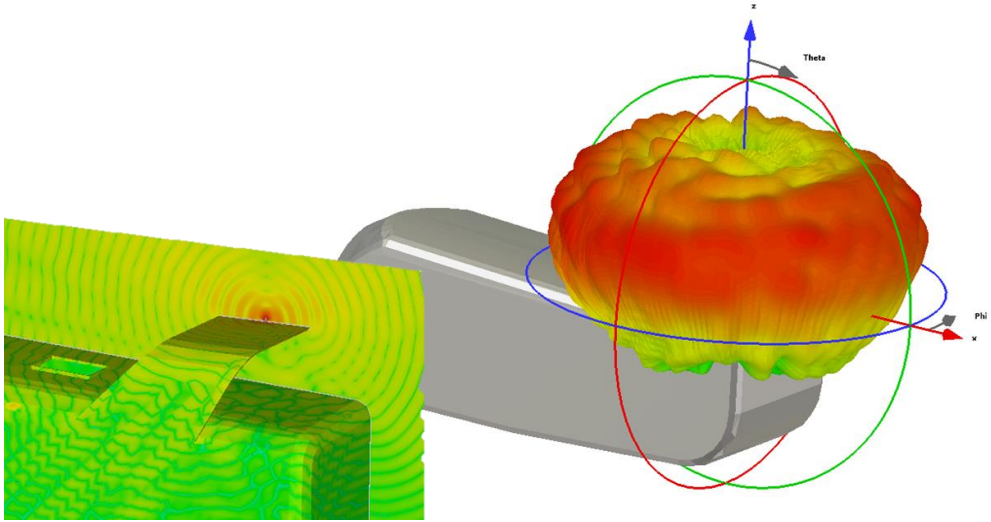


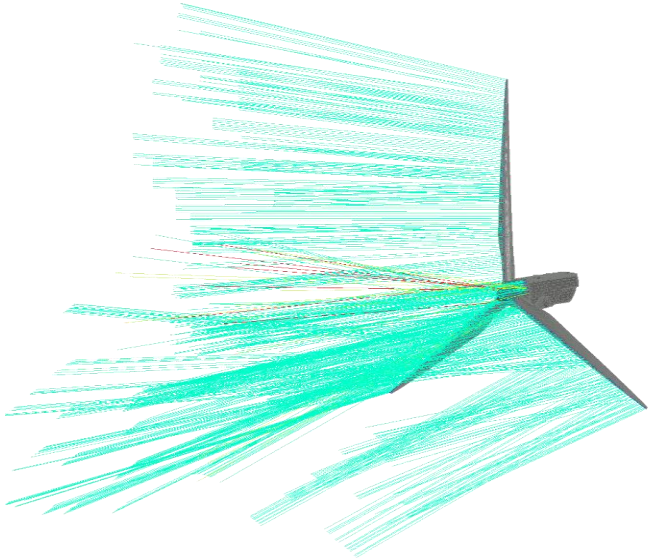


Wind Turbine Engineering | **Antenna and Radar**

Optimize antenna placement
- Ensure good communication in all relevant directions

Ensure regulations for local air traffic control are met
- Reflections from moving rotors can interfere with radar systems

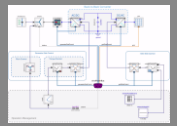




Wind Turbine Engineering | **Simpack Workflow**

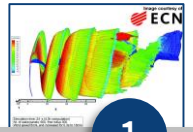
Load Calculations Model

Inputs



Select Load Case

- Wind field
- Operation mode



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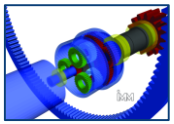
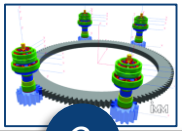
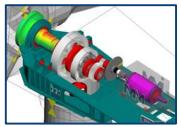
Select Component

- High fidelity component to be investigated
- Integrate within model

2

Run Scenarios

$\int \dot{x} dt$

Time integration

3

Managed Engineering Data

3DEXPERIENCE

Wind Turbine Design

Requirements

KPIs

Simulation Setup

Results

Workflows:
Load Calculation
Extreme Load Case
Components

4

Validate and Analyze Results

- Validate and analyze results for all scenarios

5

Create Alternatives

- Automatically or manually create alternatives for multi-discipline design exploration

6

Perform Trade-Off Study

- Perform trade-off study
- Select best candidate for each reference configuration

Outputs

KPI Status

Data value update proposal

Replicate

Wind Turbine Engineering | **PowerFLOW Workflow**

Inputs
- 3D CAD geometry of wind turbine (blade / section)
- Operating conditions
- High performance targets
- Low noise targets (regulations)

ENOVIA Requirements

Prepare geometry
- Assembly geometry (and noise suppression add-on)
- Prepare surface mesh

