VDI Wissensforum

DTU

DEVELOPMENT OF THE CONTROLLABLE TRAILING EDGE FLAP TECHNOLOGY FOR MW TURBINES

Peter Bjørn Andersen

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

pbja@dtu.dk

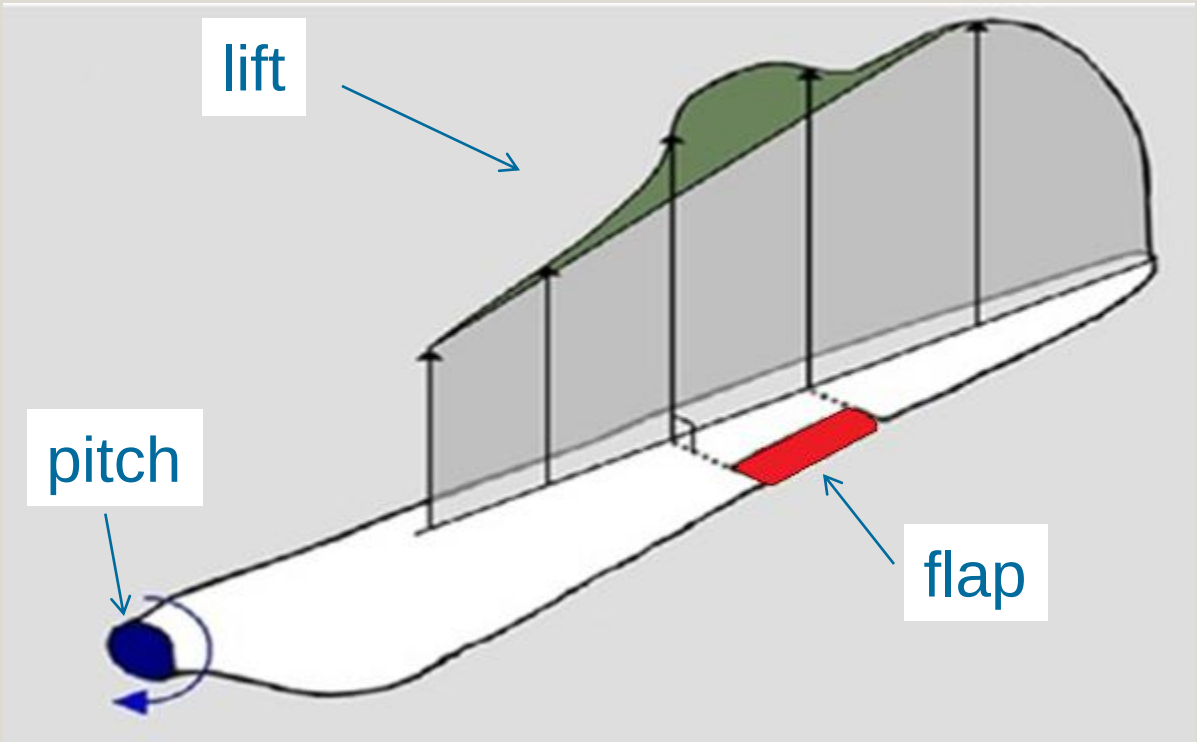
AGENDA

Load alleviation potential using trailing edge flaps

Status of the controllable rubber flap prototype tests

Challenges in the implementation of the flap system on MW turbines

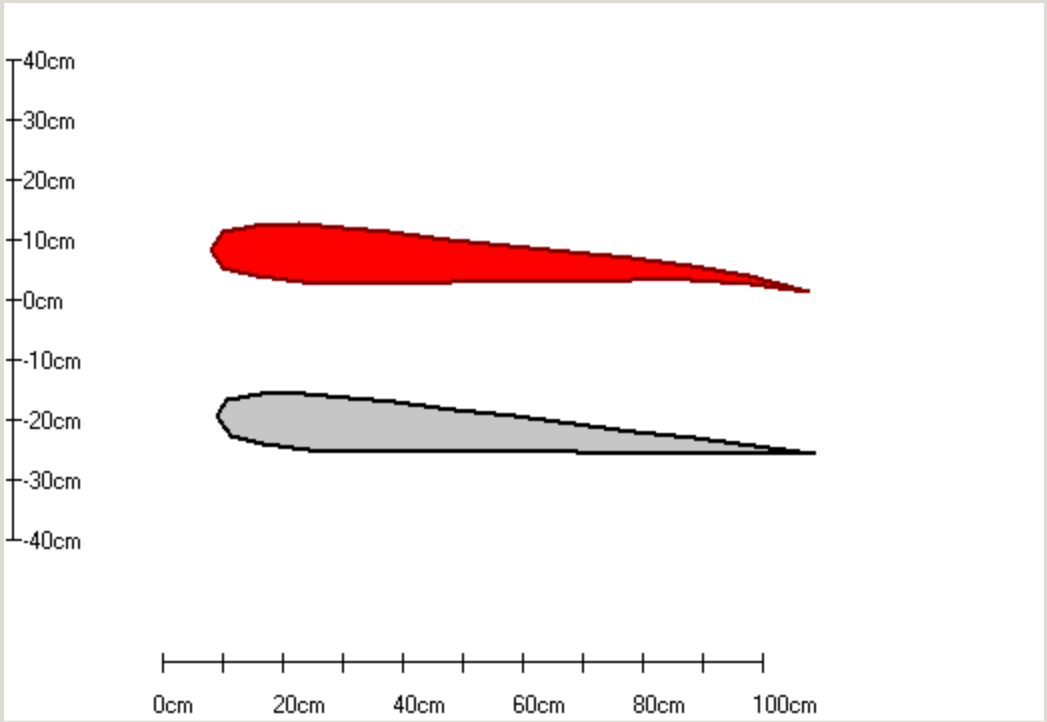
BACKGROUND (1)



Flap down (+)

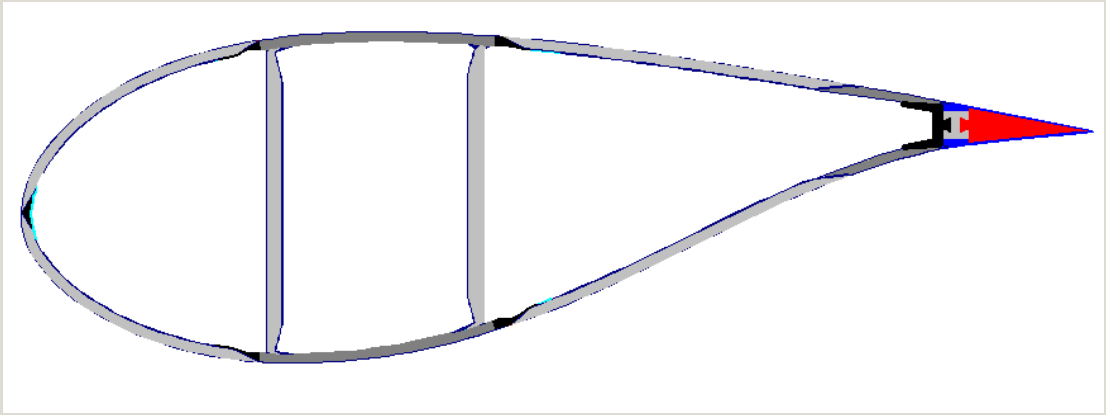
- pitch
- flap **local** load control

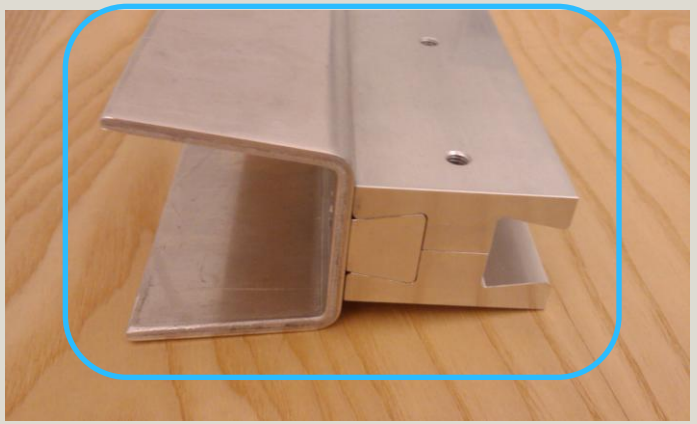
BACKGROUND (2)

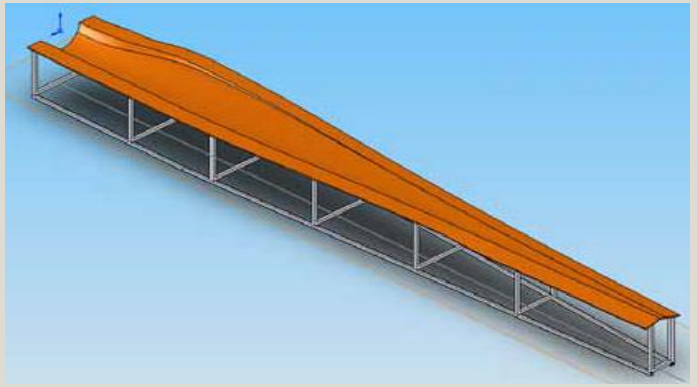


- Gray airfoil section without flap
- Red airfoil section with flap

FLAP DESIGN (1)



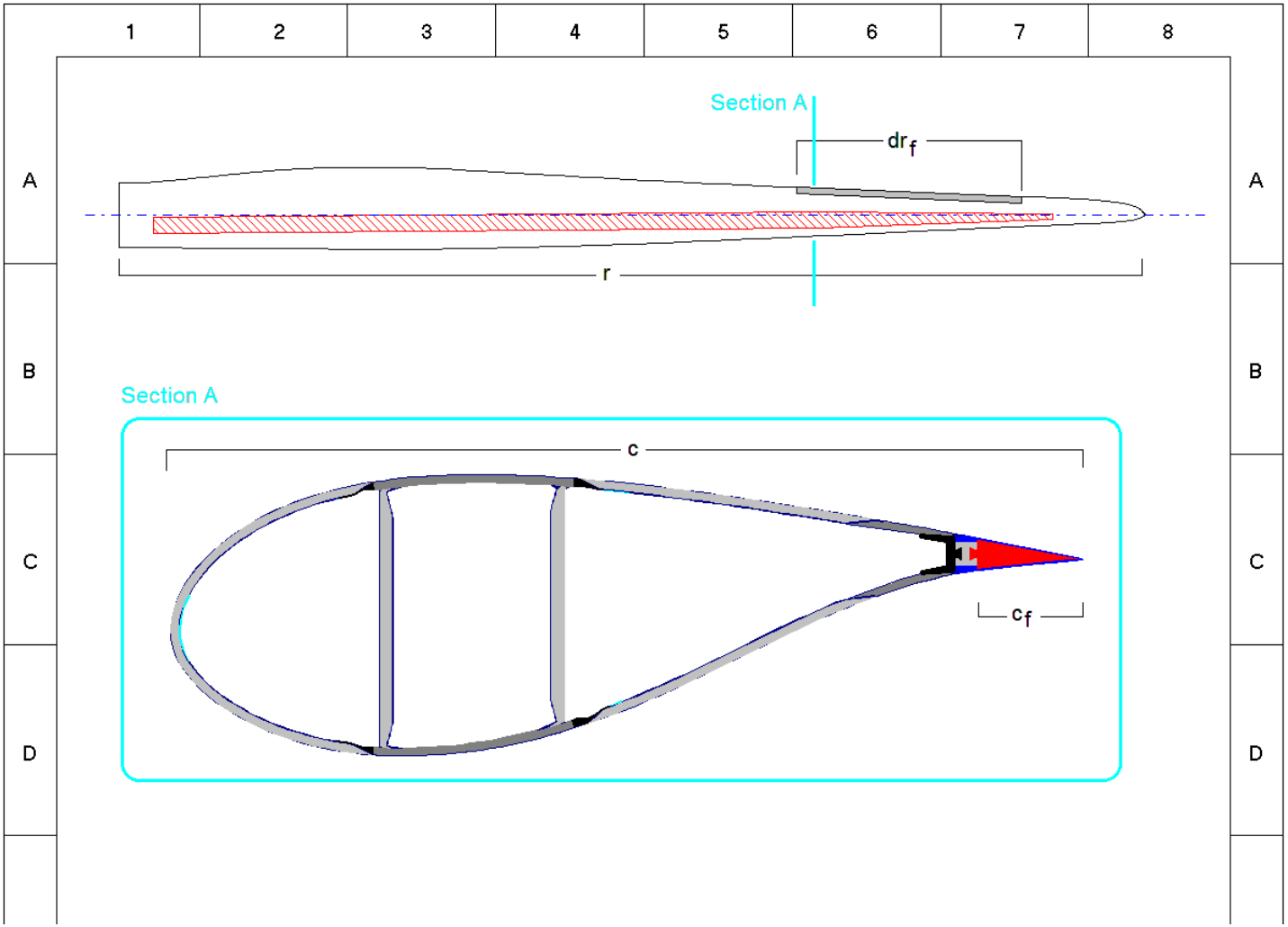




Aim to reduce mould layup time
TE thickness low - 2mm or less

OVERALL GOAL:
NO MECHANICAL PARTS IN THE BLADE

FLAP DESIGN (2)

