Strength and Endurance Predictions of Drivetrains and Rotor Blades using **Abaqus**

Jean-Daniel Lecuyer
SIMULIA Senior Portfolio
Technical Specialist
3DS Paris Campus

3DEXPERIENCE®

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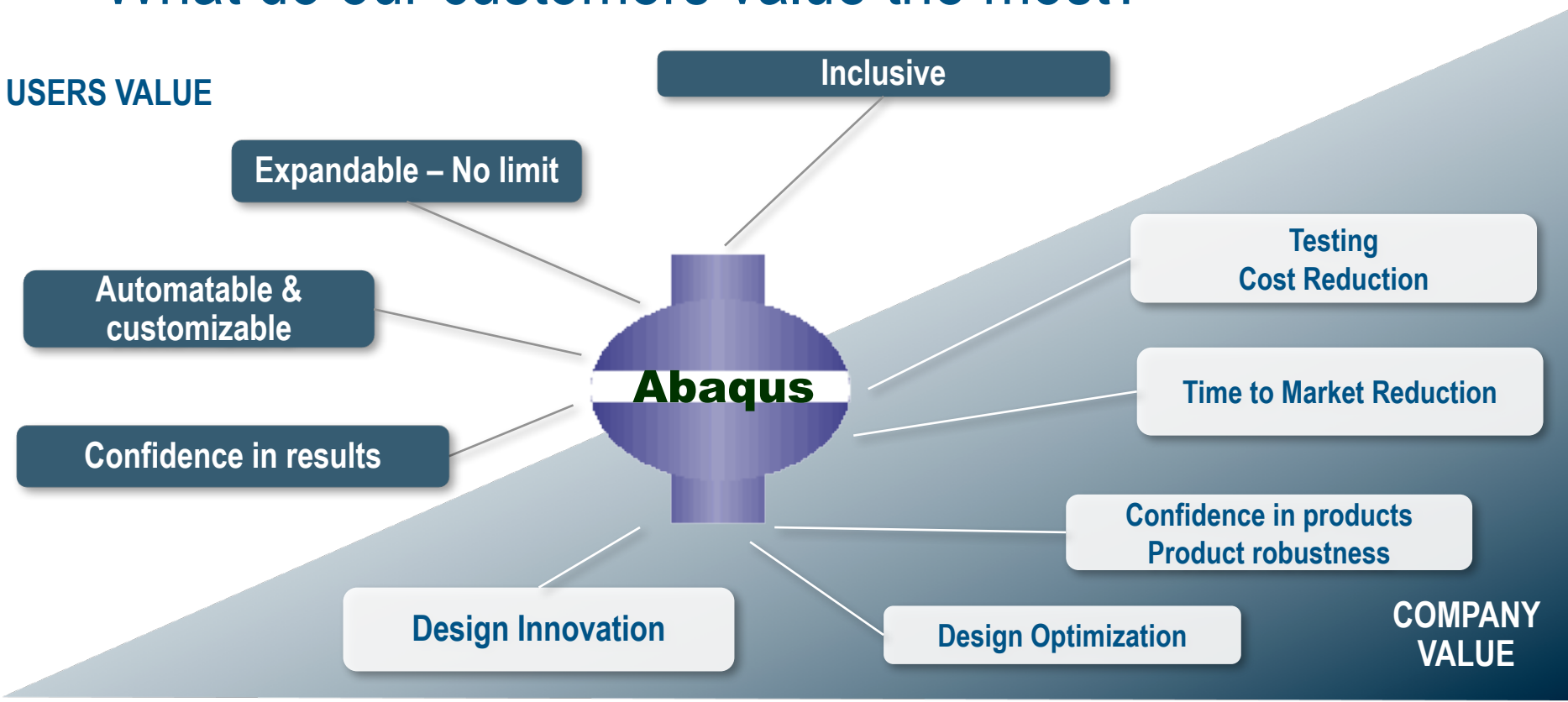
Agenda

- **Abaqus value proposition**
- Samples of workflows using Abaqus for wind turbine manufacturers
- Gear teeth optimization and Nabtesco success story
- Composite blade design and NSE Composites success story
- Jacket collision
- Takeaways

What do our customers value the most?

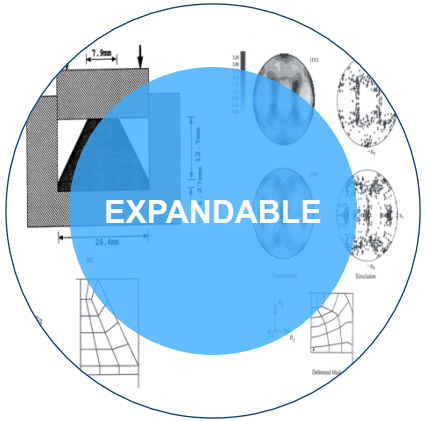


Abaqus for structural analysis with no limit

- ✓ Multiphysics
- ✓ Multi Modeling Abstractions
  Substructure & Submodeling
- ✓ Multi Element Types
- ✓ Implicit & Explicit
- ✓ Linear & Non-linear
- ✓ Static & Dynamic

Images courtesy of BMW, 2010 SIMULIA Customer Conference paper, "*Predictive Crashworthiness Simulation in a Virtual Design Process without Hardware Testing*

- ✓ Physic-based
- ✓ Proven solvers
- ✓ Accuracy in contact
- ✓ Sanctioned in many labs
- ✓ Best-in-class documentation
- ✓ Large paper library



- ✓ User materials
- ✓ User elements
- ✓ And other subroutines
- ✓ Easy addition of complexity
  - ✓ Material
  - ✓ Boundary
  - ✓ Geometric

- ✓ Scripting (Python, C++)
- ✓ Journal, Replay & Recover files
- ✓ User Interfaces development

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Samples of workflows using Abaqus for wind turbine manufacturers

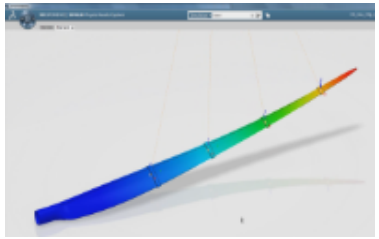
Gear teeth optimization and Nabtesco success story

Composite blade design and NSE Composites success story

Jacket collision

Takeaways

Samples of workflows using Abaqus for wind turbine engineering

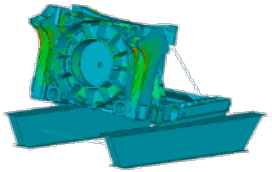


Rotor blades Engineering

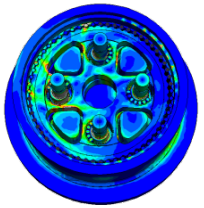
Composite blade engineering
Stress and fatigue analysis
Modal and Buckling analysis
Tip deflection analysis

Drivetrain and other equipment

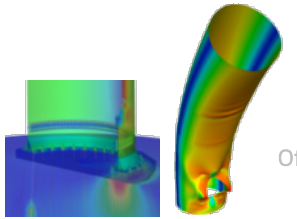
Resonance Analysis
Static Structural Analysis
Modal & Buckling Analysis
Durability & Fatigue Endurance
Topology & Shape Optimization
Rolling Bearing Analysis
Gear Box Design



