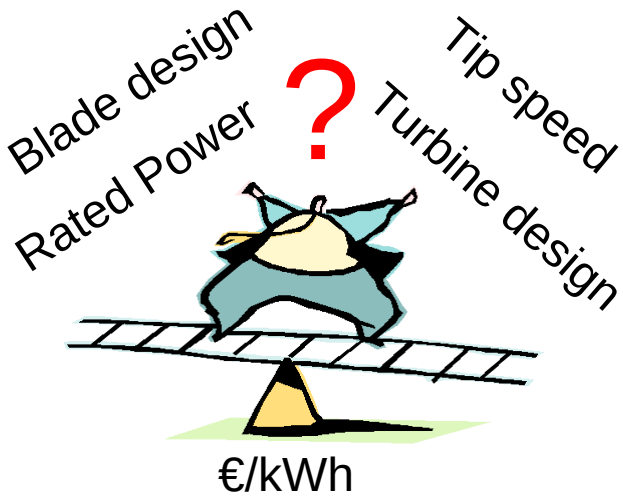
Integrated Rotor Design

Lars Fuglsang
Head of Blade Design, Research, LM Glasfiber A/S

Challenges faced in turbine and blade design

Problem Definition:

- ! Blade and turbine design is all about making the right compromises.
- ! The impact of the conceptual choices made in the initial design phase is massive and will affect CoE and competitiveness significantly.
- ! The complexity in design is significant and the associated risk of bad choices favors incremental development of existing turbines in small steps.



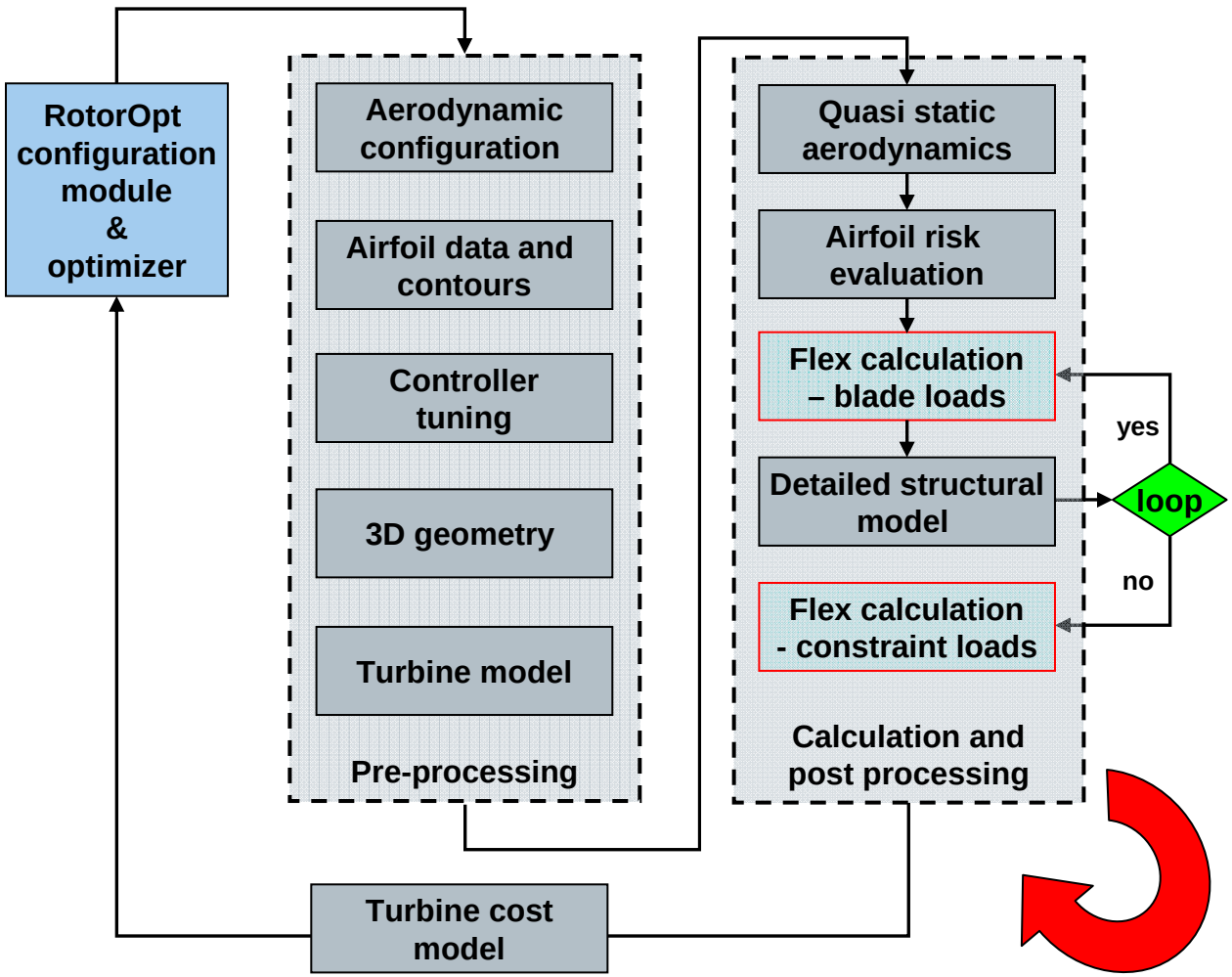
Question:

- ? How do we ensure that we make the right conceptual choices and end up with a cost efficient and reliable design?

Solution:

- ✓ A design philosophy with focus on integrated design of the turbine, the blades and the controller.
- ✓ A design tool offering a structured approach in integrated design by which risk is mitigated and CoE is reduced.

The RotorOpt Design Tool



Design variables

- Airfoils
- Blade length
- Chord, twist and thickness distribution
- Tip speed
- Controller parameters
- Tower structure
- Tilt, cone, overhang and pre-bend

Constraints

- Airfoil application risk margins
- Extreme loads
- Fatigue loads
- Deflection
- rpm or tip speed
- Frequencies

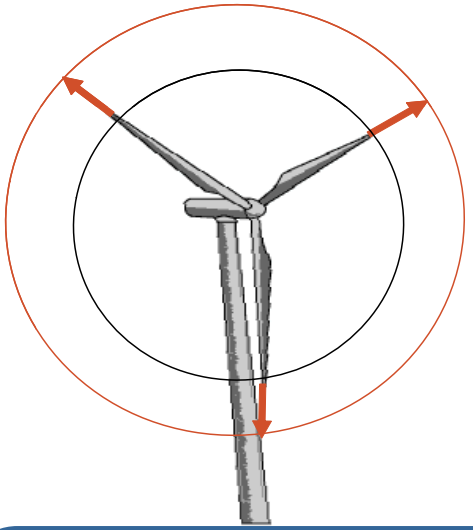
Fully integrated design environment for optimization of a rotor to a given turbine

