Wind Turbine Flap Technology Development – from laboratory to full scale

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In cooperation with

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RENEWABLE ENERGY

REHAU
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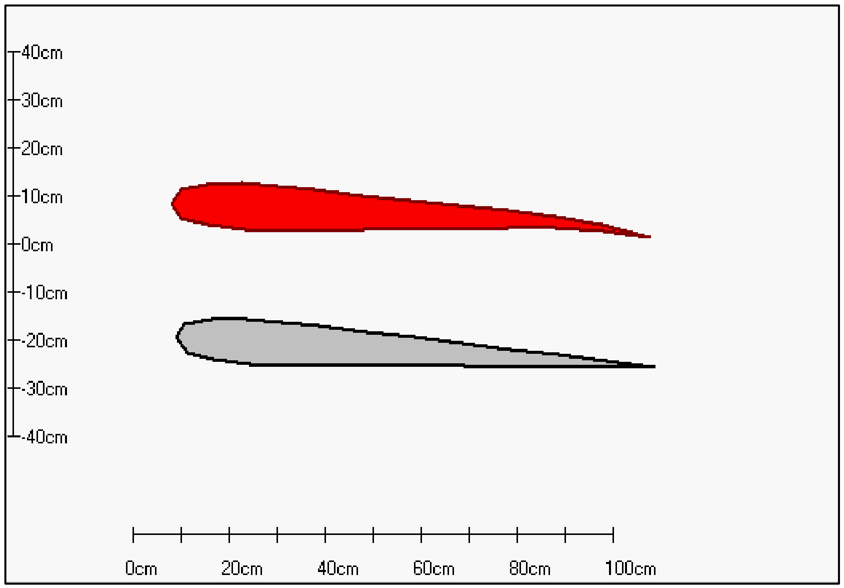
DTU Wind Energy
Department of Wind Energy

Flap or morphing airfoil

Morphing trailing edge counteract disturbances from turbulent inflow



Flaps add a third control option to the traditional rotor speed and pitch control

Wind Turbine control

- ❑ Rotor speed
  - aero loading $f_{rs}(r) \approx (r\,\Omega)^2$
- ❑ Pitch
  - aero loading $f_p(r) \approx k\,p_{ang}$
- ❑ Flap
  - aero loading $f_{fl}(r) \approx k_{fl}\ \ fl_{ang}(r)$

Ideally flap control can be very efficient and counteract most of the inflow disturbances

Measure relative velocity and inflow angle (unsteady)

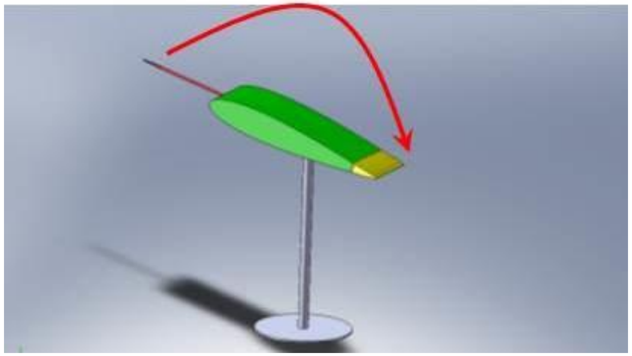
Normal force loading: $F_N = \frac{1}{2}\rho V_r^2 C_N(\alpha)c$

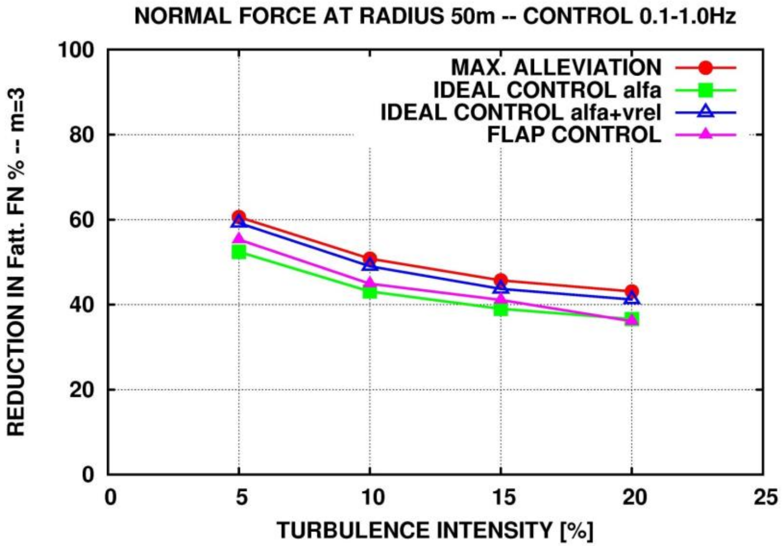
$$f_c = K_\alpha(\alpha - \overline{\alpha}) + \left(\frac{V_r^2 - \overline{V_r^2}}{V_r^2}\right)K_{V_r}$$

where $\overline{\alpha}$ $\overline{V_r}$ are exclude band filtered from 0.1 to 1Hz and f_c is the control signal