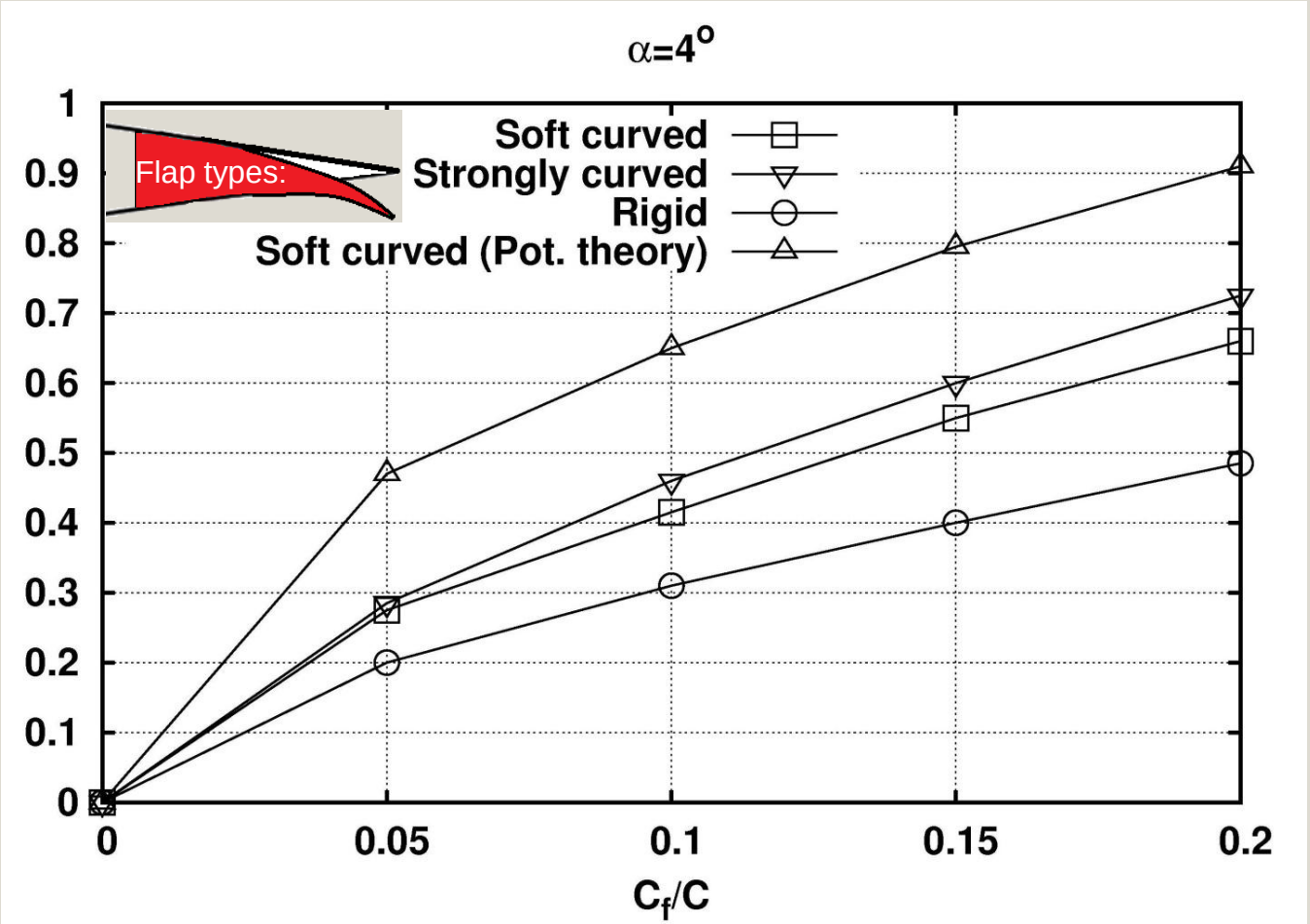


FLAP DESIGN (3)

MORE EFFECTIVE FLAP

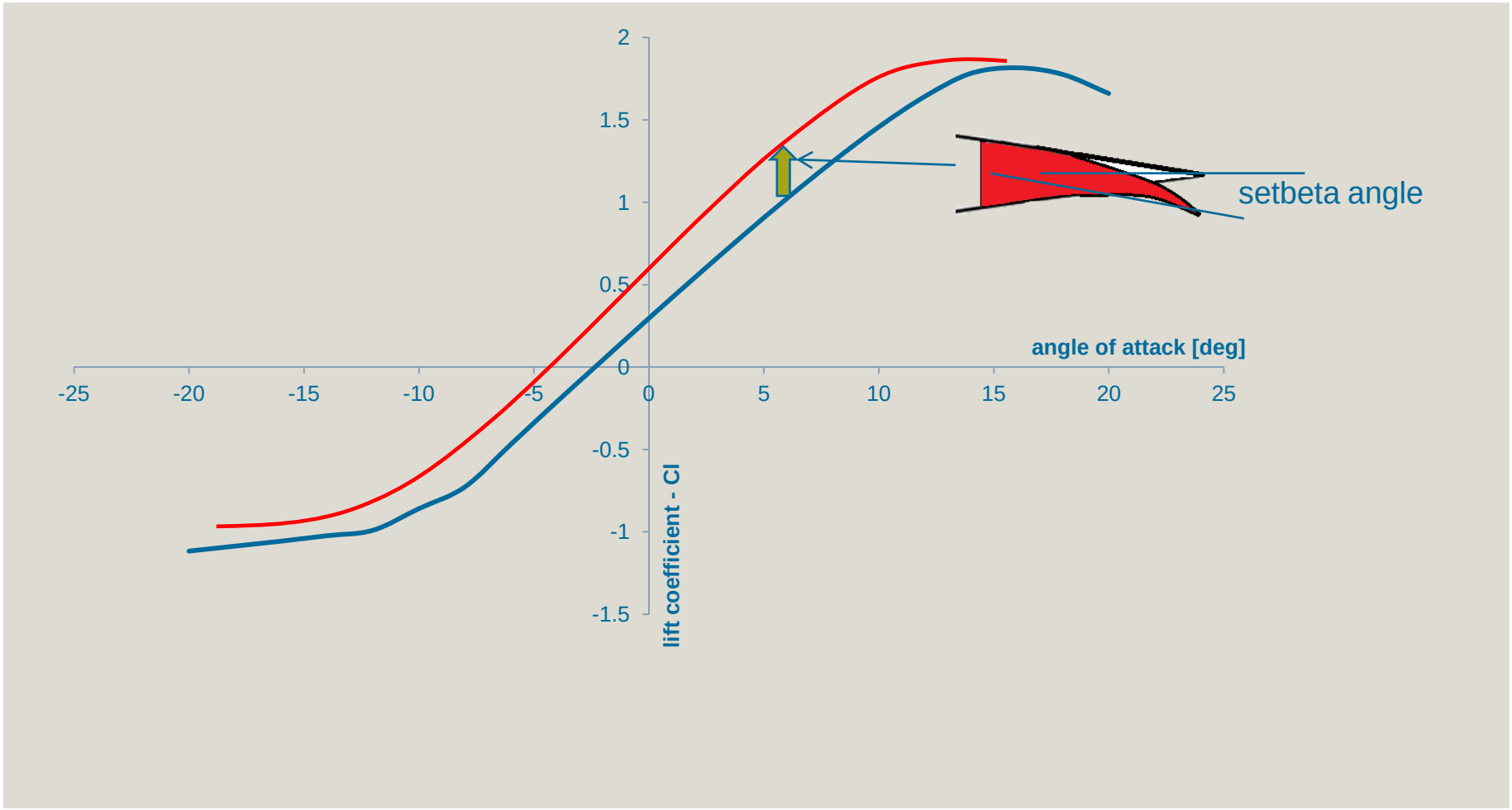
PITCH TO FLAP ACTUATOR RATIO

LESS EFFECTIVE FLAP

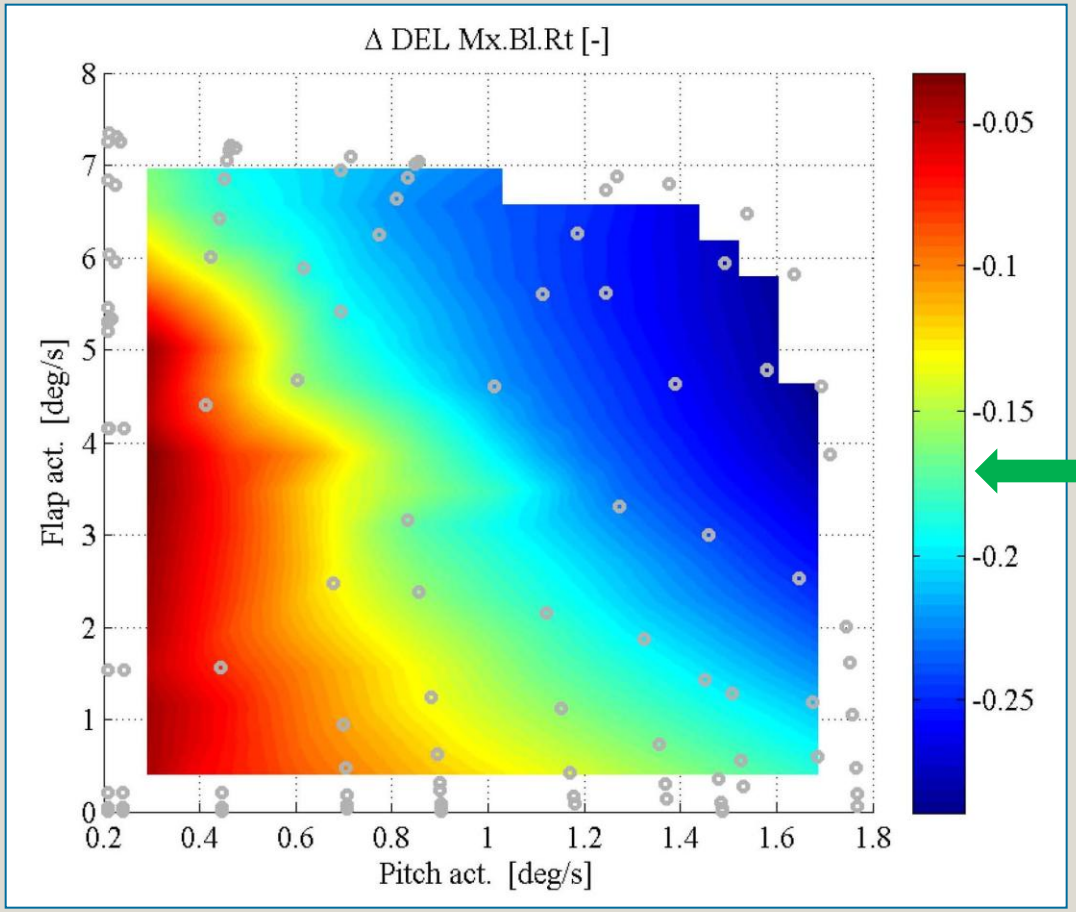


Troldborg, N., 2005, —Computational study of the RisøB1-18 airfoil with a hinged flap providing variable trailing edge geometryll, Wind Engineering, vol. 29, pp. 89–113.

FLAP “MUSCLE”


2
1.5
1
0.5
0
-0.5
-1
-1.5
-25
-20
-15
-10
-5
0
5
10
15
20
25
angle of attack [deg]
lift coefficient - Cl
setbeta angle

CONTROL BASED ON TRADITIONAL SENSORS



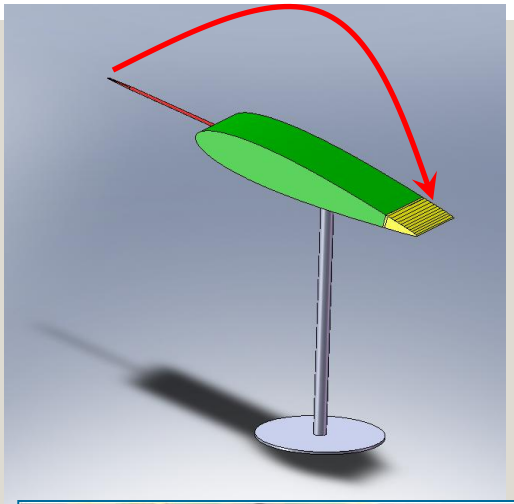
CONTROL OBJECTIVE:
Reduce the pitch activity and alleviate the loads using the same sensors as for the pitch system

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 and IEC class IA – dlc1.1 at 18m/s (4 seeds)

Christensen LC, Bergami L and Andersen 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.

INFLOW SENSORS (ADVANCED)

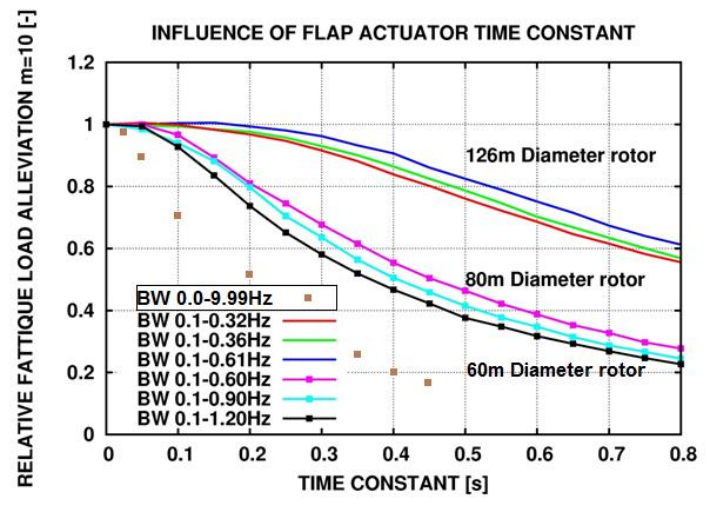
Experiment carried out within the DAN-AERO project from 2007-2010: LM, Vestas, Siemens, DONG Energy and Risø DTU

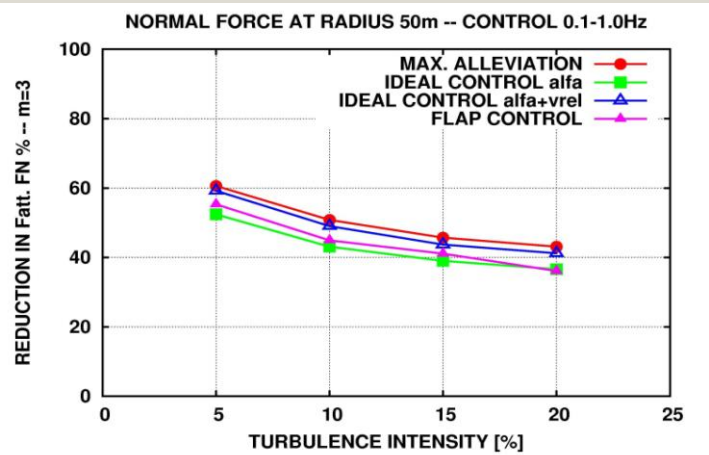


CONTROL OBJECTIVE:
Measure the incoming disturbance and adjust the flap position to keep the aerodynamic loading constant along the blade span

Wind tunnel test of flaps and inflow sensors, 2009: Velux windtunnel

ROTOR DIAMETER AND WIND SITE





Alleviating high frequency loads (small rotor) requires faster response time

Alleviating loads in high turbulence sites requires more “flap muscle”