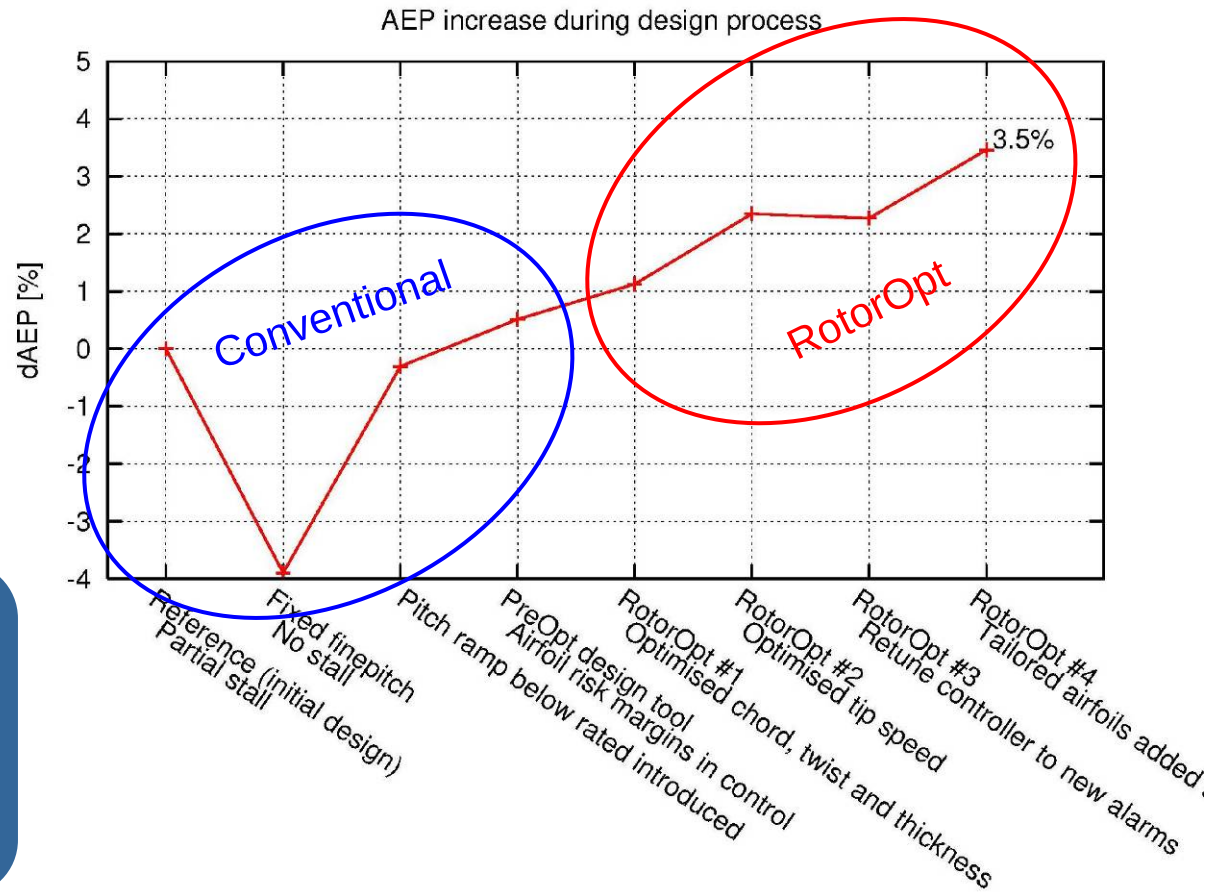
1 loop: 3-5 min.

Example of RotorOpt design

Initial step – define scope and the fixed conceptual parameters:

- ! Reduce CoE and ensure reliability
- ✓ 3 bladed upwind PVRS turbine, rated power, IEC class, power frequency converter technology, noise emission. A preferred rotor diameter was chosen for strategic reasons.