K_α *and* K_{V_r} are constants determined in order to maximize load reduction

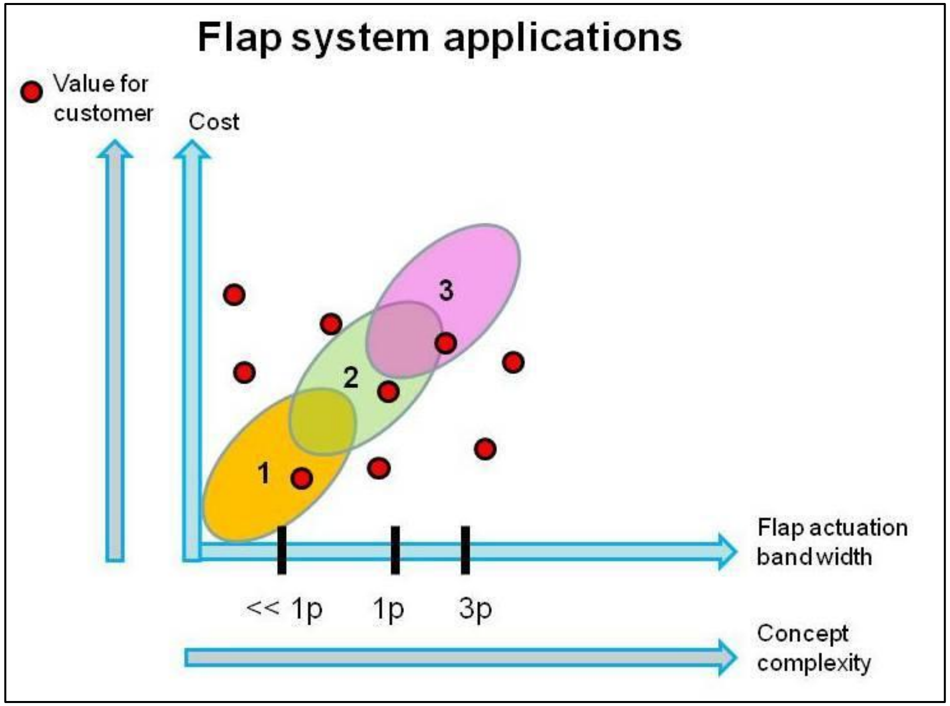
Inflow data from a five hole pitot tube





But limitations in the real world

- ❑ bandwidth of the flap actuation
- ❑ amplitude limits
- ❑ non-optimal control inputs
- ❑ cost of the technology
- ❑ robustness



Example of a flap system used in a steady position

The negative flap deflection decreases most extreme loads and reduces blade tip deflection - SWT-4.0-130 turbine

Extreme loads				
Channel	DLC	Rel. diff. positive flap deflection [%]	DLC	Rel. diff. negative flap deflection [%]
Tower bottom bending fore-aft	DLC13_	4.2	DLC13_	-3.1
Tower bottom bending side-to-side	DLC62_	0.6	DLC62_	0.0
Tower top bending fore-aft	DLC24_	-2.5	DLC24_	-0.2
Tower top bending side-to-side	DLC24_	3.1	DLC24_	0.4
Shaft torsion	DLC13_	1.2	DLC13_	-0.5
Shaft thrust	DLC13_	3.2	DLC13_	-3.1
Hub Bending	DLC13_	2.4	DLC13_	-3.1
Blade root flap (min)	DLC13_	2.9	DLC13_	-2.7
Blade root flap (max)	DLC62_	-1.3	DLC62_	-0.1
Blade root edge (min)	DLC13_	-0.2	DLC24_	-1.0
Blade root edge (max)	DLC13_	-0.2	DLC13_	-2.0
Blade tip deflection	DLC13_	4.7	DLC13_	-6.1

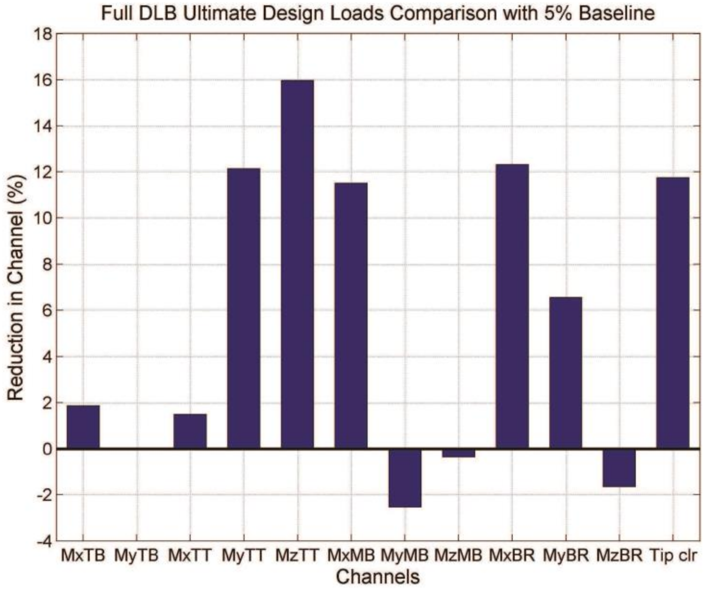
Table 1: Relative load comparison between a flap with positive and negative deflection with respect to a flap with neutral deflection

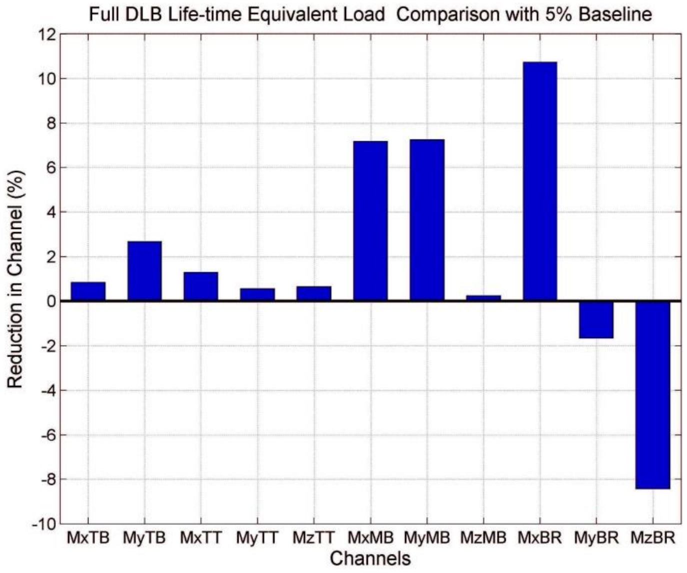
Ref. Alejandro 2018

Example of a flap system used in a dynamic control

Case: - DTU 10MW rotor stretched 5% in radius

- Increase in AEP of 3.4%
- Flap system included to reduce the increase in loads
- 30% of the blade length, starting from the tip, with 10% chordwise length, flap angles range between -15/+15 degrees.





