Development of Trailing Edge Flap Technology at DTU Wind

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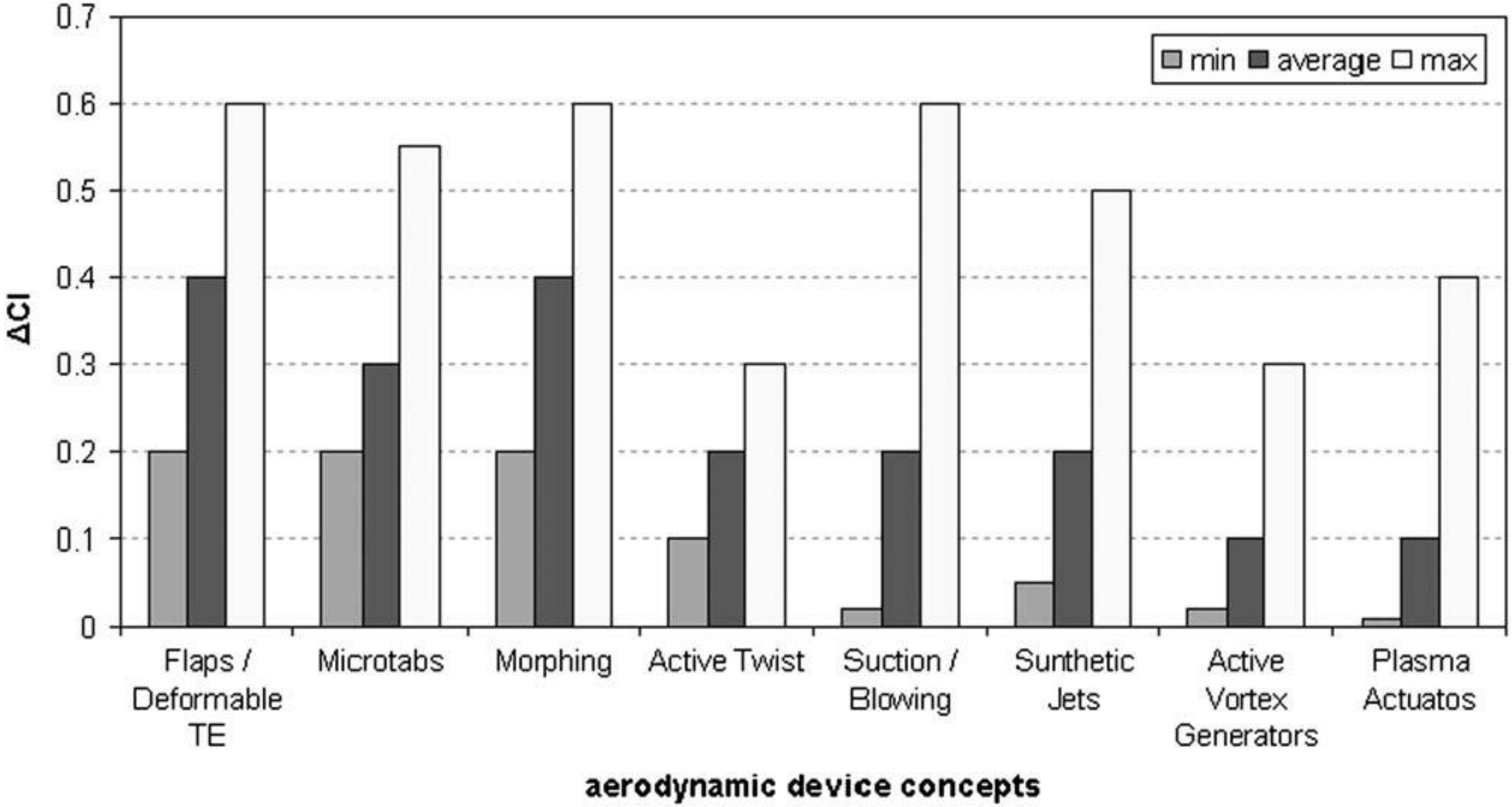
Why control at the trailing edge ?

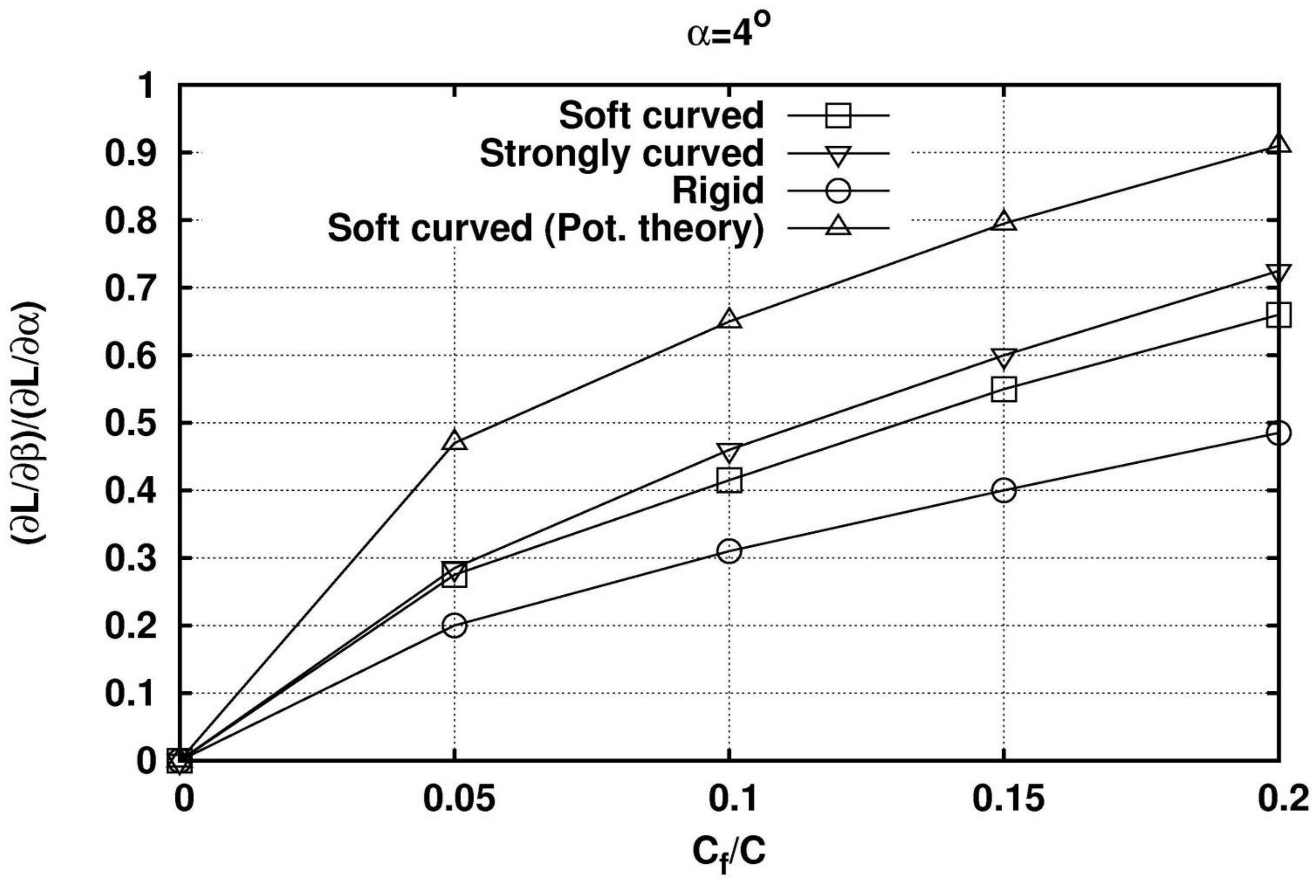
Flaps are among the best devices for changing lift



From Barlas, T.K., vanKuik, G.A.M., 2010, ―Review of state of the art in smart rotor control research for wind turbines‖, Progress in Aerospace Sciences, vol. 46, pp. 1–27

Trailing edge flap efficiency

Deflecting a flap of 10-15% of blade chord 2 deg., the same change in lift as pitching the whole blade 1 deg. can be achieved



Troldborg, N., 2005, ―Computational study of the RisøB1-18 airfoil with a hinged flap providing variable trailing edge geometry‖, Wind Engineering, vol. 29, pp. 89–113.

What are the potential load reductions by flap control ?