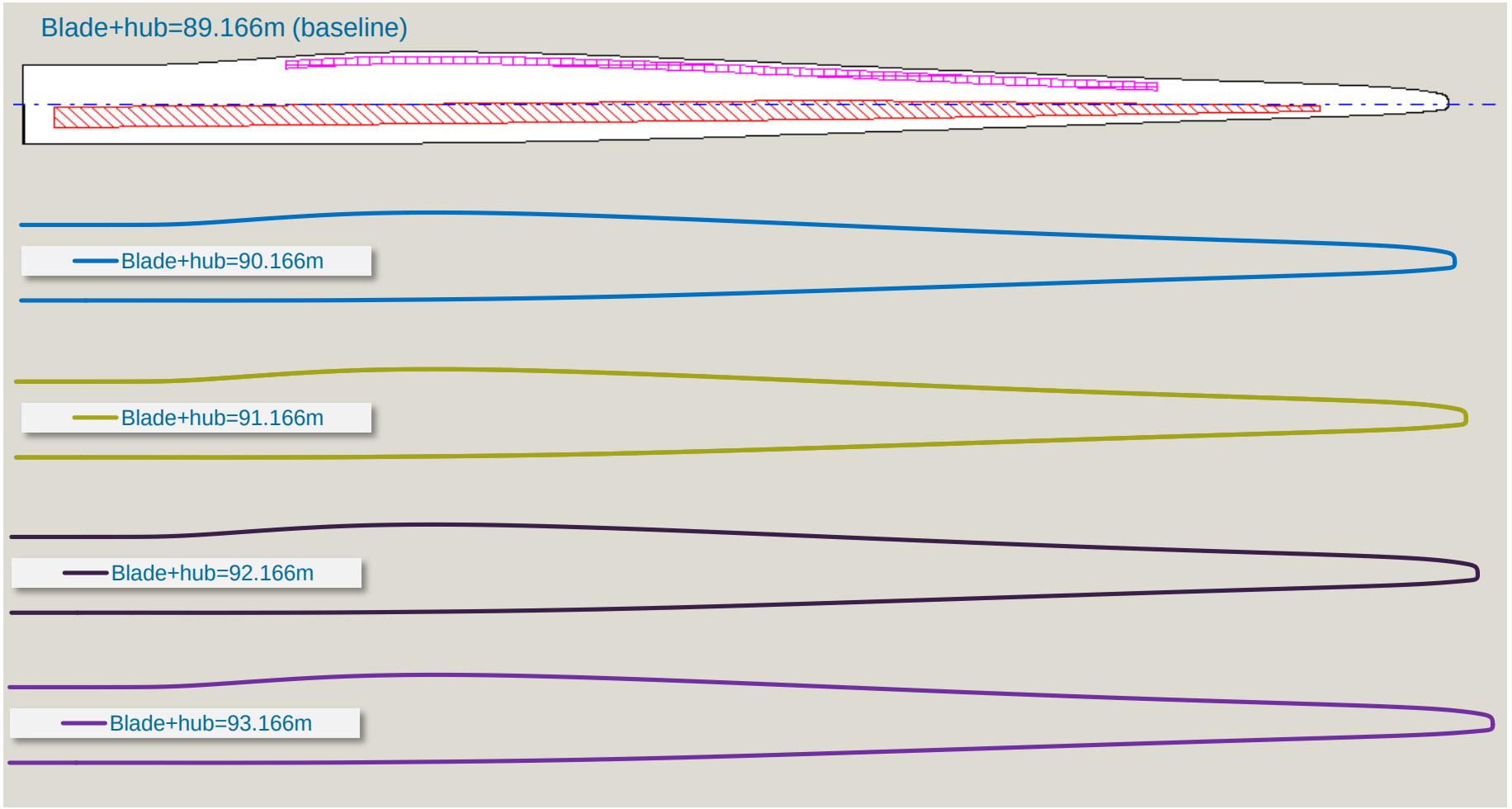
EQUIVALENT FATIGUE LOAD REDUCTIONS

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

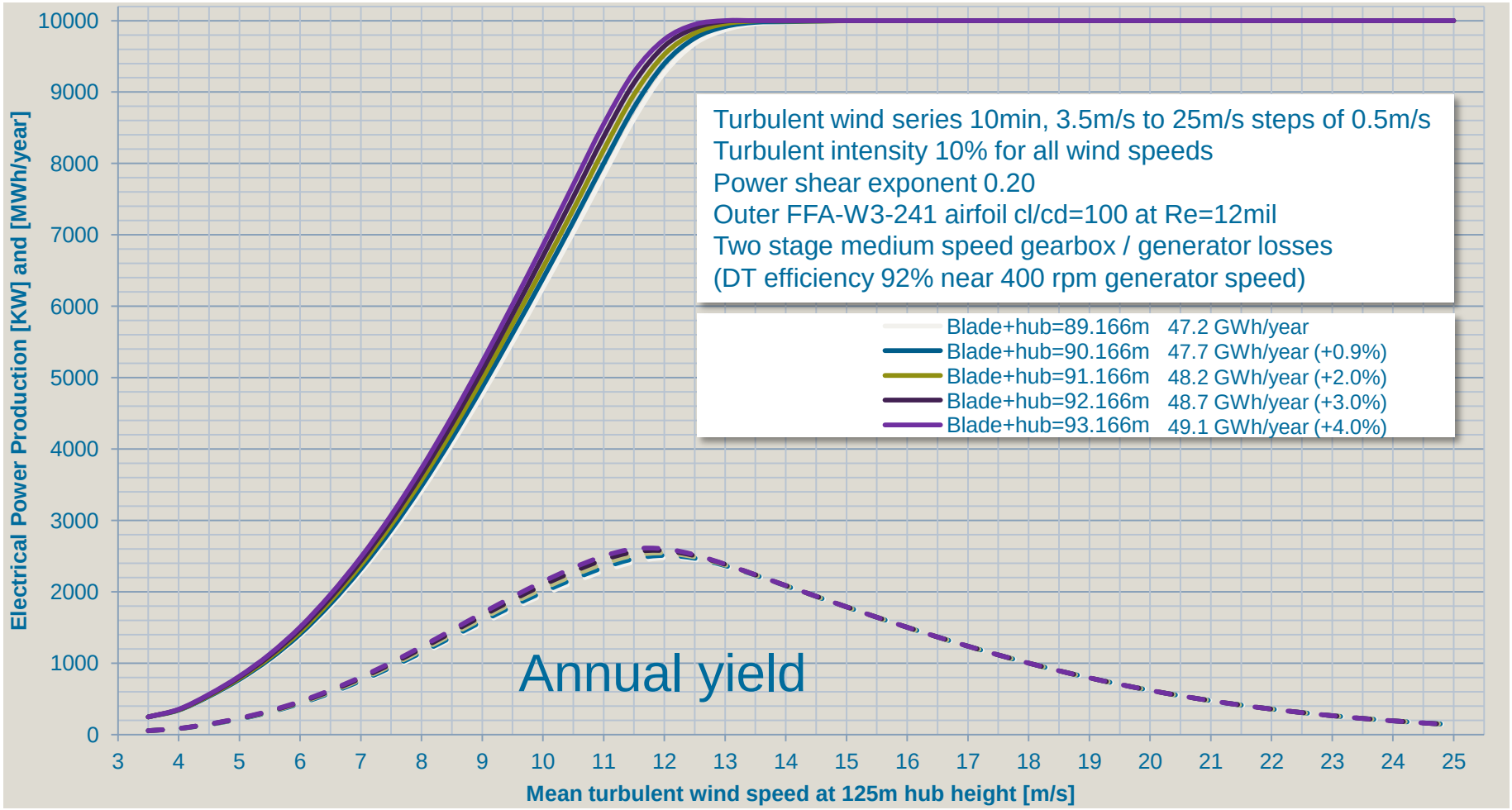
article	c_f [%]	dr_f/r [%]	δ [$\pm^\circ$]	T.I. [%]	shear exp. [-]	V_{av} [m/s]	reduction in std of RBM [%	reduction in DEL [%]	controller
Riziotis et al. 2008	10	15-47	6	-	0.2	8, 12, 16	30-35 (range)	-	PID
Andersen et al. 2008	10	63	8	14-18	0.14	7, 11, 18	-	36.2-47.9	HPF+inflow
Lackner et al. 2009	10	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

UPSCALED BLADE EXAMPLE (1)

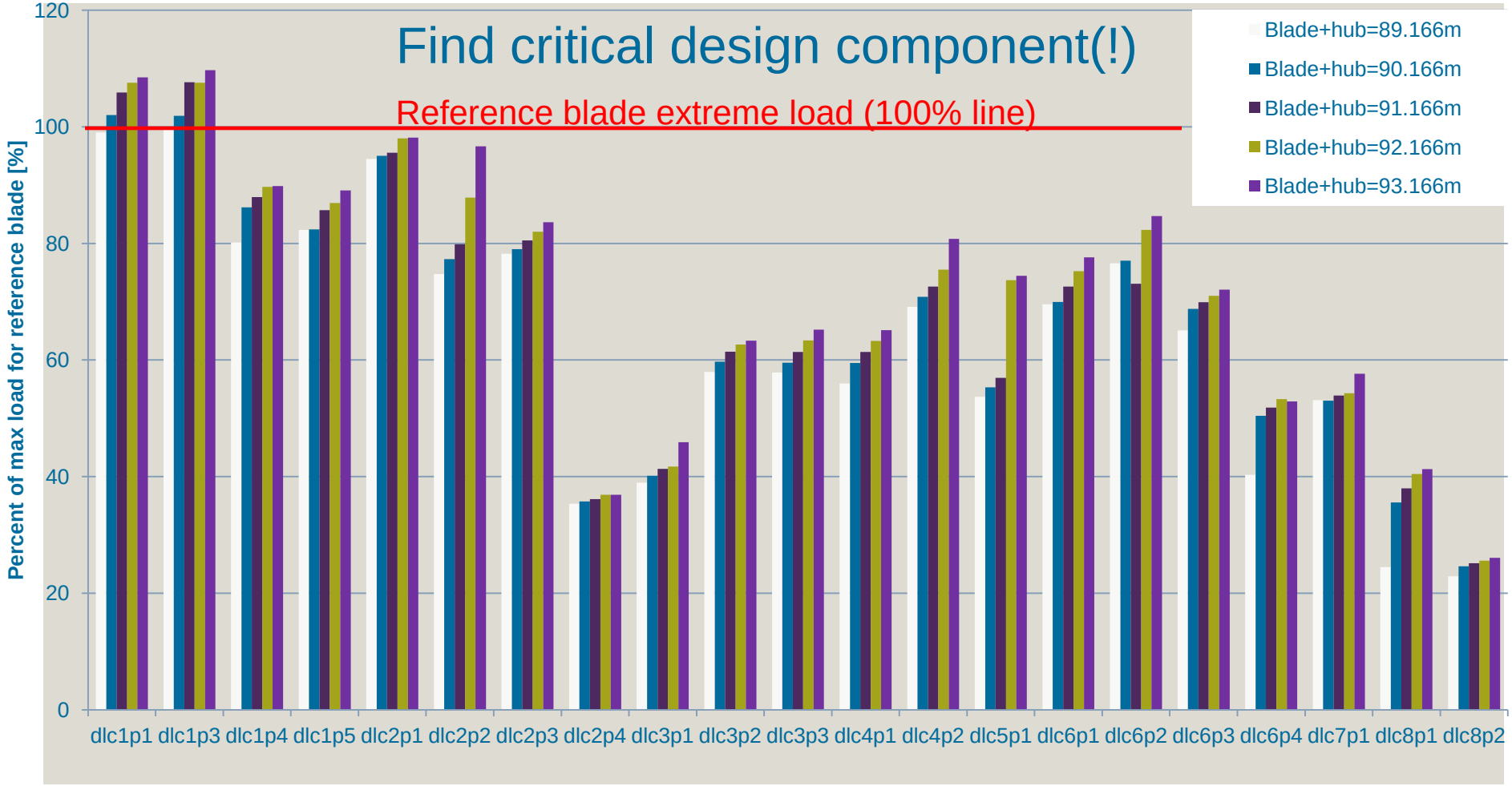


UPSCALED BLADE EXAMPLE (2)

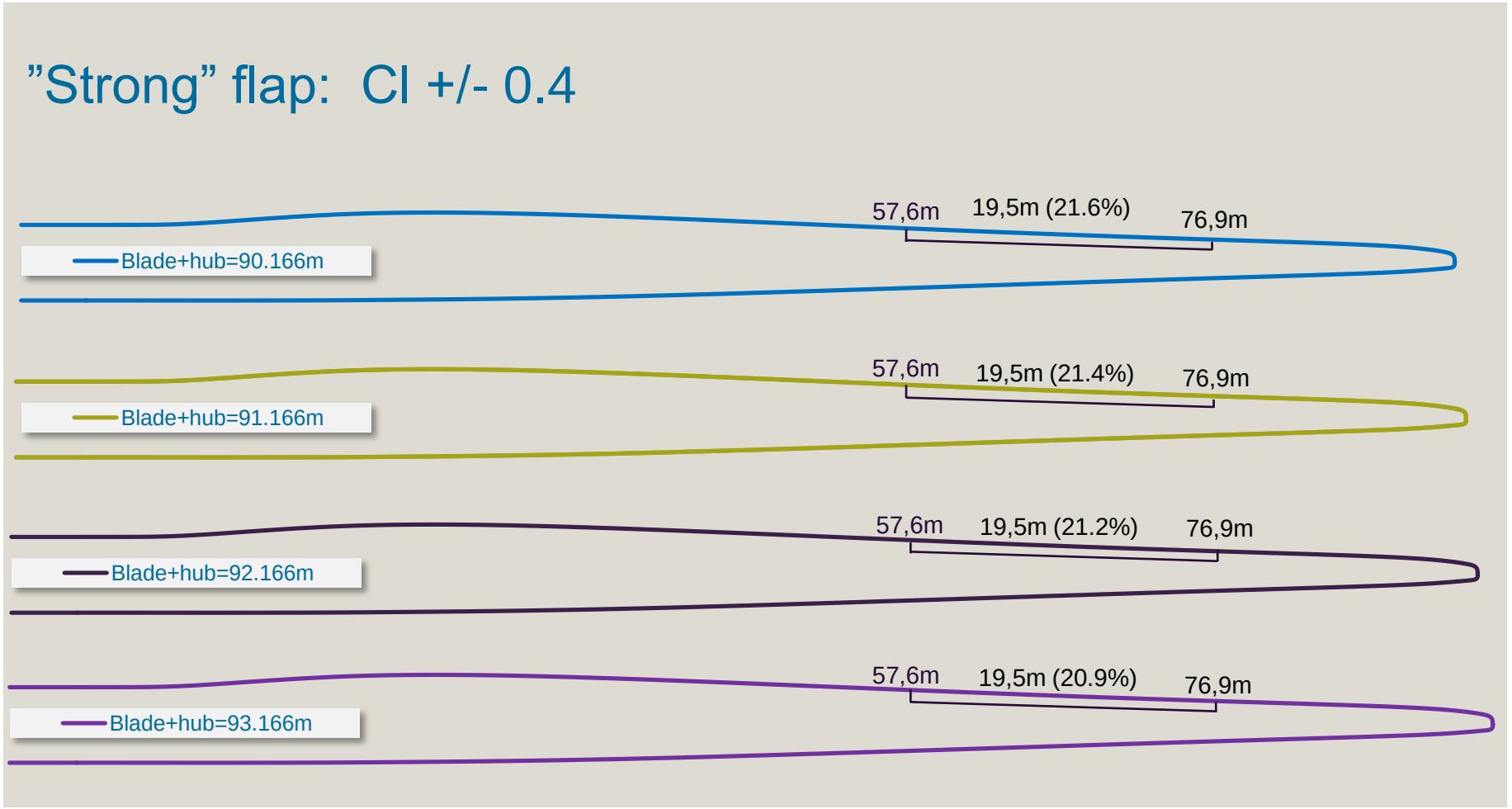


IEC 61400-1 WIND CLASS IA EXTREME FLAPWISE ROOT BENDING MOMENT

UPSCALED BLADE EXAMPLE (3)

