Adjoint Solver for Optimization of Wind Turbine Airfoils in OpenFOAM®

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Motivation

- Low cost of energy wanted
- Higher power output
- Smaller amount of material

} Possible conflict

→ Optimization needed

- Optimization → finding best possible solution of alternatives with regard to some criteria

Optimization for 2D-Airfoils

- Cost function → drag force
- Constraint → chord length
- Design variables → surface mesh points
- Optimization using adjoint method
- 2D-airfoil
- Incompressible, steady-state flow

Optimization using Adjoint Method

cost function

Navier-Stokes equations

$$\text{minimize } I_c = I_c(\beta, \mathbf{U}) \text{ subject to } \mathbf{R}(\beta, \mathbf{U}) = 0$$

design variables

flow variables

Lagrange function

$$L := I_c + \int_\Omega \mathbf{\Psi}^T \cdot \mathbf{R} \, d\Omega$$

adjoint field

0

$$\delta L = \left(\frac{\partial I_c}{\partial \beta} + \mathbf{\Psi}^T \frac{\partial \mathbf{R}}{\partial \beta} \right) \delta\beta + \left(\frac{\partial I_c}{\partial \mathbf{U}} + \mathbf{\Psi}^T \frac{\partial \mathbf{R}}{\partial \mathbf{U}} \right) \delta \mathbf{U} = 0$$

Optimal solution is independent from flow variables

1.) One solution for flow field

2.) One solution for adjoint field

3.) Using adjoints for optimal solution

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Adjoint Solver in OpenFOAM

- Adjoint solver is existing in OpenFOAM-2.1.1 for internal flows

→ *adjointShapeOptimizationFoam*

- Cost function is total pressure loss
- Using porous medium for showing optimal shape

→ no wall function

- Parts of solver can be used
- Moving boundary necessary (moving meshes)

