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Dealing with the curse of dimensionality in the blade multi-disciplinar optimization

October 24th 2017

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OBJECTIVES

- Four main OBJECTIVES / PARTS:

OBJECTIVE 1. Present blade design as multidisciplinar optimization

OBJECTIVE 2. Explain curse of dimensionality in the blade design

OBJECTIVE 3. Show global sensitivity to assess importance of variables

OBJECTIVE 4. Show frequency domain method to calculate fatigue

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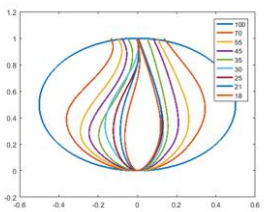
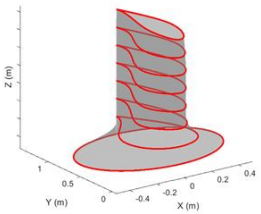
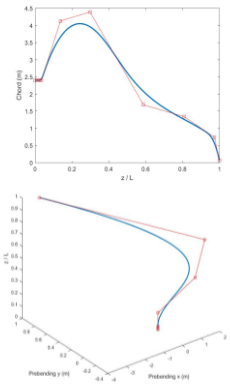
Sequential blade design process

Airfoil family

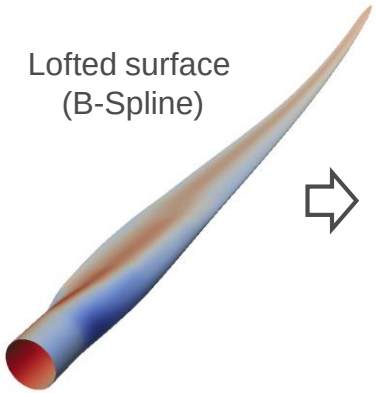




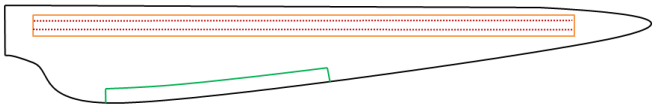
Spanwise laws

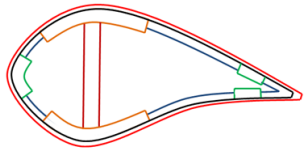


Lofted surface
(B-Spline)



