Wind Energy at Aalborg University

Reliability and Operation & Maintenance of wind turbines

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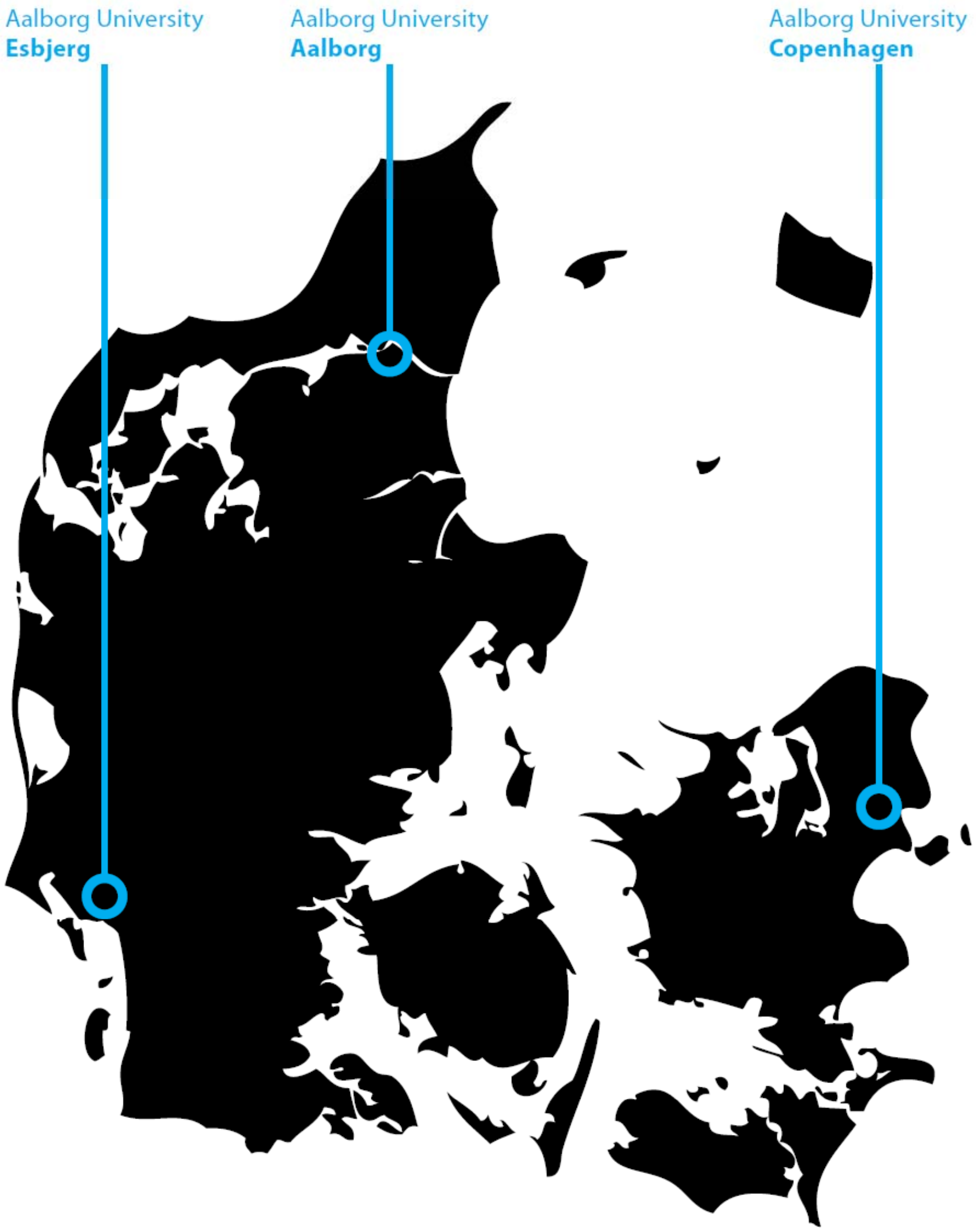
AALBORG UNIVERSITY
DENMARK


Aalborg University
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Wind Energy - Aalborg University

Departments at Aalborg University (AAU) – wind energy:

1. Department of Energy Technology
2. Department of Development and Planning
3. Institute of Electronic Systems
   - Section for Automation & Control
4. Department of Mechanical and Manufacturing Engineering
5. Department of Civil Engineering

Wind Energy - Aalborg University

Research areas:

- Energy planning
- Power electronics and power systems
- Control
- Blade design – composite materials
- Production & logistics
- Structural dynamics
- Foundation
- Load and safety

Offshore wind turbine at Aalborg Østhavn

Offshore wind turbines in Frederikshavn

Teaching

MSc programs in wind energy:

- Energy planning and sustainable energy
- Mechanical, structural and civil engineering
- Wind Power Systems (electrical aspects)

