THE POWER
TO DELIVER

lmwindpower.com

ROTOROPT 2.0

15/1/15

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AGENDA

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

Wind Turbine Optimization

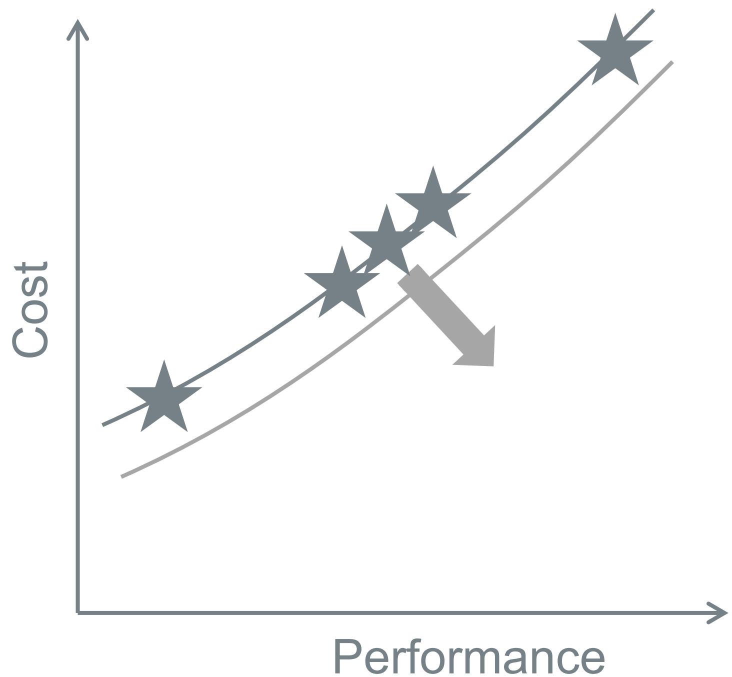
Turbine optimization objective:

- Minimize cost of energy.

Simple, but

- Each manufacturer has a different design philosofy, technology and suppliers.
- Manufacturers use platforms with varying rotor and drive train configurations to bring down costs.

Wide range of possible designs



Blade optimization:

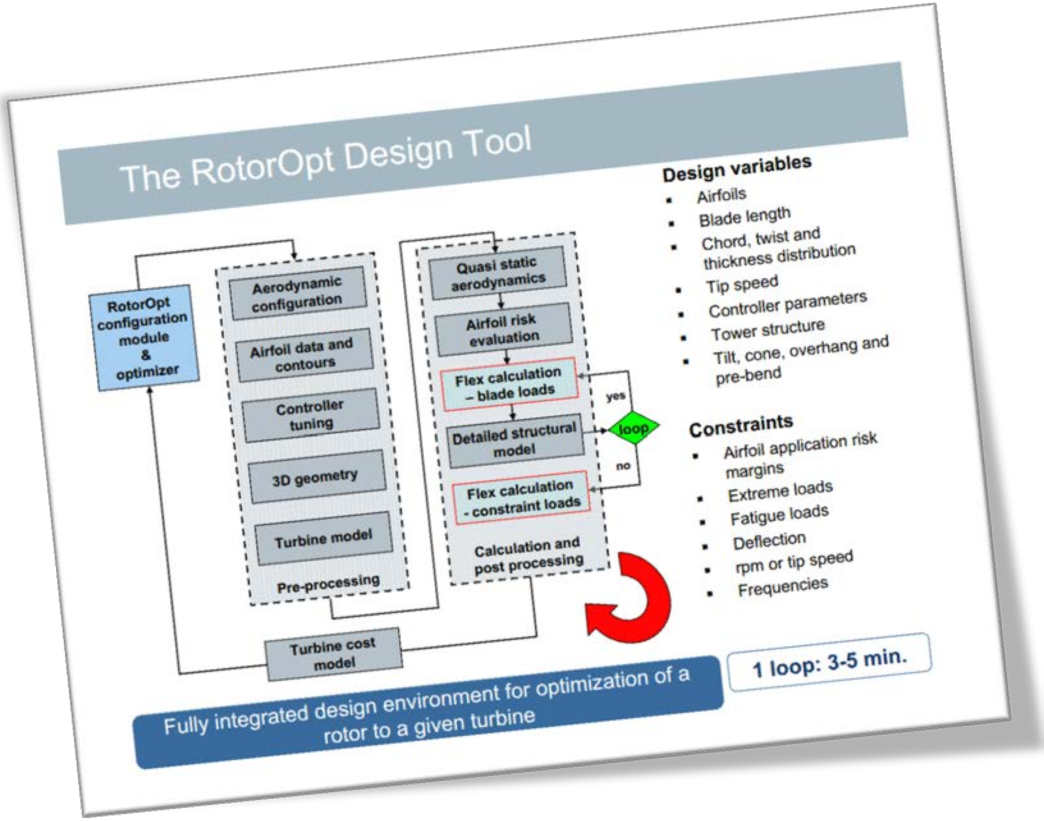
- Maximize AEP within load envelope.
- Mimimize mass/moment for given AEP

