MDAO application to a rotor blade design

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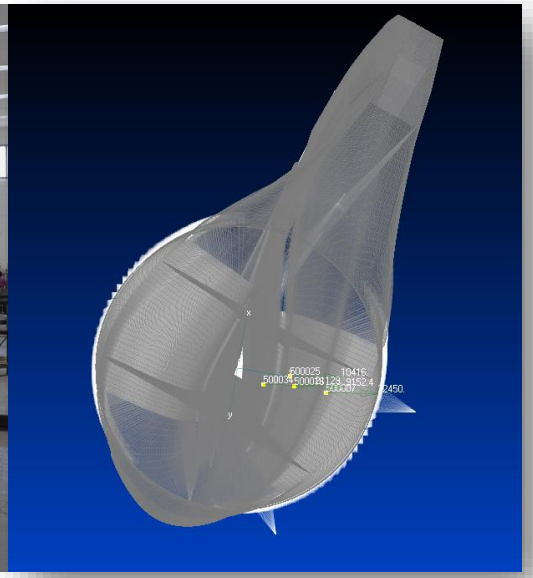
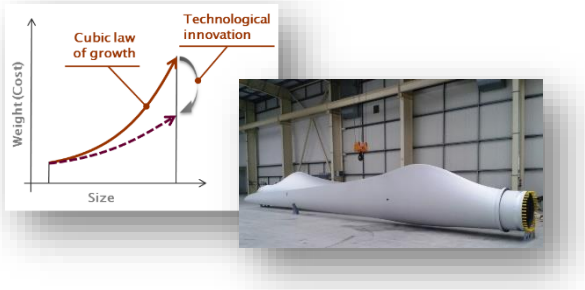
Politecnico di Milano, Italy



4th Workshop on Systems Engineering for Wind Energy
13 September 2017
Roskilde, DK

POLItecnico di MIlano

Outline



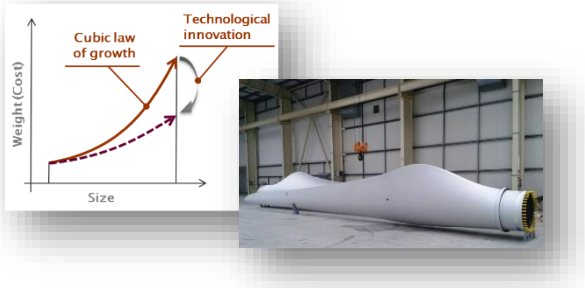
Introduction and motivation

The project and tools

MDAO Design and Testing

Conclusions and outlook

Outline



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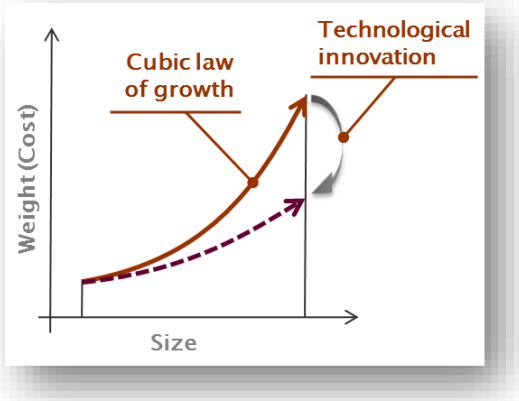
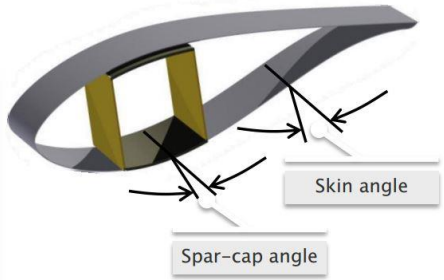
Introduction

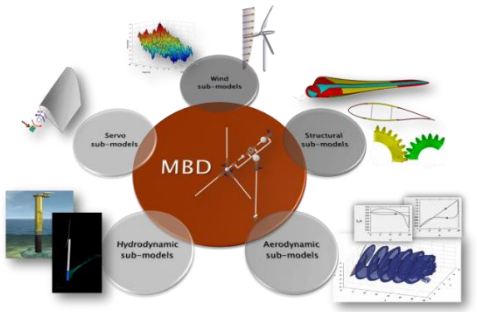
- Main goal: **CoE reduction**

$$CoE = \frac{FCR * ICC}{AEP} + AOE$$

- Innovation technology to beat the cubic law
  - Aerodynamic efficiency
  - Advanced materials
  - Active/passive load reduction controls
  - Electromechanical conversion
  - Simulations tools
  - …

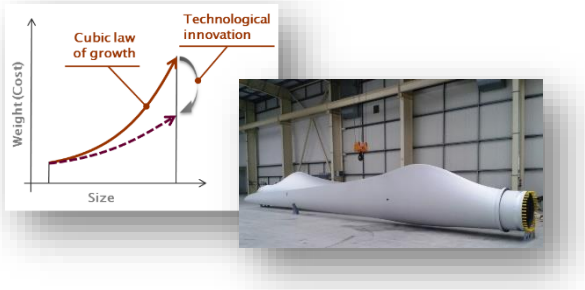






For existing wind farms: **re-blading**

Outline



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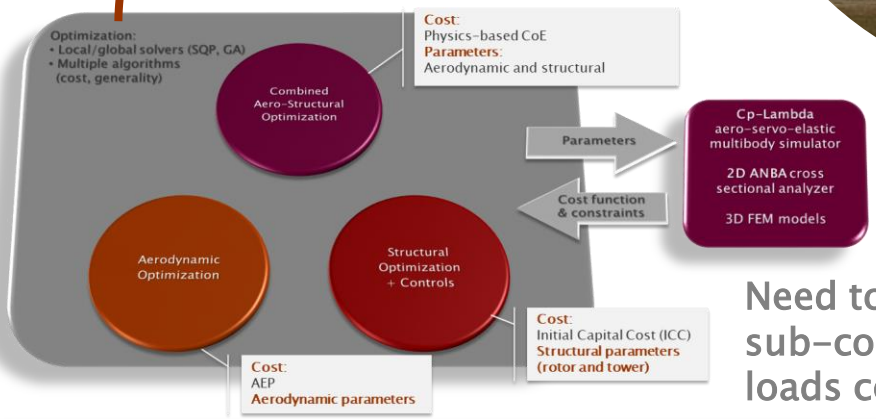
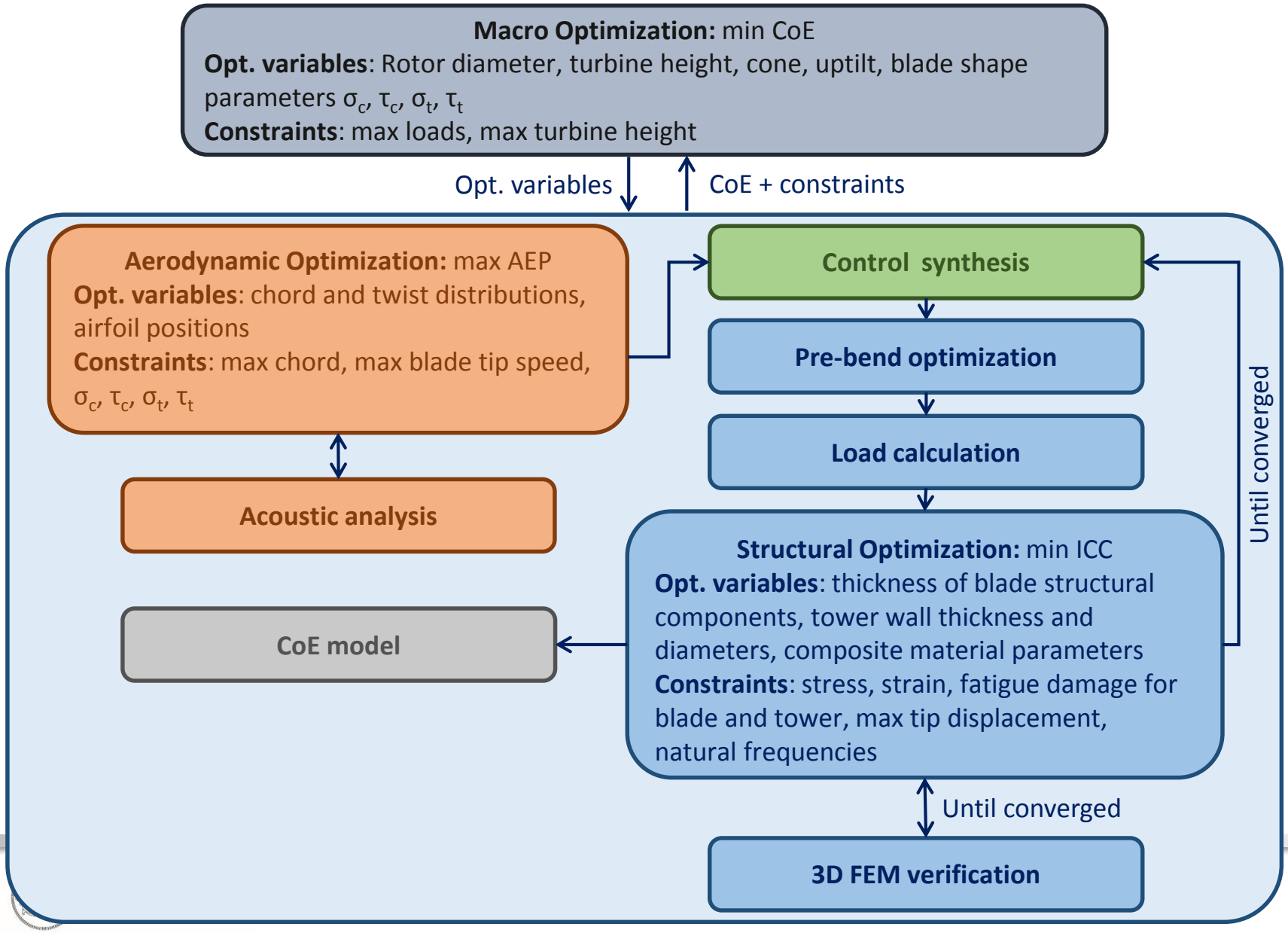
The project

