ON THE POTENTIAL LOAD REDUCTION ON WIND TURBINES BY FLAP CONTROL USING MEASUREMENTS OF LOCAL INFLOW TO THE BLADES

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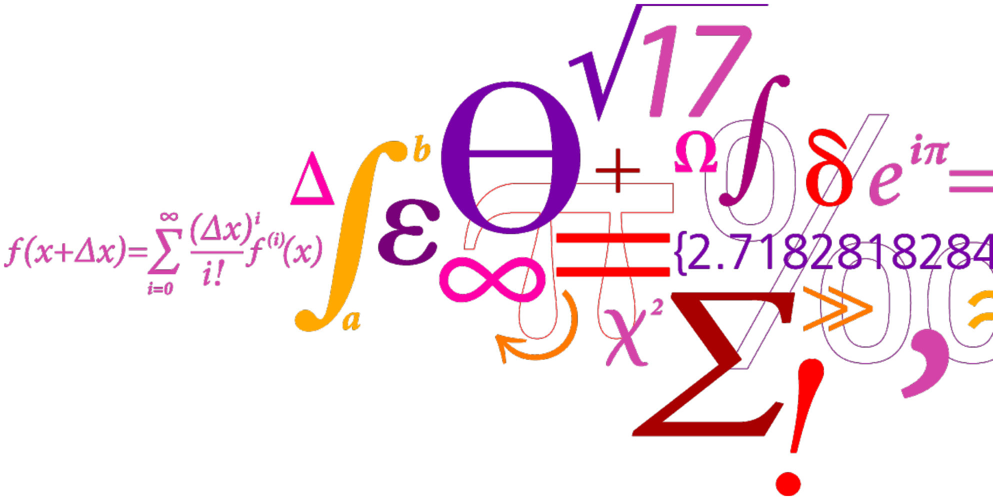


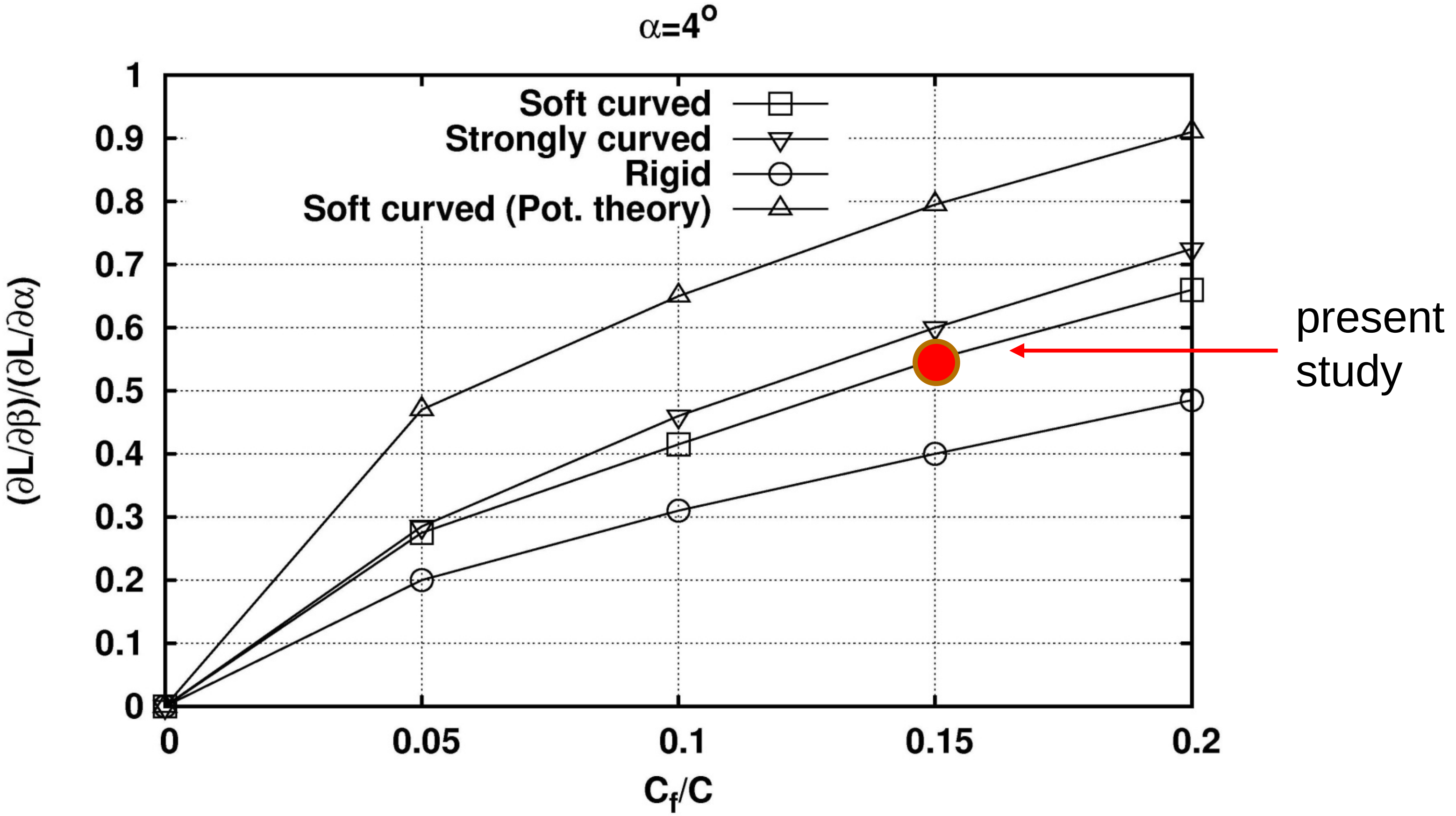
Outline

- ☐ Background/motivation
- ☐ Approach used in the study
- ☐ Results
- ☐ Summary

Potential load reductions by flap control ?

Why using trailing edge flaps ?

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 has been achieved in the past ?

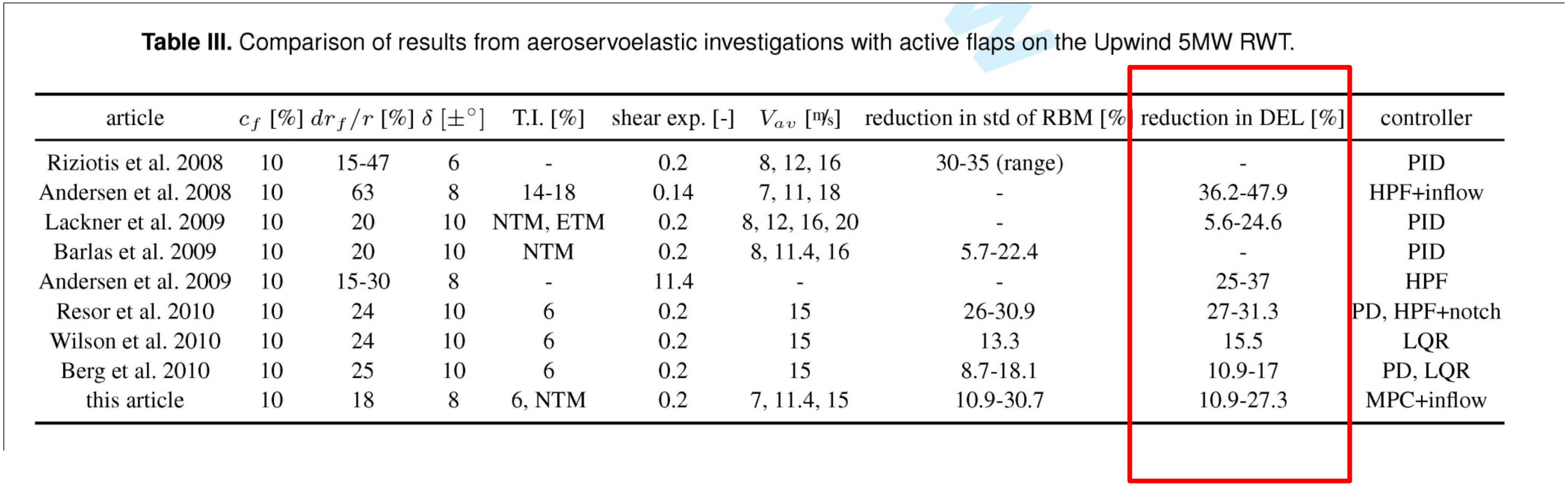


Table III. Comparison of results from aeroservoelastic investigations with active flaps on the Upwind 5MW RWT.

article	c_f [%]	dr_f/r [%]	δ [$\pm^\circ$]	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

What are the main parameters that constrain the load reduction potentials ?

- controller
- sensor input
- actuation time constants
- limits on size of flaps
- limits on actuation amplitude
- limits on flap angle velocity

Approach

We assume:

- ☐ ideal controller
- ☐ ideal flow sensor input

- ➢ what load alleviation can then be achieved ?

