High-fidelity aerodynamic shape optimization for wind turbines

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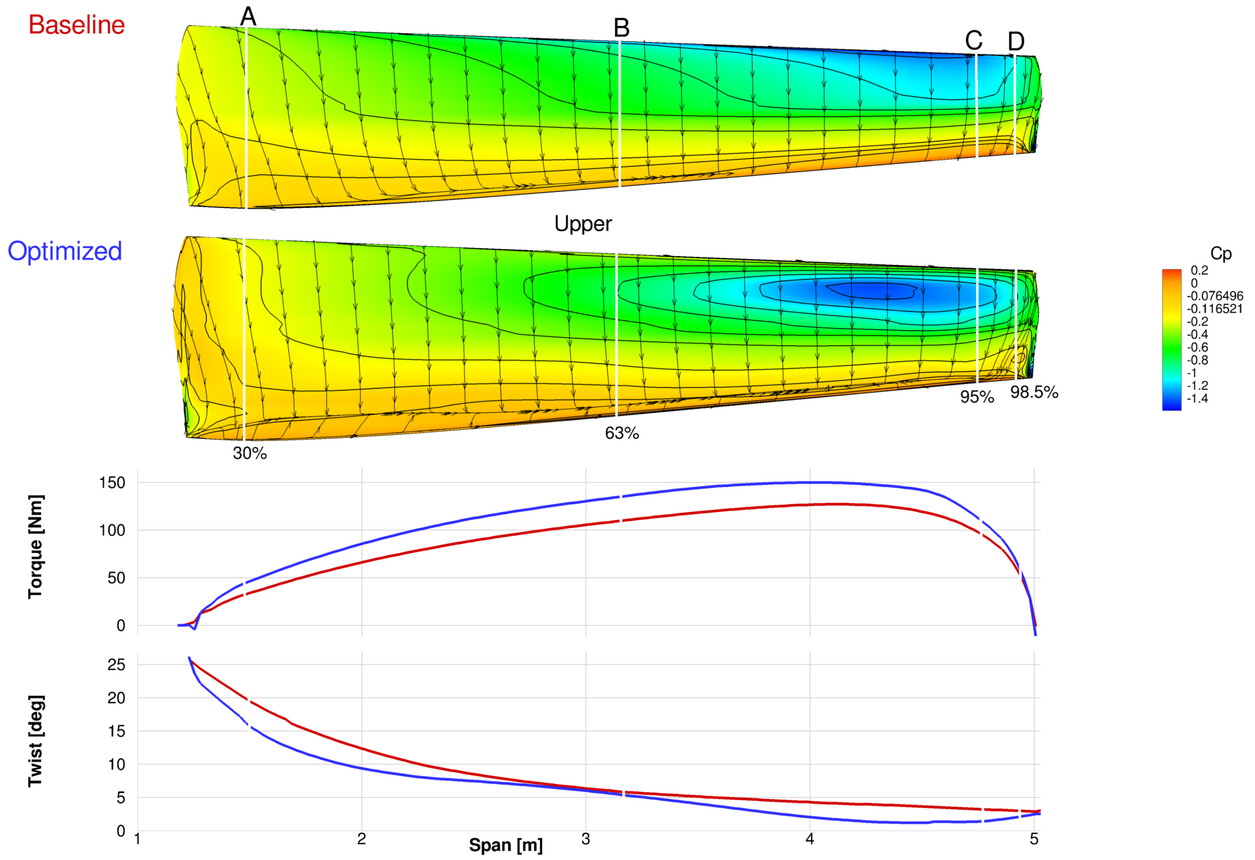

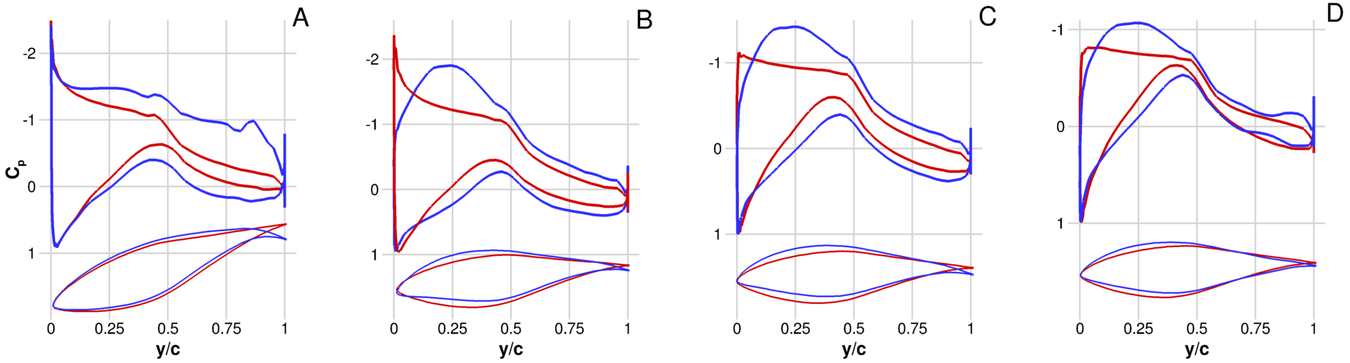

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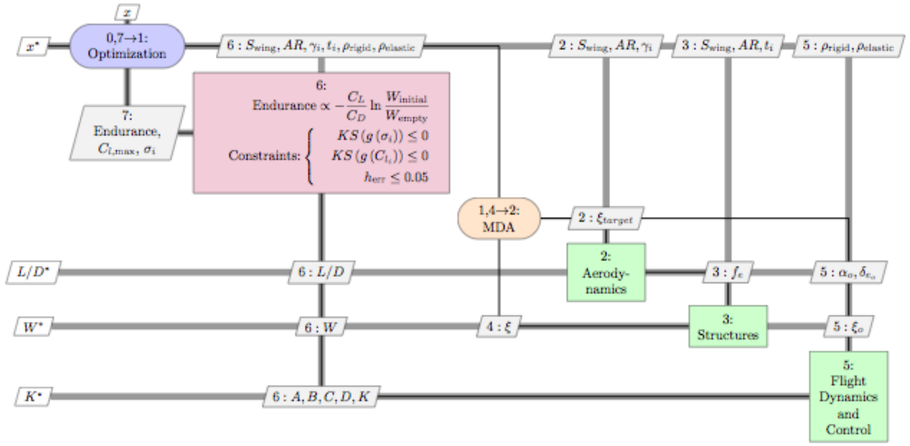
Newsletter: MDOlab

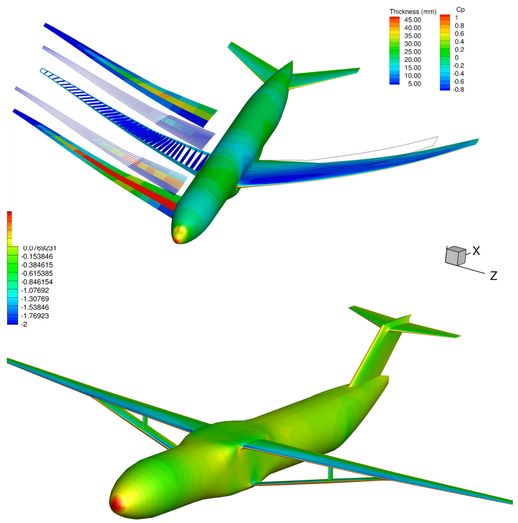
MDOlab research is divided into two main thrusts

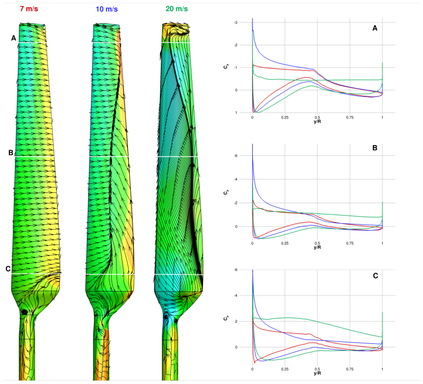
Fundamental MDO algorithms

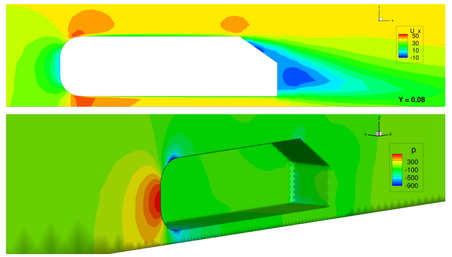


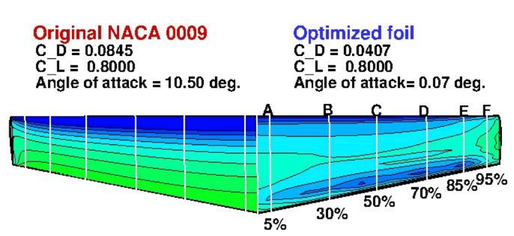
$$\frac{\partial R}{\partial u}\frac{du}{dr} = \mathcal{I} = \left[\frac{\partial R}{\partial u}\right]^T \left[\frac{du}{dr}\right]^T$$