Ref. Barlas 2016

The flap technology

Use flap technology from aircraft ?

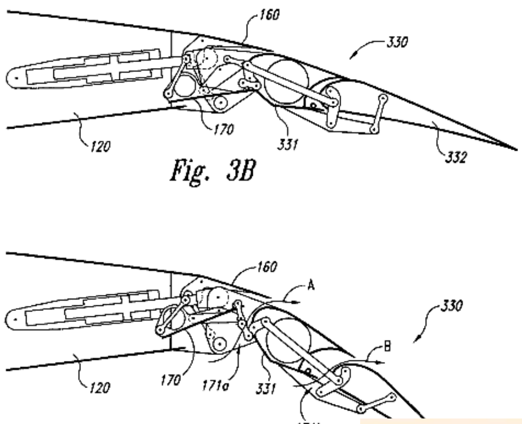
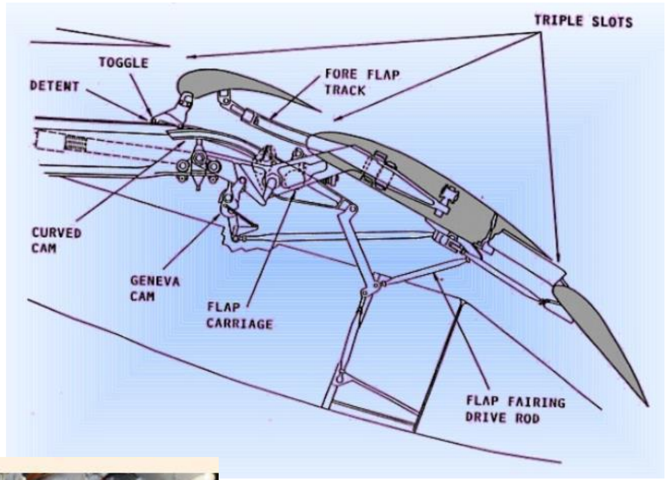


Fig. 3B

Fig. 3C

Too complex



Strong requirements from the wind turbine industry to the technology

- ❑ robust and reliable (25 years lifetime)
  - ❑ no metal parts
  - ❑ no electronics
  - ❑ no mechanical parts
  - ❑ scalable to large blade sizes (+100m)

piezzo electric actuators in wind tunnel exp. 2007

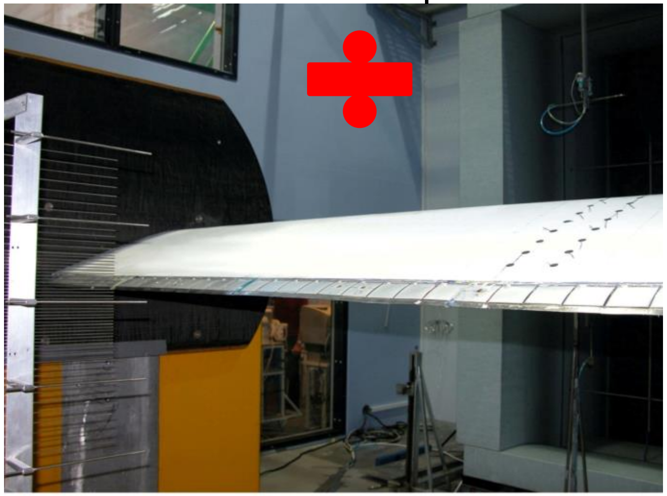
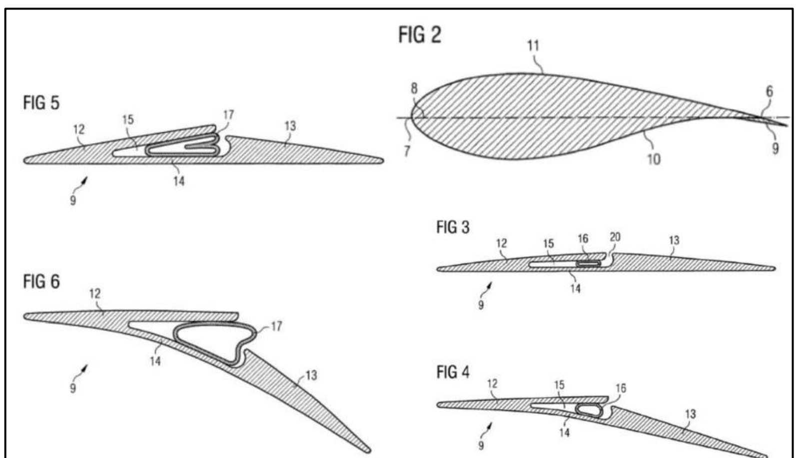


FIGURE C.2 THE TEST SECTION WITH THE TEST STAND AND THE WAKE RAKE DOWNSTREAM OF THE AIRFOIL SECTION.

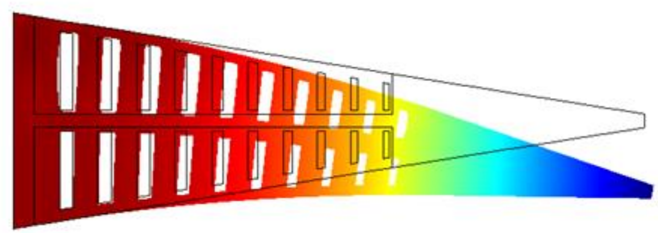
Basic flap design that full-fills these requirements

