Deformable trailing edge geometries and cyclic pitch controller

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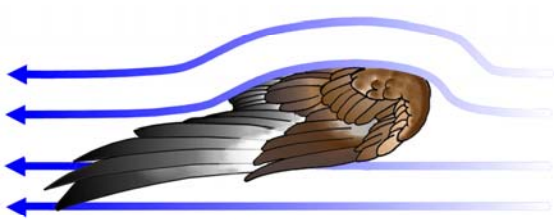

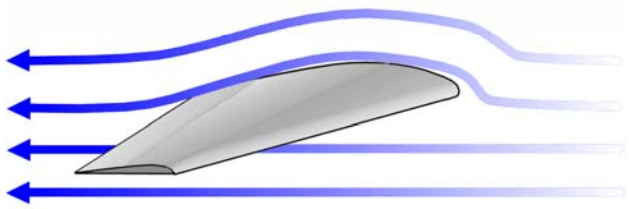

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Introduction 

Controller

Results

Conclusion

Introduction (1:8)

- **1958** Inaugurated. Purpose: Peaceful utilisation of nuclear energy
- **1976** Oil crises (1973) results in research in other Energy sources
- **1978** Research in Wind Energy starts
- **1985** Political decision of not having nuclear energy in Denmark
- **1994** State-owned enterprise
- **2000** The last nuclear reactor is shut down
- **2007** Merger with DTU, the Danish Institute for Food and Veterinary Research, the Danish Institute for Fisheries Research, the Danish National Space Centre and the Danish Transport Research Institute

