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Free-Form Aerostructural Optimization of Rotor Blades

C.L. Bottasso[†,‡], A. Croce[†], F. Grasso[*], L. Sartori[†]
[†]Politecnico di Milano, [‡]Technische Universität München, [*]ECN

Wind Energy Institute

Introduction and Motivation

Standard blade design process:

1) Select collection of existing suitable airfoils
2) Define blade chord, twist, pre-bend/cone and possibly sweep
3) Choose materials and size all blade structural members

Iterate until all constraints are satisfied and an optimal configuration is achieved

Exploration is limited to **pre-assumed** airfoils

Airfoil shape: **strong influence** on aero performance but also on structural sizing

Issues with current approach:

- **Incomplete** exploration of design space
- **Suboptimal** solutions

Objectives

1) Genuine **free-form optimization** of rotor blades:

- Airfoils are designed together with the rest of the blade
- More complete exploration of the design space

2) Relieve the designer from a priori choices

Example: flatbacks should automatically emerge as part of the solution if they represent optimal choices in certain parts of the blade

Methods

Simple proof-of-concept implementation

Blade design: multidisciplinary constrained optimization

- C.L. Bottasso, F. Campagnolo, A. Croce, S. Dilli, F. Gualdoni, M.B. Nielsen, `Structural Optimization of Wind Turbine Rotor Blades by Multi-Level Sectional/Multibody/3DFEM Analysis', Multibody System Dynamics, 2013
- C.L. Bottasso, A. Croce, F. Campagnolo, `Multi-Disciplinary Constrained Optimization of Wind Turbines', Multibody System Dynamics, 2012

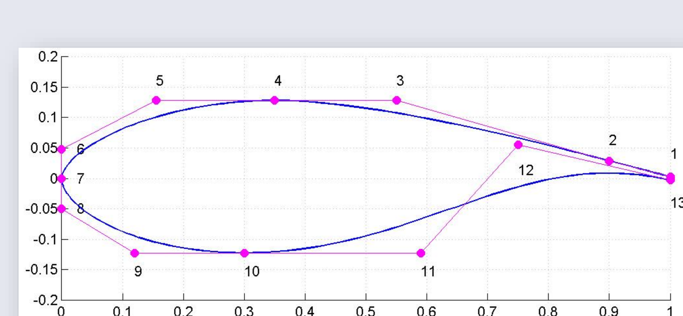
Optimization cost function: NREL LCOE model

Solution by Sequential Quadratic Programming (SQP)

Design constraints:

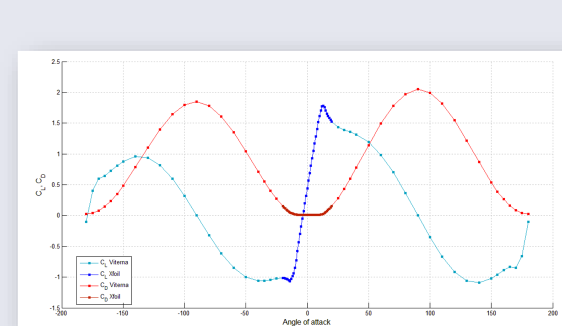
- Maximum tip deflection
- Placement of first flap natural frequency
- Not to be exceeded allowables in the spar caps

Design variables (all discretized using Bezier curves):



- Span-wise airfoil shapes
- Chord and twist distributions
- Spar-cap thickness

Models:



- Rotor aerodynamic model: classical BEM approach
- Airfoil model: M. Drela, XFOIL

(extrapolated to ±180 deg using Viterna's method)

- Structural model: beam theory with semi-monocoque cross-sectional model

Assumptions (for simplicity of proof-of-concept, can be removed easily):

- Fixed and given skin and shear web thicknesses
- Straight axis and given cone angle
- No fatigue
- Ultimate loads due storm conditions