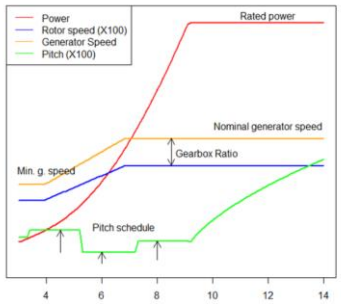
Blade internal layout





Wind turbine model

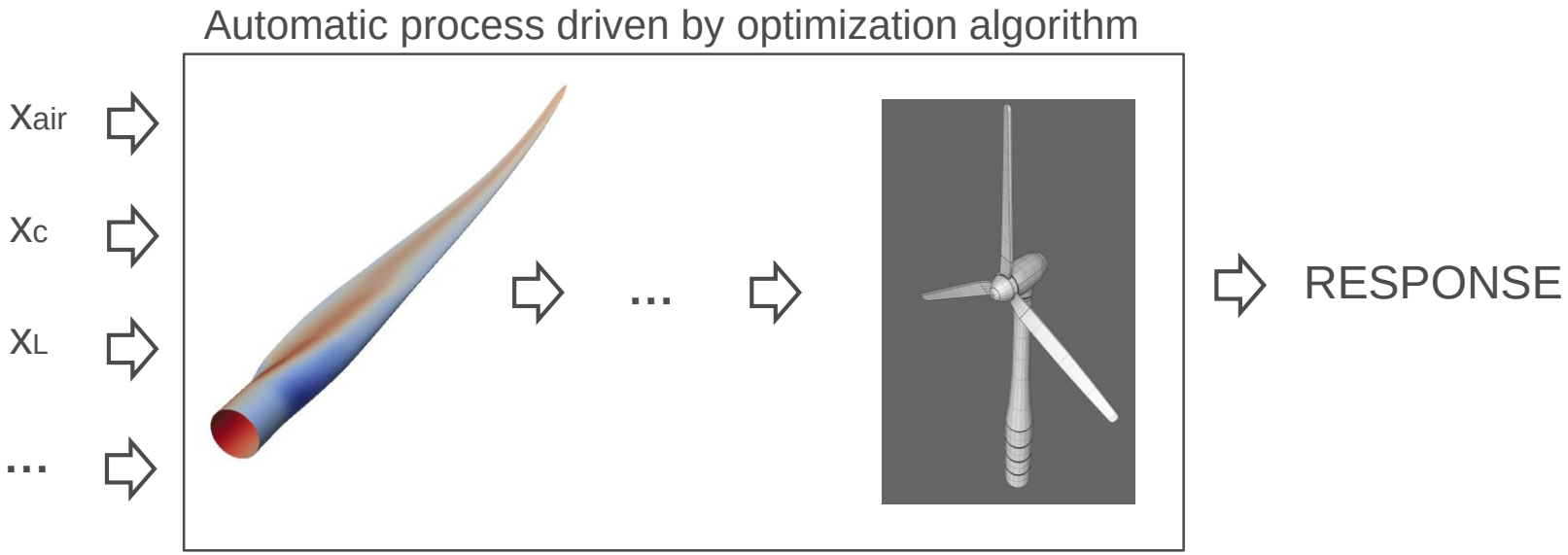
Control



RESPONSE:

AEP, ultimate loads, **fatigue**, acoustic emission, COE,…

Multi-disciplinar blade optimization



$$\text{Find } X = \left\{ \begin{array}{l} x_{air} \\ x_c \\ x_L \\ . \\ . \\ x_n \end{array} \right\} \text{ which minimizes } obj(X)$$

$$ceq_i(X) \leq 0,\ i = 1, 2, ..., m$$
$$c_i(X) \leq 0,\ i = 1, 2, ..., p$$

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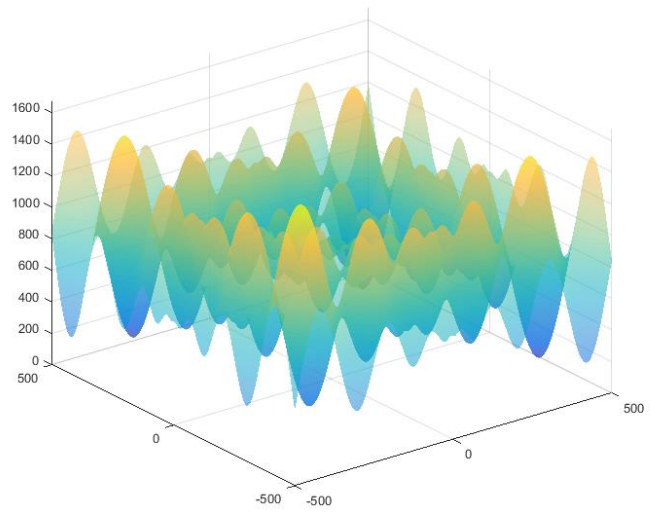
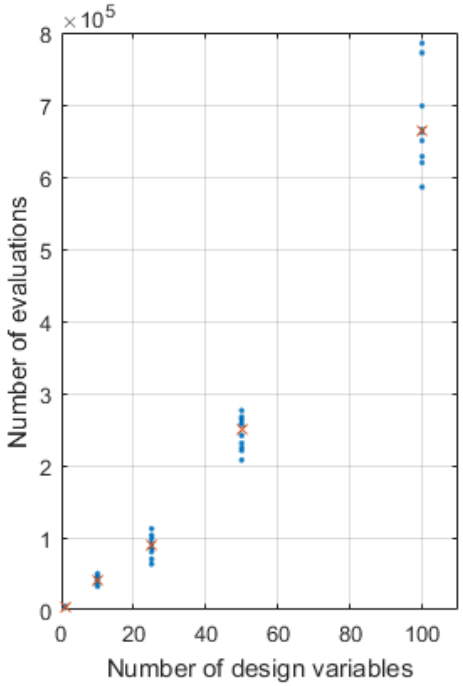
Curse of dimensionality