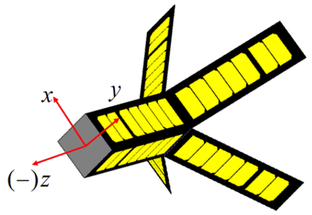
Applications of MDO

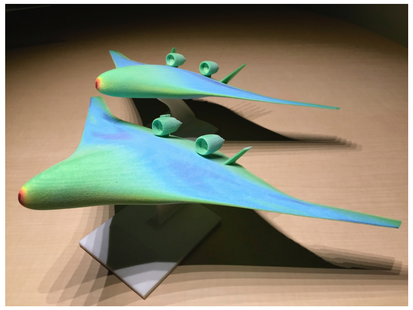


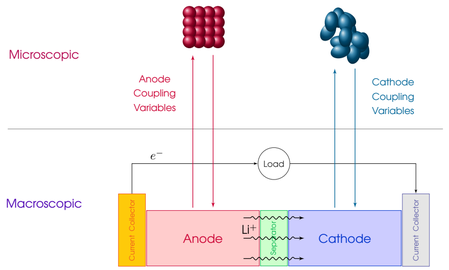




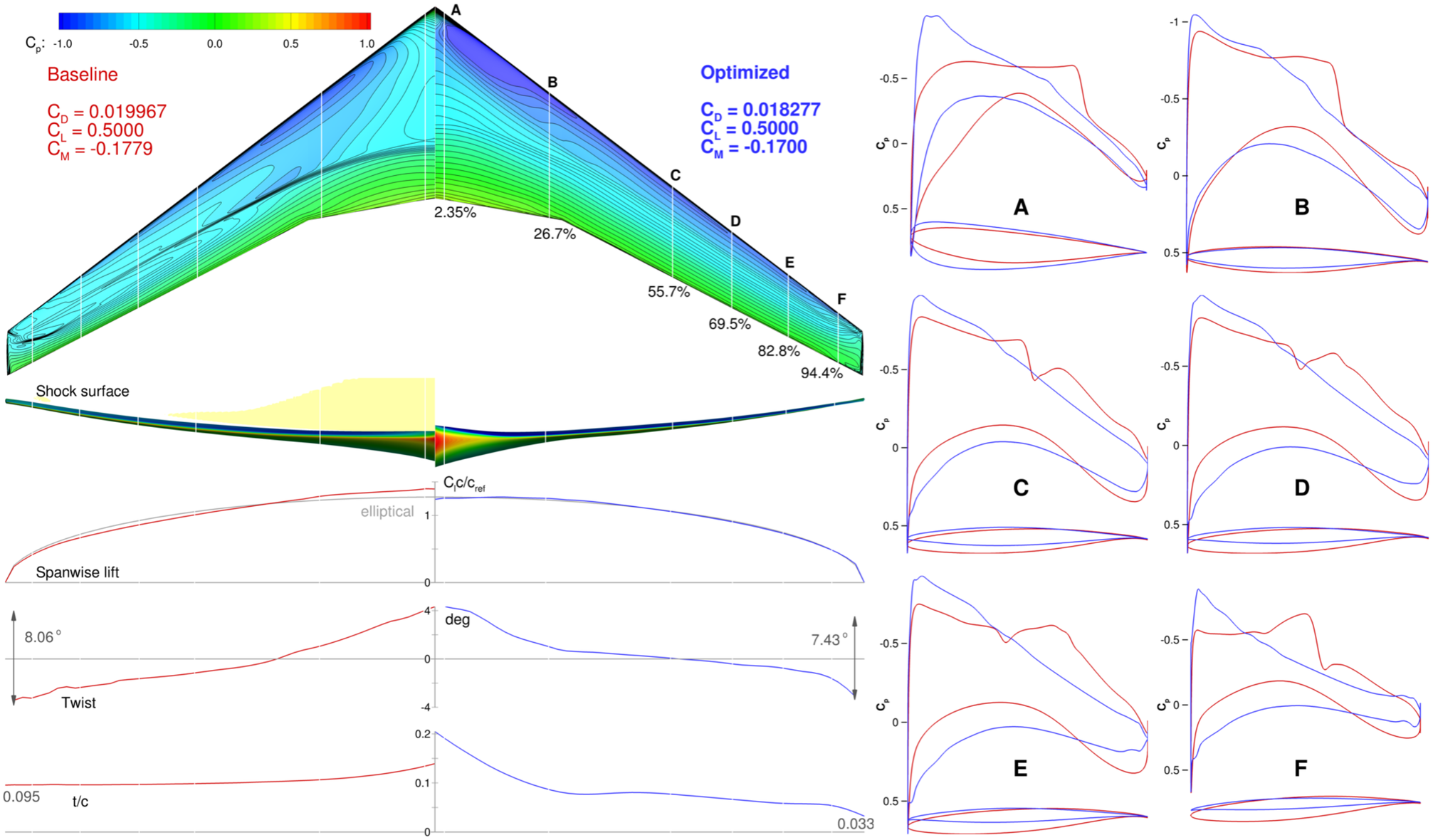






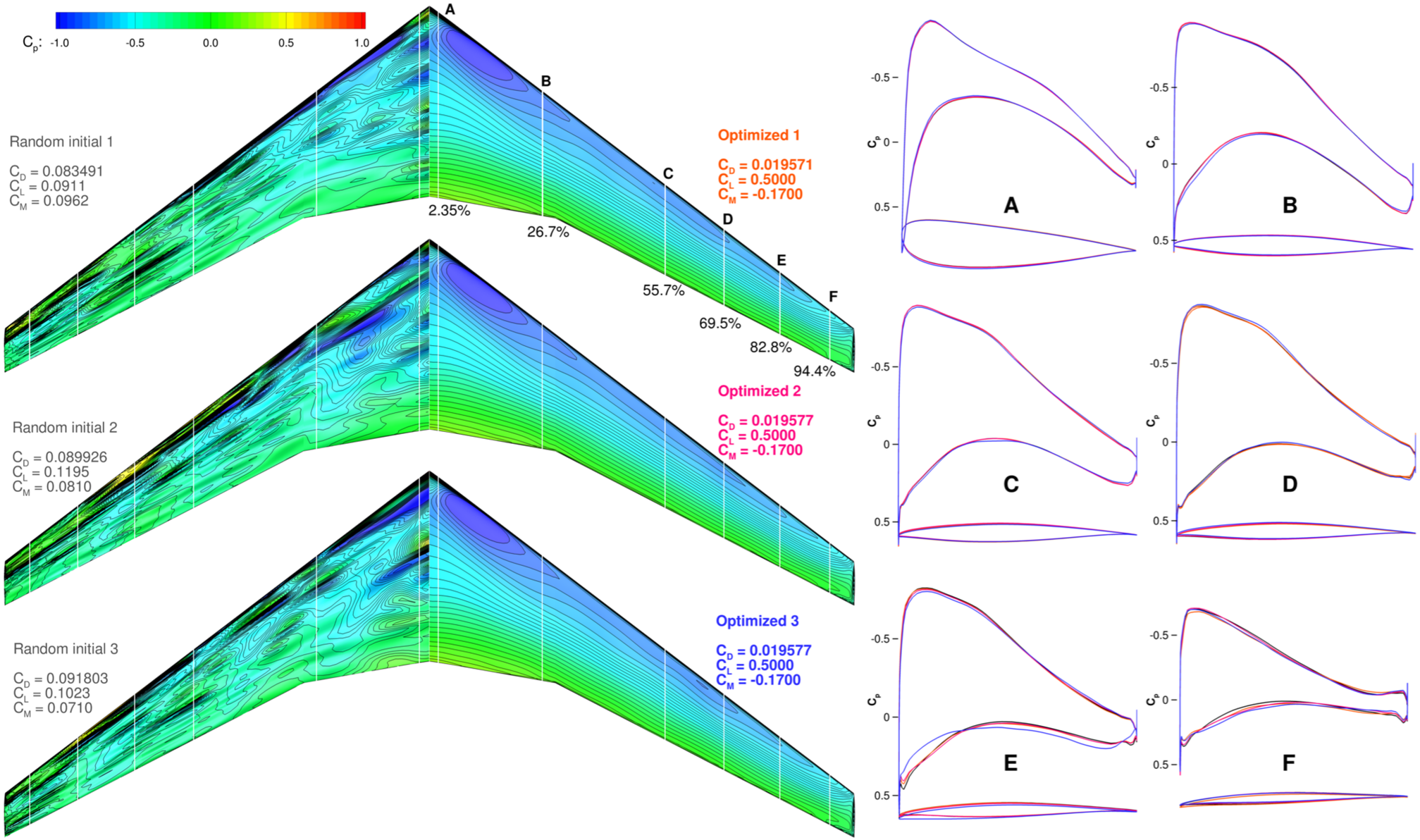


Optimization can refine good designs…

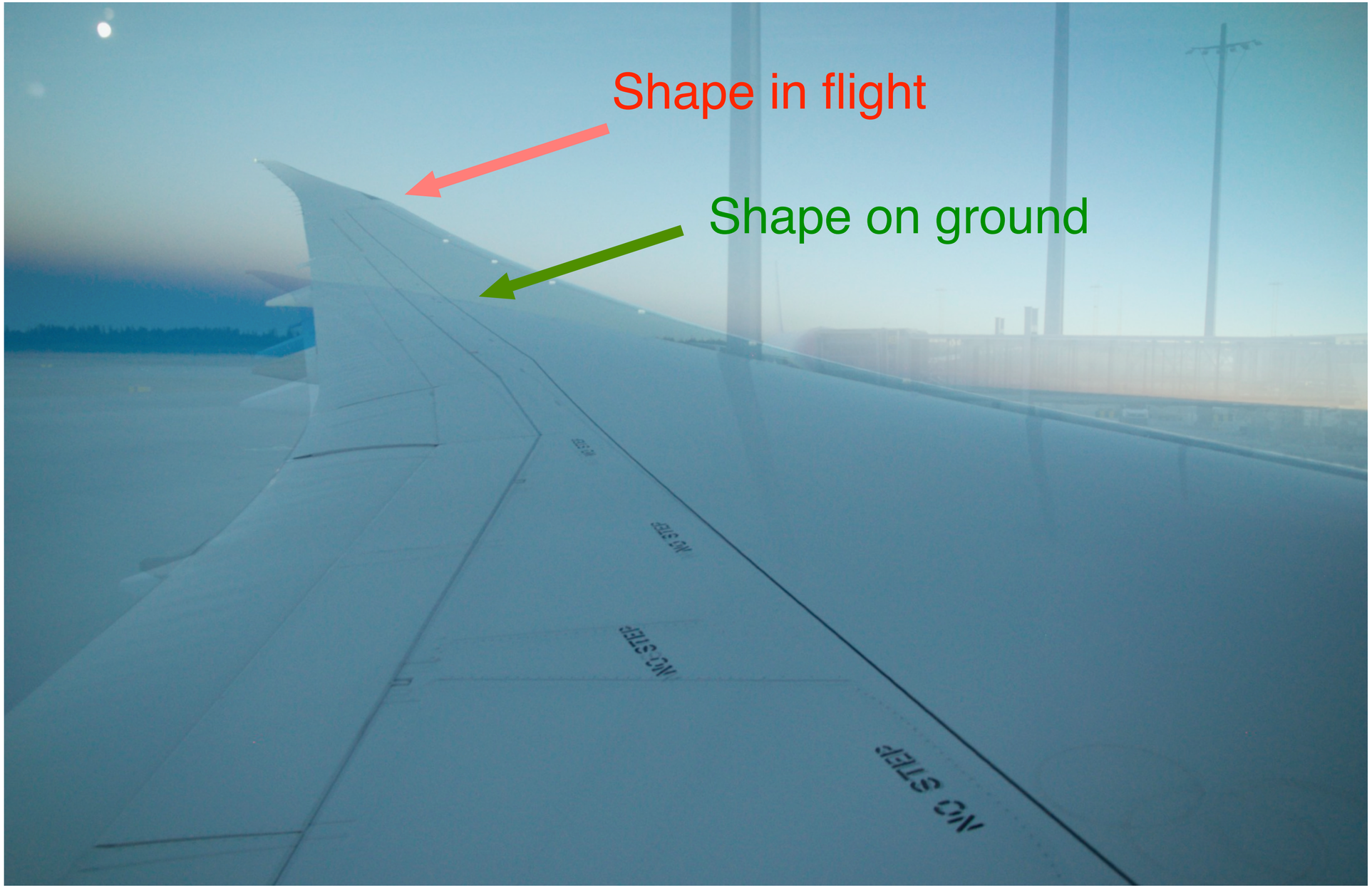


[Lyu, Kenway, and Martins, AIAA J., 2014]

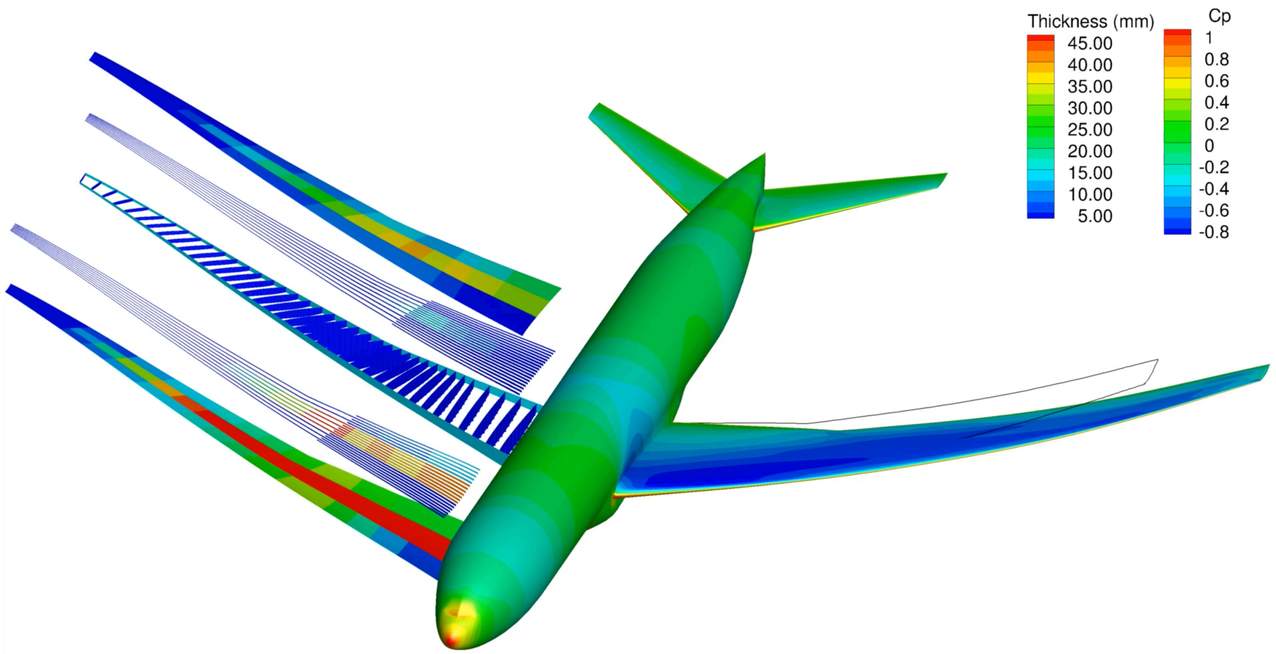
…but can we start from really bad designs?

