Transfer of flap technology from laboratory to industrial application

Helge Aa. Madsen
Tom Løgstrup Andersen
Peter Bjørn Andersen

DTU Wind
Technical University of Denmark
P.O. 49, DK-4000 Roskilde, Denmark.

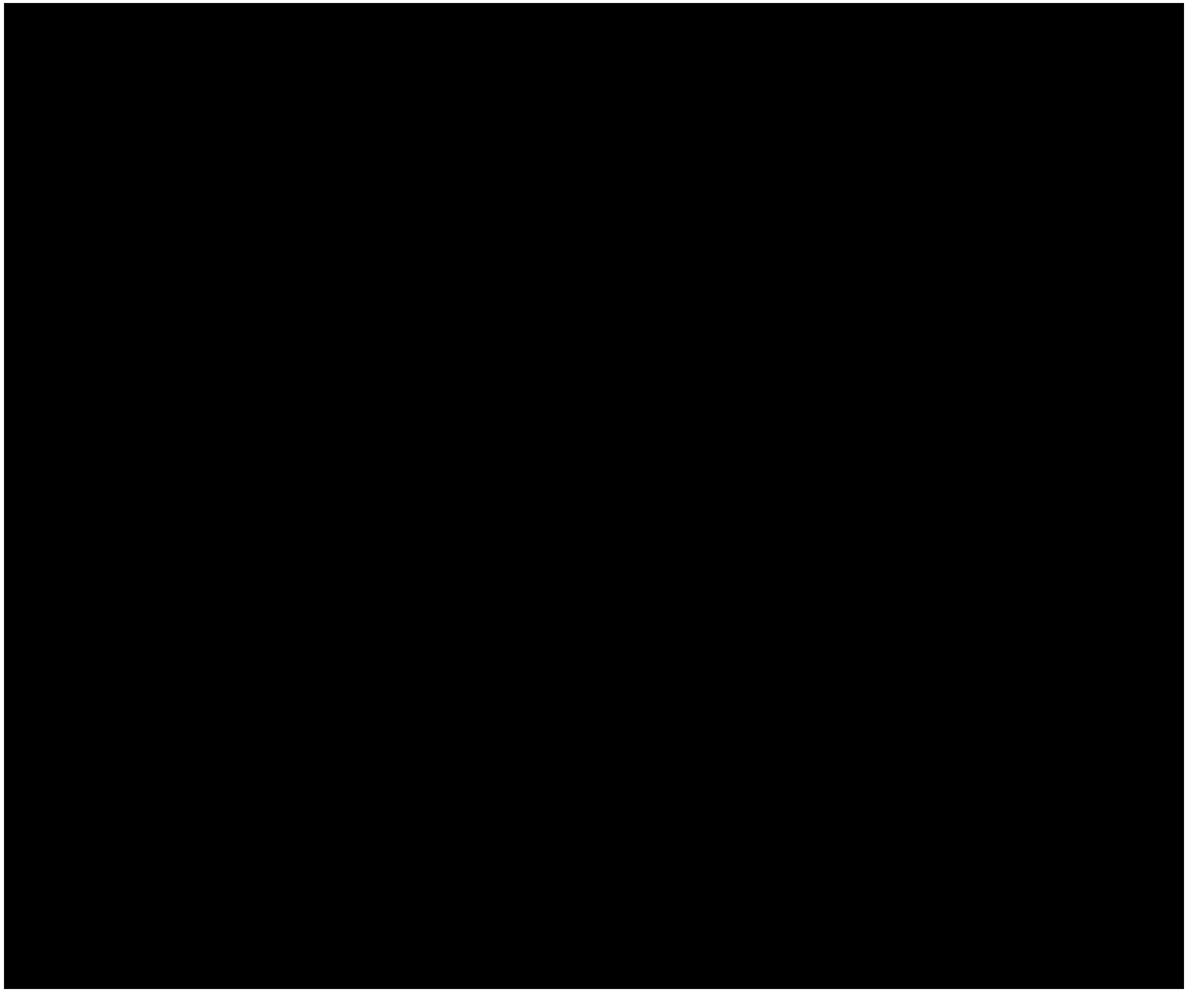
hama@dtu.dk

OUTLINE

- The vision with application of flaps
- Load input alleviation using inflow measurements
- Requirements to flap actuator performance
- Controllable rubber trailing edge flap designs
- A novel rotating test rig
- Outlook