Influence of:

- ➢ flap amplitude
- ➢ flap angle velocity
- ➢ flow sensor separation
- ➢ actuation time constants

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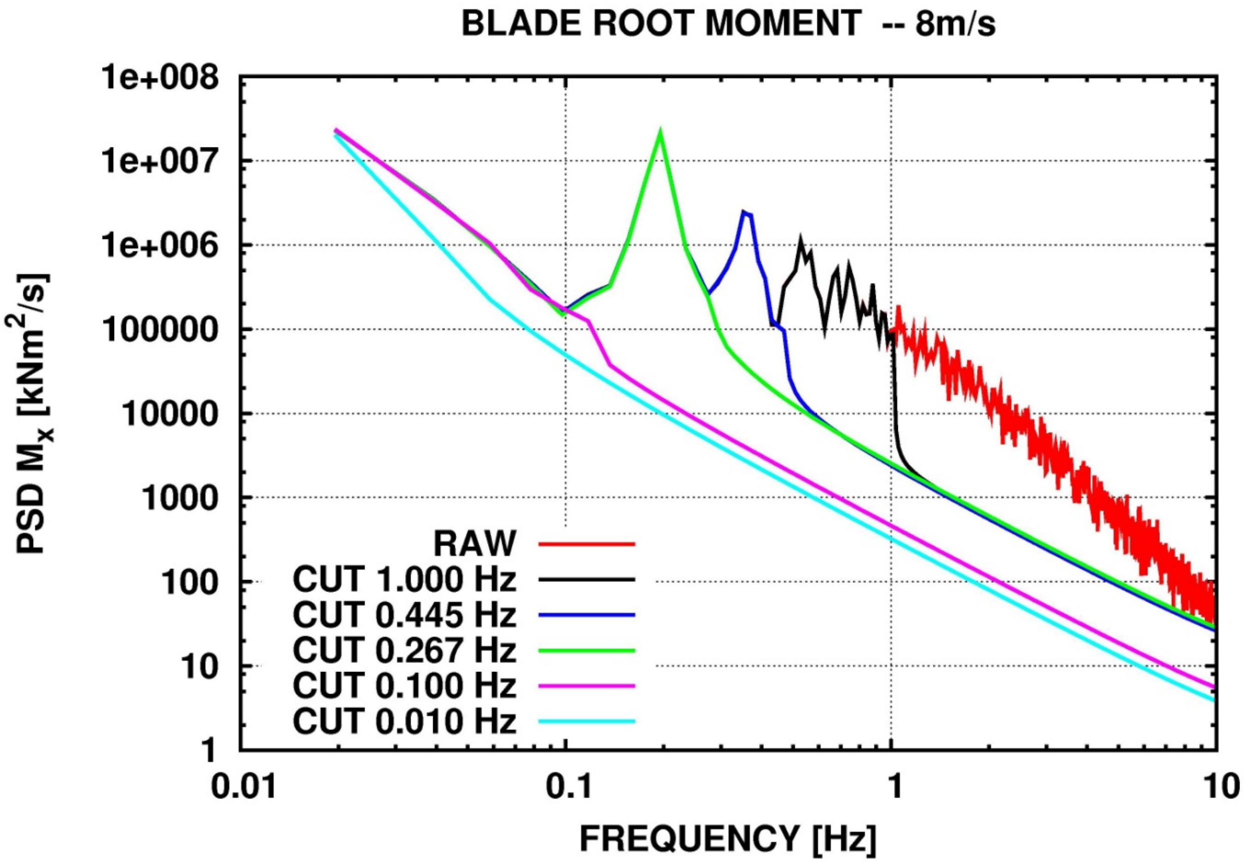
An investigation on maximum load reduction potential using inflow sensor

Aeroelastic simulations on the 5MW reference wind turbine

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

The maximum load reduction potential

The flapwise moment low pass filtered at different cut off frequencies



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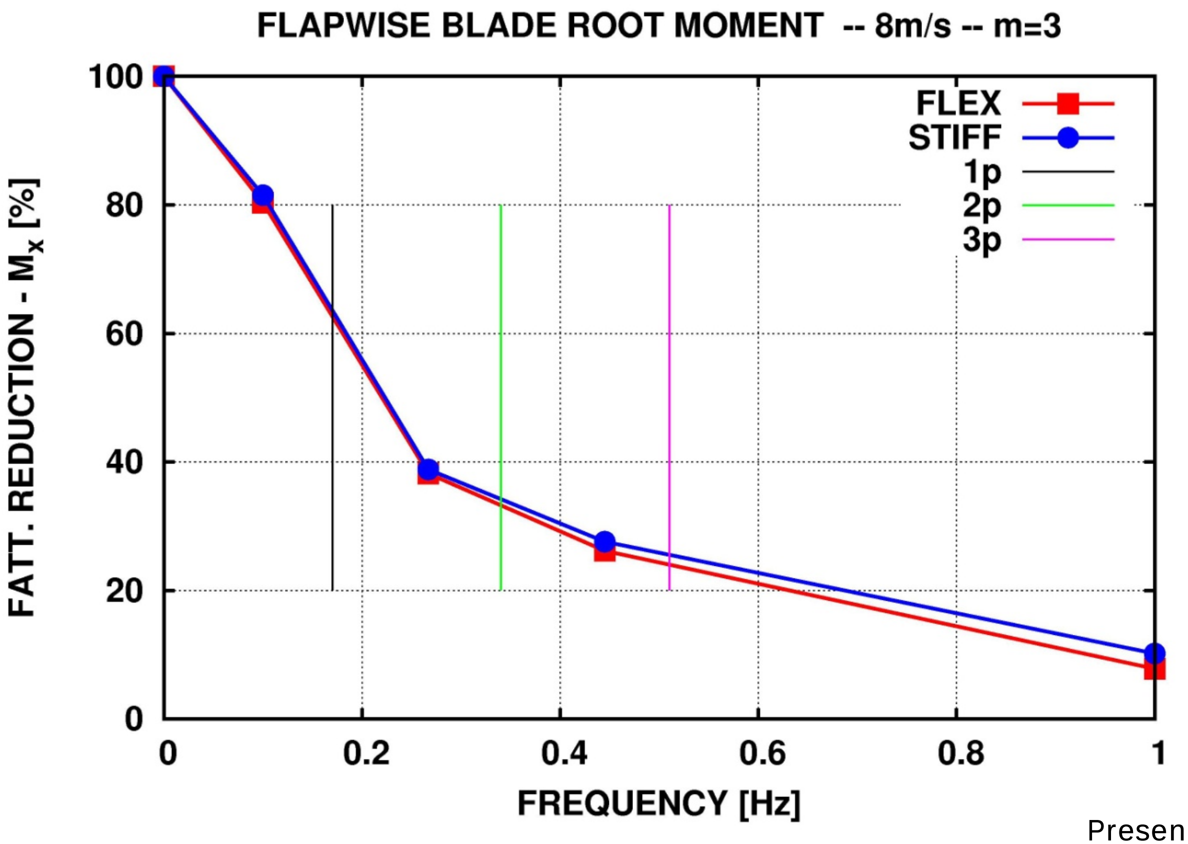
The maximum load reduction potential

- ☐ The flapwise moment low pass filtered at different cut off frequencies.
- ☐ Then rainflow counting on the processed signals



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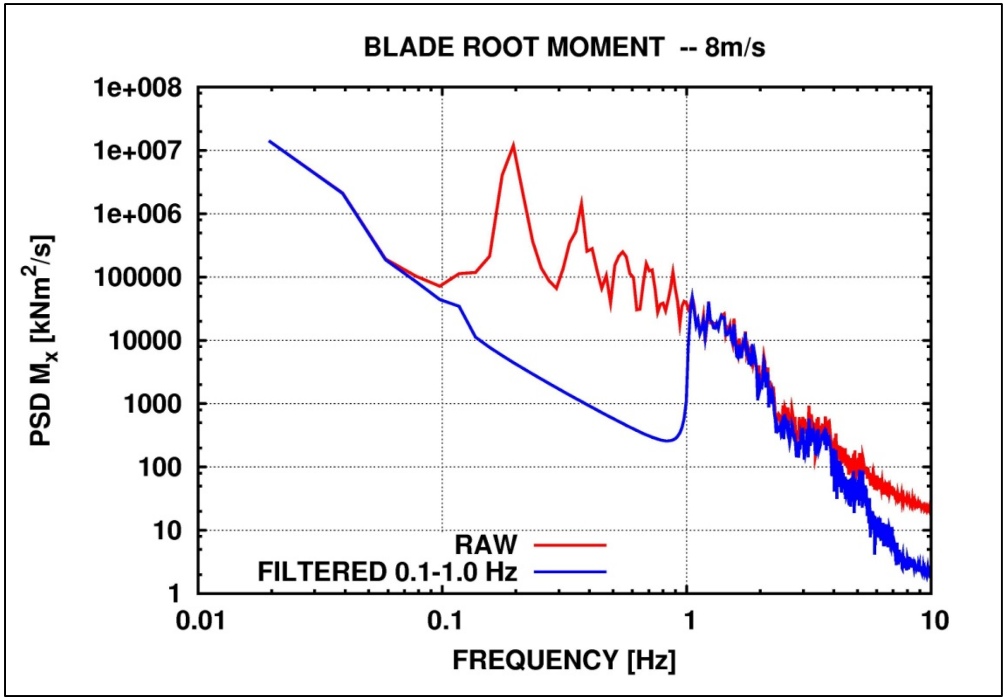
Load reduction potential – what can be achieved ?