Make the right compromizes

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

Blade Design

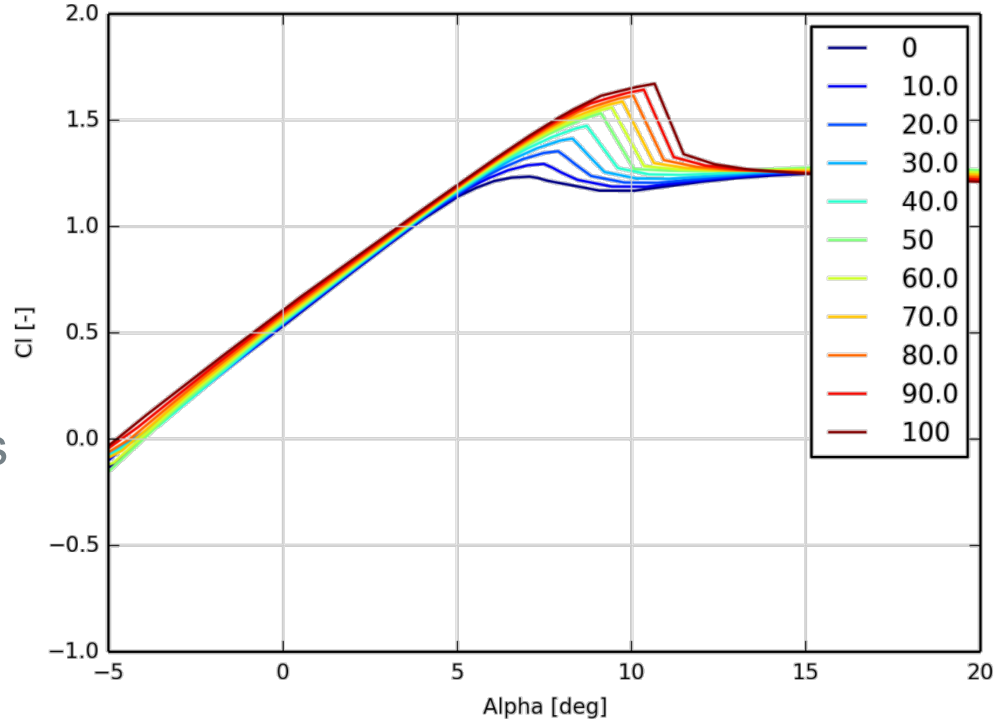
LM Airfoil Families

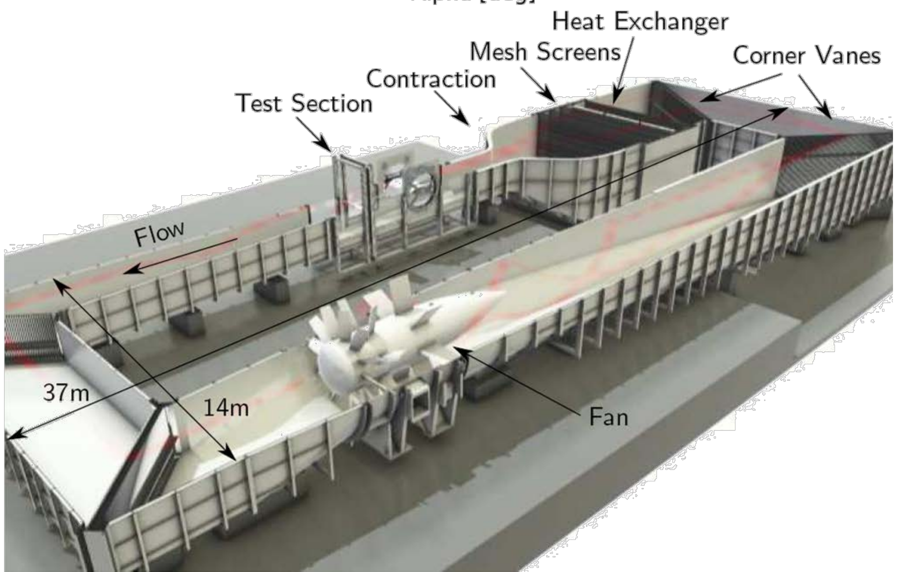
- Holds all the latest validated airfoils (shapes & polars)
- All airfoils validated in LM Wind tunnel
- Different add-on concepts available (T-Spoiler, VG's, Serrations, etc)

Airfoil Blender

Smooth airfoil data from reliable source

- Access to large database of measurements for LM-airfoils ($1.5 \cdot 10^6 < Re < 6 \cdot 10^6$) with addons (VGs, serrations, T-spoiler)
- Arranged cleverly for the optimizer to be able transition smoothly from high to low lift airfoils