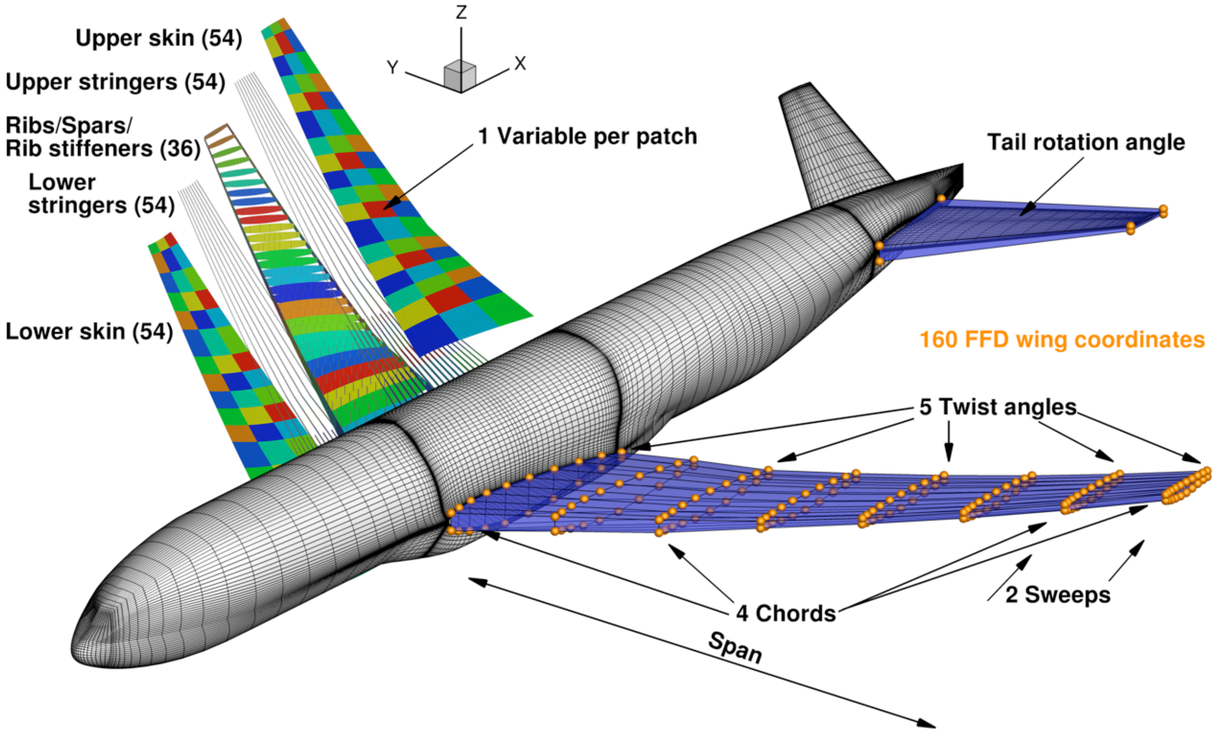


Wing design demands more than just aerodynamics

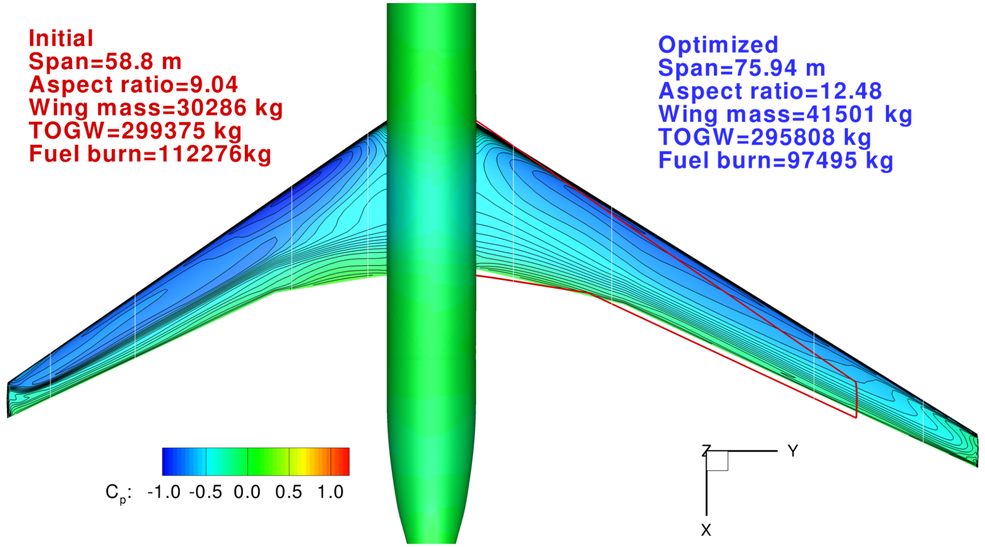


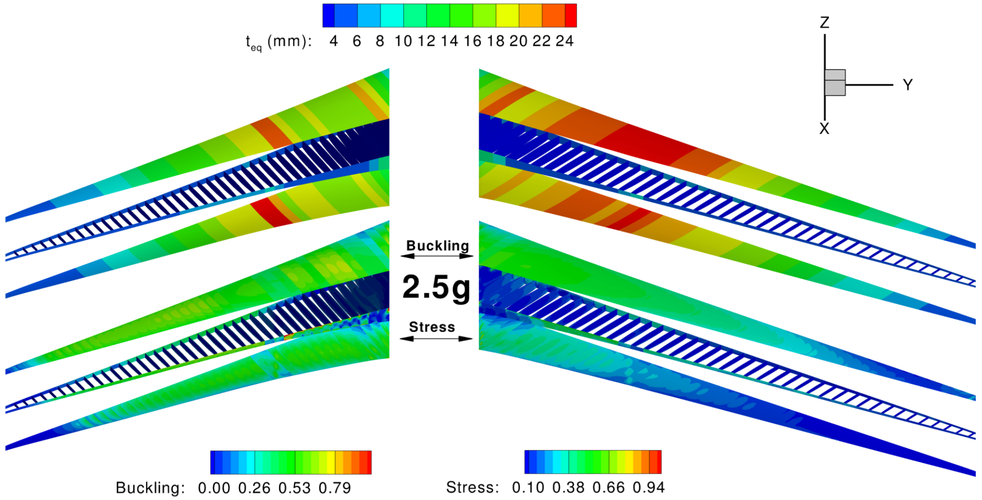
Want to optimize both aerodynamic shape and structural sizing, with high-fidelity

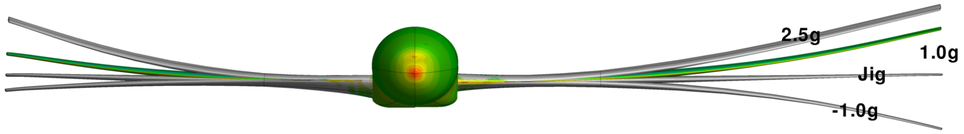


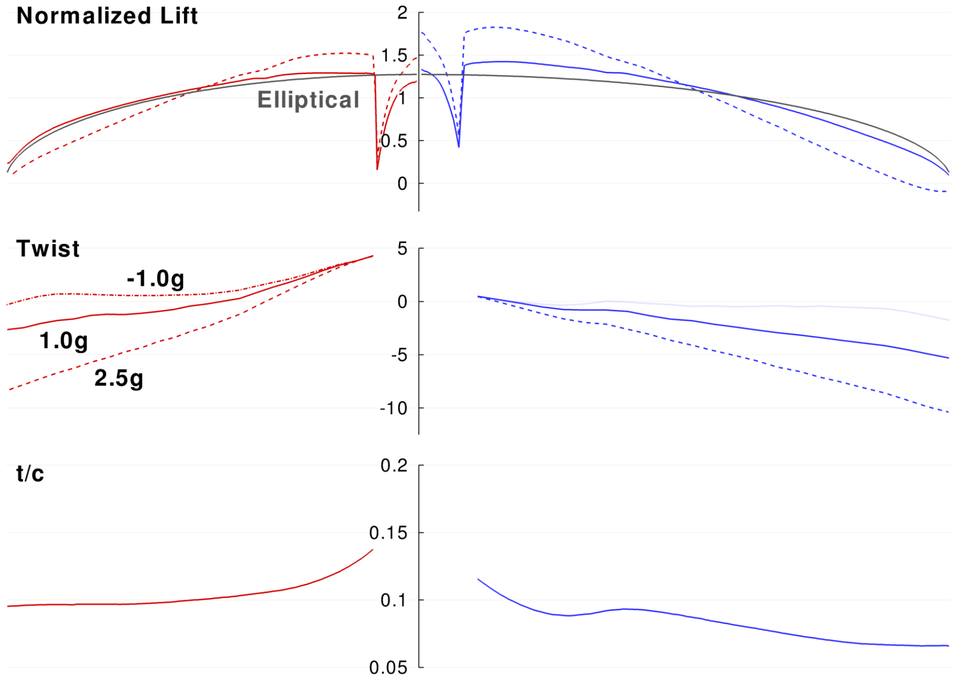


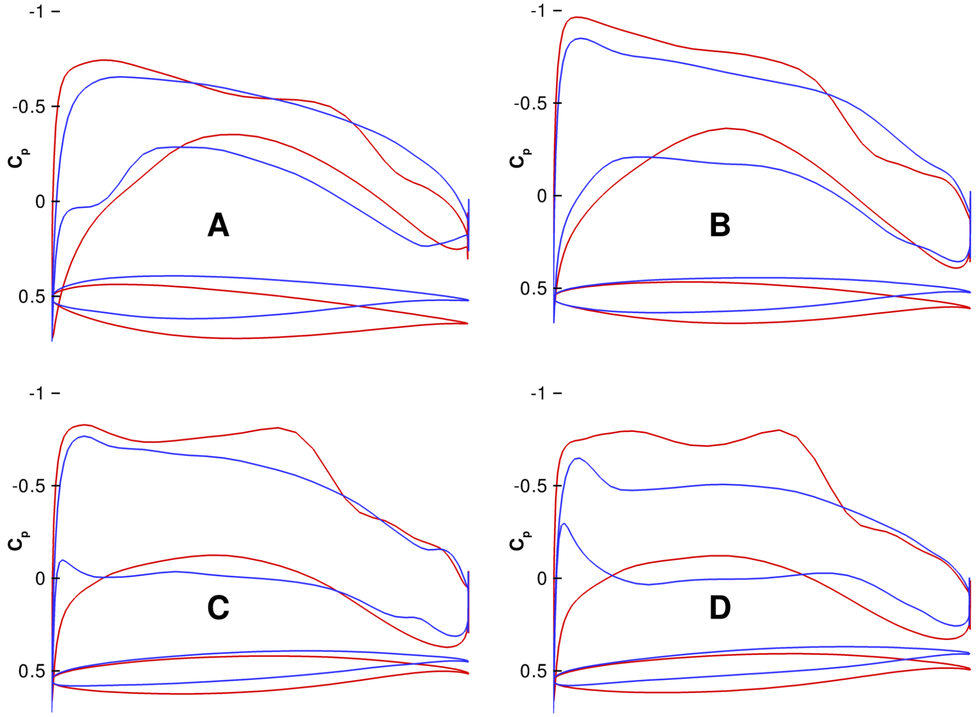
[Kenway and Martins, J. Aircraft, 2014]