PhD education

- Approx. 75 PhD students

Department of Development and Planning

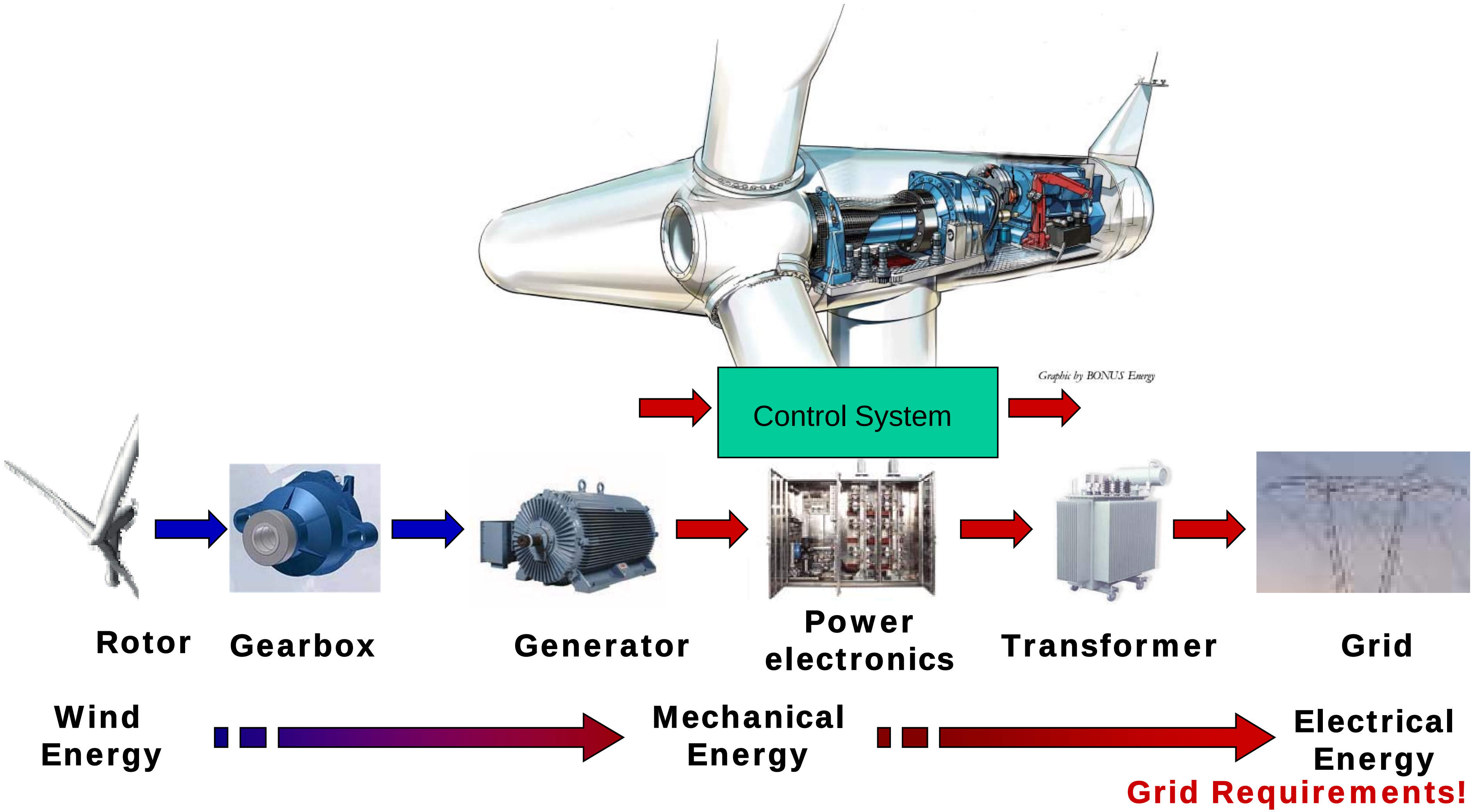
Sustainable Energy Planning Group - ***Wind energy activities*****:**

- Inter-disciplinary work on energy planning
- Technical energy systems analyses and GIS analyses of energy systems
- Business-economic and socio-economic analyses of energy systems
- Institutional analyses
- Primary focus is on the production of energy

- Professor Henrik Lund: lund@plan.aau.dk
- Assoc. Professor Poul A Østergaard: poul@plan.aau.dk

Department of Energy Technology

Research Focus on Wind Turbine Systems:



Institute of Electronic Systems

Wind power control

10 FACULTY
24 PHD / POSTDOC

10+years of collaboration with industry partners

One of the larger control groups in Europe

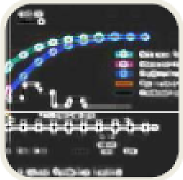
Key topics (current wind projects):

- Model predictive control
- Fault detection and fault tolerant control
- Wind farm control
- Floating wind turbines
- Concurrent Aero-Servo-Elastic Design

- Professor Thomas Bak: tba@es.aau.dk
- Professor Jacob Stoustrup: jacob@es.aau.dk
- Professor Rafal Wisniewski: raf@es.aau.dk

