Design and experimental validation of thick airfoils for large wind turbines

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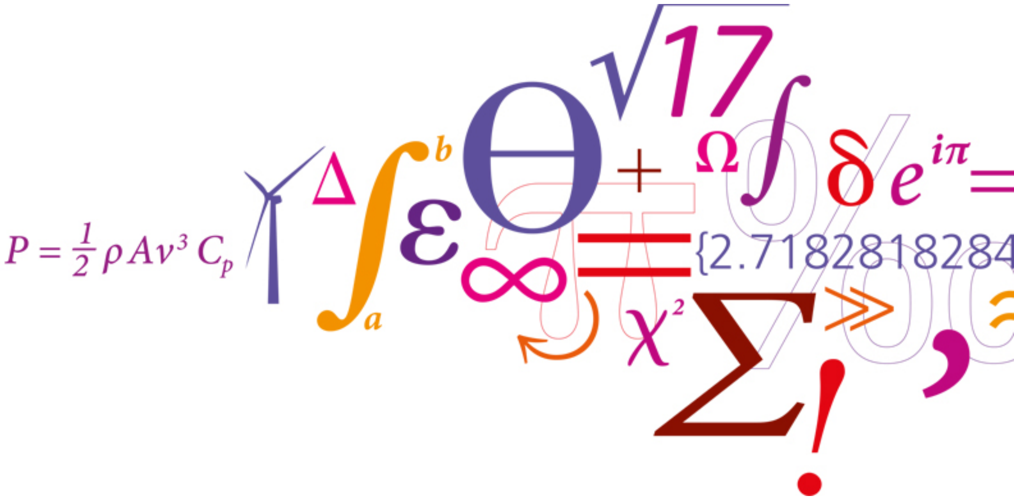

DTU Wind Energy
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Outline

- Airfoil design
  - The method
  - Optimisation algorithm
  - Optimisation results
- Experiment
  - DTU-230
  - DTU-236
- Comparison of prediction and experiment
- Conclusion

Motivation

- Increasing power requirements
- With each generation wind turbines are getting larger
- Increasing demand on structural and aerodynamic efficiency
  - Thick airfoils used on larger part of the blade
  - Aerodynamic performance becomes more important

- Objective – create new family of thick airfoils (30 % and 36% relative thickness)

Design method

- DIRECT design
  - A given geometry
  - Calculate aerodynamic performance (in as many design points)
  - Numerical optimisation

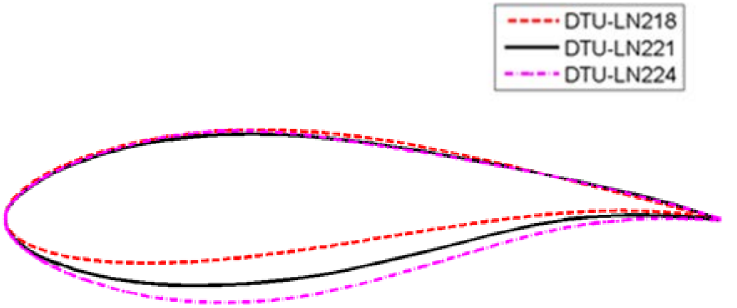
  - More flexible
  - Allows multidisciplinary optimisation with multiple constraints

Shape perturbation function

- adding smooth perturbations Δy to an initial airfoil
- Δy are a linear combination of base functions P_k as

$$\Delta y(i) = \sum_{k=1}^{N} \delta_k P_k(i)$$

$$P_k = \sin^{\xi,\eta}\left(\pi x\,(k)^{g(k)}\right)$$



- δ_k, ξ, η - design variables
- $g(k)$ - fixed parameters

- The airfoil is split to upper and lower side with leading edge and trailing edge points fixed at $x=0$ and $x=1$
- $2 \cdot N+2$ DOFs

Optimisation algorithm

gradient-based constrained optimisation algorithm

\+ general flow solver – XFOIL

- response parameters from XFOIL can be directly used as design objectives
- Maximise power coefficient in both clean and rough cases for a range of angles of attack