Re-blading: update existing wind turbine blades with new, more efficient, ones.

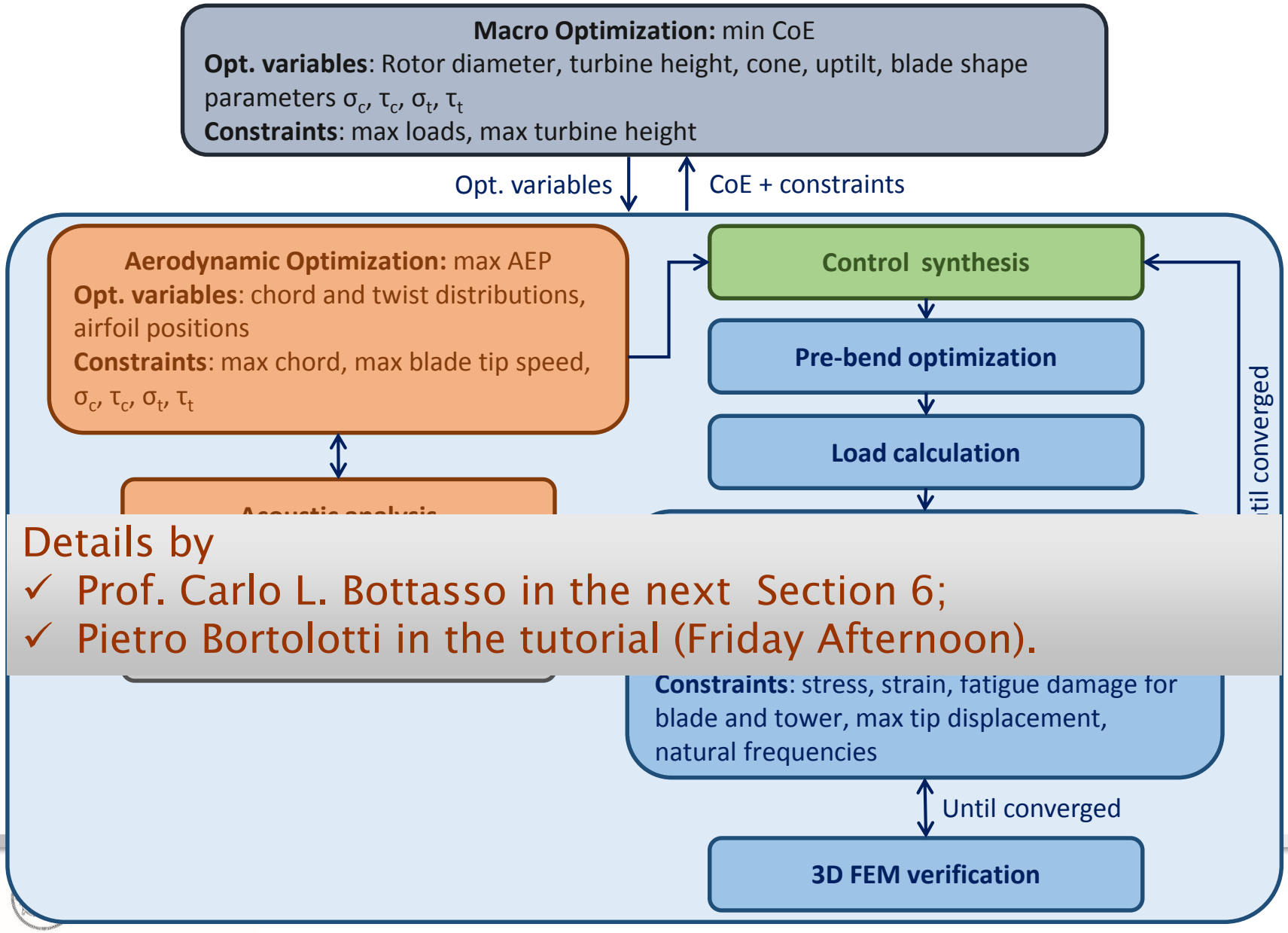


Need to maintain same loads on the other sub-components → design of blades with loads constraints → MDAO

Cp–Max Framework



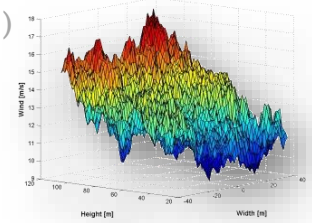
Cp-Max Framework



Multibody Dynamics Technology

Cp-Lambda highlights:

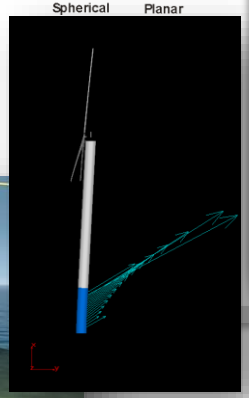
- IEC 61400 compliant (DLCs, wind models)



- **Geometrically exact composite-ready beam models**
- **Fully populated 6x6 stiffness (aeroelastic couplings)**

- Generic topology (Cartesian coordinates+Lagrange multipliers)

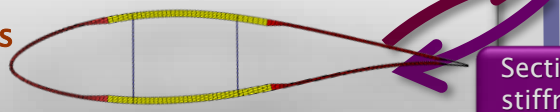
- Joints enforced by Lagrange multipliers



- Hydrodynamic loads

Cp-Lambda (**C**ode for **P**erformance, **L**oads, **A**ero-elasticity by **M**ulti-**B**ody **D**ynamic **A**nalysis): Global aero-servo-elastic FEM model

ANBA (**An**isotropic **B**eam **A**nalysis):