MODEL PREDICTIVE CONTROL

TO PROVIDE FEASIBILITY ANALYSIS OF MPC IN FULL LOAD CONTROL AND SWITCHING LOGIC



TO IDENTIFY THE KEY CHALLENGES OF USING MPC IN WIND TURBINE CONTROL

TO TRANSLATE CONTROL OBJECTIVES INTO MODELS FOR MPC PERFORMANCE FUNCTIONS, FURTHER TO EVALUATE PERFORMANCE POTENTIAL

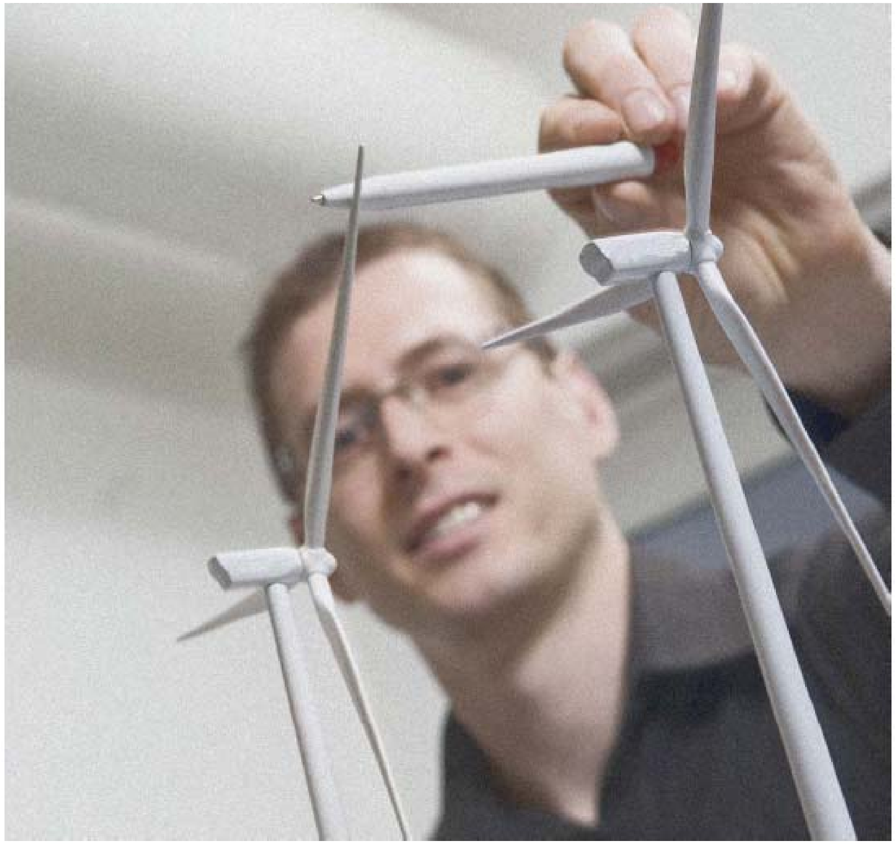
TO INVESTIGATE POTENTIAL IMPLEMENTATION ARCHITECTURES AND THEIR IMPACT ON PERFORMANCE

FAULT TOLERANT CONTROL / FAULT DETECTION

EARLY DETECTION AND ISOLATION OF FAULTS

PREVENTIVE RATHER THAN REACTIVE MAINTENANCE

GRACEFUL DEGRADATION – OPERATION IN EVENT OF FAILURE



kk-electronic a/s VATTENFALL

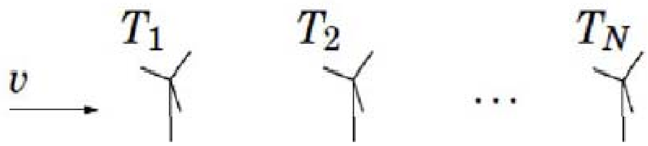
LARGE SCALE WIND FARM CONTROL

COST EFFECTIVE WIND FARM OPERATION – LOADS AND POWER

CONTROL MODELS OF AERODYNAMIC COUPLING

EXPERIMENTAL FULL SCALE VALIDATION

FARM LEVEL CONTROL



aeolus ict-aeolus.eu

FLOATING WIND TURBINES - CONTROL

ACCESS TO POPULATION AREAS WHERE OFFSHORE WATER DEPTH > 50M

ACTIVE DAMPING OF HYDRODYNAMIC FORCES

DESIGN BANDWIDTH OF PITCH SYSTEM EXPLOITED TO REDUCE PLATFORM LOADS

Department of Mechanical and Manufacturing Engineering

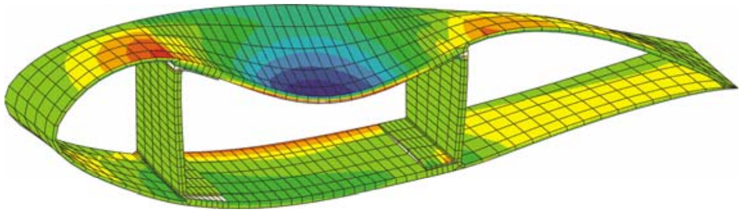
Wind energy activities:

- Logistics, production and design for manufacturing of wind turbines

  Professor Hans-Henrik Hvolby: hhh@m-tech.aau.dk

- Characterization, modeling/analysis, design and optimization of advanced composite materials and sandwich structures for wind turbine blades

  Professor Erik Lund: el@m-tech.aau.dk



Ongoing large research projects (+50 mill. kr):

- **HTF platform (2008-2013)** "Blade King" – with LM Wind Power, Comfil ApS & DTU Wind Energy.
  (HTF: Højteknologifonden – Advanced Technology Foundation)