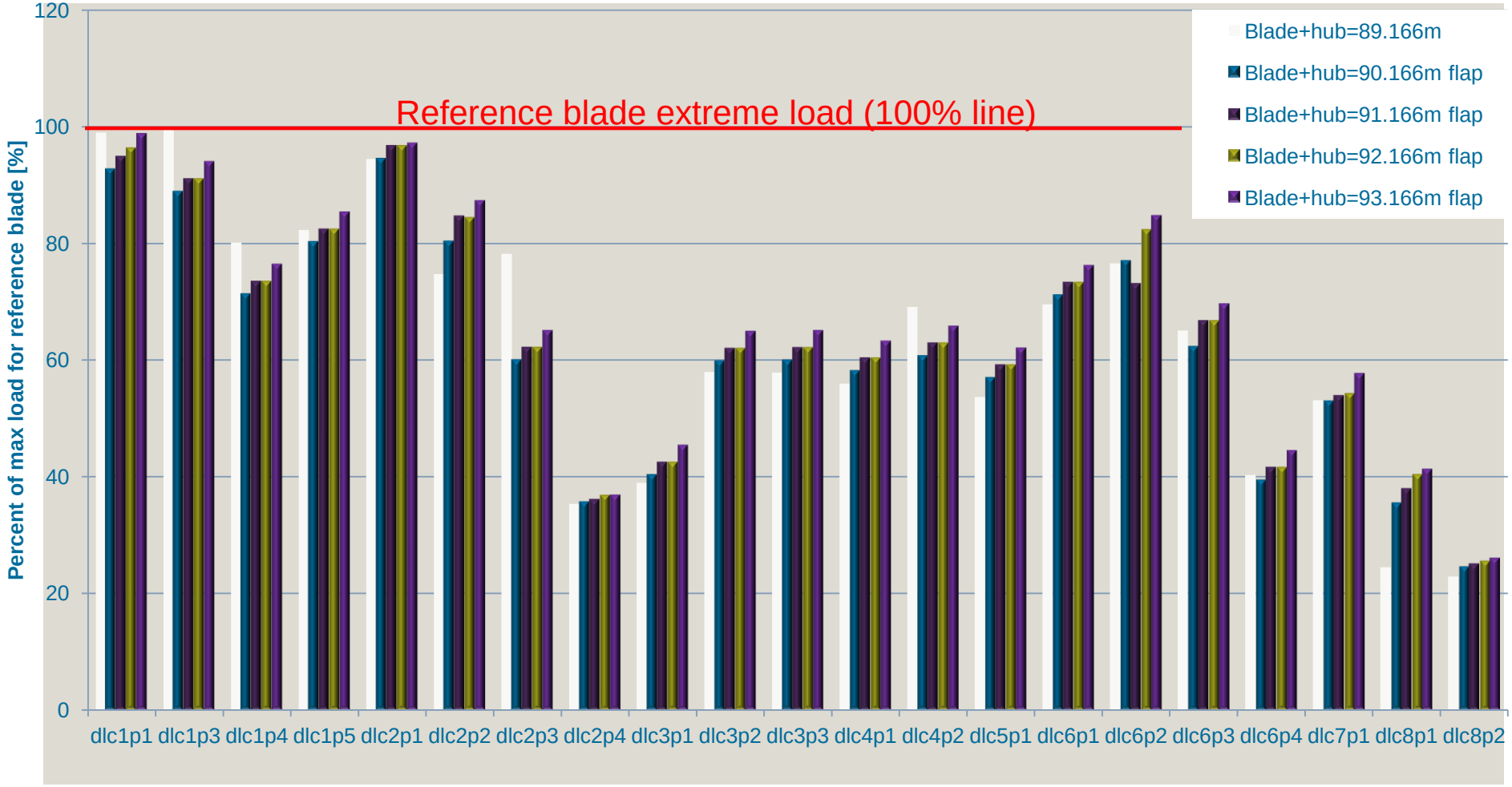


UPSCALED BLADE EXAMPLE (4)

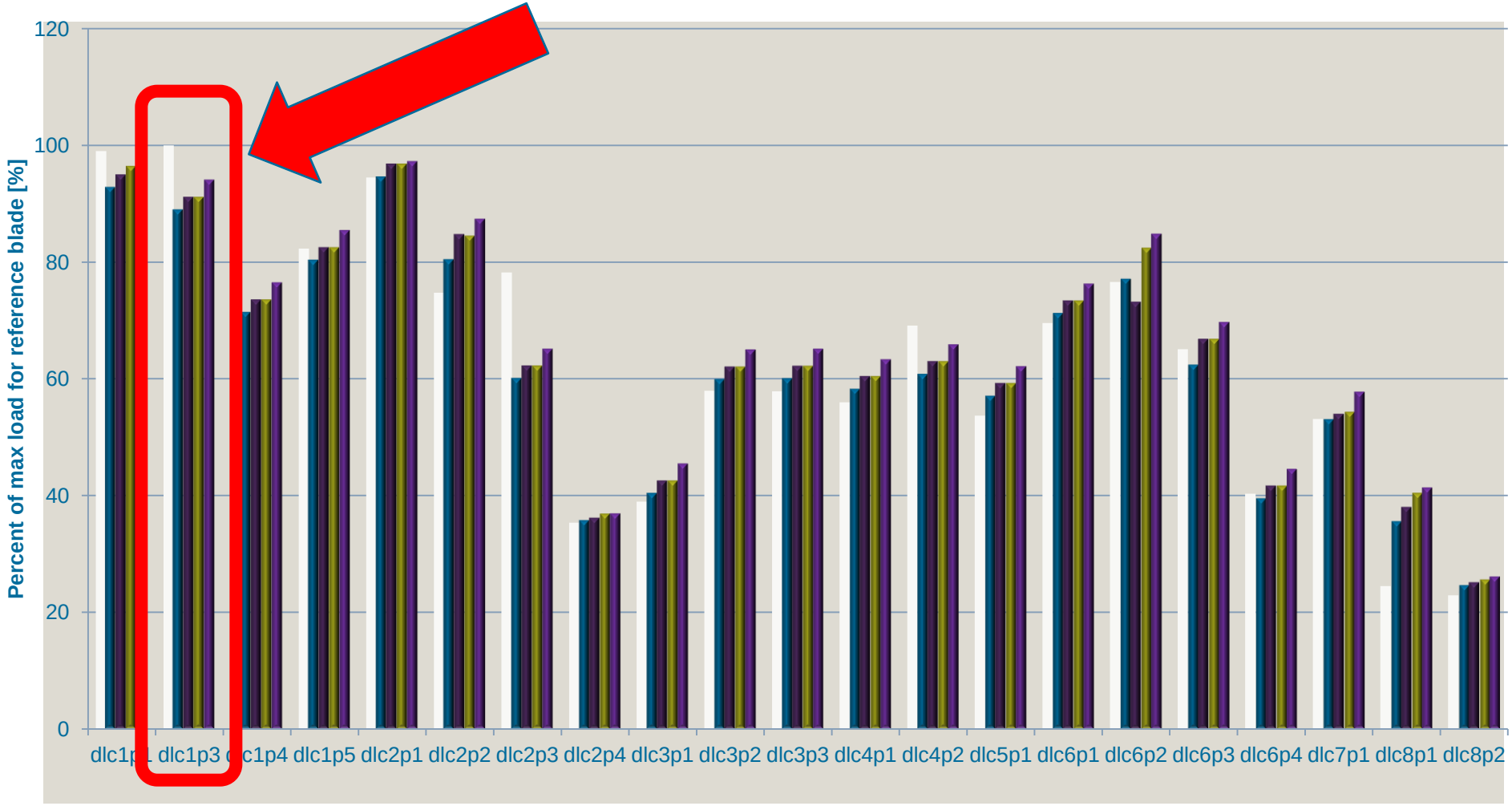


IEC 61400-1 WIND CLASS IA EXTREME FLAPWISE ROOT BENDING MOMENT

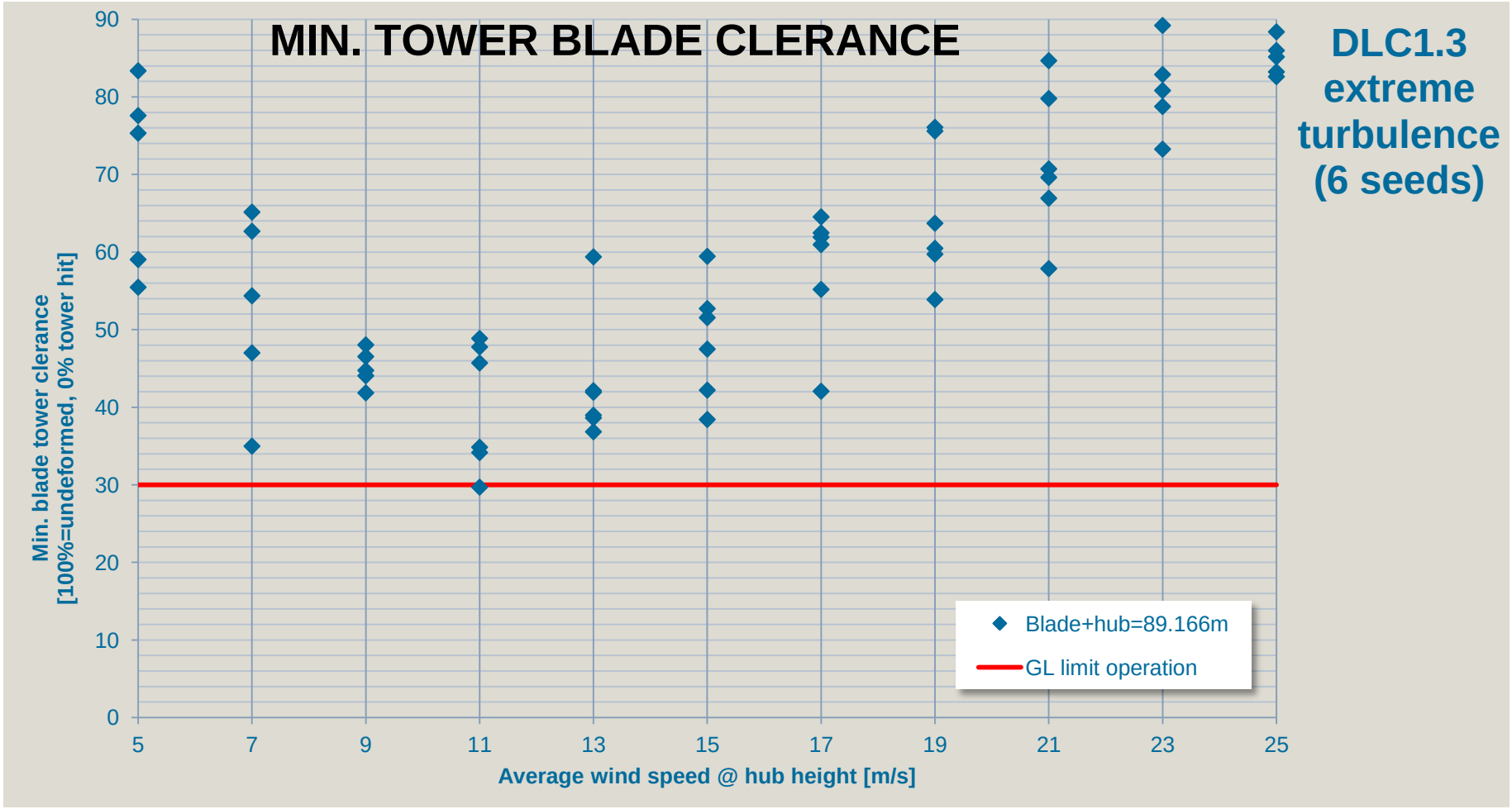
UPSCALED BLADE EXAMPLE (5)