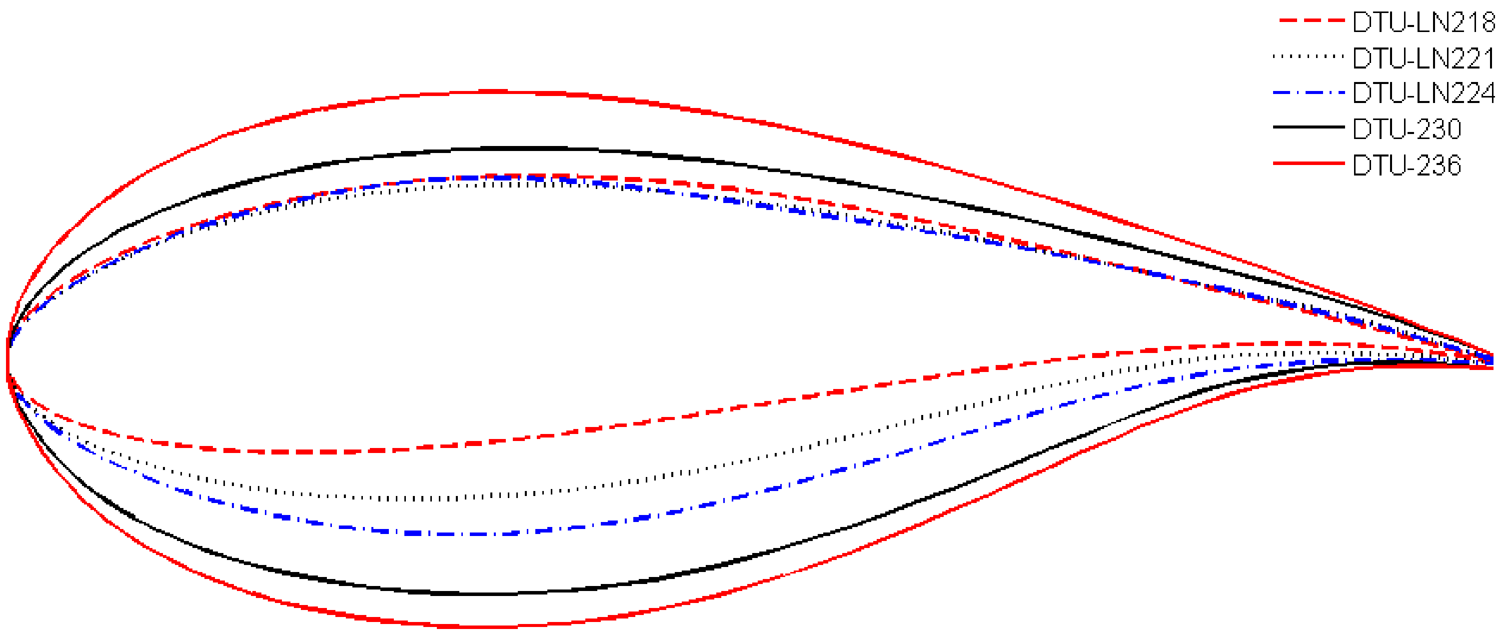
$$obj = \min\left(\frac{1}{C_p}\right), C_p = f(C_L, \frac{L}{D})$$

Subject to equality and inequality constraints

- Structural integrity is expressed through a concept of "effective thickness-to-chord ratio"

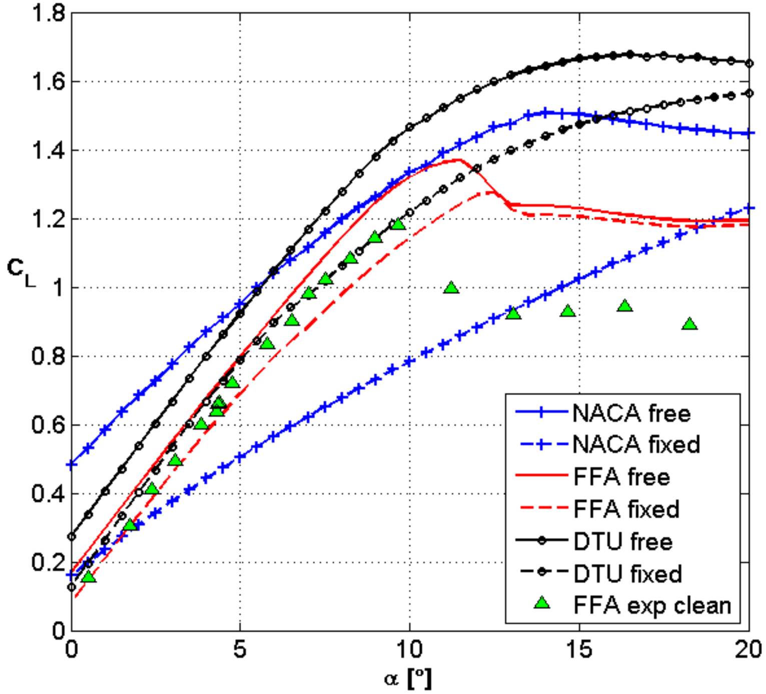
Results – DTU-230 and DTU-236

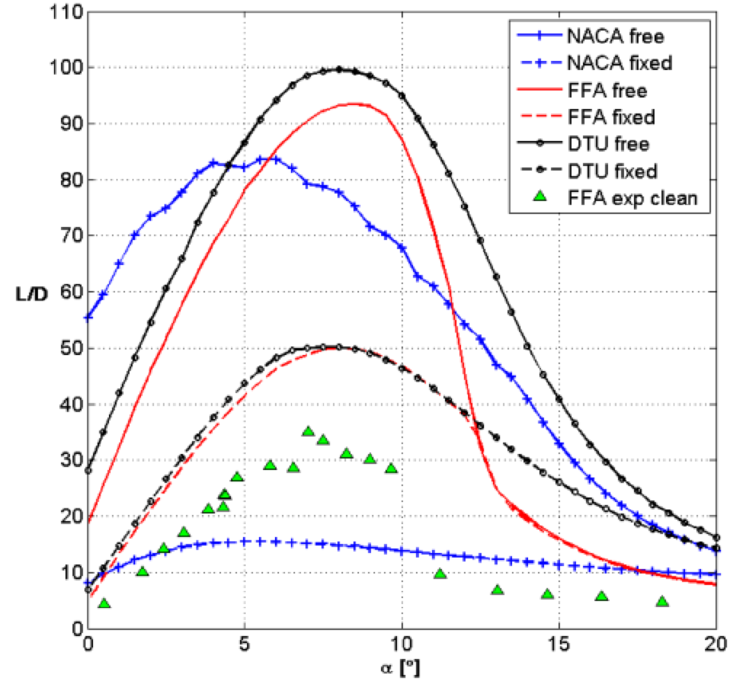
- Shape compatibility with DTU-2xx family