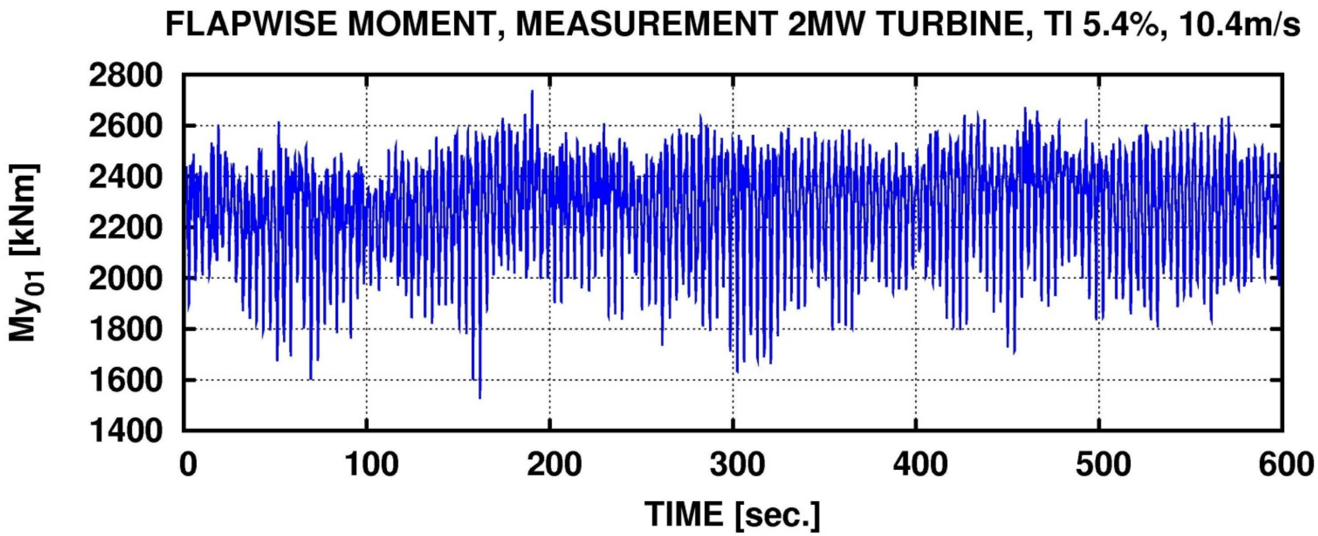
The vision by applying flaps

A 2D suspended wing section in turbulent inflow

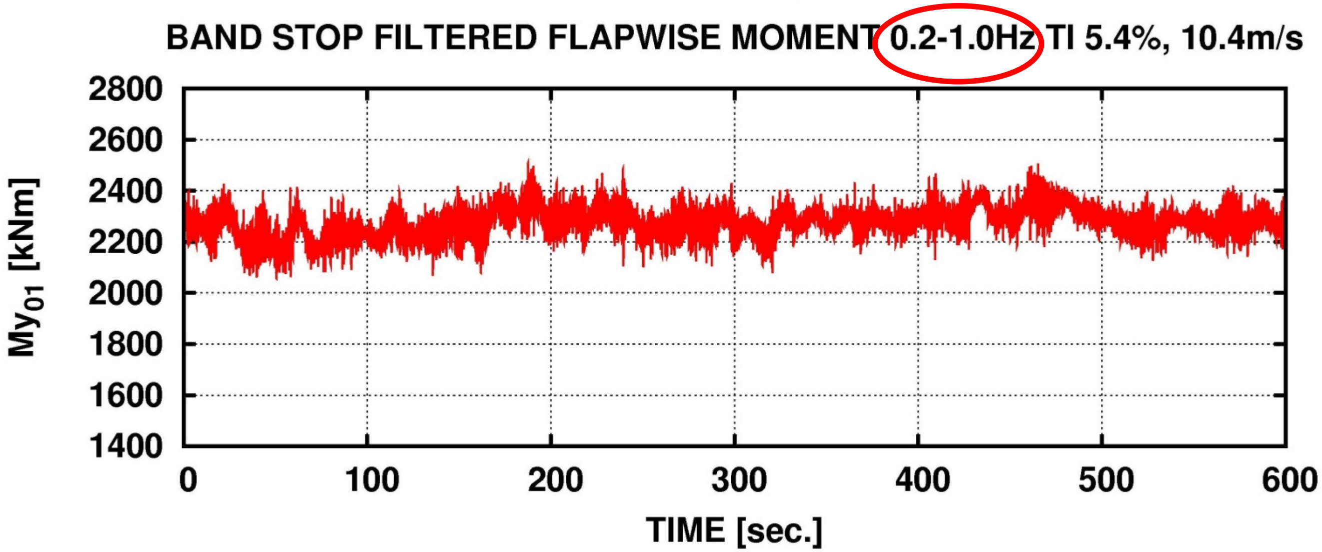


- ❑ Blue airfoil section without flap
- ❑ Red airfoil section with flap

The vision by applying flaps



Fatt. RAW
m=3 425.3 kNm
m=12 729.8 kNm

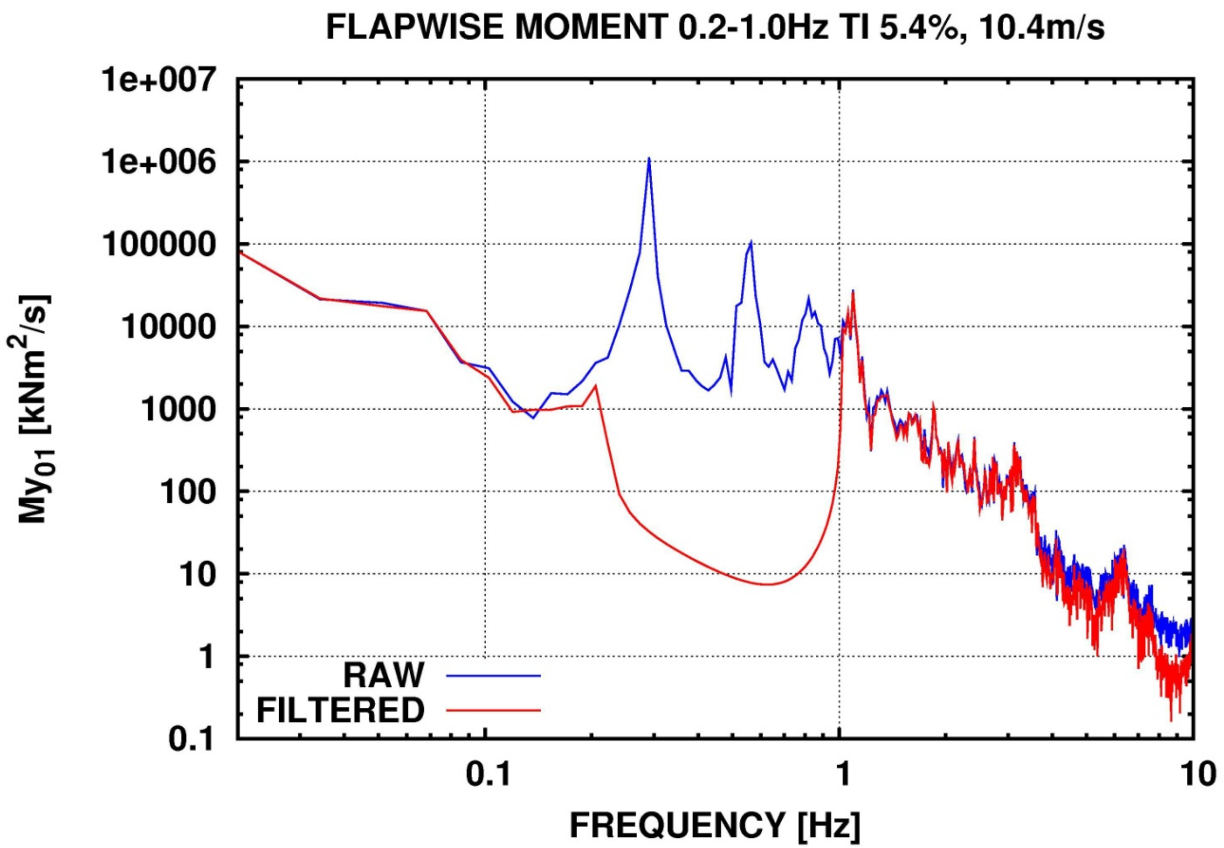


Fatt. FILTERED
m=3 172.2kNm
59% reduction

m=12 277.8 kNm
62% reduction

The vision by applying flaps

PSD spectra of the traces shown on the previous slide



Fatt. **RAW**
m=3 425.3 kNm
m=12 729.8 kNm

Fatt. **FILTERED**
m=3 172.2kNm
59% reduction

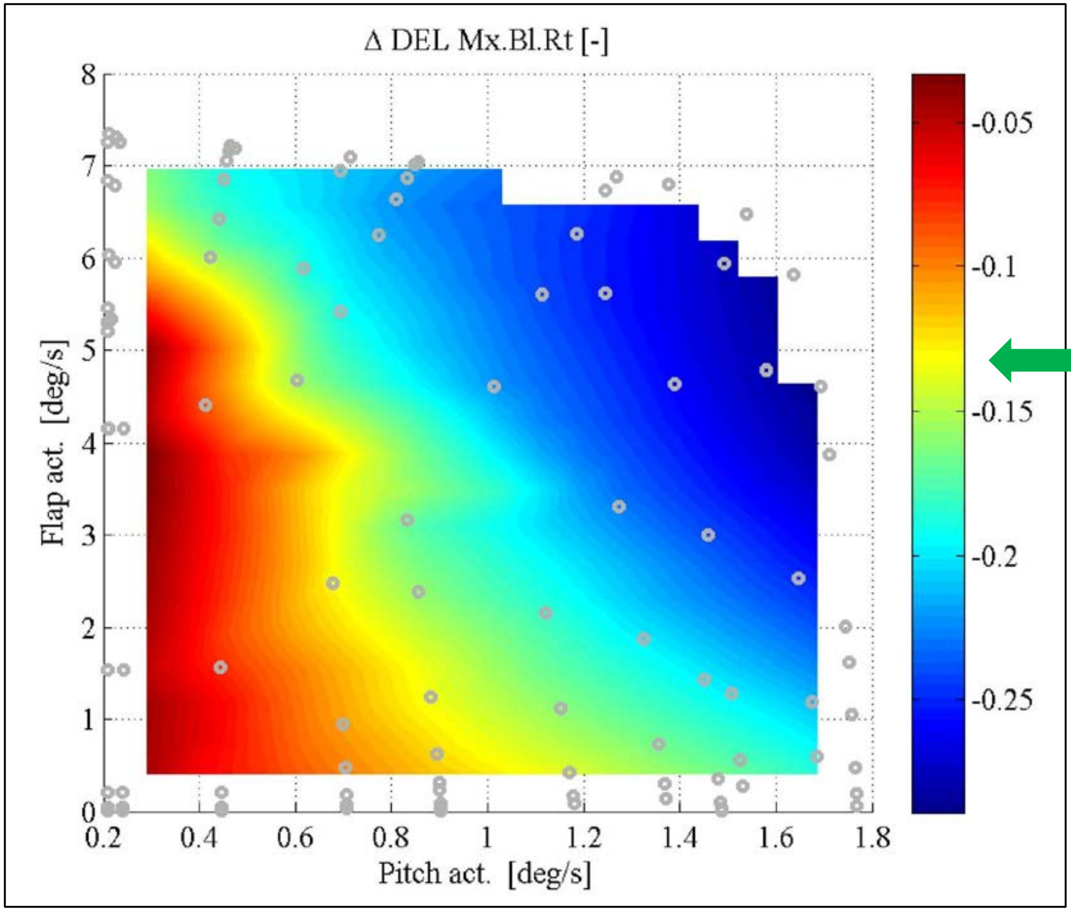
m=12 277.8 kNm
62% reduction

How do we apply the flaps:

- ❑ reduce the pitch activity and alleviate the loads using the same sensors as for the pitch system

- ❑ utilize the distributed control potential along the blade span and alleviate the unsteady aerodynamic loads locally along the blade span

Reduce the pitch activity and alleviate the loads using the same sensors as for the pitch system

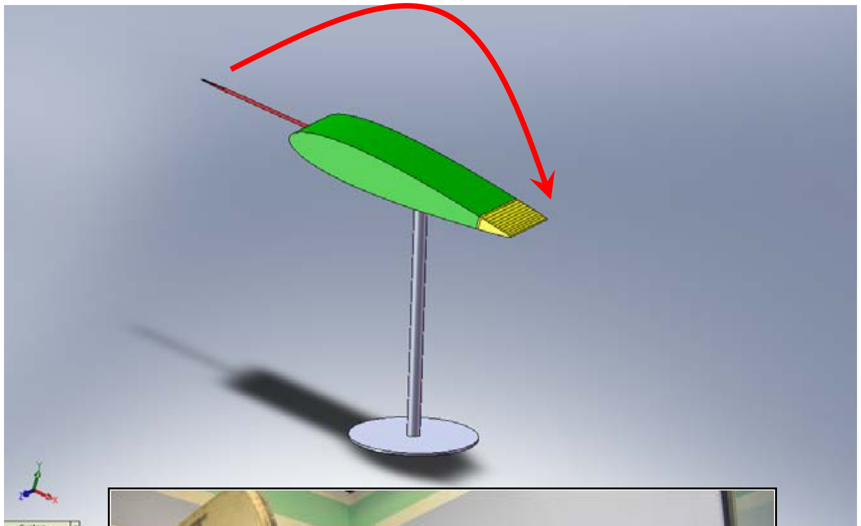


Fatigue Damage Equivalent Loads (DEL) alleviation at the blade root flapwise bending compared to the baseline NREL 5 MW turbine, Wöhler curve exponent of 10.

Christensen LC, Bergami L and Ander PB "A Model Based Control methodology combining Blade Pitch and Adaptive Trailing Edge Flaps in a common framework" Presented at EWEA2013 in Vienna, 4-7 February 2013.

Measure the incoming disturbance and adjust the flap position to keep the aerodynamic loading constant along the blade span

Inflow data from a five hole pitot tube



Wind tunnel test of flaps and inflow sensors, 2009

Inflow measurements, 2MW turbine

Experiment carried out within the DAN-AERO project from 2007-2010: LM, Vestas, Siemens, DONG Energy and Risø DTU

Control by inflow signals – aero force loading at one radial position considered

Measure relative velocity and inflow angle (unsteady)

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

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

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

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Control by inflow signals – aero force loading at one radial position considered

Ideal control:

$$F_{Nc} = F_N - f_c V_R^2$$

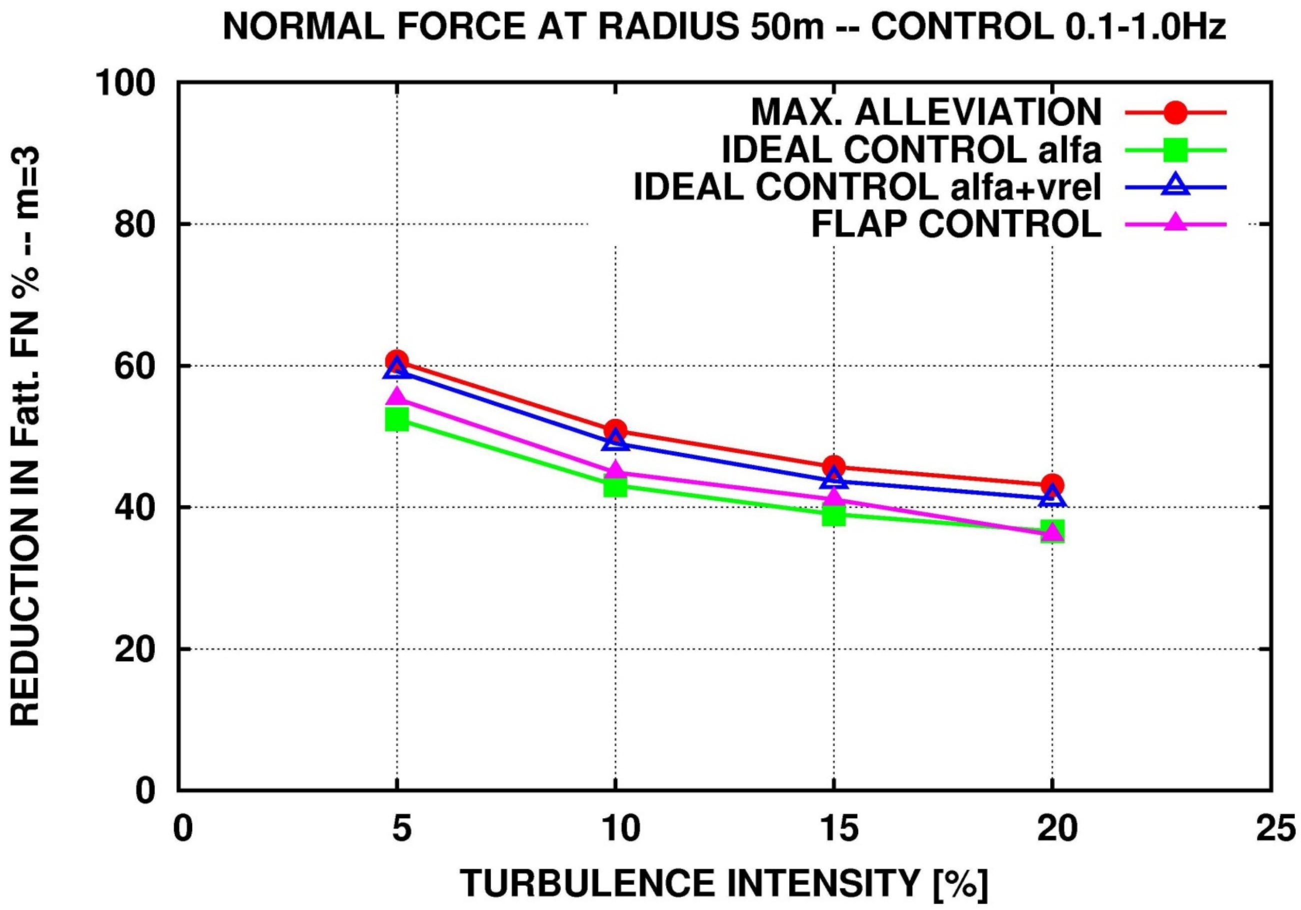
where F_{Nc} is the controlled normal force

Flap control: f_c → Flap aerodynamics + flap actuator dynamics → F_{Nc}

The flap control is numerically simulated by the aeroelastic code HAWC2 where the flap aerodynamics and flap actuator dynamics are modeled

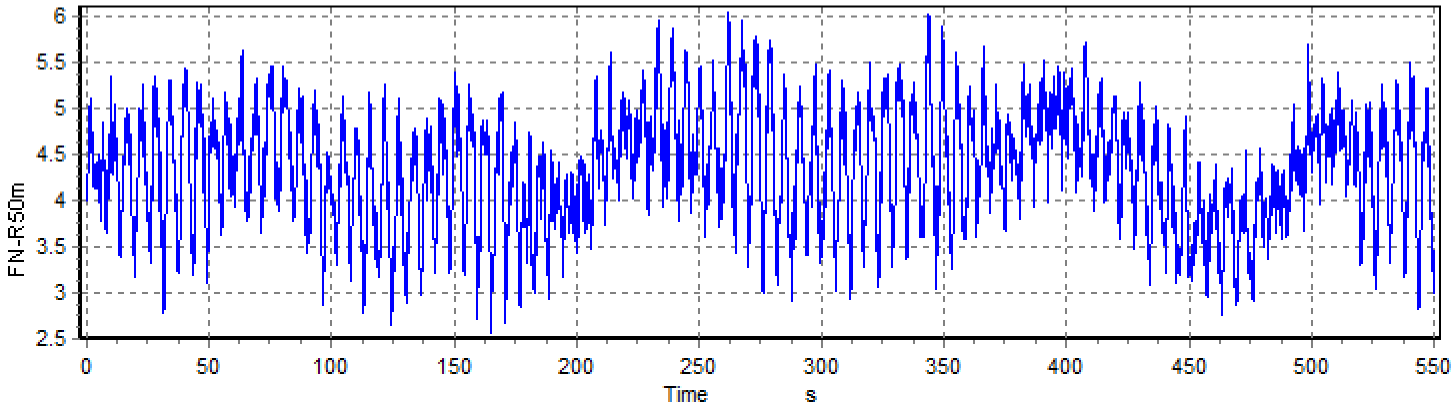
Load reduction of normal force at radius 50 m – influence of turbulence intensity

Flap angle constrained to : +- 5 deg.