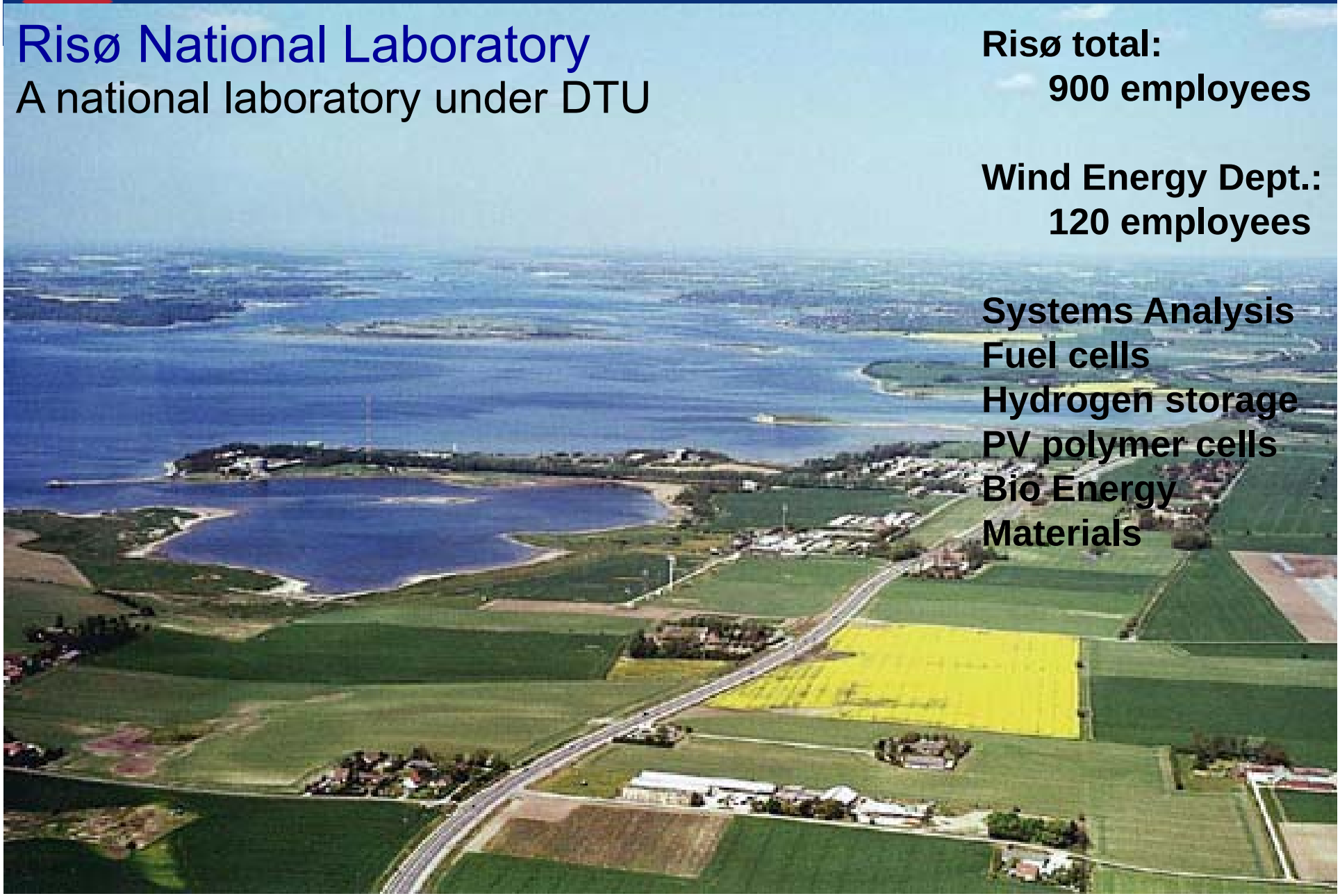
Risø National Laboratory

A national laboratory under DTU