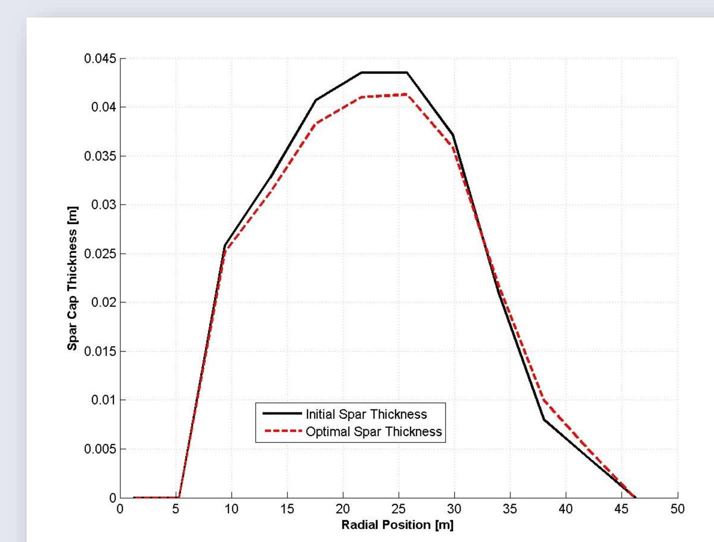
Results

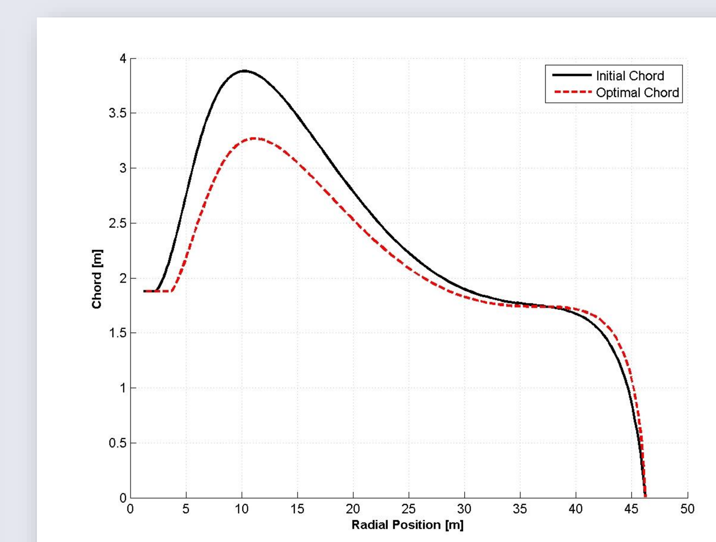
Test case: 2MW HAWT, rotor diameter 92m

Initial blade: five DU airfoils (thicknesses between 18 and 40%)

Free-form optimization results:

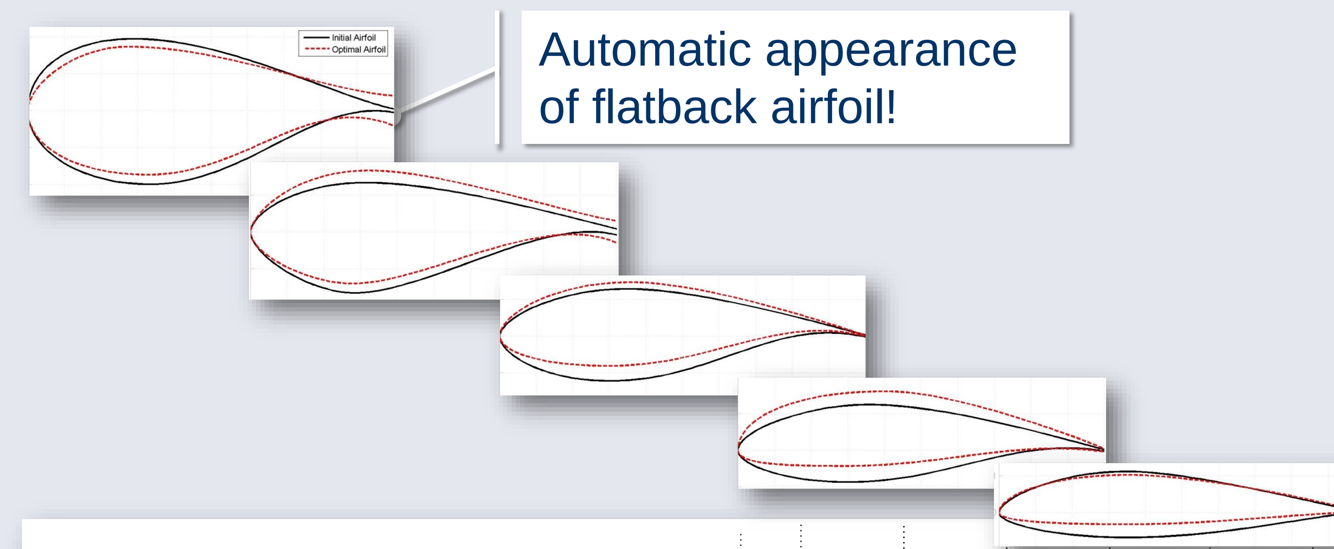
	Gain %
Blade Mass	5.77
AEP	1.24
CoE	1.57