In blade design optimization:

- Many design variables ⇨ Global Sensitivity Analysis [1]
- Fatigue is computationally expensive ⇨ Fatigue in frequency domain [2]

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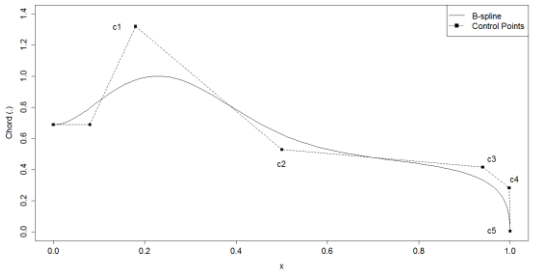
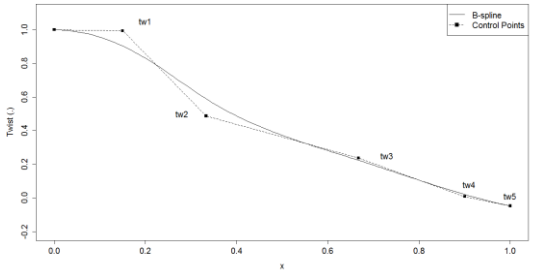
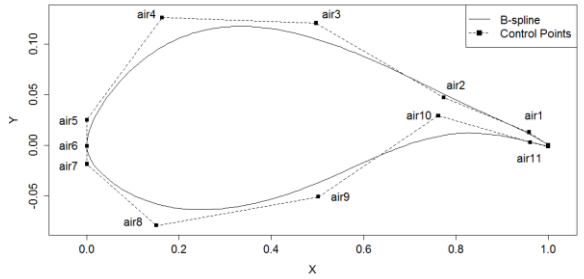
Global Sensitivity Analysis

- **Latin hypercube sampling** [3] (with *R* [4]).







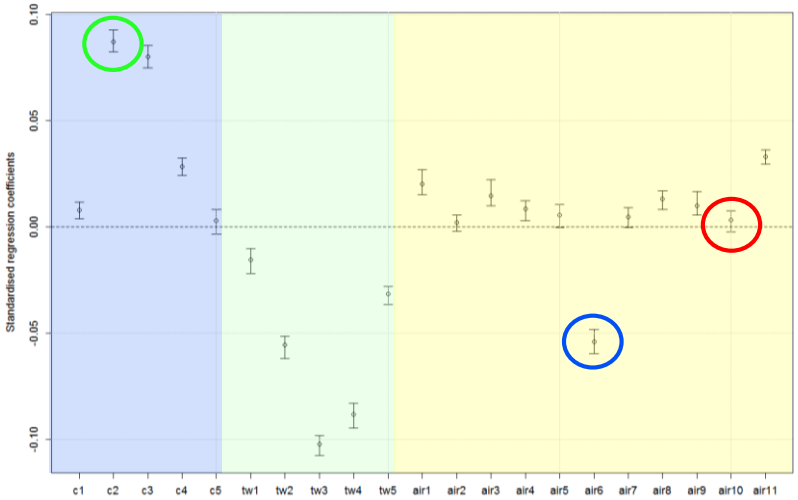
- Automatic calculation of responses:
  - MATLAB [5]
  - Rfoil [6]
  - PreComp [7]
  - BLADED [8]
  - SILANT [9]

- **Multi-variable linear regression** fitted for each response.
  Standardized regression coefficients measure the impact.