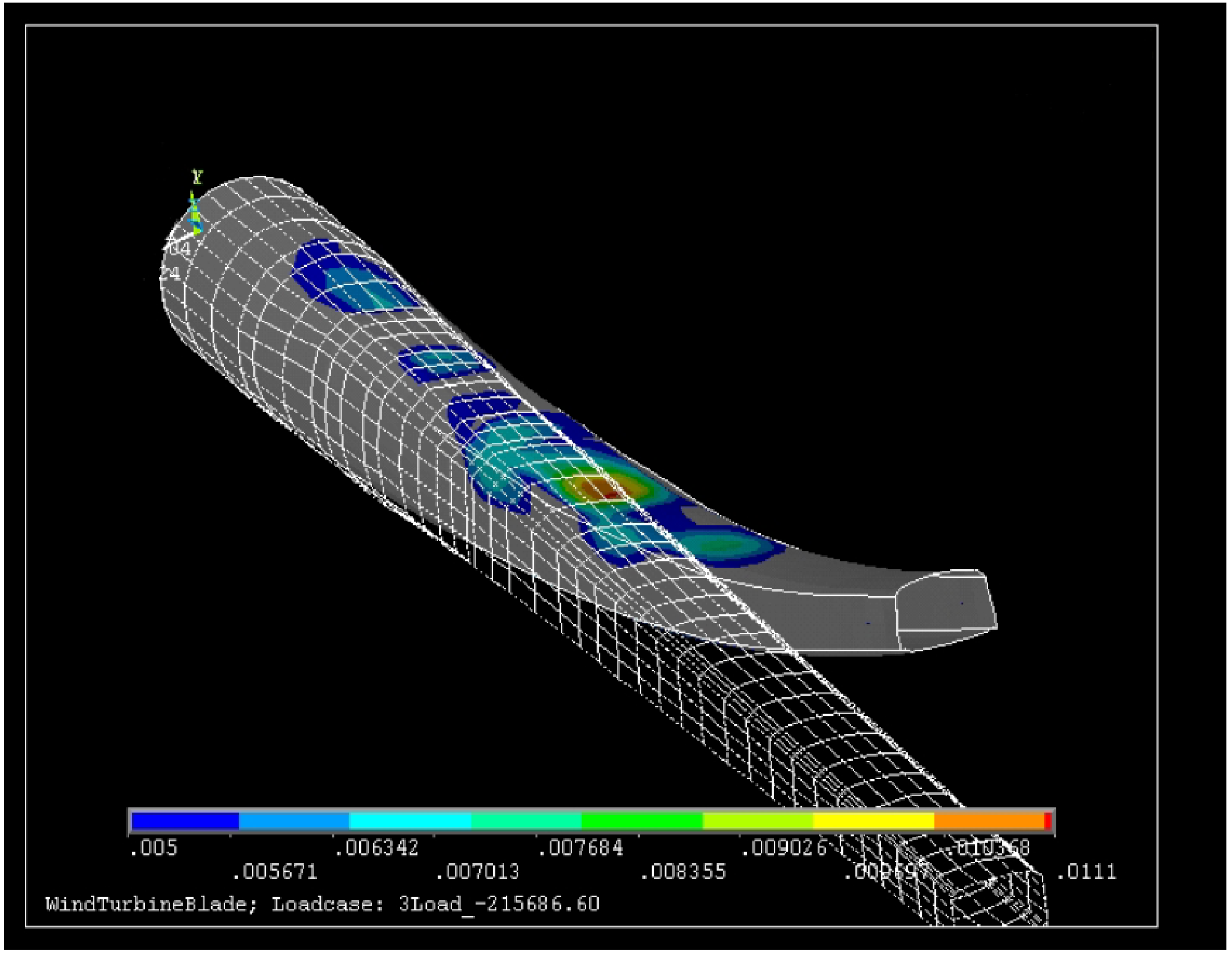
- **Large-scale integration project under EU-FP7** (FP7-NMP-2007-2.1-1, Grant agreement no.: 214148): "NanCore - Microcellular Nanocomposite for Substitution of Balsa Wood and PVC Core Materials". Many partners including LM Wind Power.

