Multi-Disciplinary Aerofoil Development at Vestas

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Table of contents

Introduction

- The choice of the proper aerofoils to be adopted on a blade is a crucial step of the design process since they will have large influence on rotor performance:
    - AEP
    - Noise
    - Loads
    - Stability
- Starting from shapes originally designed for aeronautical applications (e.g. NACA 6 digits families), due to the specific requirements of , dedicated sets of aerofoils for wind turbine application have been developed:
    - NREL aerofoils (Somers and Tangler)
    - FFA aerofoils (Bjork)
    - Stuttgart aerofoils (Althaus, Wortmann)
    - DU aerofoils (Timmer et al.)
    - Risoe aerofoils
    - In house developed aerofoils (Industry)

Aerofoils for Wind Turbines

- The aerofoils should not be considered as standalone products but integrated components of the rotor. In this sense, the aerofoil requirement specifications must address different disciplines rather than pure aerodynamics

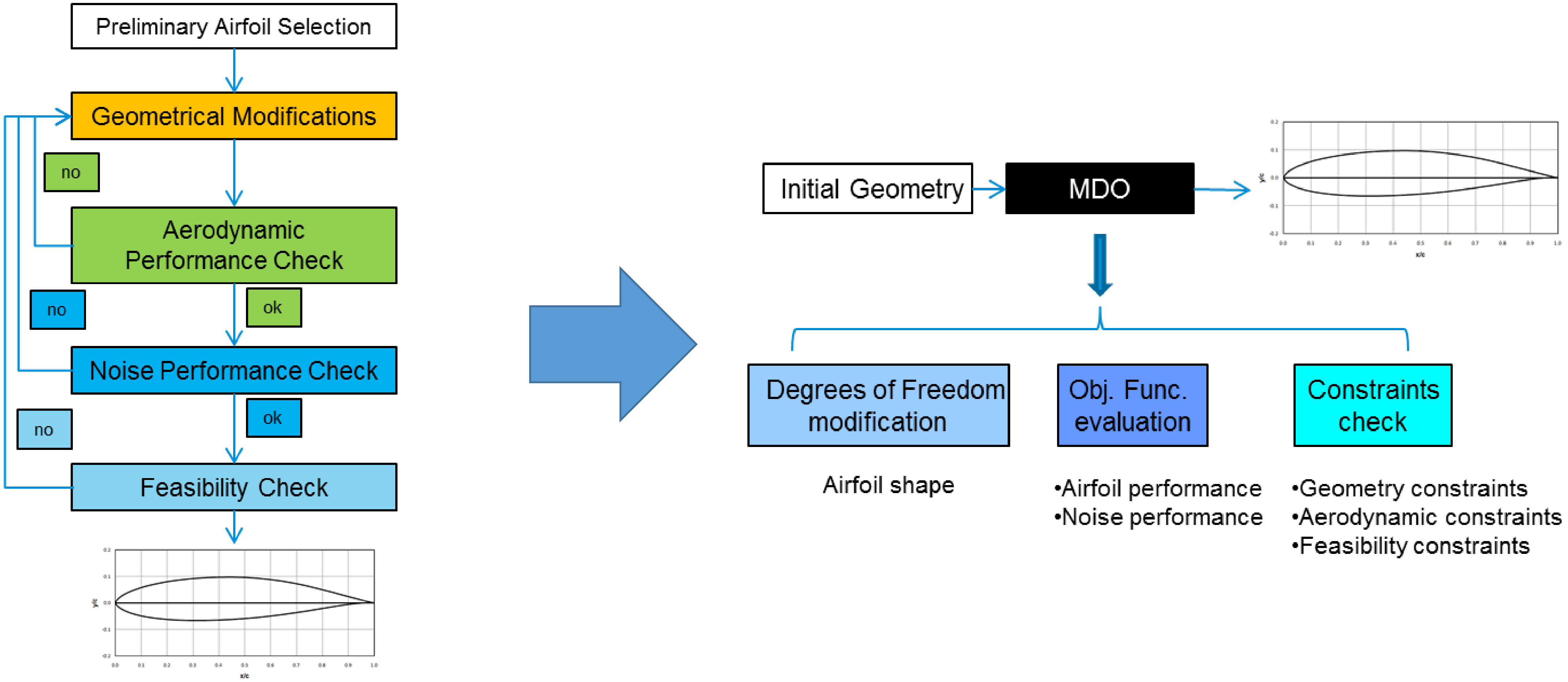
- Considering the outboard portion of pitch-regulated blade, typical requirements could look like:

- **Rotor Power – Aerofoil Aerodynamics**
  - High aerodynamic efficiency (L/D)
  - Robust performance in off-design conditions
  - Insensitivity to roughness
- **Rotor Loads/Stability – Aerofoil Aerodynamics**
  - Robustness to gusts
  - Smooth and gradual stall characteristics
  - Sufficient stall margin
  - Limited moment coefficient
- **Rotor Manufacturing – Aerofoil Geometry**
  - Aerofoil thickness and thickness location
  - Shape compatibility with the other aerofoils along the blade
  - Sufficient thickness at the trailing edge area
- **Rotor Noise – Aerofoil Noise**
  - Low OASPL level

Multi-Disciplinary Design Approach - Overview

- In order to consider different disciplines, a traditional approach would result in not efficient design process in respect of time, costs and product quality.

- Instead, multi-disciplinary design approach should reduce costs and development time by looking different disciplines together, which should also provide better/optimal solution.



Multi-Disciplinary Design Approach – Design Variables

Limited number of parameters

VS

Flexible and complete geometrical control

VS

Easy usage

- **Constructive methods**
  - B-splines
  - Parametrized sections (PARSEC)
- **Deformation methods**
  - Hicks-Henne functions
  - Legendre functions
  - Bezier deformations

- **B-splines**
  - User defined polynomial order for flexibility based on actual problem
  - Piece-wise approach for local shape control
  - Capability for independent control of camber and thickness

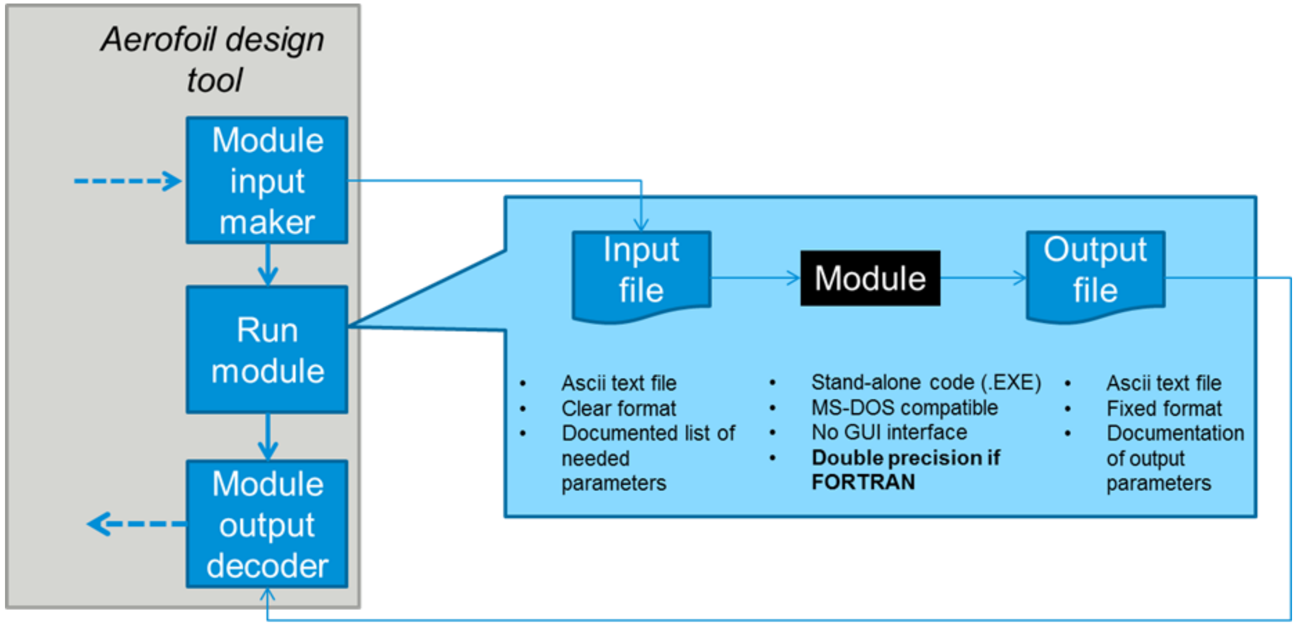
Multi-Disciplinary Design Approach – Optimization Algorithm