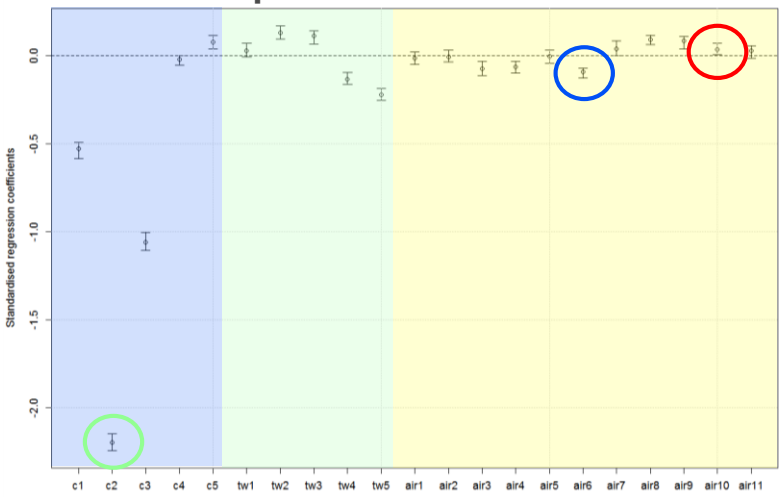
- 95% confidence intervals are obtained with **bootstrapping** method [10].