Courtesy: Schaeffler



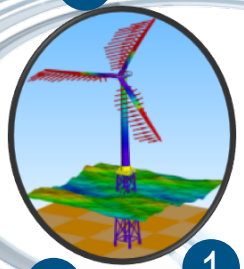
Courtesy: Nabetsco



Courtesy DNV

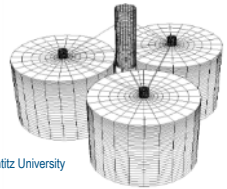
Tower Engineering

Concrete damage and failure analysis
Modal and Buckling analysis
Static Structural analysis
Offshore – Wave, Wind & current effects



Foundation Engineering

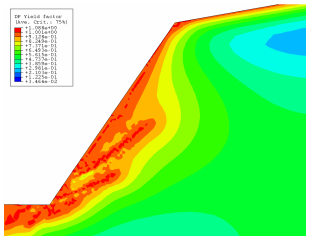
Dynamic Analysis and Load Generation
Detailed Structural Analysis
Soil-Structure Interaction
Post-cyclic pile capacity
Offshore – Wave & current effects



Courtesy: Leibntitz University

Wind Farm Siting

Earthworks and geotechnical analysis



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Nabtesco Corporation

Company Overview

Established: Septembre 29, 2003
Headquarter: Tokyo, Japan
Capital: 10 billion yen (44M Eur)
Employees: 7,162
Business: Precision reduction gears, Yaw and Pitch drives (wind turbines), Flight control actuation systems, Traveling units for hydraulic excavators, air dryers, etc.

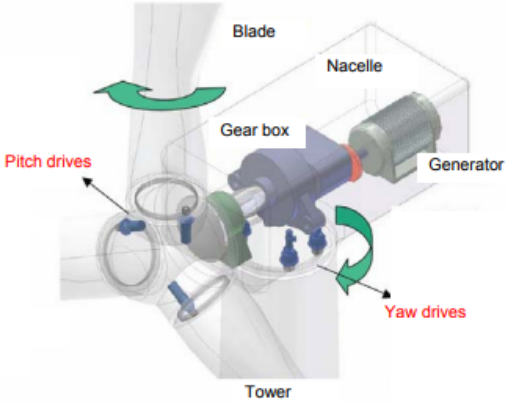
Nabtesco papers at SIMULIA events

2006 Japan RUM & 2007 AUC: An attempt at complete assembly contact analysis of a high precision reduction gear
2009 SCC: Dynamic Behavior Of Low Rigidity Frame Under Impact Load
2010 SCC: A challenging problem: the dynamic analysis of a high precision reduction gear
2011 SCC: A Numerical Study on Buckling for Thin Shell Structures Made of Rubber
2012 SCC: An innovative gear tooth analysis and evaluation technique
2013 SCC: Solution of Inverse Problem of Elastic-Plastic Deformation using Isight and Abaqus
2014 SCC: Fluid-Structure Interaction Analysis of Closing Valves Using Abaqus/Explicit coupled with SC/Tetra

Nabtesco paper: An innovative gear tooth analysis and evaluation technique

Objective:

Design the most advantageous crowning for pinion gear teeth to minimize gear tooth damage risk.



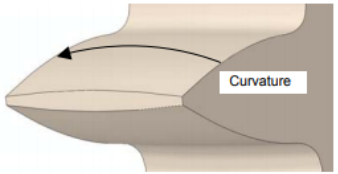


Figure 2. Crowning.

Images courtesy of Nabtesco, 2012 SIMULIA Customer Conference paper, "*An innovative gear tooth analysis and evaluation technique*

The solution:

Reduce maximum contact stress by increasing contact areas for all phases of engagement through design optimization

Physical testing issues:

Too many pinions to be manufactured (cost & time issues), no information on maximum stress

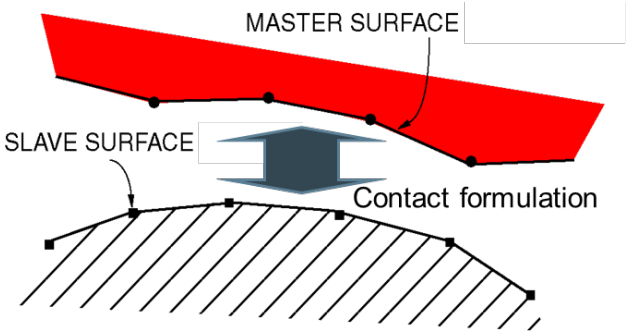
Challenge:

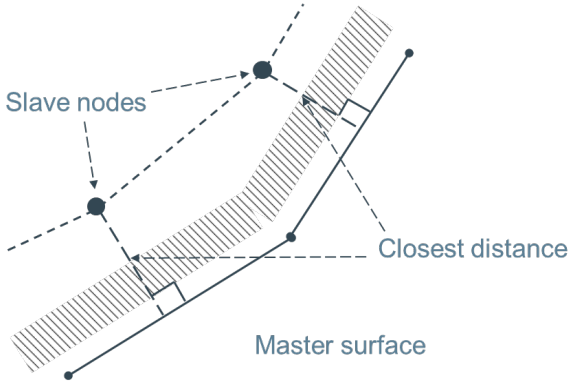
Accurately evaluate surface stress with deformable parts with an acceptable simulation run duration

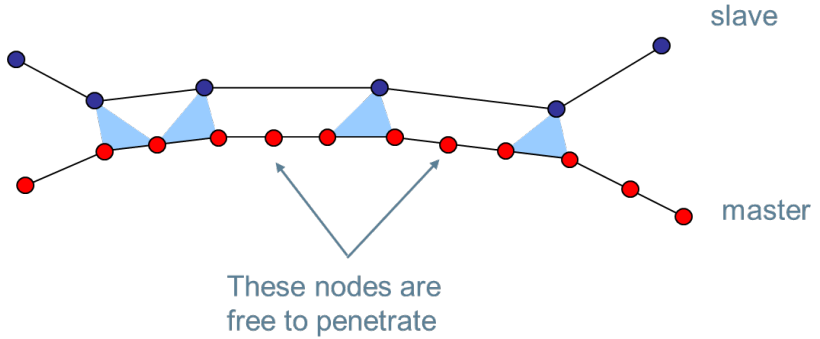
Nabtesco paper: An innovative gear tooth analysis and evaluation technique

Contact in a FEA solver such as Abaqus:

Accuracy in results require very fine mesh here (edge contact).