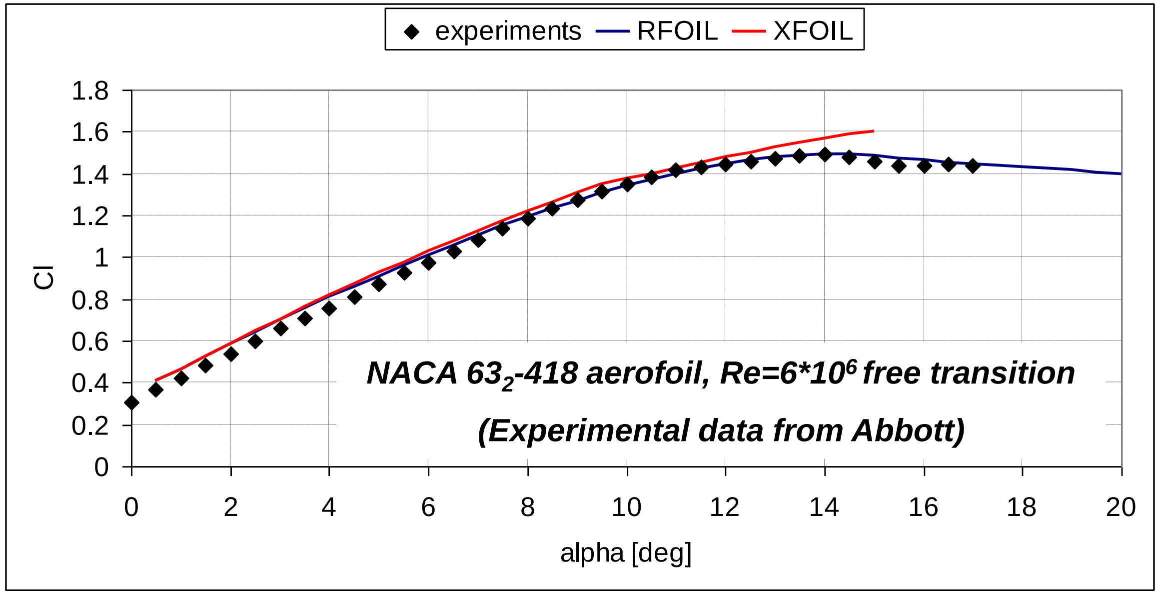
Algorithm family	**Algorithm type**	**Advantages**	**Disadvantages**
Deterministic	Gradient	little computational time/complexity	sensitivity to initial solution
		accurate in identifying the (local) optimum (exploitation)	sensitivity to local optima
Evolutionary	Genetic	suited for large design spaces (exploration)	computational expensive
		robust against multiple local optima	risk of not finding feasible solution
			constraints to be implemented as penalty functions
	Particle swarm	suited for large design spaces (exploration)	computational expensive
		robust against multiple local optima	
Stochastic	Simulating Annealing	capability for combining exploring and exploiting phases	sensitivity to the SA parameters
	Response Surface	capability of multi-fidelity approach	computational expensive

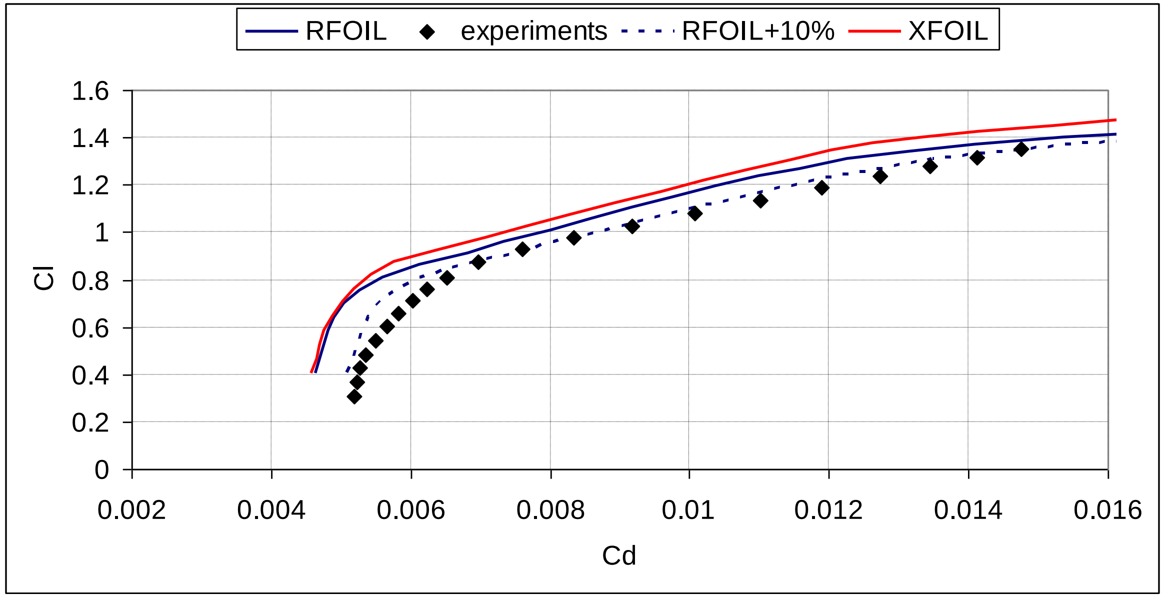
- Hybrid approach is in development where genetic algorithm is used design space exploration and optimal region definition, while the gradient algorithm is adopted to exploit the optimal solution