- ❑a flap in an elastic material
- ❑ pneumatically activated
- ❑ two main concepts

separate hose
add/on flap



internal voids
full morphing TE



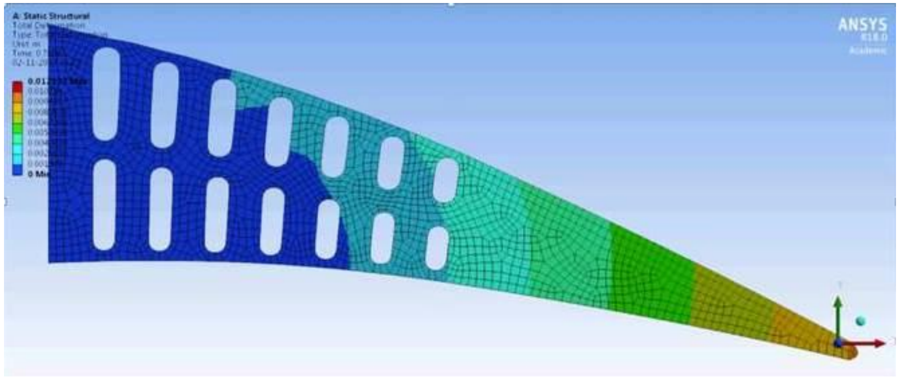
The development stages

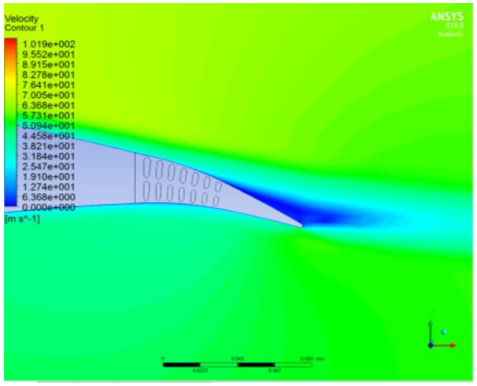
- ❑ CAD version
- ❑ FEM simulations
- ❑ Design iterations – FSI based optimization
- ❑ Lab model – simplified manufacturing
- ❑ Lab testing – performance - fatigue
- ❑ Wind tunnel tests (typical leading to new design iteration)
- ❑ Lightning testing
- ❑ Final prototype manufacturing – co-extrusion
- ❑ Testing functionality and performance on an outdoor rotating test rig in atmospheric flow
- ❑ Full scale testing

FEM – FSI optimization

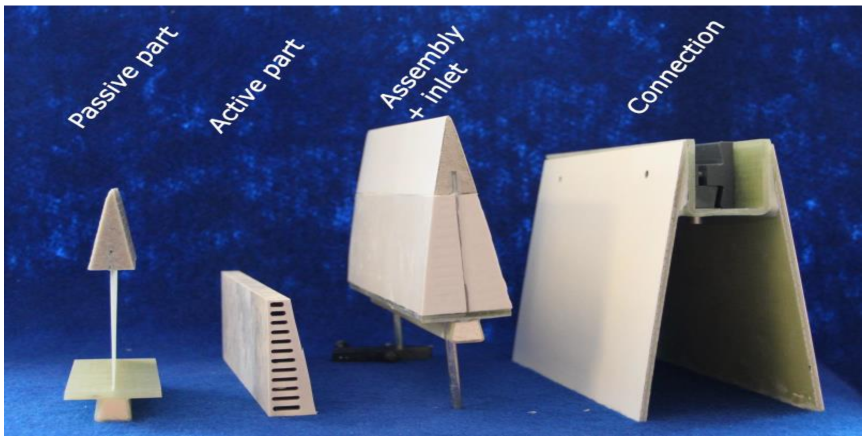
- Design variables: voids position/size
- Response: Cl, Cd, safety factor
- Optimization with Multi-Objective Genetic Algorithm (max(Cl), min(Cd), SF≥1.5

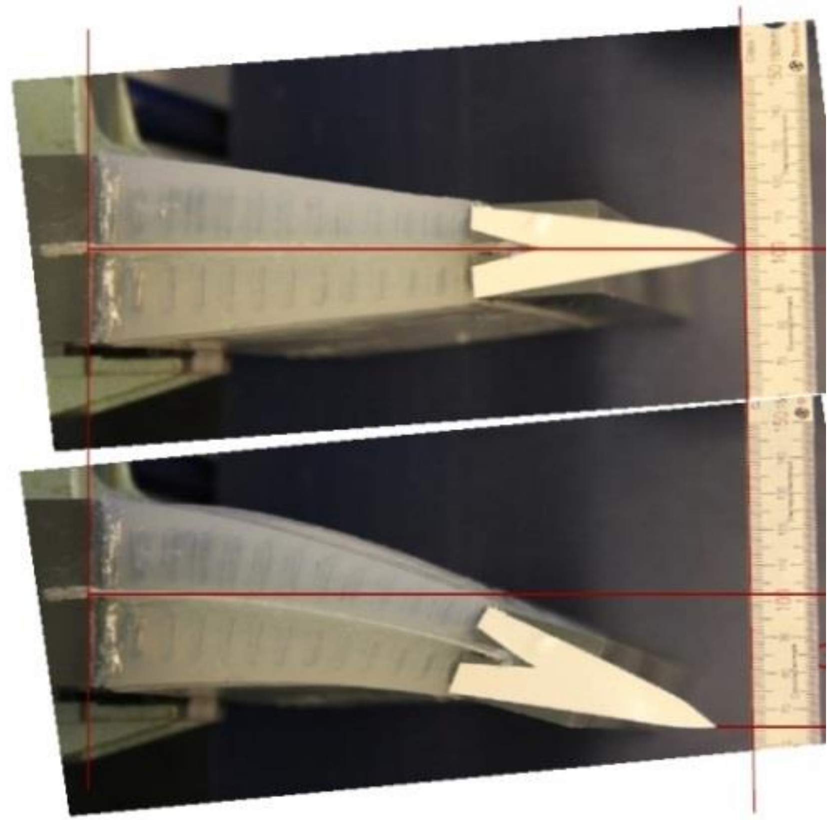
	DX [mm]	DW [mm]	DH [mm]	delta [deg]	SF [-]	δCl [-]	δ(Cl/Cd) [%]
FEM	7	3	9	7.9	2.9	-	-
FSI	6.94	2.72	8.98	6.9	3.1	0.22	-12%