LM WIND POWER

Load Calculation with LM-Flex

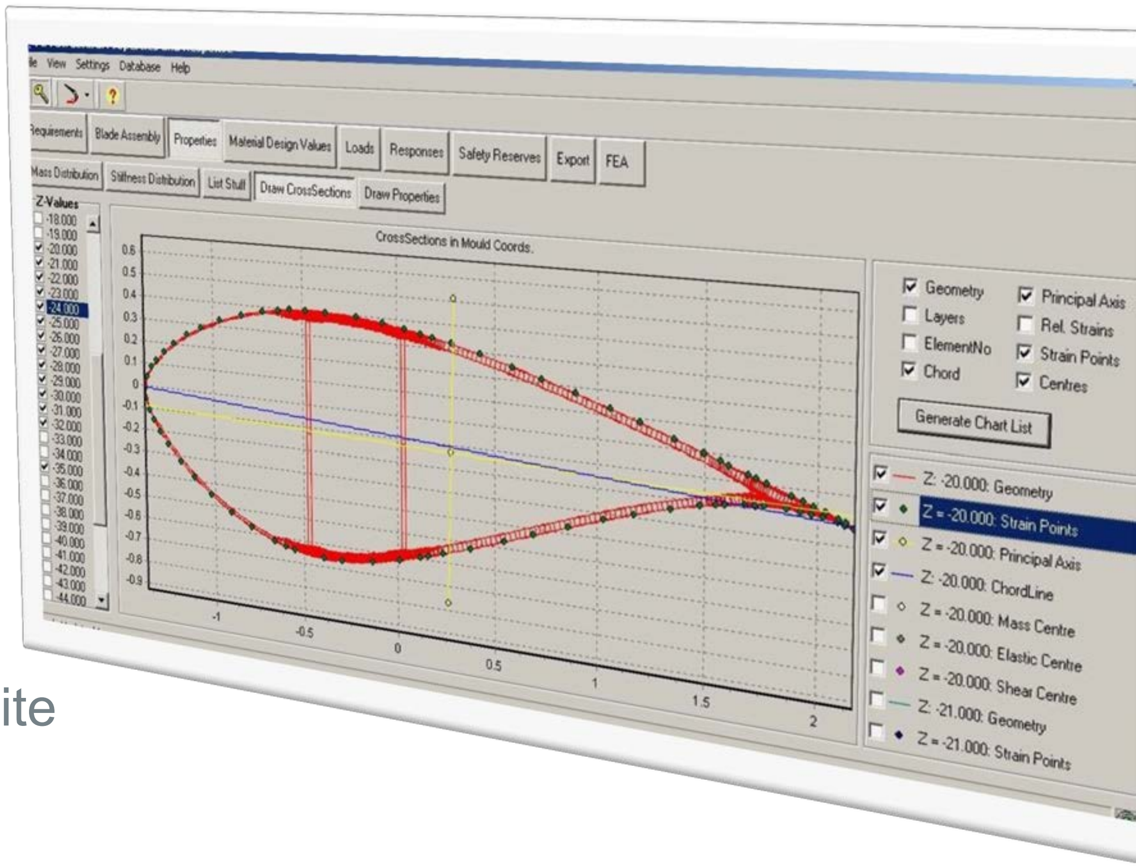
Standard IEC load cases

- 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

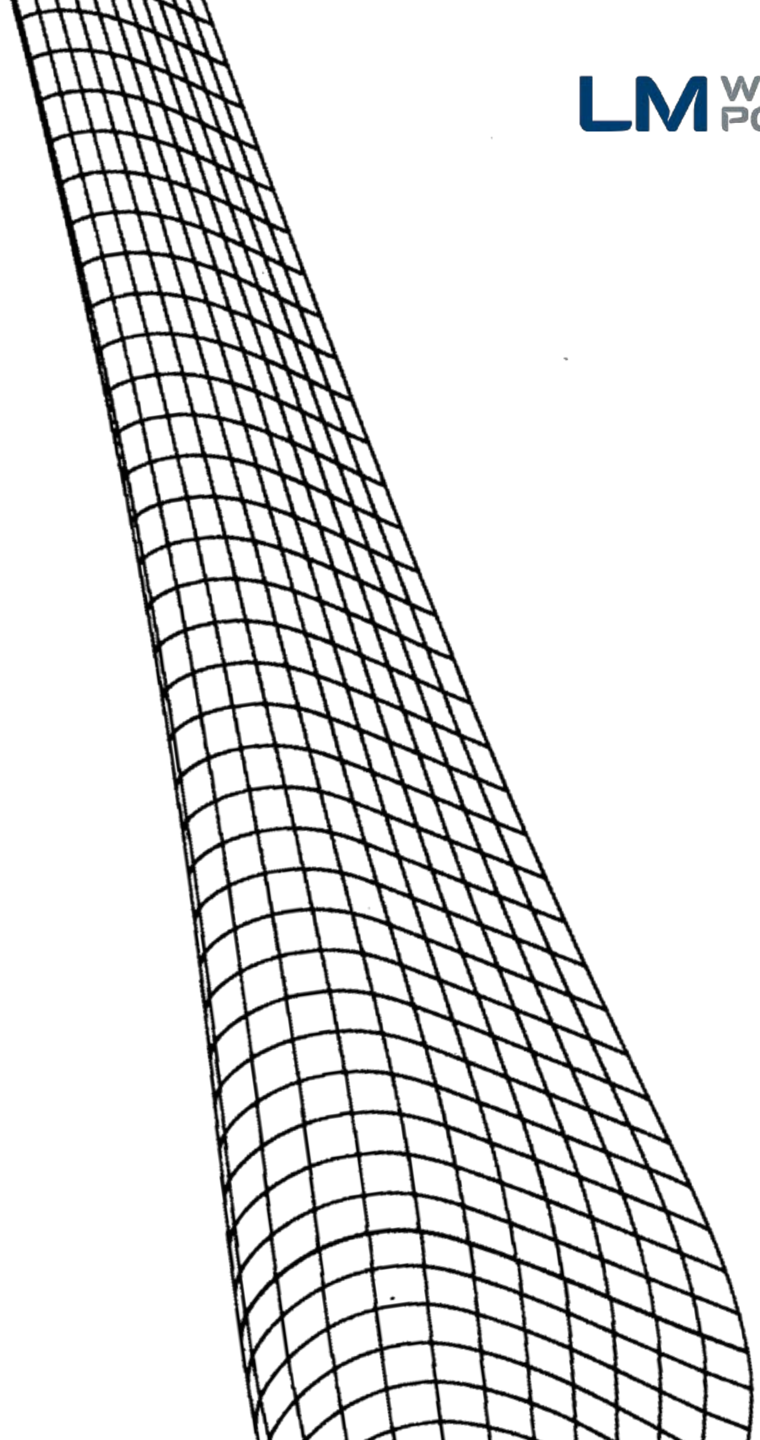
Design Variables

Distributions of:

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

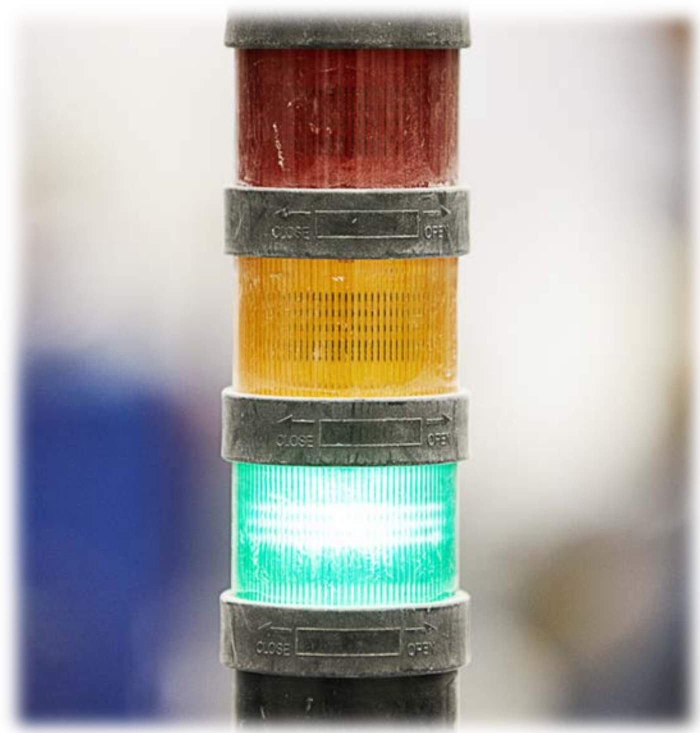
Scalars

- ✓ Blade length,
- ✓ Rotation Speed

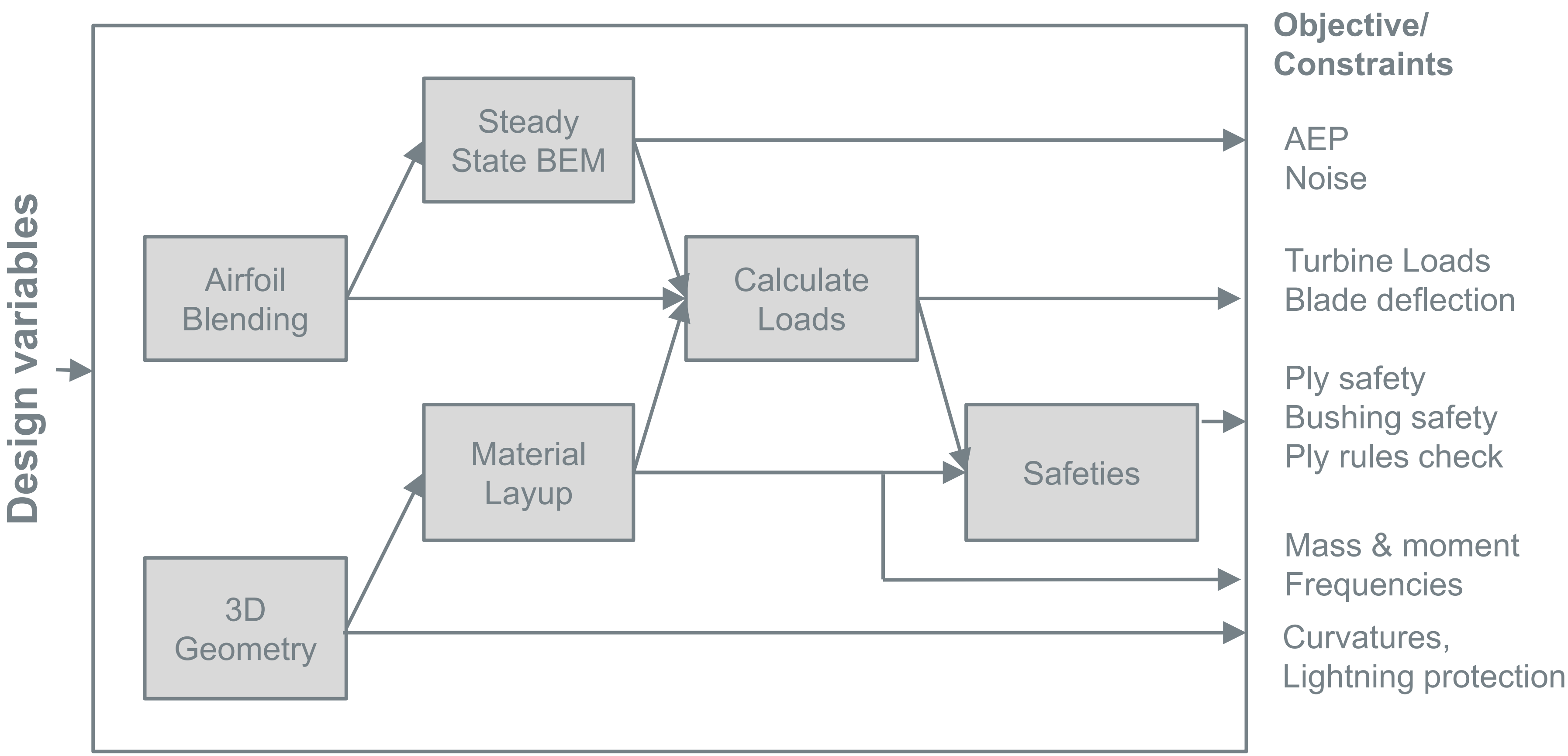


Constraints

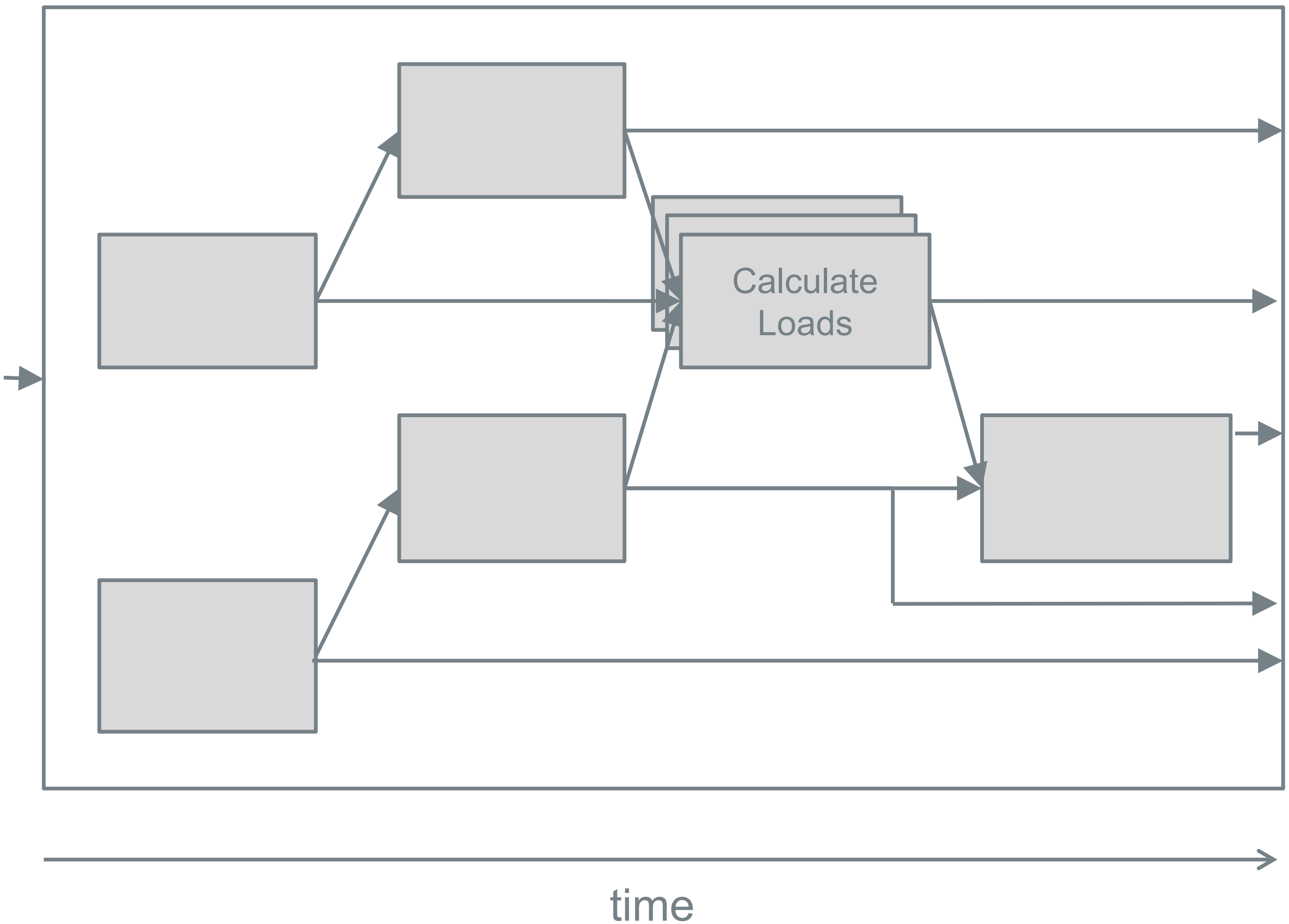
- ✓ Maximum loads,
- ✓ Tip-to-tower clearance
- ✓ Minimum AEP,
- ✓ Maximum mass/moment,
- ✓ Minimum structural safety (plys, glue, bushings, etc.),
- ✓ Layup rules (e.g. tapering contraints),
- ✓ Mininumum aerodynamic safeties,
- ✓ Maximum sound emission,
- ✓ Blade frequencies,
- ✓ Geometric constraints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