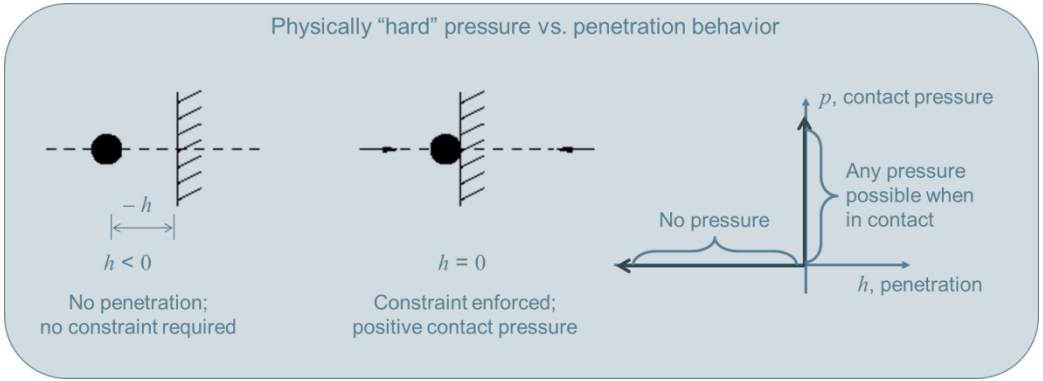


Nabtesco paper: An innovative gear tooth analysis and evaluation technique

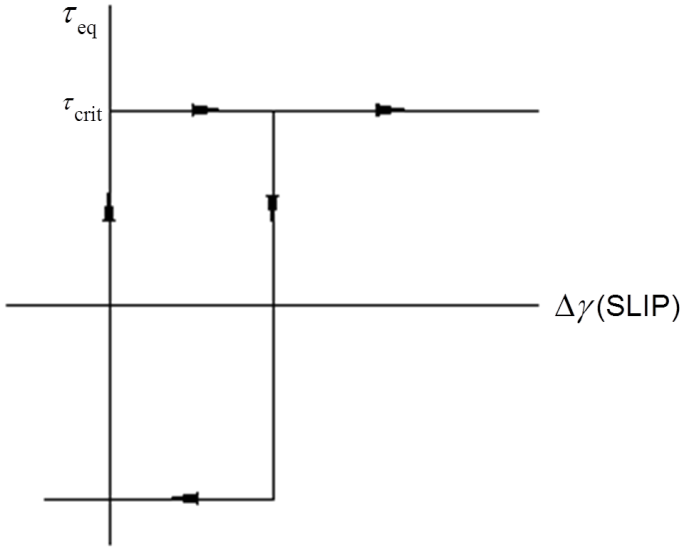
Contact in a FEA solver such as Abaqus:

Normal vs. tangential behaviors

Pressure-overclosure hard model



Isotropic Coulomb friction model

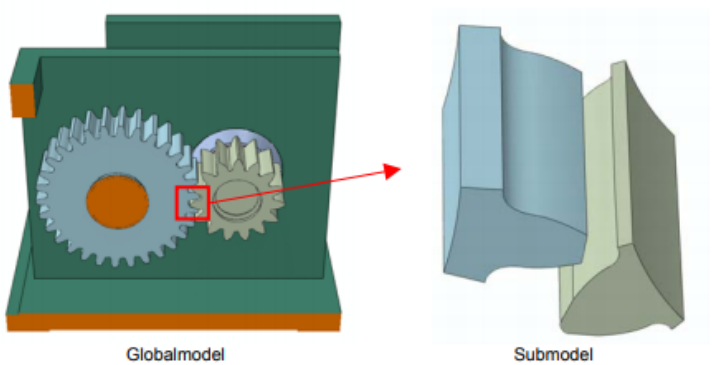


Nabtesco paper: An innovative gear tooth analysis and evaluation technique

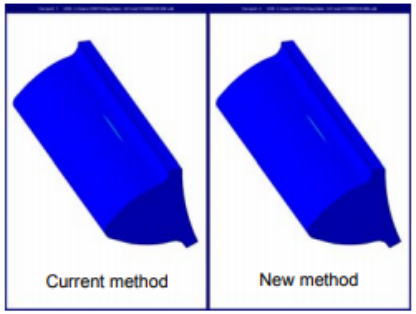
Customers added values:

Submodeling for reducing simulation run durations

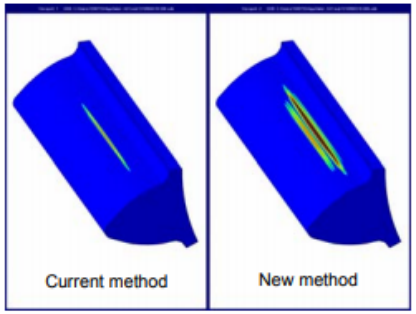
Subroutines to create dedicated outputs



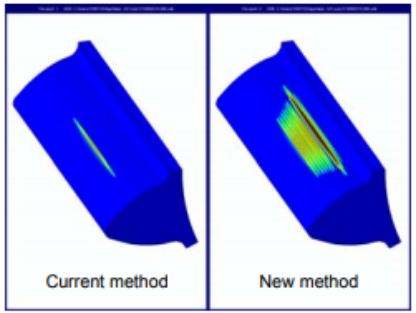
Images courtesy of Nabtesco, 2012 SIMULIA Customer Conference paper, "*An innovative gear tooth analysis and evaluation technique*



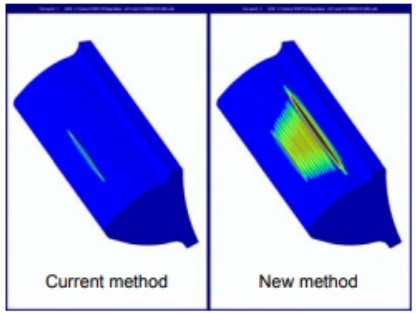
(1) Start of engagement



(2) Change rotation angle



(3) Change rotation angle again



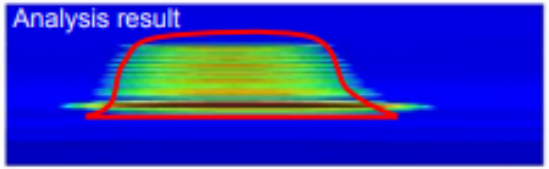
(4) End of engagement

Nabtesco paper: An innovative gear tooth analysis and evaluation technique

Results:

Good correlation with physic tests data

Improved tooth shape



Images courtesy of Nabtesco, 2012 SIMULIA Customer Conference paper, "*An innovative gear tooth analysis and evaluation technique*

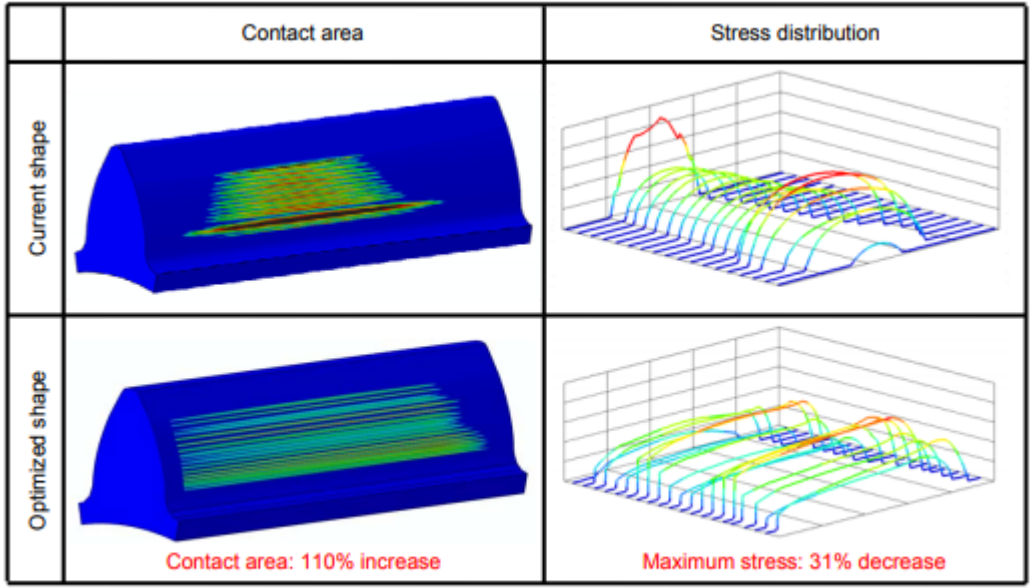


Figure 10. Improved shape results.