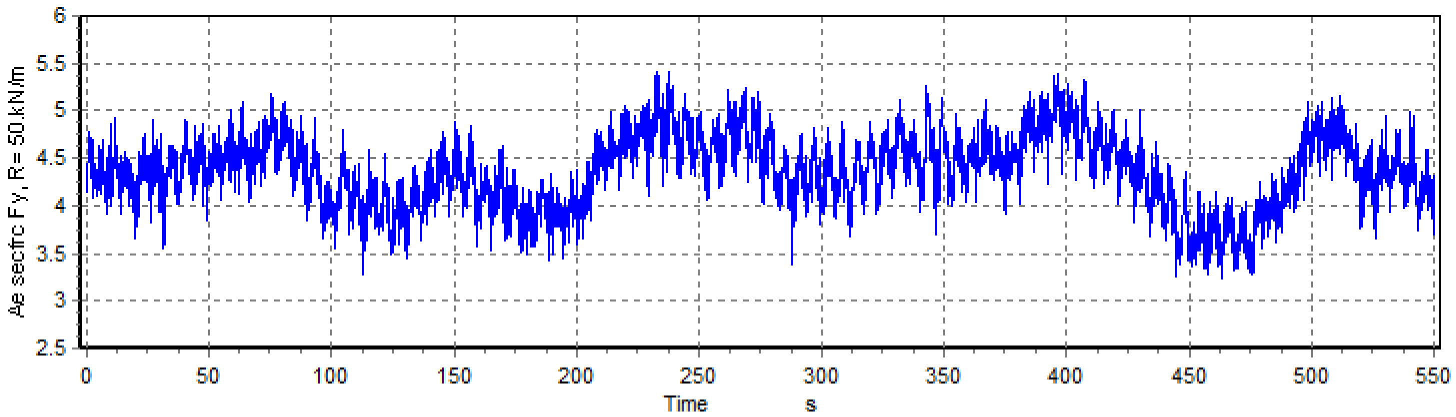


Load reduction of normal force at radius 50 m – 10% TI

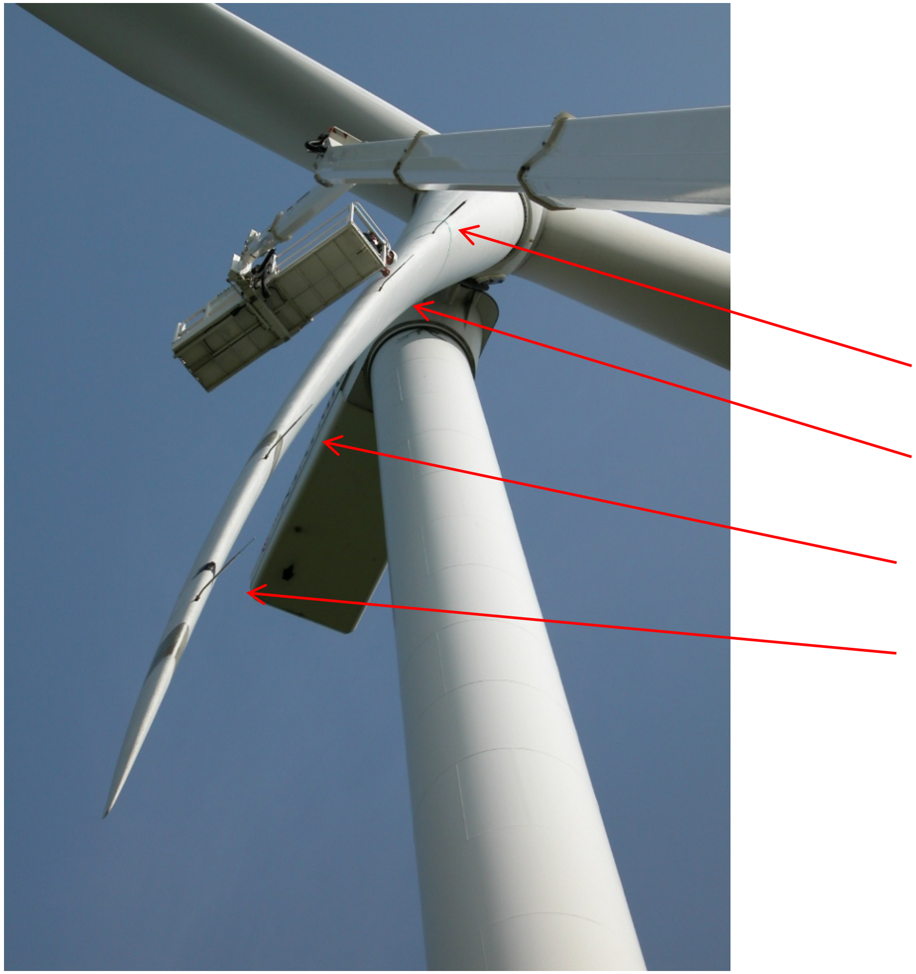
Raw normal force



Flap controlled normal force-red. 44.9%



Example of 2MW rotor with inflow sensors



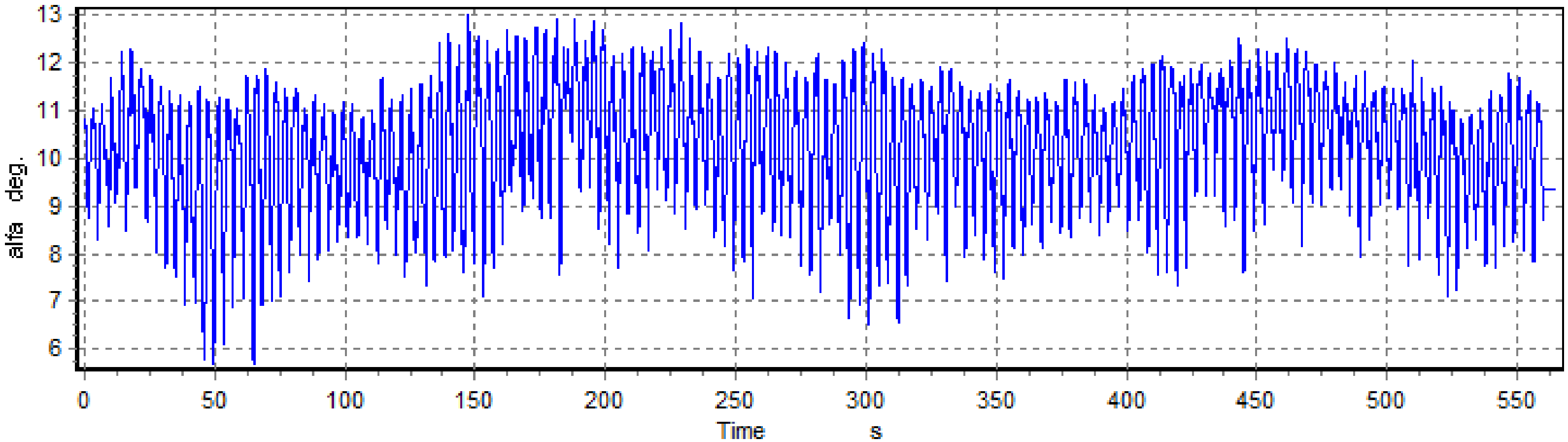
Four 5 hole pitot tubes installed on a NM80 turbine with an 80m rotor

Aero normal forces measured at four radial positions by pressure holes

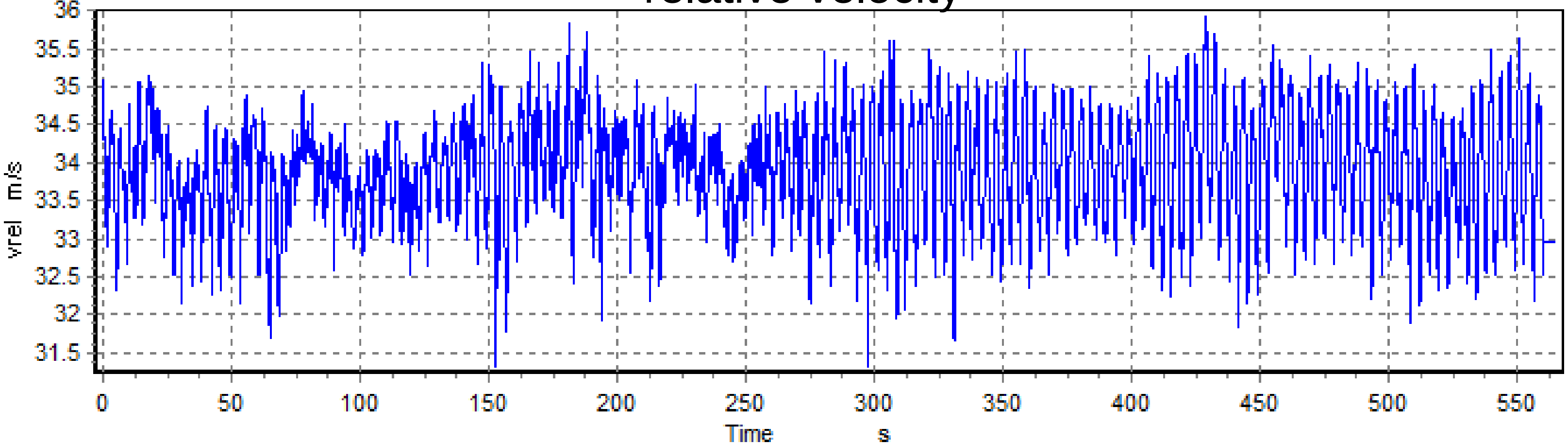
Experiment carried out within the DAN-AERO project from 2007-2010: LM, Vestas, Siemens, DONG Energy and Risø DTU

