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Wind Turbine Blade Design Optimization using High Fidelity Analysis

Objective

The objective of this research project is to improve wind turbine blade design **optimization** by considering **realistic wind loads** corresponding to each individual blade **design** applied in **structural analysis**.

Past Optimization Research

The **fundamental goal** was to find the **variation** of the chord length of a NREL 5MW blade to produce the **minimal simple payback period** (capital cost over average annual return).

Chord variation alters blade **mass** and **power** production potential. We assume that mass variation alters capital cost by 11.32% and that power production variation alters average annual return proportionally. Power production is estimated using NREL's **FAST** [1].

This research seeks to minimize the payback period—a function of design variables **x**—calculated via the following expression:

$$SP(\mathbf{x}) = C_0 \frac{1+0.1132\left(\frac{M(\mathbf{x})-M_0}{M_0}\right)}{1+\left(\frac{P(\mathbf{x})-P_0}{P_0}\right)}$$

C_0 = Constant portion of simple payback, SP
M = Blade mass (subscript zero indicates original)
P = Power (subscript zero indicates original)

Design Variables and Constraints

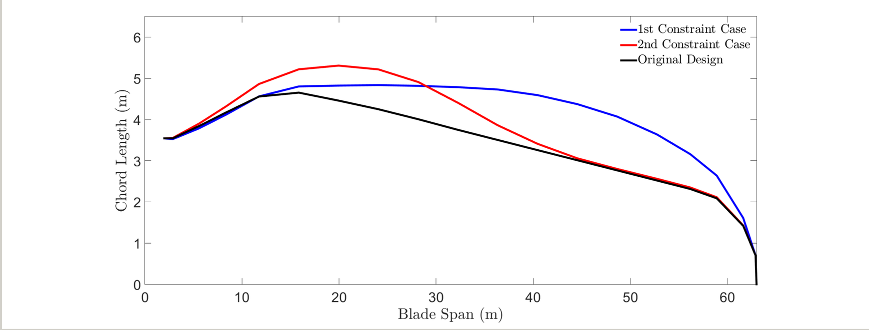
1st Constraint Case: **Tip deflection** constrained to be **less than or equal to** original

2nd Constraint Case**: Tip deflection** and **strain** constrained to be **less than or equal to** original

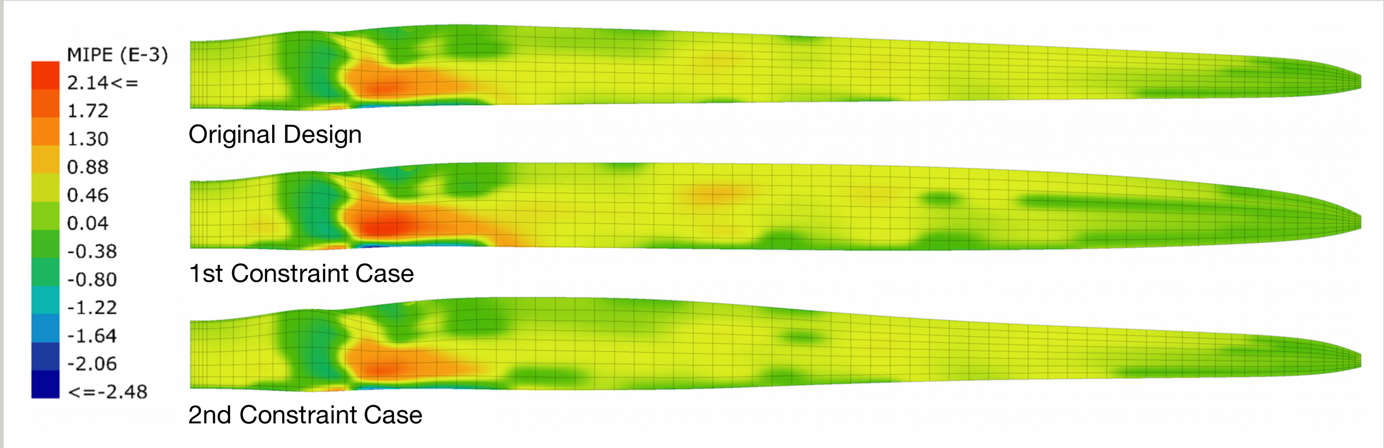
Results

Optimization performed using MATLAB's pattern search algorithm. The results table (right) indicates that payback period is reduced in both constraint cases. We note that, because this is a proof of concept, we do not consider—among other things—influence of rotor mass on tower cost or blade performance at multiple wind speeds.