MDAO application to a rotor blade design

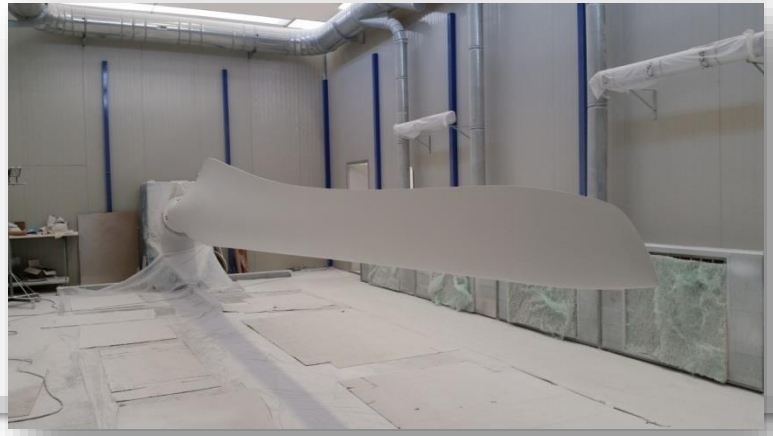
Manufactured Blades

2MW – 45m (MAIT–Gurit) ▼

300kW – 16m (Italtech–Gurit–Euros) ▼

700kW – 24m (ETA–Gurit–ECN) ▼

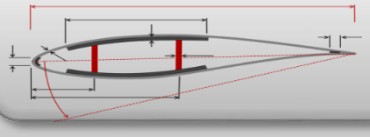
100kW – 10m (ETA) ▼



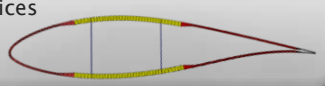
Aero-structural blade design loop

MDAO application to a rotor blade design

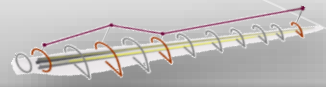
Blade definition of aerodynamic & structural design parameters



Blade:
- ANBA 2D FEM sectional analysis
- Computation of 6x6 stiffness matrices

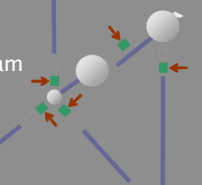


Blade:
- Geometrically exact beam model
- Span-wise interpolation



"Coarse" level: 2D FEM section & beam models

Update complete HAWT Cp-Lambda multibody model
- DLCs simulation
- Campbell diagram
- AEP



DLC post-processing:
load envelope, DELs, Markov, max tip deflection

Blade constraints
- Maximum tip deflection
- Natural Frequencies
- Max stress/strain (ANBA)
- Fatigue analysis (ANBA)

WT constraints
- U/F loads on hub/tower

➢ **Update Blade mass & cost**

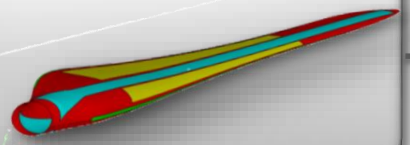
S.Q.P. Optimizer

Min cost
subject to constraints

When SQP converged

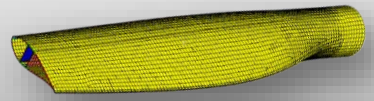
Constraint/model update heuristic (to repair constraint violations)

Automatic 3D CAD model generation

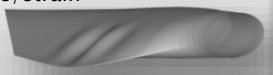


Automatic 3D FEM meshing

Update of blade mass (cost)

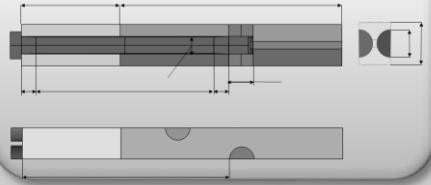


Analyses:
- Max tip deflection
- Max stress/strain
- Fatigue
- Buckling

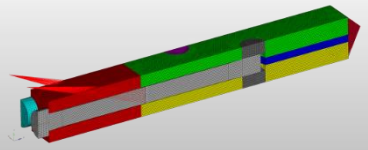


Verification of design constraints

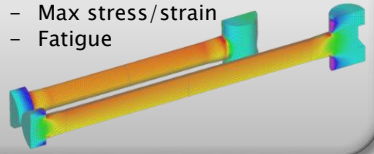
Root detailed analysis:
Geometry parameterization



Automatic FE model generation

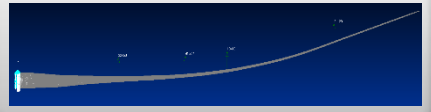


Sizing of bolted joint and blade root laminate
- Bolts preload calculation
- Max stress/strain
- Fatigue

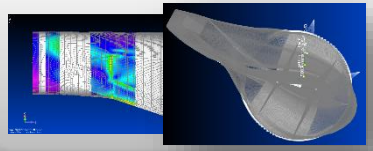


"Fine" level: 3D FEM

Computation of static/fatigue loads for lab testing

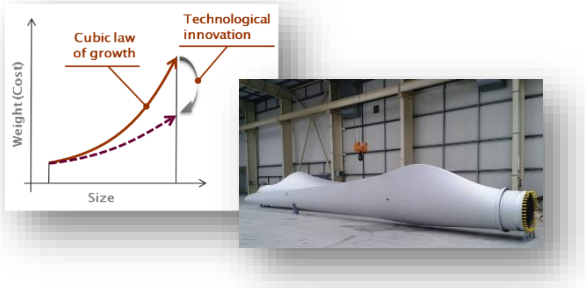


Analyses on 3D FEM model



Testing
- Verification of 3D FEM model
- Verification on construction

Outline



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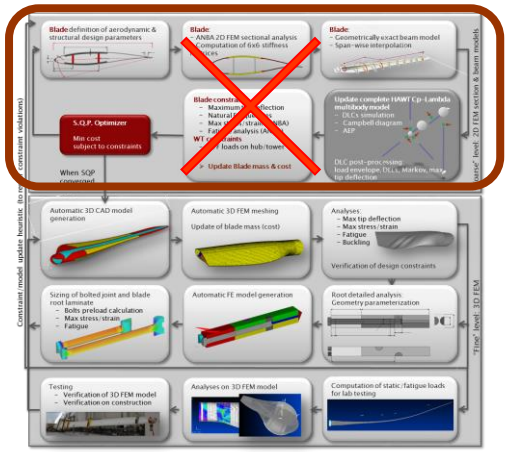
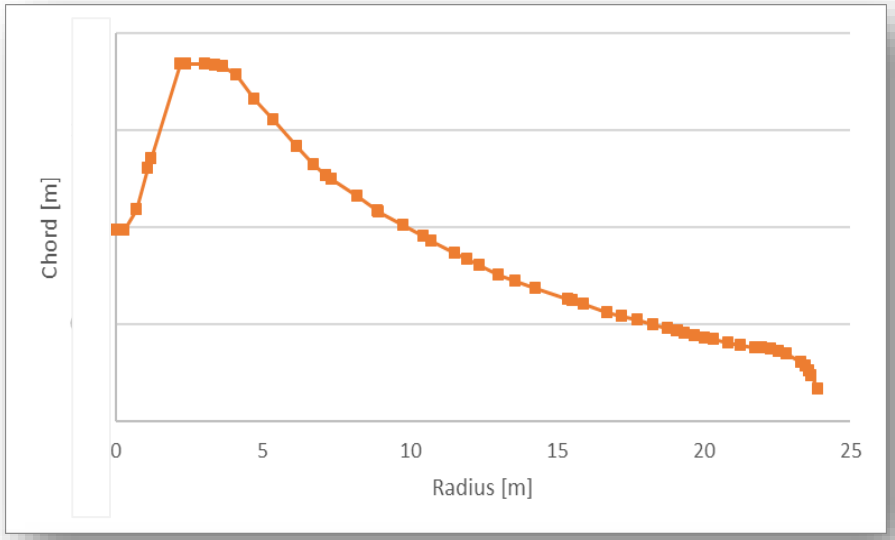
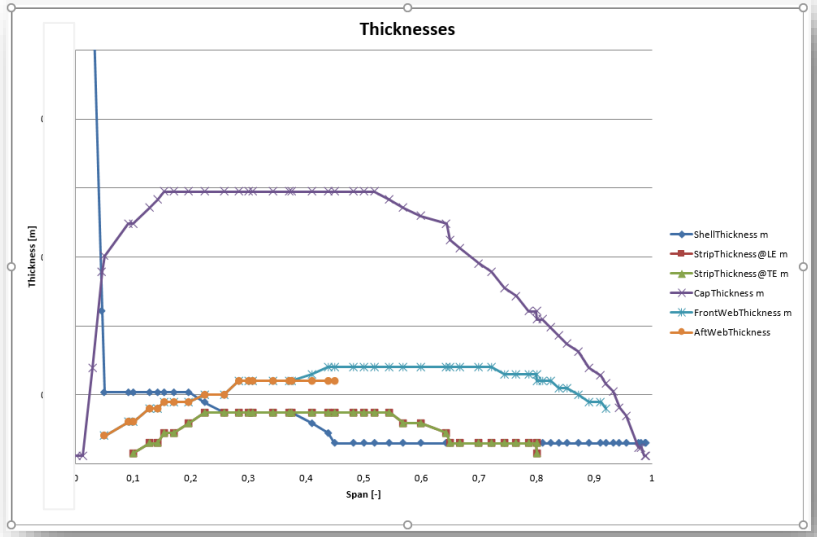
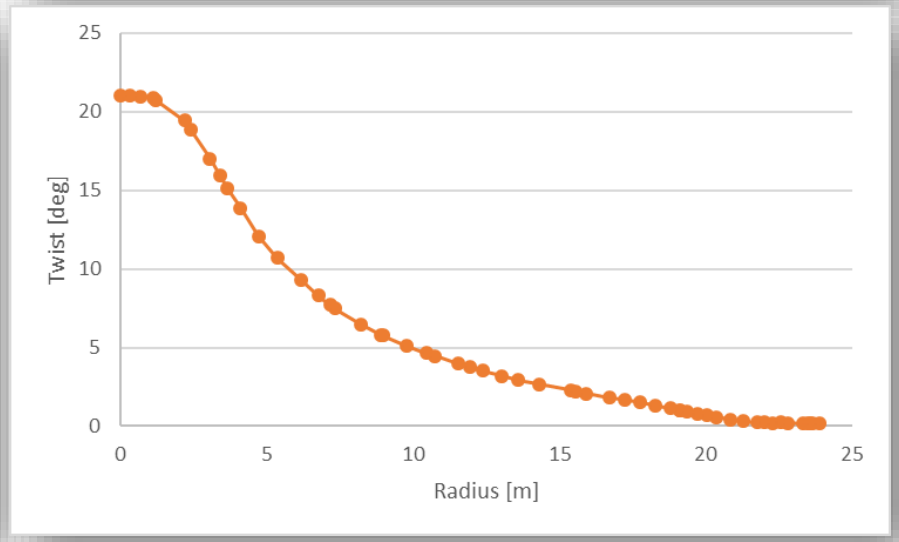
MDAO Design – coarse level