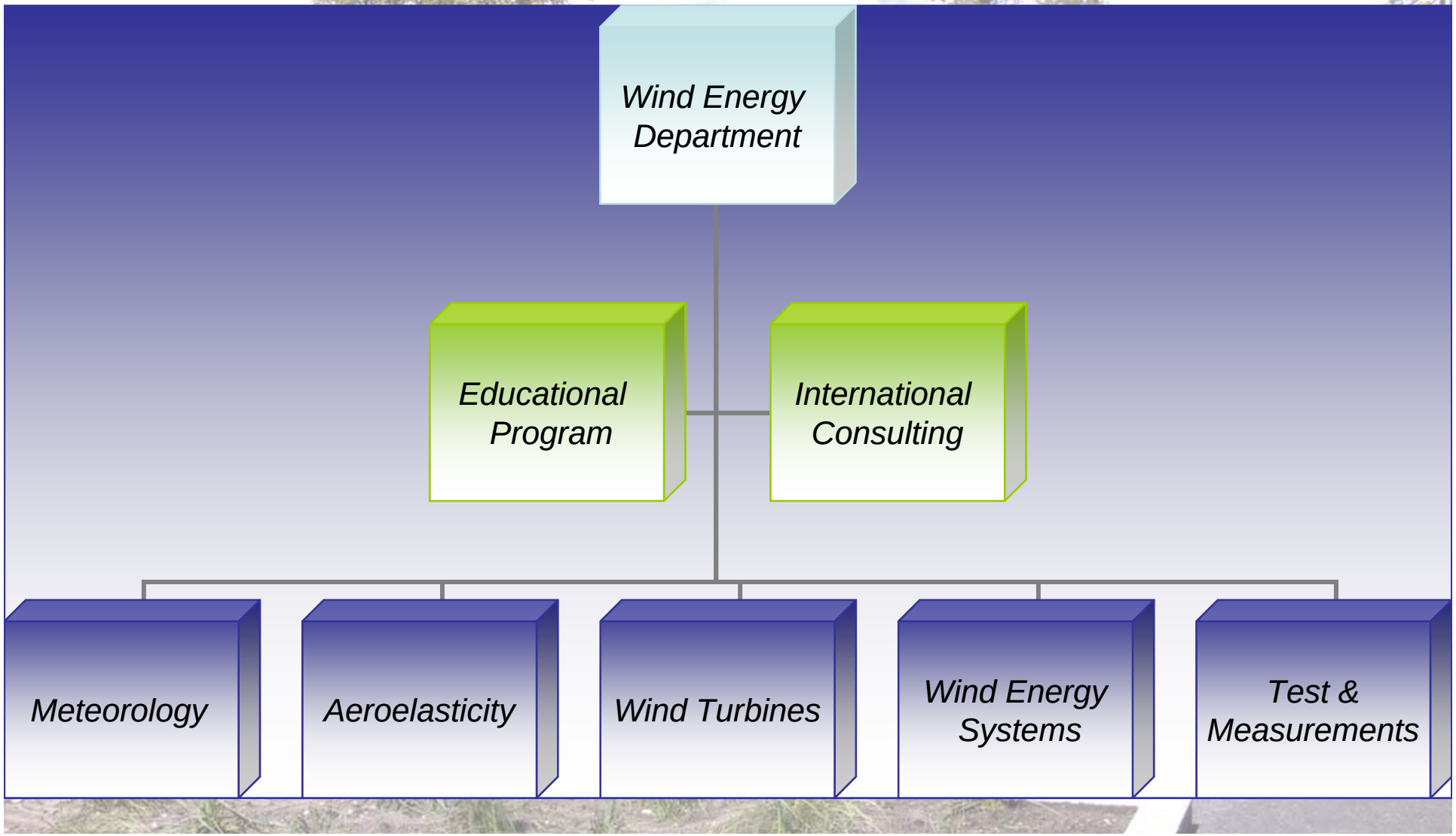
Risø total:
900 employees

Wind Energy Dept.:
120 employees