Multi-Disciplinary Design Approach – Objective Function Evaluation

- **XFOIL and RFOIL solvers implemented for aerodynamics**
  - Enhanced version of Drela's XFoil (rel. 5.4)
  - Improvements in BL description
  - Effects due to the rotation taken into account
- **VETNOM in house developed solver implemented for acoustics**





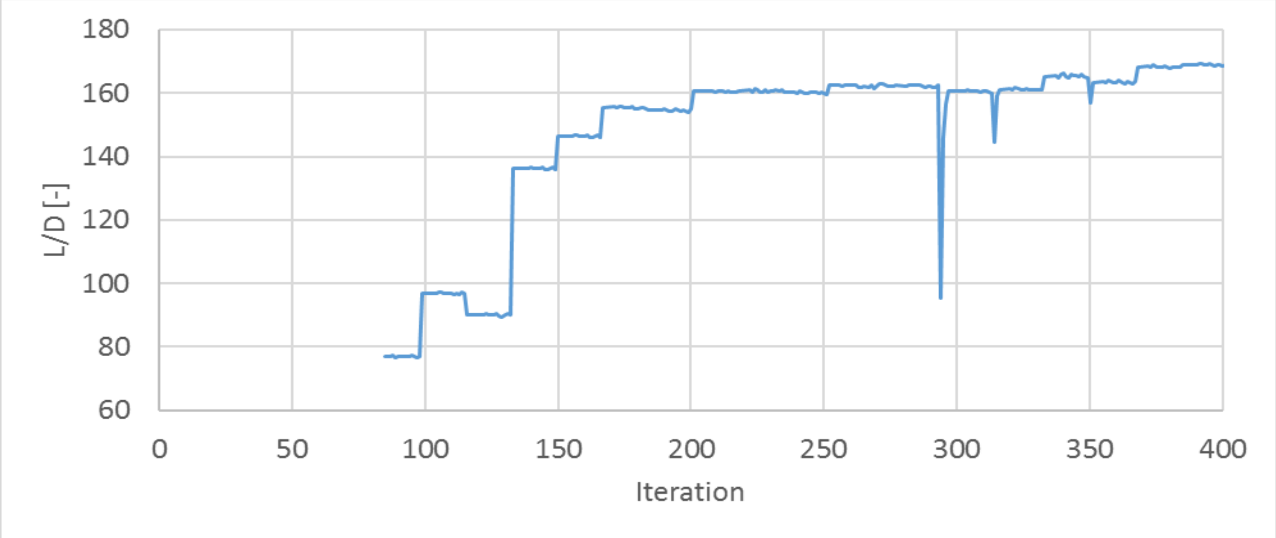


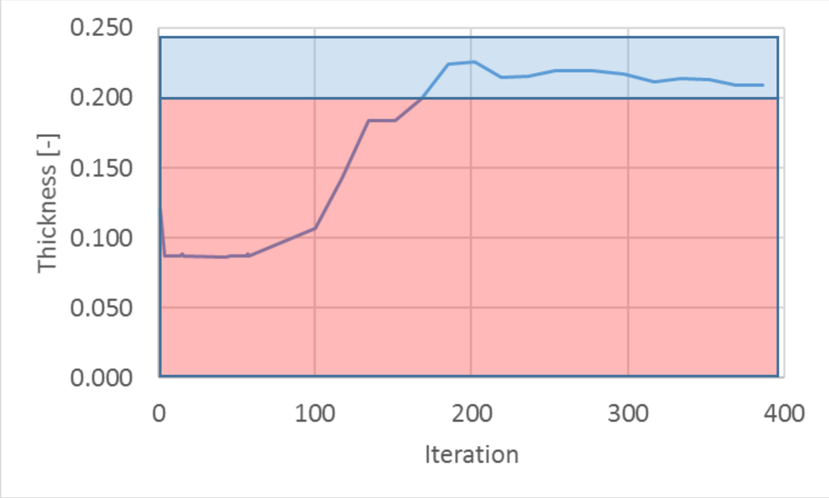
Numerical Example

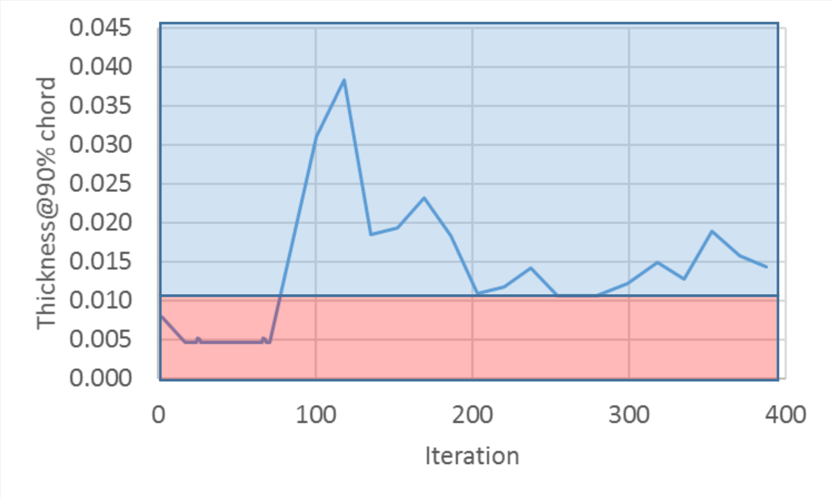
- Objective function: maximize L/D
- Initial solution: 12% symmetrical shape
- Design variables: 13
- Conditions:
  - Design Cl: 1.1
  - Re number: 3e06
  - Transition: free
- Constraints
  - Aerofoil thickness >21%