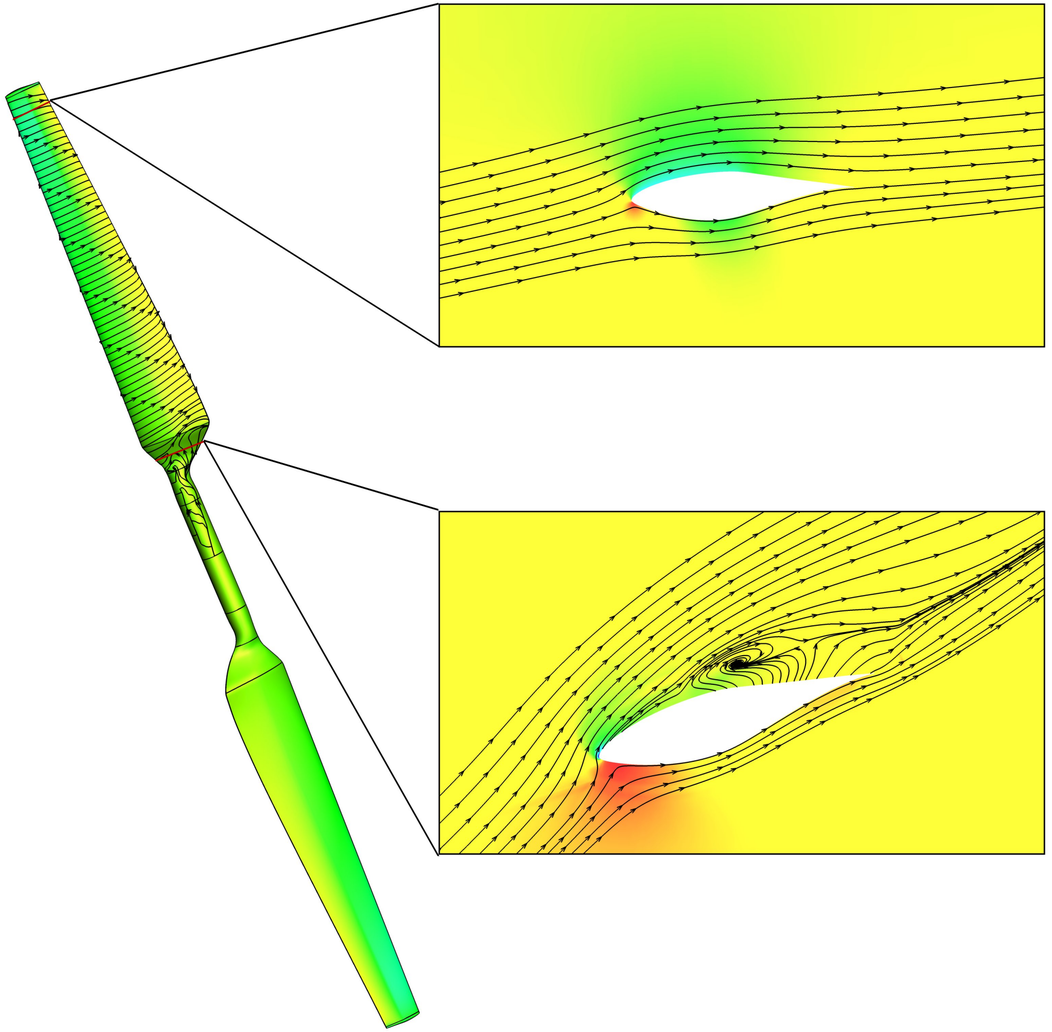


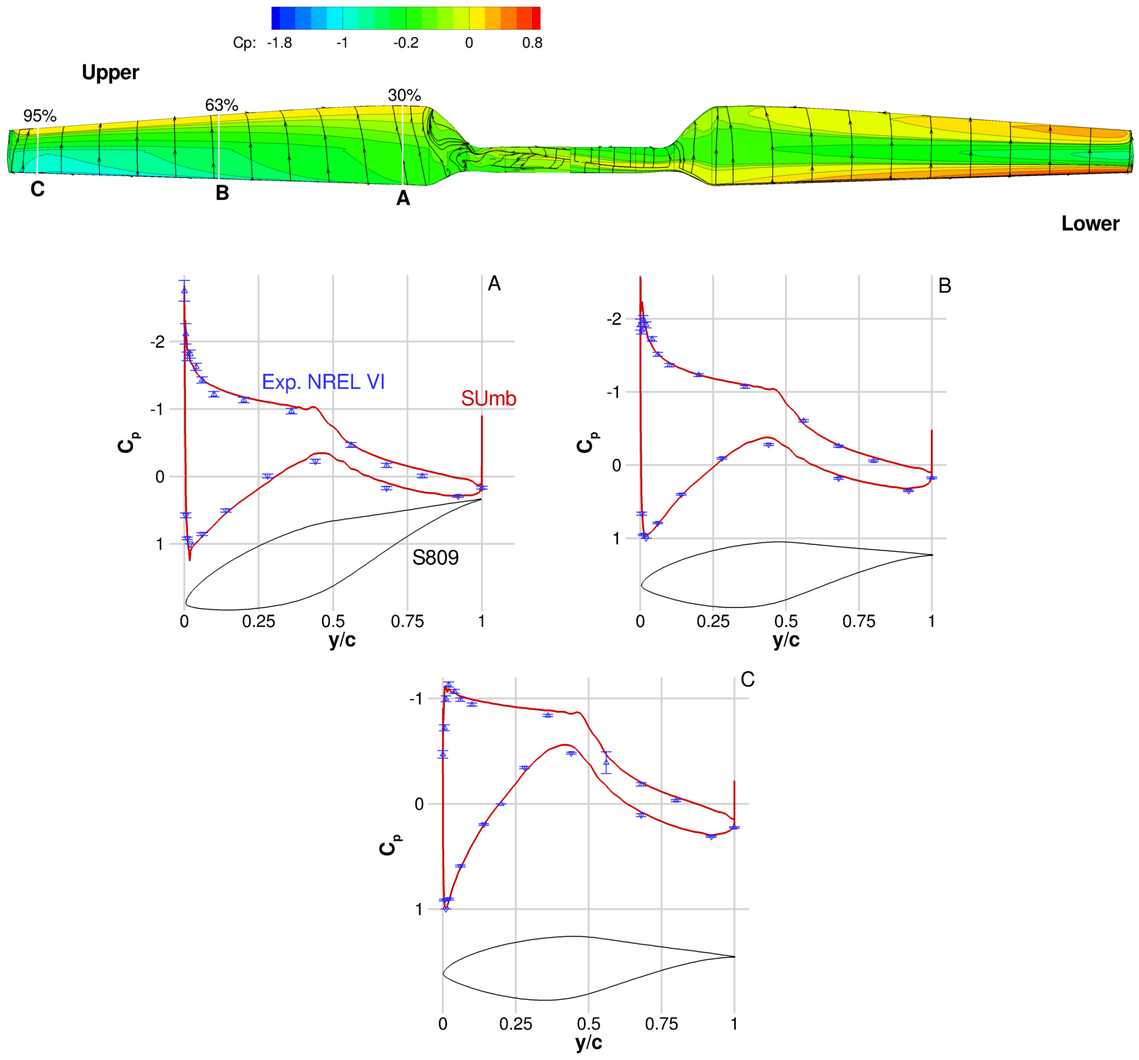




[Kenway, Kennedy, and Martins, AIAA J., 2014]

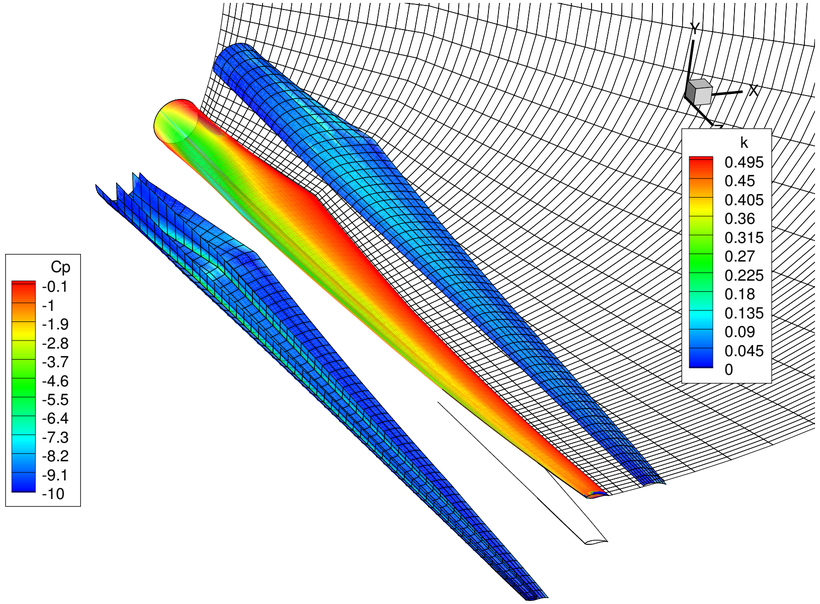
This aerostructural optimization framework can be adapted for the design of wind turbine blades

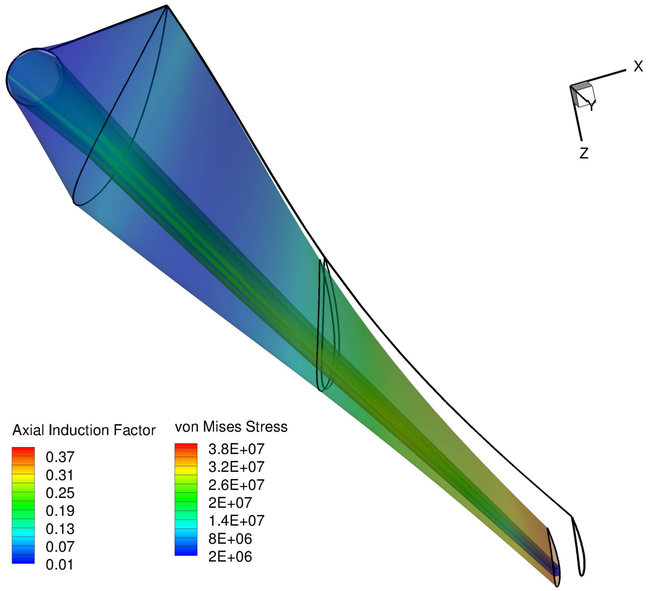




Our previous effort were limited to low-fidelity aerodynamic models

- Aerostructural analysis using 3D panel method and FEM
- Aerostructural optimization with BEM theory and beam finite elements
- Aerodynamic shape optimization by use of BEM theory