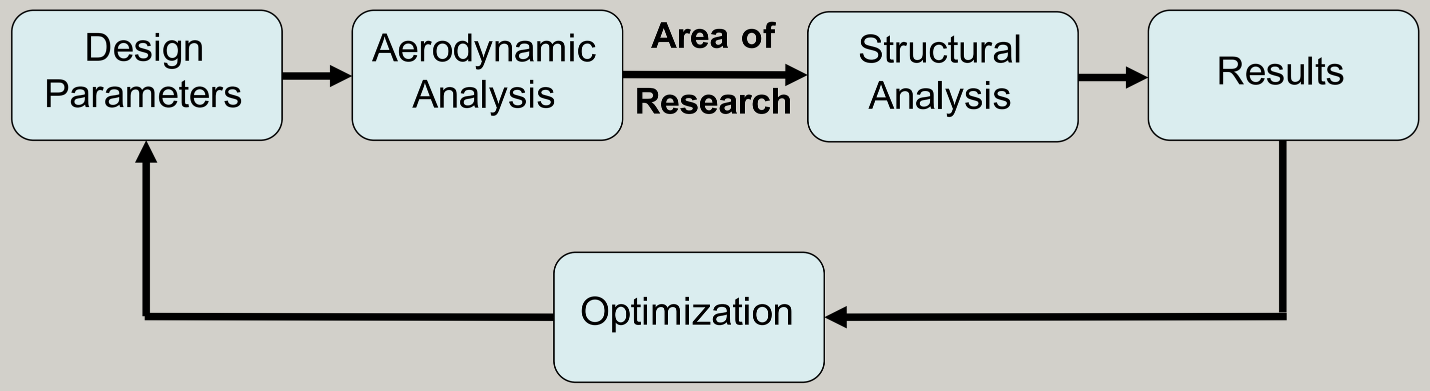
Design	Func. Evals	Tip Defl. (m)	Max Strain	Mass (kg)	Power (kW)	SP
Original	-	1.11	0.0016	16,557	5,521	100%
Case 1	289	1.11	0.0021	19,588	5,902	**95.69%**
Case 2	141	0.96	0.0016	18,160	5,650	**98.79%**



Progression of best fitness function evaluation throughout optimization for both constraint cases (far left). Original and optimized chord profiles (near left). Actual shapes of original and optimized blades with color contour indicating maximum in-plane strain (below).