Comparison with similar airfoils

DTU-230, NACA 63-430, FFA–W3-301





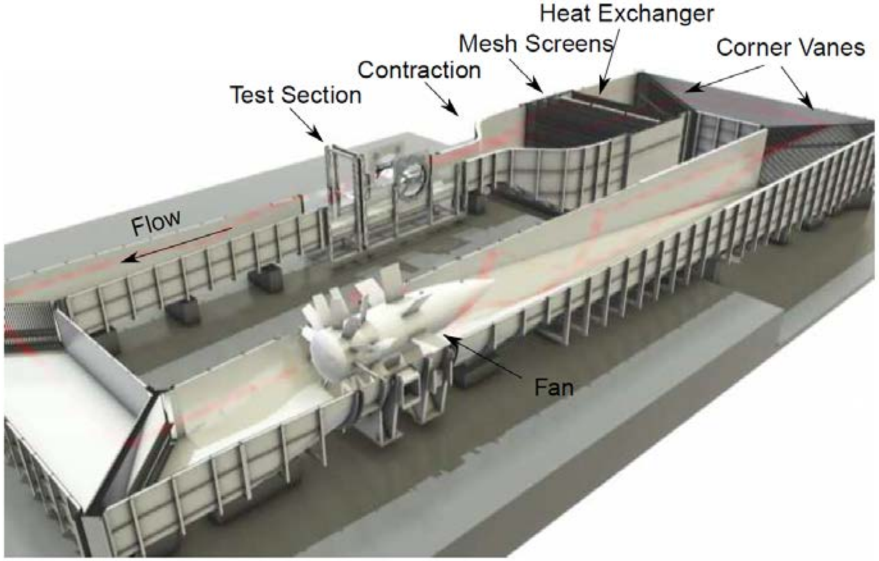
Re = $1.47 \cdot 10^6$, XFOIL, $e^N = 9$

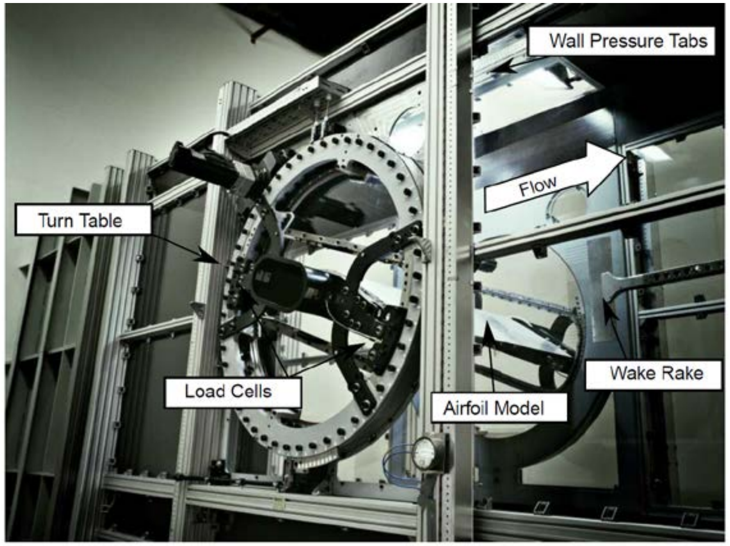
Experiments

- Low-speed wind tunnel at LM Wind Power Blades (Lunderskov)
- Closed circuit, variable fan-speed,
  with temperature control
- TI around 0.1%
- Max speed 105m/s

$$Re = 6 \cdot 10^6 \text{ for } c = 0.9 \text{ m}$$

$$M = 0.3$$





Source :