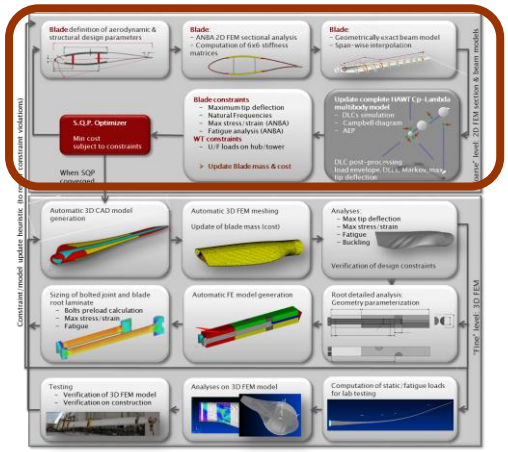


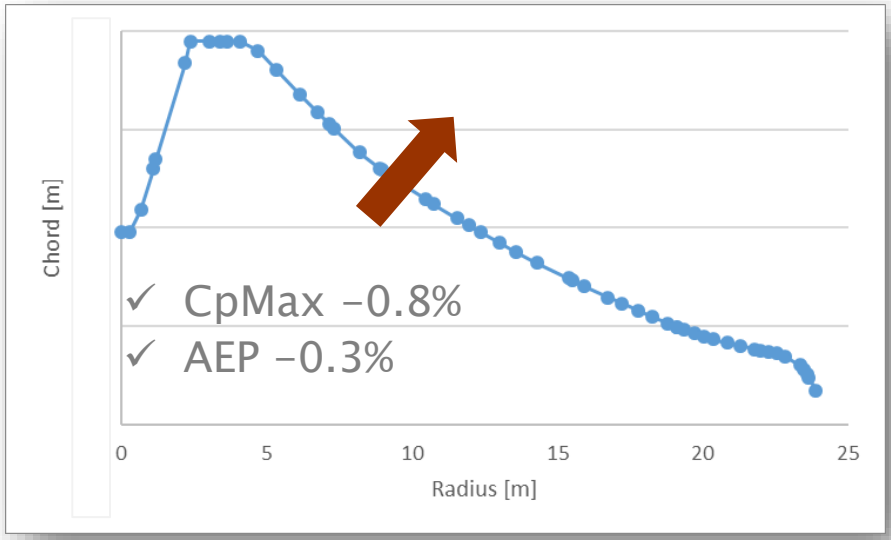


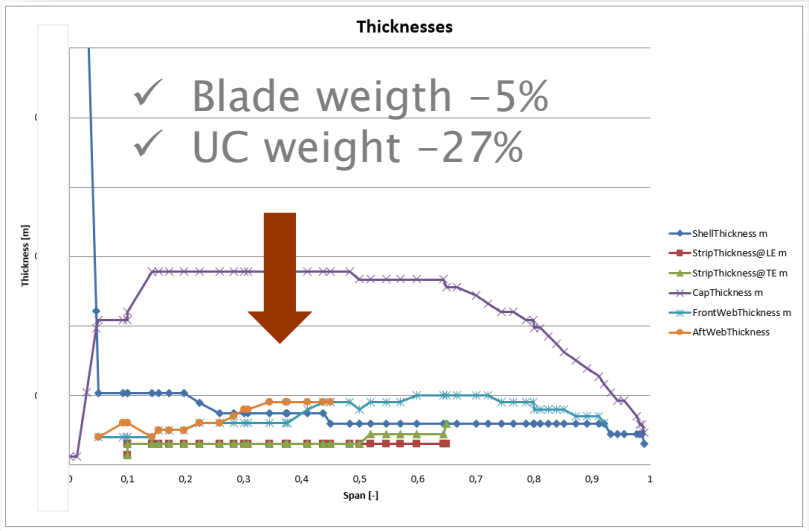


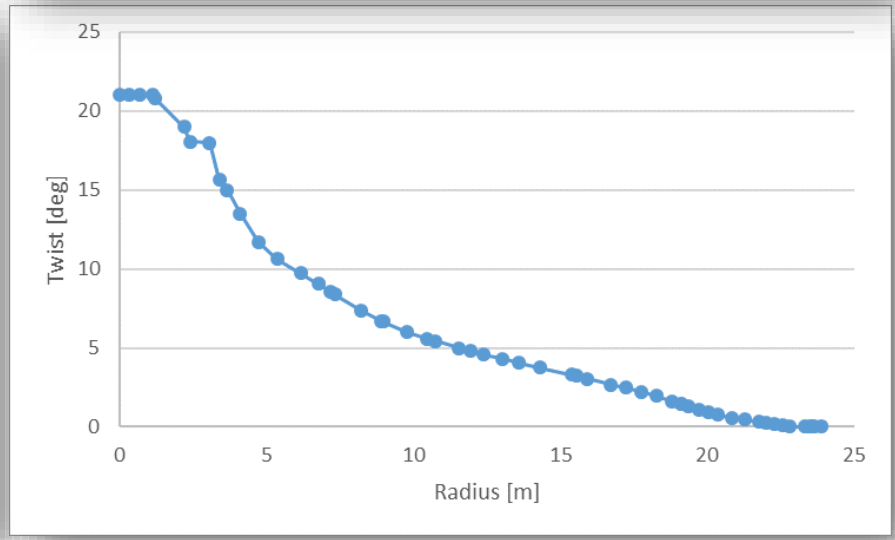
MDAO application to a rotor blade design

MDAO Design – coarse level







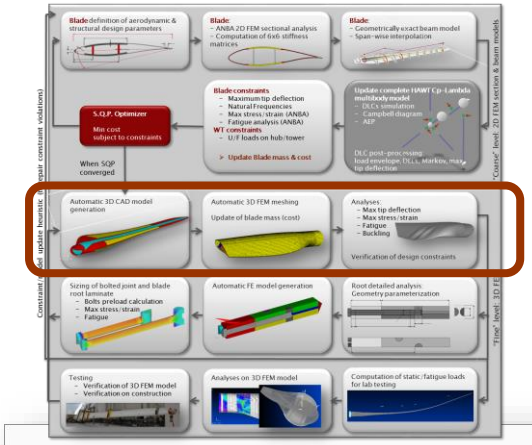


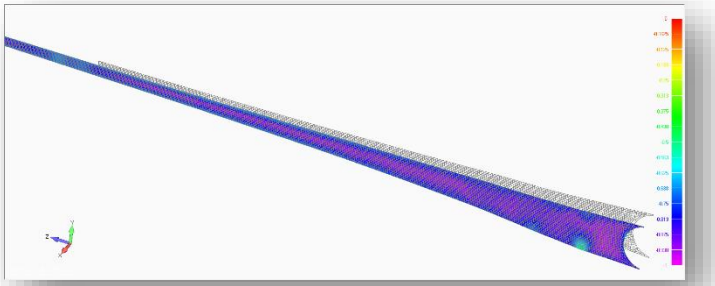
MDAO application to a rotor blade design