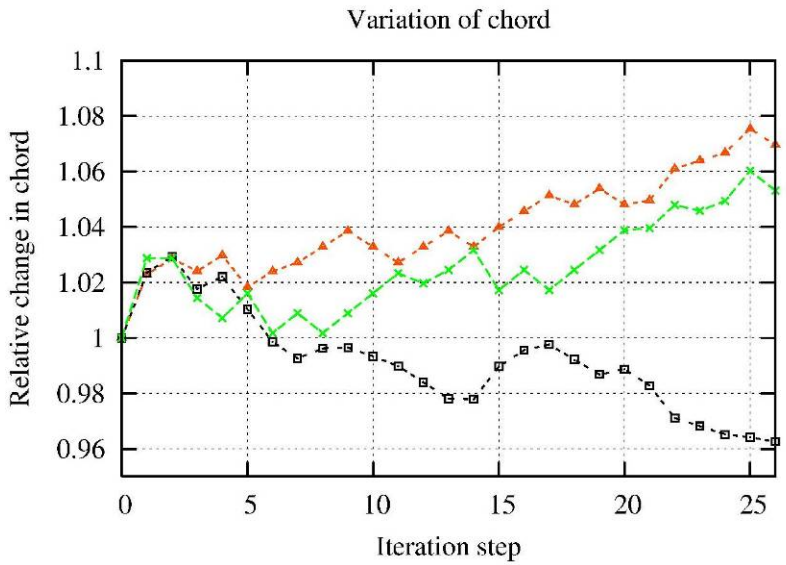


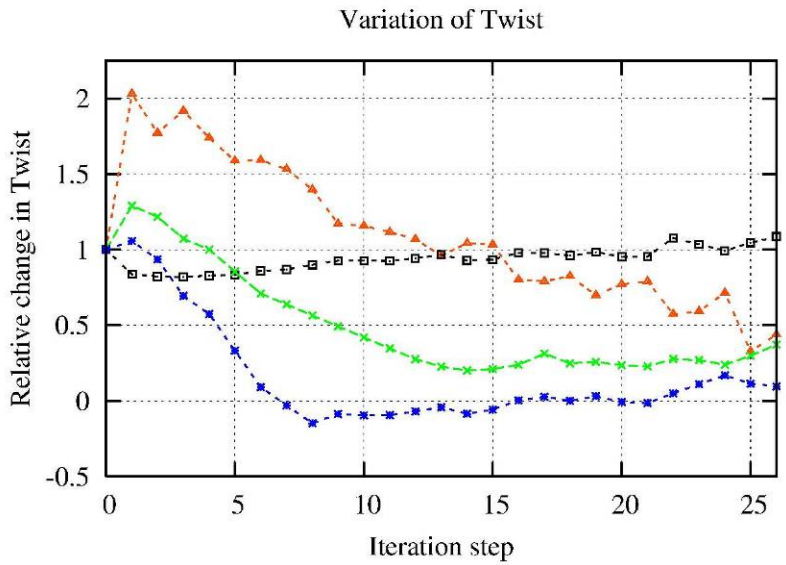


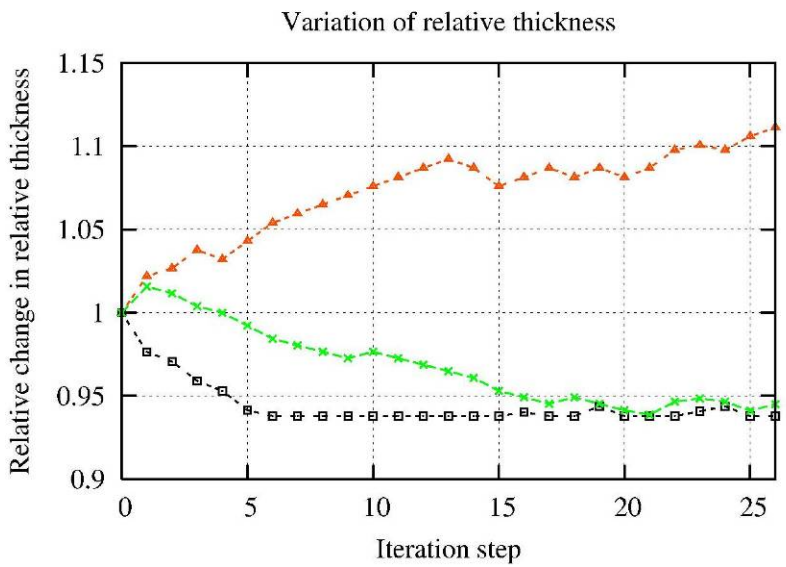
AEP up by 3.5%

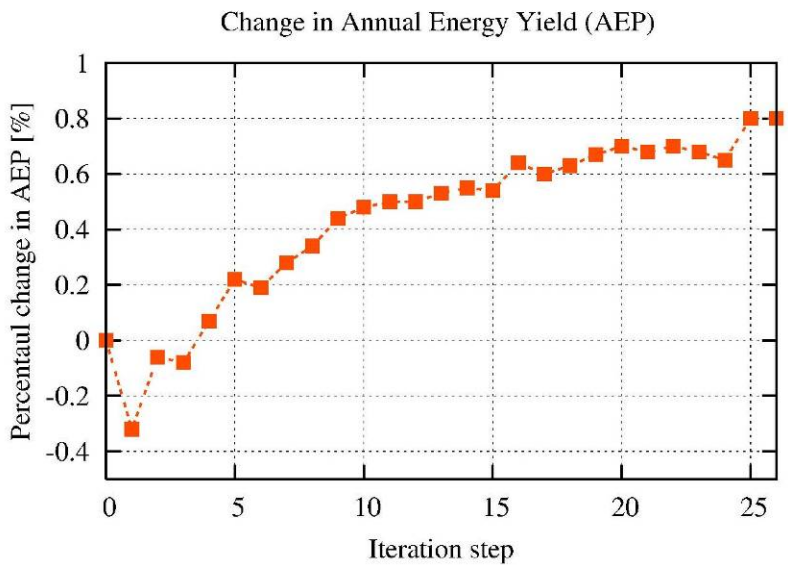
Final loads within initial load envelope