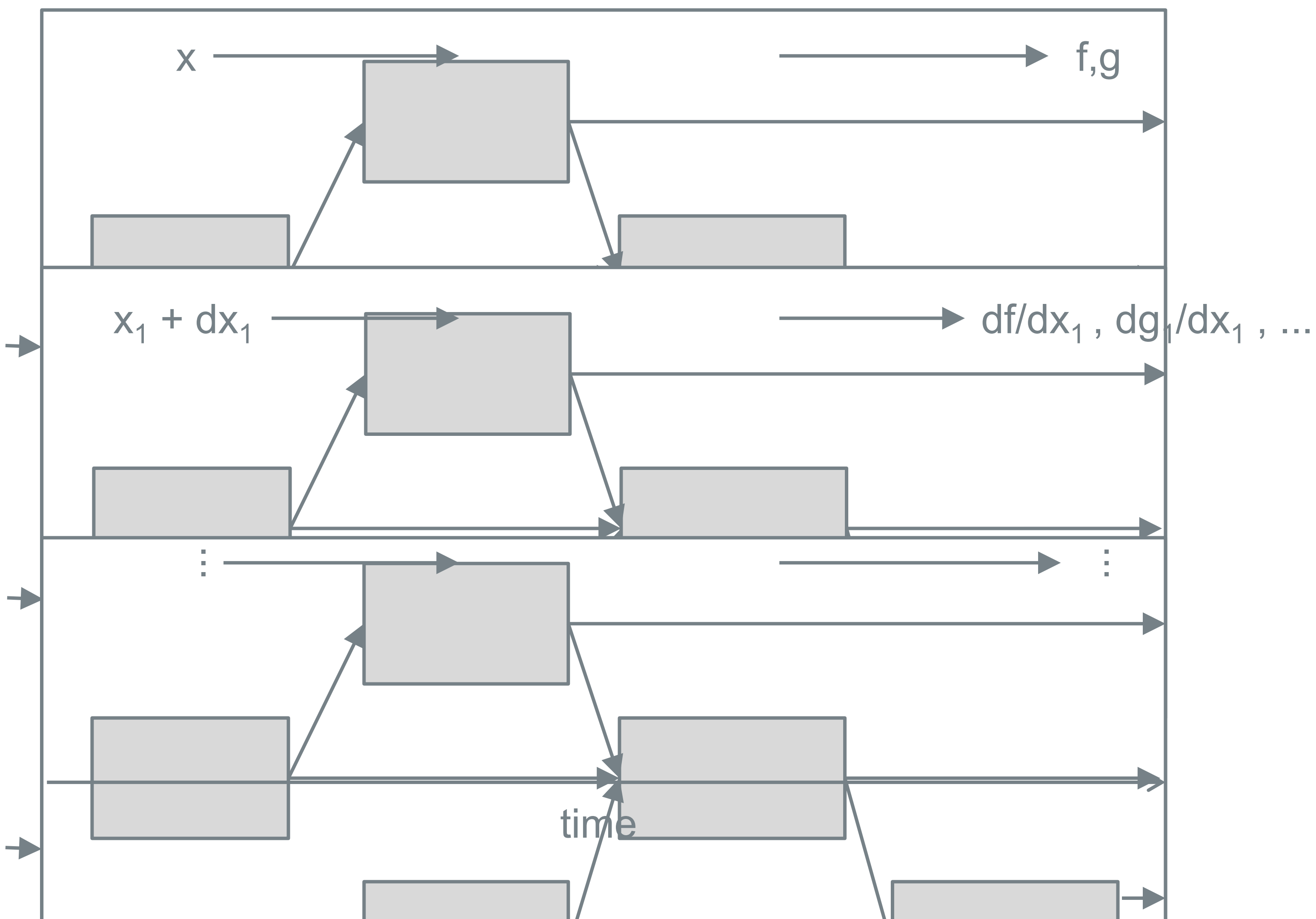
One Design Evaluation



Parallel Tasks in one Evaluation



Many parallel evaluations



Inhouse HPC Cluster

Hardware

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

Software

- ✓ Linux operating system
- ✓ Sun Grid Engine
- ✓ Python

LM101

