THE POWER TO DELIVER

ROTOROPT 2.0

15/1/15

By Peter Baek, Conceptual Design
AGENDA

1. Integrated Design Challenge
2. Blade Design Components
3. RotorOpt 2.0
4. Design Example
Wind Turbine Optimization

Turbine optimization objective:

» Minimize cost of energy.

Simple, but

» Each manufacturer has a different design philosophy, technology and suppliers.

» Manufacturers use platforms with varying rotor and drive train configurations to bring down costs.
Wide range of possible designs

Blade optimization:

» Maximize AEP within load envelope.

» Minimize mass/moment for given AEP

Make the right compromises
RotorOpt 1.0 (2008)

First generation blade optimizer

- Weak structural coupling
- Few load cases
- Serial perturbations
- Desktop computer power
Main Blade Design Components

LM Material Database
- All validated materials available for production
- Including the Material Design Values (strength)
- Based on extensive testing.

LM Standard Laminate Plan
- Parametric, Scalable & “Optimizable”
- Ensures 80% production ready structural design
- Draws on 30+ years of experience
- Used directly by LM tools

LM Airfoil Families
- Holds all the latest validated airfoils (shapes & polars)
- All airfoils validated in LM Wind tunnel
- Different add-on concepts available (T-Spoiler, VG’s, Serrations, etc)
Airfoil Blender

Smooth airfoil data from reliable source

- Access to large database of measurements for LM-airfoils \((1.5 \cdot 10^6 < \text{Re} < 6 \cdot 10^6)\) with addons (VGs, serrations, T-spoiler)

- Arranged cleverly for the optimizer to be able transition smoothly from high to low lift airfoils
Load Calculation with LM-Flex

Standard IEC load cases

» 20-100 IEC load cases (normal operation and extreme load cases) are simulated with LM-Flex (based on FLEX5)

» LM-Flex can be swapped with Hawc2 for higher fidelity modelling – but 50-100x slower

» Post processing using rain flow counting and extreme value extrapolation
Layup and Safety Evaluation

Structural Engineering

- Layup using "LM Standard Laminate Plan"
- Properties from "LM Material Database"
- Cross section calculations with 2D finite element model
- Evaluation of structural integrity due to fatigue and extreme loads (and buckling)
Setting the scene

Boundary Conditions
✓ Wind climate (e.g IEC 1A),
✓ Material (e.g. glass, carbon, hybrid),
✓ Turbine properties (height, cone, tilt, masses, …)
✓ Turbine load envelope (fatigue and extreme)
✓ Turbine Controller Strategy (e.g. IPC, curtailment, …)

Object Function. Pick one:
• AEP
• Mass or static moment
• Match blade
Design Variables

Distributions of:
- Chord,
- Twist,
- Relative thickness,
- Airfoil families,
- Airfoil addons (e.g. VGs),
- Blade centerline (x & y),
- Ply groups.

 Scalars
- Blade length,
- Rotation Speed
Constraints

- Maximum loads,
- Tip-to-tower clearance
- Minimum AEP,
- Maximum mass/moment,
- Minimum structural safety (plys, glue, bushings, etc.),
- Layup rules (e.g. tapering constraints),
- Minimum aerodynamic safeties,
- Maximum sound emission,
- Blade frequencies,
- Geometric constraints (lightning protection, maximum curvatures)
One Design Evaluation

Diagram:
- Design variables
  - Airfoil Blending
  - Material Layup
  - 3D Geometry
- Steady State BEM
- Calculate Loads
- Safeties

Objective/Constraints:
- AEP
- Noise
- Turbine Loads
- Blade deflection
- Ply safety
- Bushing safety
- Ply rules check
- Mass & moment
- Frequencies
- Curvatures, Lightning protection
Parallel Tasks in one Evaluation

Calculate Loads

time
Many parallel evaluations

\[ x \rightarrow f, g \]

\[ x_1 + dx_1 \rightarrow df/dx_1, dg_1/dx_1, \ldots \]

duration

\[ \ldots \]
Inhouse HPC Cluster

Hardware

✓ 48 nodes (8 cores each)
✓ InfiniBand network
✓ Scalable

Software

✓ Linux operating system
✓ Sun Grid Engine
✓ Python
LM101

Conceptual Design Demonstrator
Conceptual Design Demonstrator

- 101m Blade length
- 101m/s Tip speed
- 10.1 MW Rated power
- Wind Class IEC 1A
- Carbon fiber technology
- Collective Pitch Control, Variable Speed
Convergence History

- **Objective function (Mass)**
- **Maximum constraint**
- **Max Step Size**
Convergence History

<table>
<thead>
<tr>
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<th>Red</th>
<th>Green</th>
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<tbody>
<tr>
<td>Objective</td>
<td>Max AEP</td>
<td>Min mass</td>
</tr>
<tr>
<td>Constraint</td>
<td>...</td>
<td>-2% AEP</td>
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Diagram showing convergence history with iteration 0.
Convergence History

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Design Variables

Blade Definition
Mass vs. Annual Energy Production

-0.0% chord [m]
-1.0% chord [m]
-2.0% chord [m]

Mass [%]

AEP [MWh]

80 - 100

Mass [kg]

97.5 - 100.0

97.5 - 99.5

Next steps

Faster, better accuracy, bigger

- Faster with frequency domain load calculations.
- More precise with Hawc2 and FEM shell/solid model in the loop.
- Tap into cloud computing ressources
Conclusion

Rapid Design Process

» There is no universal optimum blade geometry.

» RotorOpt is a fast way to get the best compromise between structure and aerodynamics for the specific customer case

» RotorOpt uses validated blade design components to minimize project risk with an almost production ready output
Thank you for your time

Contact details:  
Peter Baek  
Senior Engineer  
Conceptual Design  
E  [pbk@lmwindpower.com]

Head quarters:  
LM Wind Power  
Jupitervej 6  
6000 Kolding  
Denmark  
Tel  +45 79 84 00 00  
Fax  +45 79 80 00 01  
E  info@lmwindpower.com  
W  lmwindpower.com

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