RotorOpt#1 Optimization Log





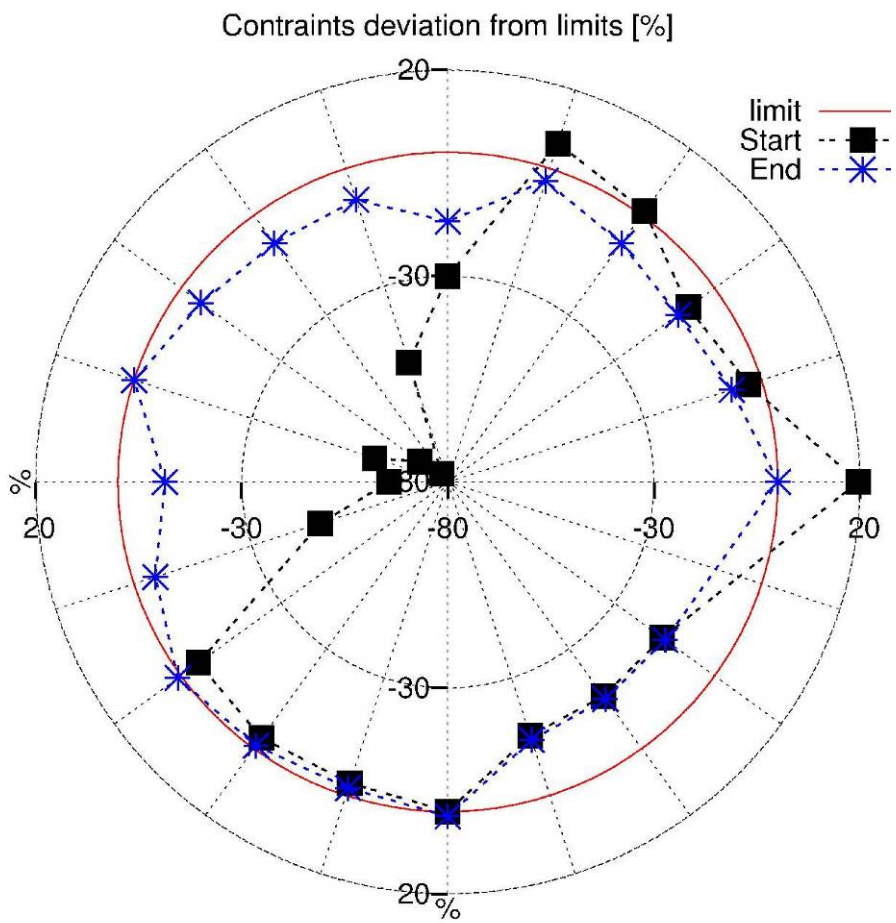




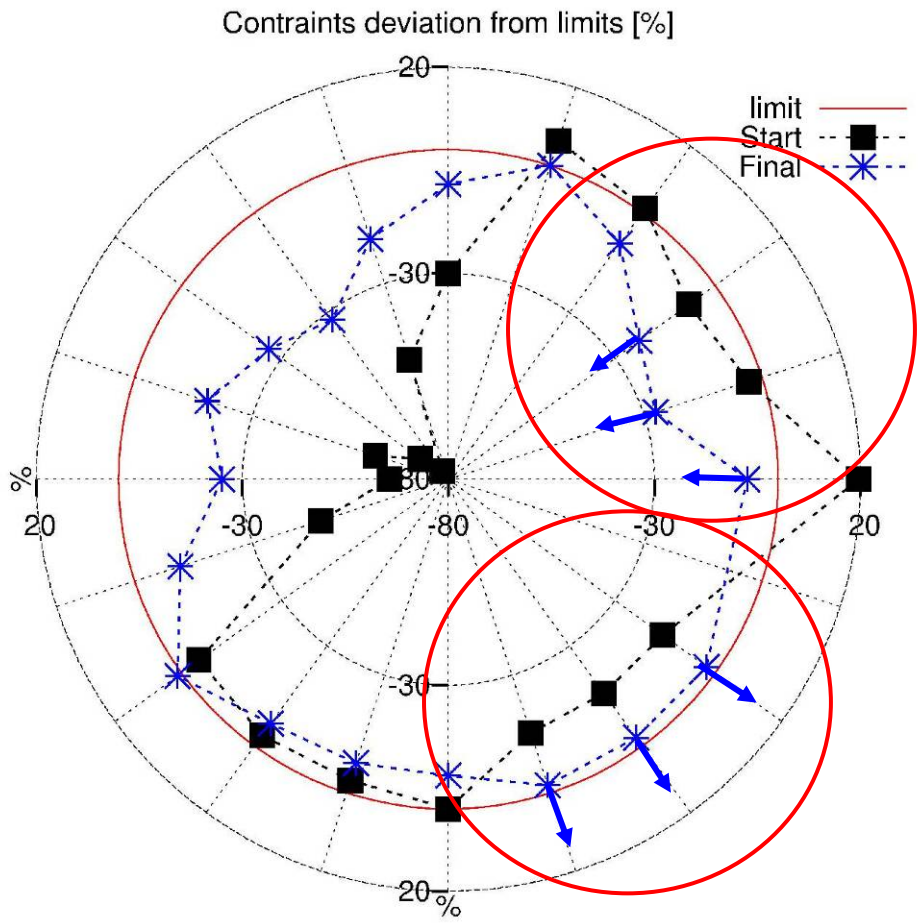
The strength of optimization

Constraint variable plots

RotorOpt#1



First compared to final



LM Glasfiber

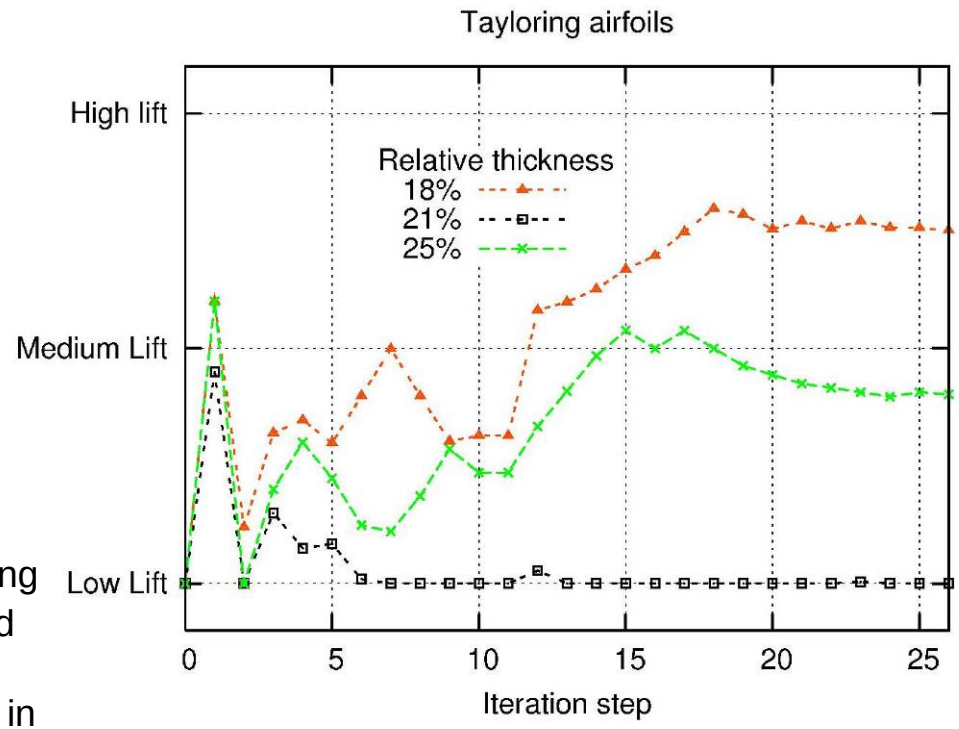
LM airfoils as design variables

- ! **Very strong coupling between airfoils, aerodynamic performance, loads and structural design**

- ✓ **An excellent example of integrated design**.
  - Resulting airfoils do not have the highest Cl/Cd ratio but supports structural design, load reduction and controller response. Hereby CoE are decreased.