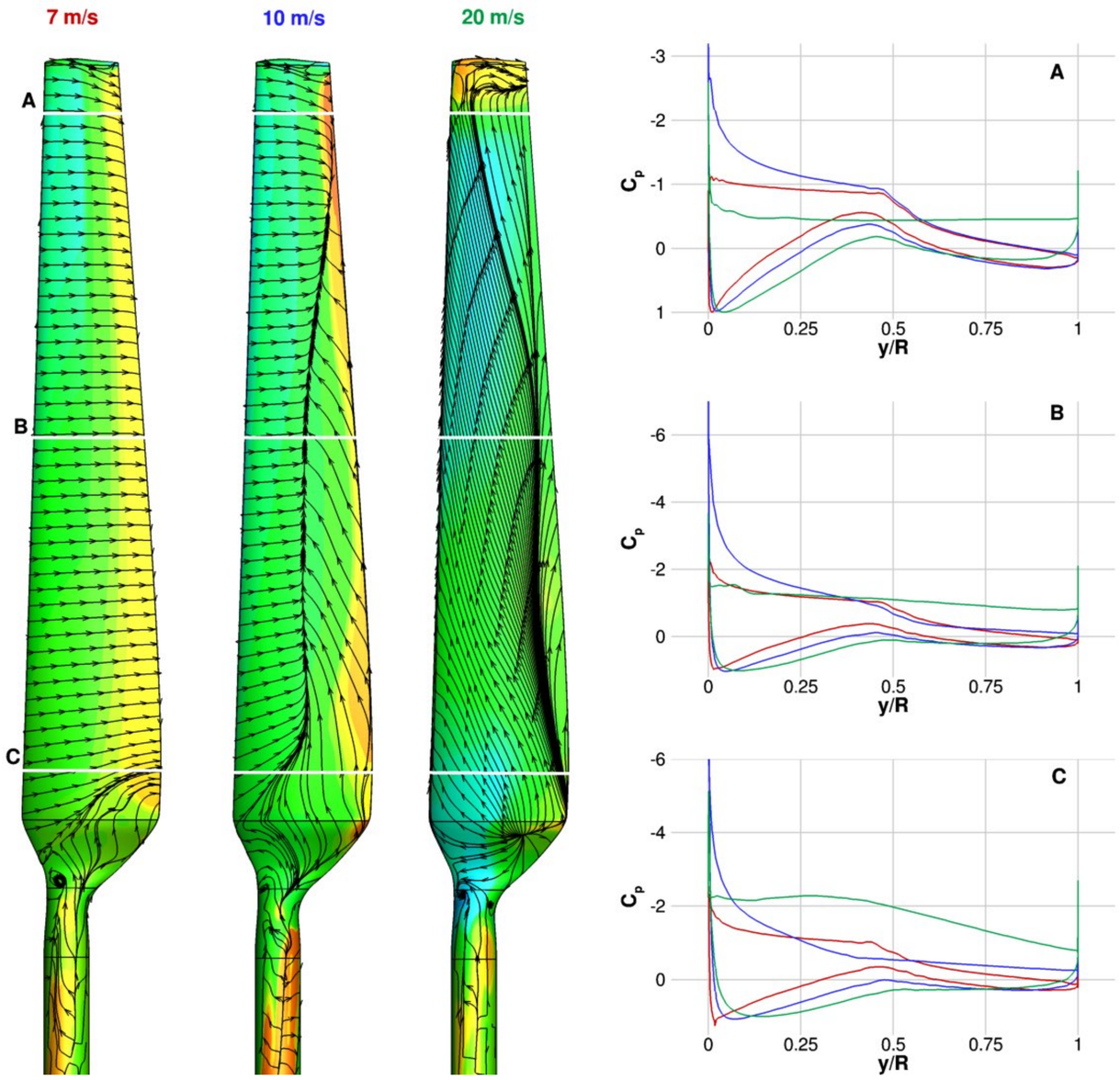




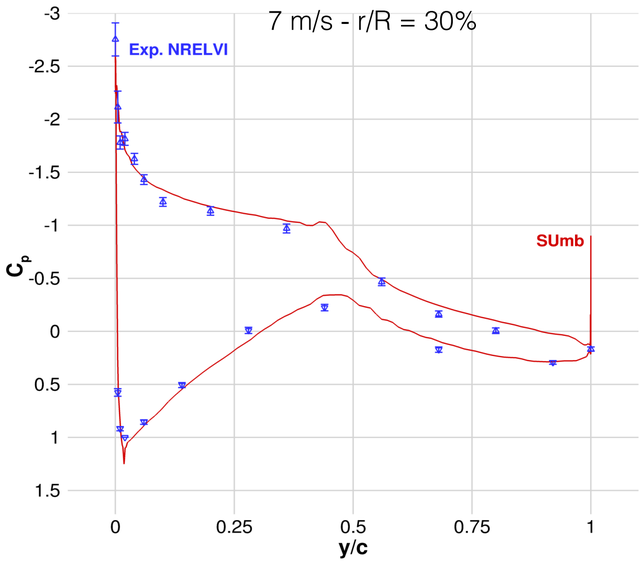
[Kenway and Martins, AIAA J., 2008]

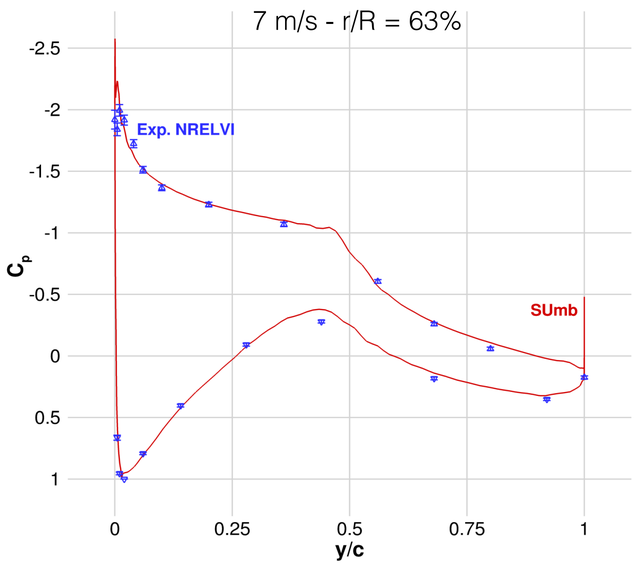
We can now perform steady-state RANS analysis in the rotating frame

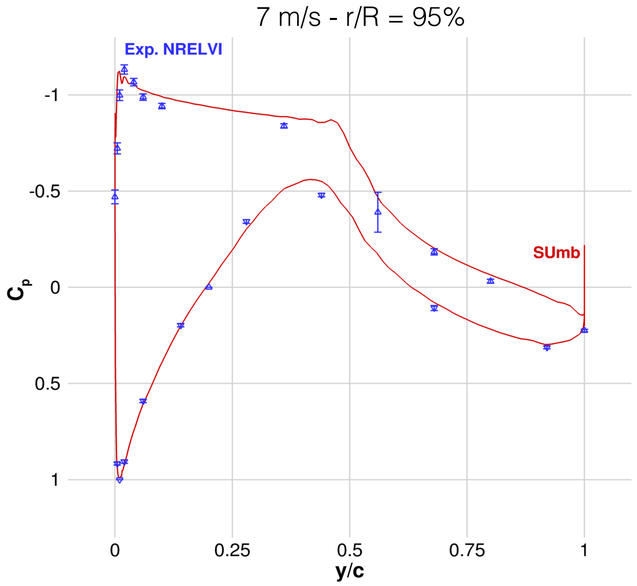
- Structured compressible RANS-based solver ‘SUmb’
- Roe scheme without limiter
- Spalart–Allmaras turbulence model
- Wind speeds: 5, 7, 10, 13, 15, 20, and 25 m/s



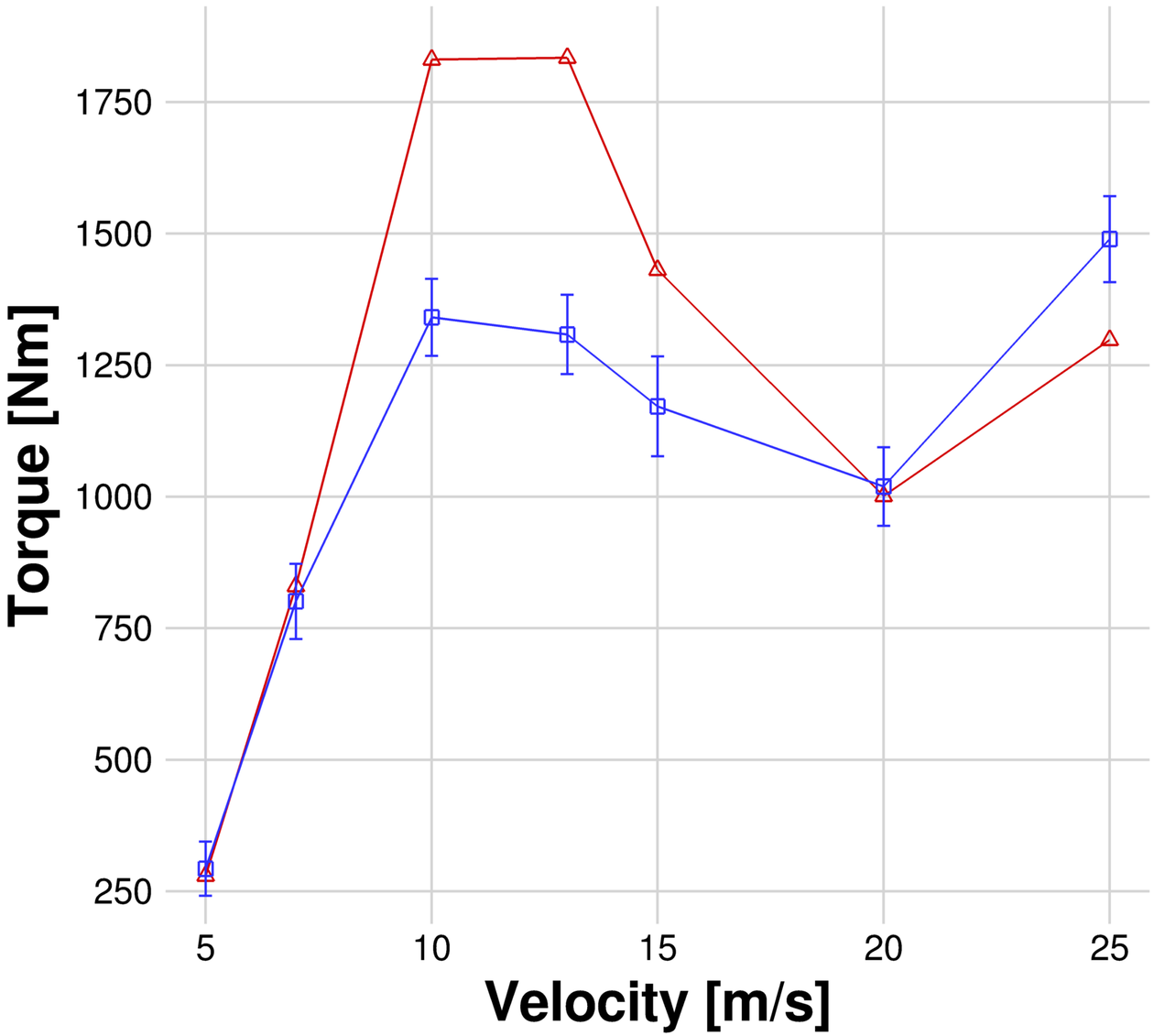
Attached flows are well predicted for the NREL VI sequence S experiment