- ☐ the maximum load alleviation potential is found by numerical filtering
- ☐ can we achieve something like this with flap control if we have the ideal control signals ?
- ☐ what would it require of the flap characteristics, e.g. by trying to alleviate the dynamic loads between 0.1 and 1Hz

The maximum load reductions for 0.1-1Hz are:

m=3 63%
m=10 48%



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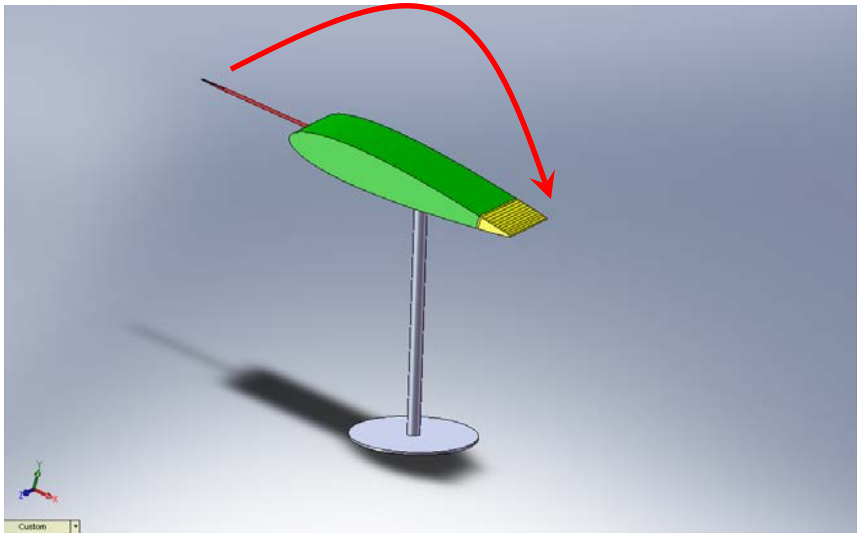
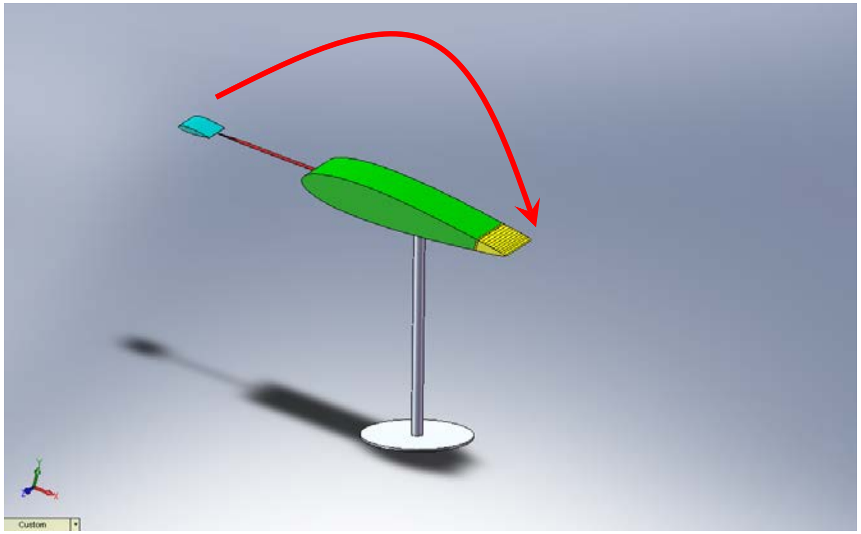
Ideal control signals – inflow data in the form of inflow angle and relative velocity

Inflow data from a five hole pitot tube



Inflow data from a small sensor airfoil



Wind tunnel test of flaps and inflow sensors

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

unsteady

$$F_N = \frac{1}{2}\rho V_r^2 C_N\left(\alpha\right)c$$

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

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

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: $$f_c \Rightarrow \boxed{\begin{array}{l}\text{Flap aerodynamics +}\\ \text{flap actuator dynamics}\end{array}} \Rightarrow F_{Nc}$$

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

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

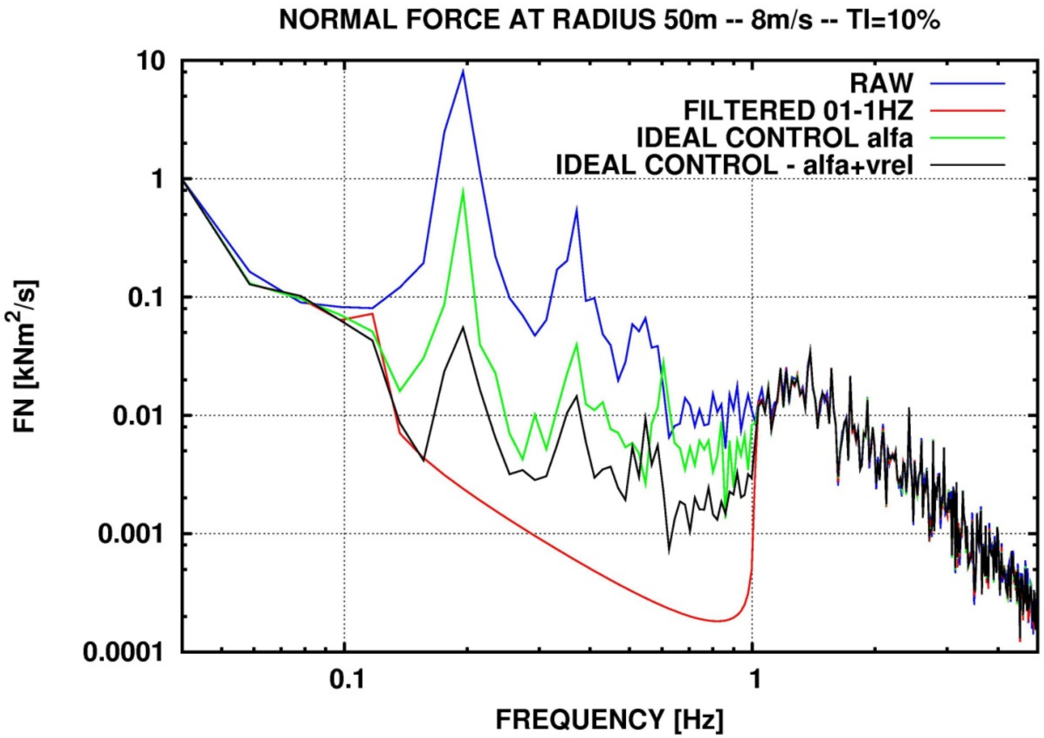
Ideal control – fatigue reductions

m=3

Maximum	50.8%	
Alfa control:	43.1%	
percentage of max.:		84.9%
Alfa+vrel control:	49.0%	
percentage of max.:		96.5%

m=12

Maximum:	42.7%	
Alfa control:	39.1%	
percentage of max.:		91.7%
Alfa+vrel control:	41.5%	
percentage of max.:		97.4%



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

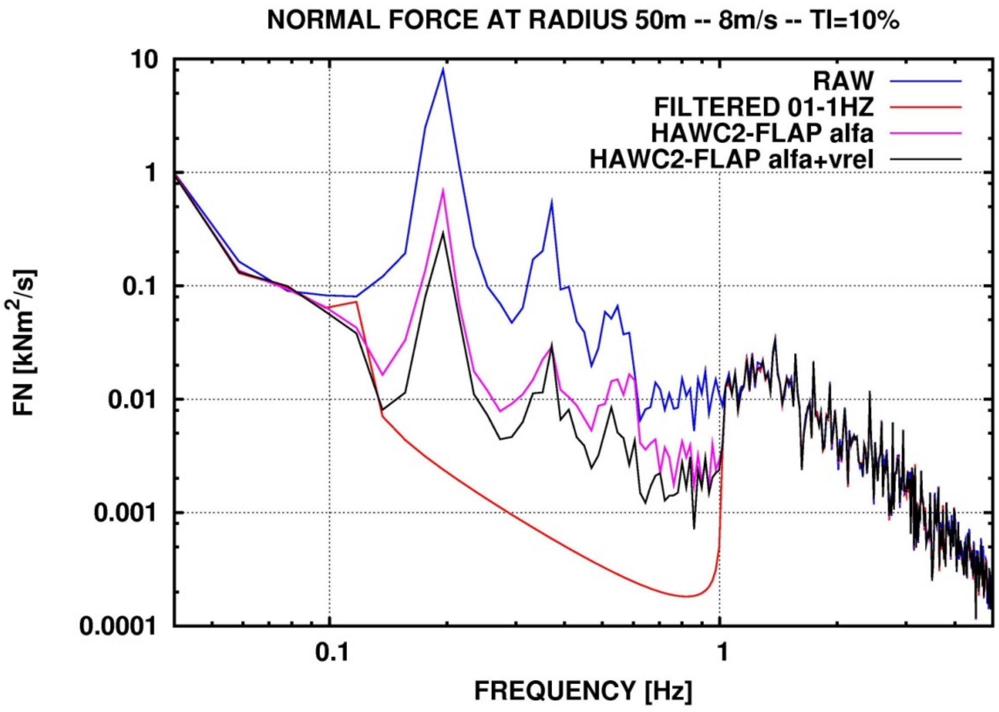
Flap control – fatique reductions

m=3

Maximum	**50.8%**	
Flap – alfa:	41.2%	
percentage of max.:		**81.2%**
Flap – alfa-vrel:		44.9%
percentage of max.:		**92.3%**