What has been achieved in the past ? - numbers from a review paper

Table III. Comparison of results from aeroservoelastic investigations with active flaps on the Upwind 5MW RWT.

article	c_f [%]	dr_f/r [%]	δ [$\pm°$]	T.I. [%]	shear exp. [-]	V_{av} [m/s]	reduction in std of RBM [%]	reduction in DEL [%]	controller
Riziotis et al. 2008	10	15-47	6	-	0.2	8, 12, 16	30-35 (range)	-	PID
Andersen et al. 2008	10	63	8	14-18	0.14	7, 11, 18	-	36.2-47.9	HPF+inflow
Lackner et al. 2009	10	20	10	NTM, ETM	0.2	8, 12, 16, 20	-	5.6-24.6	PID
Barlas et al. 2009	10	20	10	NTM	0.2	8, 11.4, 16	5.7-22.4	-	PID
Andersen et al. 2009	10	15-30	8	-	11.4	-	-	25-37	HPF
Resor et al. 2010	10	24	10	6	0.2	15	26-30.9	27-31.3	PD, HPF+notch
Wilson et al. 2010	10	24	10	6	0.2	15	13.3	15.5	LQR
Berg et al. 2010	10	25	10	6	0.2	15	8.7-18.1	10.9-17	PD, LQR
this article	10	18	8	6, NTM	0.2	7, 11.4, 15	10.9-30.7	10.9-27.3	MPC+inflow

Barlas, Thanasis; Van Der Veen, Gijs; van Kuik, Gijs; Model Predictive Control for wind turbines with distributed active flaps: Incorporating inflow signals and actuator constraints. Article first published online: 17 NOV 2011 DOI: 10.1002/we.503

The main parameters that constrain the load reduction potentials

- control algorithm
- sensor input to control
- actuation time constants
- size of flaps chordwise
- spanwise extension of flaps
- flap actuation amplitude

The potential load reduction by flap control

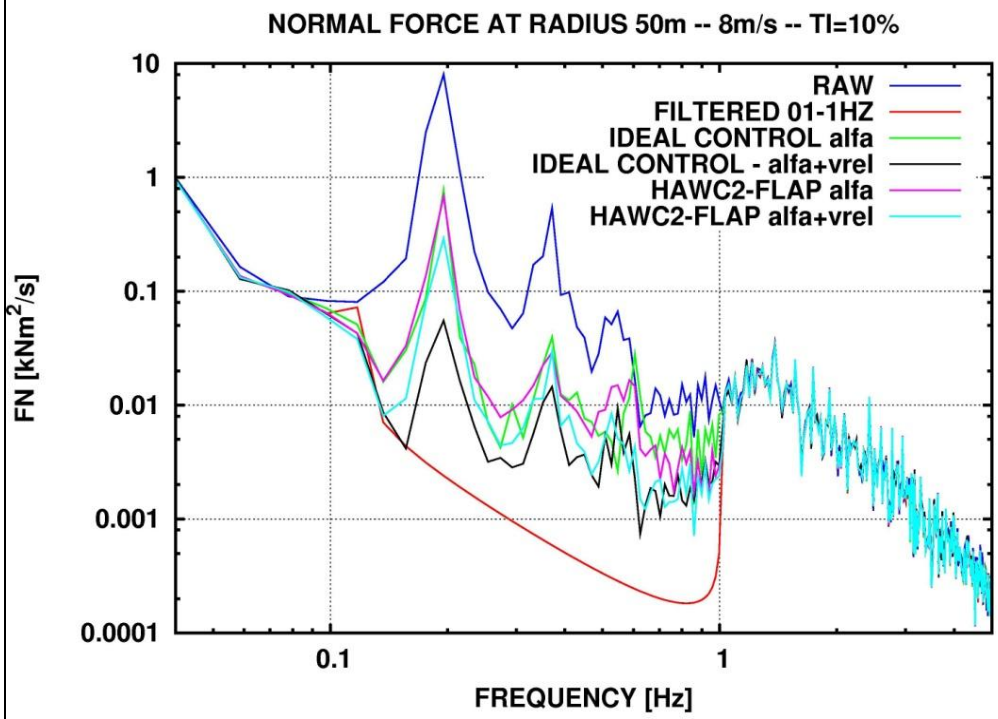
– a case from an ongoing study assuming ideal information on the inflow (angle of attack and relative velocity) :

Aeroelastic simulations on the 5MW reference wind turbine

- constant rpm
- 8m/s turbulent inflow
- both a flexible and stiff structural model simulated

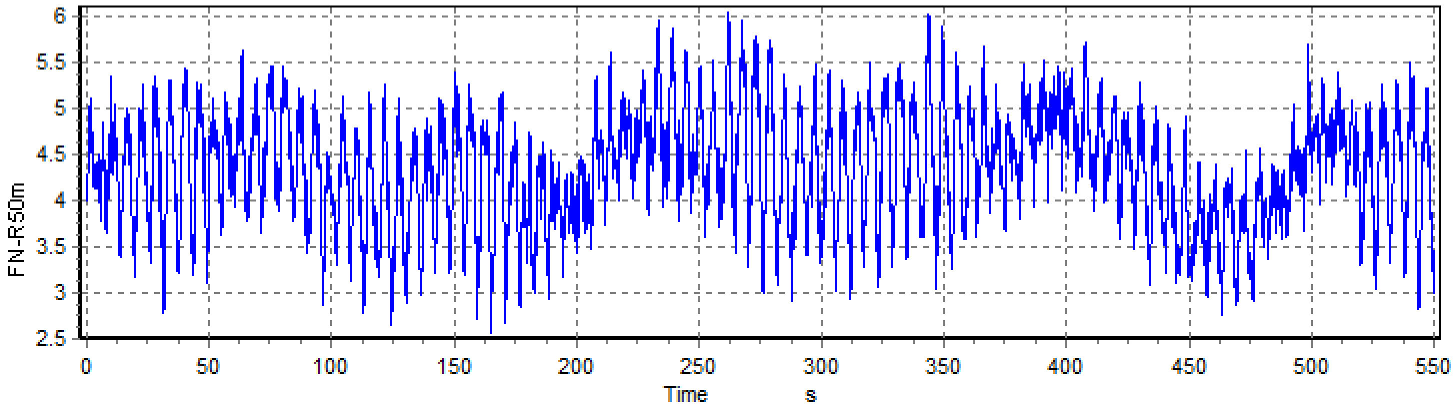
Load reduction of normal force at radius 50 m – 10% TI

m=3			
Ideal:	50.8%		
Alfa control:	43.1%	percentage of ideal:	84.9%
Alfa+vrel control:	49.0%	percentage of ideal:	96.5%
Flap – alfa:	41.2%	percentage of ideal:	81.2%
Flap – alfa-vrel:	44.9%	percentage of ideal:	92.3%
m=12			
Ideal:	42.7%		
Alfa control:	39.1%	percentage of ideal:	91.7%
Alfa+vrel control:	41.5%	percentage of ideal:	97.4%
Flap – alfa:	37.9%	percentage of ideal:	88.9%
Flap – alfa-vrel:	41.5%	percentage of ideal:	97.4%