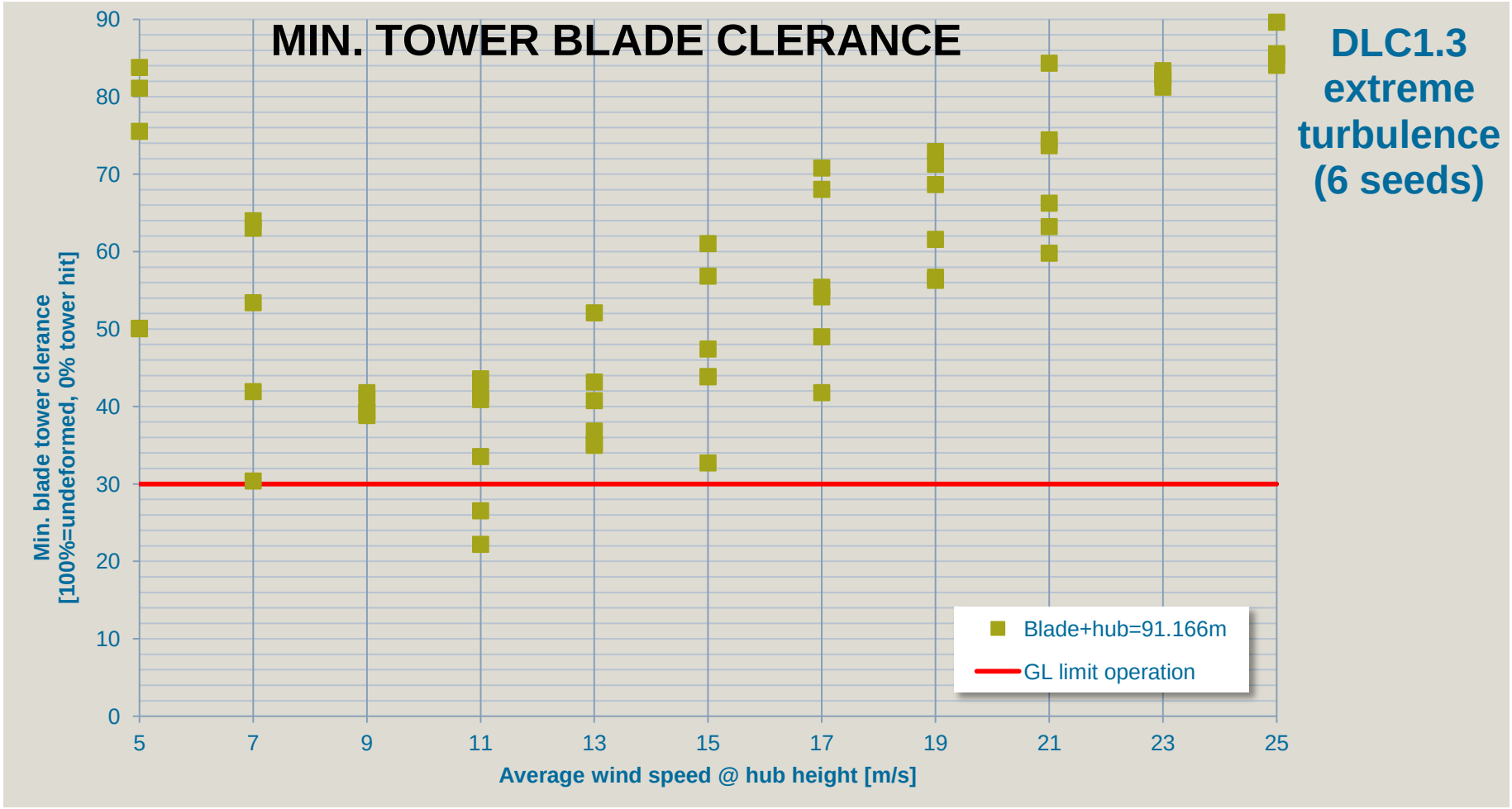
EXTREME LOADS -> TOWER-BLADE MIN. CLEARANCE



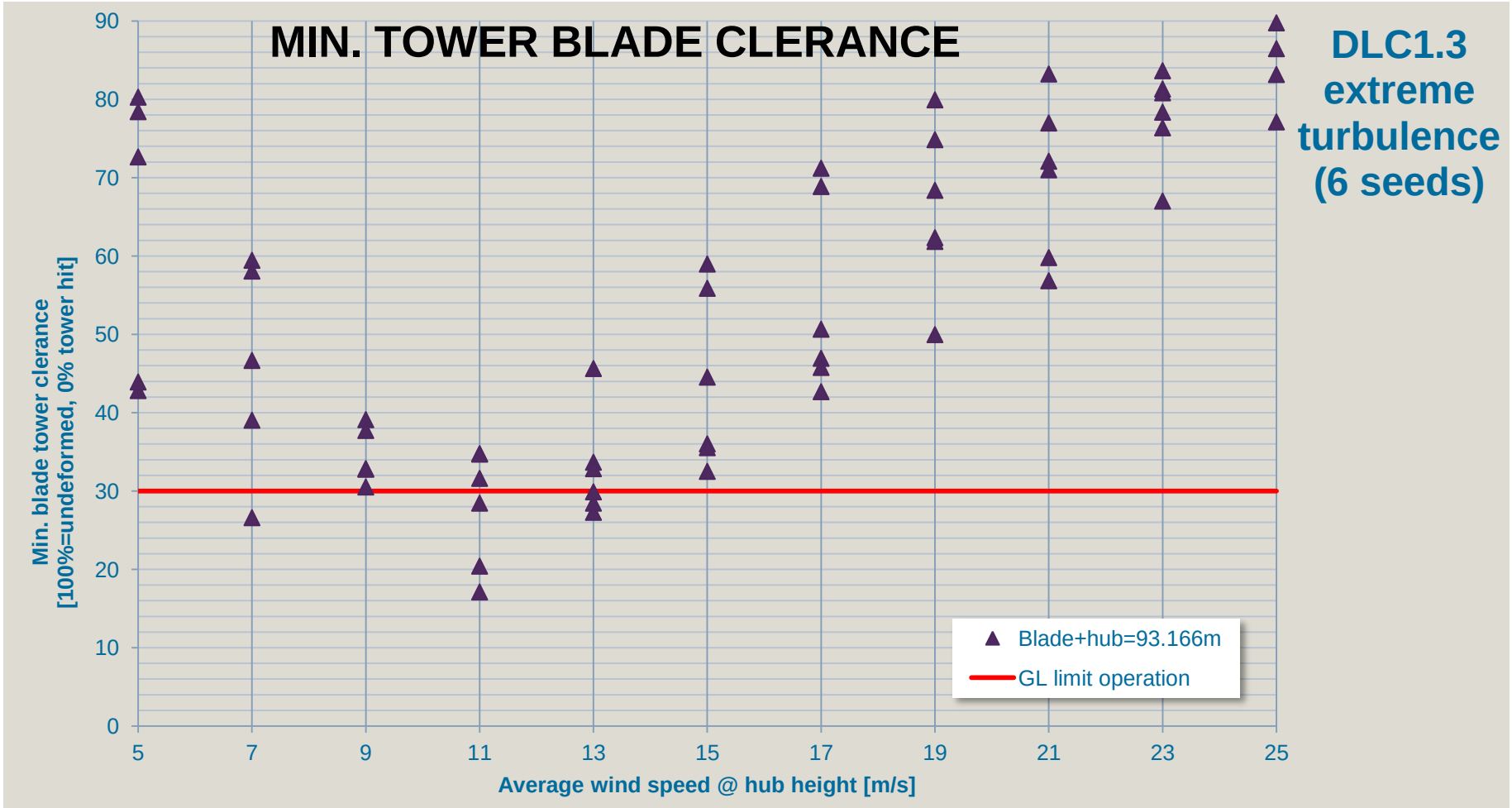
TOWER-BLADE MIN. CLEARANCE – BY GL 30% OPERATION DEMAND



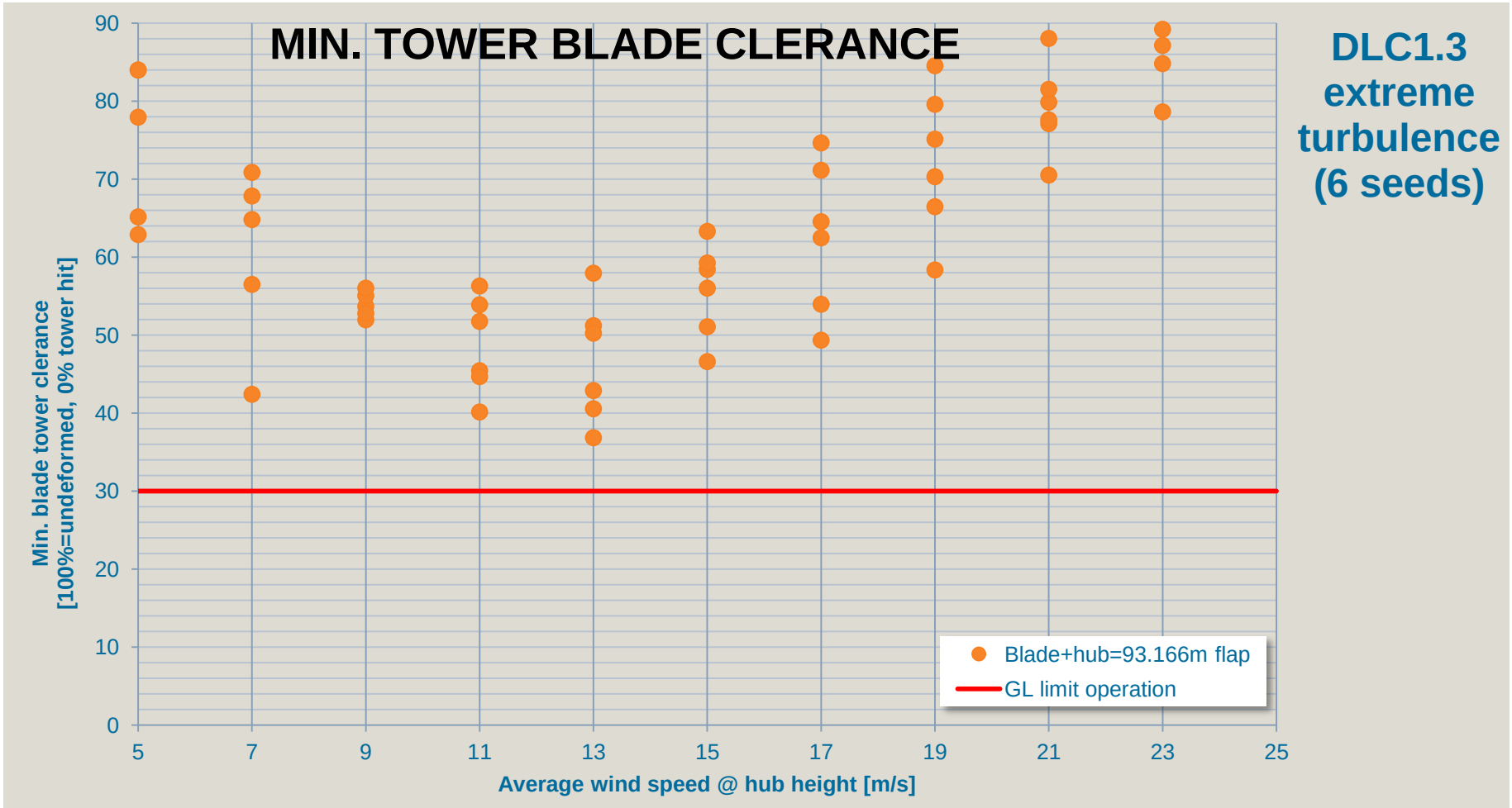
TOWER-BLADE MIN. CLEARANCE – BY GL 30% OPERATION DEMAND



TOWER-BLADE MIN. CLEARANCE – BY GL 30% OPERATION DEMAND

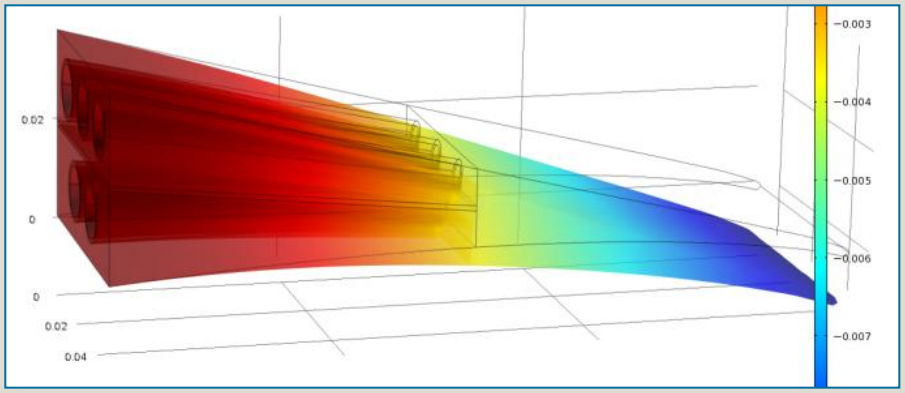


TOWER-BLADE MIN. CLEARANCE – BY GL 30% OPERATION DEMAND

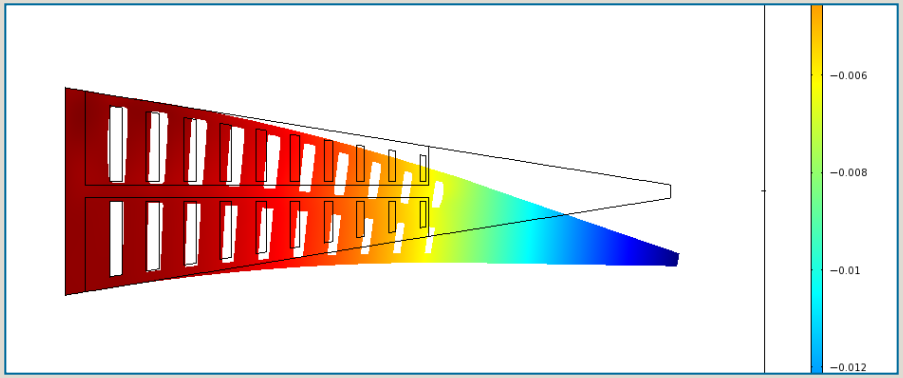


Status of the controllable rubber flap prototype tests

RUBBER FLAP (1)