→ *icoFsiFoam* → OpenFOAM-1.6-ext

➡ Combination and extension of different existing solvers

Simple Test Case

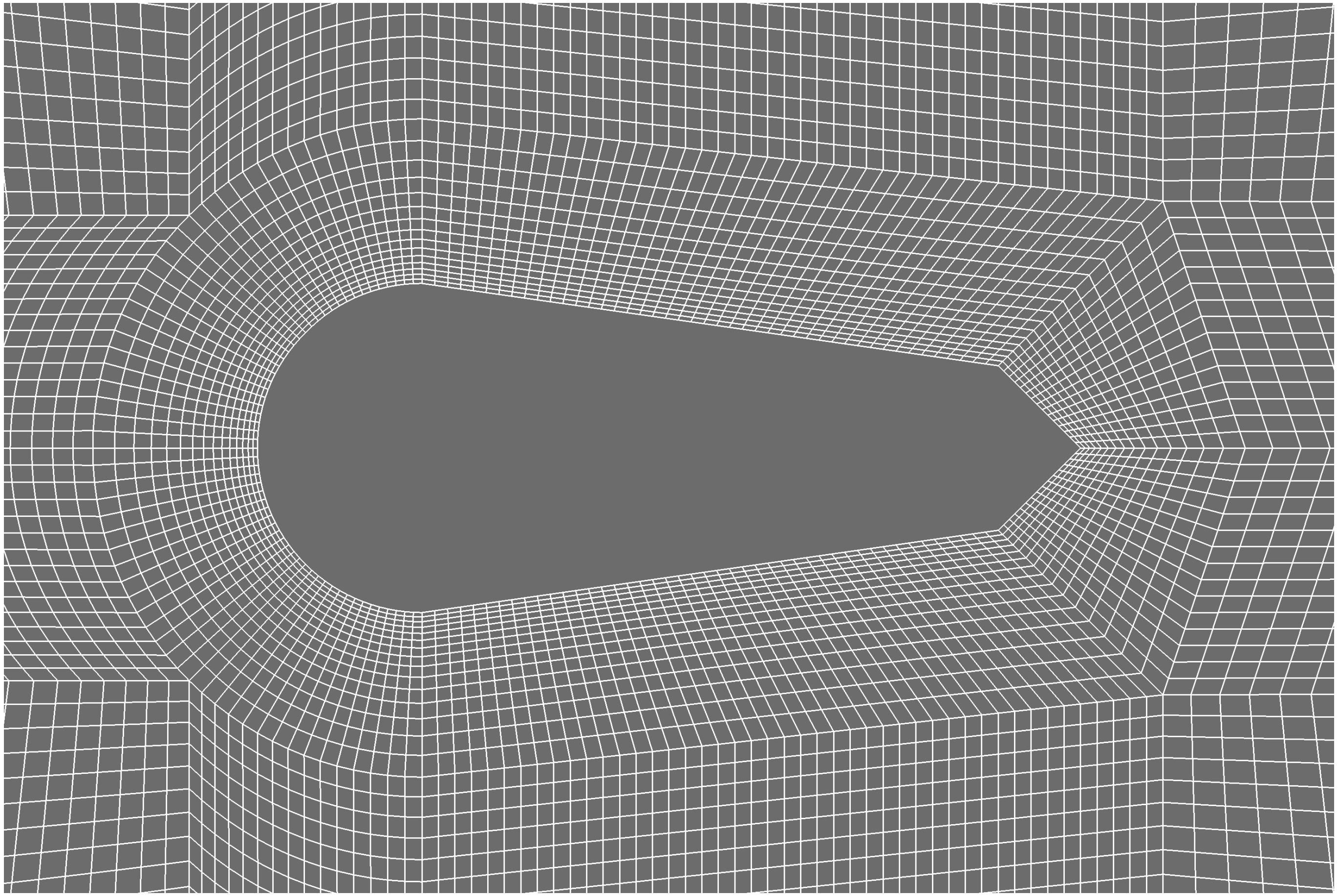
≈ 30,000 cells

u = 5 m/s

Re = 2 mio.

AOA = 10°

kωSST-model



Without Constraints I

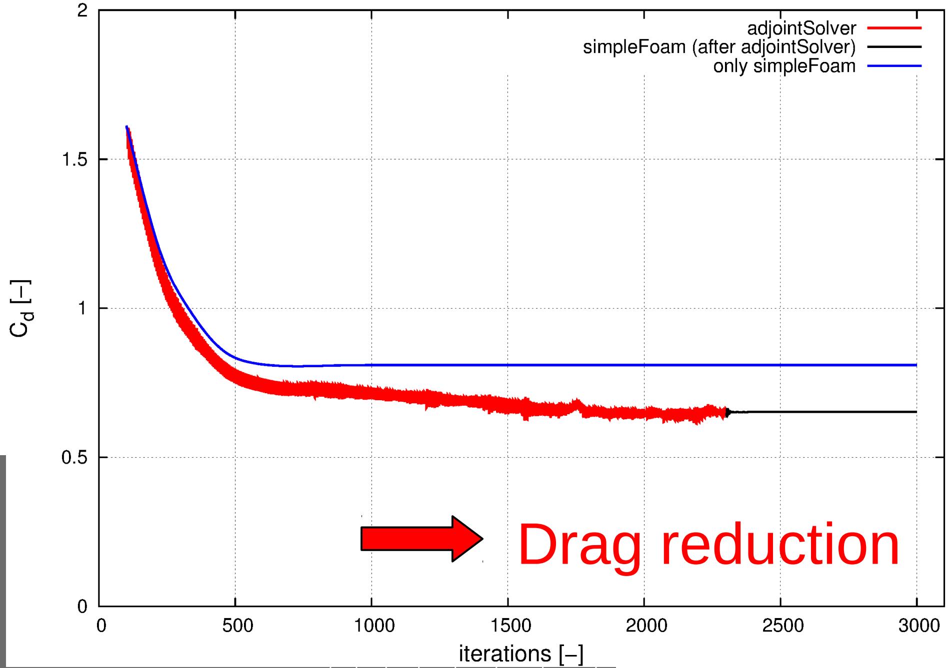
Without Constraints II

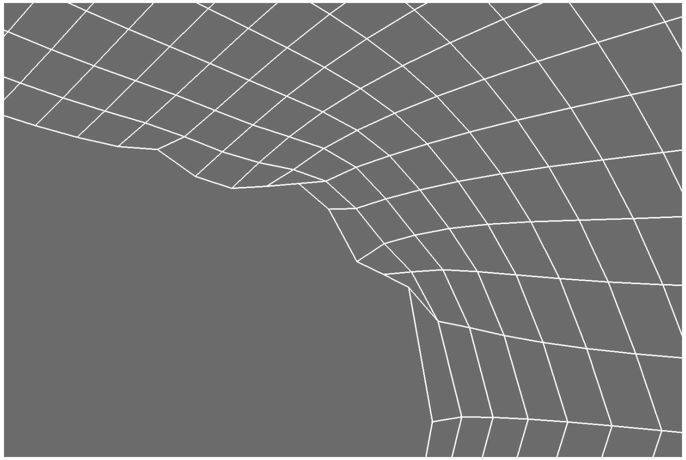
- Free movement

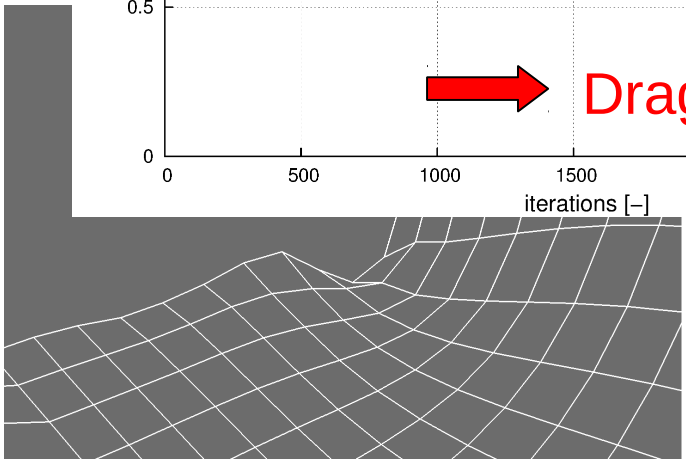
→ chord length changes, whole profile moves