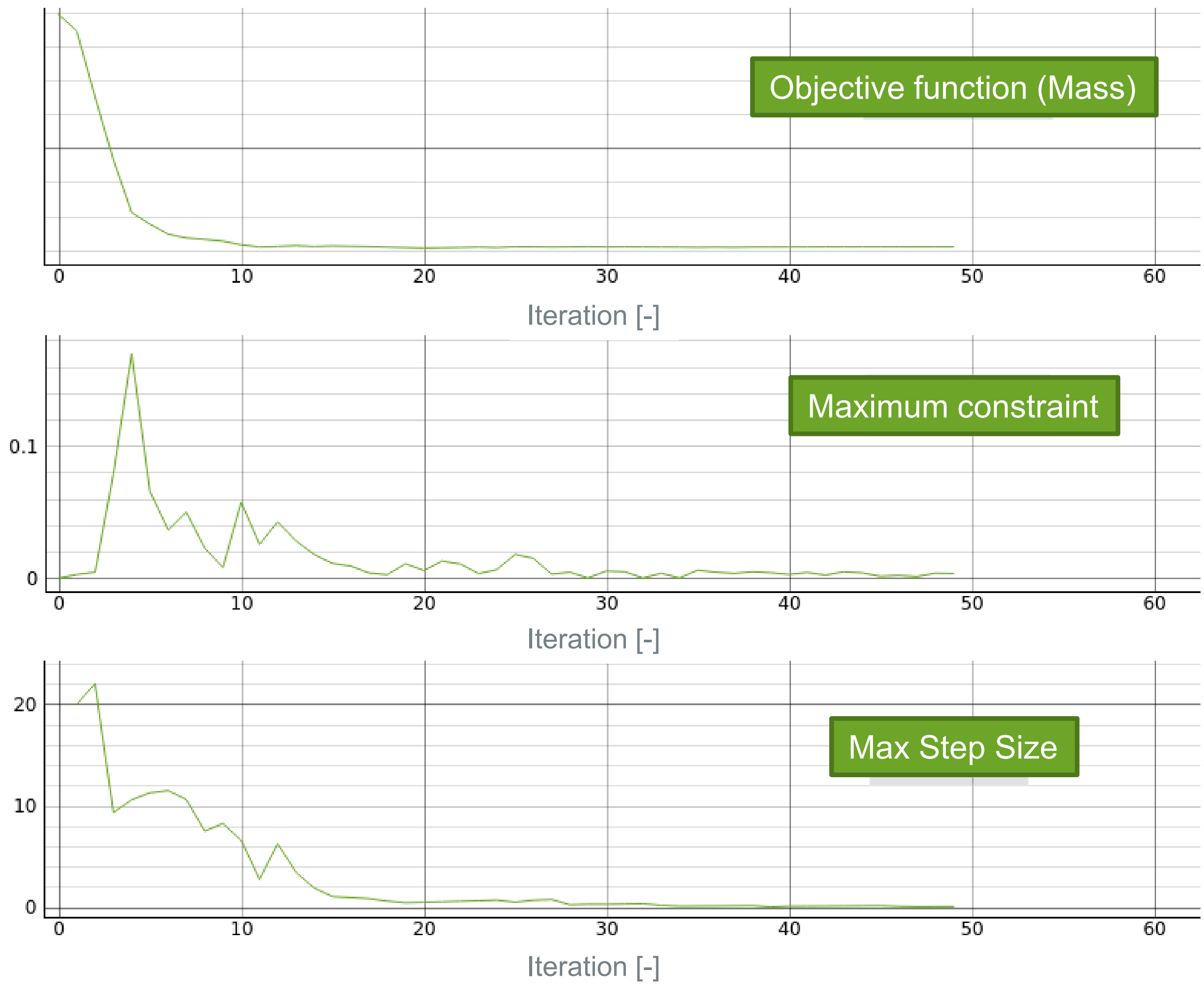
Conceptual Design Demonstrator

LM101

Conceptual Design Demonstrator

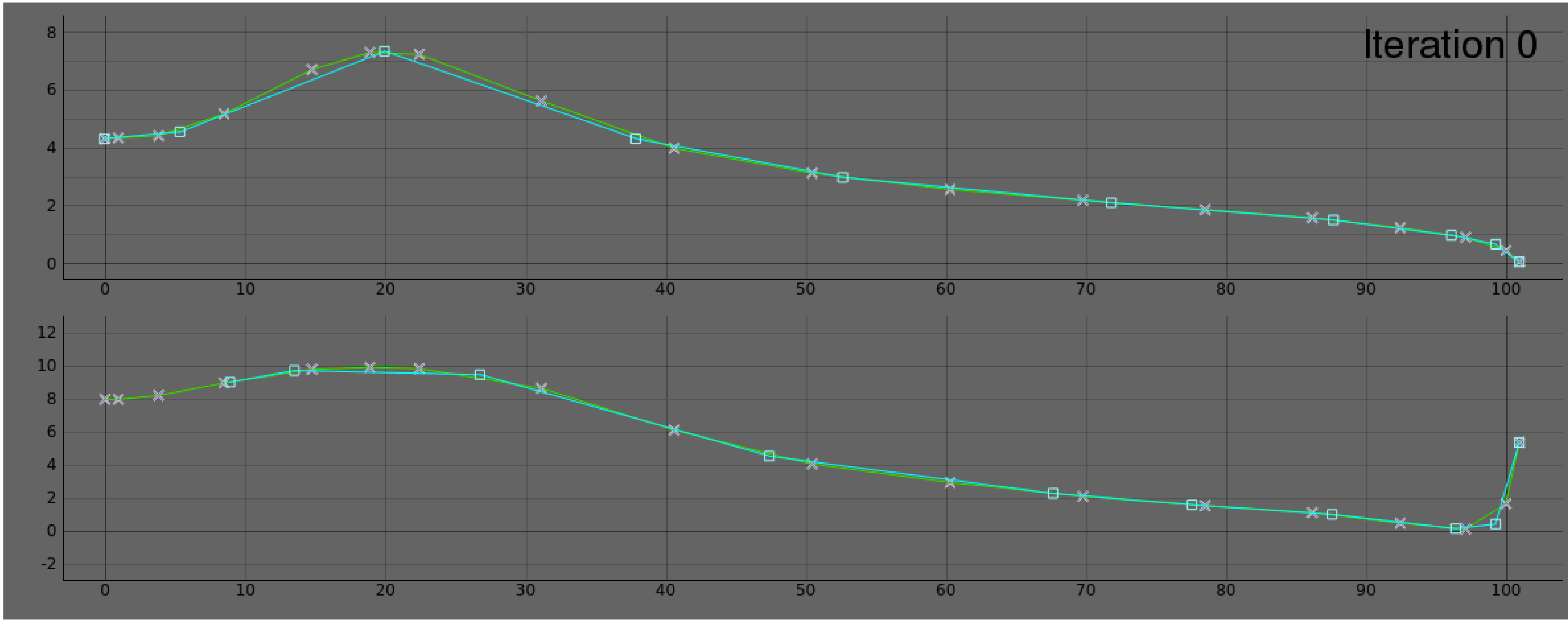
- 101m Blade length
- 101m/s Tip speed
- 10.1 MW Rated power
- Wind Class IEC 1A
- Carbon fiber technology
- Collective Pitch Control, Variable Speed