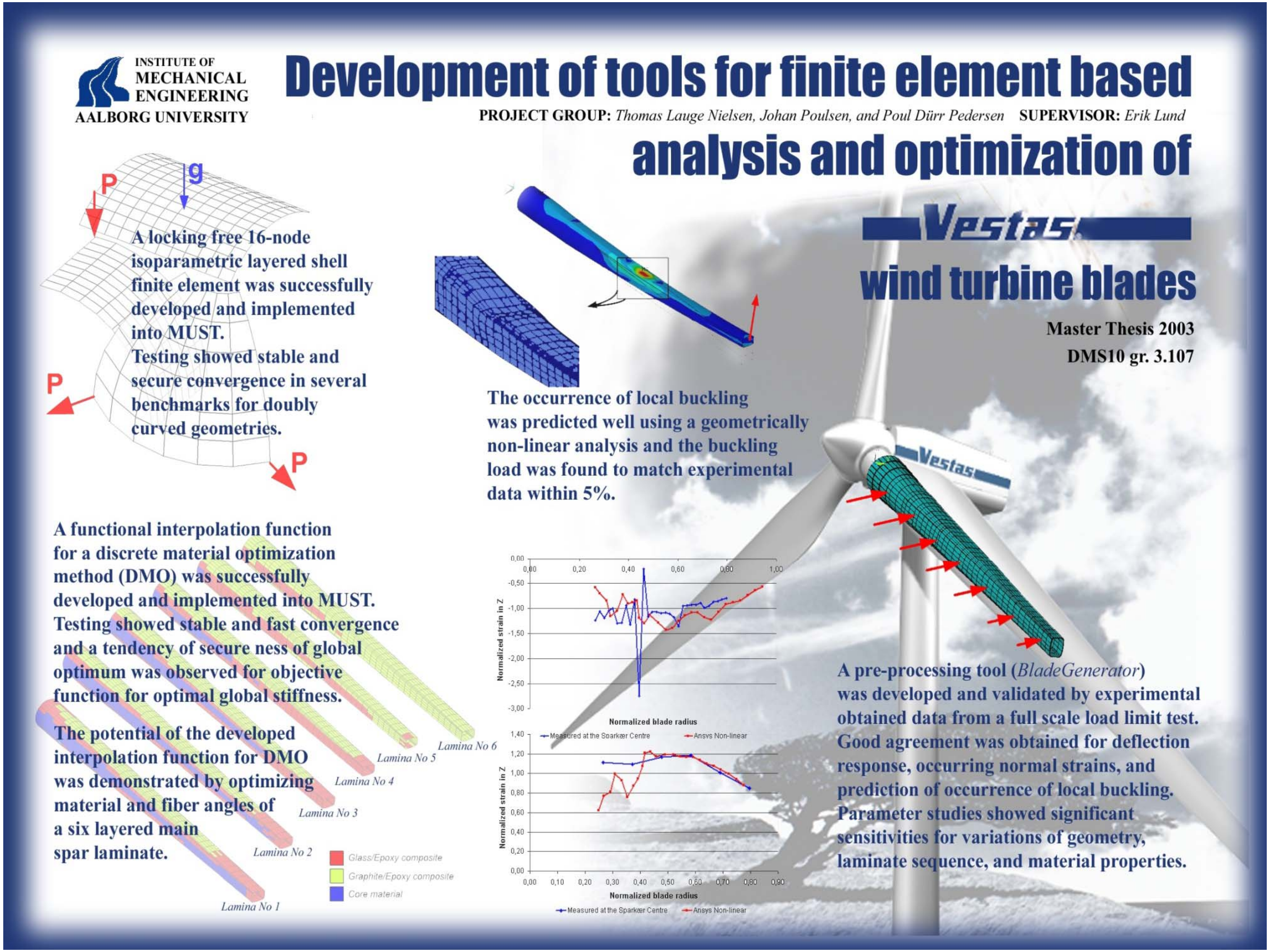
- **DSF project (2010-2017)**: "Danish Centre for Composite Structures and Materials for Wind Turbines" – with DTU, AAU, LM Wind Power, Siemens Wind Power, …
  DSF: Danish Council for Strategic Research.
  Nearly all key persons from Danish Universities working on composite materials and structures for wind turbines are involved in this center.
  AAU will have 7 Ph.D. students in relation to this center.

Ongoing Industrial Ph.D. Projects within Wind Energy

- 2008-2012: **"The Influence of Defects on the Failure of Wind Turbine Blades".** Industrial Ph.D. project with Siemens Wind Power.
- 2011-2014: **"Progressive Damage Simulation of Laminates in Wind Turbine Blades under Quasistatic and Cyclic Loading".** Industrial Ph.D. project with Siemens Wind Power.
- 2011-2014: **"Design of Sandwich Structures with Grid Scored Core Materials for Wind Turbine Blades".** Industrial Ph.D. project with Suzlon Wind Energy.
- 2008-2011: **"Dynamic Drive Train Simulation".** Industrial Ph.D. project with Vestas Wind Systems.
- 2009-2012: **"Optimal Design of Wind Turbine Drive Trains".** Industrial Ph.D. project with Vestas Wind Systems.
- 2009-2012: **" Development of a New Hydraulic Yaw System for Wind Turbines".** Industrial Ph.D. project with Liftra Aps.

Simulation of wind turbine blade main spar made by students:




INSTITUTE OF
MECHANICAL
ENGINEERING
AALBORG UNIVERSITY
Development of tools for finite element based
PROJECT GROUP: Thomas Lauge Nielsen, Johan Poulsen, and Poul Dürr Pedersen SUPERVISOR: Erik Lund
analysis and optimization of
Vestas
wind turbine blades
Master Thesis 2003
DMS10 gr. 3.107
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A locking free 16-node isoparametric layered shell finite element was successfully developed and implemented into MUST.
Testing showed stable and secure convergence in several benchmarks for doubly curved geometries.
The occurrence of local buckling was predicted well using a geometrically non-linear analysis and the buckling load was found to match experimental data within 5%.
Vestas
A functional interpolation function for a discrete material optimization method (DMO) was successfully developed and implemented into MUST.
Testing showed stable and fast convergence and a tendency of secure ness of global optimum was observed for objective function for optimal global stiffness.
The potential of the developed interpolation function for DMO was demonstrated by optimizing material and fiber angles of a six layered main spar laminate.
Lamina No 6
Lamina No 5
Lamina No 4
Lamina No 3
Lamina No 2
Lamina No 1
Glass/Epoxy composite
Graphite/Epoxy composite
Core material
Normalized strain in Z
Normalized blade radius
Measured at the Sparkær Centre
Ansys Non-linear
A pre-processing tool (BladeGenerator) was developed and validated by experimental obtained data from a full scale load limit test.
Good agreement was obtained for deflection response, occurring normal strains, and prediction of occurrence of local buckling.
Parameter studies showed significant sensitivities for variations of geometry, laminate sequence, and material properties.