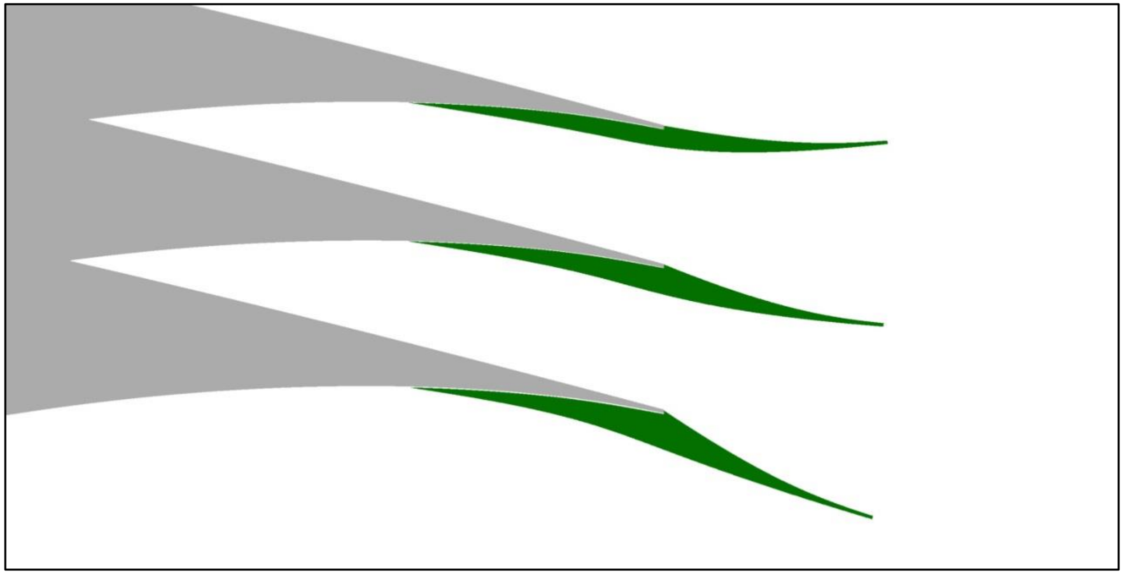


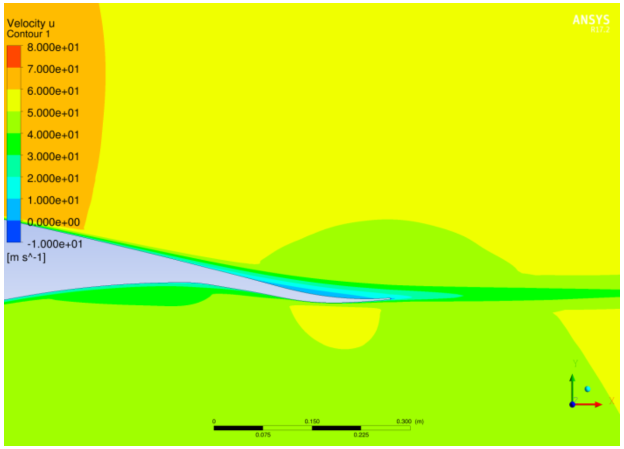
Lab models – simplified testing

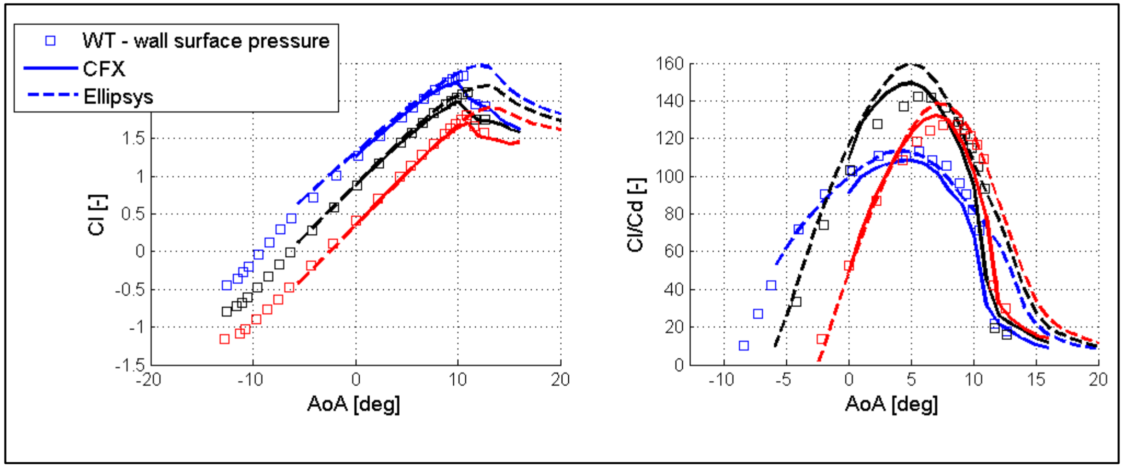


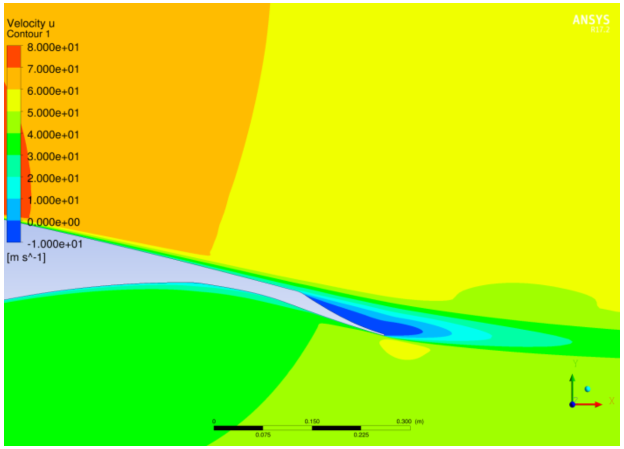


Wind tunnel tests – CFD computations



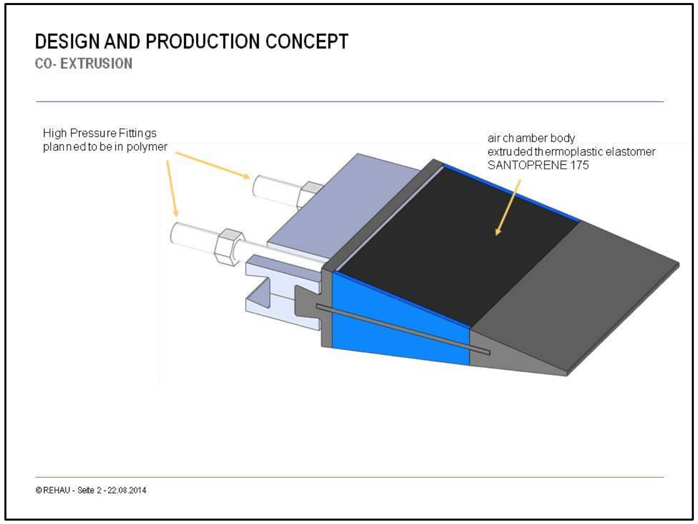


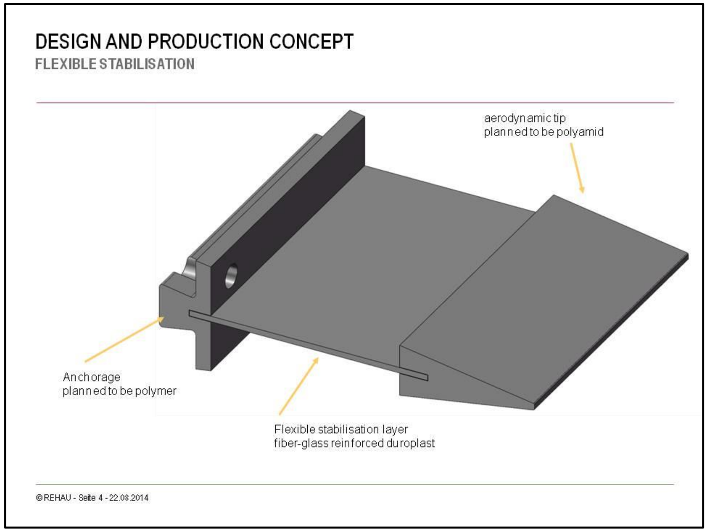




Final prototype manufacturing - co-extrusion