NM80 turbine – measured inflow at R=30m

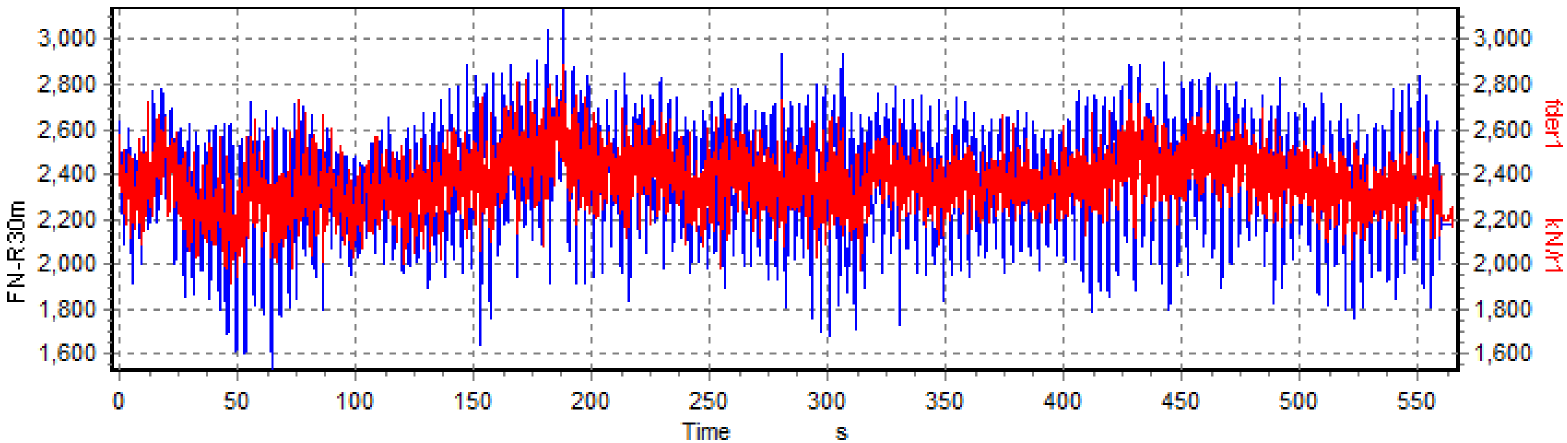
alpha

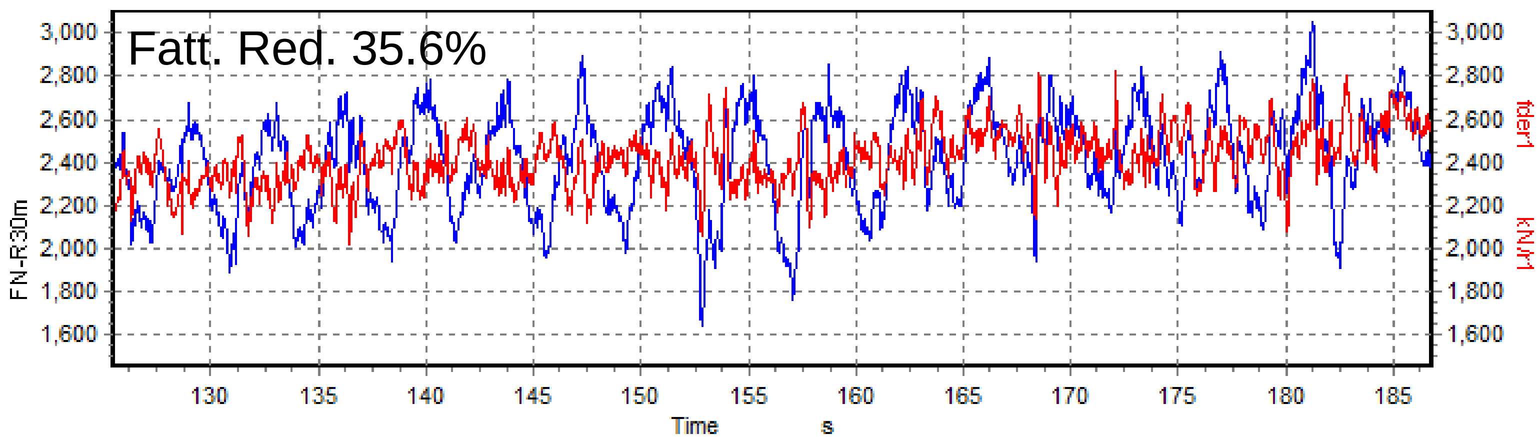


relative velocity

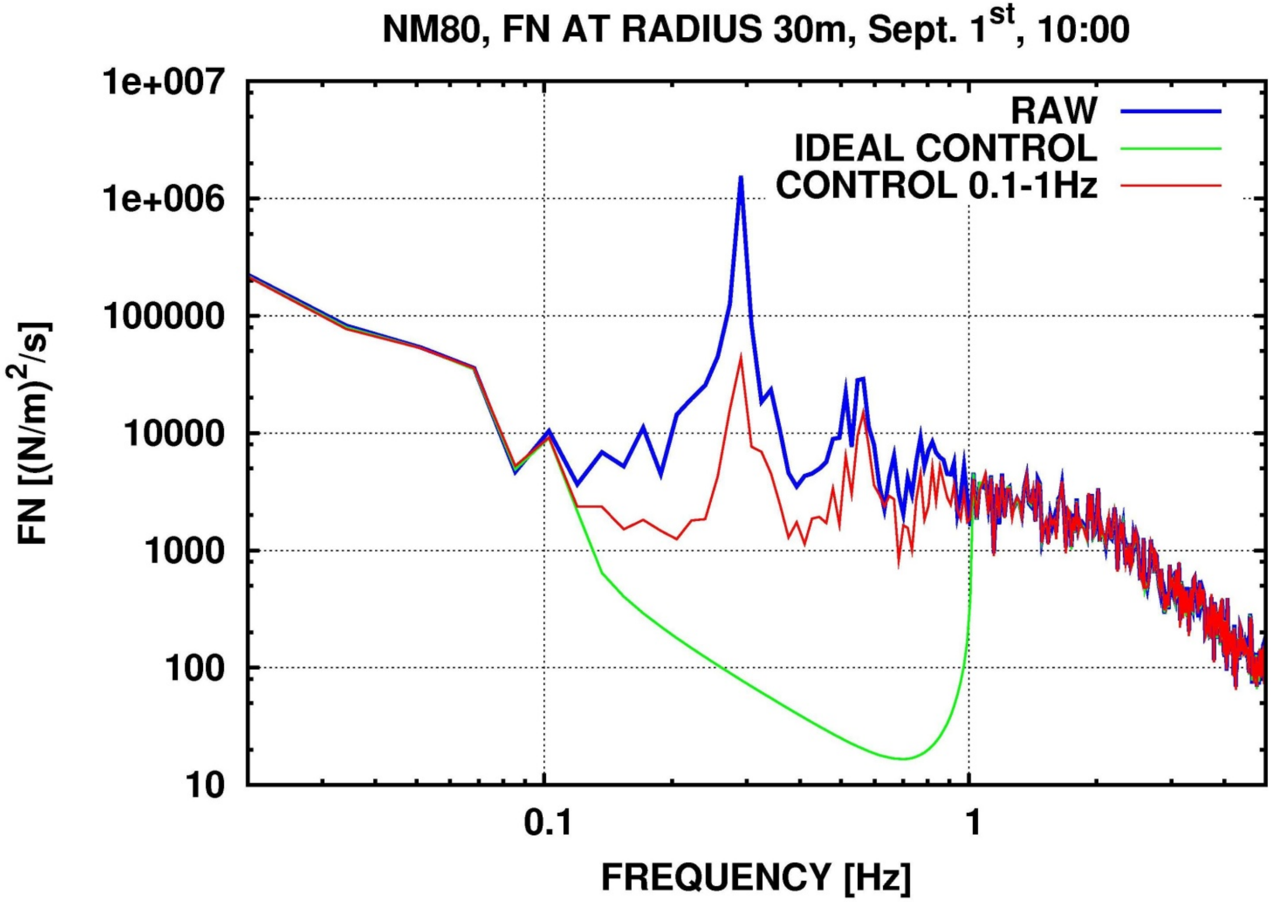


NM80 turbine – control of FN at R=30m from inflow measurement





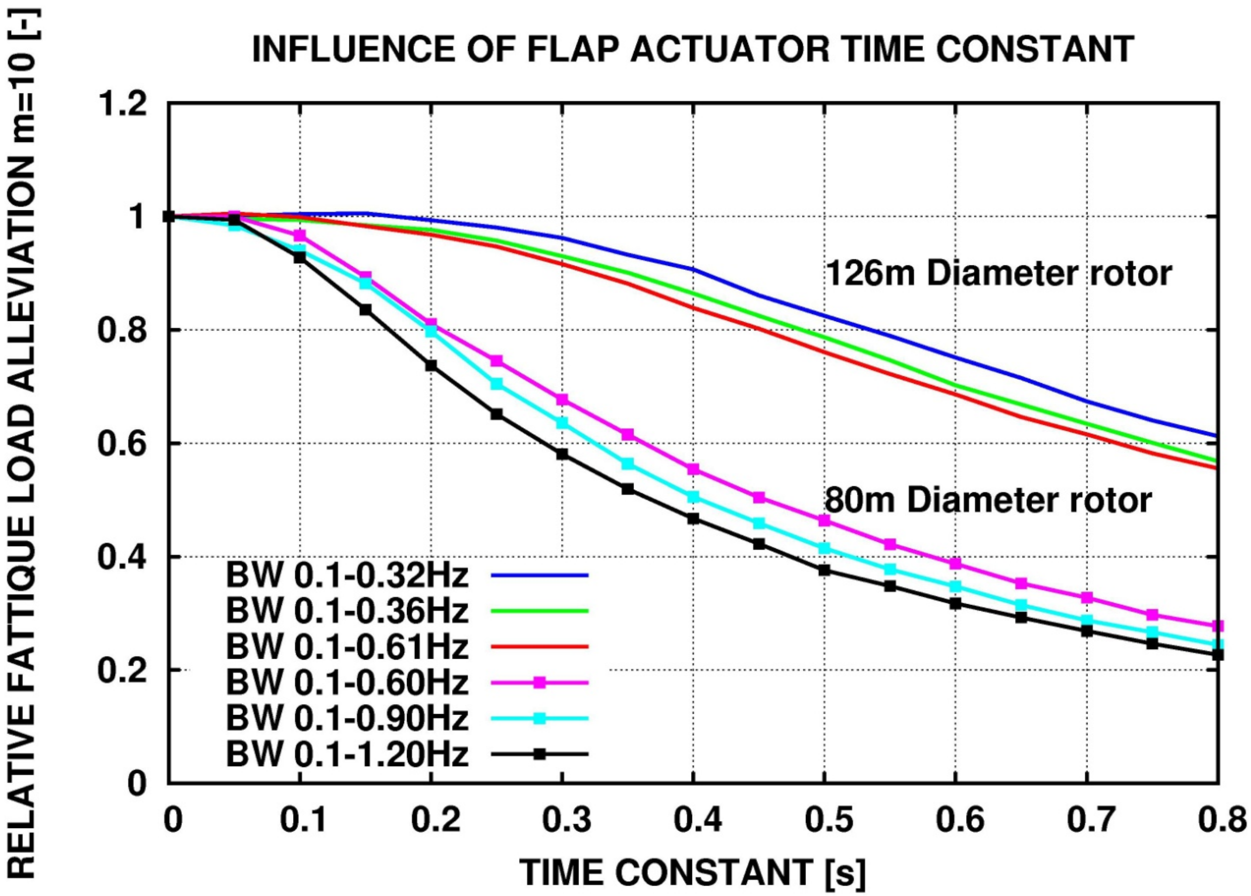
NM80 turbine – control of FN at R=30m from inflow measurement



Fatt. Red. 35.6%

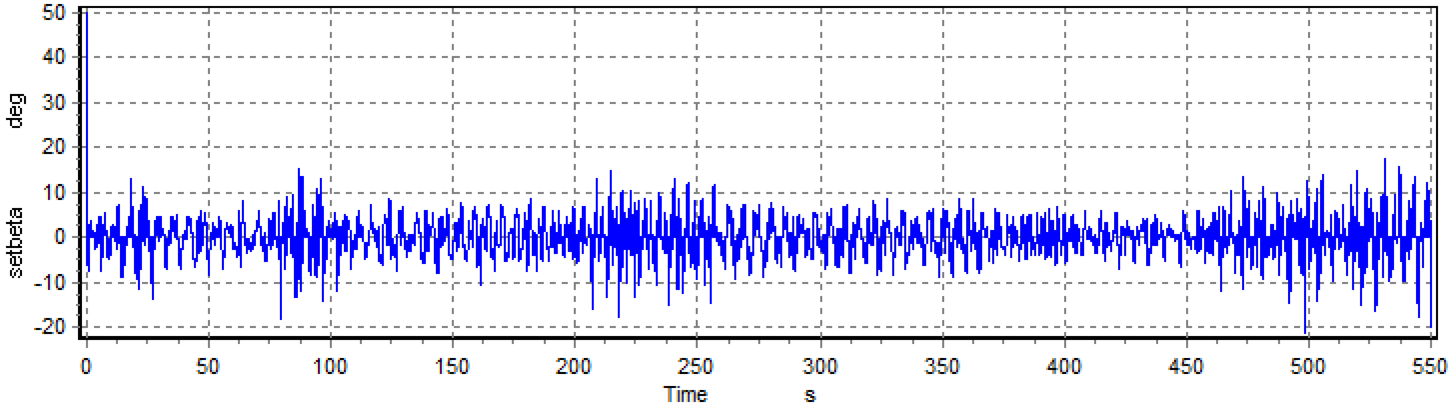
Requirements to flap actuator performance