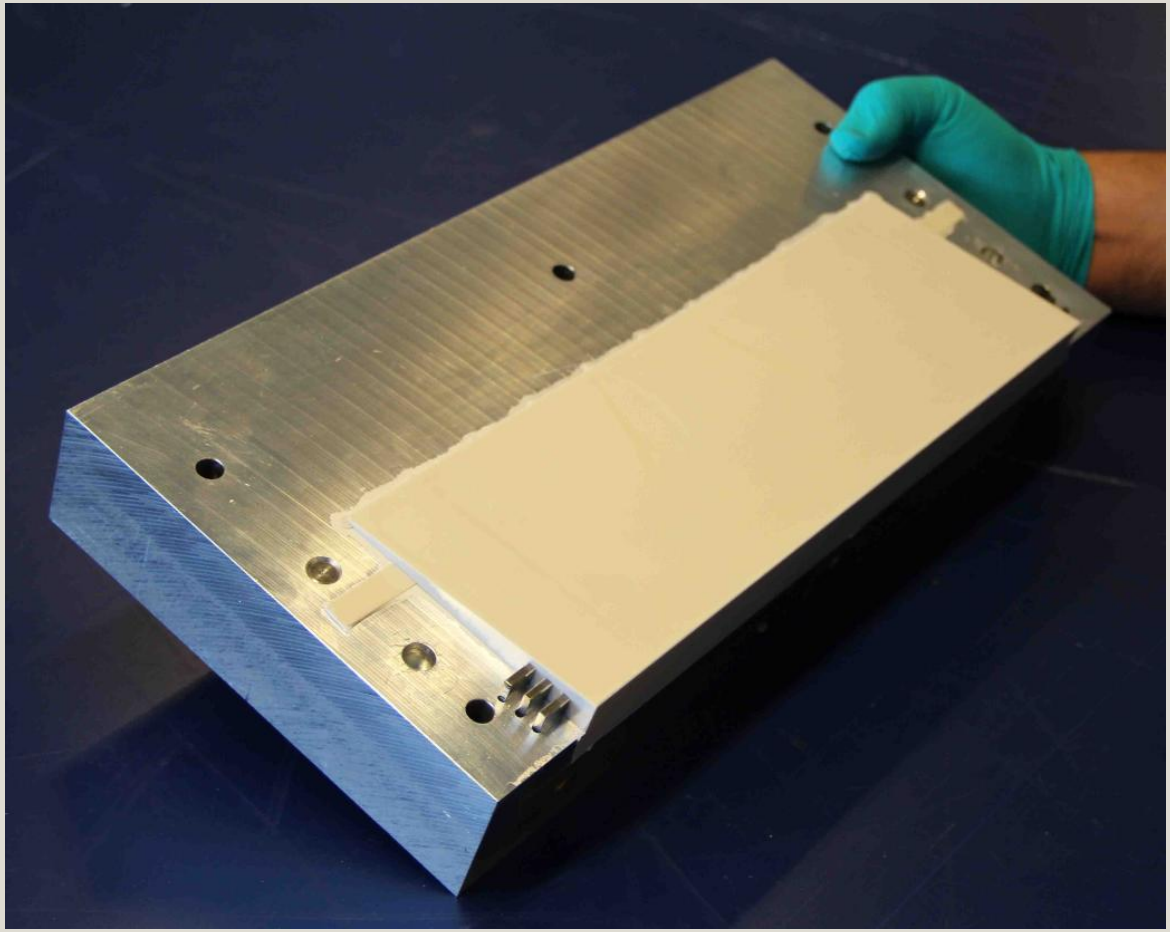


CHORDWISE CAVITIES FOR MOULD MANUFACTORING



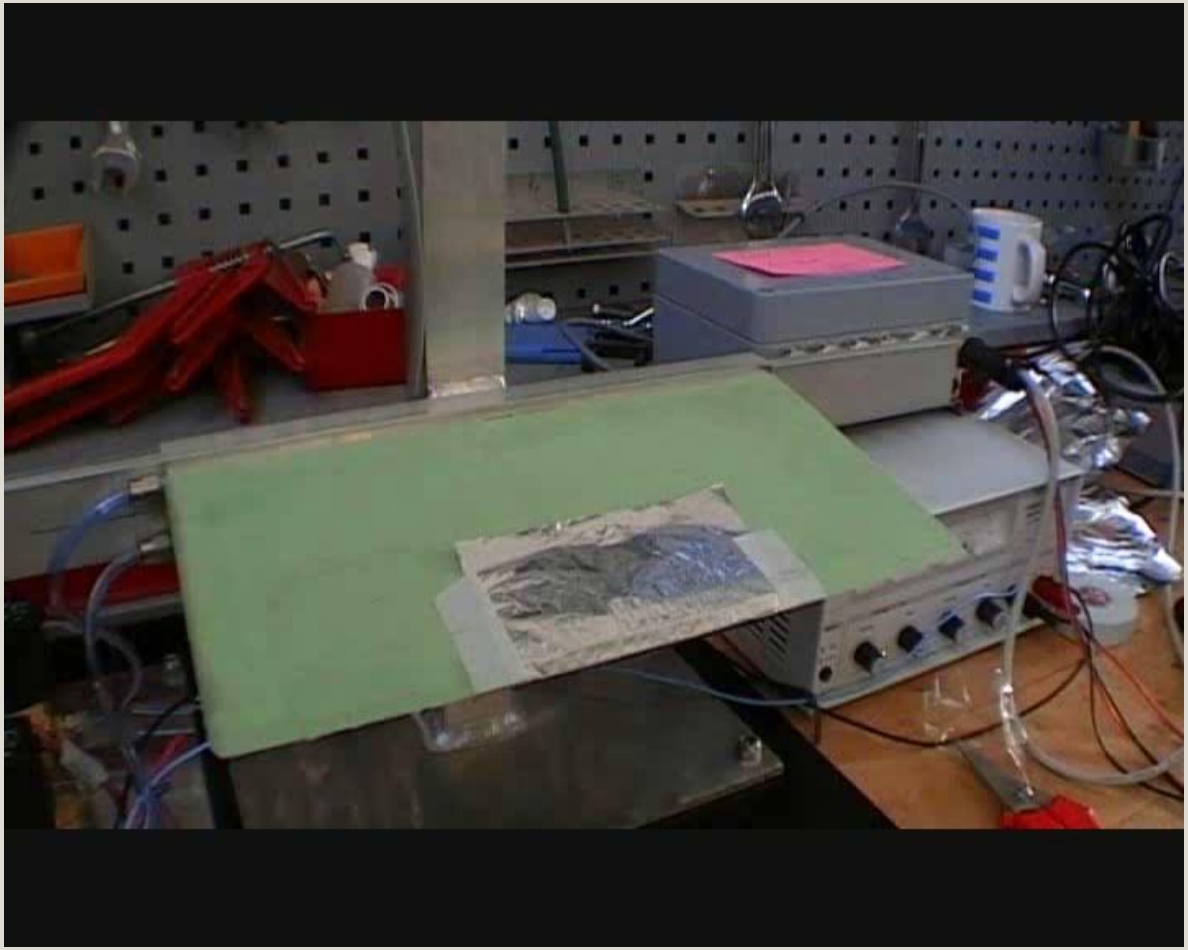
SPANWISE CAVITIES FOR EXTRUSION

RUBBER FLAP (2)



PHENOMATICS HYDROLICS

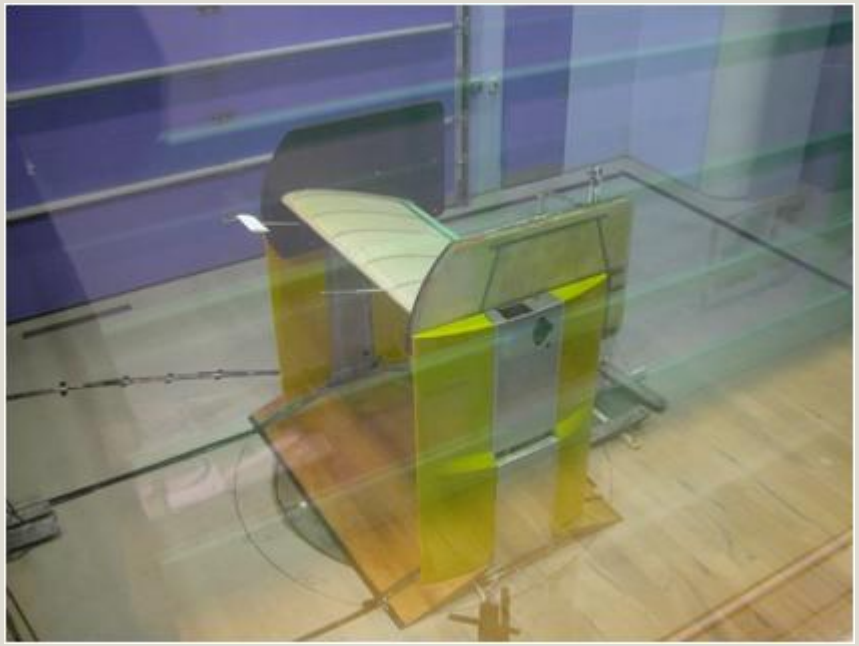
RUBBER FLAP (3)



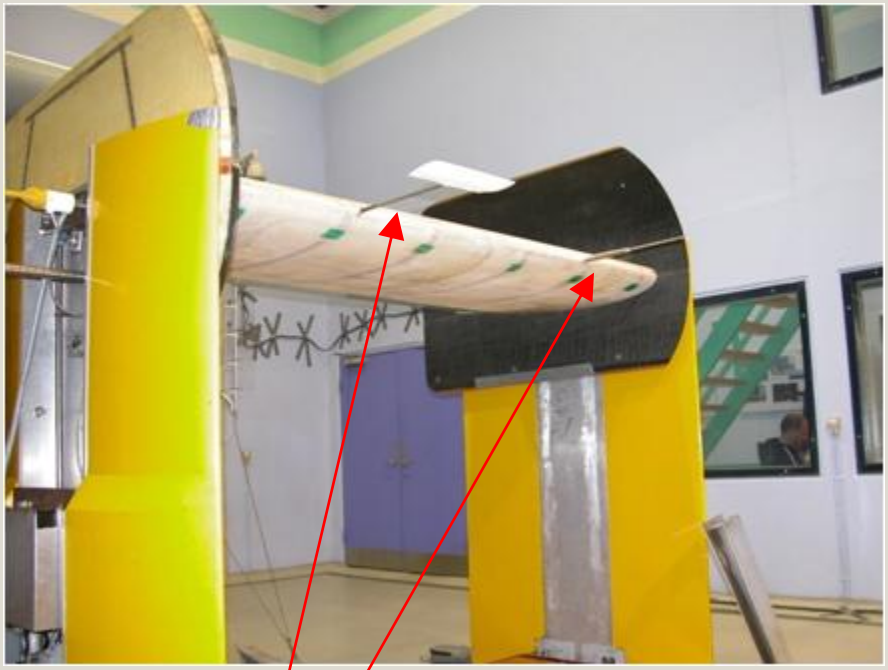
RUBBER FLAP WINDTUNNEL TEST (1)

Instrumentation
2m airfoil section

VELUX wind tunnel
December 2009

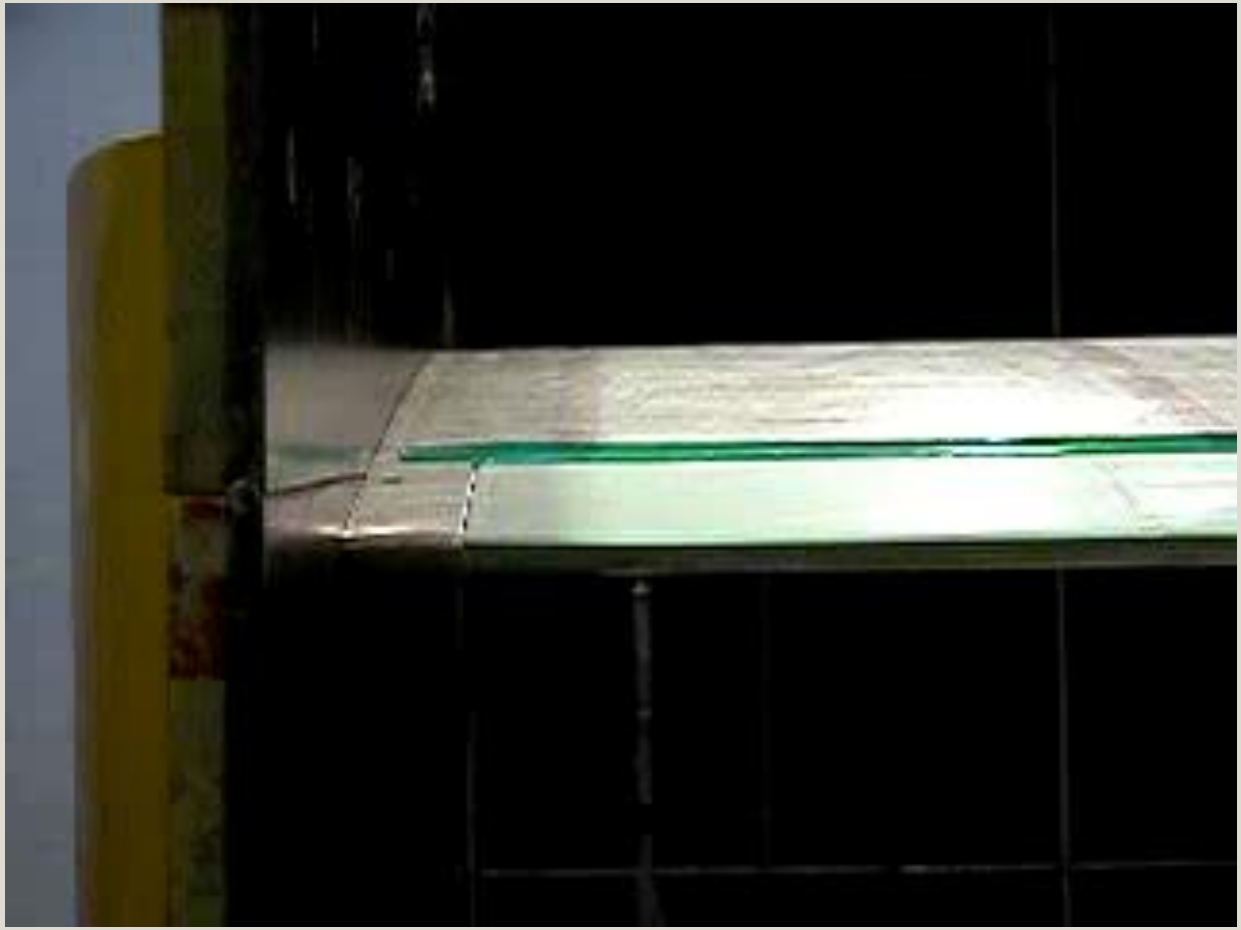


RUBBER FLAP WINDTUNNEL TEST (2)