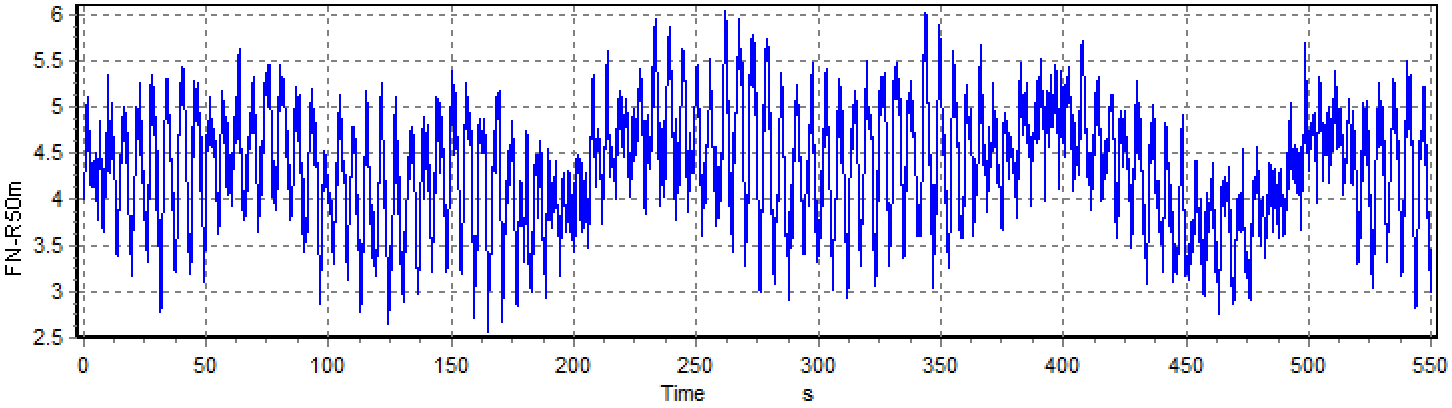
m=12

Maximum:	**42.7%**	
Flap – alfa:	37.9%	
percentage of max.:		**88.9%**
Flap – alfa-vrel:		41.5%
percentage of max.:		**97.4%**