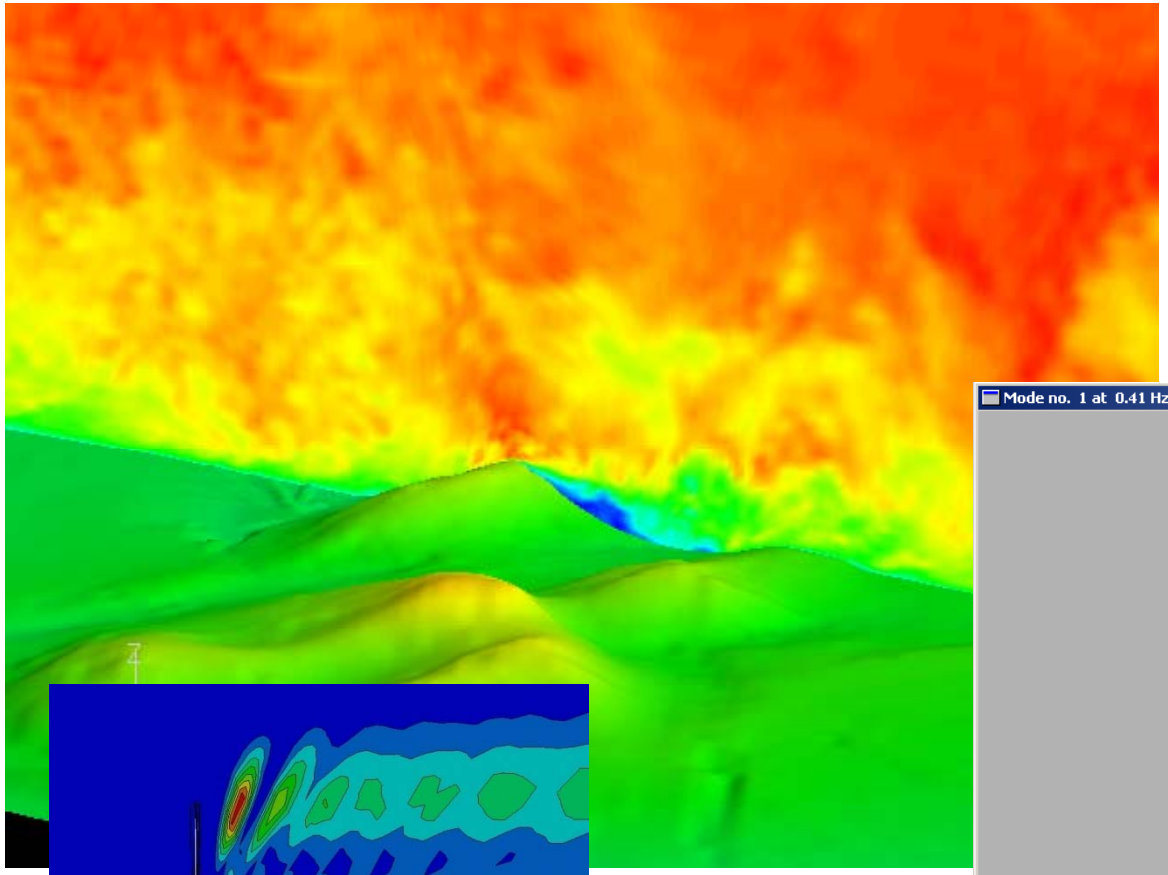
Systems Analysis
Fuel cells
Hydrogen storage
PV polymer cells
Bio Energy
Materials