Applying Realistic Wind Loads

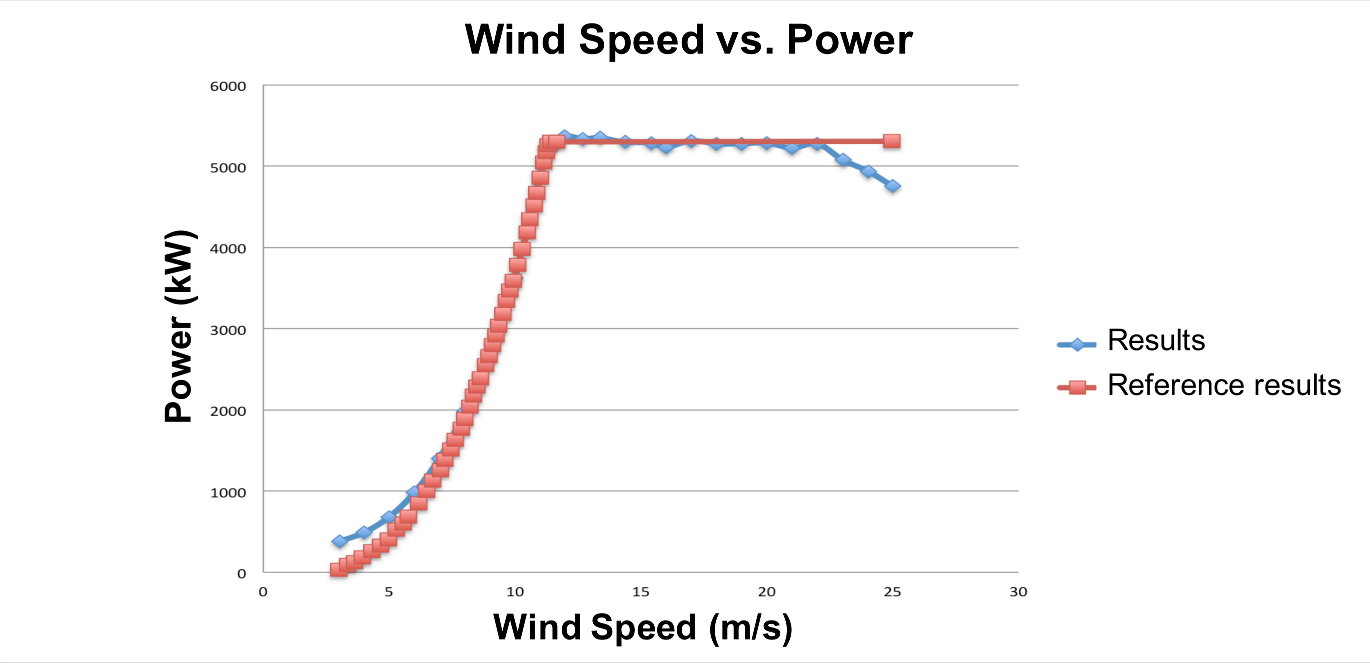


Gathering the **realistic forces** acting on a wind turbine blade and applying the **realistic wind loads** to a wind turbine blade surface takes place between **aerodynamic analysis** and **structural analysis**.

FAST (Fatigue, Aerodynamics, Structures, and Turbulence) includes an **aeroelastic computer-aided engineering tool** that was used to generate **realistic forces** acting on wind turbine blades.

Reference results relating to rotor power at specific wind speeds were generated previously using FAST and can be seen in the *Definition of a 5-MW Reference Wind Turbine for Offshore System Development* technical report [2].

To prove that the parameters of FAST were correct, the rotor power at specific wind speeds that was generated needed to **correlate** to the **reference results**.



The generated rotor power at specific wind speeds generated by FAST and compared to the reference results from FAST.

The wind speed and the correlating blade pitch were modified in FAST to obtain a **accurate rotor power** between wind speeds of 7 m/s to 23 m/s.

After proving the accuracy of FAST, the outputs of the **normal and tangential forces** on each blade element are gathered.

The normal and tangential forces acting on the blade element are **distributed** evenly to all integration points on the blade surface in the optimization code to get the **realistic wind loads** around the blade.

The load variable is passed into the optimization code and applied to a **high-fidelity structural simulation**.

High Fidelity Analysis

The normal and tangential **forces** are **projected** from an **aerodynamic model** used in FAST to a **structural model** used for high fidelity analysis.

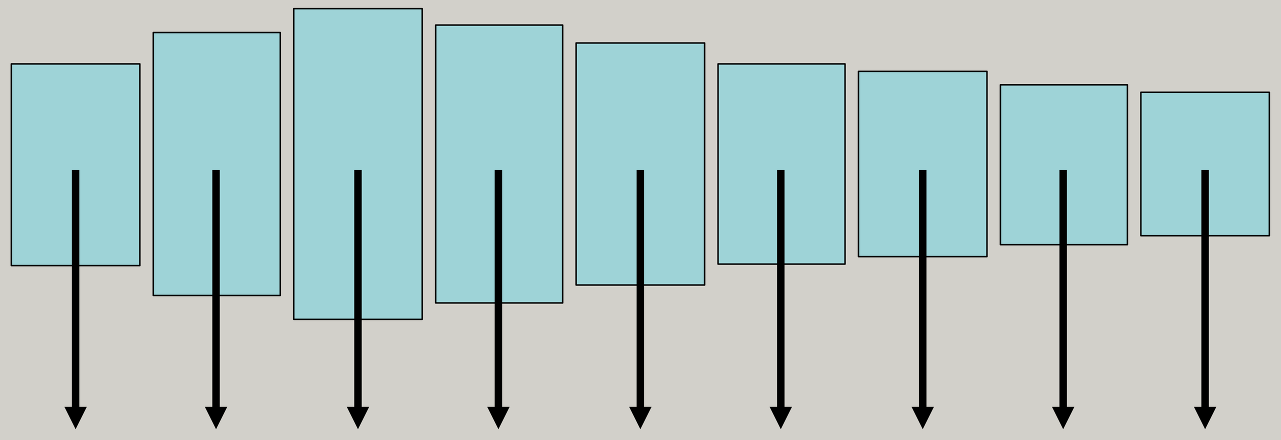


Figure of an aerodynamic model used in FAST.