- **Essential to have**
  - ✓ Airfoils specifically designed to support tailoring
  - ✓ Consistent methods for airfoil comparison and risk assessment
  - ✓ Airfoil data measured at various Re-numbers in the same wind tunnel

- **Final airfoil designs are verified in the LM wind tunnel**



AEP up by 1.2% compared to DU airfoils initially applied

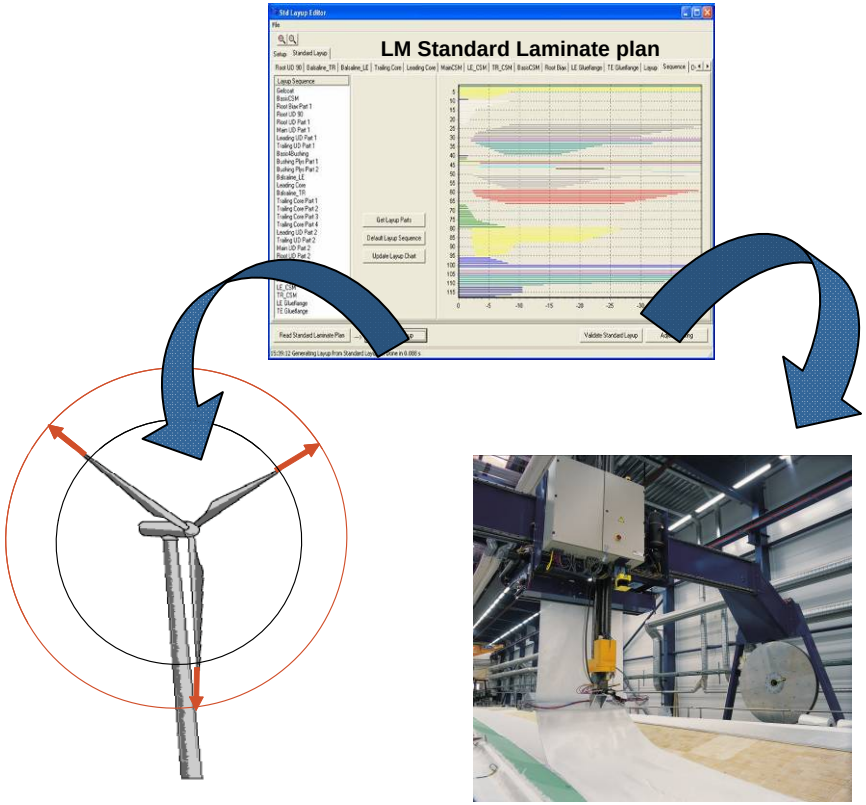
Detailed structural design required

- ! **Very strong coupling between structural design and turbine component loads.**

- **Detailed structural design is essential**
  - The coupling between structural design and loads is non-trivial; a change in load will not always cause a structural design change.
  - Precise gradient calculation required for stable and meaningful optimization

- **The LM 'Standard Laminate plan is included. It offers:**
  - ✓ fully automated generation of detailed 3D lay-up with 85% detail of final design in less than 2 minutes
  - ✓ Accurate correlation of all effects to structural design.

- ✓ **An excellent example of integrated design.**
  - The possibility to increase load components that do not change structural design is exploited.



The LM Standard Laminate Plan: 3D lay-up with 85% detail in less than 2 minutes

Conclusions

- **Main characteristics of the design tool are**
  - ✓ it exploits the potential of integrated holistic design
  - ✓ it offers a structured approach to reduction of cost of energy.

- **It has been shown that**
  - ✓ The integrated design approach is effective for making both conceptual choices and detailed design.
  - ✓ The optimization is stable and provides meaningful results decreasing CoE within the load envelope.
  - ✓ LM airfoils as design variables adds significant value.
  - ✓ Very detailed structural design is essential and adds to the integrated design philosophy

- **Main result**
  - ✓ 3.5% increase in annual energy yield with insignificant increase in cost. Earning defined by the margin between yield and cost is hereby increased substantially.

Paper

For details the papers is available at

www.lmglasfiber.com/downloads

Thank you!