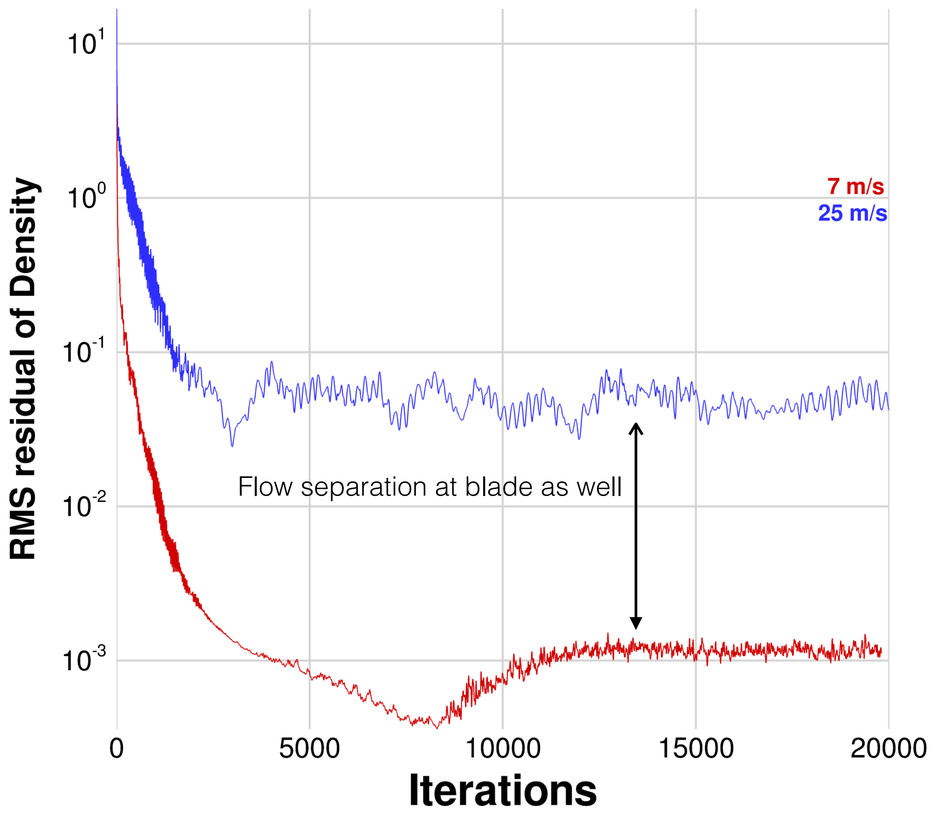


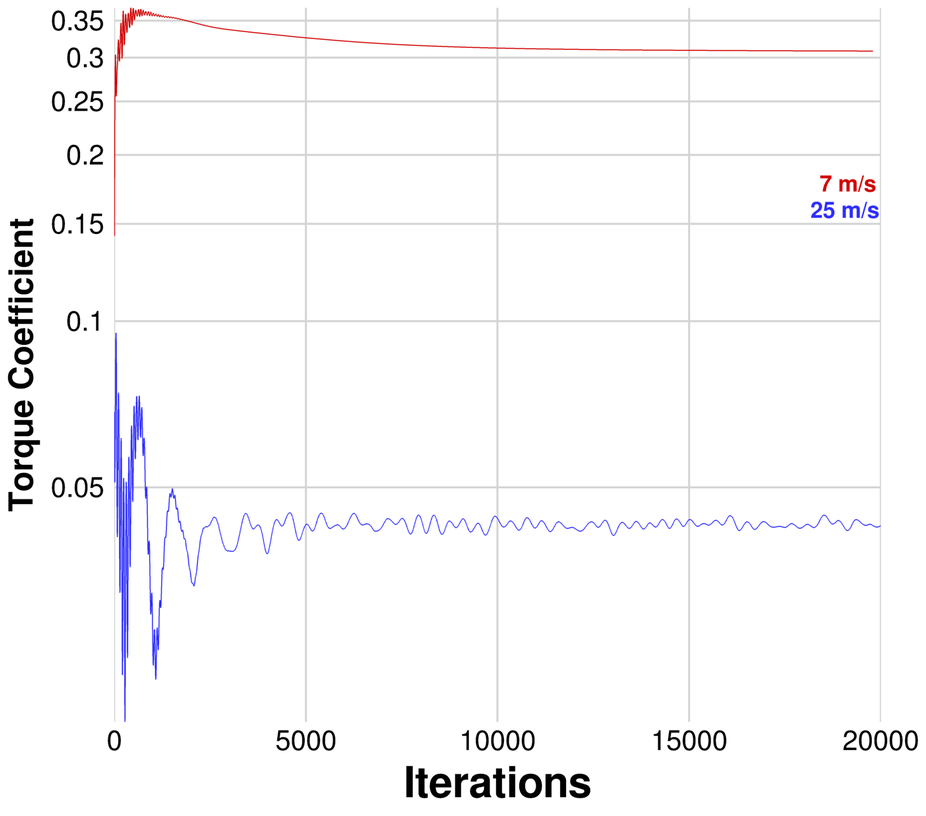


While attached flows are well predicted, the separated flow conditions are not



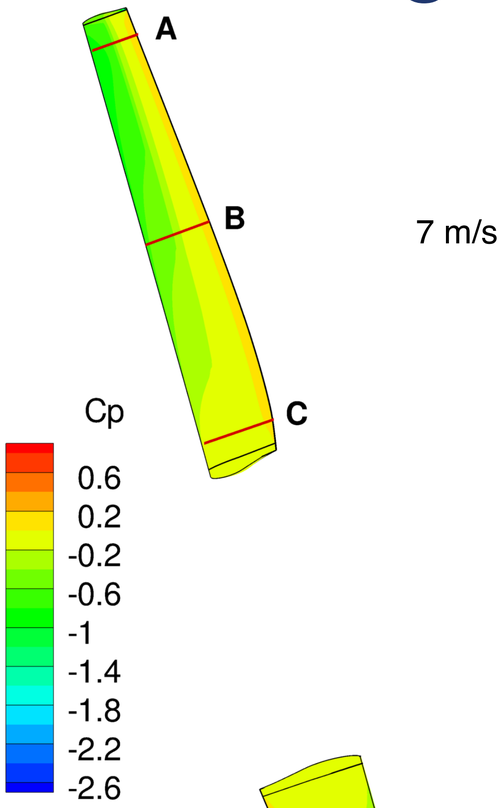
… but stagnation in residuals due to unsteadiness at cylindrical -and transition part



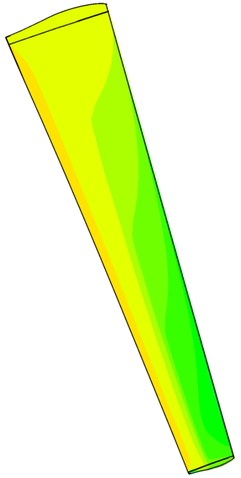


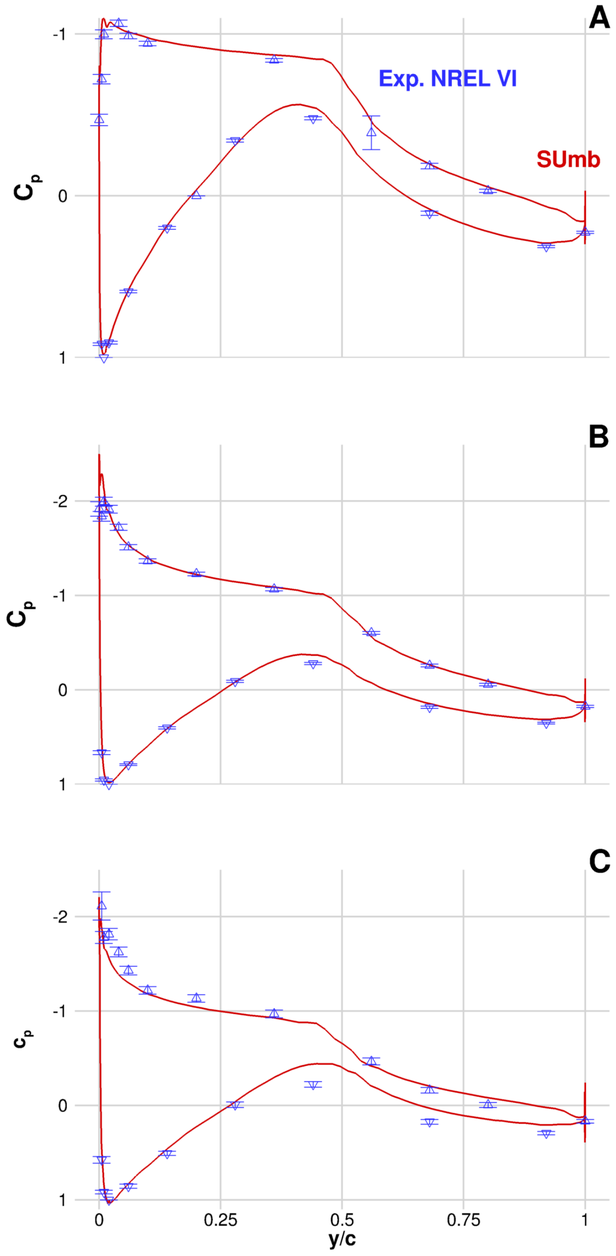
Steady-state adjoint stagnates! ⟶ No optimization possible

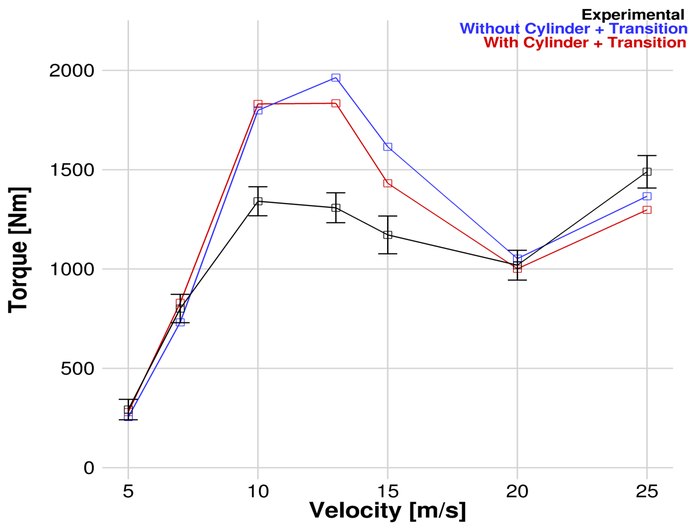
Removing cylinder and transition part works!