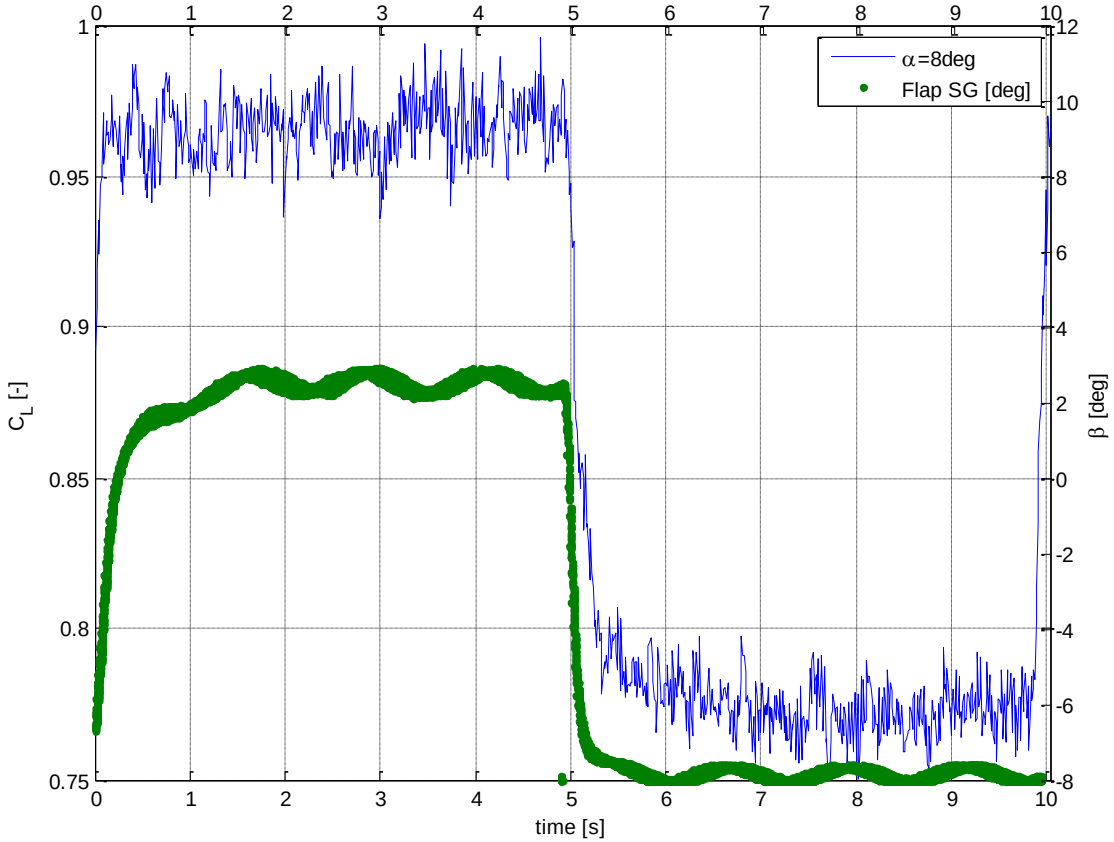


two different inflow sensors

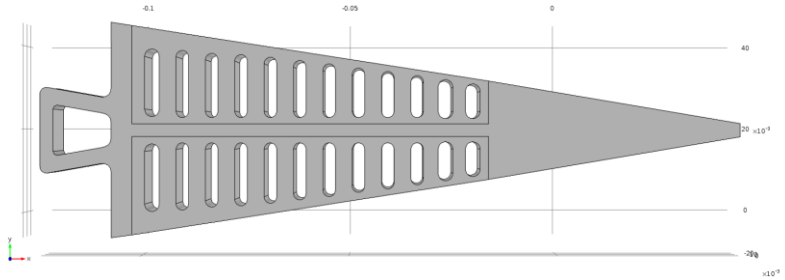
RUBBER FLAP WINDTUNNEL TEST (3)



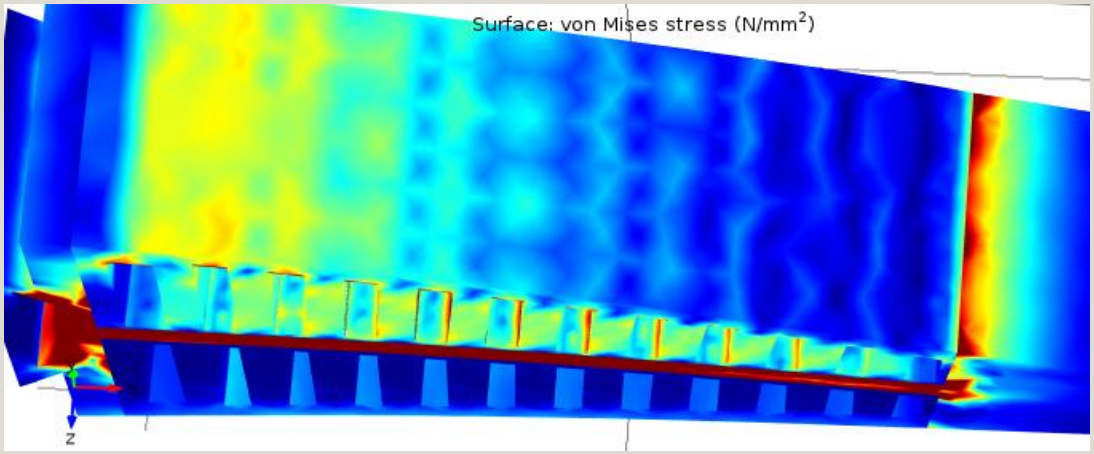
RUBBER FLAP WINDTUNNEL TEST (4)



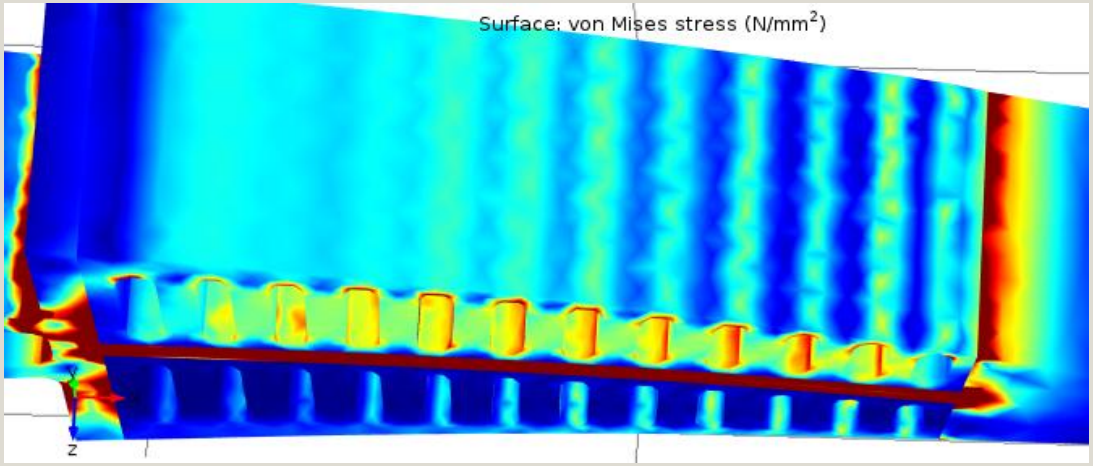
Lift change integrated from airfoil surface pressure taps



NEXT GENERATION DESIGN (1)

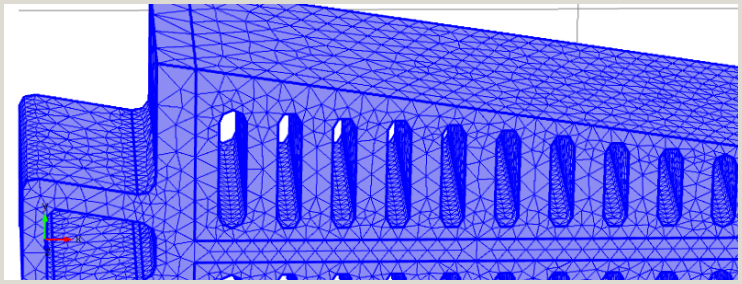


Original design



Next generation

NEXT GENERATION DESIGN (2)



IN COLLABORATION WITH REHAU

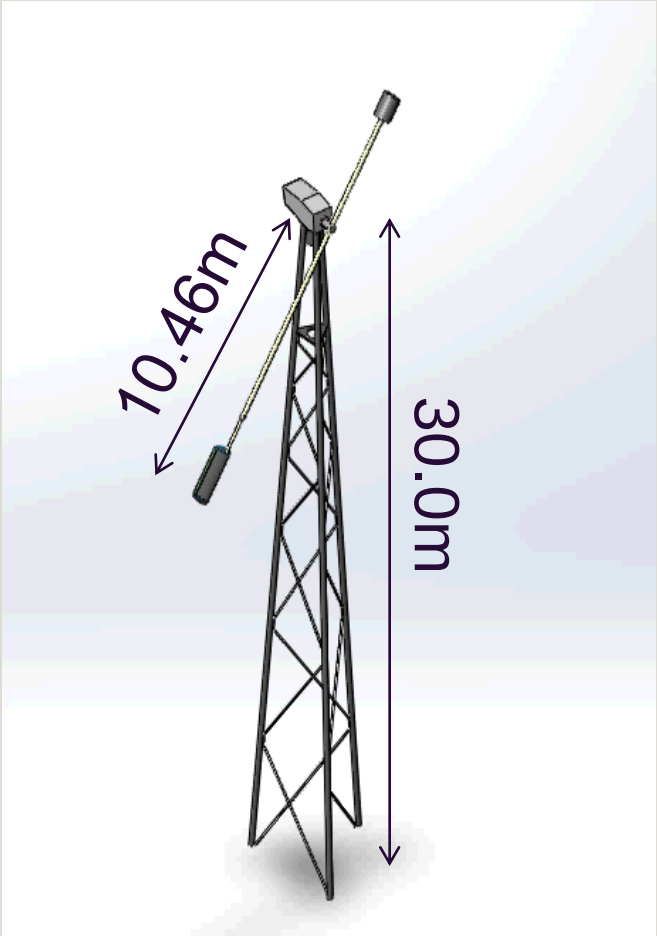
VDI Wissensforum

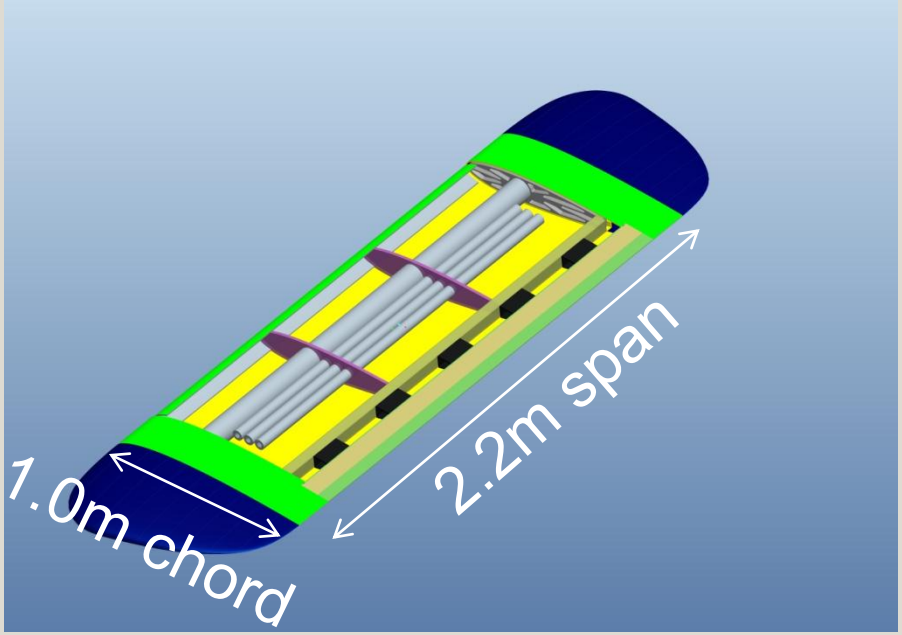
DTU

Challenges in the implementation of the flap system on MW turbines

A NOVEL ROTATING TEST RIG (1)

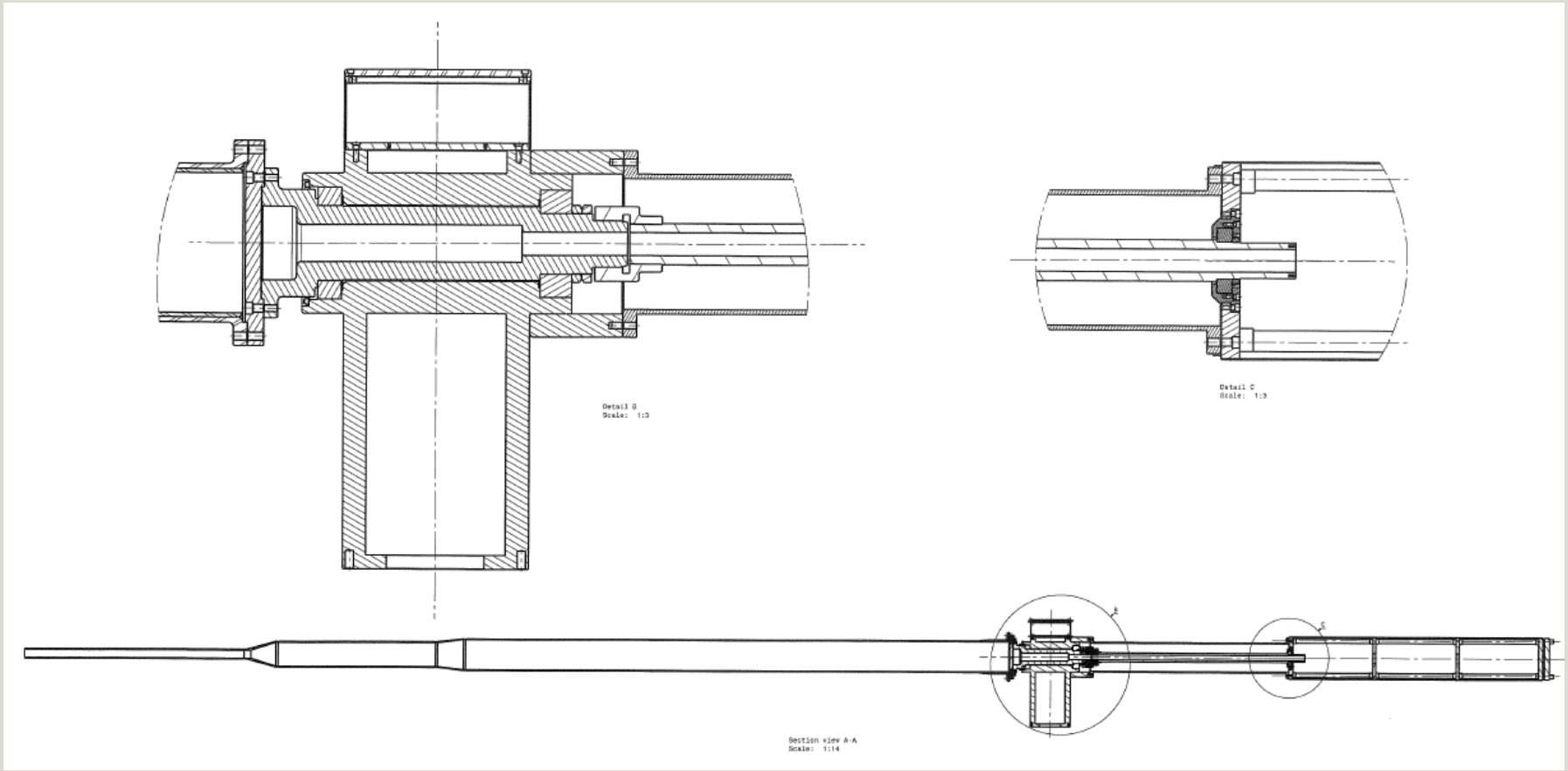
A NOVEL ROTATING TEST RIG (2)