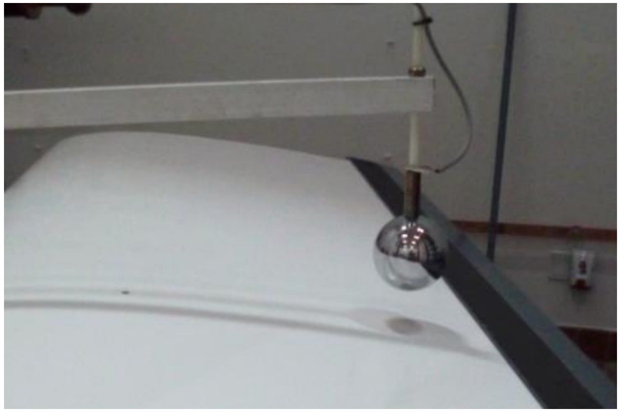
- Allows designs with optimal combination of soft and stiff material
- Solve gluing problems with Santoprene as the surface can be covered with a layer suited for gluing

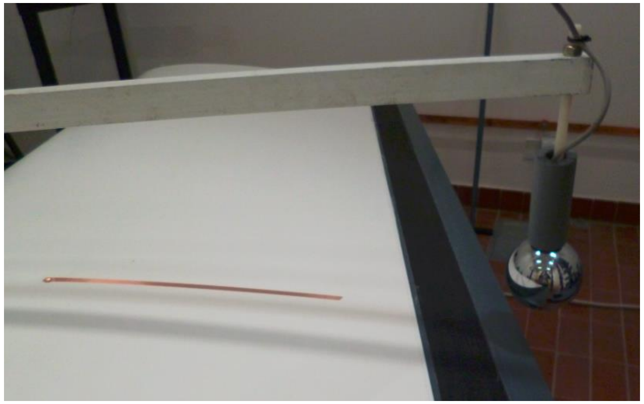


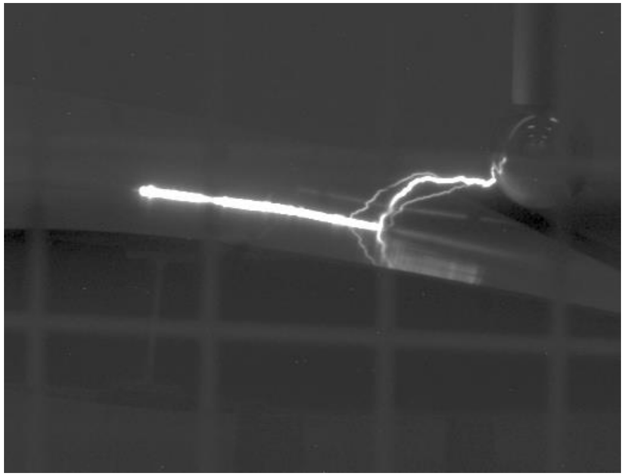


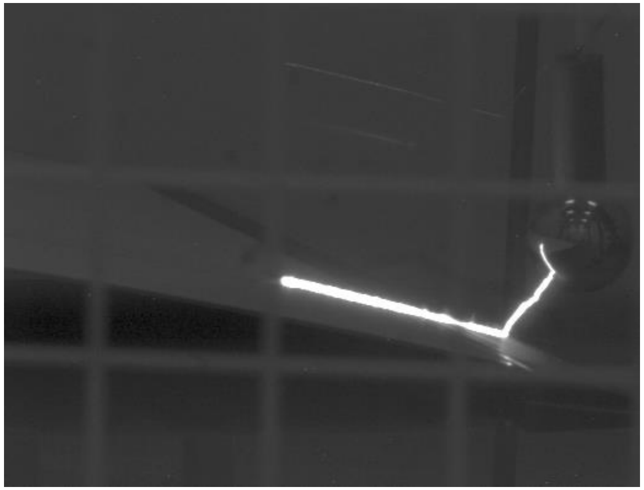
One flap system tested for lightning damage