Department of Civil Engineering

Wind energy activities:

- Foundation – Geotechnics
- Rotordynamics
- Wave and current loads – scour
- Loads and safety – risk analysis

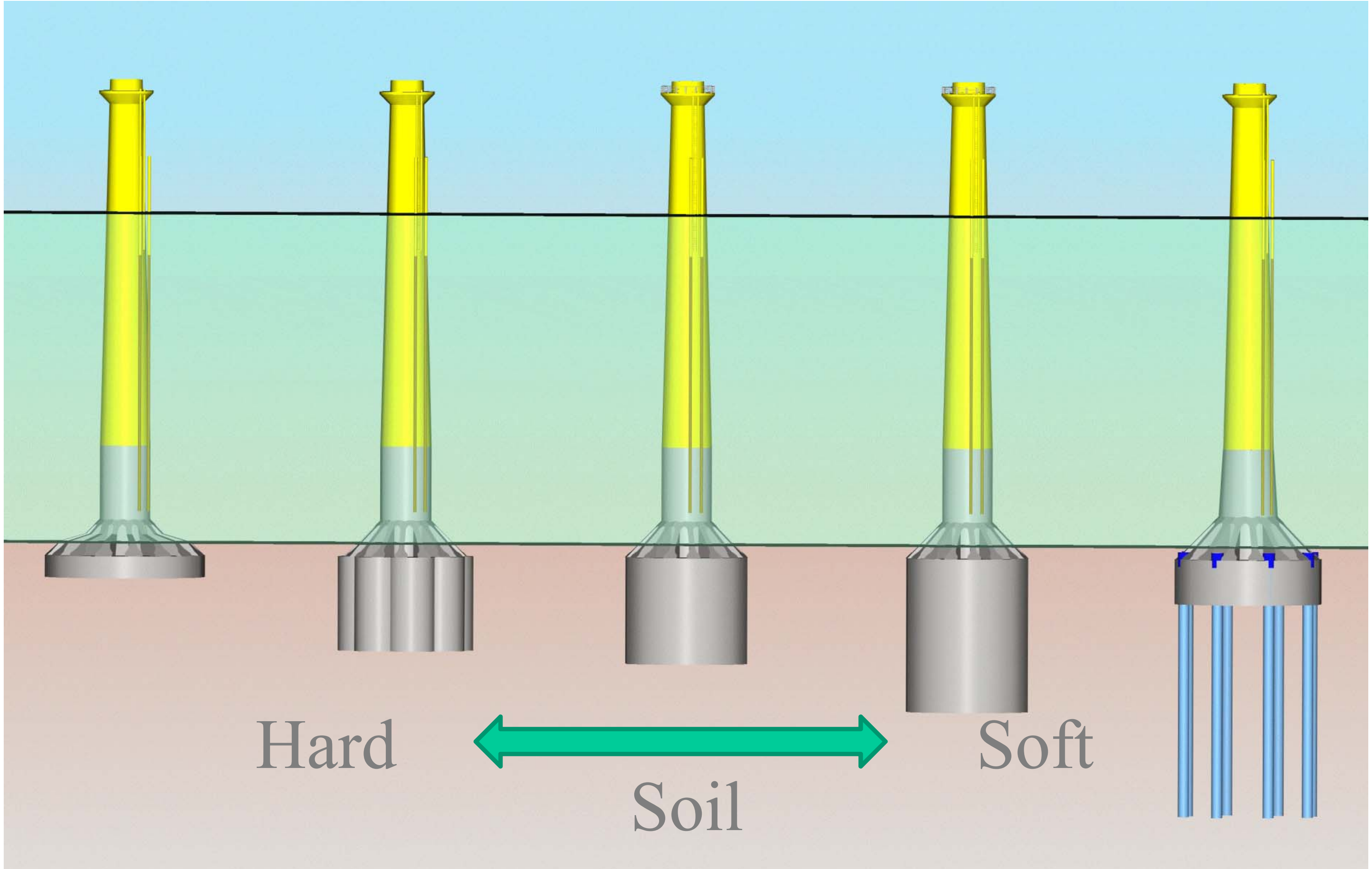
Foundation and Geotechnics

- Mono-pile foundation for offshore wind turbines
- Bucket foundation for offshore wind-turbines
- Soil - Structure interaction of foundations for wind turbines

- Professor Lars Bo Ibsen: lbi@civil.aau.dk
- Assoc. professor Lars Andersen: la@civil.aau.dk

Test site for offshore wind turbine research in Frederikshavn

Universal foundation solutions



Reliability and Risk analysis

- Reliability of wind turbine components and systems
- Risk-based planning of operation & maintenance for offshore wind turbines

- Professor John Dalsgaard Sørensen: jds@civil.aau.dk

Reliability and Risk analysis

Goal: minimize the total expected life-cycle costs
→ minimize COE (Cost Of Energy)