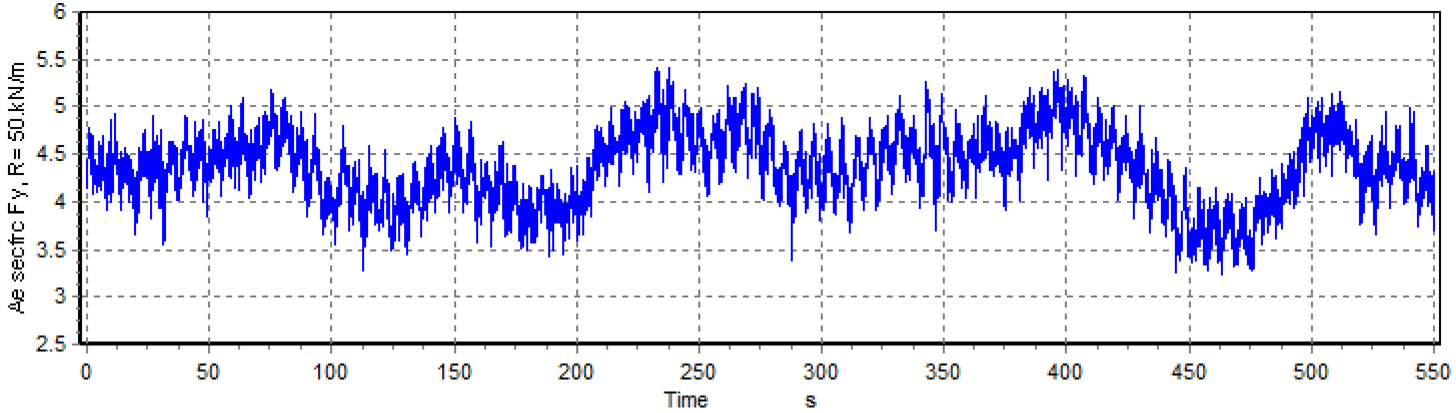


Load reduction of normal force at radius 50 m – 10% TI

Raw normal force

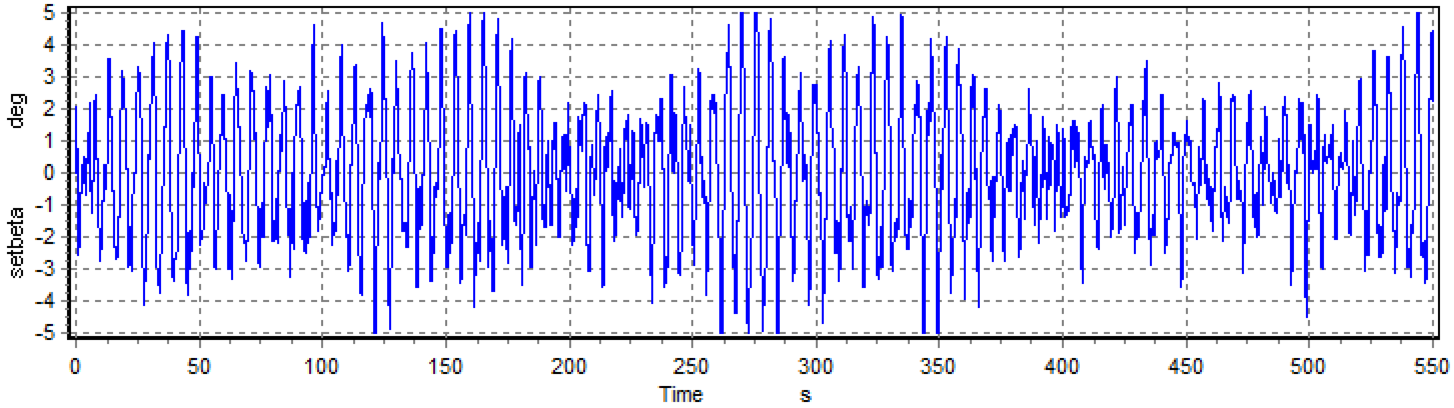


Flap controlled normal force- red. 44.9%

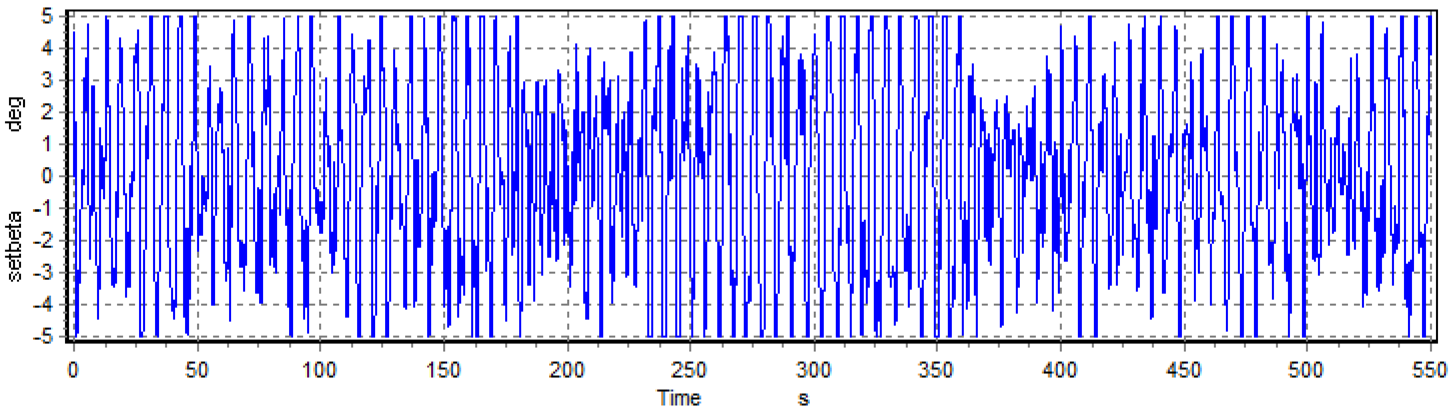


Flap amplitude saturates considerably at TI=20%

TI=10%

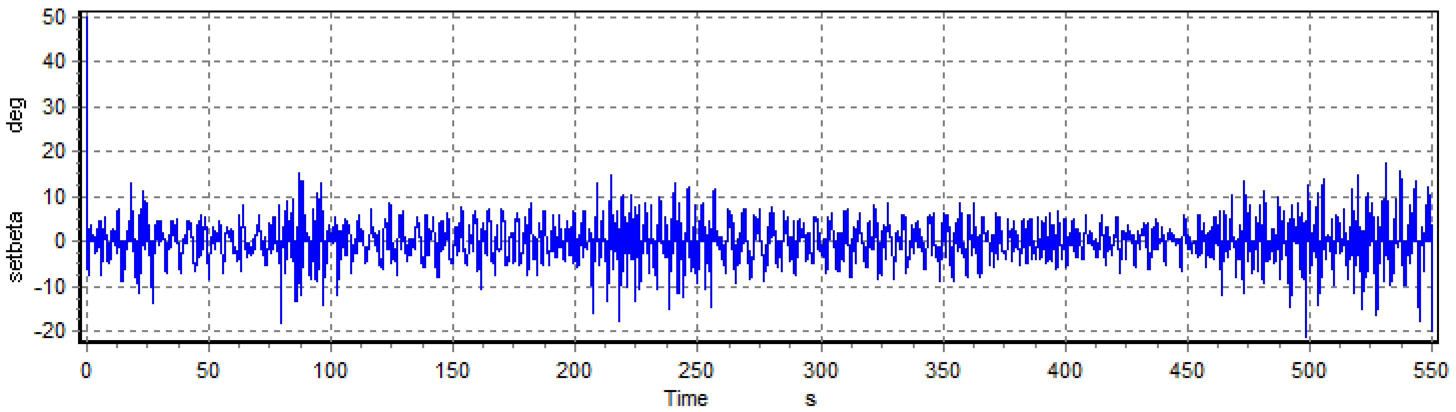


TI=20%



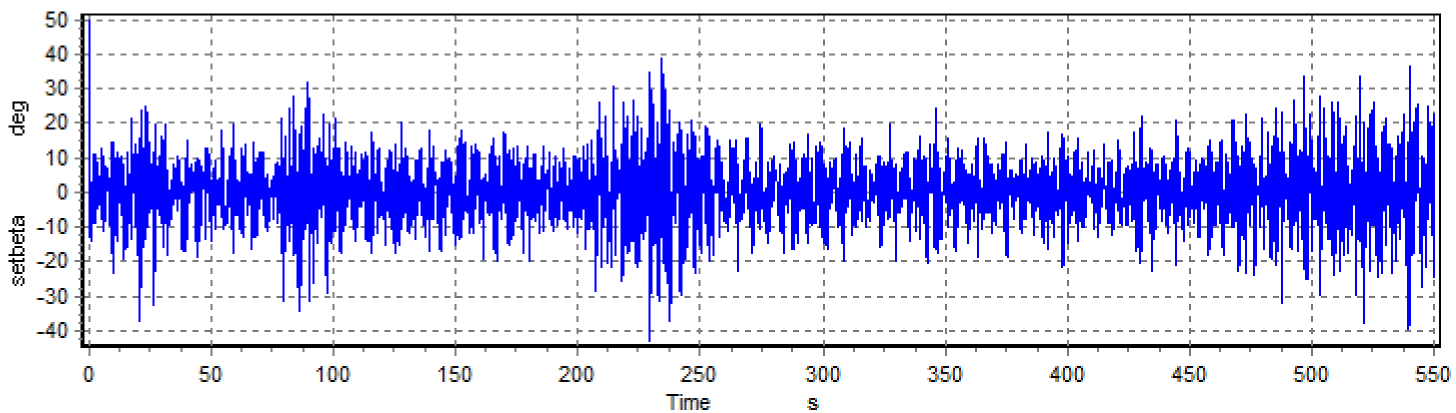
Influence of frequency band on flap actuation speed – ti=10%