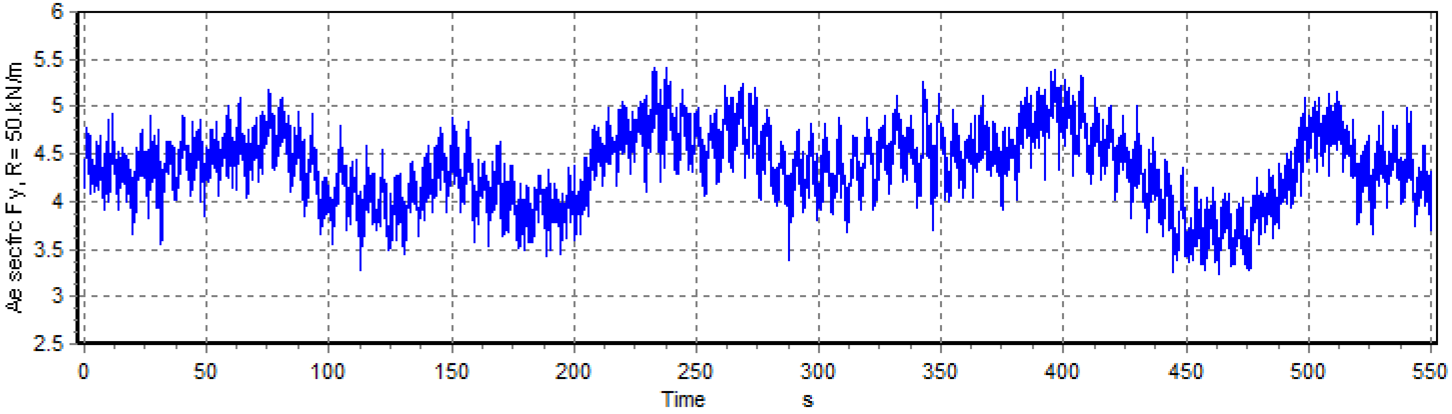


Load reduction of normal force at radius 50 m – 10% TI

Raw normal force

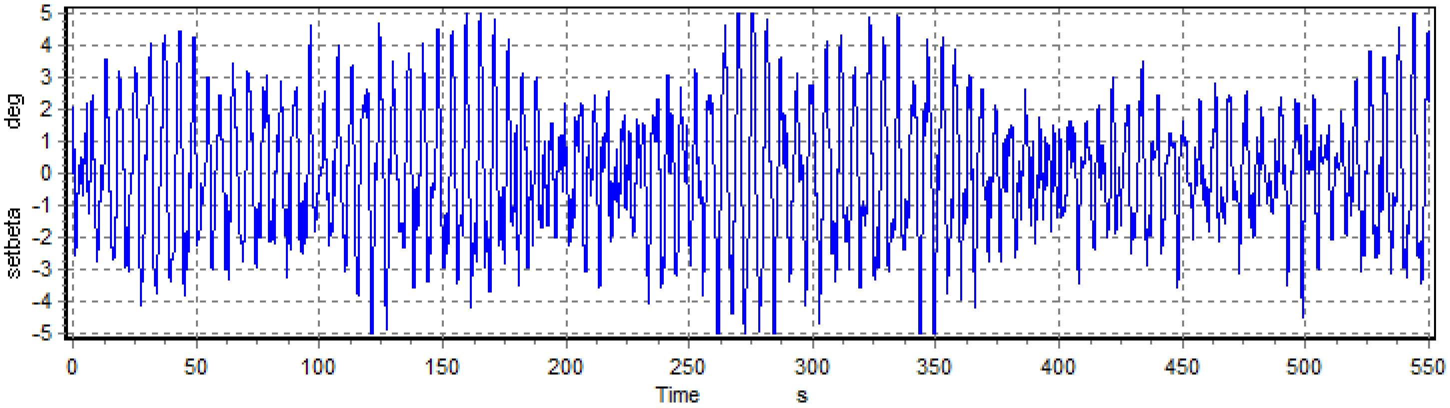


Flap controlled normal force

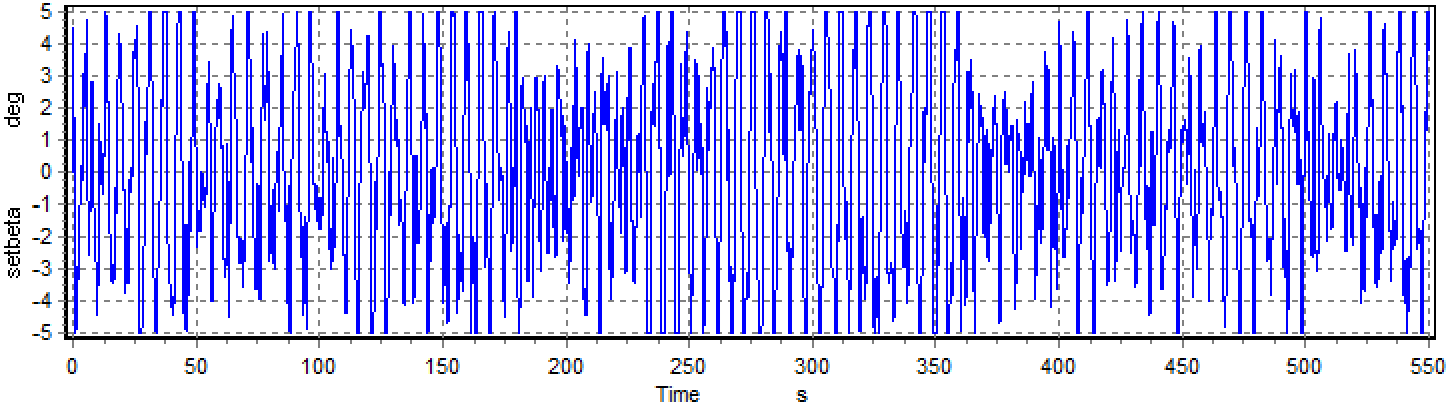


Flap amplitude saturates considerably at TI=20%

TI=10%

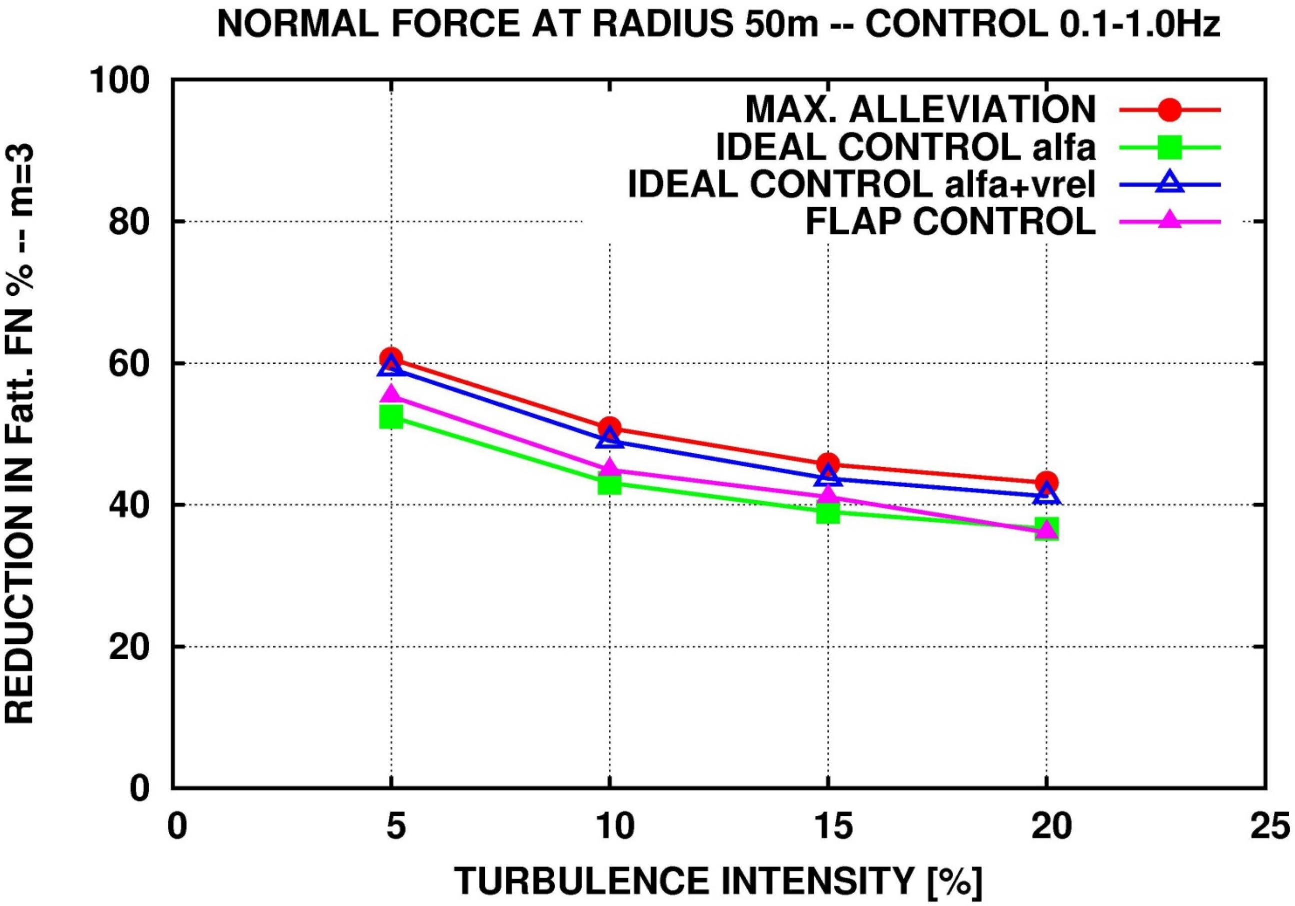


TI=20%



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

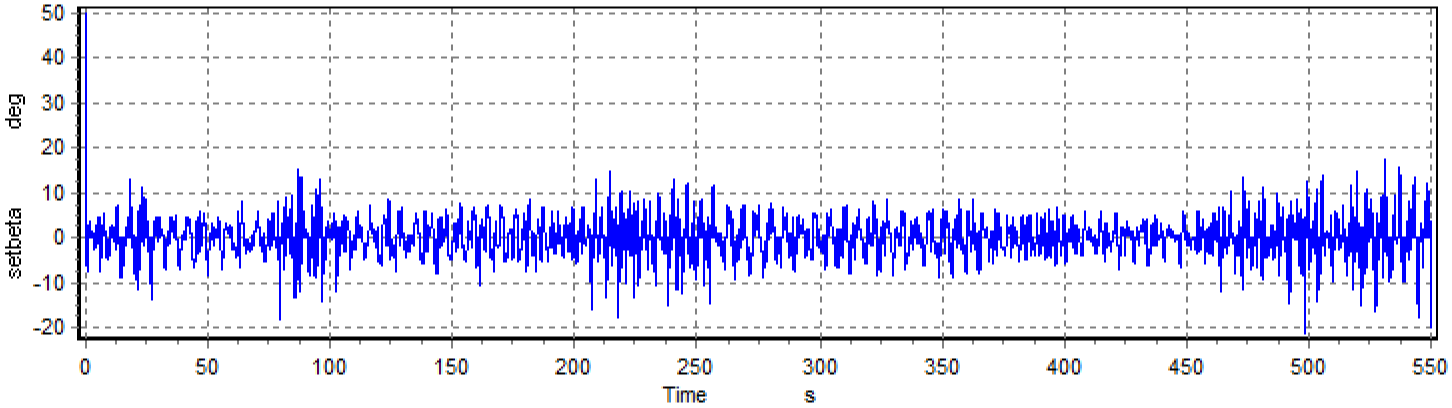
Flap angle constrained to : +- 5 deg.