Flap actuator time constant



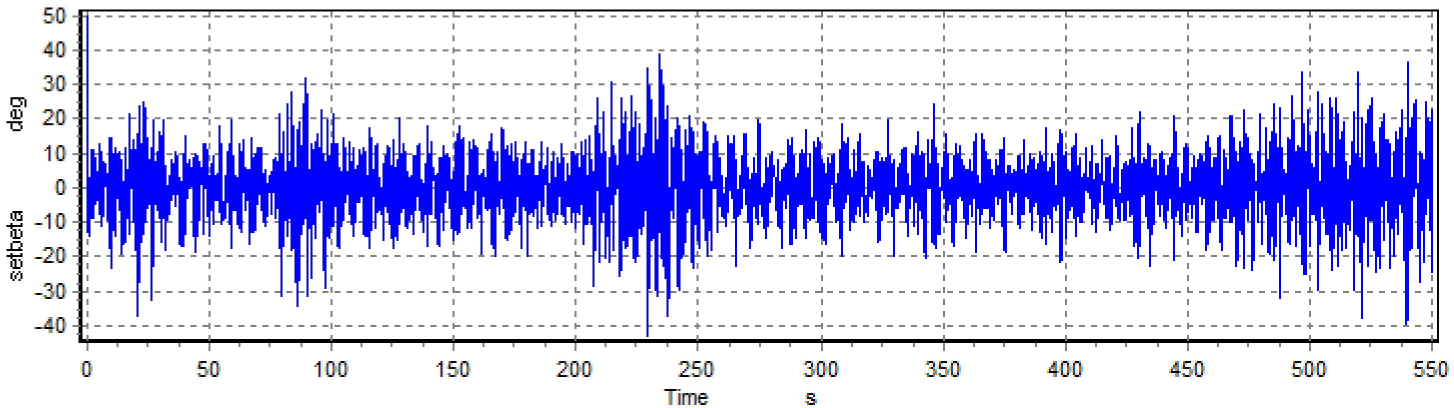
Flap actuator speed
– 5MW ref. Turbine, 8m/s, ti=10%