Standandarized regression coefficients

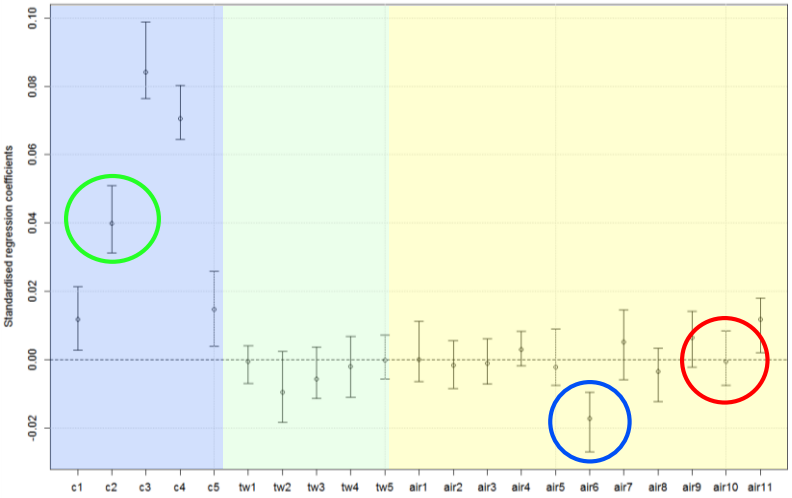
AEP

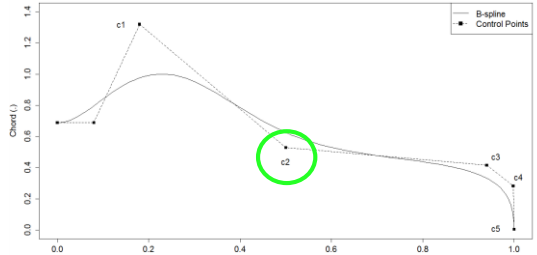


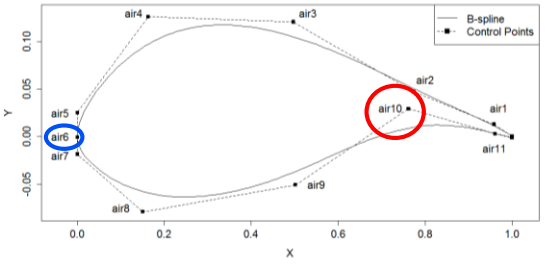
Maximum tip deflection



OAWPL

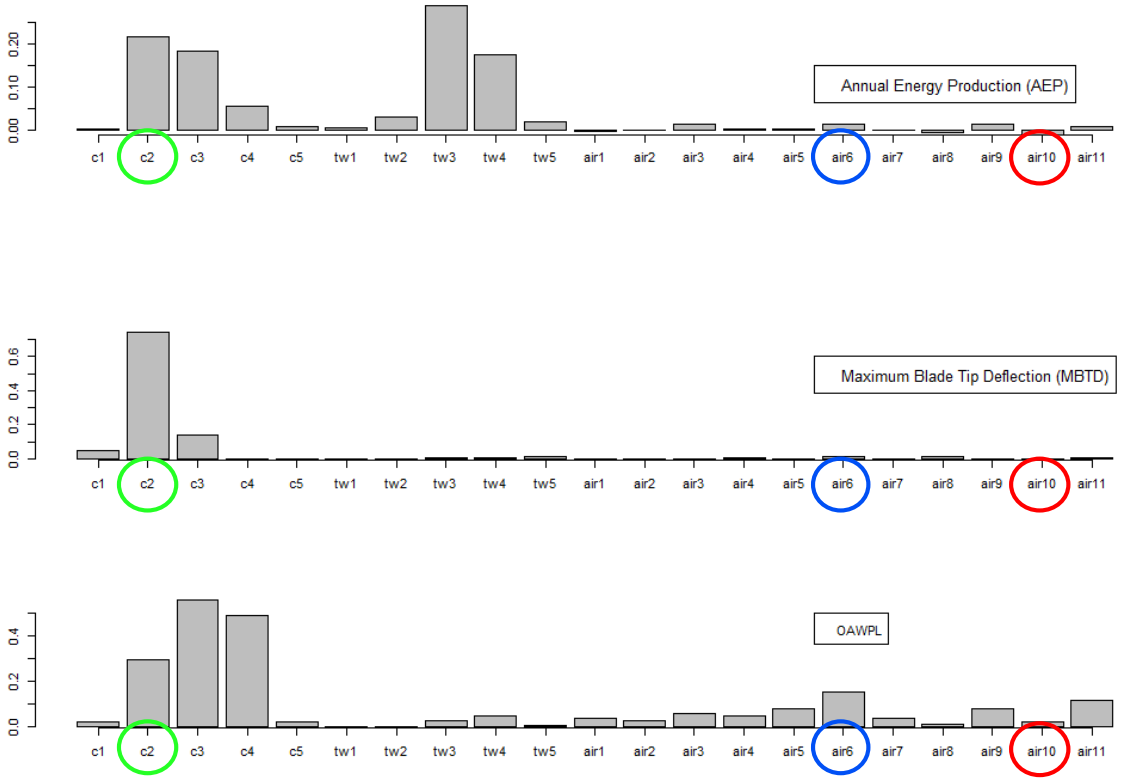






Sobol-Saltelli method

- Linear regressions can lead to incorrect conclusions.
- **Sobol-Saltelli** variance based method [3] (with *R* [4]) validates regressions.