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



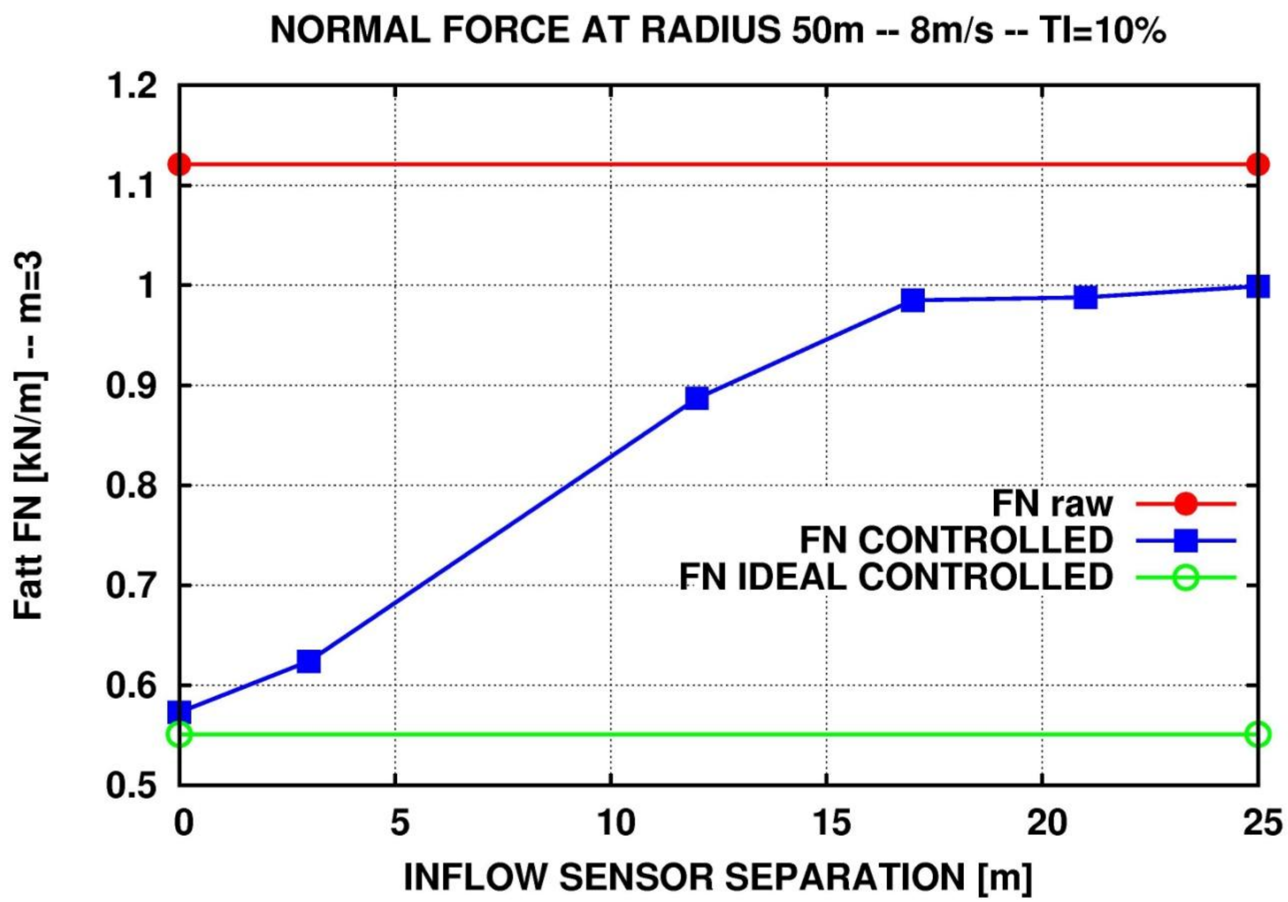
Fatt red. = 42.9%

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



Fatt red. = 57.9%

FN at radius 50 m controlled from an inflow sensor at different inboard separation distances



Example of an 80m rotor with inflow sensors

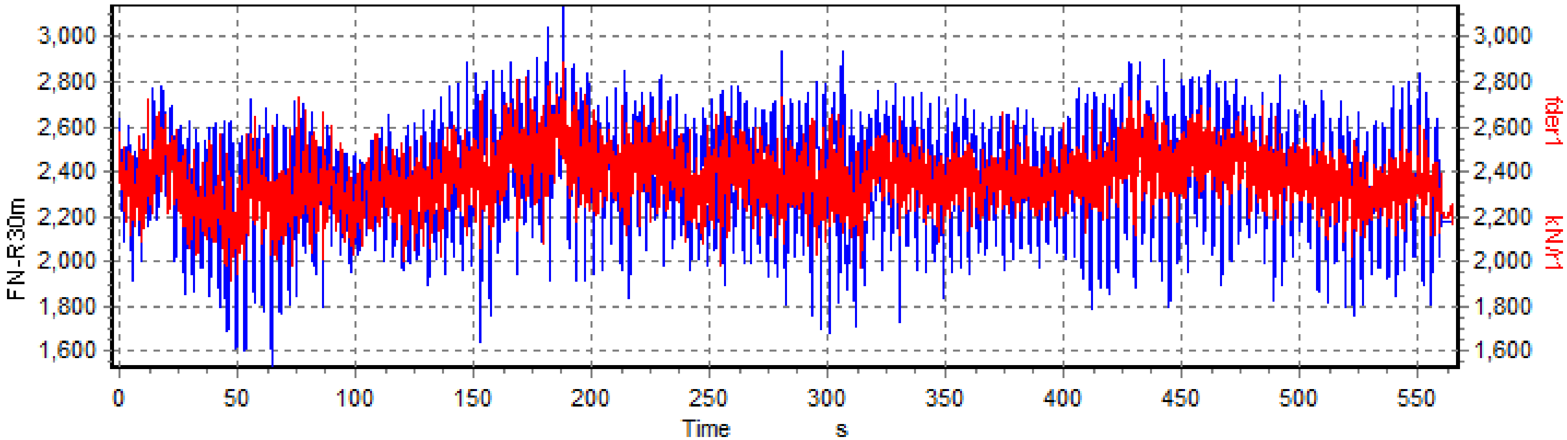
Normal force measured at four radial positions by pressure holes

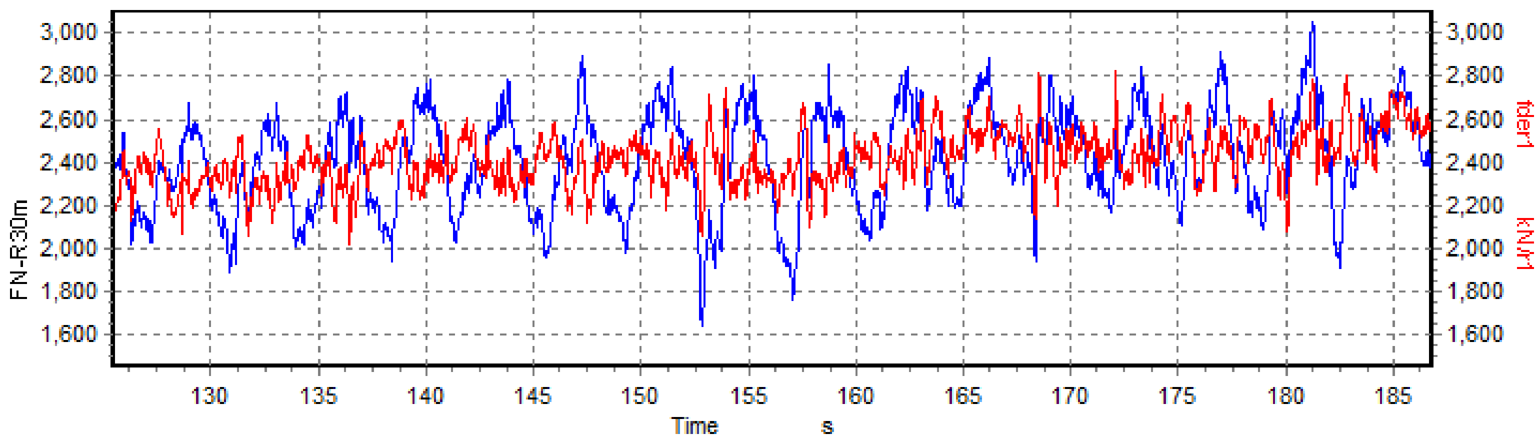
Four 5 hole pitot tubes installed on a NM80 turbine with an 80m rotor