  - TE thickness > 0.2%
  - Thickness @ 90% chord > 1.1%
  - Cm@ Cl1.12 > -0.133

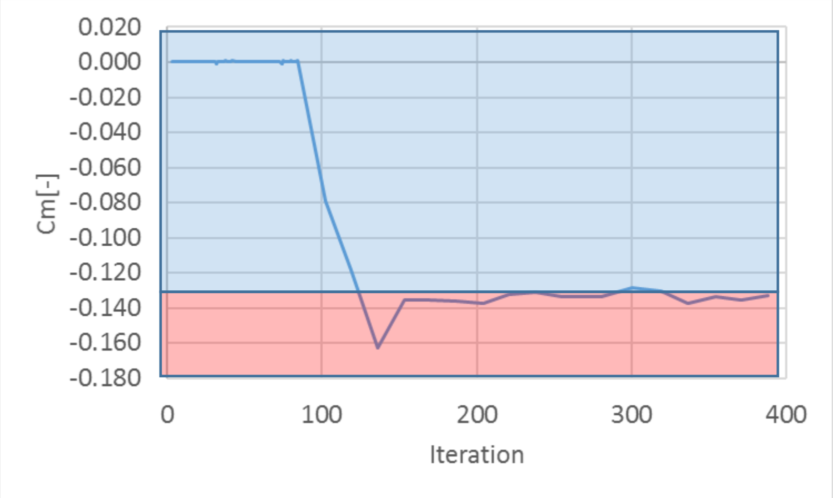
Numerical Example

- L/D @ Cl 1.1: 176 (RFOIL data)
- Max L/D: 183 (RFOIL data)
- Computational time: 398sec on laptop (I5 2.6GHz, 4Gb RAM)









Conclusions

- The first results obtained on aerofoil design based on multi-disciplinary optimization showed significant reduction in design time/costs (by 50%).

- The reduction in time/costs did not affect the quality of the results. On the contrary, the new approach proved to be effective in finding optimal-high-performance solution in high conflicting design space, such as aerodynamics vs noise vs manufacturing.