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

Band 0.1-1.0 Hz

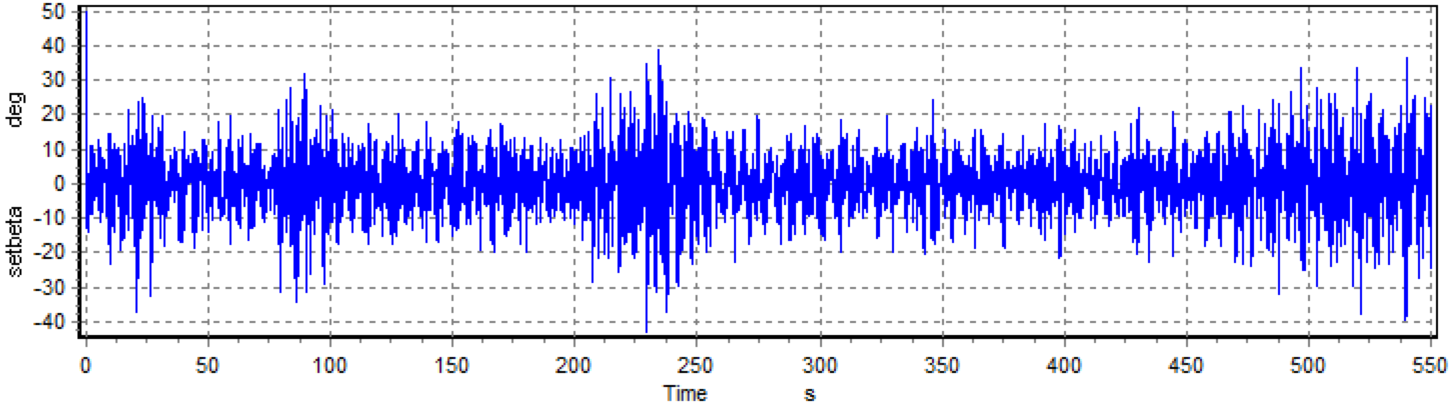
Std. dev. = 3.52 deg/s



Fatt red. = 42.9%

Band 0.1-2.0 Hz

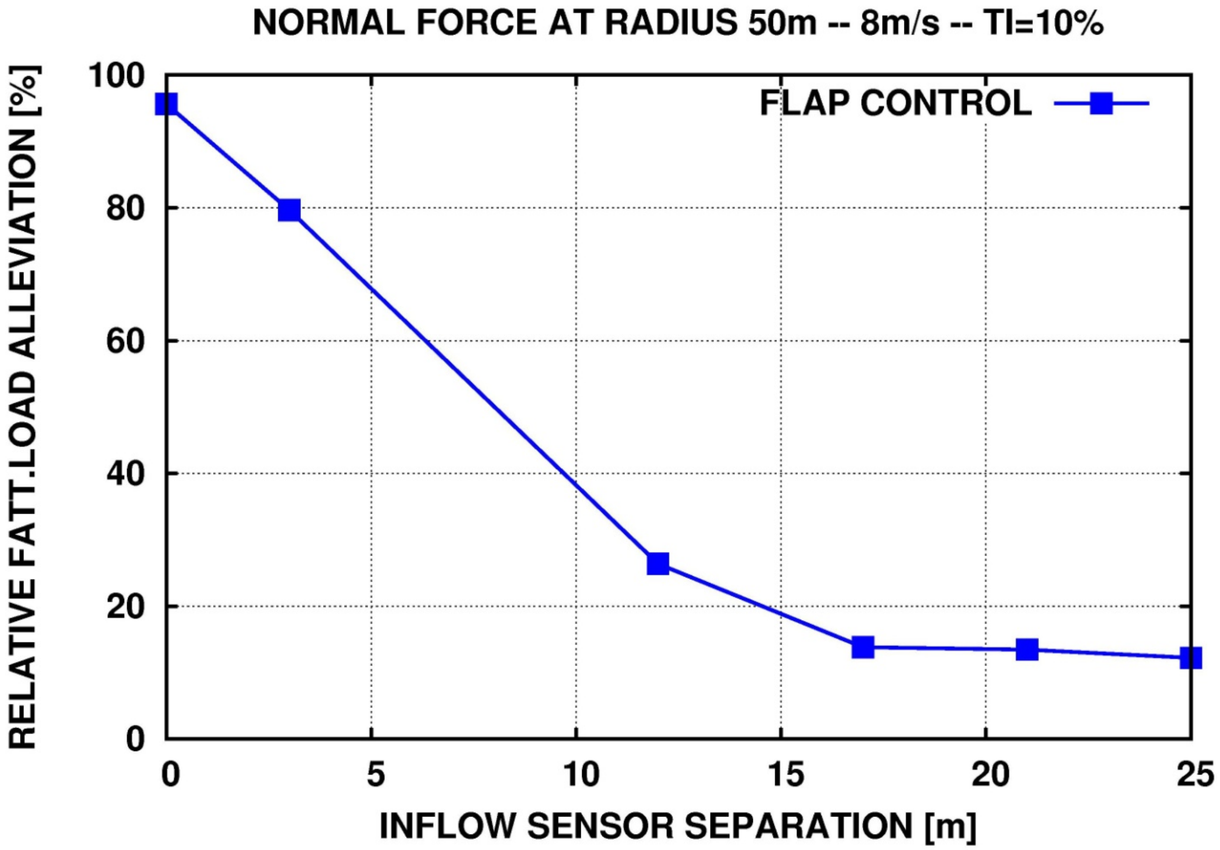
Std. dev. = 6.93 deg/s



Fatt red. = 57.9%

Influence of separation of flow sensor position from flap position

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



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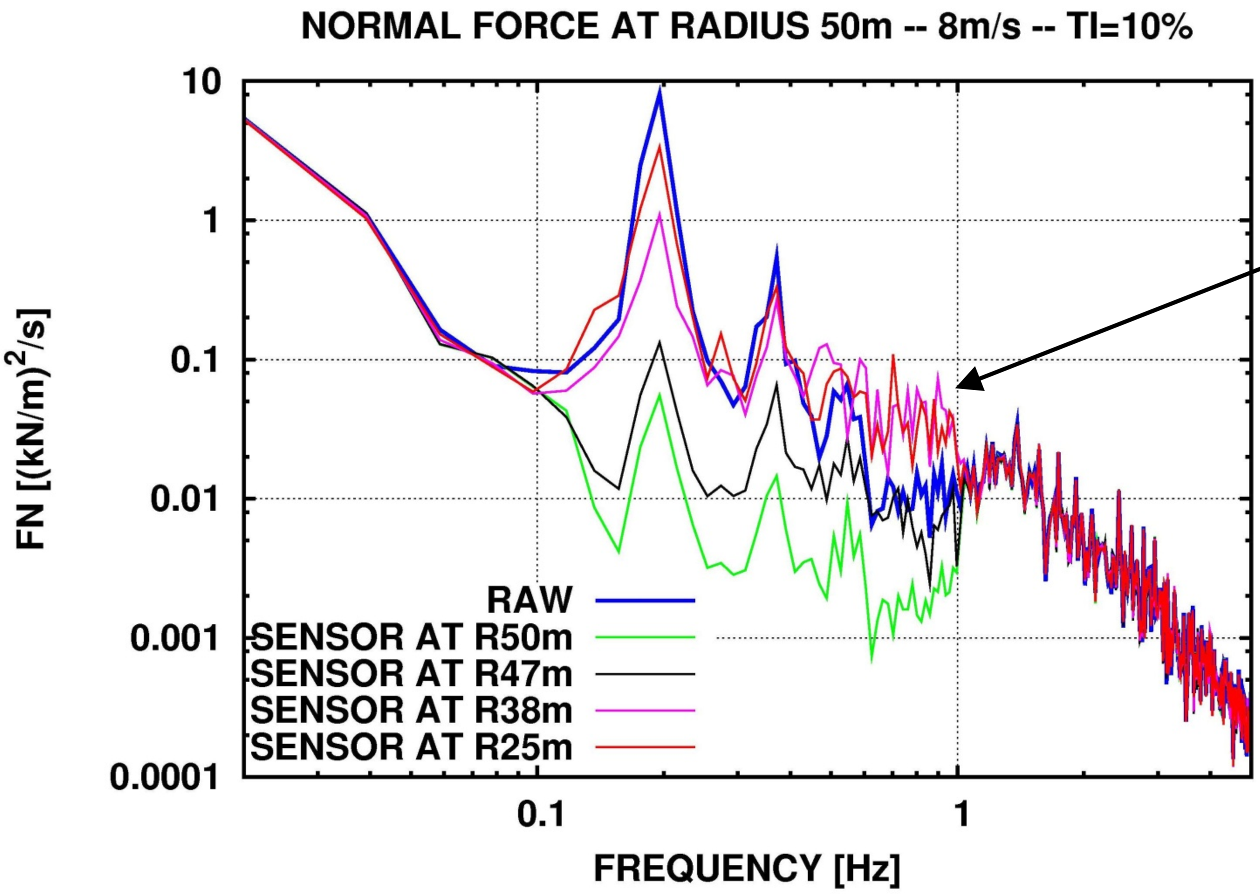
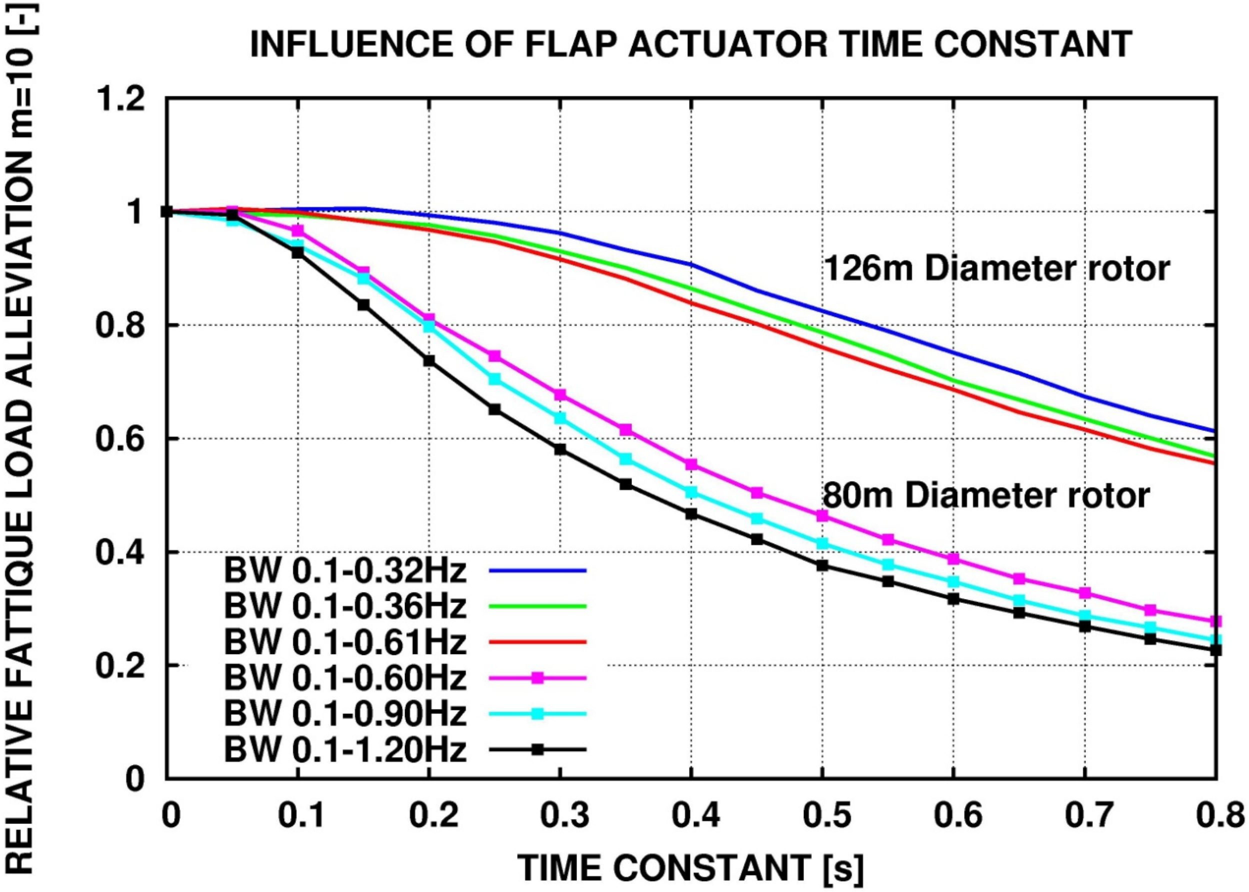
FN at radius 50 m controlled from an inflow sensor at different inboard separation distances