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

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

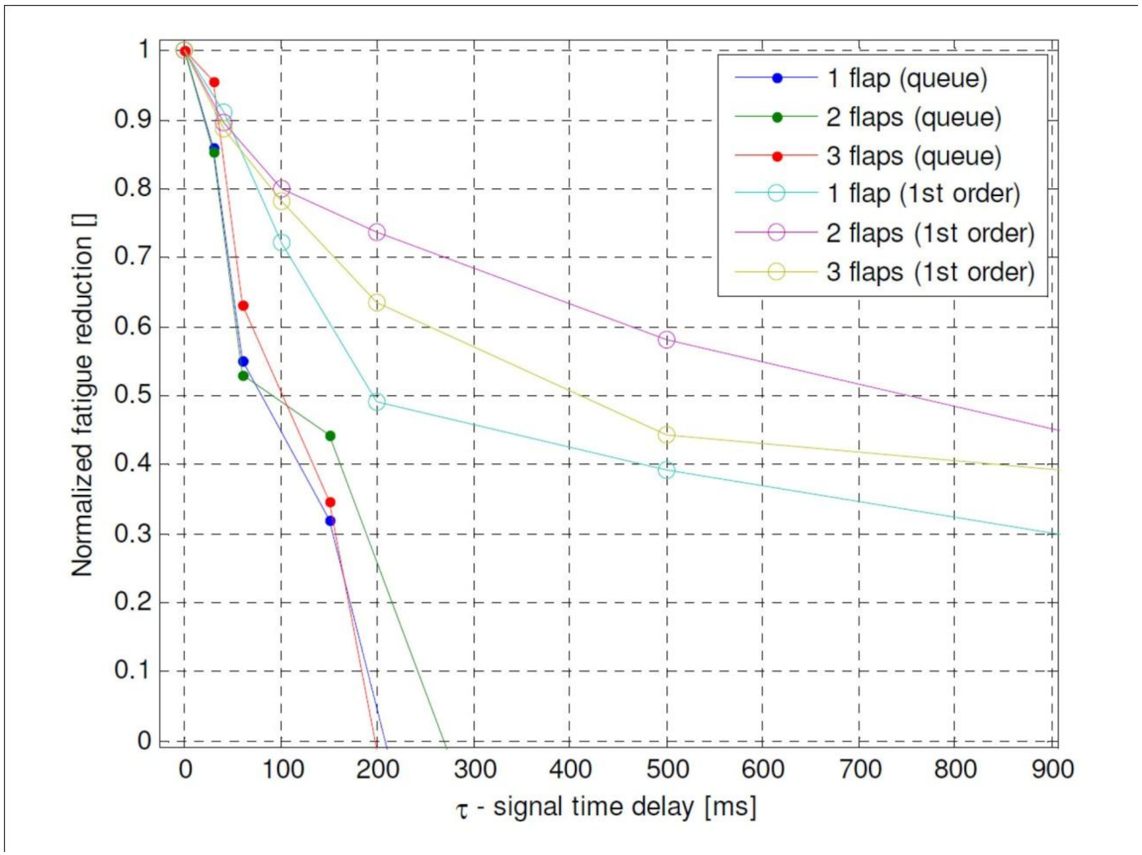
Red curve is simulated flap controlled normal force using measured inflow





Fatt. Red. 35.6%

Influence of flap actuation time constants



Andersen, P.B. "ADVANCED LOAD ALLEVIATION FOR WIND TURBINES USING ADAPTIVE TRAILING EDGE FLAPS: SENSORING AND CONTROL". PhD thesis report, Risø DTU, February 2010

The potential load reductions by flap control ?

- **considerable but**
  - dependent on high quality sensor input
  - control set-up
  - sensitive to flap actuator time constant

Development of the trailing edge flap technology

- can a flap technology be developed that enables the potential load reductions ?

In the past

- piezo electric flaps (Bak et al. 2007)
- deployable tabs (van Dam et al. 2007)

Bak C, Gaunaa M, Andersen PB, Buhl T, Hansen P, Clemmensen K, Møller R. Wind tunnel test on wind turbine airfoil with adaptive trailing edge geometry. [Technical Papers] Presented at the 42 AIAA Aerospace Sciences Meeting and Exhibit 45 AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 2007; 1–16.

van Dam CP, Chow R, Zayas JR, Berg DA. Computational investigations of small deploying tabs and flaps for aerodynamic load control. Journal of Physics 2007; 5. 2nd EWEA, EAWE The Science of Making Torque from Wind Conference, Lyngby, 2007; 1–10.

The Controllable Rubber Trailing Edge Flap CRTEF development

Development work started in 2006

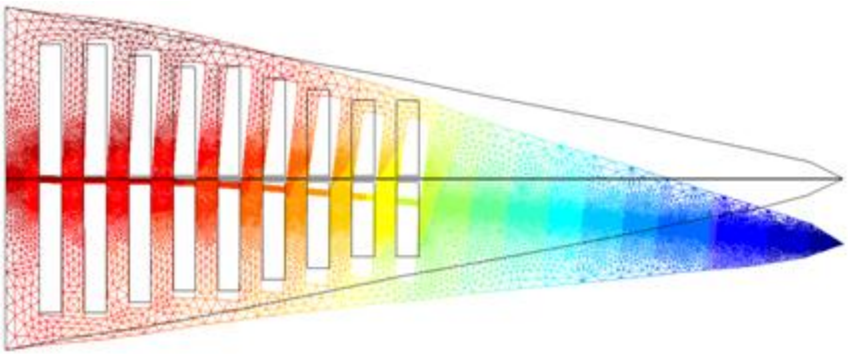
Main objective: Develop a robust, simple controllable trailing edge flap

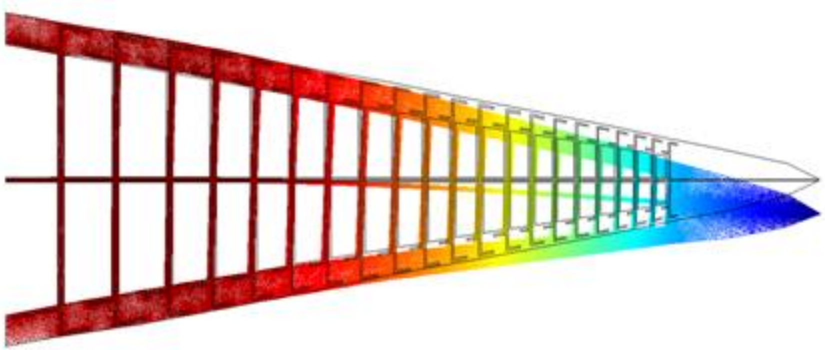
The CRTEF design:

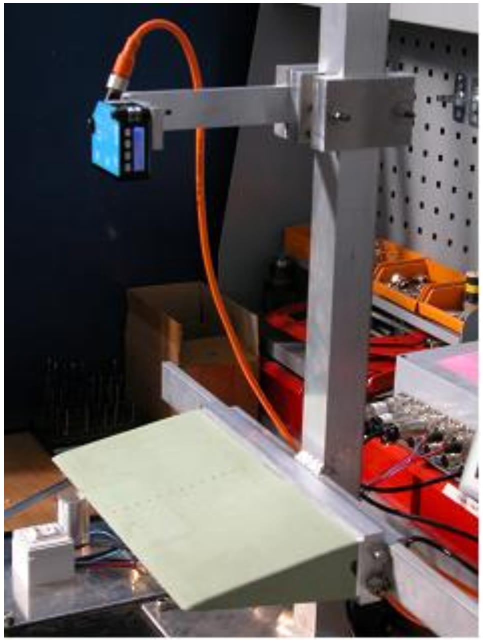
A flap in an elastic material with a number of reinforced voids that can be pressurized giving a deflection of the flap

The CRTEF development - early work (2008)