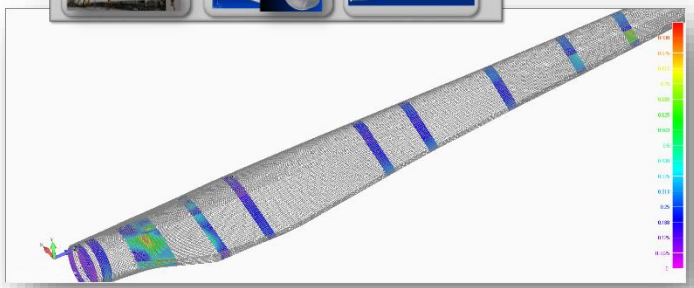
POLITECNICO MILANO 1863

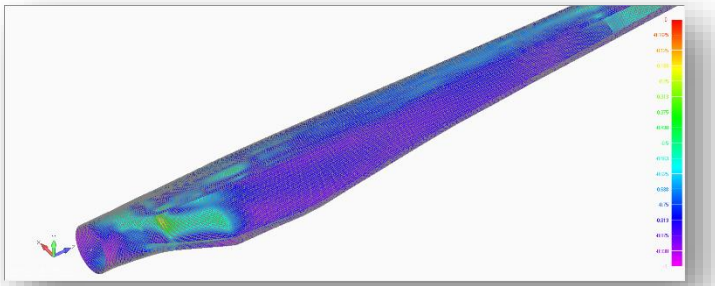
POLI-Wind Research Lab

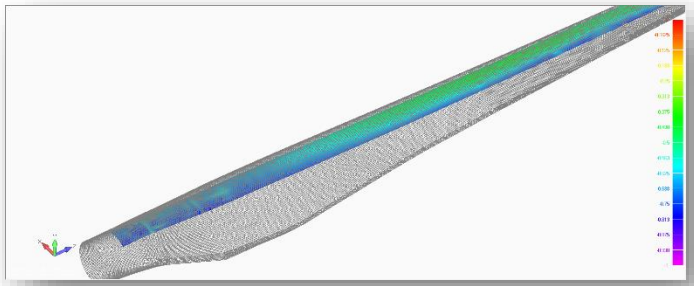
MDAO Design – fine level

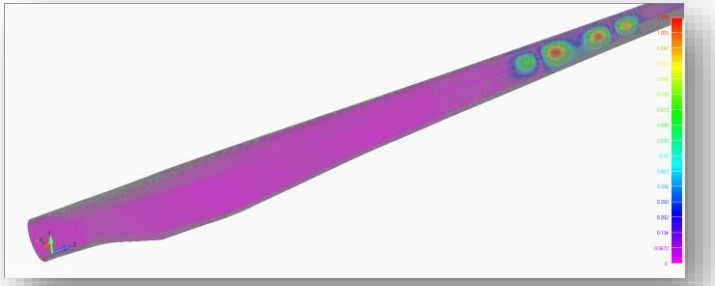






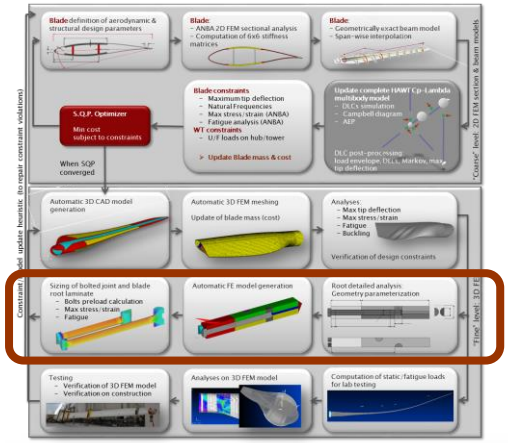


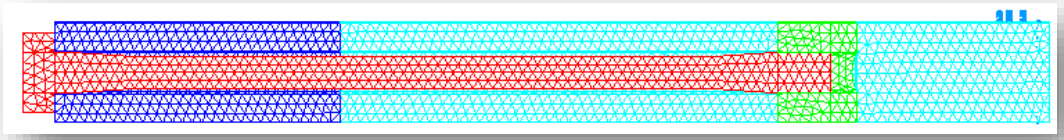


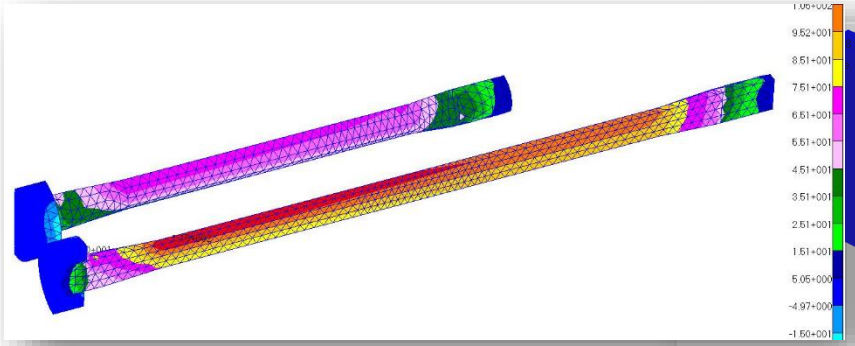


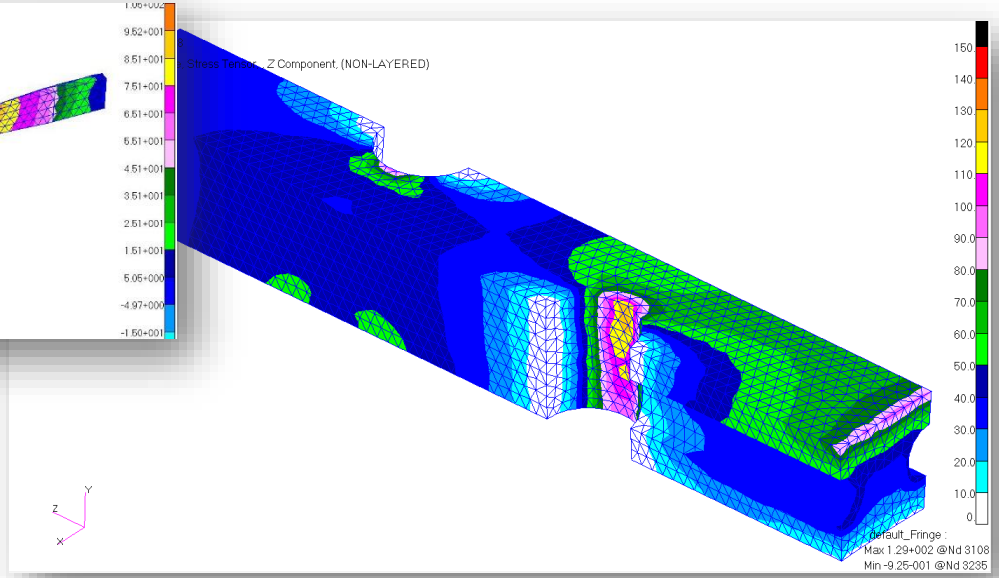
MDAO application to a rotor blade design