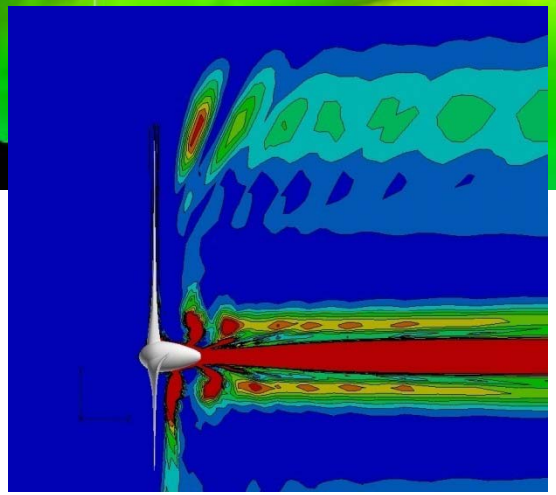


Introduction (3:8)



Introduction (4:8)



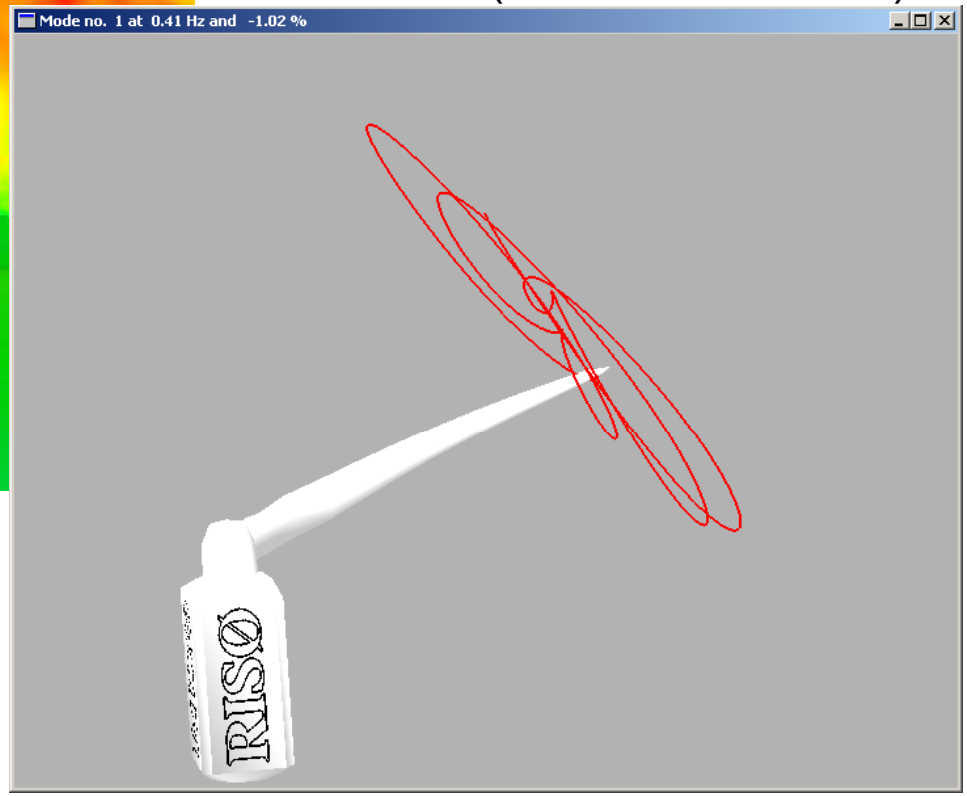


EllipSys (2D and 3D)