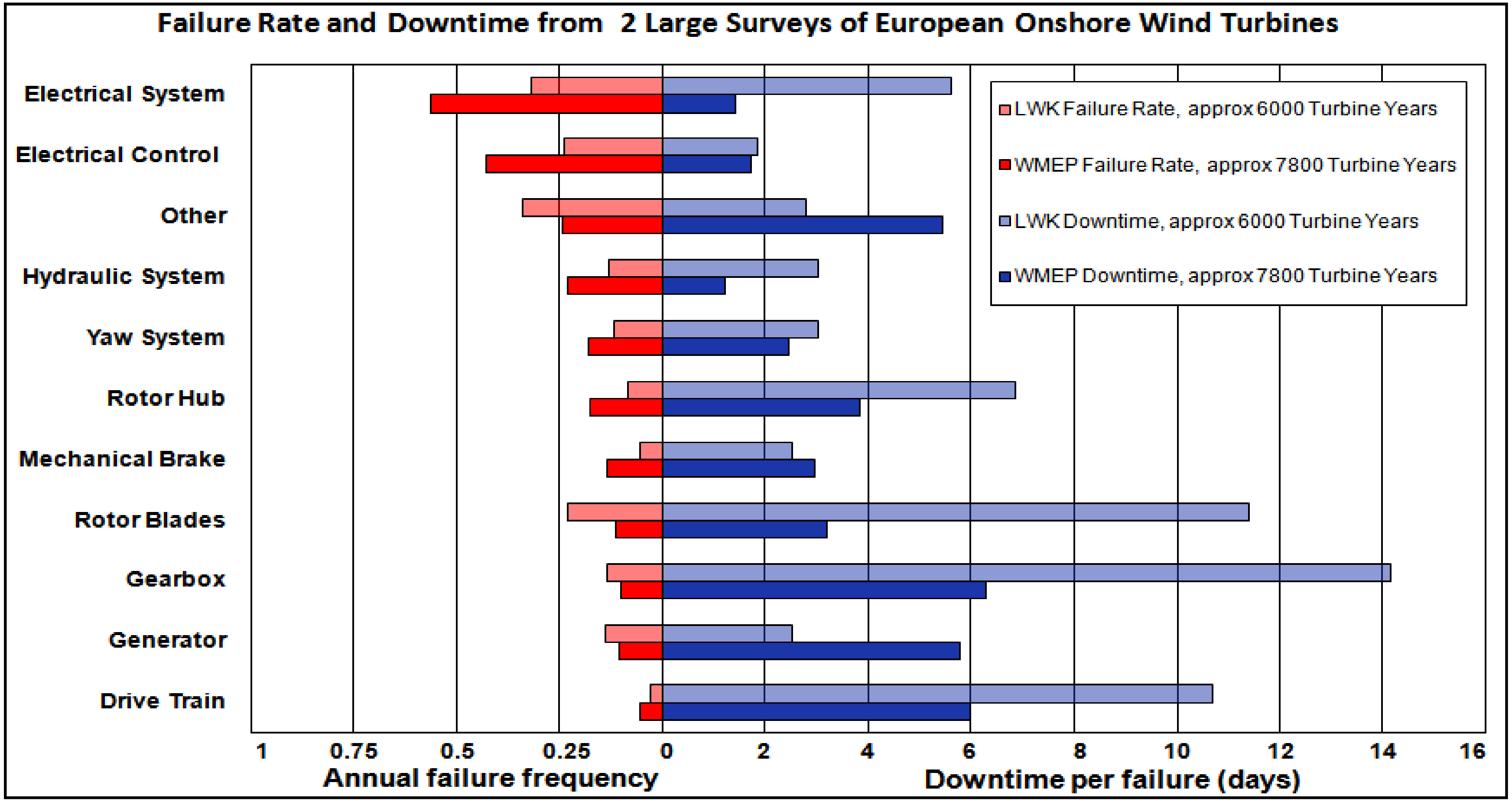
Initial costs: dependent on **reliability** level

O&M costs: dependent on **O&M strategy**, availability and **reliability**

Failure costs: dependent on **reliability**

Load & Safety – Risk analysis

Failure Rates and Downtimes (examples)