Prepare Component Setup
- Prepare simulation based on operating conditions
- Fully automated process from STL to PowerCASE

Run Component Simulation
- Follow automated processes and best-practice strategies
- Extract aerodynamic performance data/polars
- Far-field noise analysis

1 → 2 → 3

Managed Engineering Data

3DEXPERIENCE

Wind Turbine Design
Requirements
KPIs
Simulation Setup
Results

Workflows:
Trailing Edge Noise
Blade Aerodynamics
WT Aerodynamics and Aeroacoustics
Thermal Cooling

6 ← 5 ← 4

Outputs
- Higher performance wind turbines
- Quieter wind turbines
- Minimize Cost of Energy

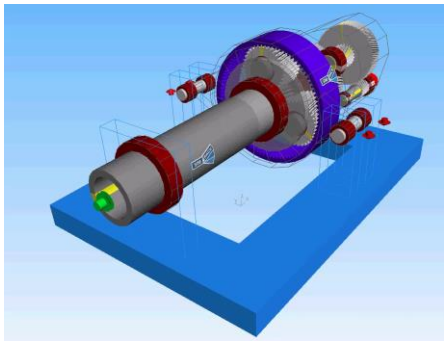
Documentation & Certification
- Use simulation result to compliment and support wind tunnel and field tests
- Optimize wind farms

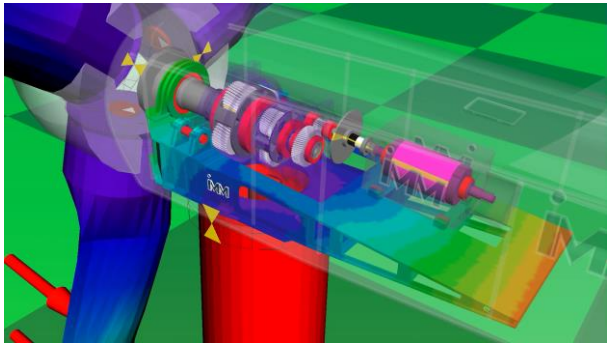
Prepare System Setup
- Full wind turbine system analysis
- Real life operating conditions
- Tailored to desired outcome

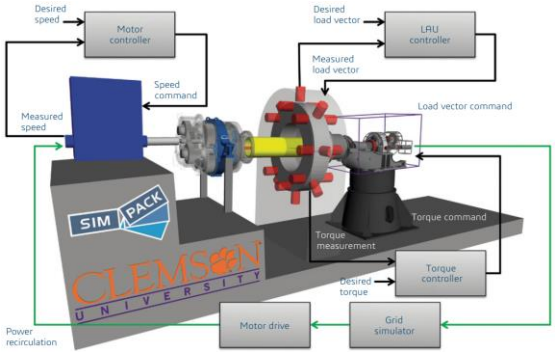
Verification & Geometry Modification
- Check KPIs, aerodynamic and noise targets
- Iterate noise-suppression concepts

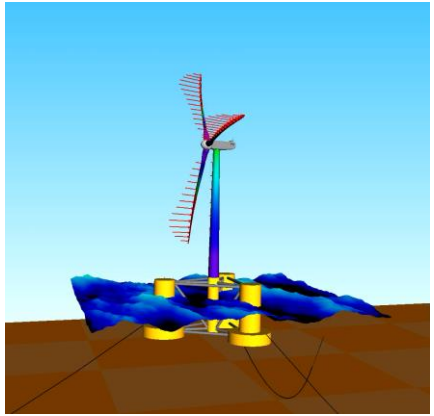
DASSAULT SYSTEMES

Wind turbine Engineering | **Summary**









DASSAULT SYSTEMES

Wind turbine Engineering | **Summary**

Dassault Systèmes, harmonizing product, nature and life.

- Sustainable Future
- Optimize Products
- Cost Savings
- Avoid Risk
- First-to-Market

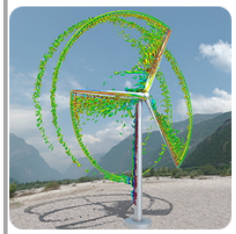
Wind turbine Engineering | **On Demand E-Seminars**

For more technical information please watch these E-seminars which can be found on **www.3DS.com**:

E-SEMINAR

ON DEMAND

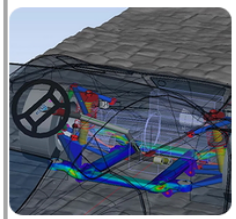
Wind Turbine Dynamics



E-SEMINAR

ON DEMAND

Wind Turbine Aerodynamics and Acoustics



E-SEMINAR

ON DEMAND

Structural, Multibody and Durability Simulation

DASSAULT SYSTEMES

DASSAULT SYSTEMES