HAWC2 (and HAWC)

HAWTOpt

HAWCStab (soon HAWCStab2)



Introduction (5:8)

Sensors and DTEG positions

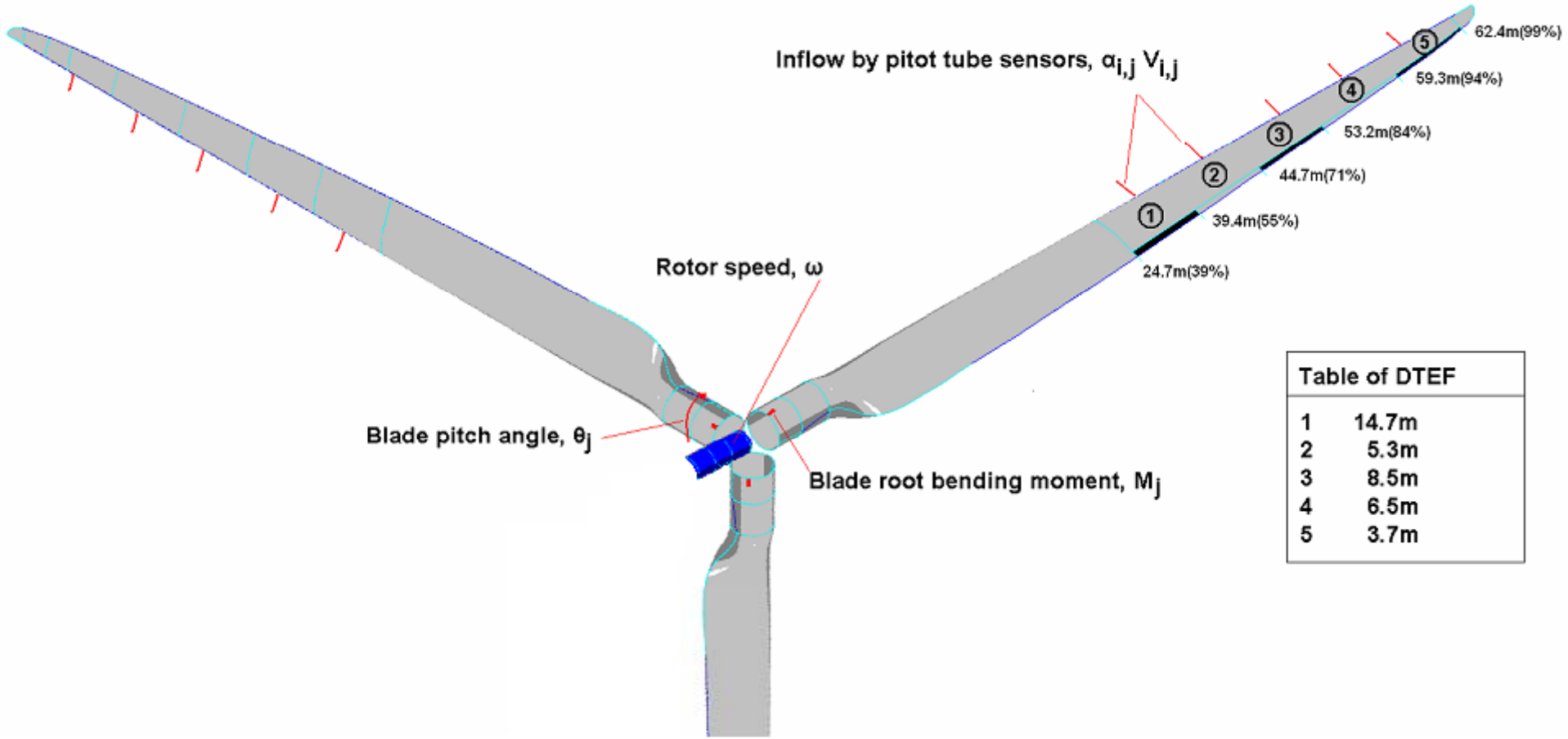


Table of DTEF	
1	14.7m
2	5.3m
3	8.5m
4	6.5m
5	3.7m

Peter B. Andersen, Mac Gaunaa, Christian Bak, Helge Aa. Madsen
Frederik Zahle, Joachim Heinz, Leonardo Bergami, Li Na, Andreas Fisher

DTEG Property assumptions:

10% of chord

+/- 8 degree deflection possible

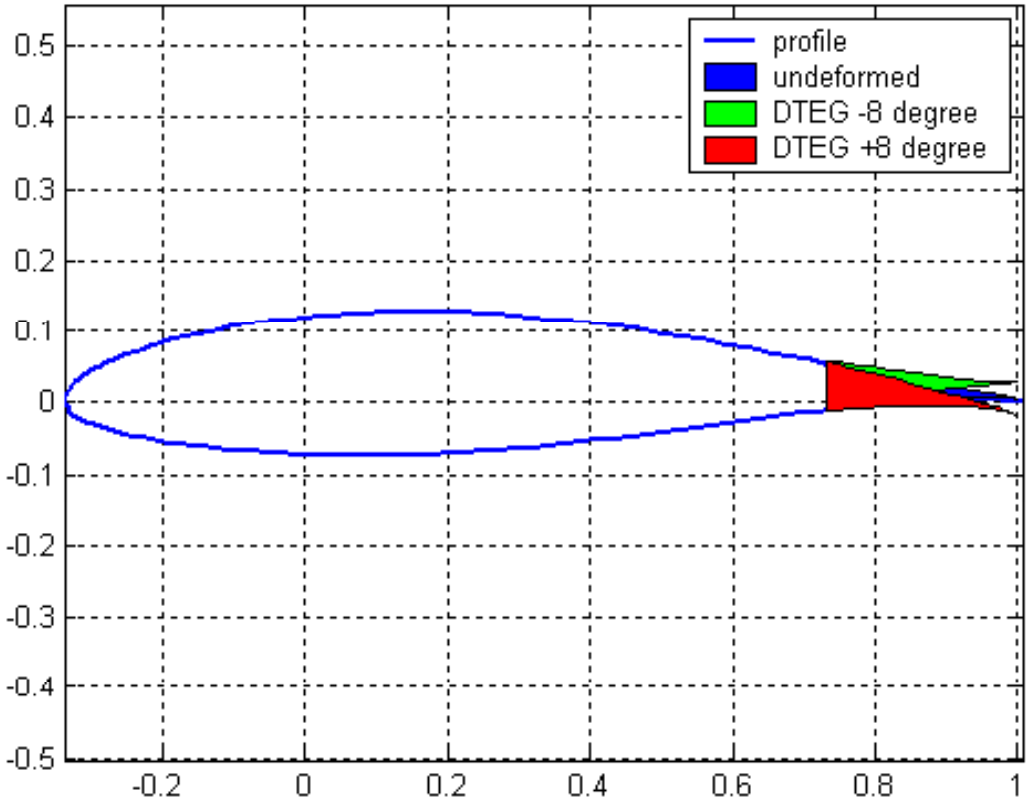
from +/-8 to -/+8 in simulated “dt” (=0.01s)