- No smoothing function

→ cells with high skewness



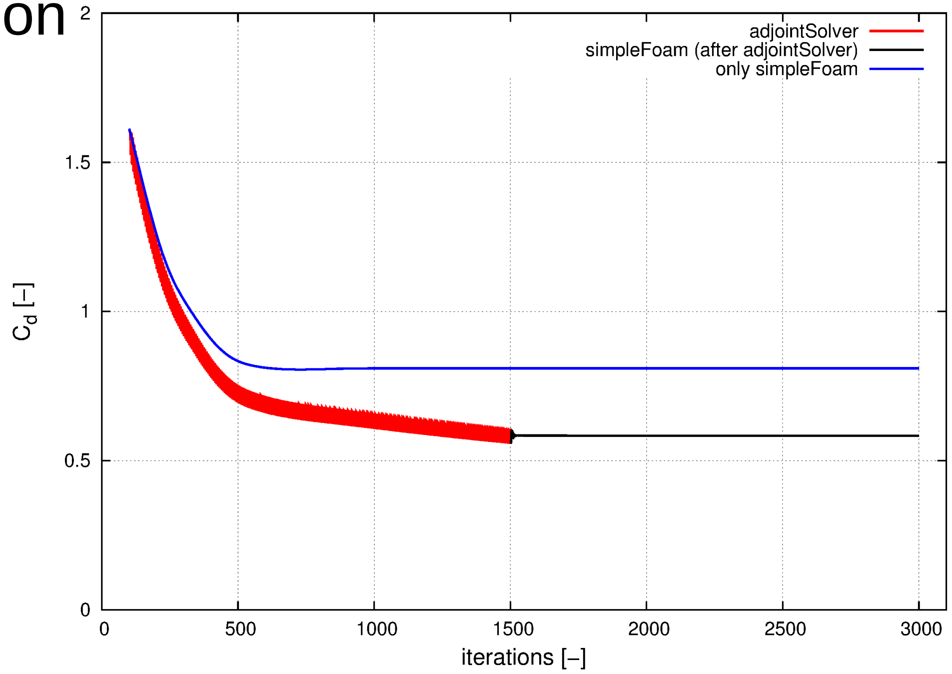




With Constraints and Smoothing I

With Constraints and Smoothing II

- Fixed chord length
- Simple smoothing function



Drag reduction

NACA 7420 I

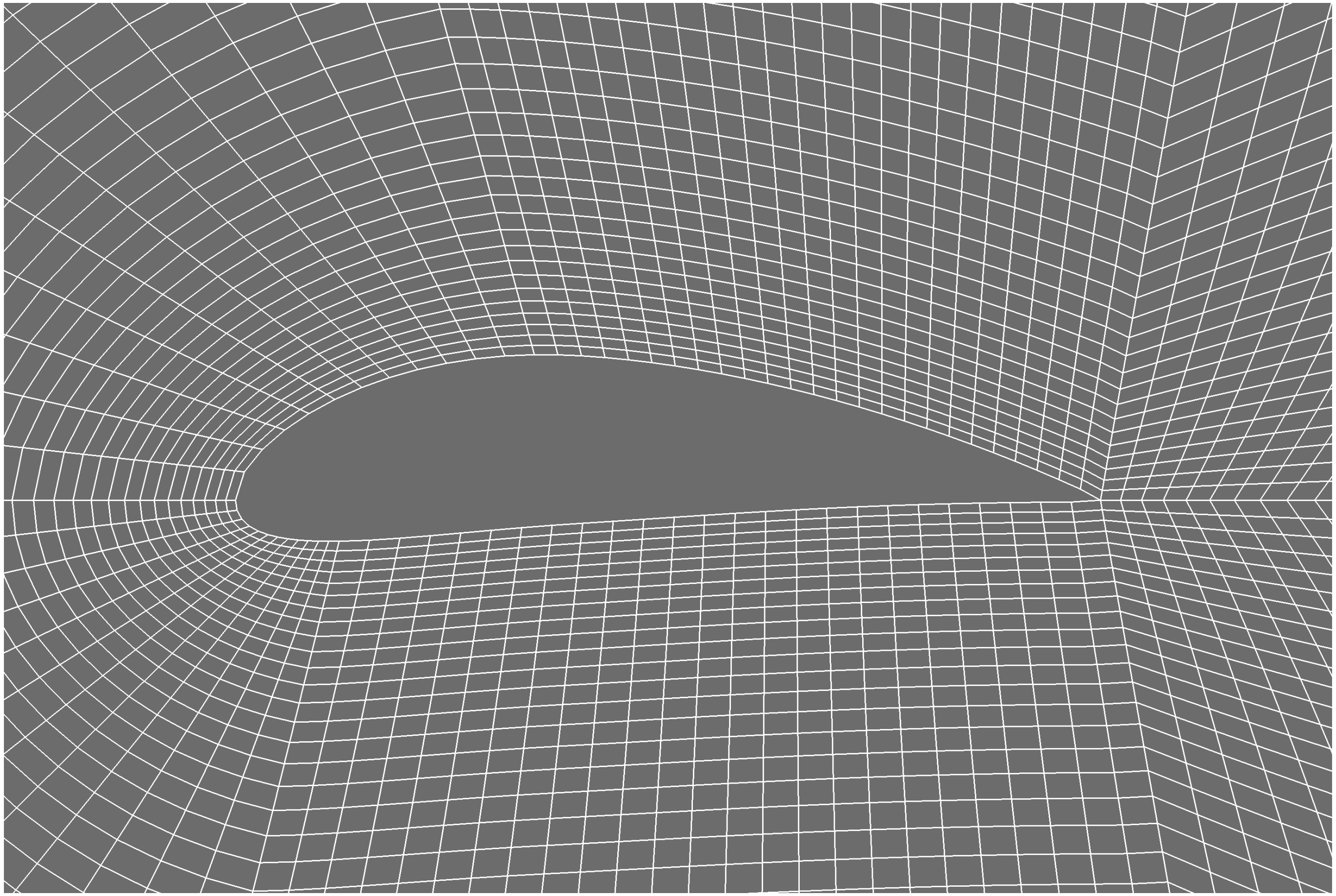
≈ 20,000 cells

u = 10 m/s

Re = 700,00

AOA = 10°

kωSST-model



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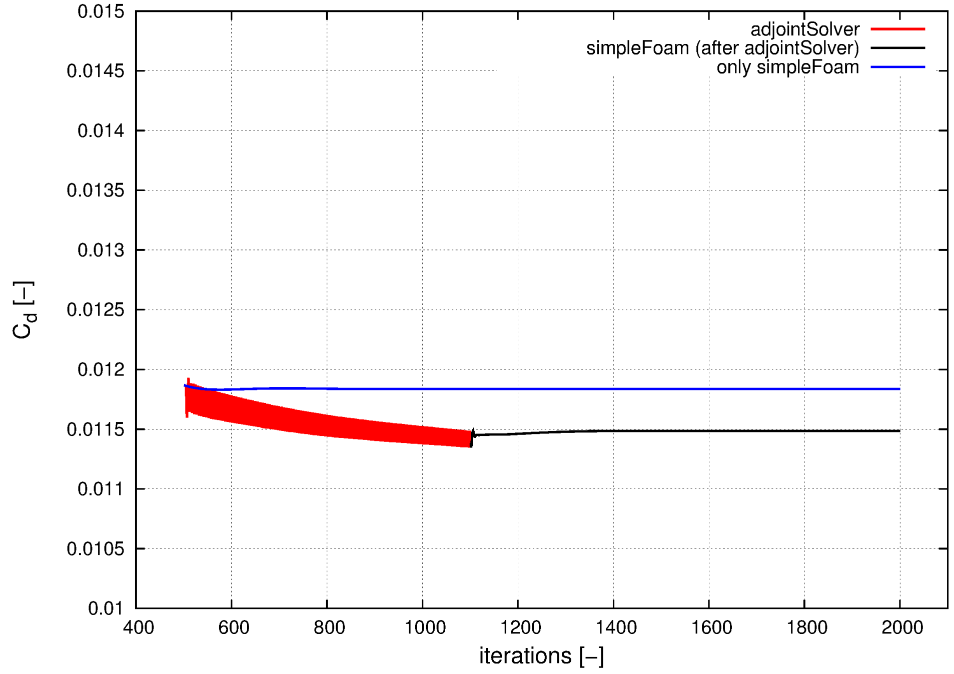
NACA 7420 II

NACA 7420 III

- Simple smoothing function
- First points of leading and trailing edge are fixed
- Fixed chord length



→ Drag reduction

Conclusions & Outlook

- Implementation of adjoint solver for external flows
- Minimization of drag for simple test cases

- Improvement in surface smoothing
- Extension to other cost functions
- Including structural constraints

Thank you!