Band 0.1-1.0 Hz Std. dev. = 3.52 deg/s



Fatt red. = 42.9%

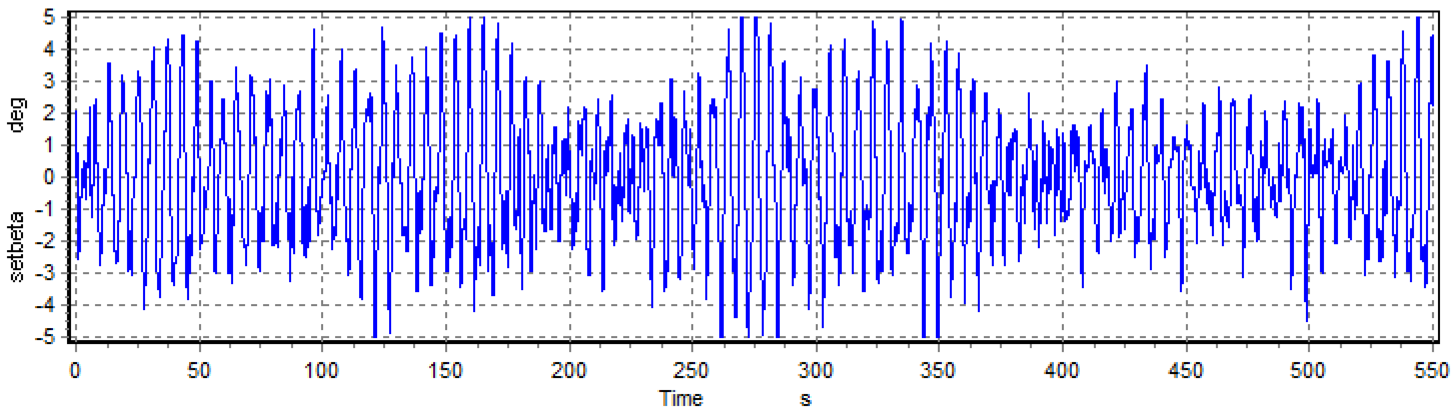
Band 0.1-2.0 Hz Std. dev. = 6.93 deg/s



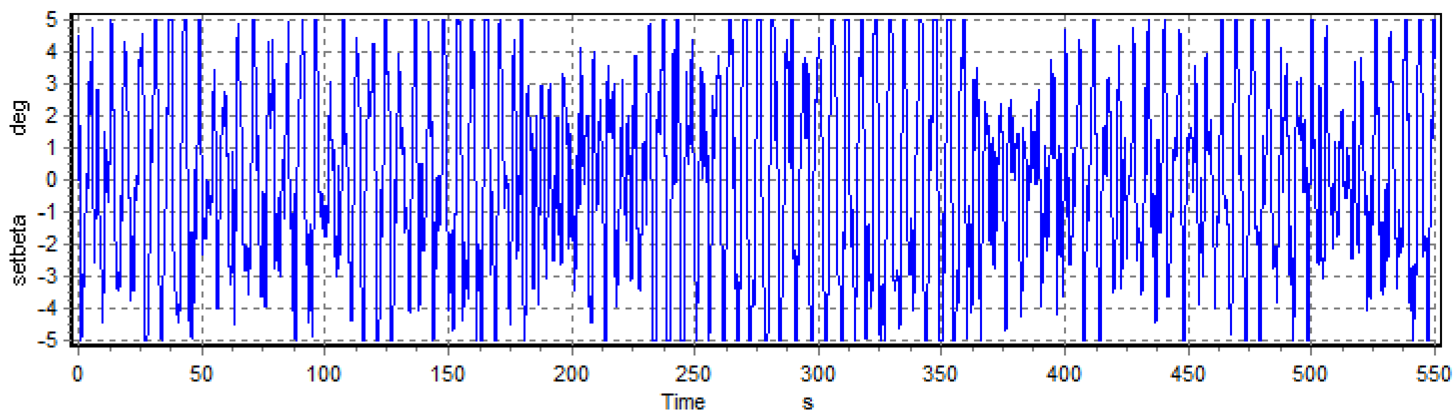
Fatt red. = 57.9%

Flap amplitude
5MW ref. Turbine, 8m/s

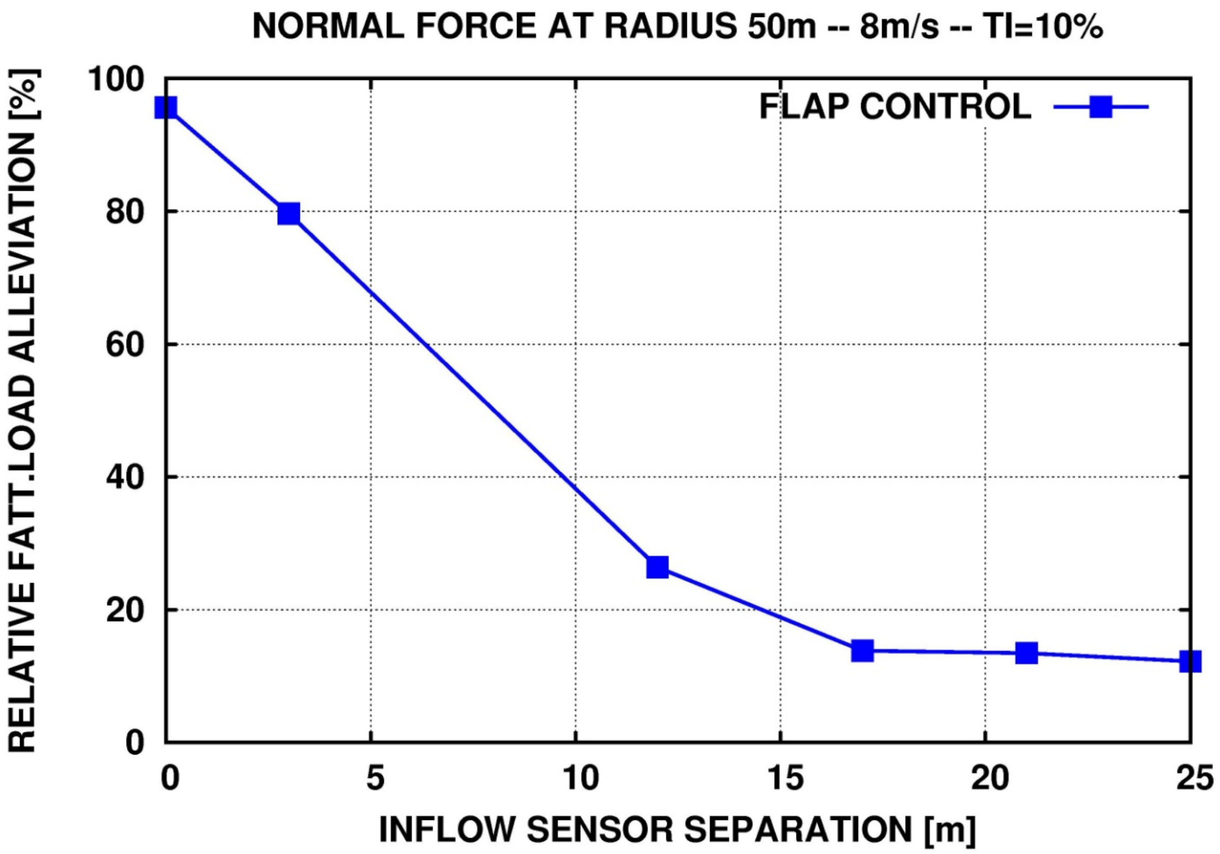
TI=10%



TI=20%



Inflow sensor separation in radial direction from flap position



Controllable rubber trailing edge flap (CRTEF) designs

development of the technology

The Controllable Rubber Trailing Edge Flap CRTEF development

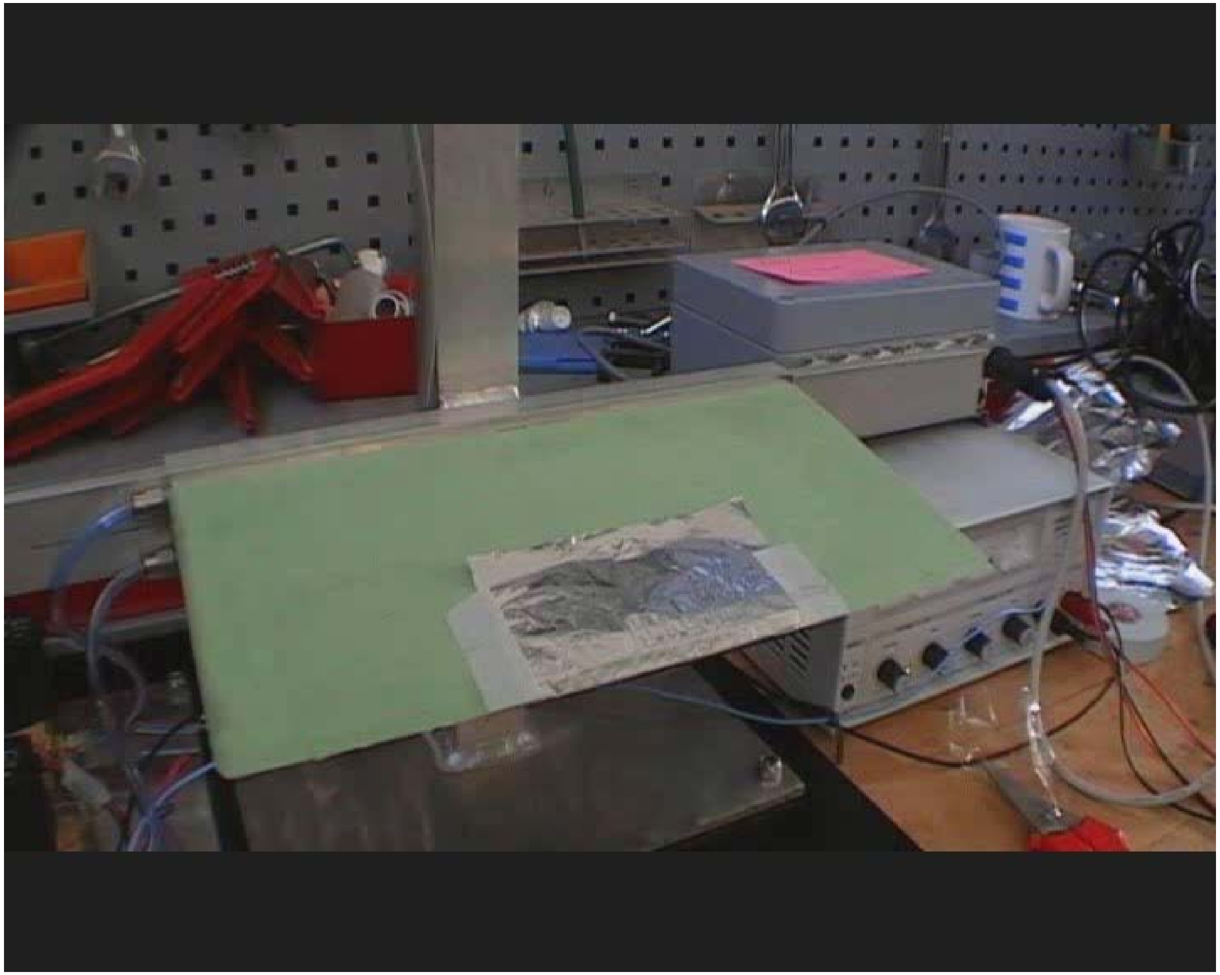
Development work started in 2006

Main objective: Develop a robust, simple controllable trailing edge flap

The CRTEF design:

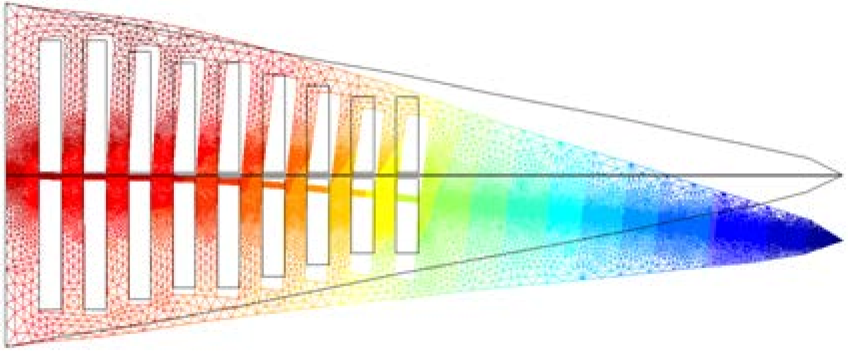
"A flap in an elastic material with a number of reinforced voids that can be pressurized giving a deflection of the flap"

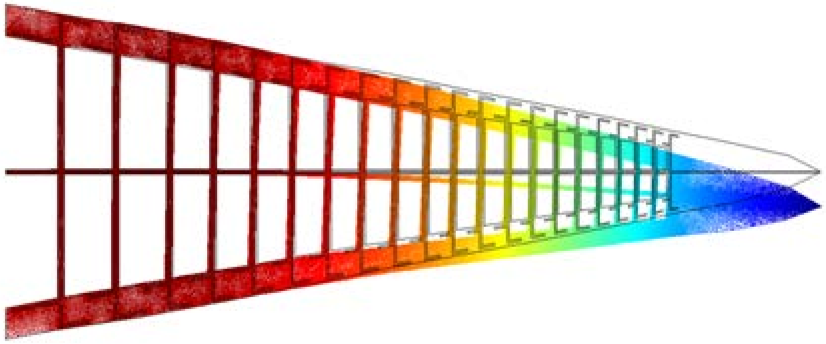
The Controllable Rubber Trailing Edge Flap CRTEF – test of prototype in 2008

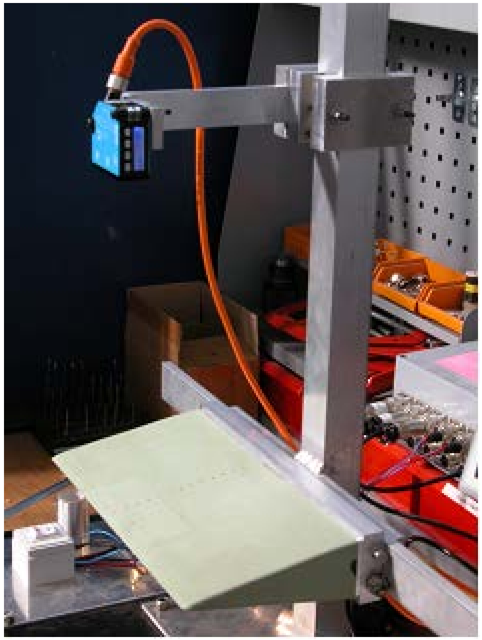


The CRTEF development
- early work (2008)

Comsol 2D analyses







Some milestones in the CRTEF development

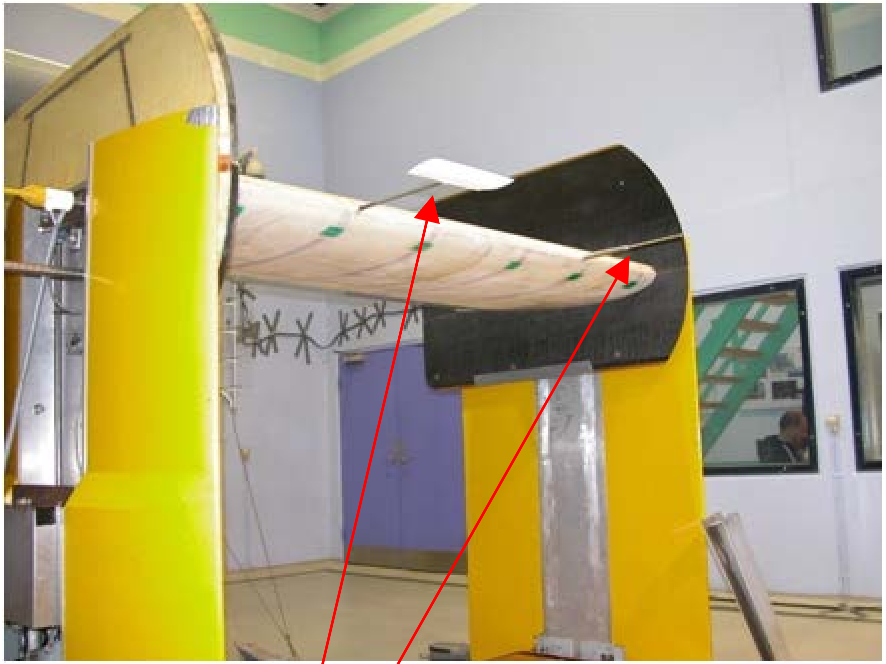
- in **2007** a 1m long prototype rubber trailing edge flap was tested – problems with its robustness
- in autumm **2008** promissing results with a 30 cm prototype with chordwise voids
- December **2009** wind tunnel testing of 2m long flap section

Wind tunnel experiment Dec. 2009

airfoil section + flap during instrumentation

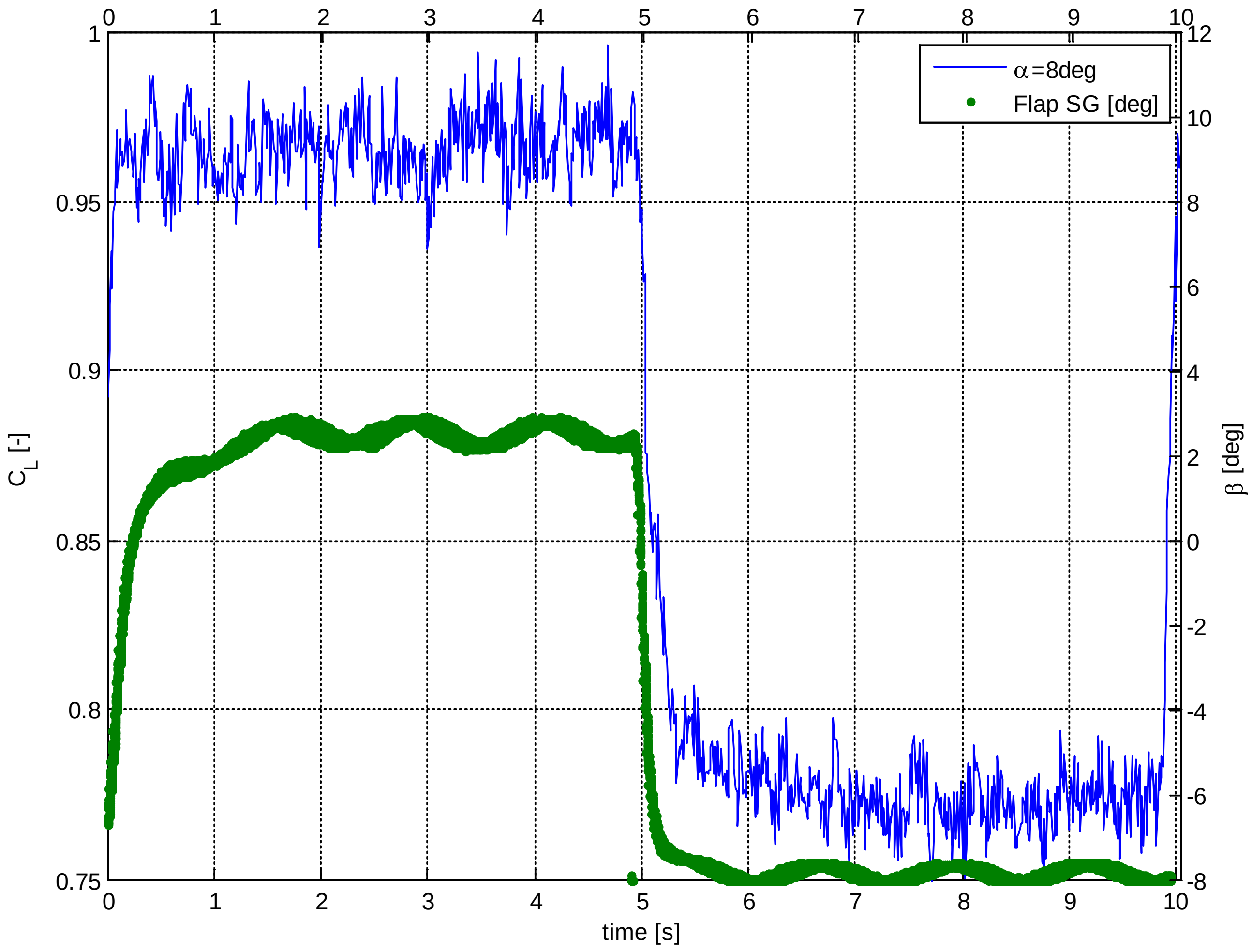
the 2m airfoil section with the flap in the VELUX wind tunnel, December 2009

Wind tunnel experiment Dec. 2009



two different inflow sensors

Lift changes integrated from pressure measurements



March 2011

A three years research and development project **INDUFLAP** with participation of three **industrial partners** was initiated

The INDUFLAP project

Start of project — Project — End of project

Prototype CRTEF tested in laboratory → Prototype ready for test on MW turbine

Participants:

DTU Elektro

DTU AED

DTU Fiberlab

Industrial partners

Rehau A/S (flap manufacturing)