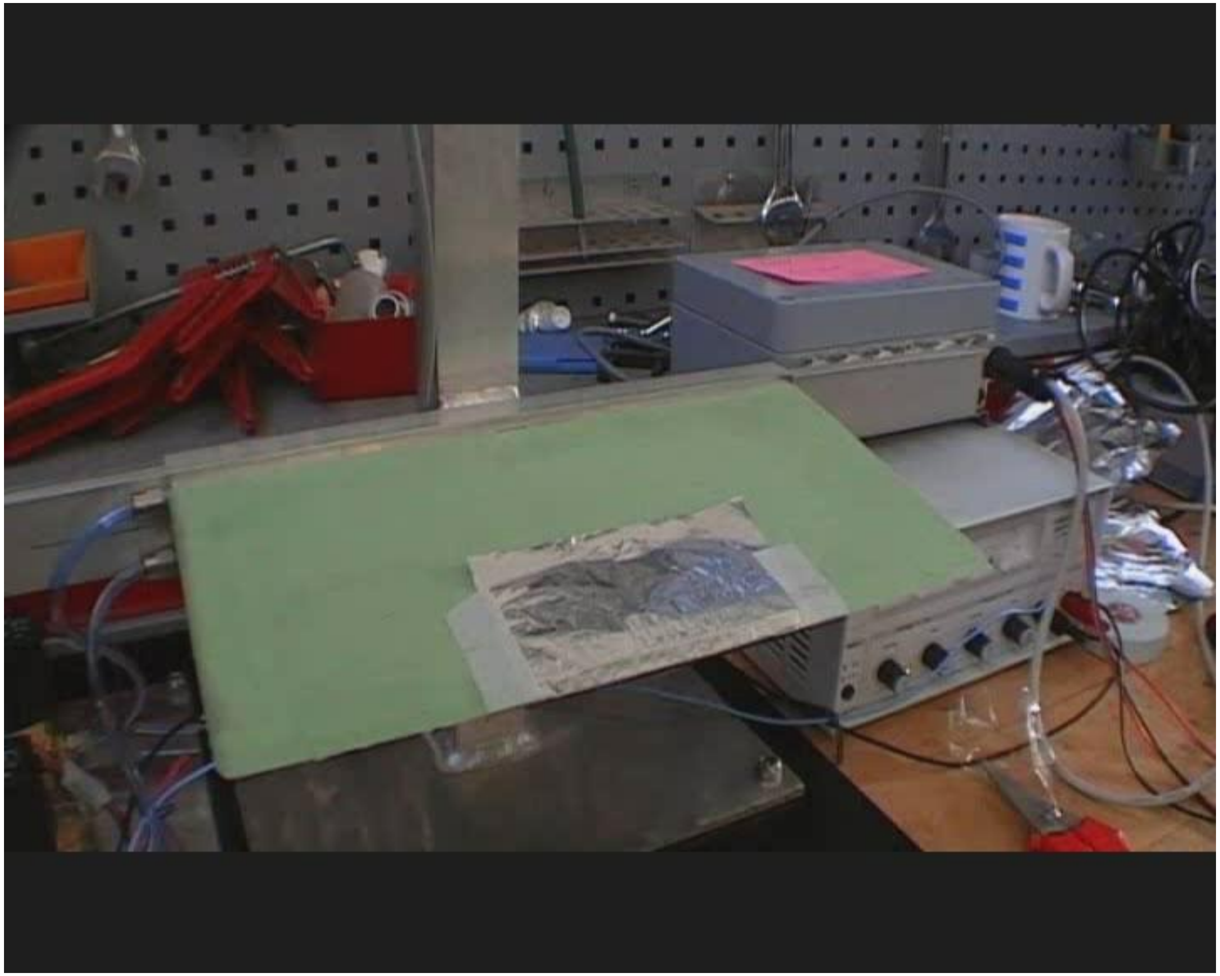
Comsol 2D analyses







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



Wind tunnel experiment Dec. 2009

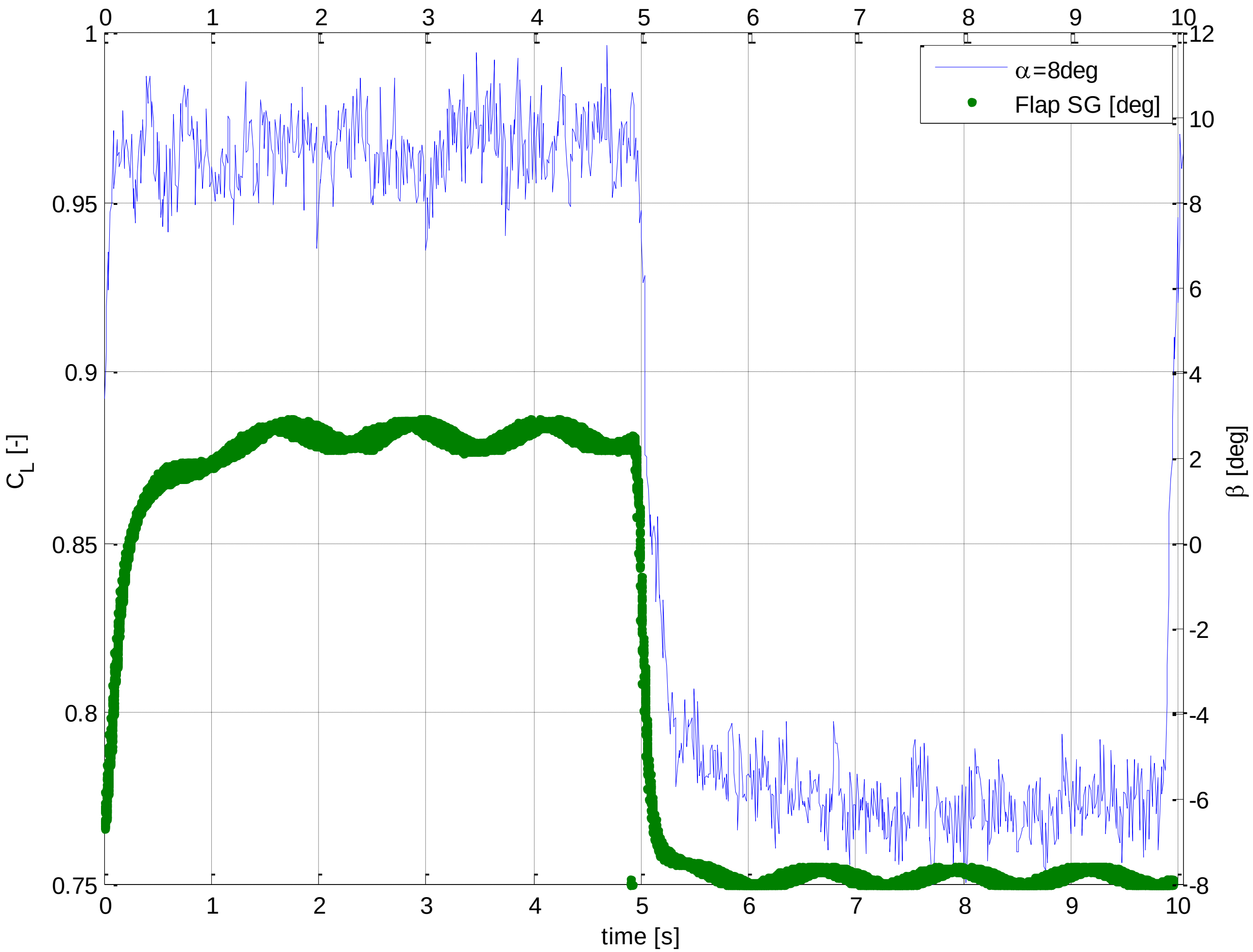
airfoil section + flap during instrumentation

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



New project on the CRTEF development

The 3 years project **Industrial adaptation of a prototype flap system for wind turbines –INDUFLAP** was initiated in March 2011