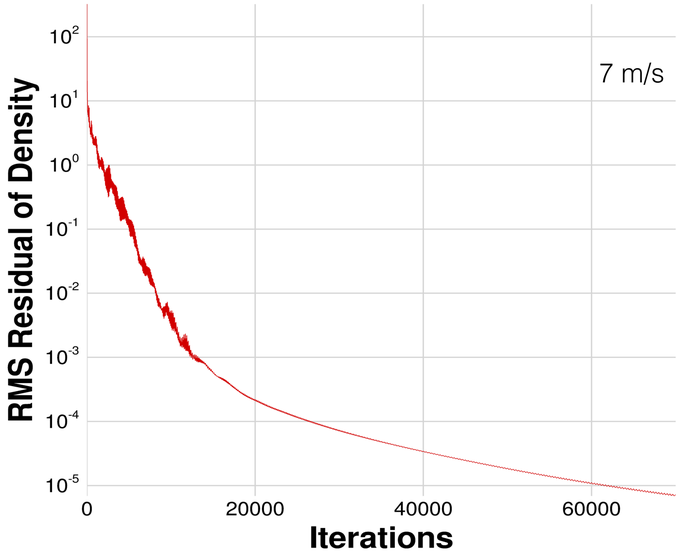


7 m/s



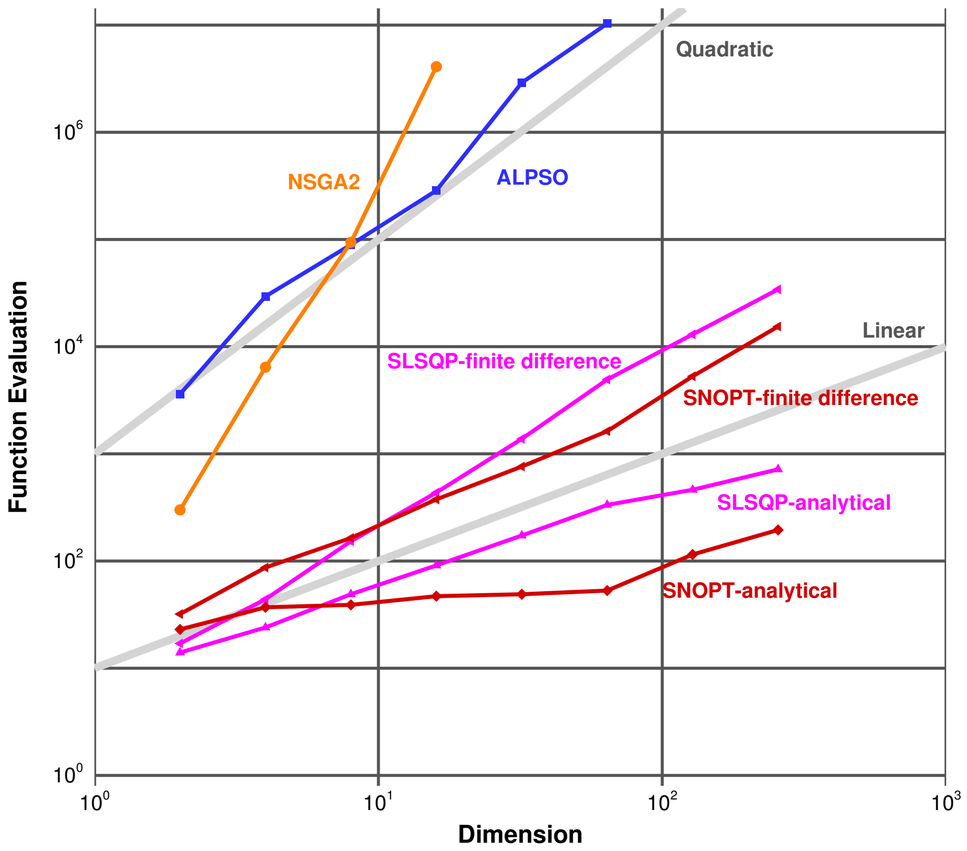


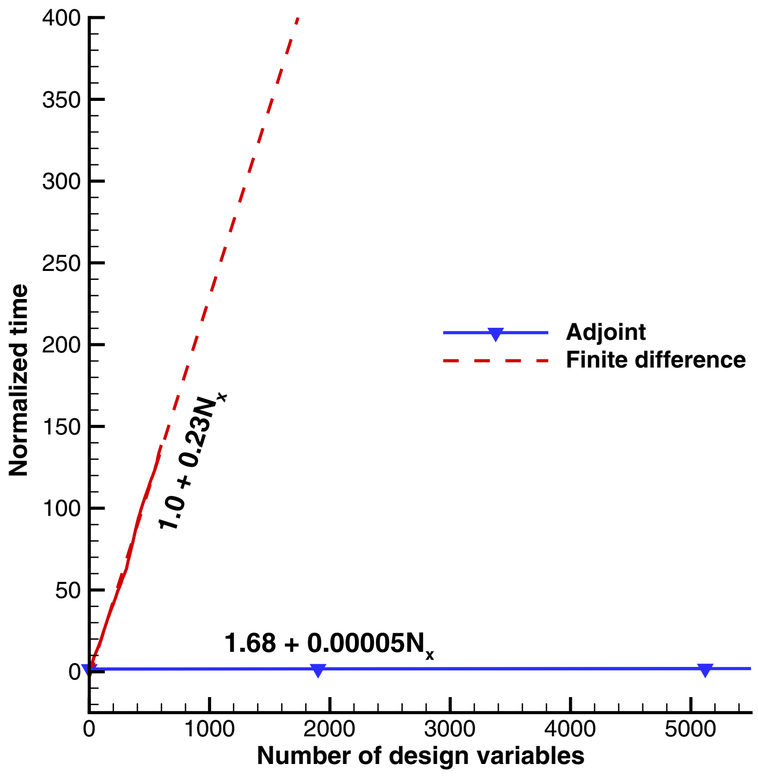


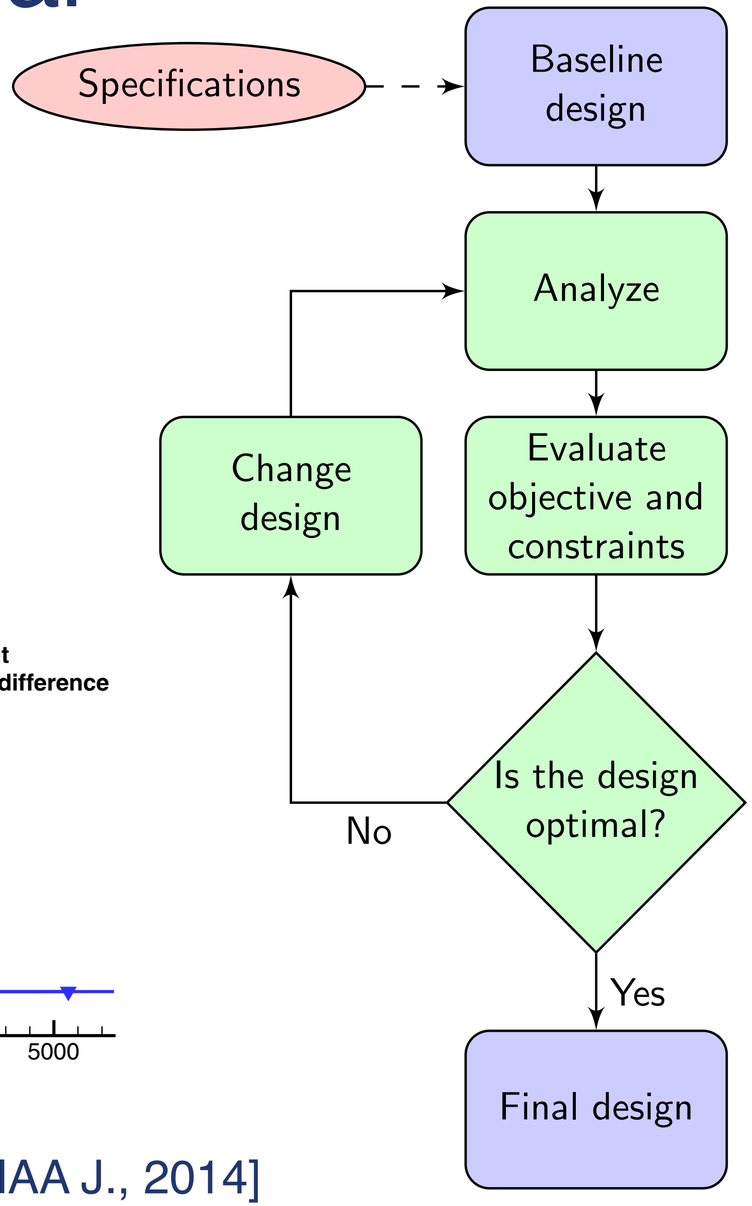


Optimization is feasible in attached flow region

Gradient-based optimization is essential for large set of design variables



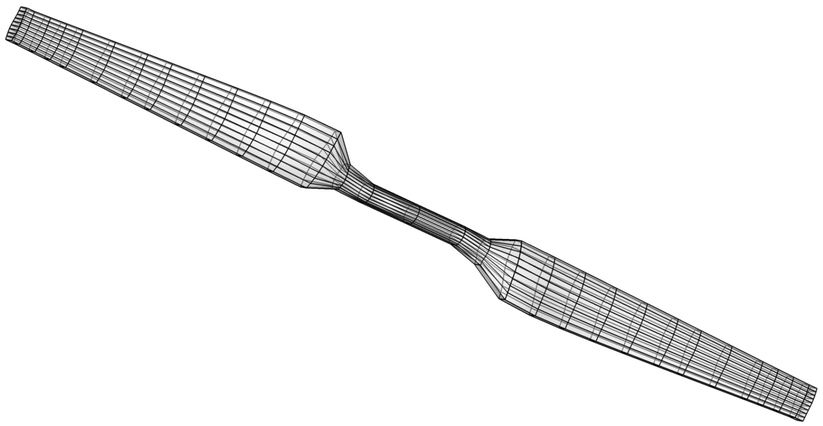


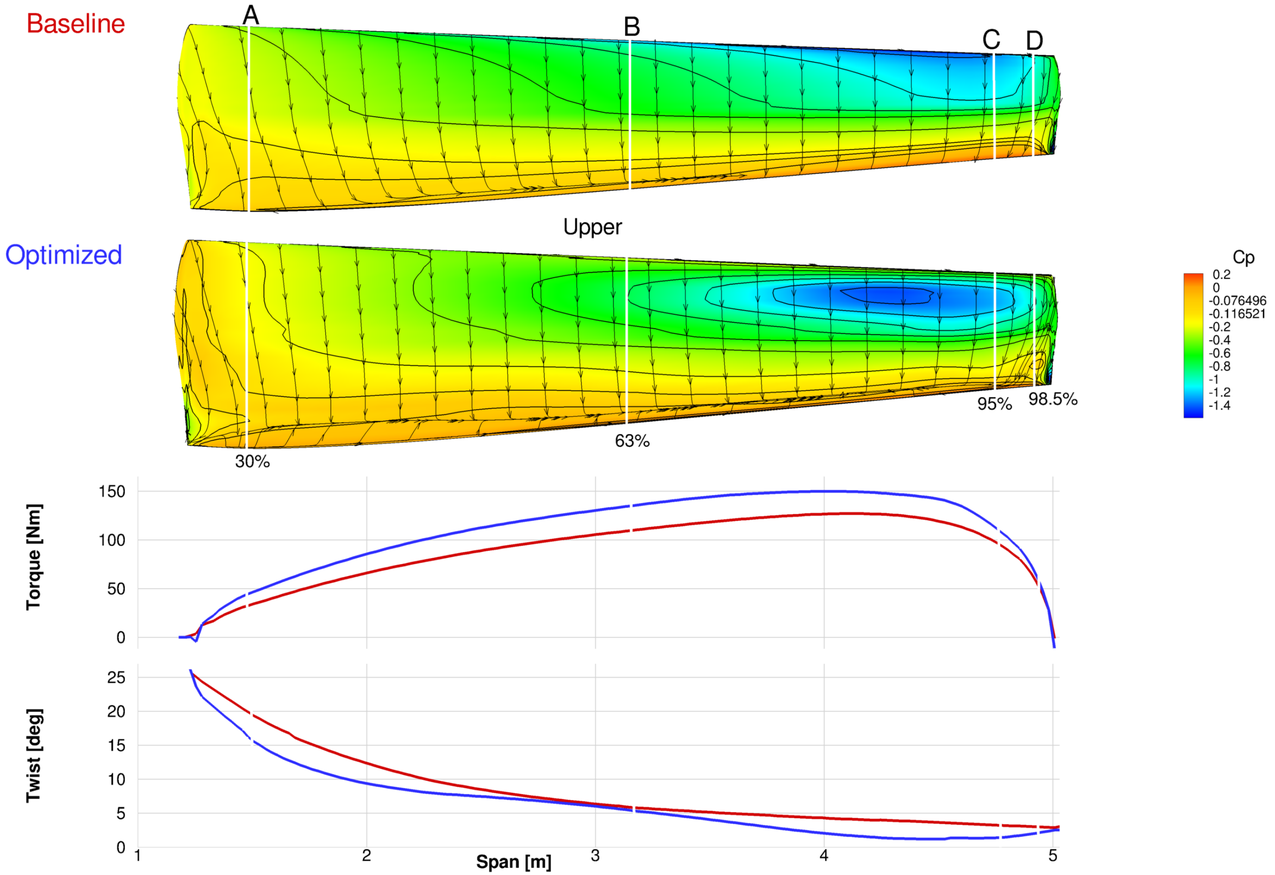


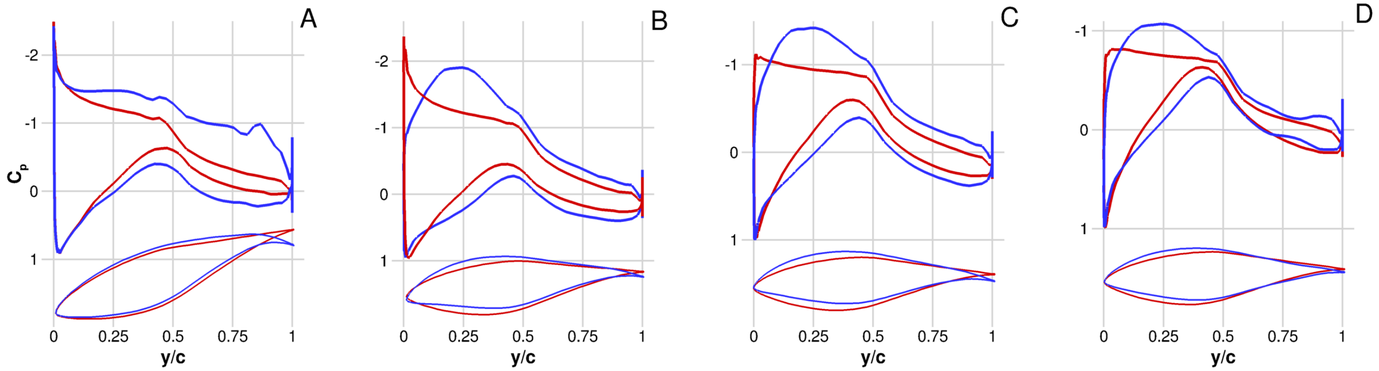
[Kenway, Kennedy, and Martins, AIAA J., 2014]

22.4% increase in torque by subtle changes in shape and twist

- Maximizing torque
- 496 design variables: shape and twist
- thickness -and linear constraints