Source: ISET: 2006

Reliability modeling of wind turbines

Mechanical / electrical components

Observed failure rates

Classical reliability theory

Probabilistic models for failure events

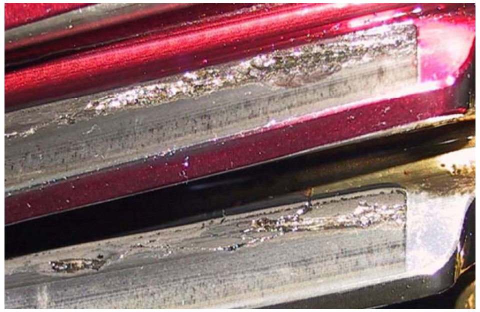
Structural Reliability Theory

Structural components

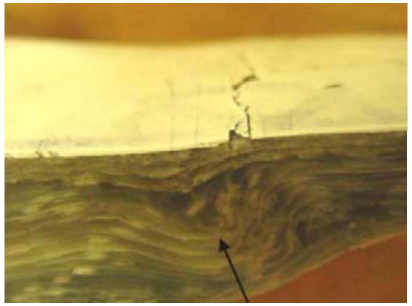
Reliability modeling of wind turbines

Blades

Gearbox, …



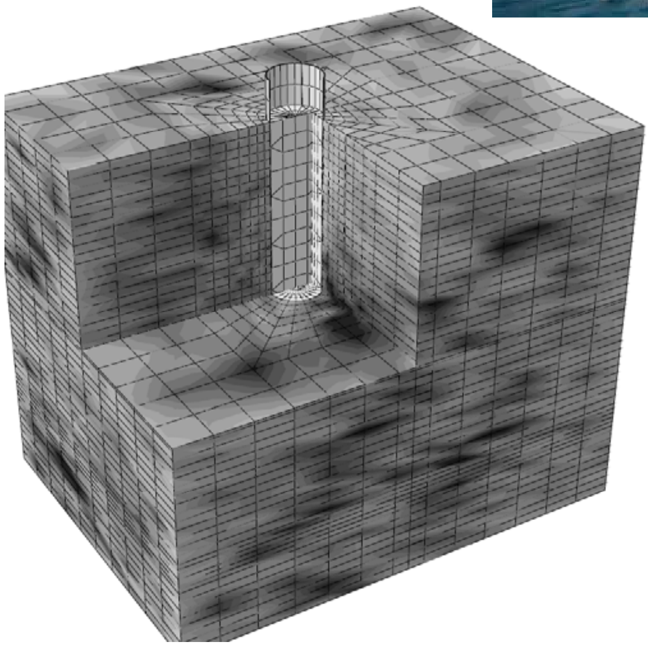
Power electronics:

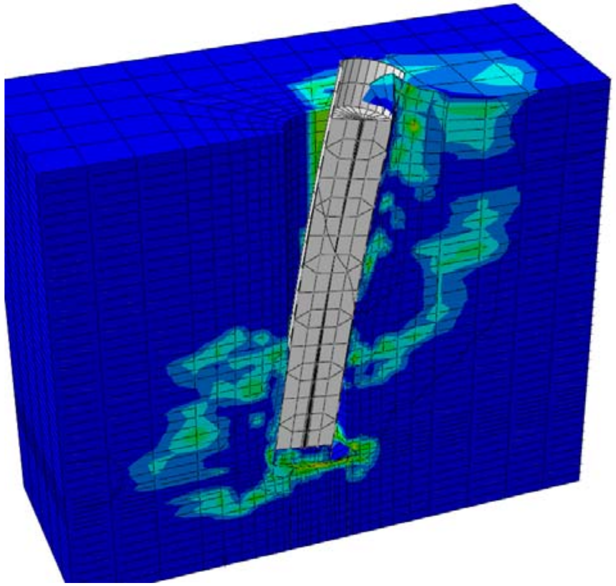


Reliability modeling of wind turbines

Tower & Substructures:

Foundation:





Operation & Maintenance

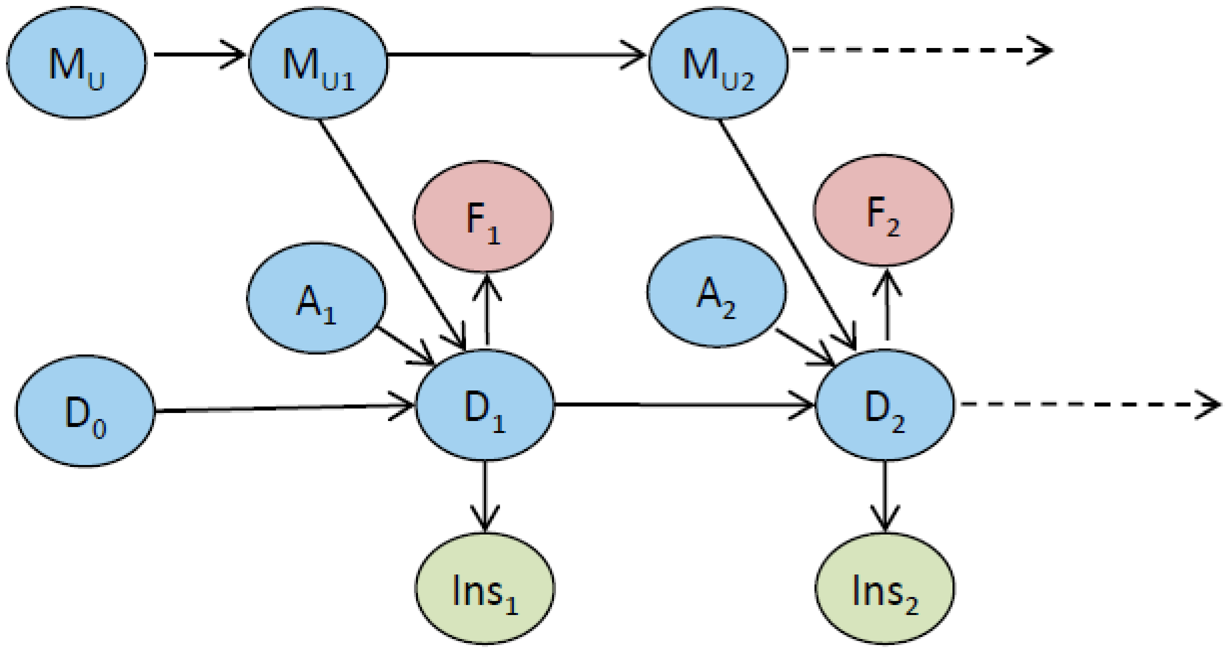
- **High costs** for operation and maintenance for offshore wind farms
  - High failure rates?
  - Access difficult: boat, helicopter, …
  - Limited weather windows
  - Loss of production
  - Mobilization
- Deterioration processes are always present and associated with **High uncertainty**

→ Maintenance could optimally be planned by using **risk-based** methods

Operation & Maintenance

Theoretical basis for risk-based planning: Bayesian decision theory

Implementation: Bayesian Networks



Thank you for your attention!

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