Bandwidth on inflow signal should be adjusted to avoid non-correlated control signals for increasing distance to flow sensor

Influence of actuator time constant

Influence of actuator time constant



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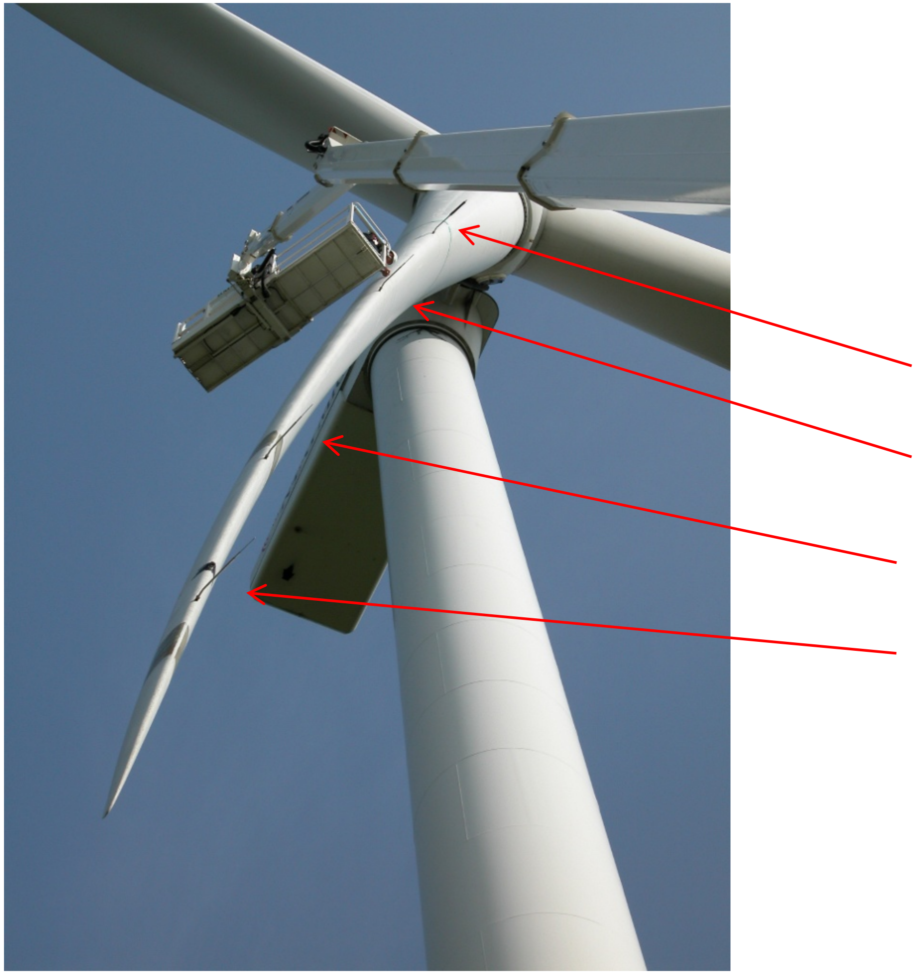
Preliminary analysis of measurements on an 80m diameter rotor

Example of 2MW rotor with inflow sensors



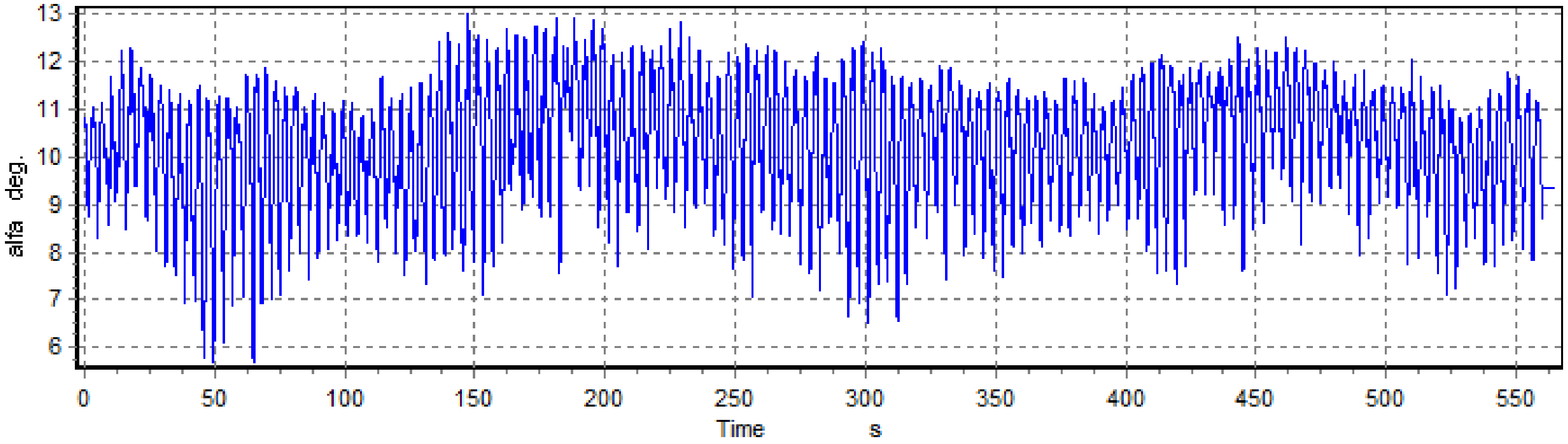
Four 5 hole pitot tubes installed on a NM80 turbine with an 80m rotor

Aero normal forces measured at four radial positions by pressure holes

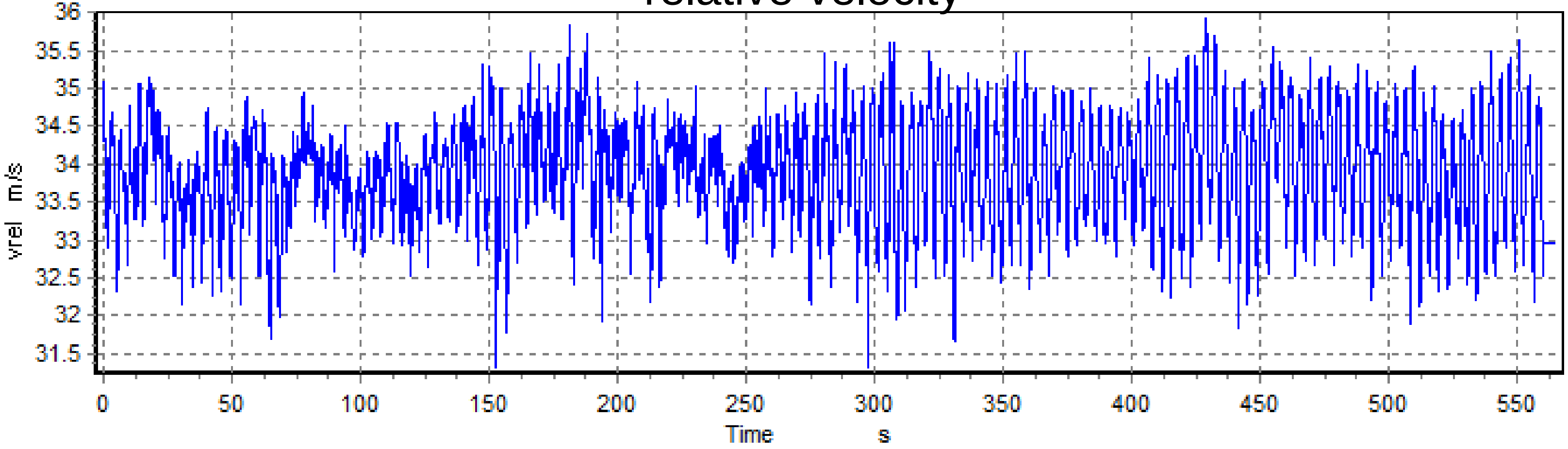
Experiment carried out within the DAN-AERO project from 2007-2010: LM, Vestas, Siemens, DONG Energy and Risø DTU