The Santoprene flap material showed a higher withstand voltage in tracking tests than GFRP







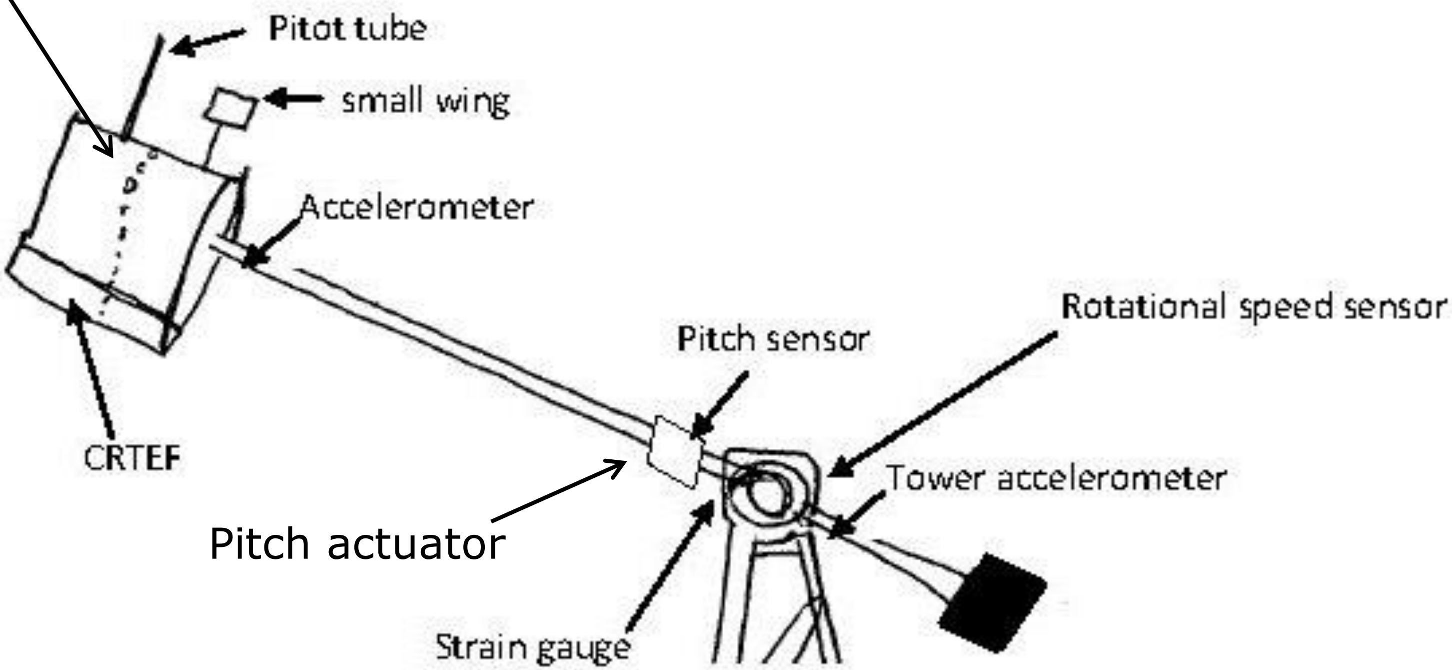


Sketch of the rotating test rig

- Intended to close the gap between wind tunnel and full scale testing

Pressure
measurements

Test rig based on a 100 kW turbine.
Rotation of a 10m long boom with an airfoil section of 2x1m