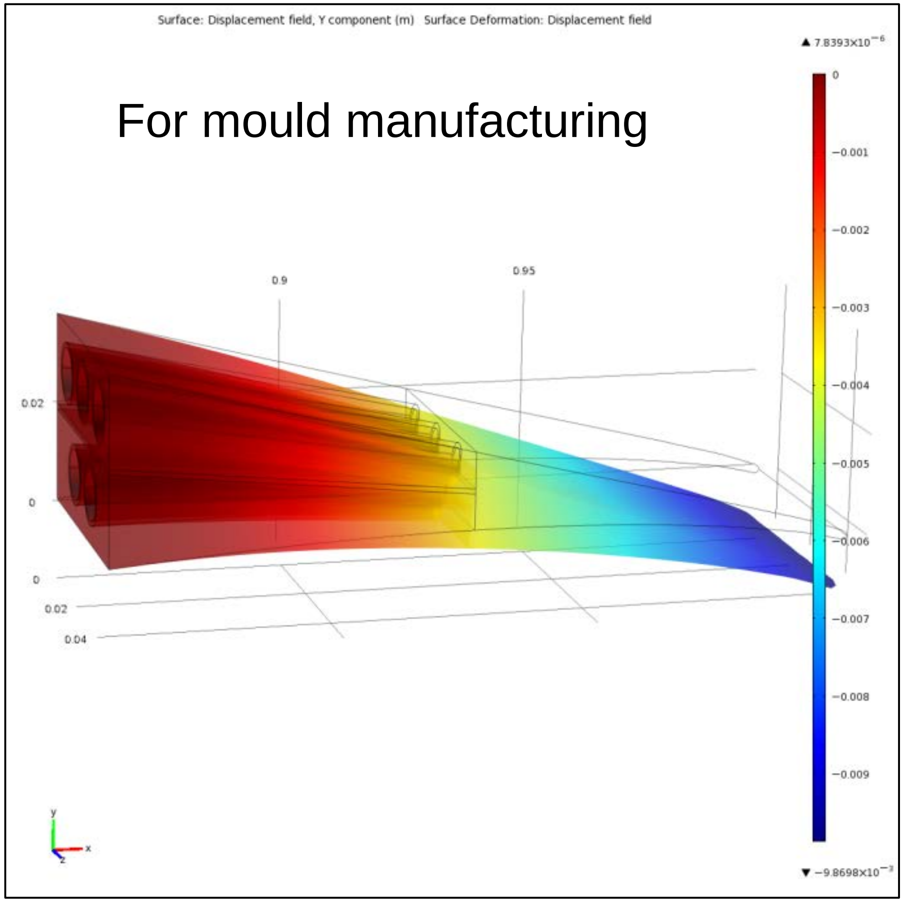
Hydratech Industries Wind Power (pneumatic power supply/control)

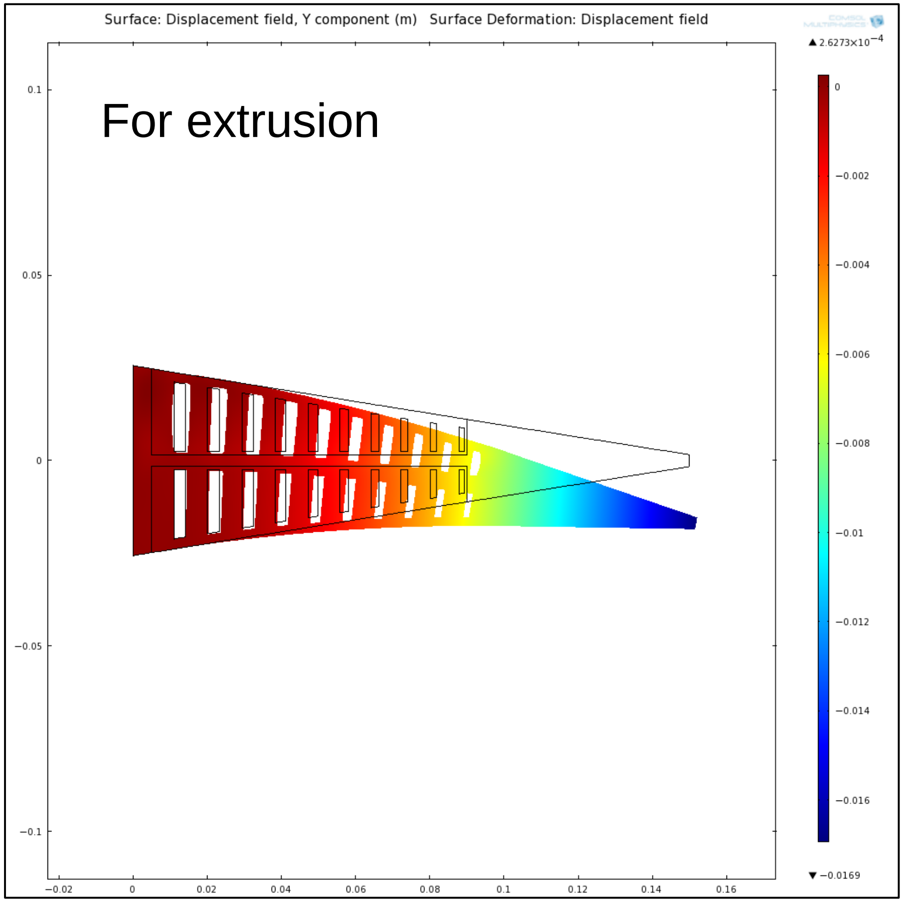
Dansk Gummi Industri A/S (flap manufacturing)

Project activities / investigations

- new designs (void arrangement, reinforcement, manufacturing process)
- determine the best materials/develop new materials
- performance (deflection, time constants)
- robustness, fatigue, lightning
- manufacturing of 30 cm and 2 m prototypes
- integration of flap system into the blade
- pneumatic supply
- control system for flap and integration with pitch
- testing of 2 m sections in outdoor rotating rig
- preliminary sketch of system for MW turbine blade

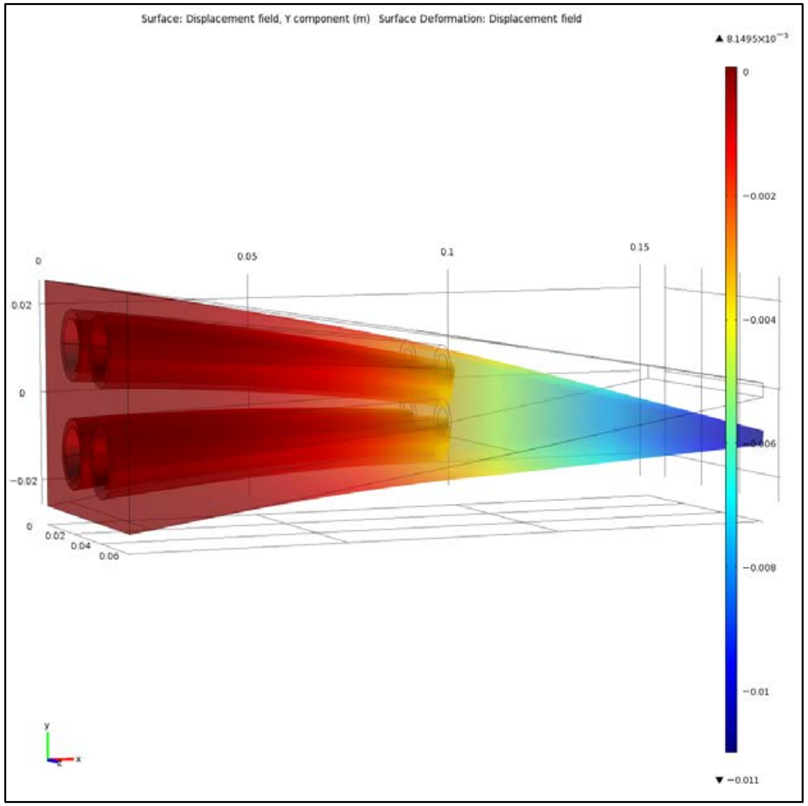
Two basic different types: chordwise or spanwise voids