NM80 turbine – measured inflow at R=30m

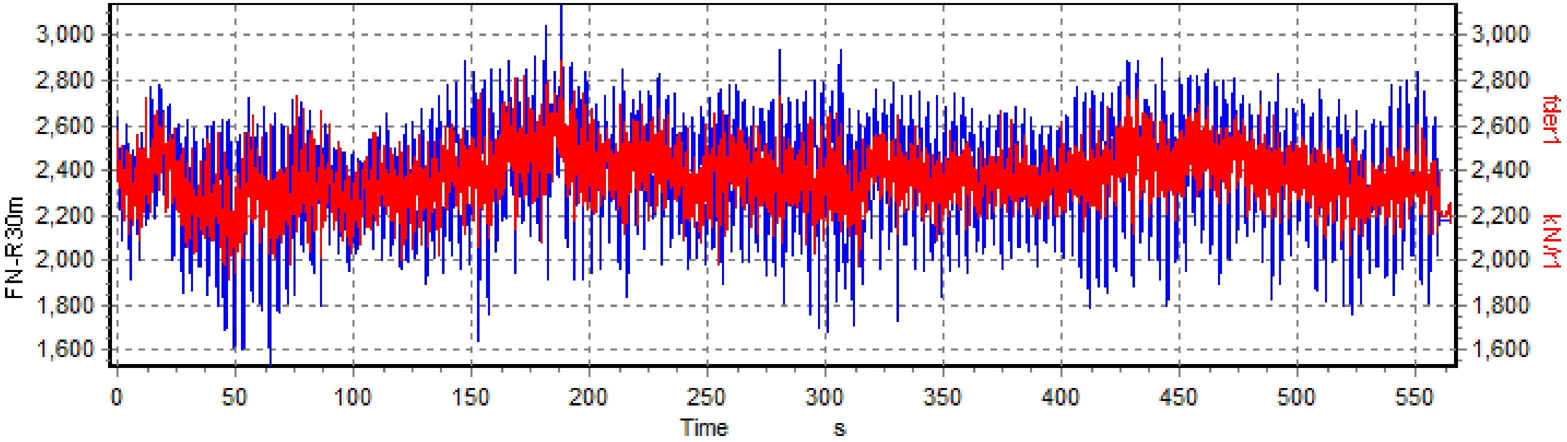
alpha

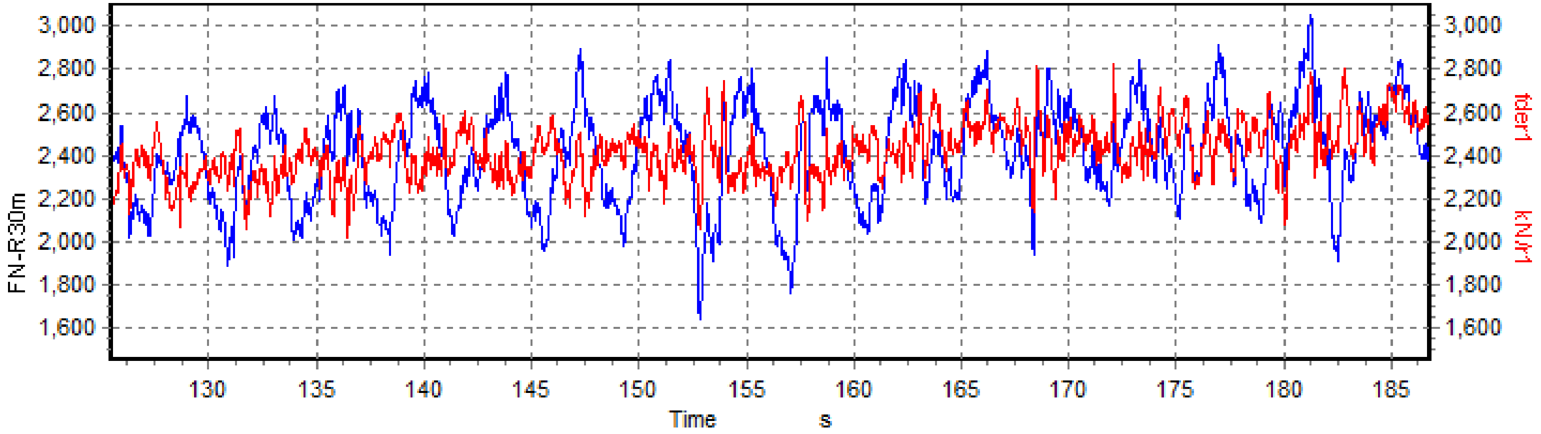


relative velocity



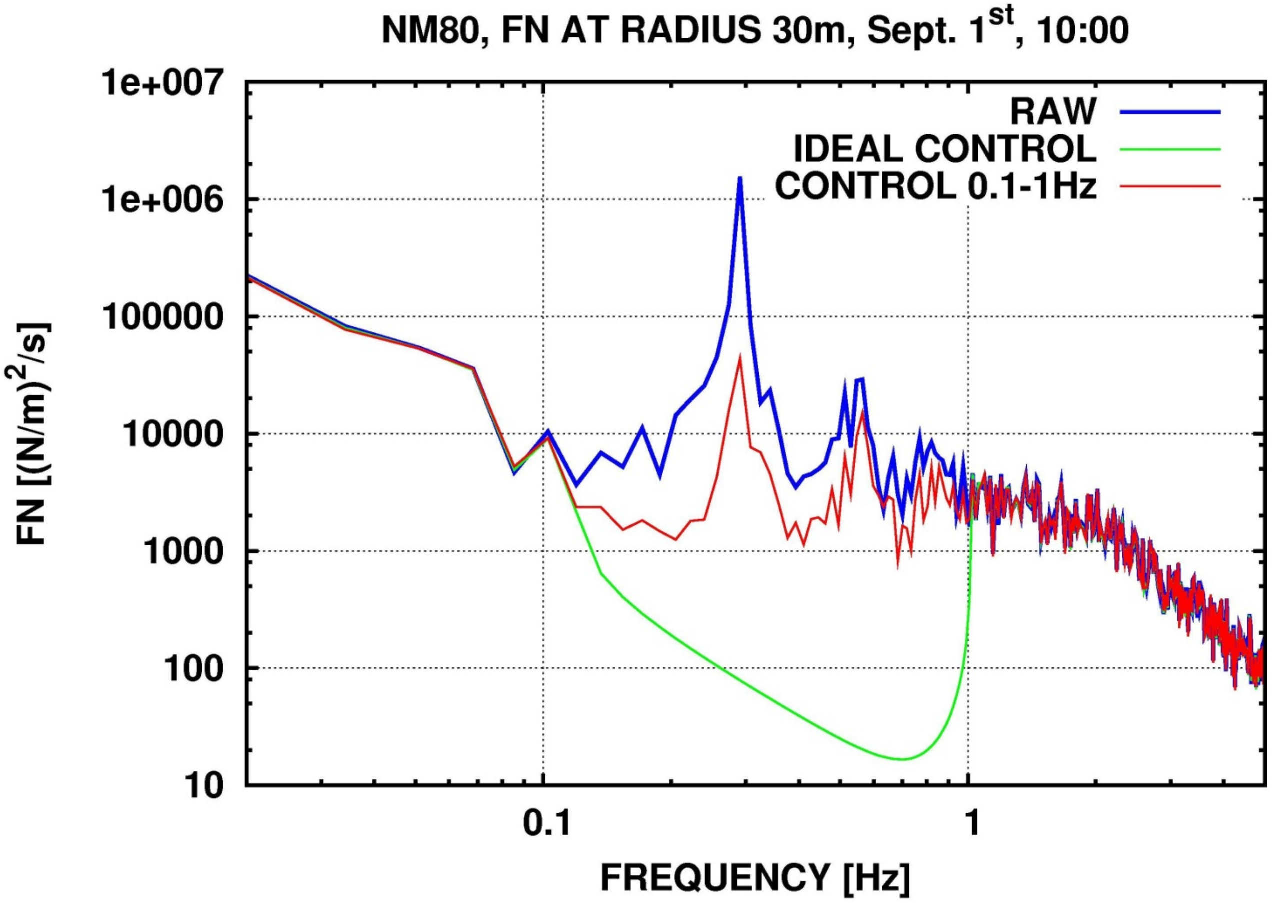
NM80 turbine – control of FN at R=30m from inflow measurement





Fatt. Red. 35.6%

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



Fatt. Red. 35.6%

Conclusions (1of2) on use of inflow data for load alleviation control

- ☐ for the optimal positioned inflow sensor more than 90% of the absolute achievable load reduction can be obtained by a flap
- ☐ information on the relative velocity variations contributes with about 10% to the load reduction
- ☐ flap aerodynamics (aerodynamic response delay) reduce only minorly the ideal load reduction potential

Conclusions (2 of 2) on use of inflow data for load alleviation control

- ☐ one inflow sensor could be used for a 5-10m long flap, bandwidth 0.1-1Hz
- ☐ for bigger separation distance the control signal bandwidth should be reduced
- ☐ rotor size has considerable influence on reduction of load alleviation due to flap actuator time constant

Thank you for your attention!