Convergence History



Convergence History

	Red	Green
Objective	Max AEP	Min mass
Constraint	...	-2% AEP



□ Design Variables

✖ Blade Definition

Convergence History

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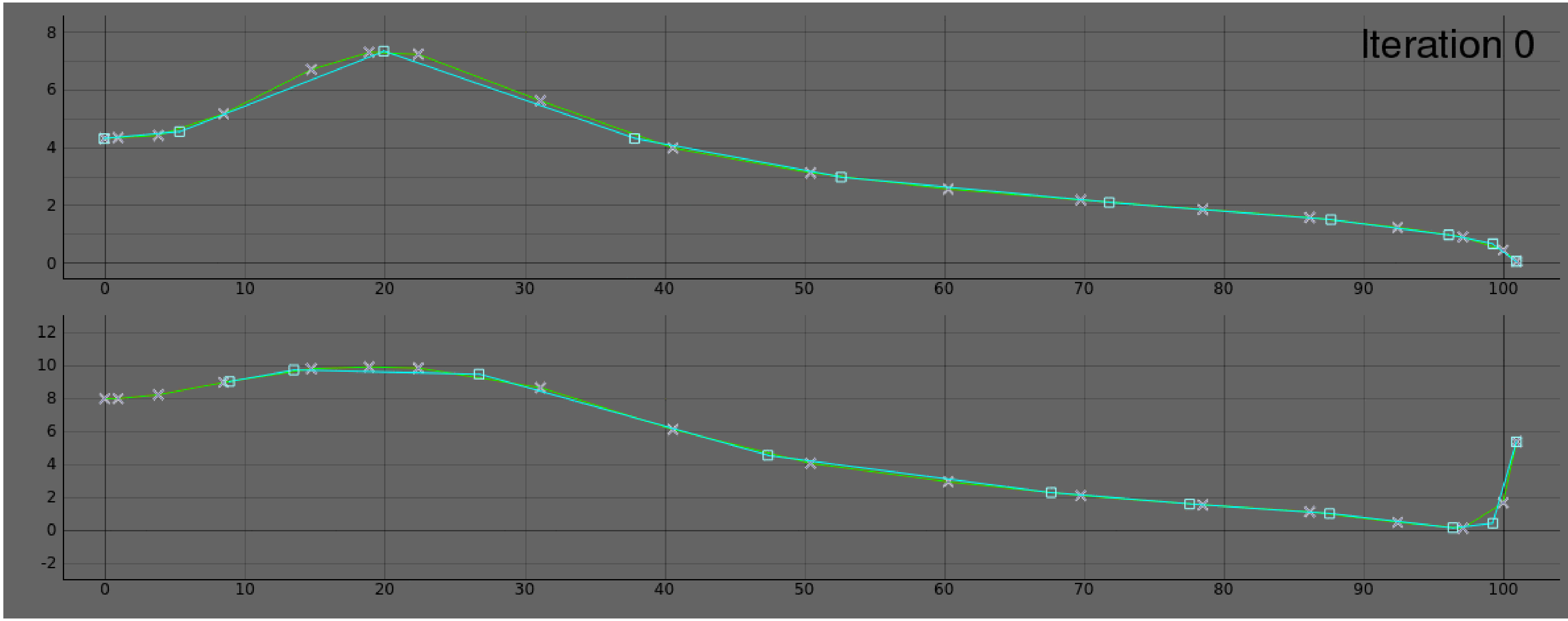
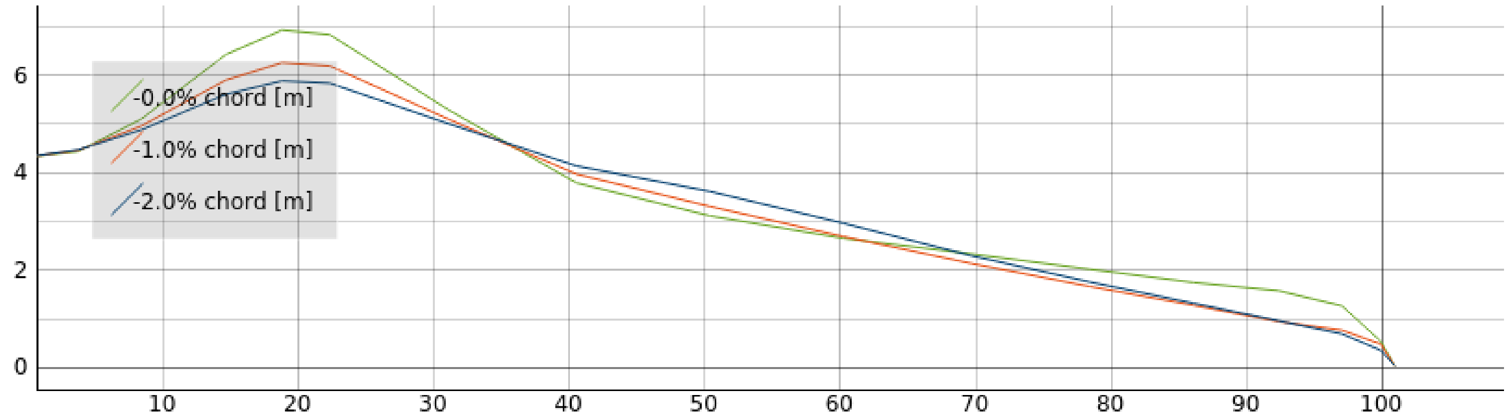