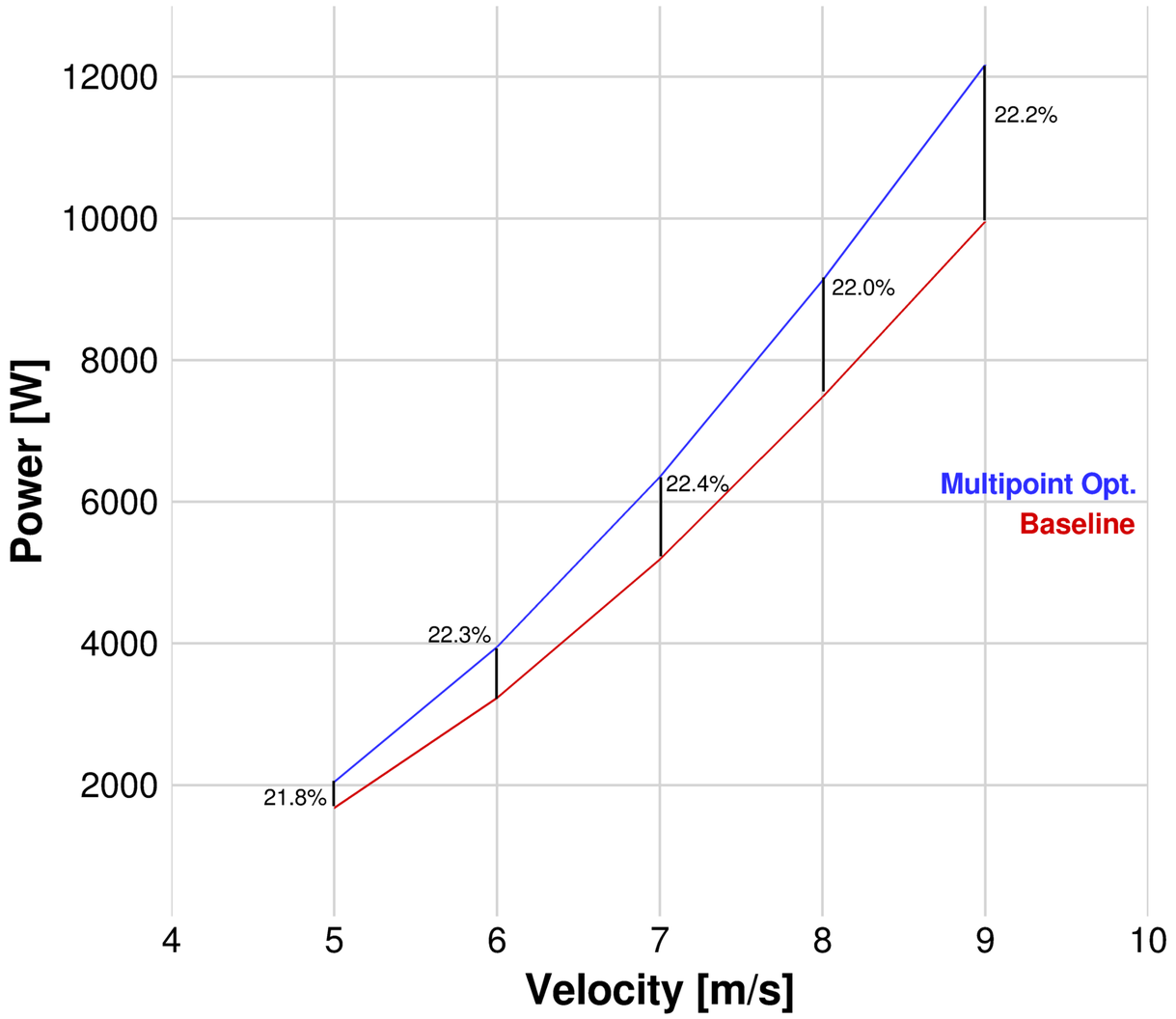




26.5% improvement in Annual Energy Production

- Optimize the design for various wind speeds (cut-in to rated wind speeds)
- AEP based on Rayleigh distribution
- Dutch part of the North Sea

AEP Initial :19.9 MWh
AEP Optimal: 25.3 MWh



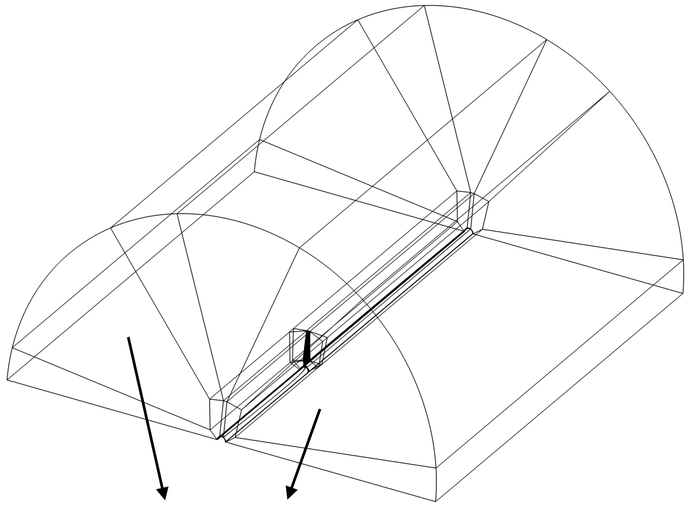
Summary

A gradient-based aerodynamic shape optimization methodology is developed for wind turbine blades

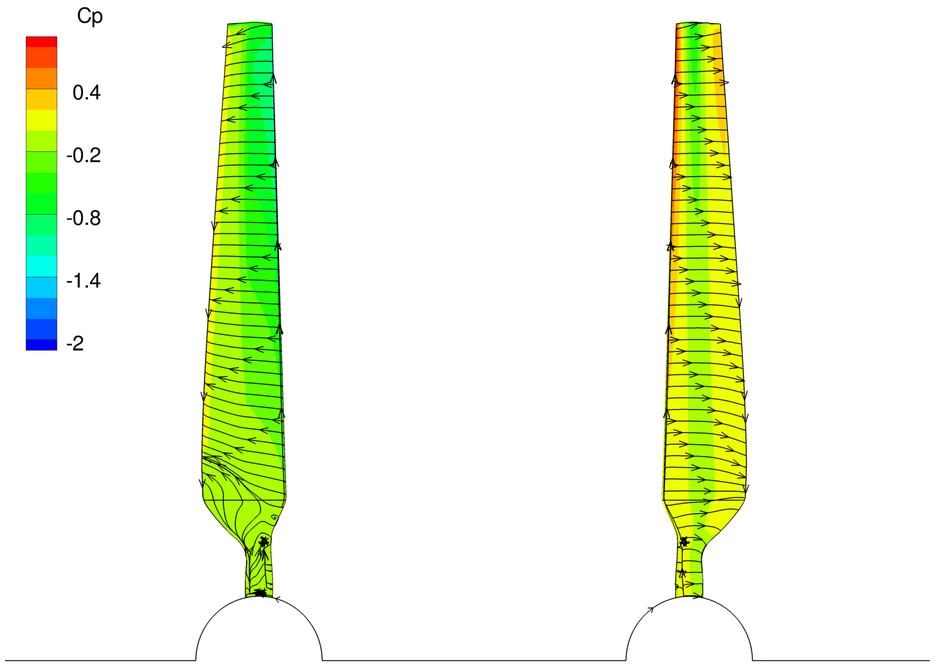
- Gradient computation and optimization
- Unsteadiness results currently in non-solvable optimization
- Fast and robust aerodynamic shape optimization

Future Work

- Unsteady adjoint solver for optimization of quasi-steady solutions
- Mesh perturbation method for periodic boundary conditions
- Adding more design variables (pitch, rotating speed, and planform) and constraints (separation, bending moments) for more realistic designs
- Aerostructural optimization



periodic boundary conditions



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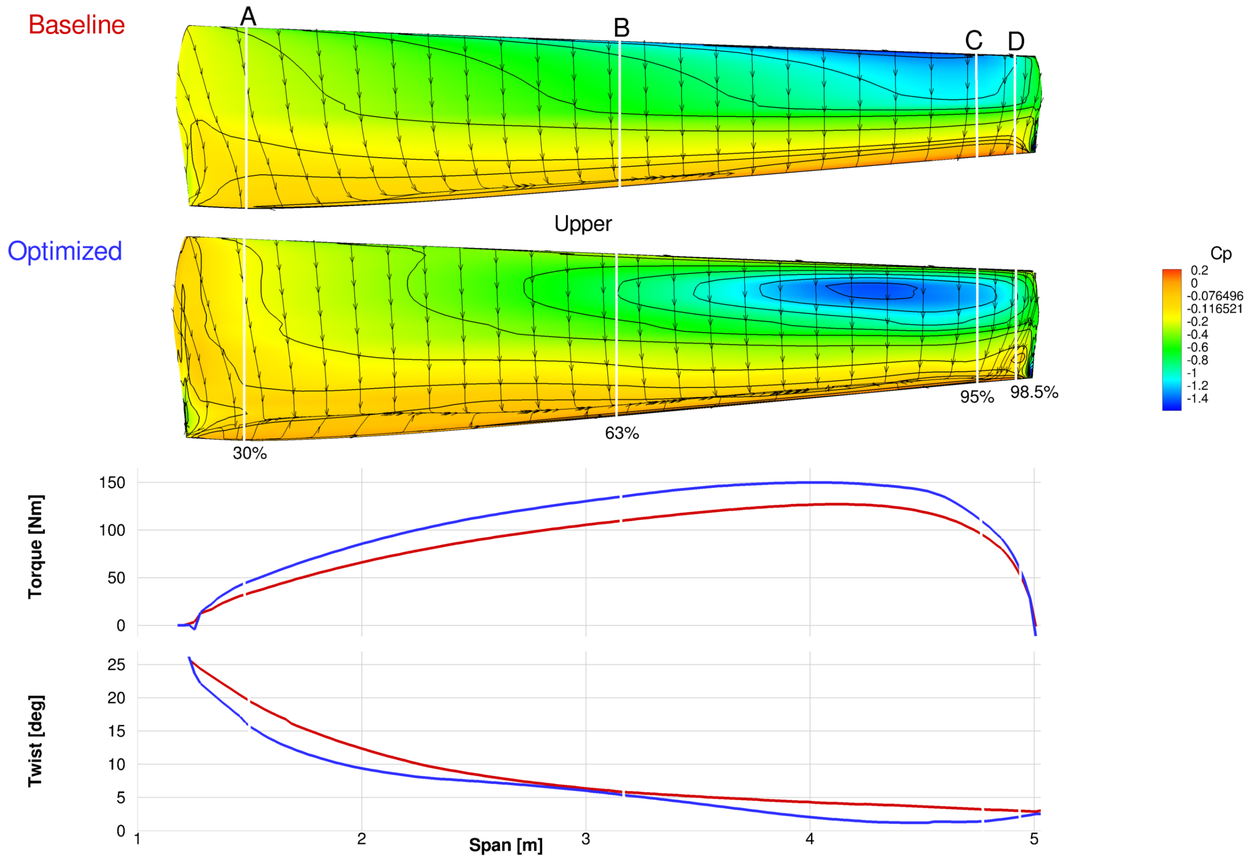

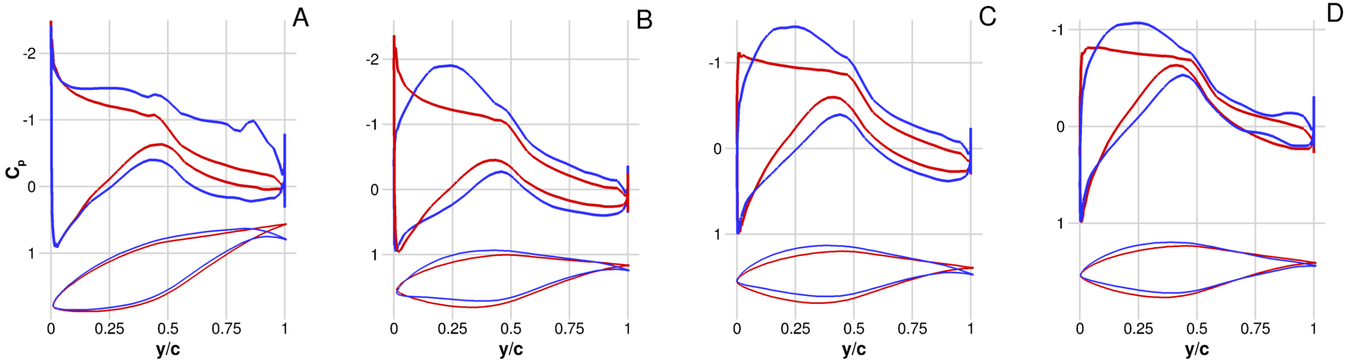

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