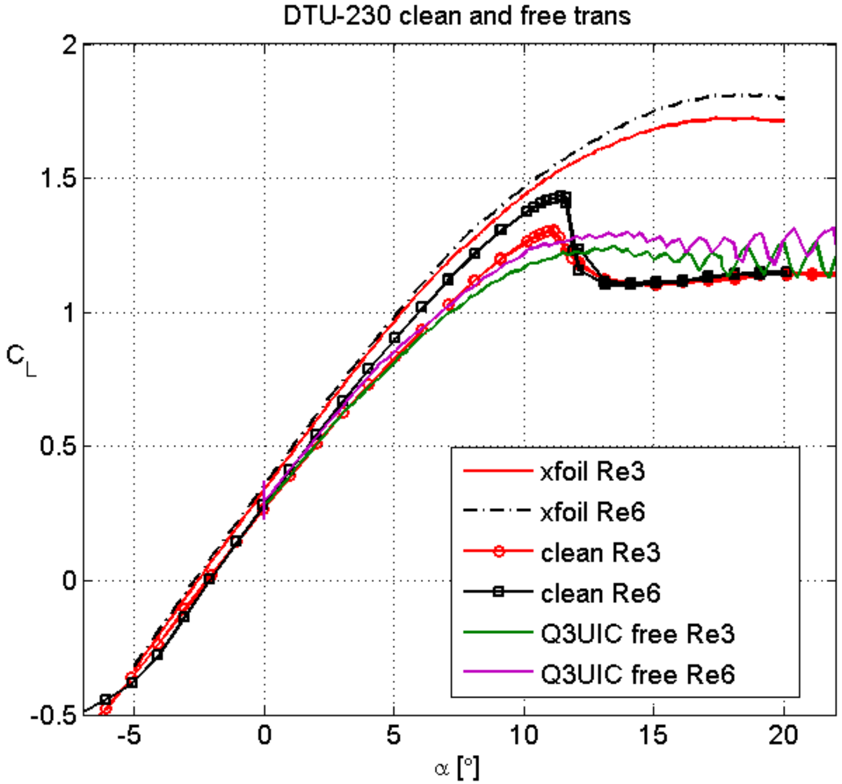
Bæk,Fuglsang, (2009) Experimental Detection of Transition on Wind Turbine Airfoils

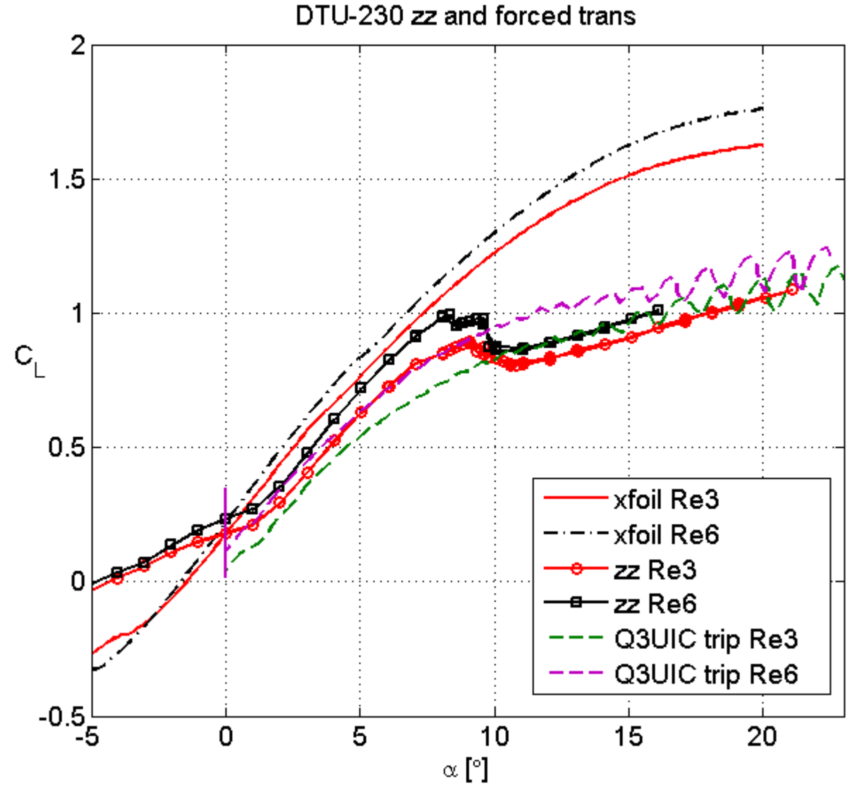
Experiments

- Campaigns - March and April 2014.

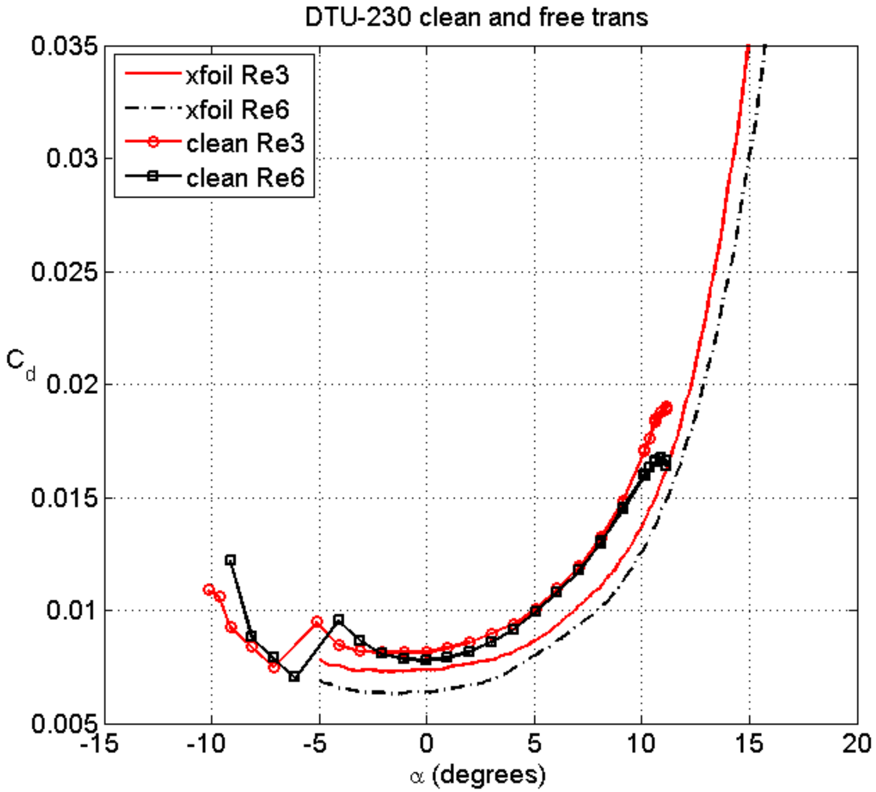
- Reynolds numbers (1.5), 3, (4), (5) and 6 millions
- Added leading edge roughness
  - Zigzag tape at 2% chord on the upper surface
  - Zigzag tape at 5% chord on the upper surface and 10% chord on the lower surface
  - Bump tape at 2% chord on the upper surface
- Devices
  - Gurney flaps
  - Vortex generators at 30% and 40% chord
- Combinations of different devices and LER
- In total 45 and 48 series