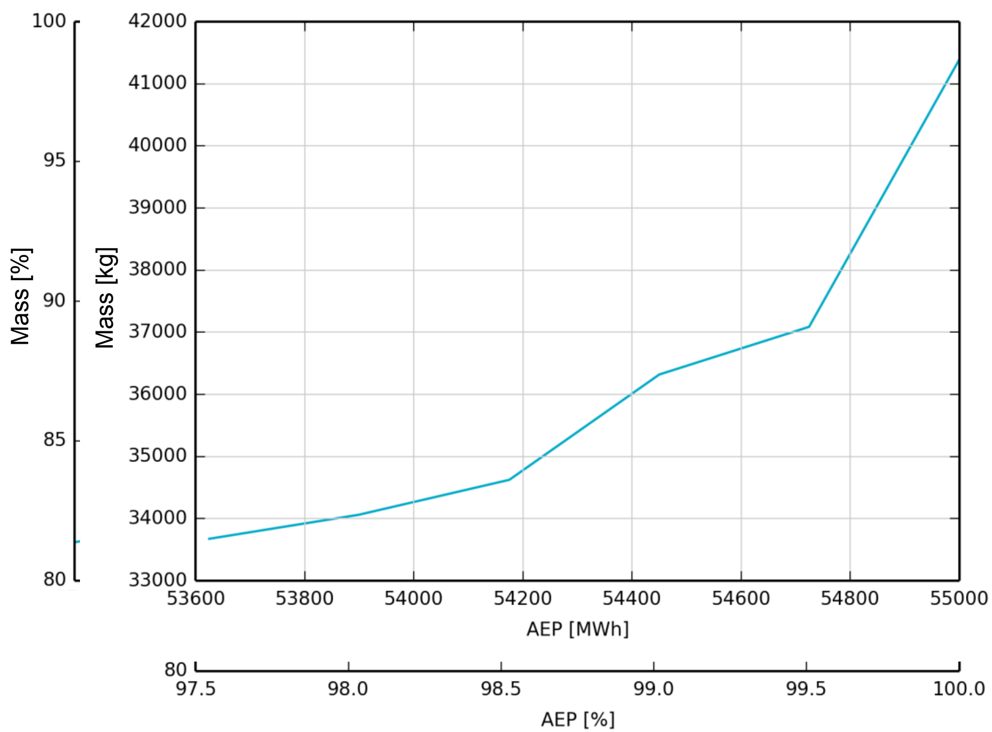


- Design Variables
- Blade Definition

Mass vs. Annual Energy Production

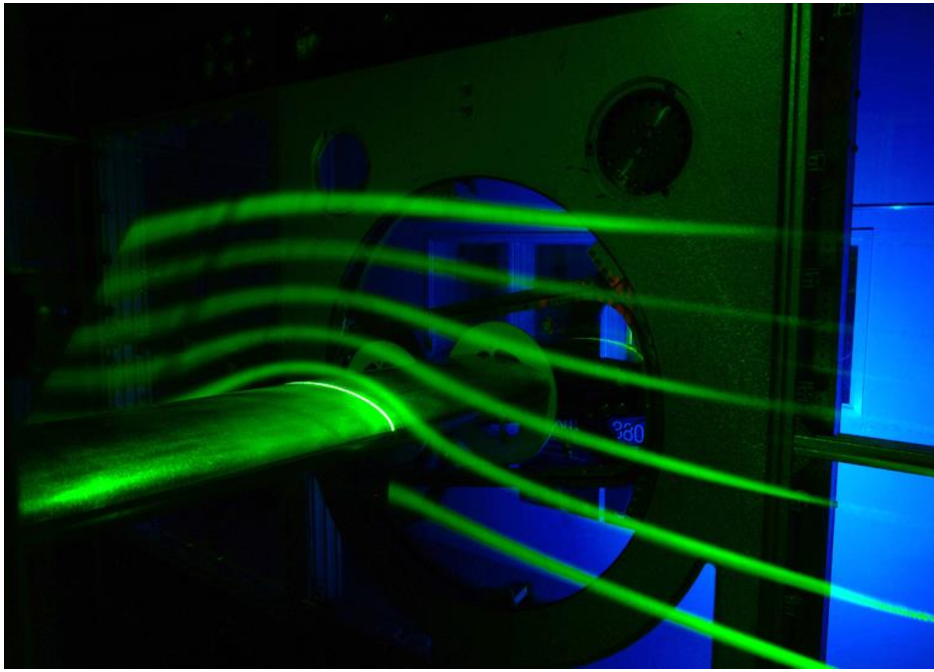




Next steps

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 compromize 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

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