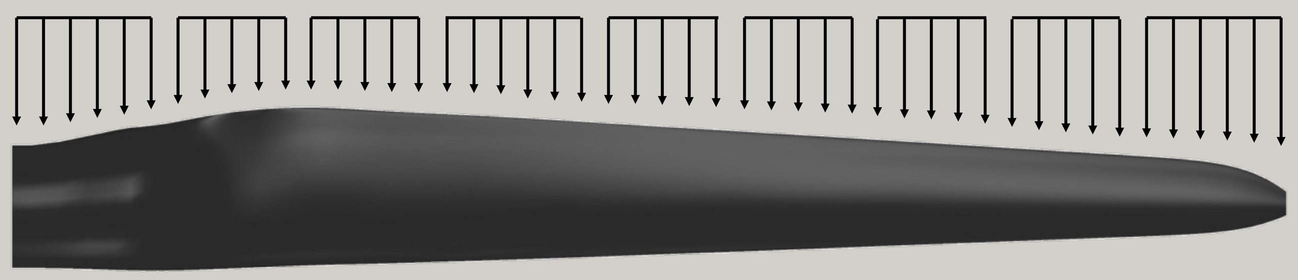
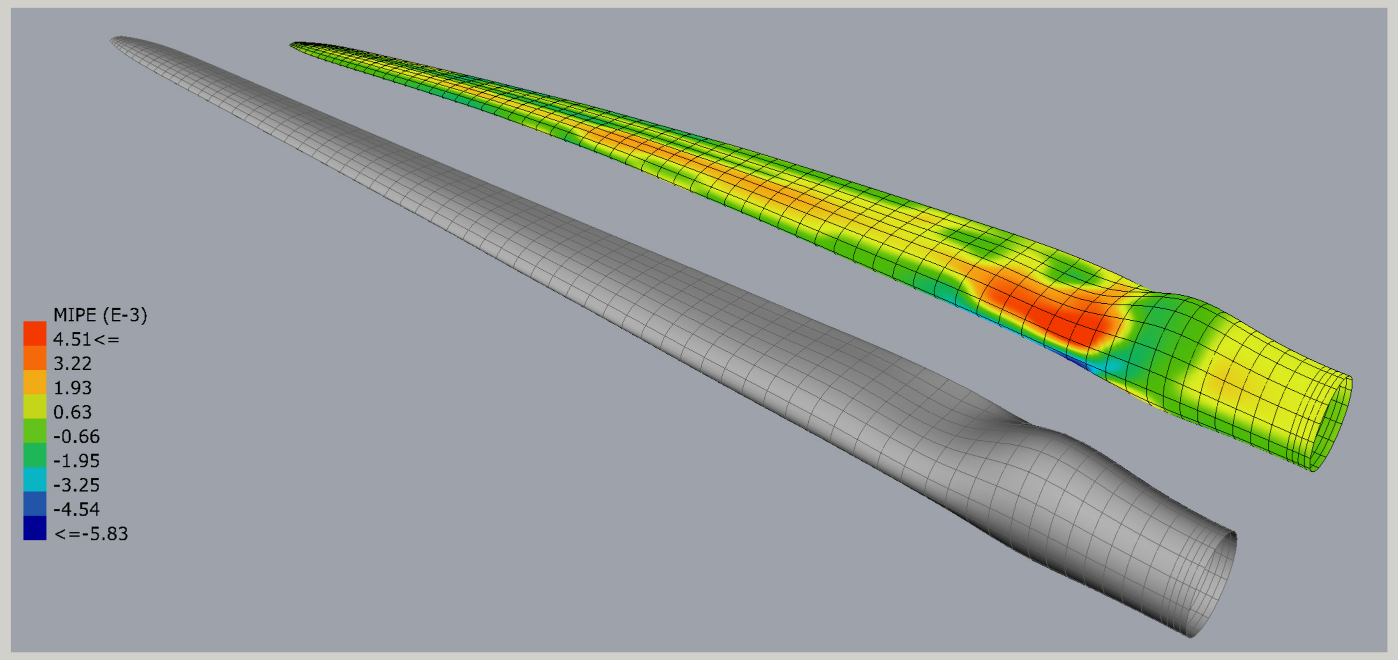


Figure of a structural model used for high fidelity analysis.

Using the proposed framework, the **realistic wind loads** acting on a wind turbine blade at **various wind speeds** can be applied to structural **simulations**.



High Fidelity Analysis of a NREL 5 MW Blade with 12.6849 m/s wind speed and 5.76872 degree blade pitch.

Ongoing Research and Perspectives

Utilize more **realistic** analysis framework to perform design **optimization**.

Incorporation of additional realistic elements such as **realistic composite layup**, **shear web**, and **aerodynamic loading**.

Utilization of more advanced **optimization** techniques such as **surrogate modeling**.

[1] Jonkman, J.M. and Buhl Jr., M.L. "FAST user's guide." Technical Report NREL/EL-500-38230, NREL, Golden, CO, 2005.
[2] Jonkman, J., Butterfield, S., Musial, W. and Scott., G. "Definition of a 5-MW reference wind turbine for offshore system development." Technical Report NREL/TP-500-38060, NREL, Golden, CO, 2009.

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