MDAO Design – root analysis



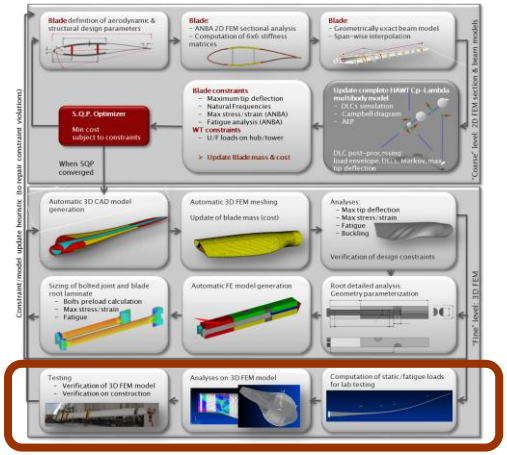


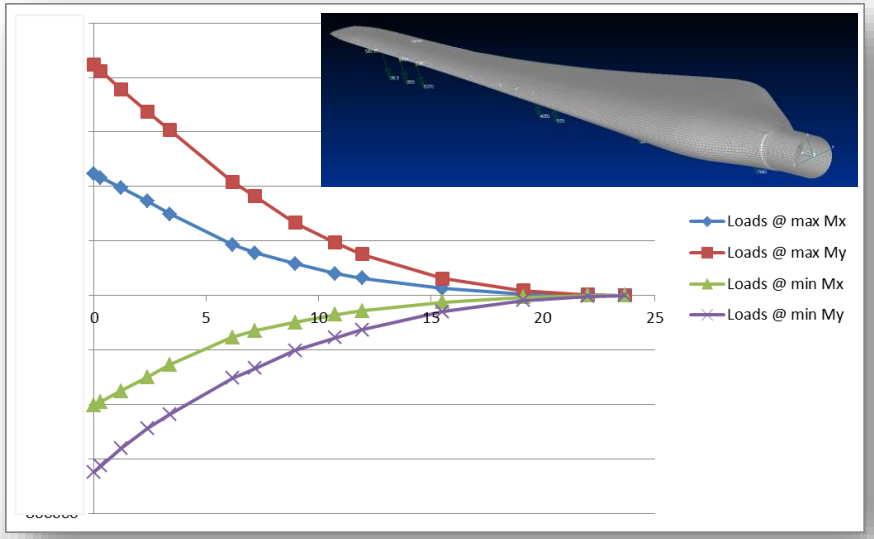


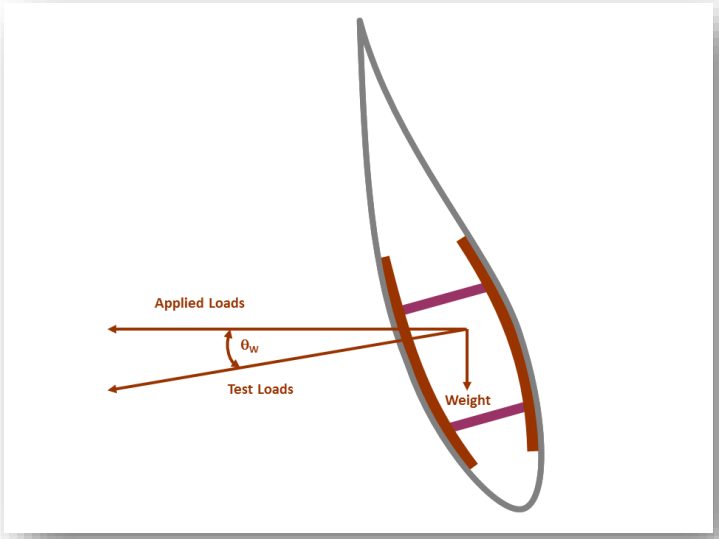


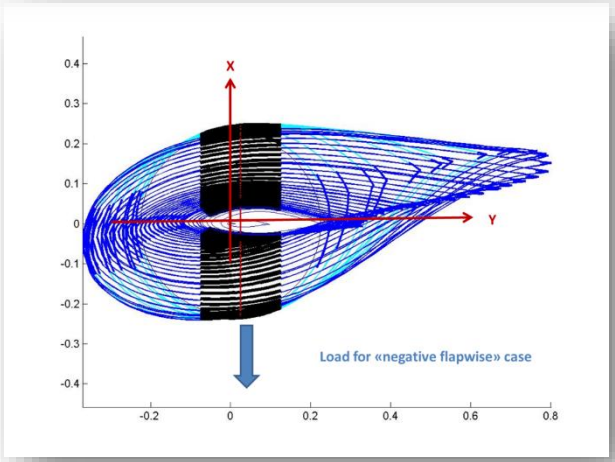
MDAO application to a rotor blade design

MDAO Design – load testing





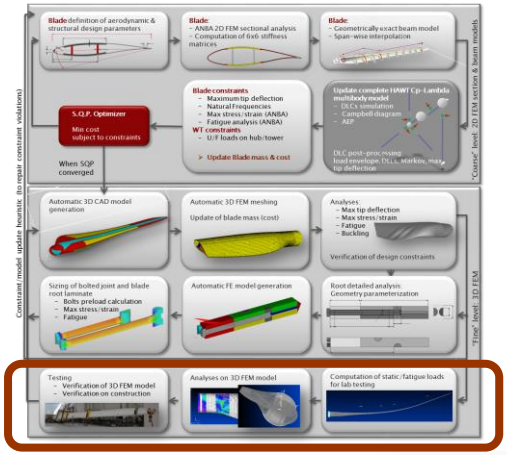


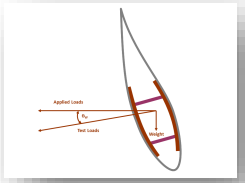


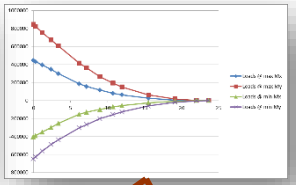
MDAO application to a rotor blade design

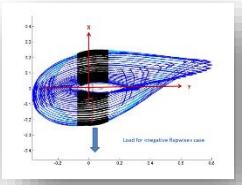
MDAO Design – load testing

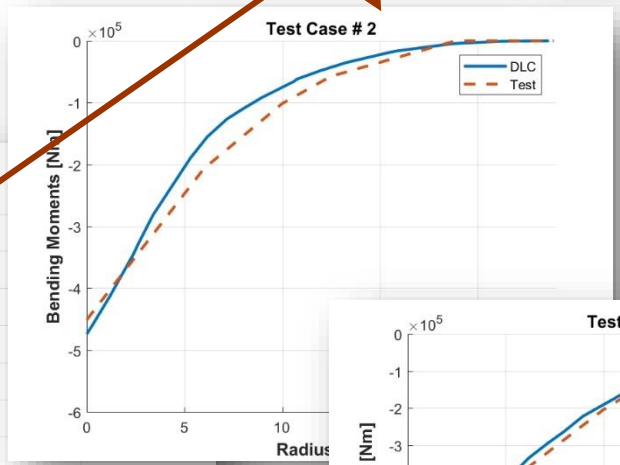
Optimization problem to find loads/load application points