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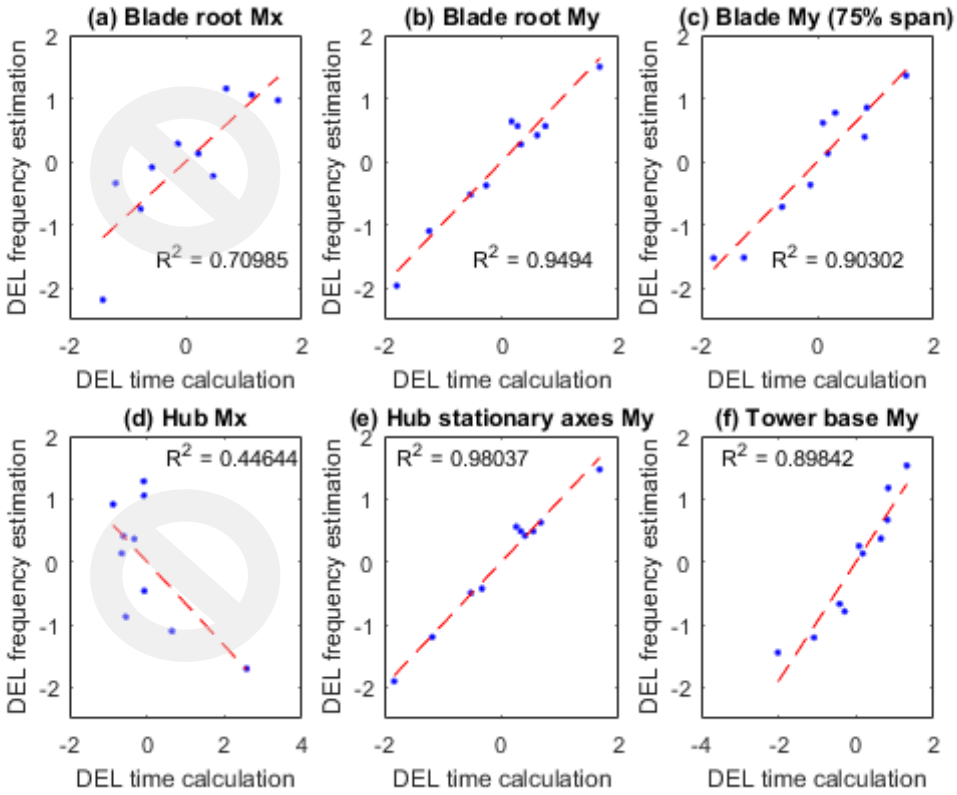
Frequency domain method to calculate Fatigue

- Fatigue damage equivalent load **(DEL)** calculation in time domain requires time consuming simulations.
- An alternative in **frequency domain** is proposed [2].
- State-space matrices are calculated with aero-elastic code and transformed into Frequency Response Function.
- The **Dirlik equations** [11] are applied to estimated response signal.
- DEL is calculated.

Validation of frequency domain method

- Ten blades are subjected to time and frequency domain DEL calculation.
- Frequency domain method provide **reasonable results for out of plane loading (My)**.



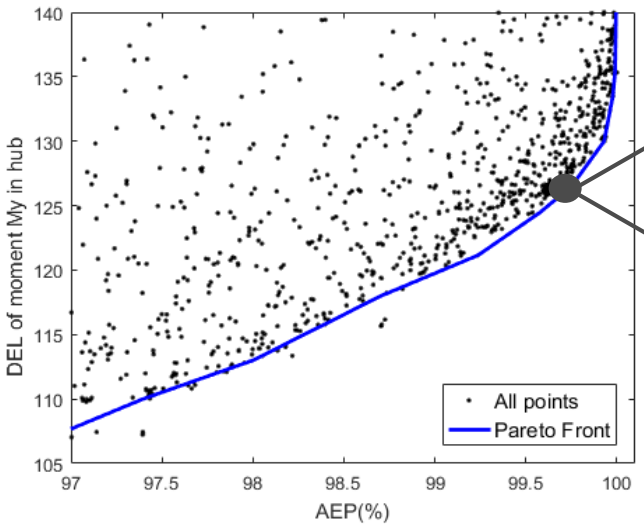
Optimization with frequency domain method

$$\text{Find } X = \{x_c, x_{tw}, x_{tc}\}$$
$$\text{which minimizes } HubM_yDEL_{Freq} \text{ \& maximizes } AEP$$

Subjected to constraint:

$$Tower\ Closest\ Approach > Gap$$

Pareto Front



Frequency: **13%** reduction DEL wrt baseline:
Time: **11%** reduction
(within confidence intervals)

Conclusions

- The sequential blade design process is being evolved to a **multi-disciplinar holistic optimization**.

- The increasing number of design variables causes a high number of necessary evaluations of the objective function. Previous **Global Sensitivity Analysis** is an useful tool to identify the significant variables.

- Besides, calculation of damage equivalent loads requires time consuming aero-elastic simulations. A fast **frequency domain method** is proposed as alternative in the first stages of the design.

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Thanks for your attention

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on the same course

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