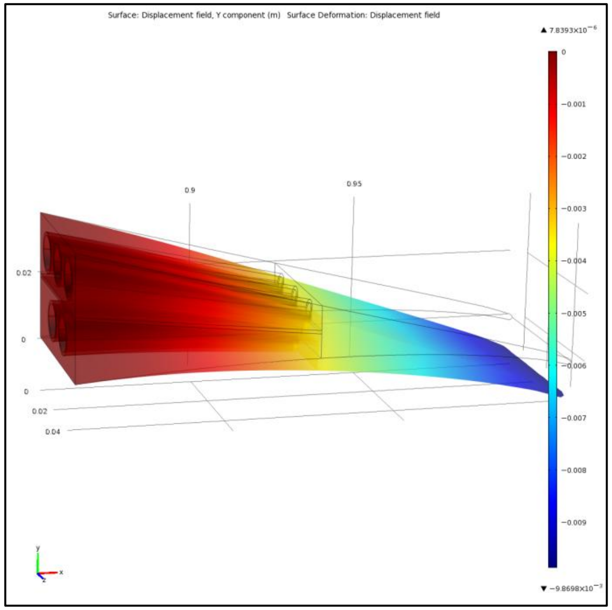
Start of project	Project	End of project
Prototype CRTEF tested in laboratory	→	Prototype ready for test on MW turbine

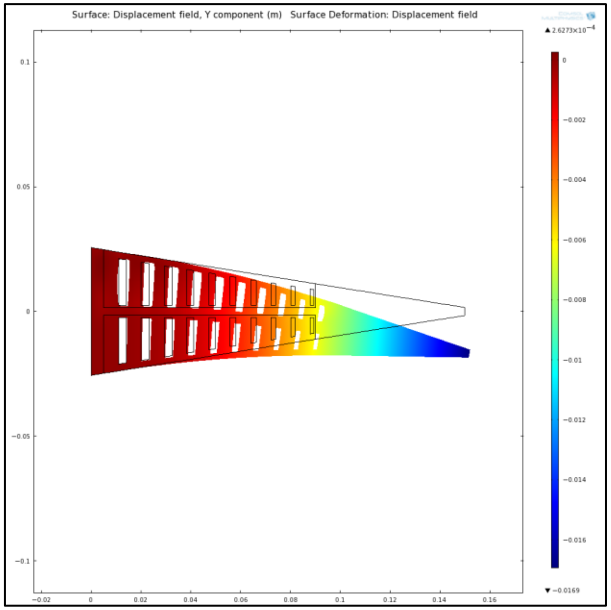
Participants:	**Industrial partners**
DTU Elektro	Rehau A/S
DTU AED	Hydratech Industries Wind Power
DTU Fiberlab	Dansk Gummi Industri A/S

Project activities/investigations

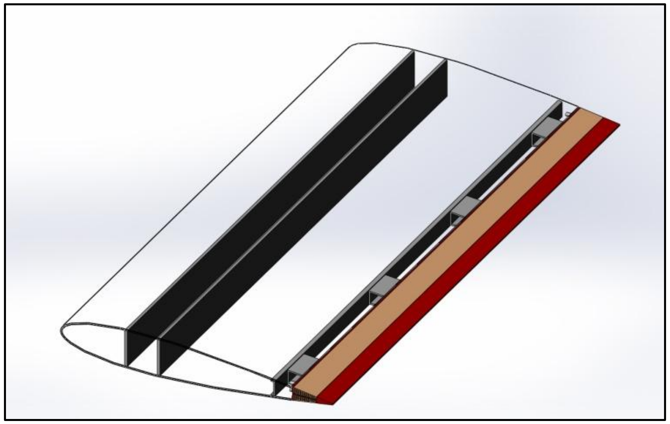
- ❑ new designs (void arrangement, reinforcement, manufacturing process)
- ❑ new materials
- ❑ performance (deflection, time constants)
- ❑ robustness, fatigue, lightning
- ❑ manufacturing of 30 cm and 2 m prototypes
- ❑ integration of flap system in blade
- ❑ pneumatic supply
- ❑ control system for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

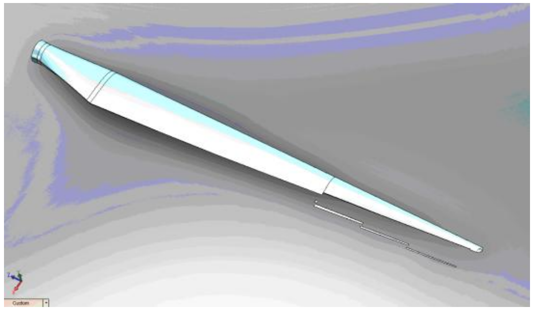
Two basic different types: chordwise or spanwise voids