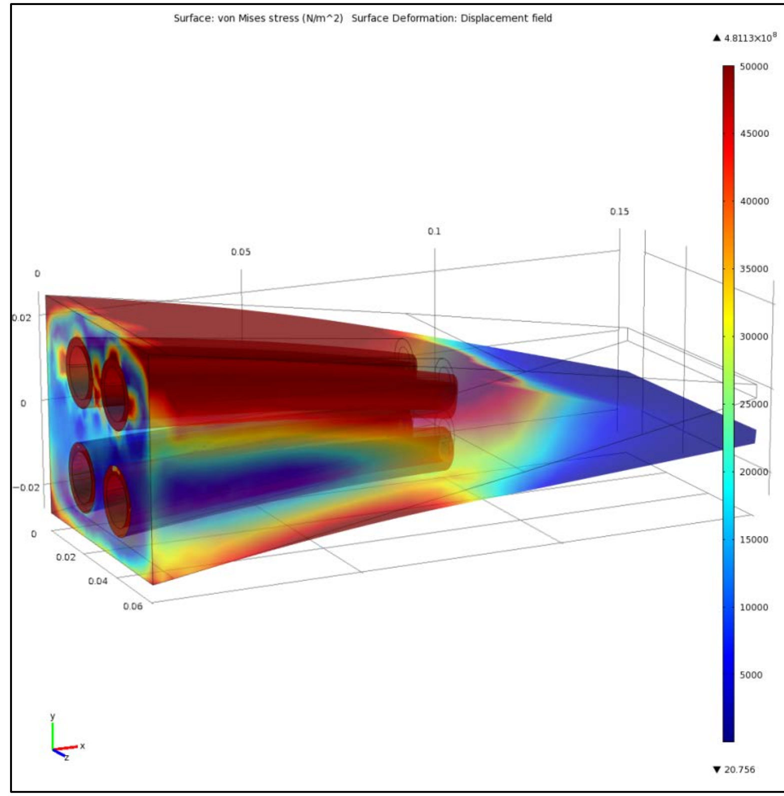


Example of COMSOL simulations on a new prototype with chordwise voids

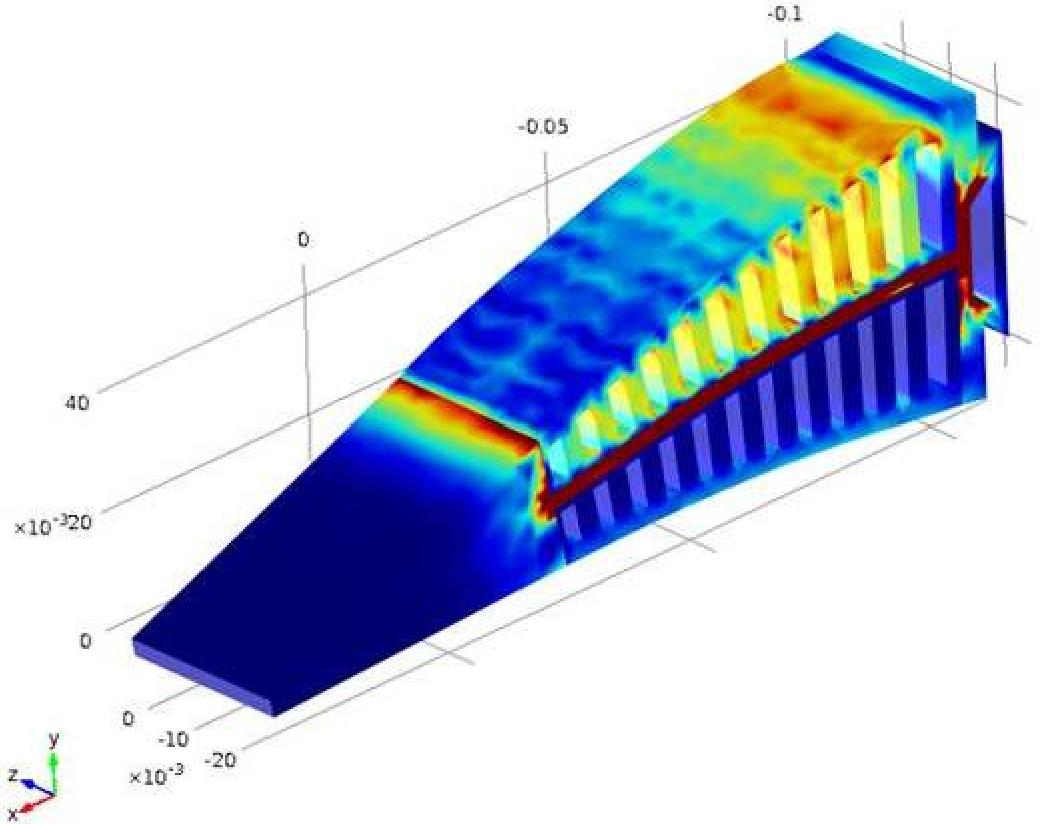
Contour plot of deflection



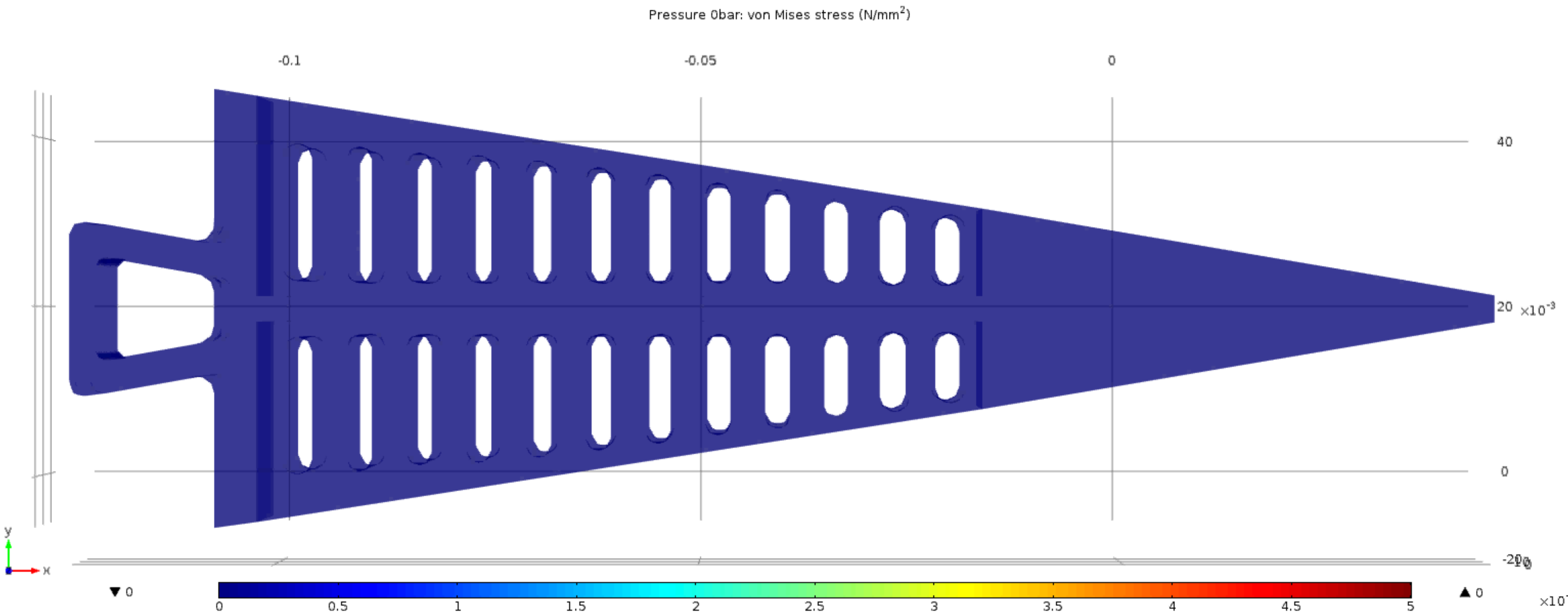
Contour plot of stress



Design to be tested in the spring/summer 2013



Example of COMSOL simulation of stress contours



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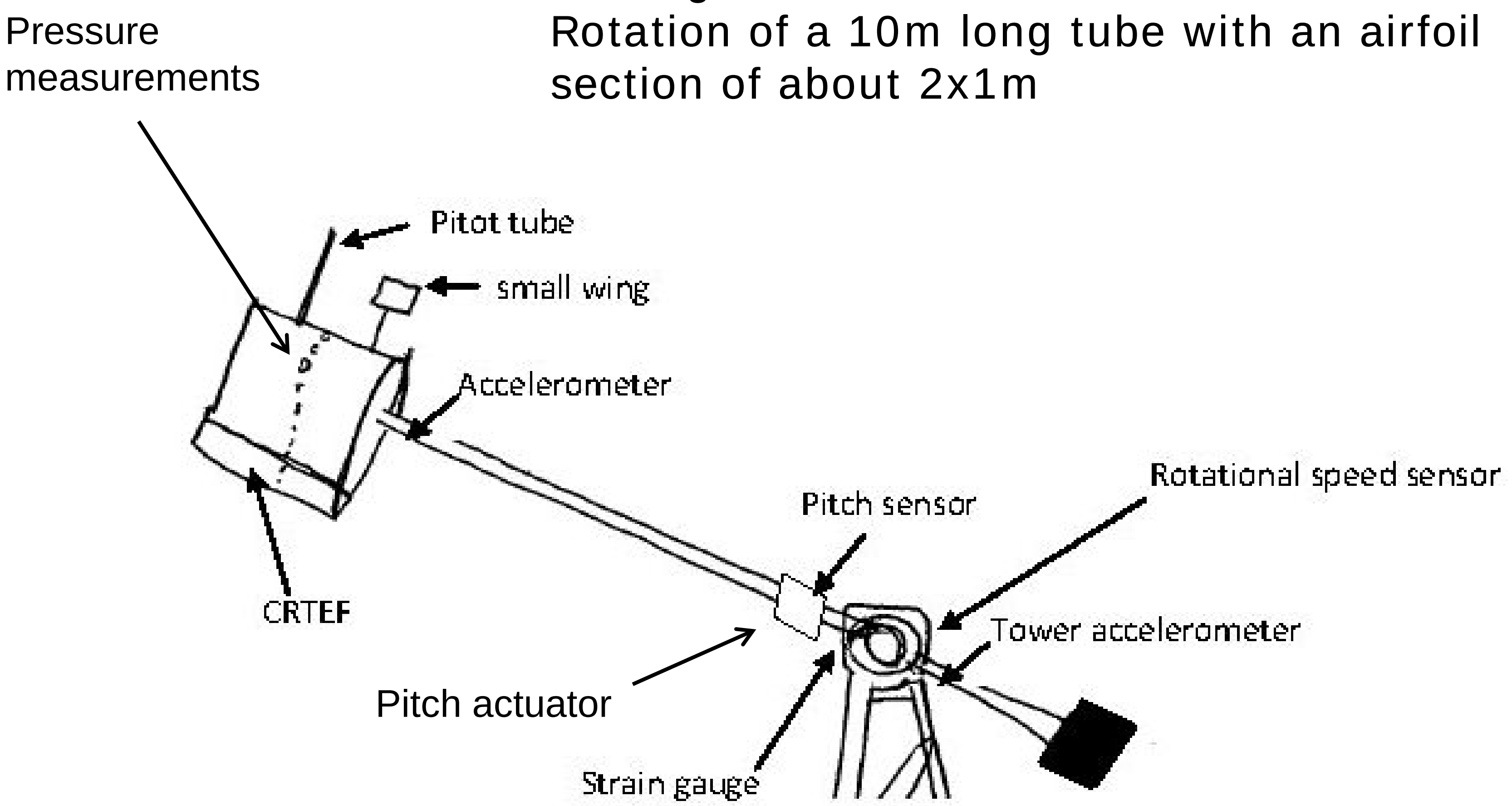
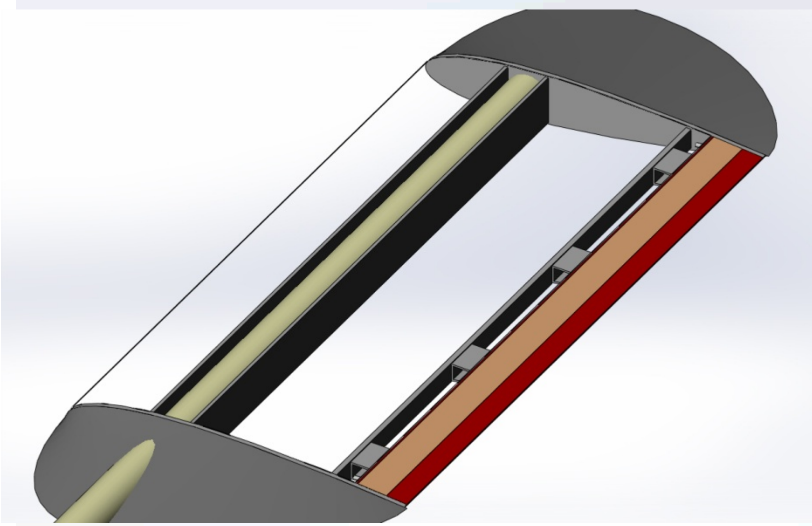
A novel rotating test rig based on a 100 kW turbine platform

Flaps to be tested on a rotating outdoor test rig

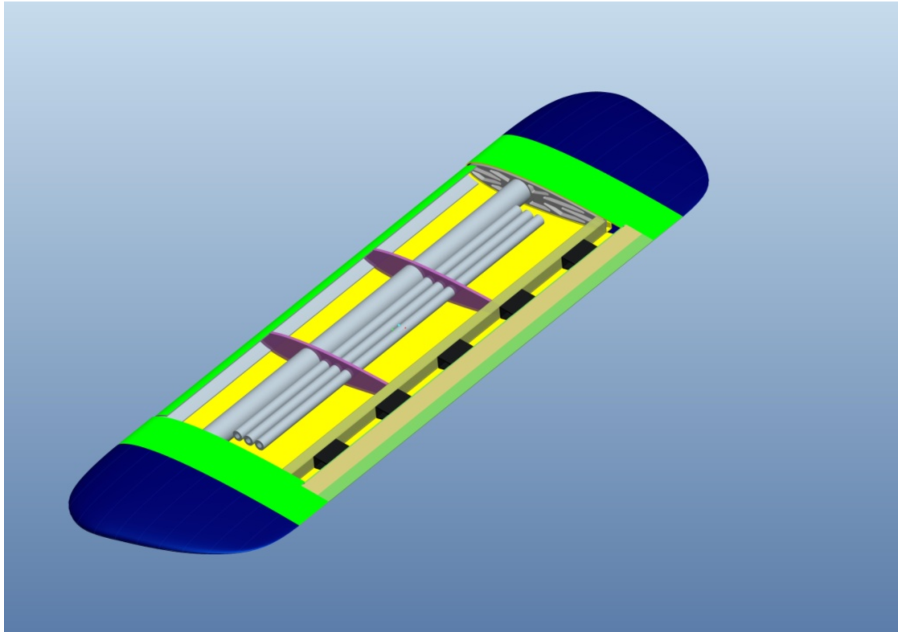
Test rig based on a 100 kW turbine.
Rotation of a 10m long tube with an airfoil section of about 2x1m



The rotating outdoor test rig based on a 100kW turbine platform



Design and manufacturing of 2m wing section with a 15% flap



Outlook

- tests of flap system and control procedures on the rotating rig in spring/summer 2013
- fatigue tests of flap system in laboratory autumn 2013
- late 2013 evaluation of the flap system for a full scale turbine

Acknowledgement

The work has been funded by the Danish Energy Agency EUDP and by eigen contribution from the partners:

- ❑ Rehau
- ❑ Hydratech Industries Wind Power
- ❑ Dansk Gummi Industri
- ❑ DTU (Elektro, Fiberlab, AED)


Thank you for your attention
Helge Aagaard Madsen
hama@dtu.dk