Nabtesco paper: An innovative gear tooth analysis and evaluation technique

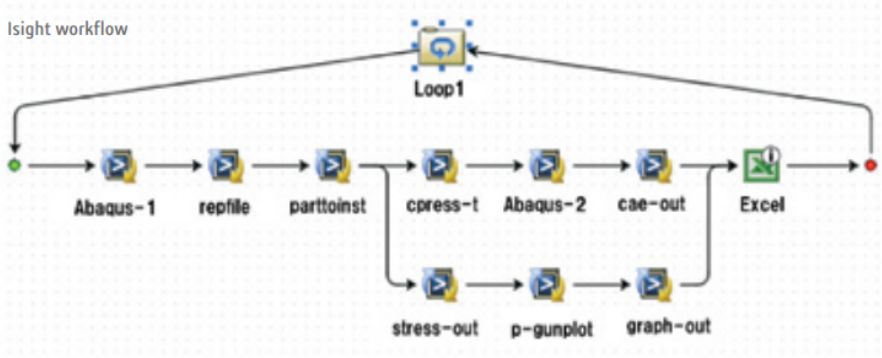
Following step after confidence in the simulation results:

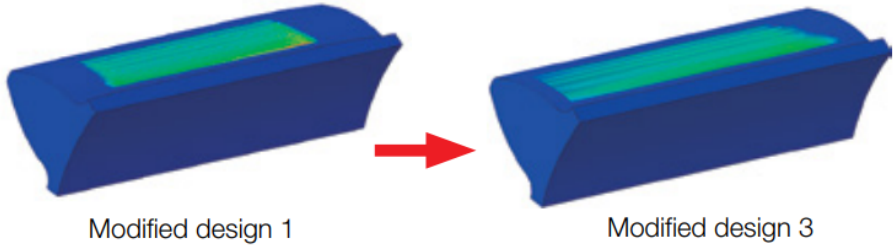
Process Integration and Design Optimization
With Isight technologies

- Connection with in-house programs
  - For durability assessment for example
- Gear crowning contours as alterable input

"This method reduces design times dramatically."

"Abaqus and Isight give us confidence that we can design durable gears that can stand up to the rigors of wind power generation."





Images courtesy of Nabtesco, Nabetsco Corporation SIMULIA case study

Nabtesco paper: An innovative gear tooth analysis and evaluation technique

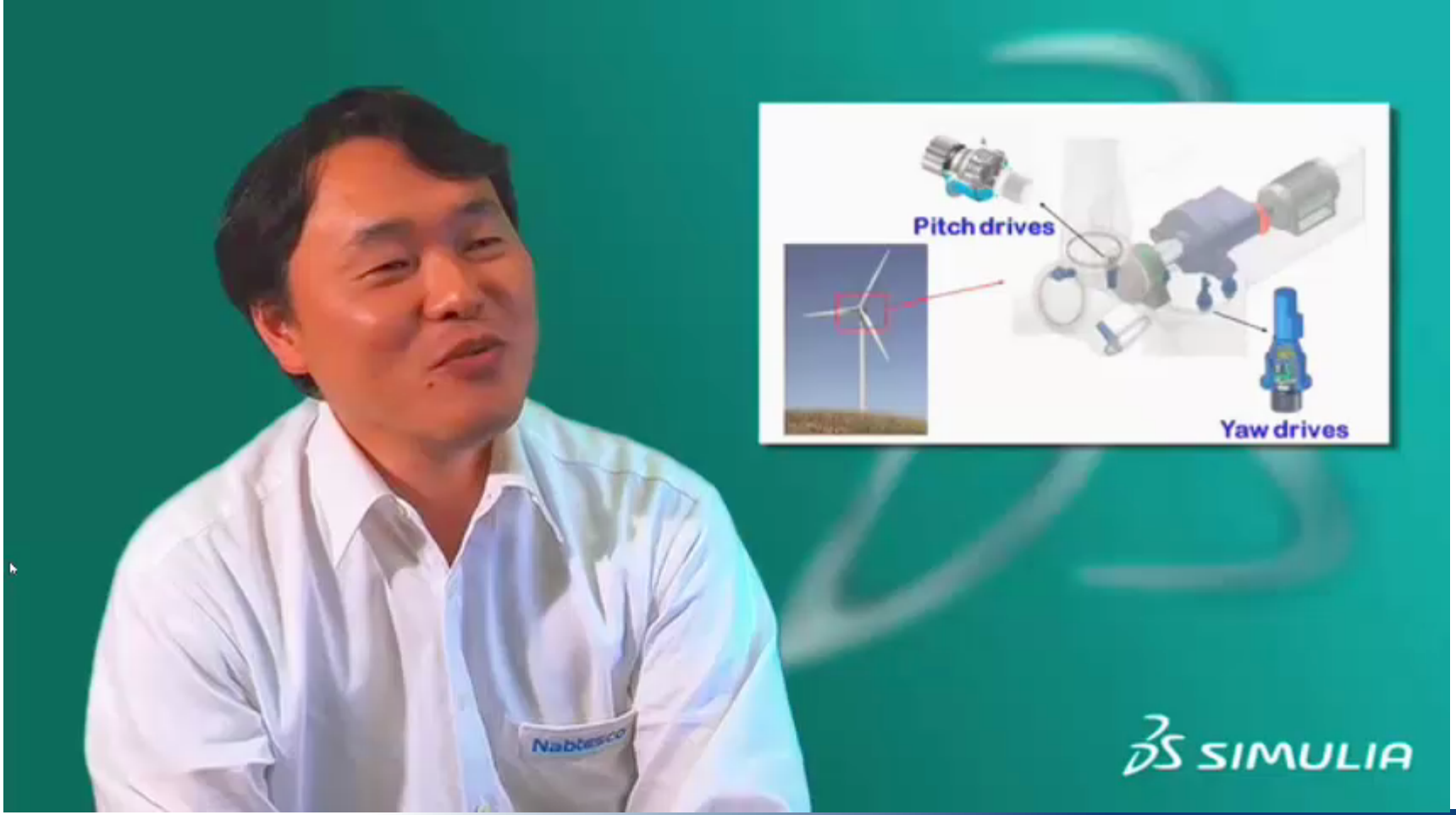
Some Nabtesco statements:

“Abaqus has a high functionality in solving contact problems”

“High accuracy between test and analysis results”

“Abaqus/Explicit can be a useful tool for designing low rigidity frame structures that require strength evaluation under impact conditions”

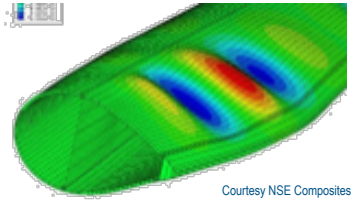
“Abaqus/Explicit has significant potential to be utilized as the ultimate analysis tool for general machine motion”



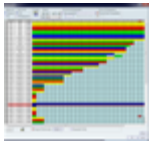
Agenda

- Abaqus value proposition
- Samples of workflows using Abaqus for wind turbine manufacturers
- Gear teeth optimization and Nabtesco success story
- **Composite blade design and NSE Composites success story**
- Jacket collision
- Takeaways

Composite Blade Design Workflow Overview (one instance)

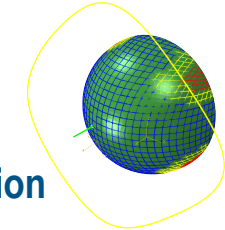


Courtesy NSE Composites



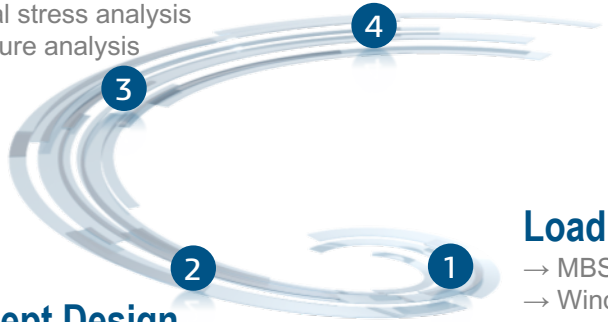
Composite Detailed Design

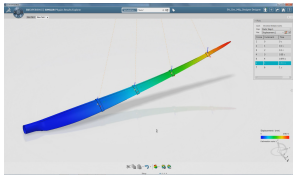
→ Detailed Composite plies design
→ Plies drop-off
→ Buckling and local stress analysis
→ Damage and Failure analysis



Composite Manufacturing Preparation

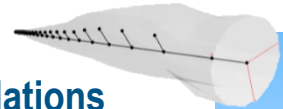
→ Producibility analysis
→ Work instructions





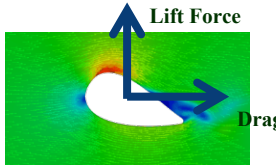
Composite Concept Design

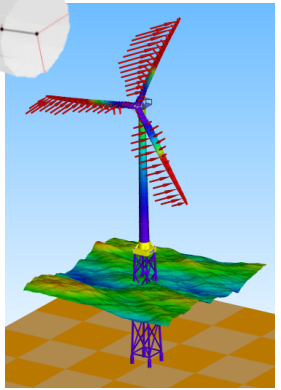
→ Shear Section Properties Analysis
→ Composite Composition Definition
→ Blade flexibility analysis (tip deflection, dynamic analysis)