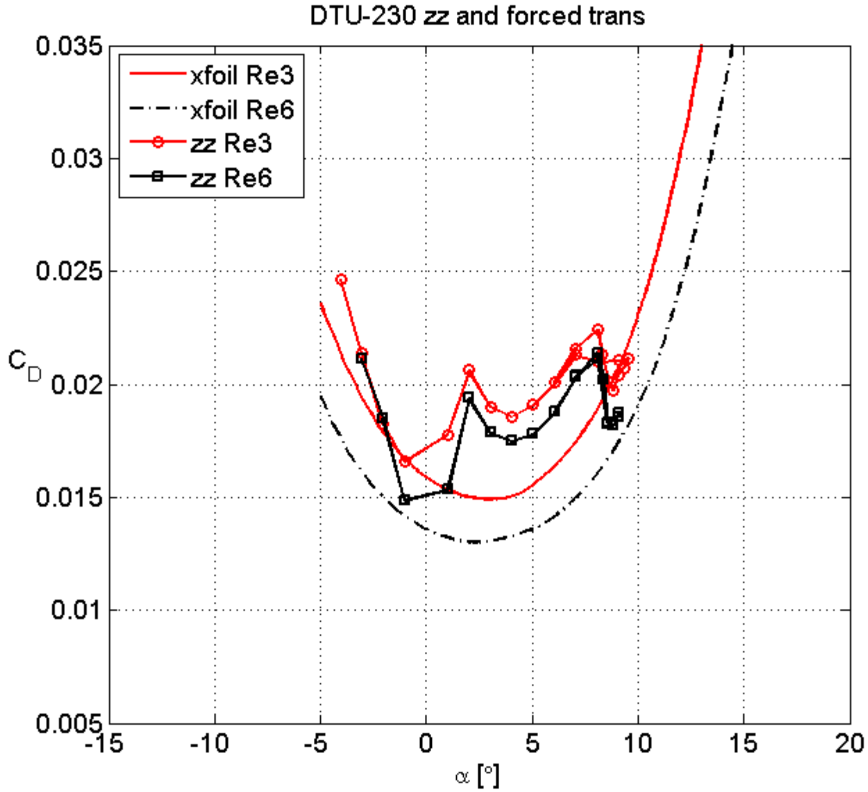
Comparison of XFOIL and experiment DTU-230