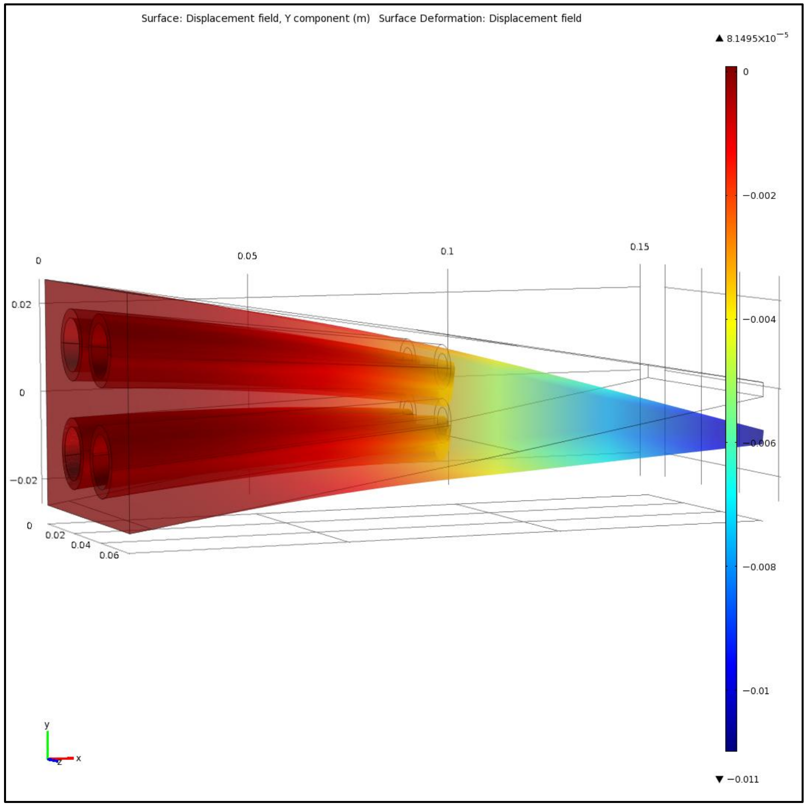
Integration of flaps into the blade



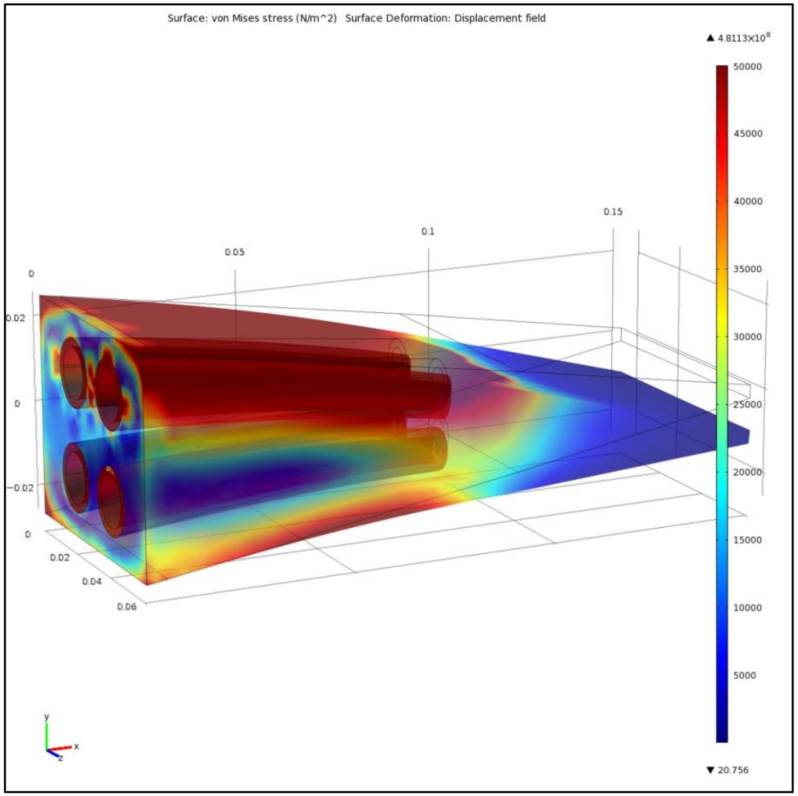


Example of COMSOL simulations on a new prototype with chordwise voids

Contour plot of deflection

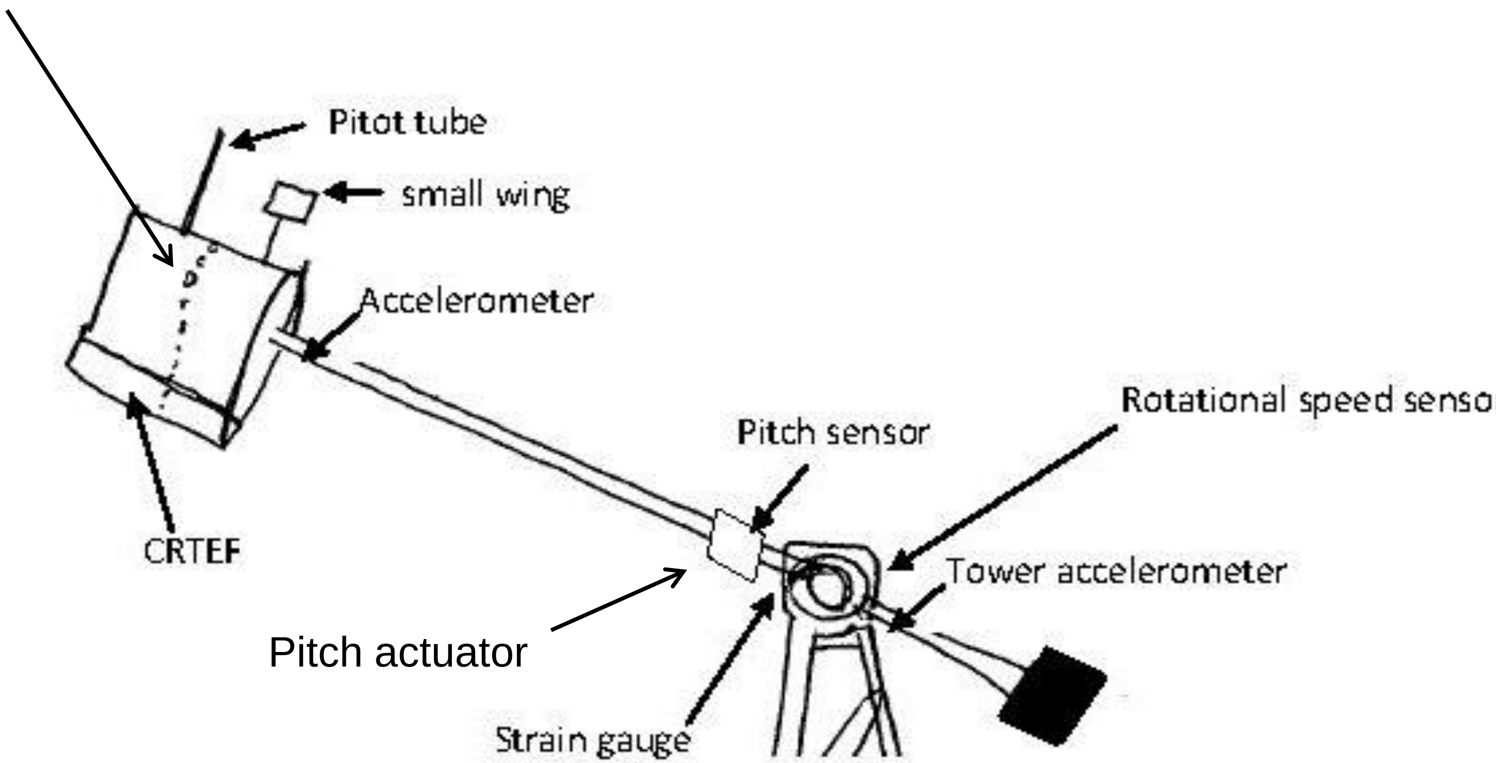


Contour plot of stress

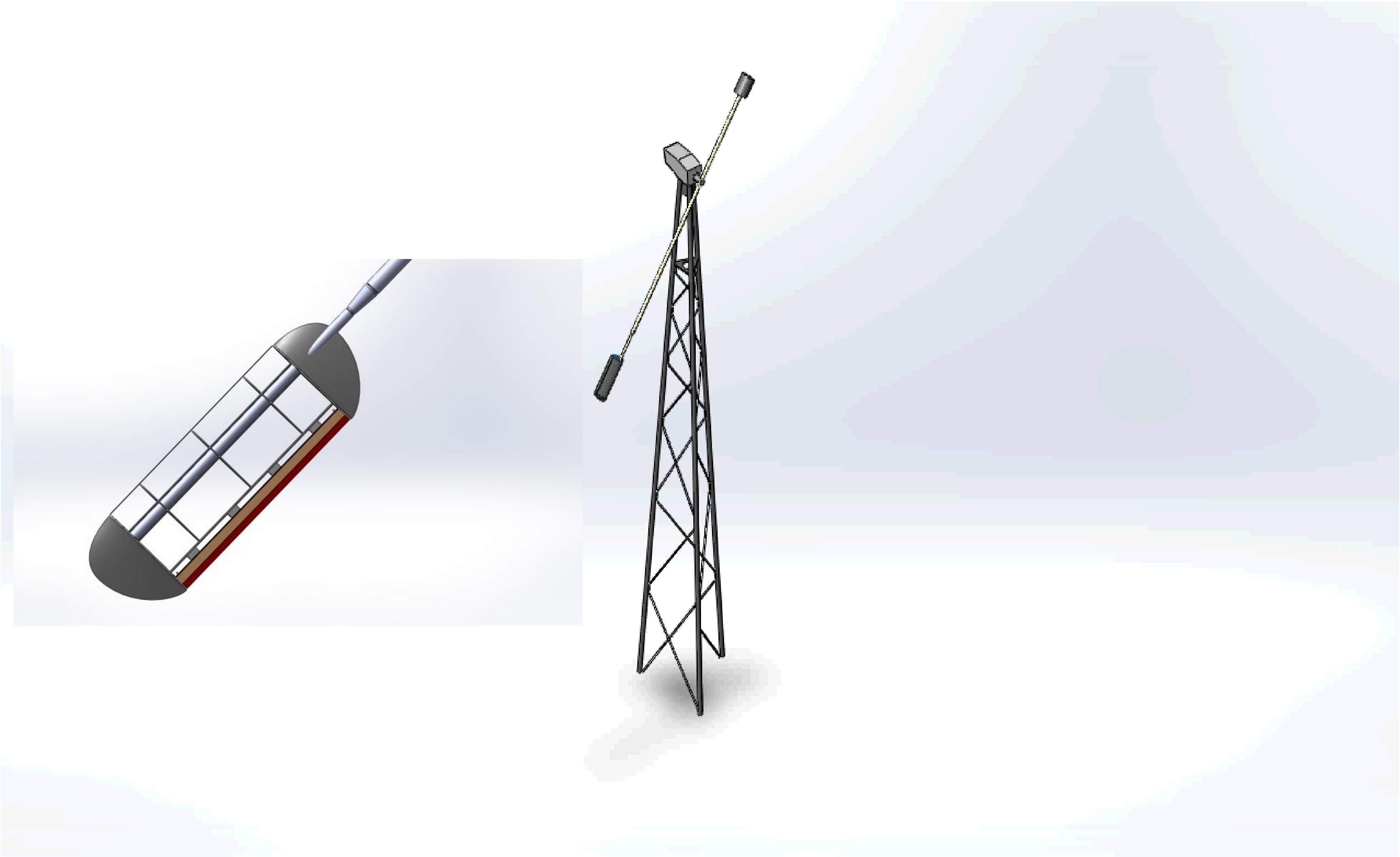


Flaps to be tested on a rotating outdoor test rig

Test rig based on a 100 kW turbine
- rotation of a 10m long flexible arm with an airfoil section of about 2x1m



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



Outlook

- The INDUFLAP project with three industrial partners will show if the CRTEF technology can be ported from laboratory to industrial applications
- Rotating tests of 2m flap sections will start in 2012 to measure aerodynamic response from surface pressure measurements and to test sensors and control systems
- If the development work continues as expected a CRTEF prototype system will be ready for testing on a MW turbine at the end of the project (end of 2013)

Acknowledgement

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Thank you for your attention!