Load Calculations

→ MBS/CFD simulations
→ Wind tunnel tests



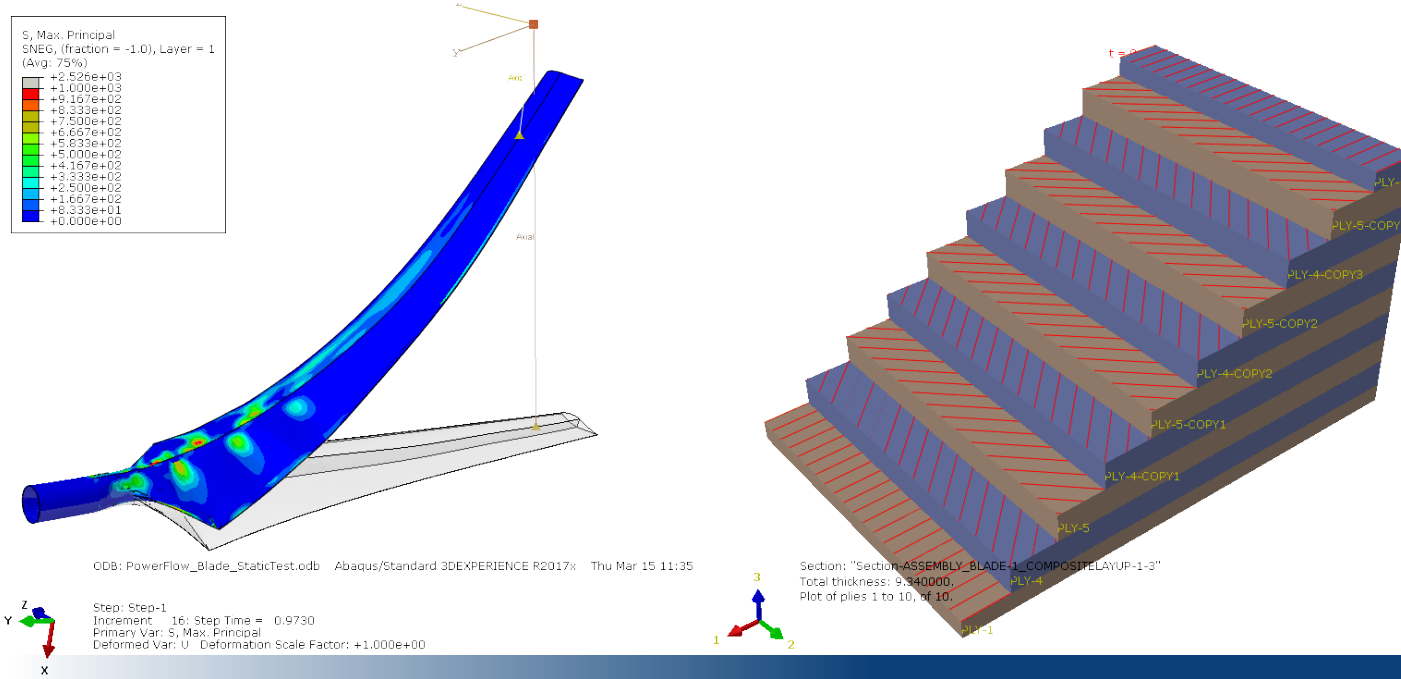


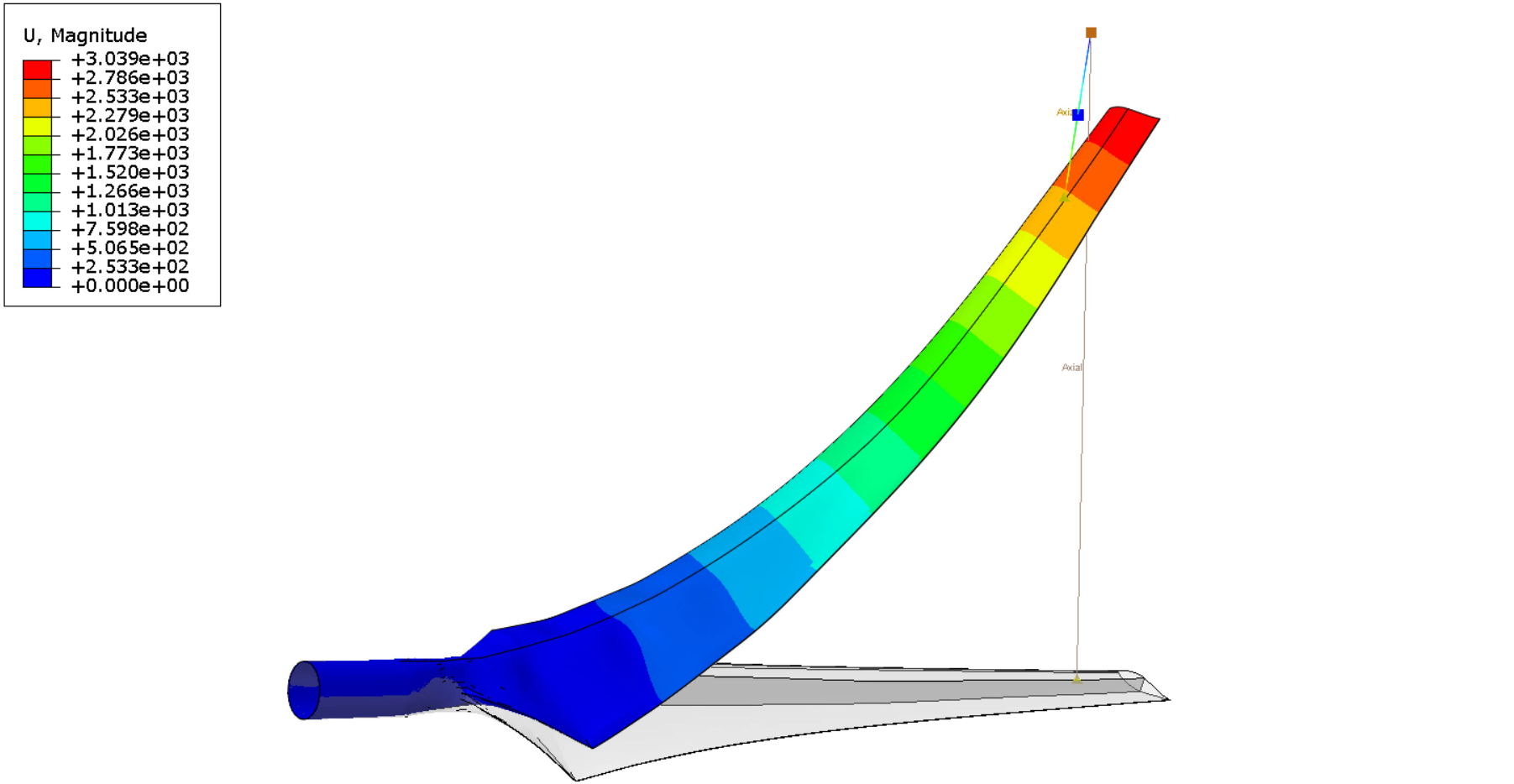
Tip deflection simulation

Static test simulation:

- Ultimate load case
- Stiffness and strength assessment
- Buckling prediction
- Shear web position optimization
- Composite design optimization

Use case based on NREL 2001 Technical Report

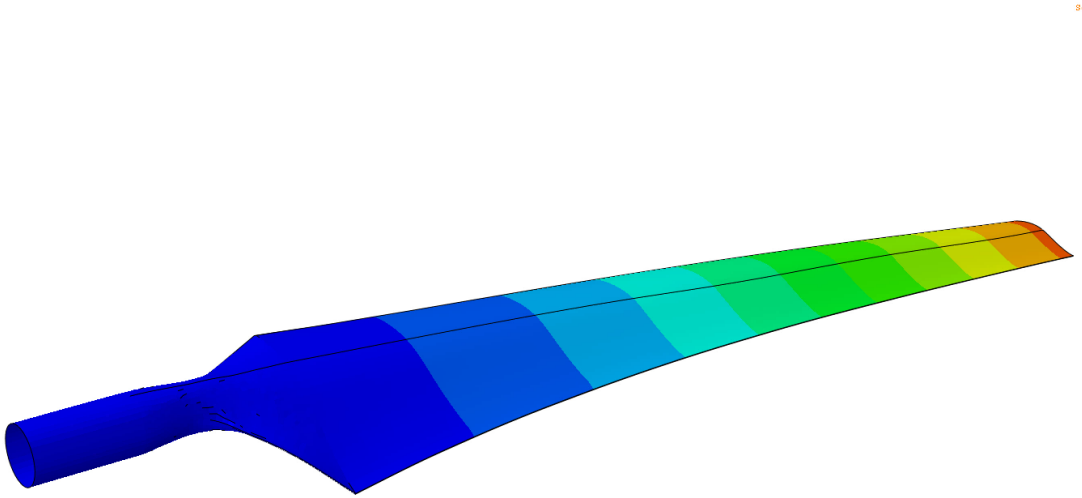




Linear Dynamic Simulation

Natural frequency extraction:

- Calculation of the natural frequencies and the corresponding mode shapes
- Can include initial stress and load stiffness effects due to preloads
- Can be reuse for a dynamic analysis in Simpack



Blade deformation under operational condition

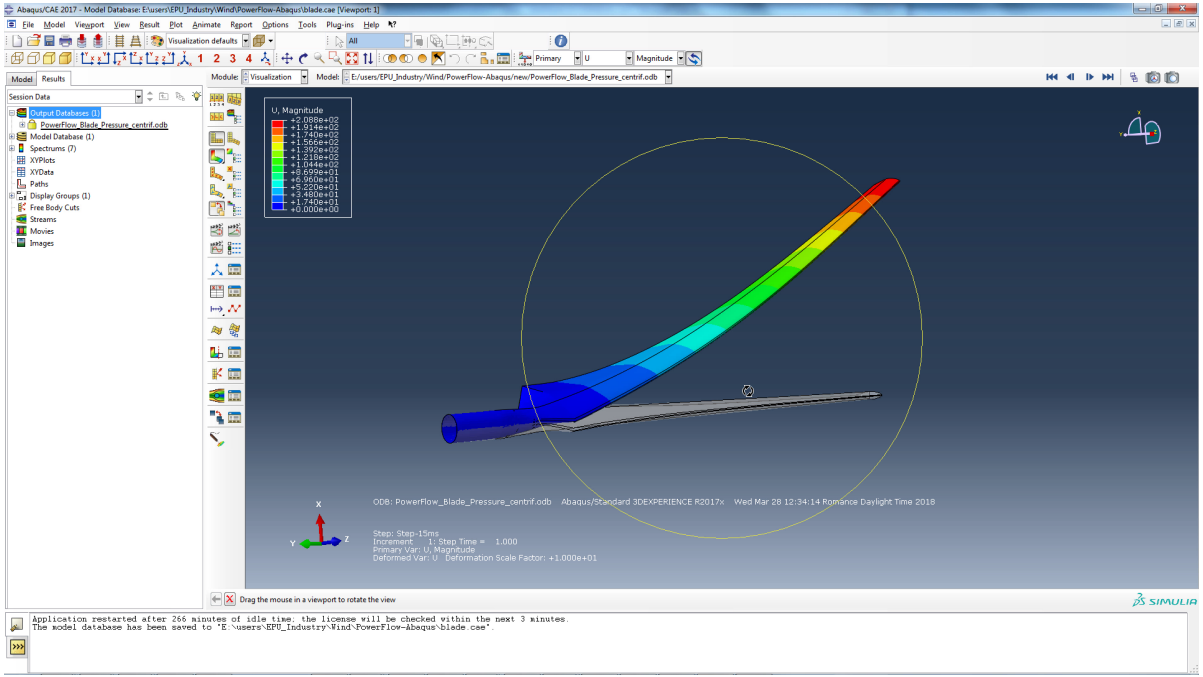
CFD to FEA analysis:

PowerFlow CFD

- Drag and lift forces
- Pressure field on blade surface

Abaqus FEA

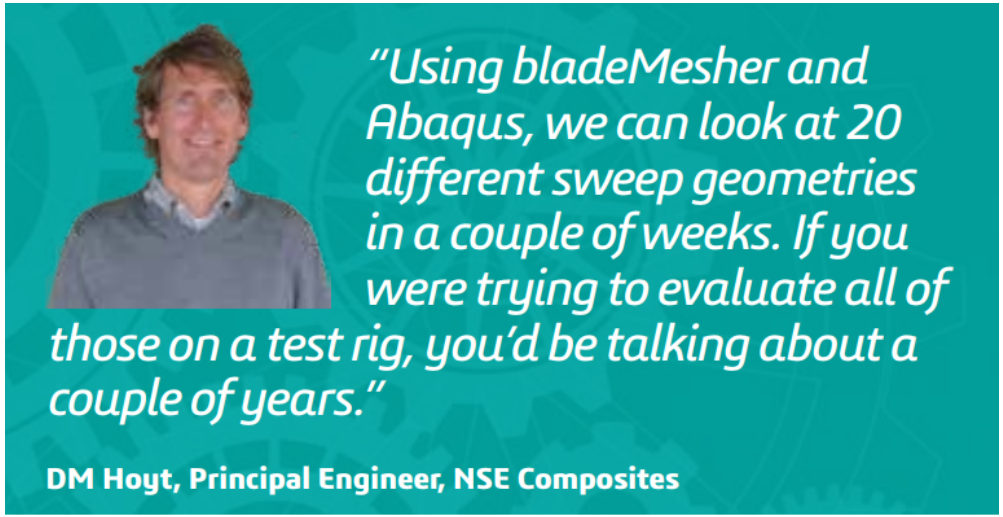
- Blade deformation & local buckling
- Stress and strains information



NSE Composites

Company Overview

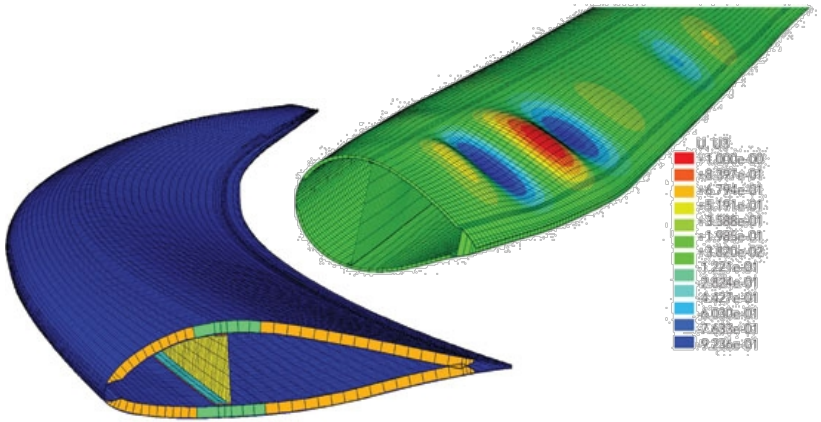
Established: 1996
Headquarter: Seattle, WA
Employees: 6
Business: Provider of engineering services in the areas of design, analysis, testing, and structural certification in aerospace and wind industries



NSE Composites Use case: Sweep-twist adaptive rotor (STAR) prototypes

Objective:

Analyze loads, stresses, and fatigue for an innovative, sweep-twist wind turbine blade design that is targeted to capture significantly more energy on light-wind speed sites



Images courtesy of NSE Composites, SIMULIA Case Study

The solution:

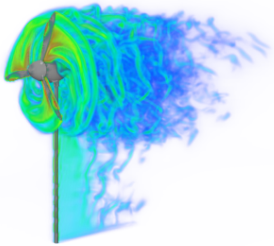
Calculate blade-tip deflection (to avoid “tower strike”)
Predict both torsional response (including twist angle) and shear-compression buckling stability of composite sandwich structures

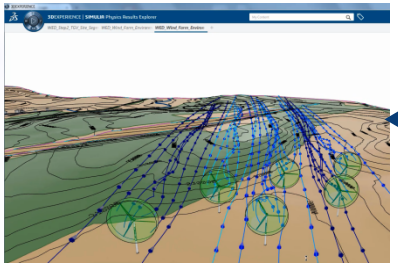
Results:

Realistic simulation enabled NSE to validate a Sandia-funded sweep-twist design that captures 12 percent more energy.

A platform approach for composite blade design

A platform approach for composite blade design





Flow analysis (CFD -RANS and LBM)

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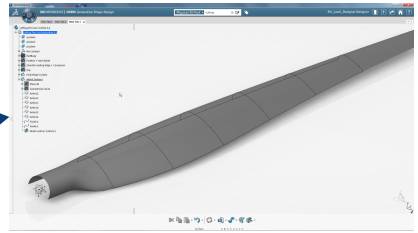
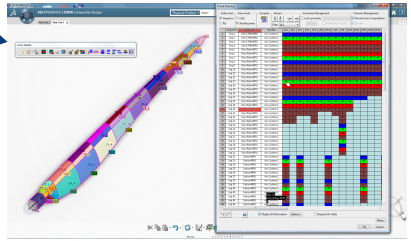
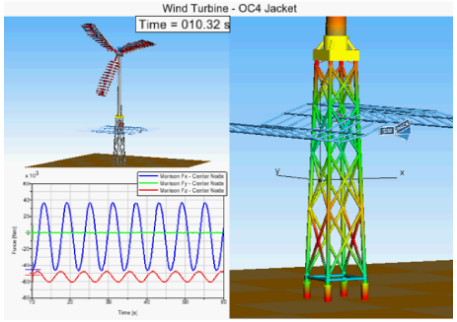


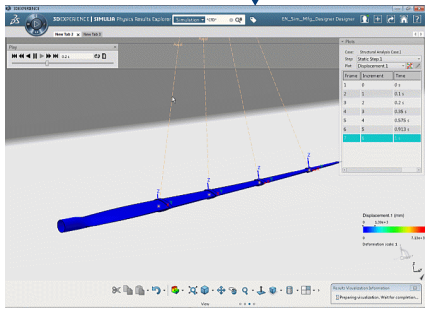
Surface design (CATIA)