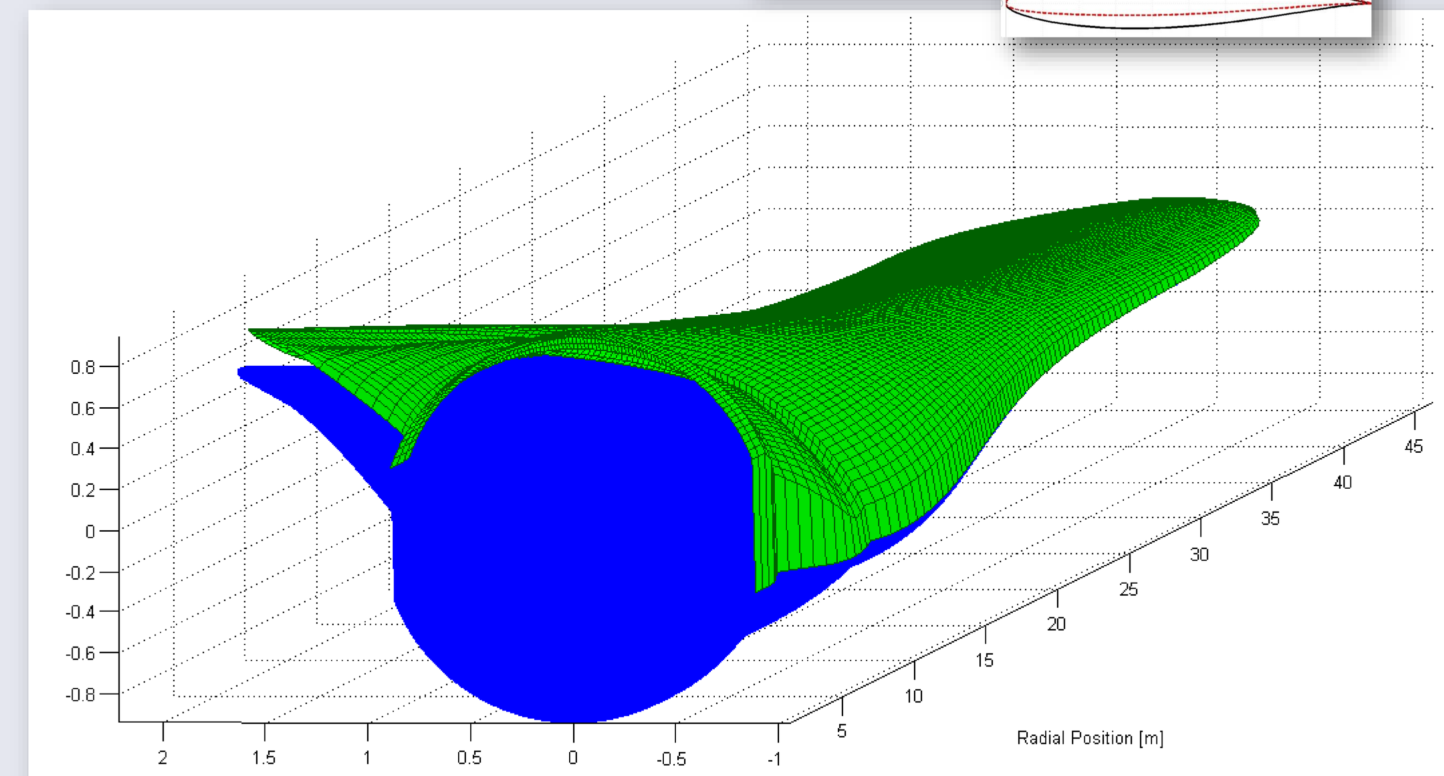




Natural emergence of thick flatbacks at the inner spanwise stations

Automatic appearance of flatback airfoil!





Conclusions

New approach for aero-structural optimization of wind turbine rotor blades:

- Simultaneous design of the airfoils, together with the rest of the aerodynamic and structural parameters of the blade
- General and flexible free-form optimization
- Does not require a priori assumptions on the most appropriate airfoils

Results:

- Converges to convincing blade configurations
- When starting from simple symmetric airfoils, exhibits expected emergence of positively cambered airfoils
- Natural emergence of flatbacks in the inner span portion of the blade, as seen on many modern large wind turbine blades

Outlook:

- Complete structural sizing, considering all structural members and a full set of extreme and fatigue loading conditions
- Blade shape design parameters should also include sweep and prebend/cone

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