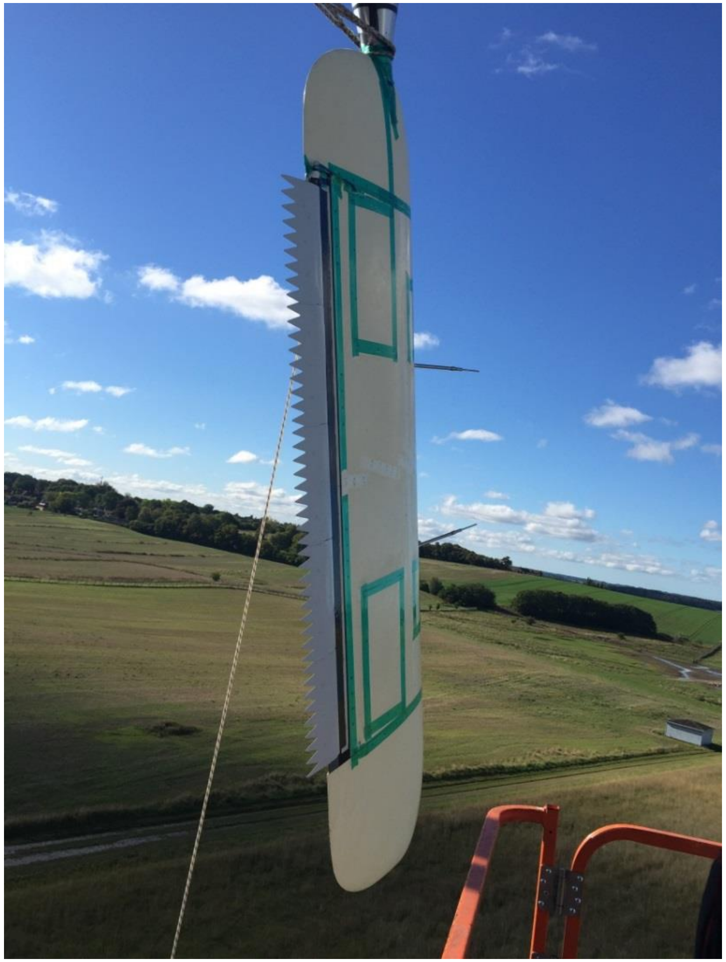
Blade section for rotating test rig

2x1 m blade section + end caps

Blade section mounted on the 10m long boom in the workshop - instrumentation

Pressure taps in chordwise and spanwise direction

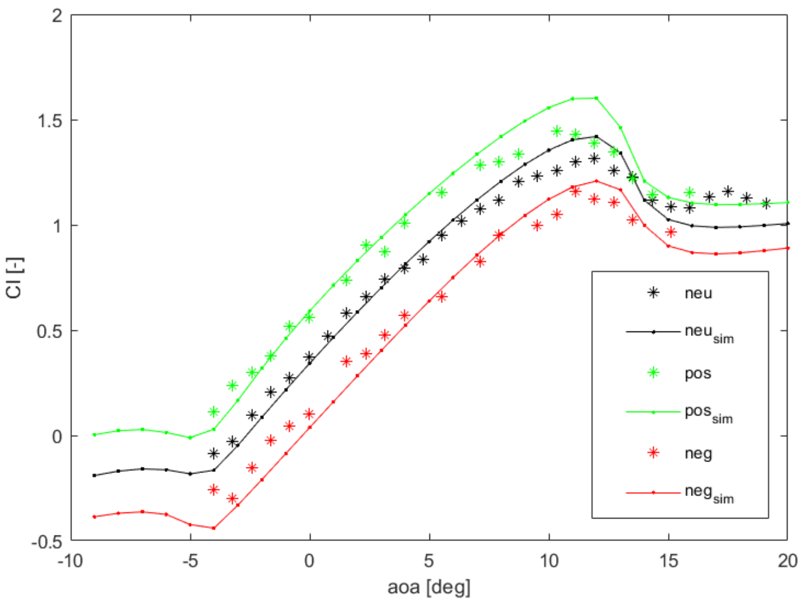
Flap testing on the rotating rig

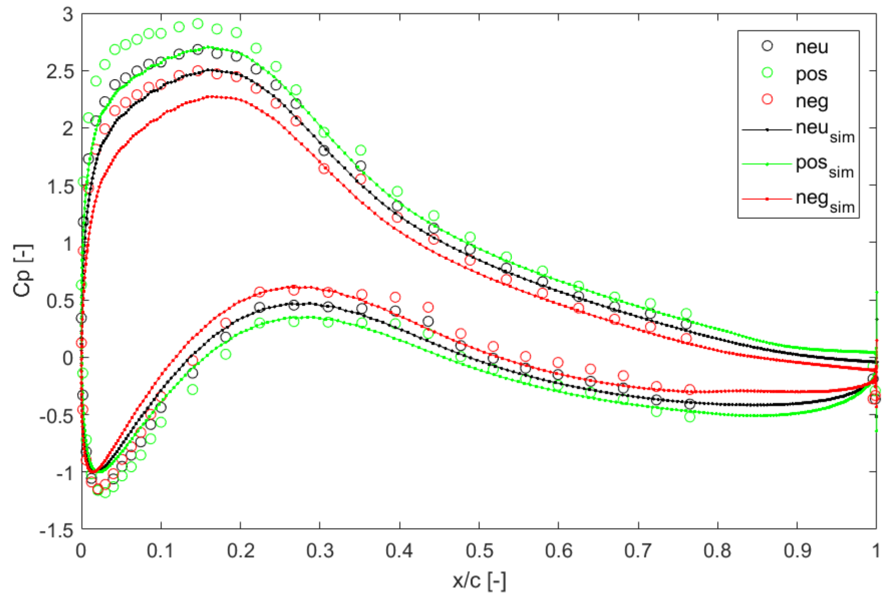


Example of measured flap performance on the rotating rig

Flap design from the Innwind.EU project

ΔC_L @ 8º		
Case	**+ΔC_L**	**-ΔC_L**
CFD	+0.21	-0.25
Wind tunnel*	+0.18	-0.24
Rotating rig	+0.18	-0.20

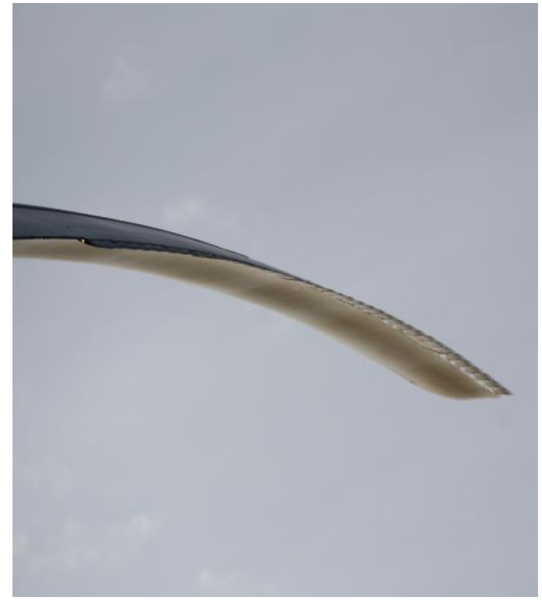




*  Poul La Cour wind tunnel - DTU (!)

Full-scale tests

- Testing on a multi-MW turbine in Denmark since Dec 2017
- Test and validation under real weather conditions
- Testing planned until end of 2018
- For further information: http://www.induflap.dk/



Conclusions

- a complete development line for flap technology from prototype to full scale has been developed in cooperation with two industrial partners

- A considerable amount of testing in wind tunnels and on a rotating rig has been conducted

- Full scale testing of first prototypes initiated and will contribute with new important information about a possible commercialization of the technology

Thank you

for your attention