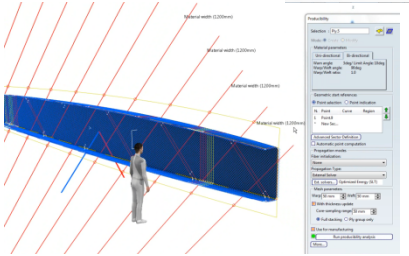
Conceptual and detailed composite design (CATIA)



Multibody Simulation (MBS)



Structural Analysis (FEA)

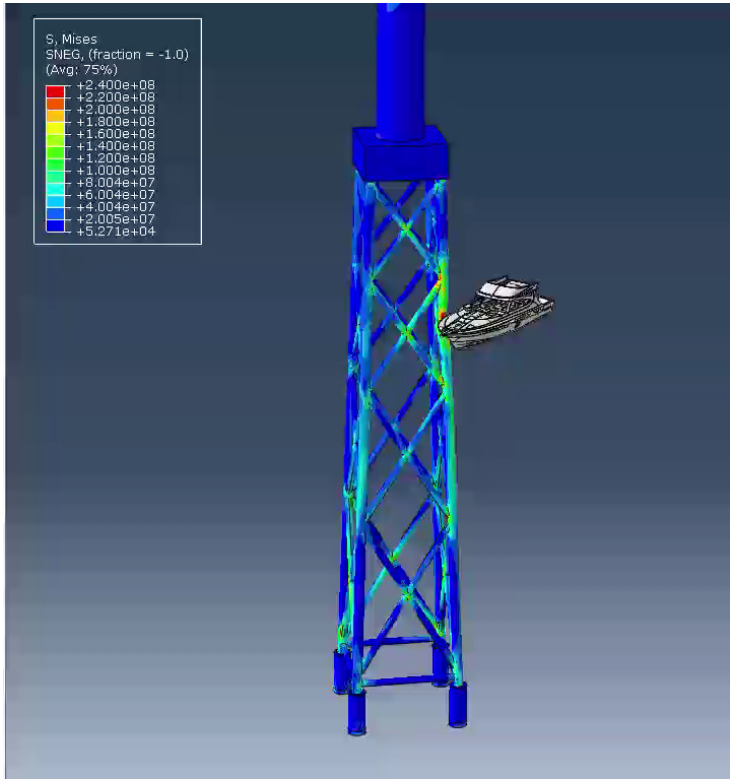


Manufacturing preparation (producibility)

Agenda

- Abaqus value proposition
- Samples of workflows using Abaqus for wind turbine manufacturers
- Gear teeth optimization and Nabtesco success story
- Composite blade design and NSE Composites success story
- **Jacket Collision**
- Takeaways

Jacket Collision



Objective:

Asset structural integrity of a jacket (offshore wind turbine) after an impact

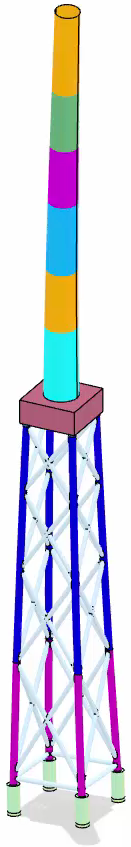
The solution:

Dynamic Explicit analysis, steel material with plasticity, damage and failure modeling

Use cases:

What if scenarios during design phase

Assess maintenance effort and understand damage after an unknown impact



Plots

Case: Result Of Structural Analysis Case.1

Step: Frequency Step.1

Plot: Color Code: by Section.1

Frame	Mode	Frequency
1	1	0.02232 Hz
2	2	0.02234 Hz
3	3	0.05114 Hz
4	4	0.05117 Hz
5	5	0.10094 Hz
6	6	0.11566 Hz
7	7	0.11591 Hz
8	8	0.15641 Hz

Color Code: by Section.1

- Shell Section.Braces
- Shell Section.Lower_Level_Legs
- Shell Section.Legs_2_4_Levels
- Shell Section.Legs_TP
- Solid Section.TP
- Solid Section.Grout
- Shell Section.Tower32
- Shell Section.Tower30
- Shell Section.Tower28
- Shell Section.Tower24
- Shell Section.Tower22
- Shell Section.Piles

Deformation scale: 15.1598

Agenda

Abaqus value proposition

Samples of workflows using Abaqus for wind turbine manufacturers

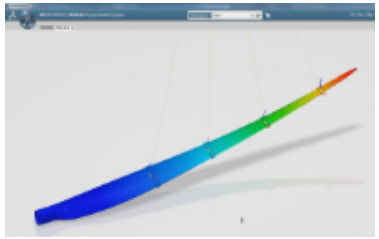
Gear teeth optimization and Nabtesco success story

Composite blade design and NSE Composites success story

Jacket Collision

Takeaways

Samples of workflows using Abaqus for wind turbine manufacturers

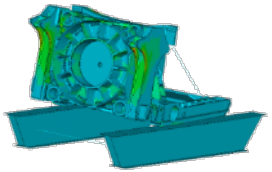


Rotor blades Engineering

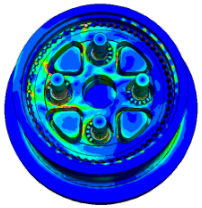
Composite blade engineering
Stress and fatigue analysis
Modal and Buckling analysis
Tip deflection analysis

Drivetrain and other equipment

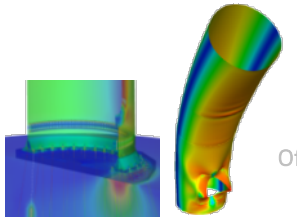
Resonance Analysis
Static Structural Analysis
Modal & Buckling Analysis
Durability & Fatigue Endurance
Topology & Shape Optimization
Rolling Bearing Analysis
Gear Box Design



Courtesy: Schaeffler



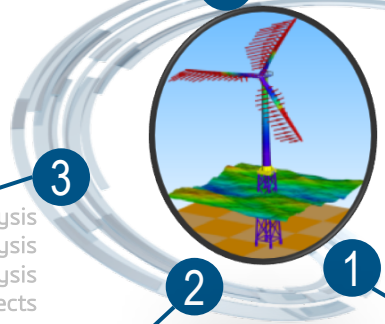
Courtesy: Nabetsco



Courtesy DNV

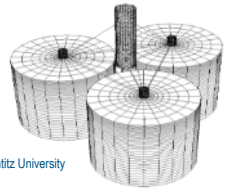
Tower Engineering

Concrete damage and failure analysis
Modal and Buckling analysis
Static Structural analysis
Offshore – Wave, Wind & current effects



Foundation Engineering

Dynamic Analysis and Load Generation
Detailed Structural Analysis
Soil-Structure Interaction
Post-cyclic pile capacity
Offshore – Wave & current effects



Courtesy: Leibntitz University

Wind Farm Siting

Earthworks and geotechnical analysis