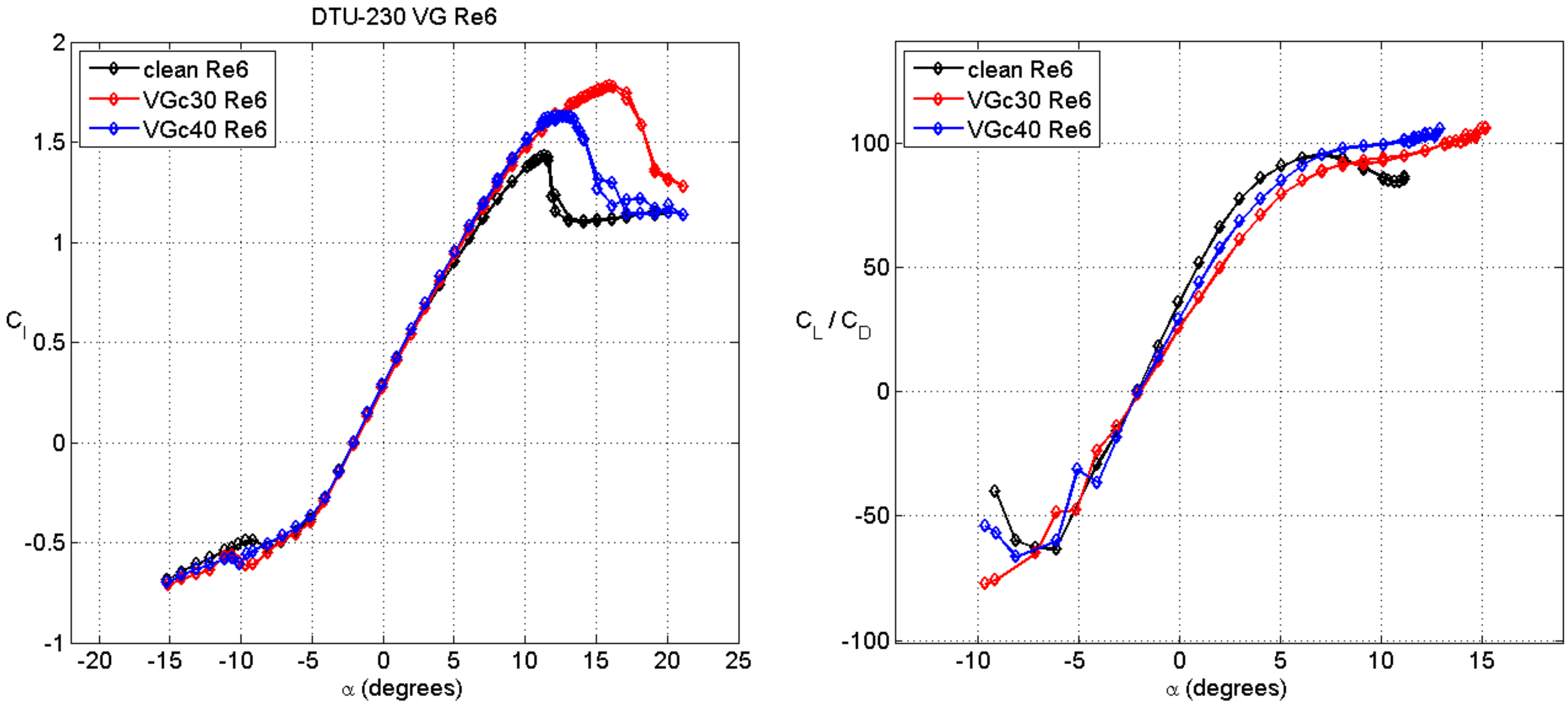


Comparison of XFOIL and experiment DTU-230

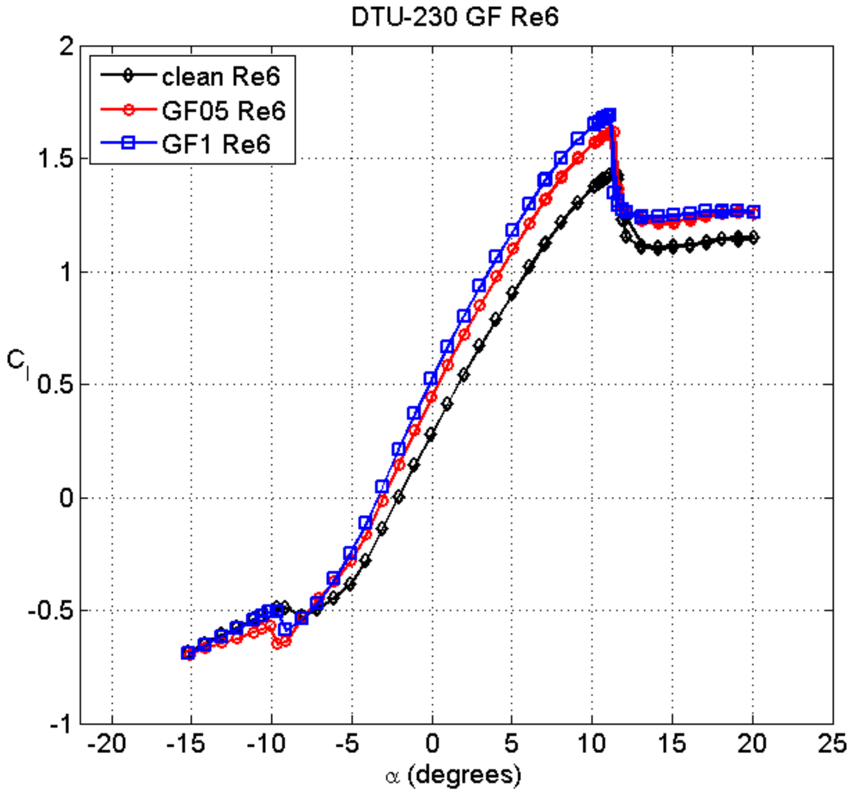


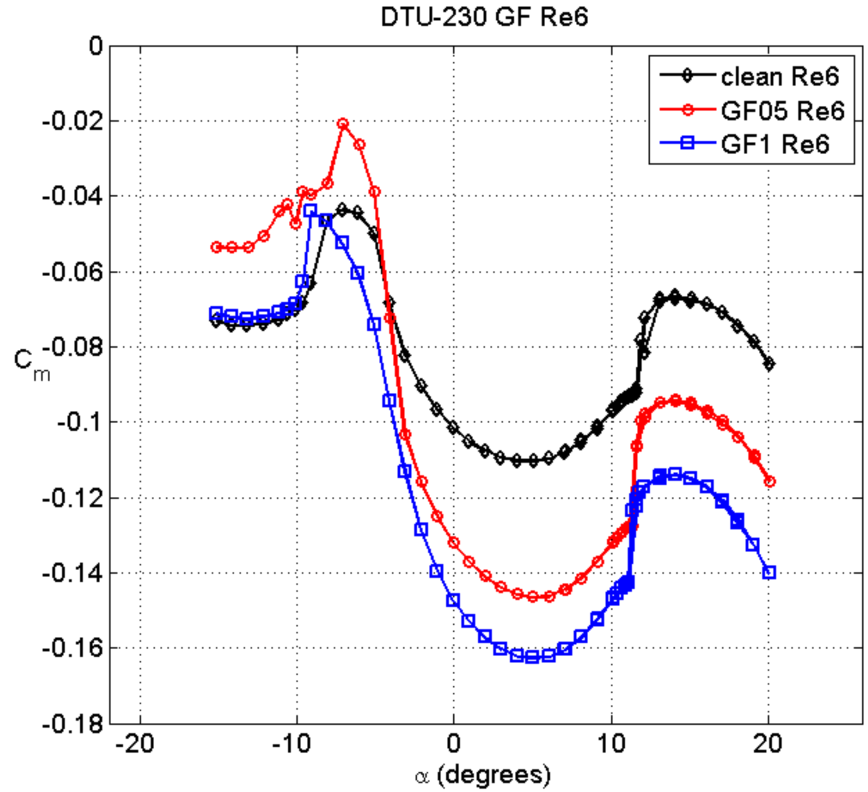


DTU-230 Vortex Generators



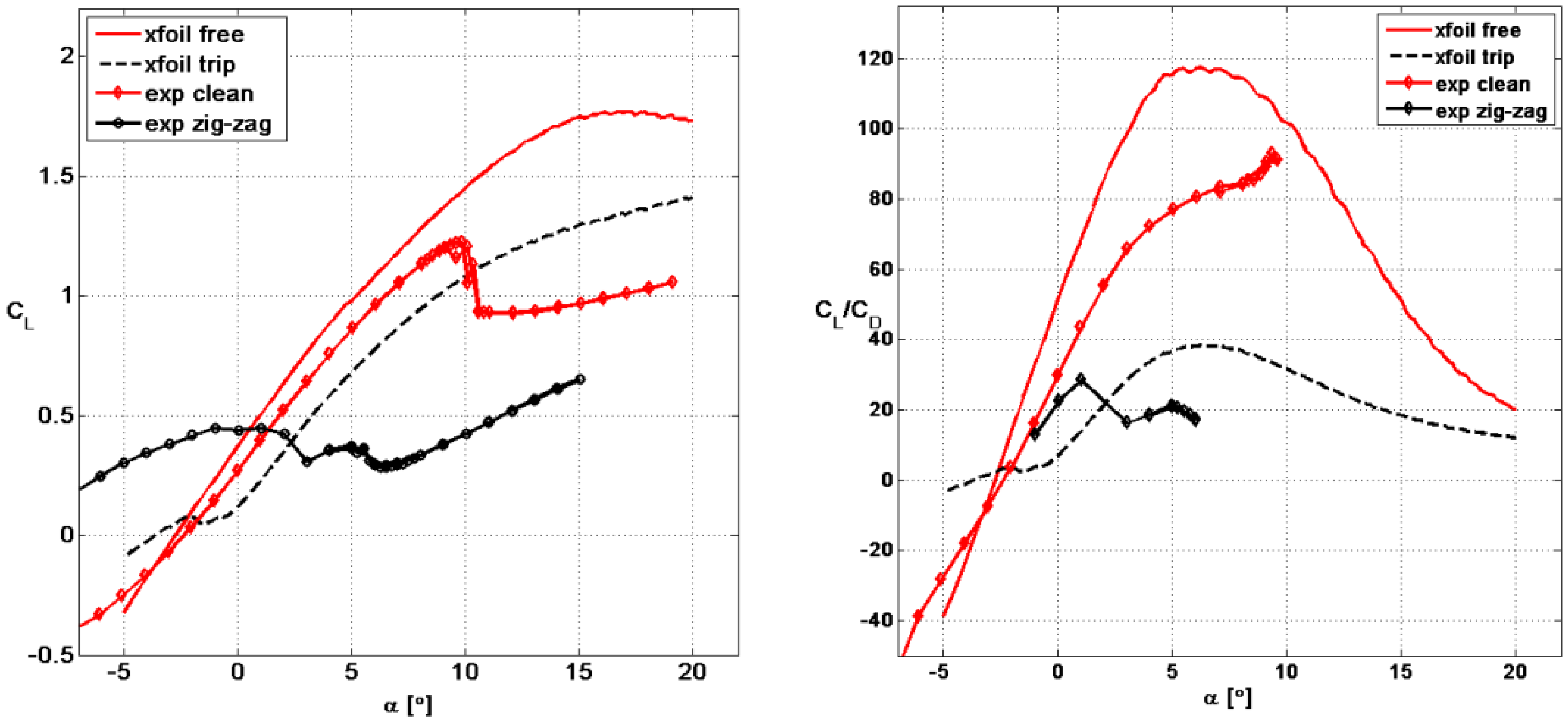
DTU-230 with Gurney flaps



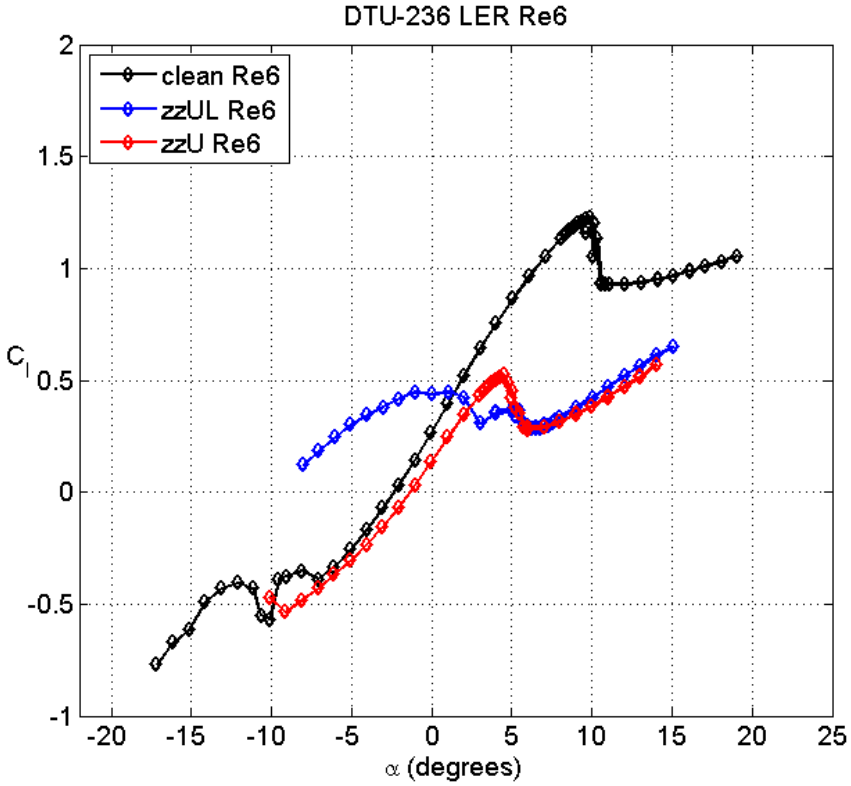


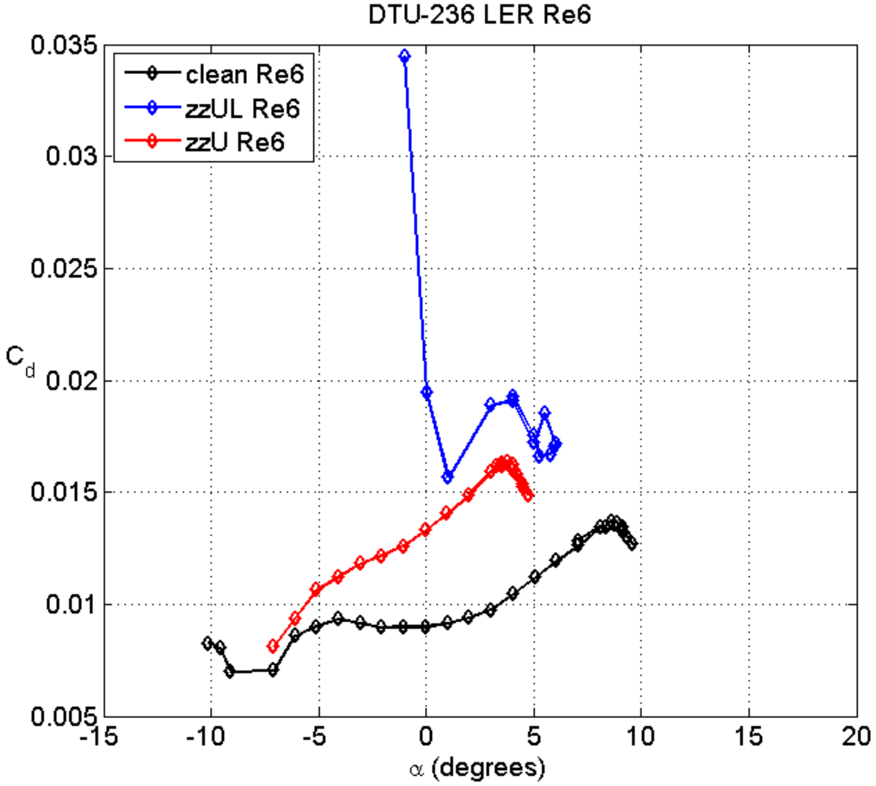
DTU-236

Comparison of XFOIL and experiment DTU-236



DTU-236 leading edge roughness





Conclusion

- Shape perturbation function is a good method – easy to implement and manageable
  - Small number of design variables
  - Many possibilities regarding constraints
- new airfoils DTU-230 and DTU-236 – satisfying performance

- More research on flow solvers for thick airfoils is needed
- Experimental data should be also taken with precaution- very important to know details about the tunnel and the campaign

- Future work - use the new airfoil family for full blade design
  - Optimise planform to reduce the noise
  - Validate with CFD

Thank you for your attention