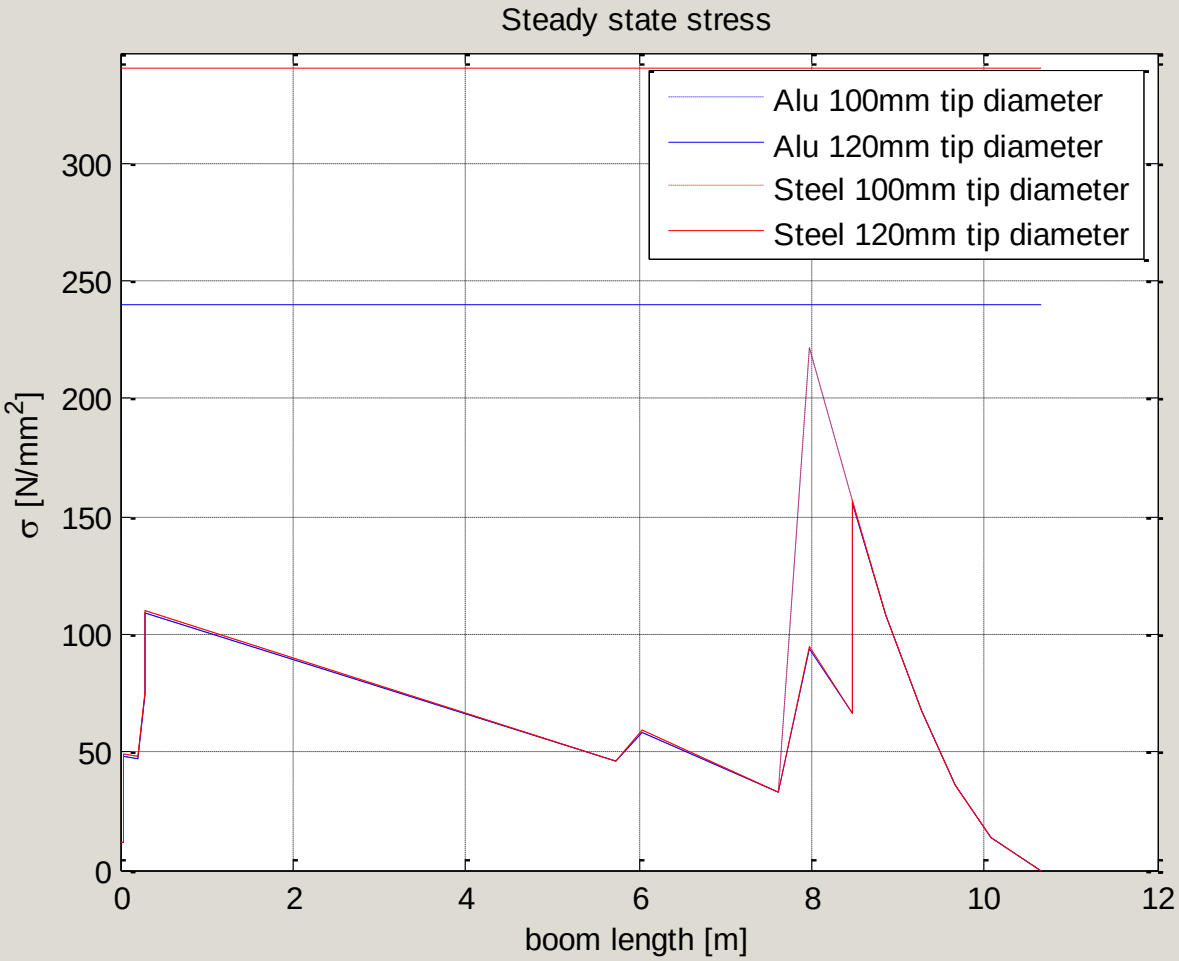


A NOVEL ROTATING TEST RIG (3)

BOOM DESIGN (1)

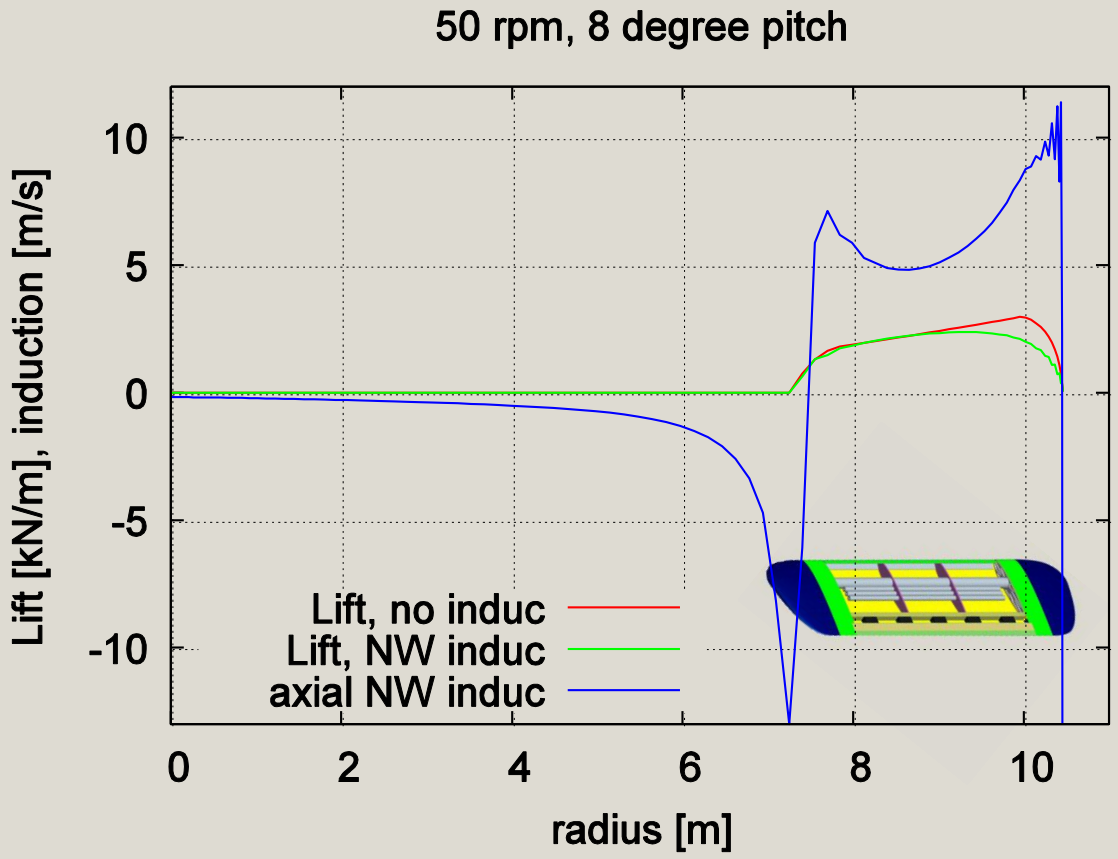


BOOM DESIGN (2)



AERODYNAMICS (1)

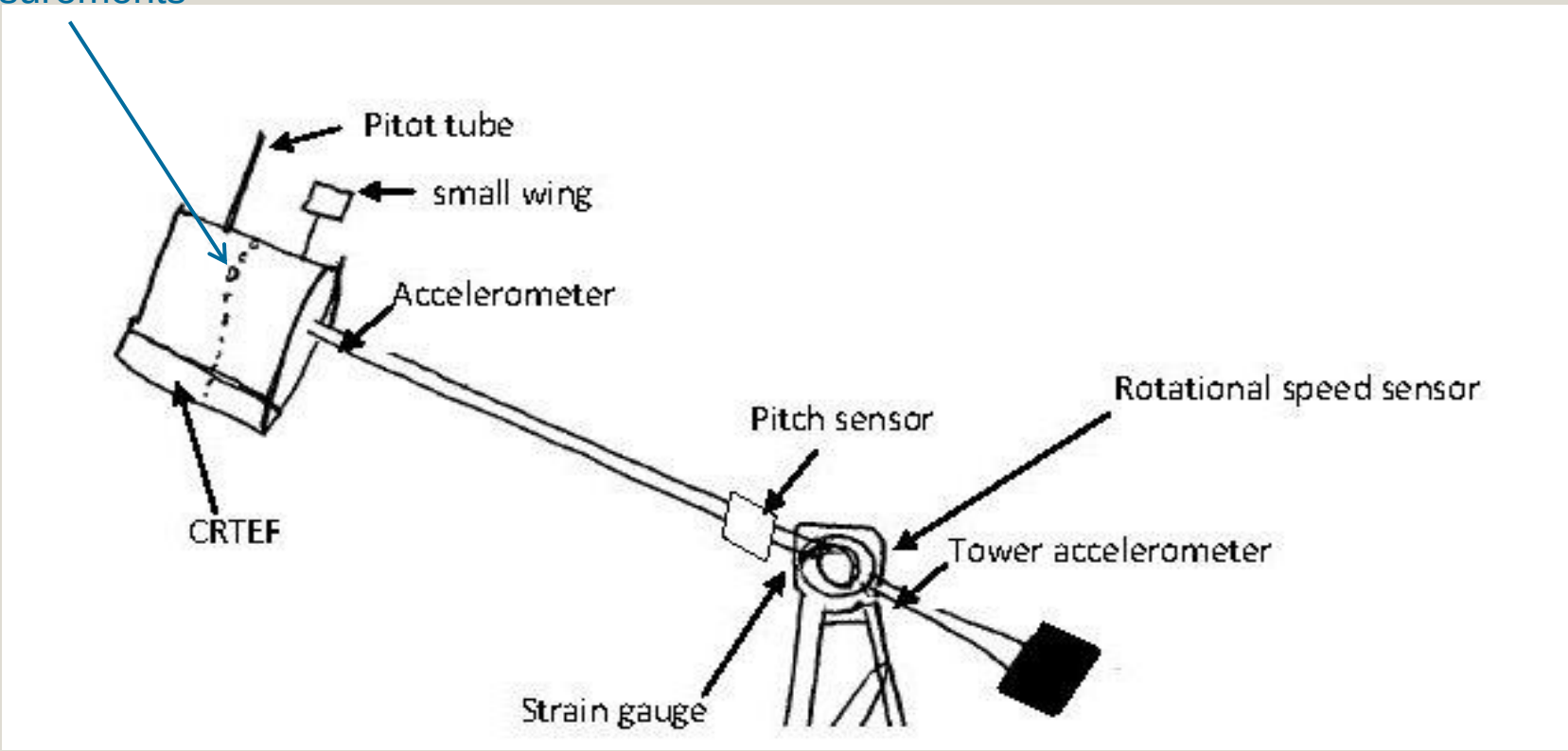
AERODYNAMICS (2)



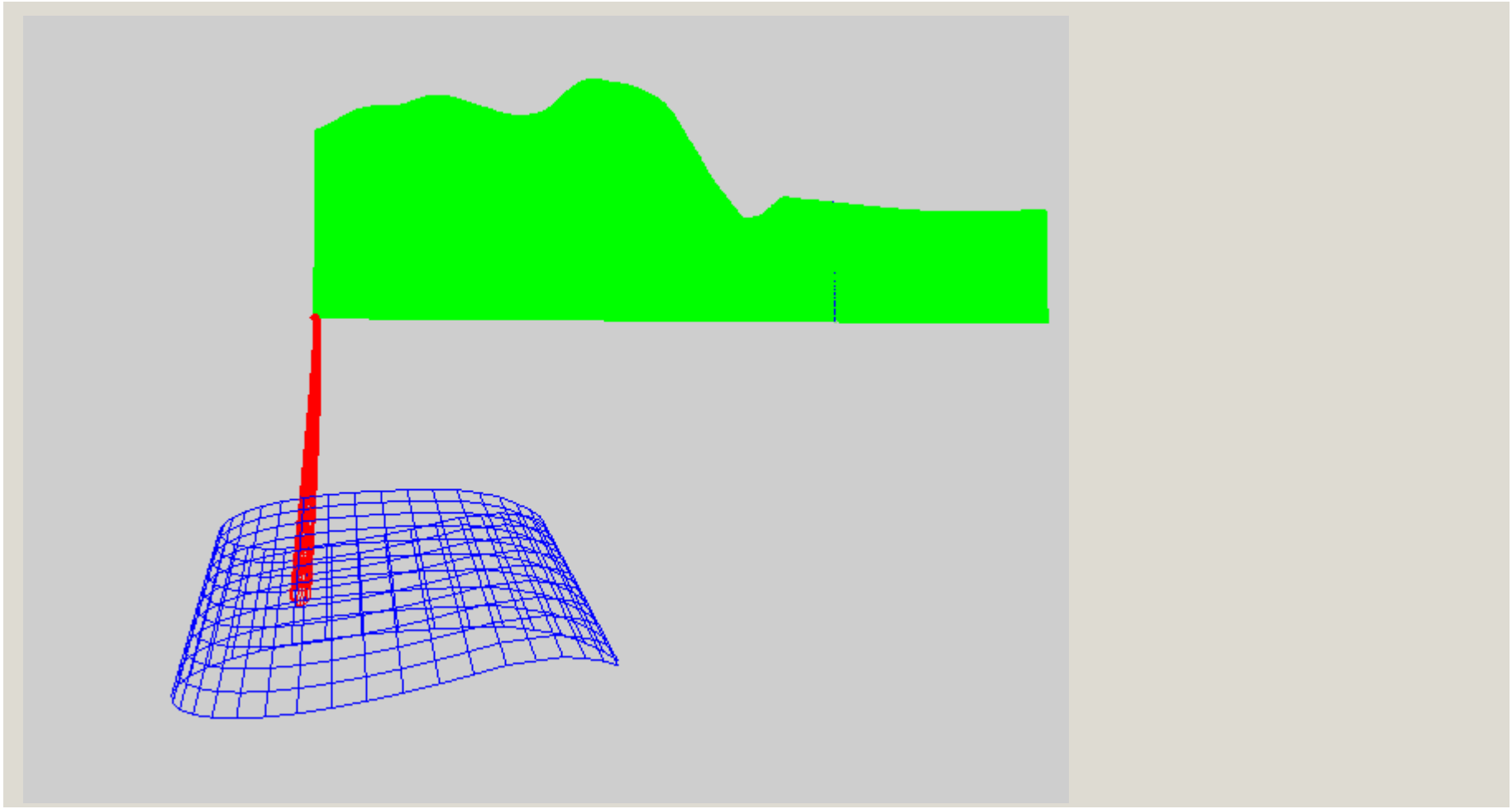
Cortesy of Georg Pirrung

AERODYNAMICS (3)

Pressure measurements



WHAT WE HOPE TO SEE...



OUTLOOK

- tests of flap system and control procedures on the rotating rig in 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 eigencontribution from the partners:

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