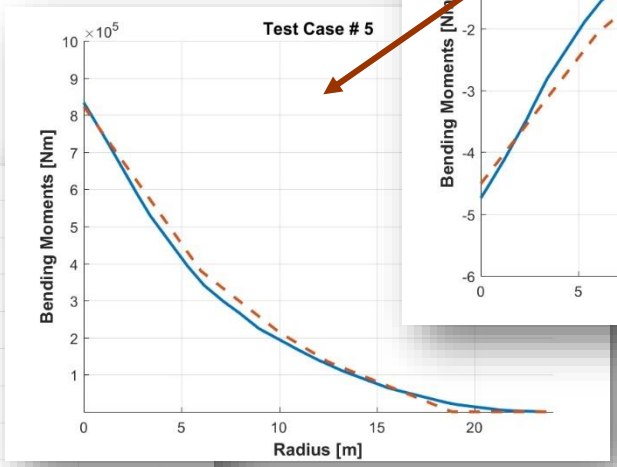


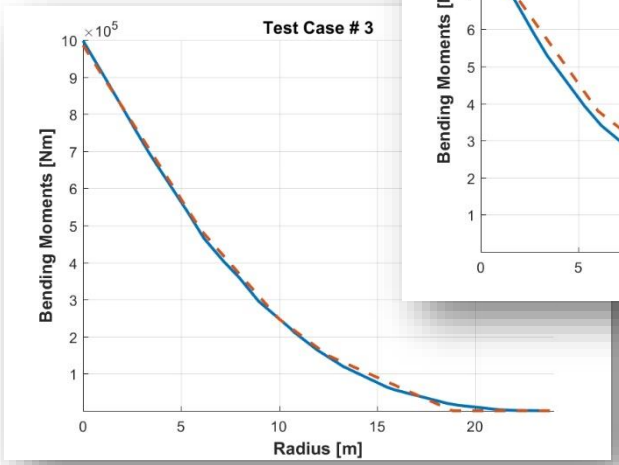


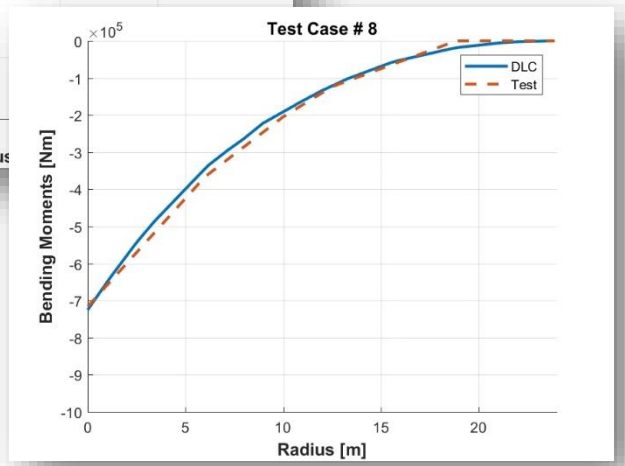






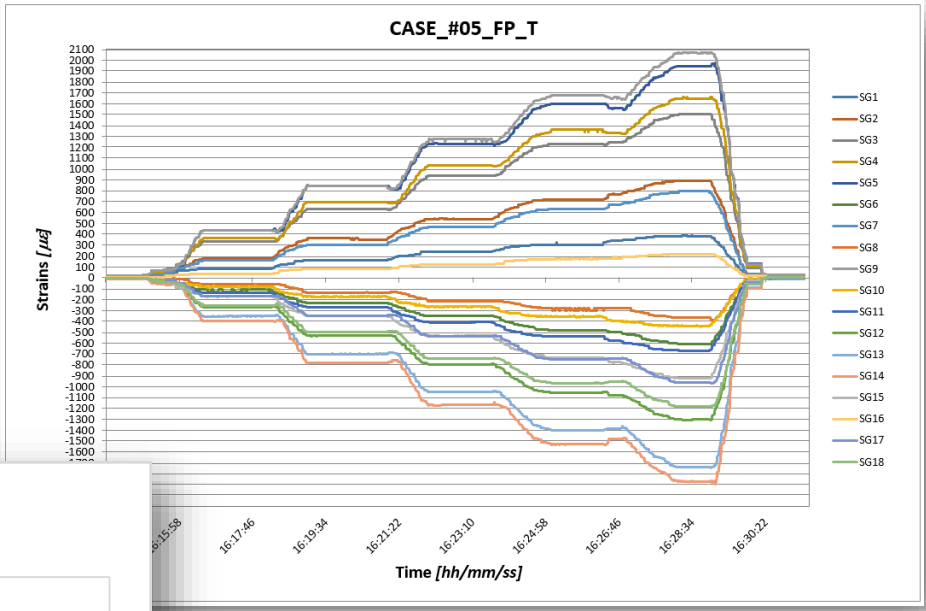


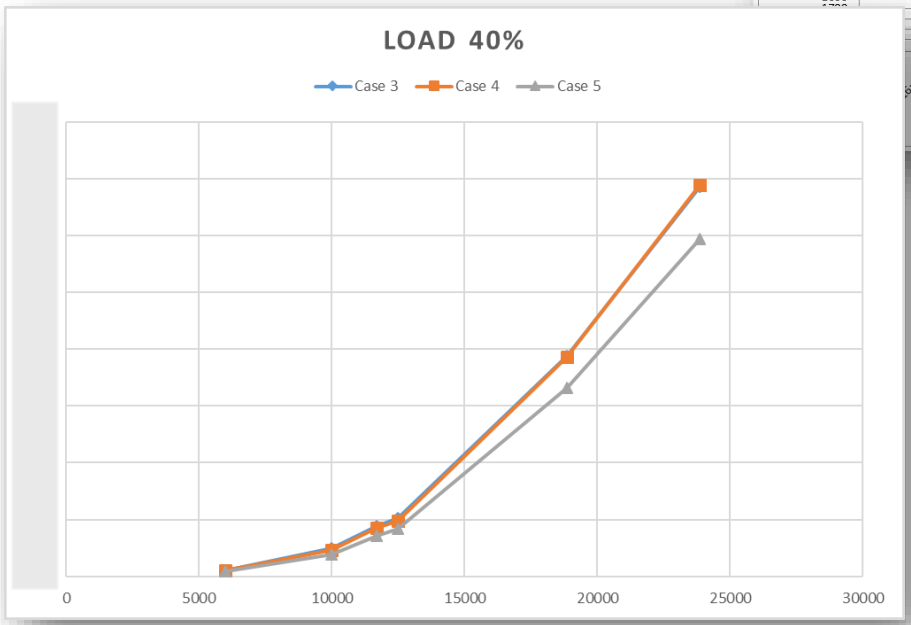




MDAO application to a rotor blade design

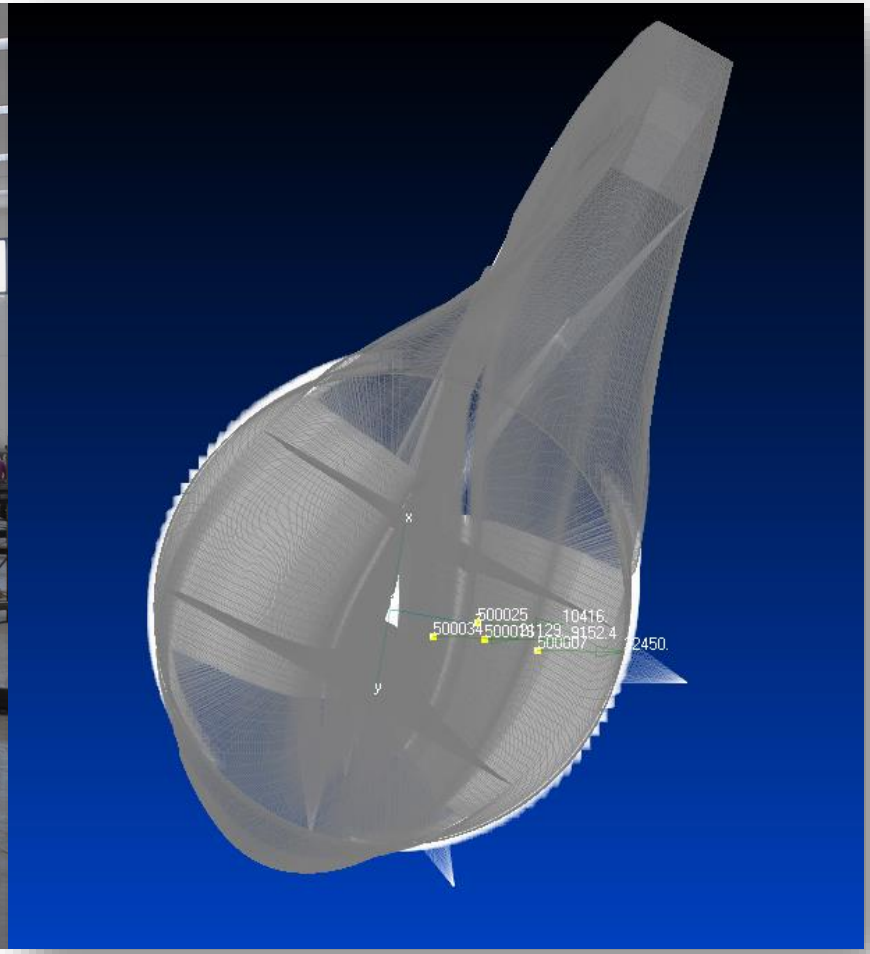
Testing



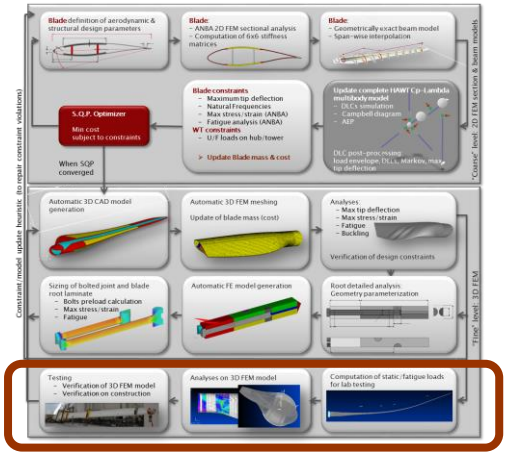


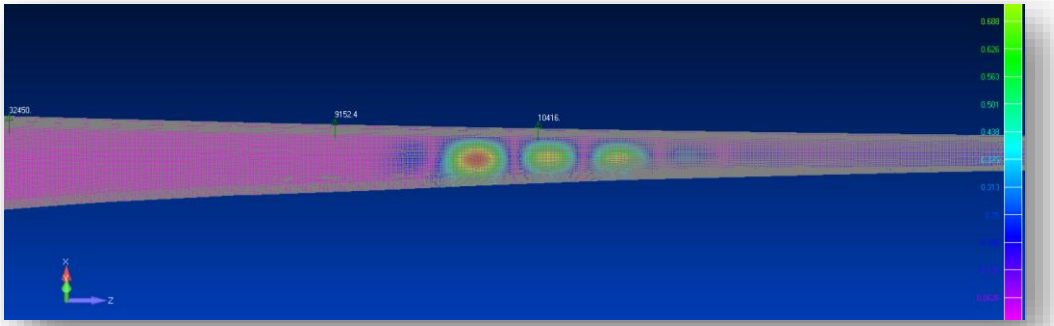
MDAO application to a rotor blade design

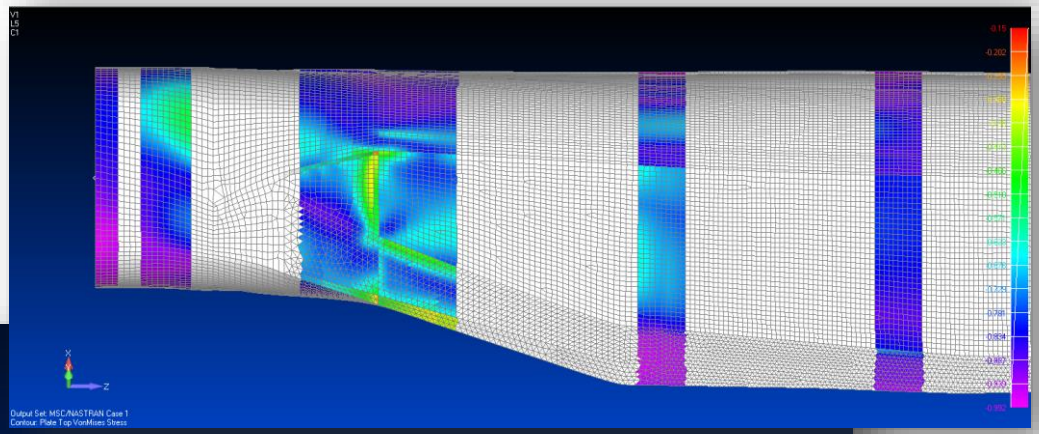
MDAO Design – Testing

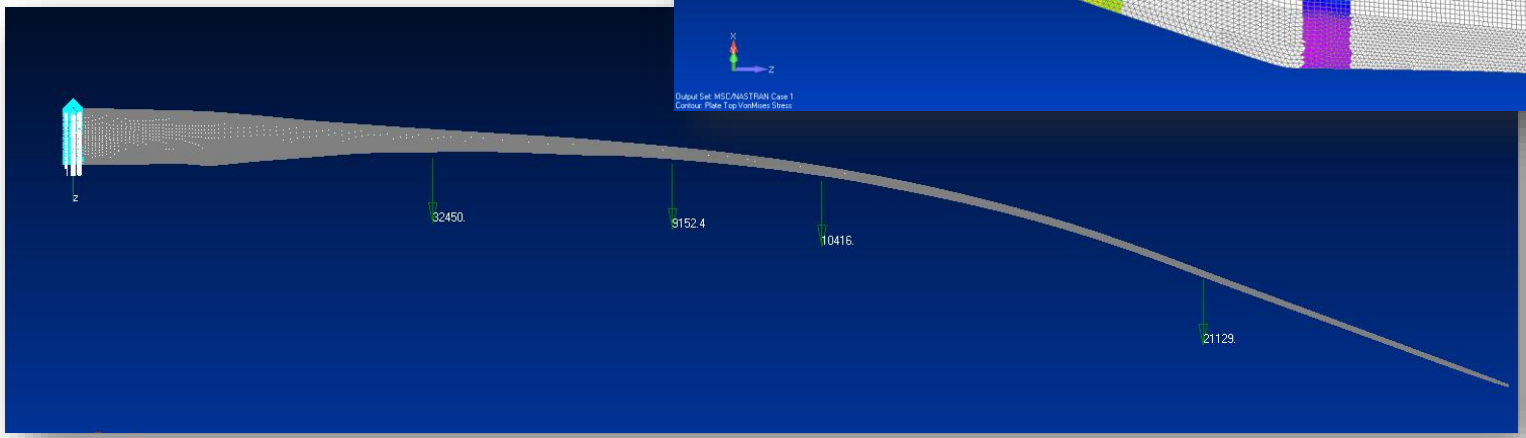


MDAO Design – Testing



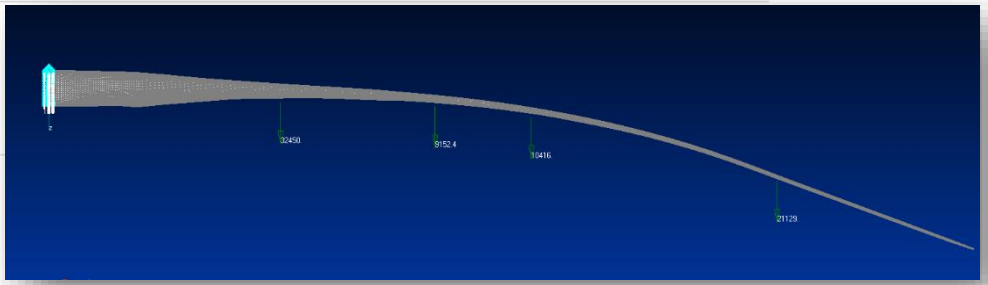






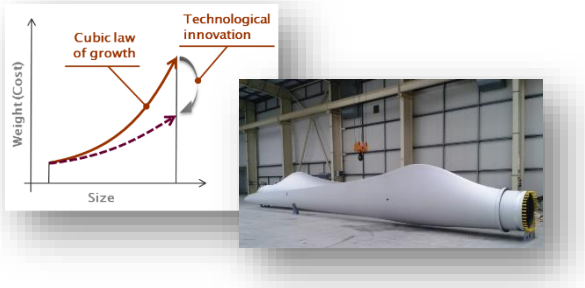
MDAO application to a rotor blade design

Testing



Tip Deflection [mm]
Applied load
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Case 5
Measurements

Outline



Introduction and motivation

The project and tools

MDAO Design and Testing

Conclusions and outlook

Conclusions

- Strong coupling between the aerodynamic and the structural design variables (and the electro-mechanics ones…)
- A multi-level approach may satisfy the need to run high fidelity analyses with "reduced" computational effort (coherent with industry deadlines…)
- MDAO is required to account for the interdependence physics of the problem

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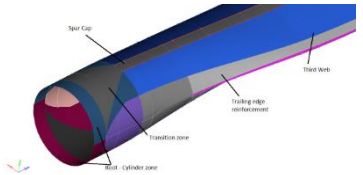

Thank you!

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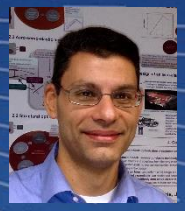
TORQUE 2018

Milano, Italy
20-22 June 2018

SAVE THE DATE!

The seventh edition of the conference «The Science of Making Torque from Wind (TORQUE 2018)» will take place in June 20-22, 2018 at Politecnico di Milano, Campus Bovisa, Milano, Italy

Topics, call for papers and important dates will be available soon at the conference web site:
www.torque2018.org



Alessandro Croce
Chairman of TORQUE 2018