no effects of hysteresis

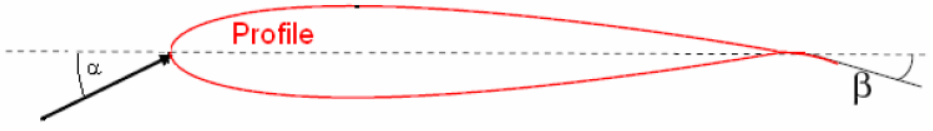
no overshoot or other dynamics

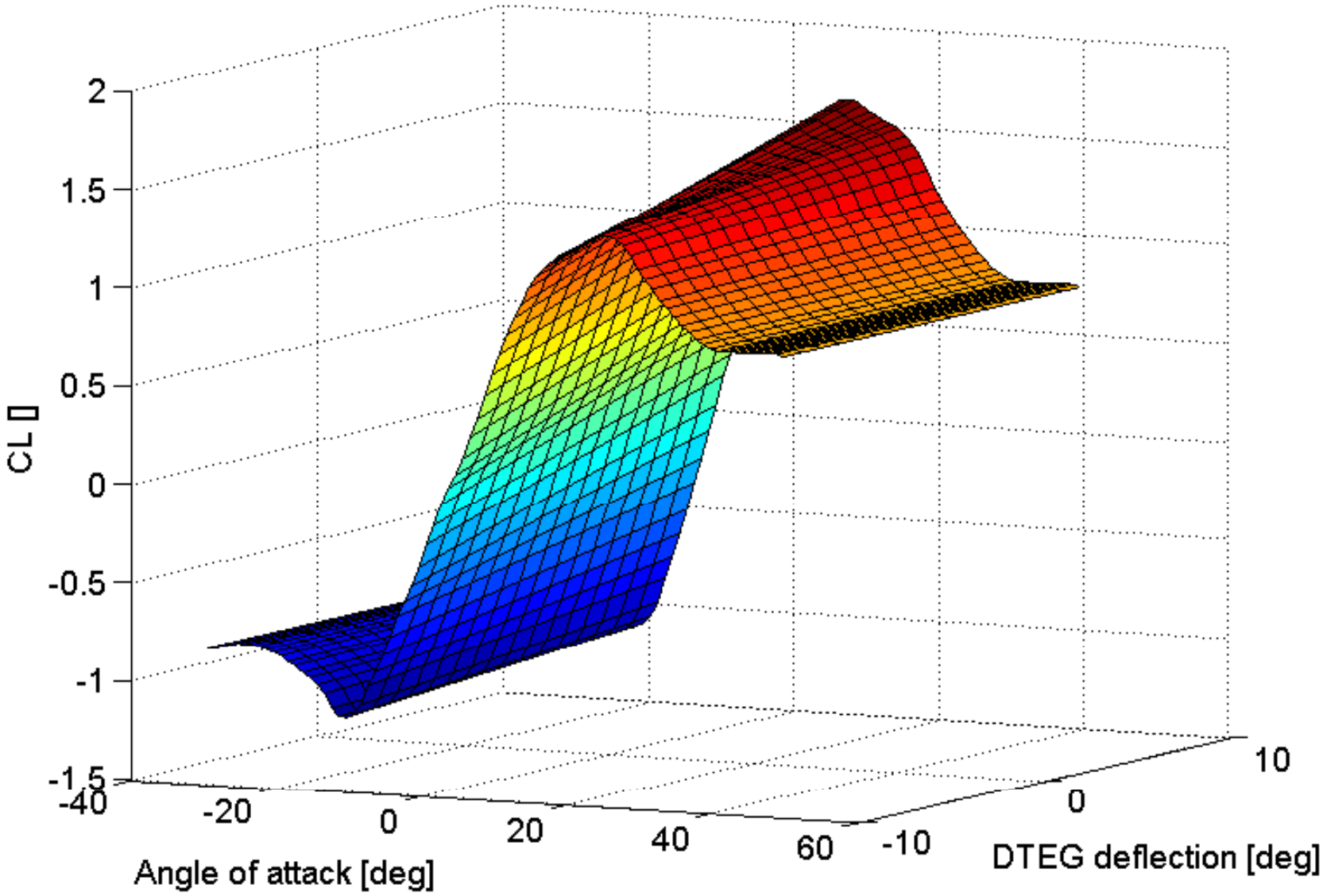
max ΔCL(α,β=8deg) = 0.29

min ΔCL(α,β=-8deg) = -0.29

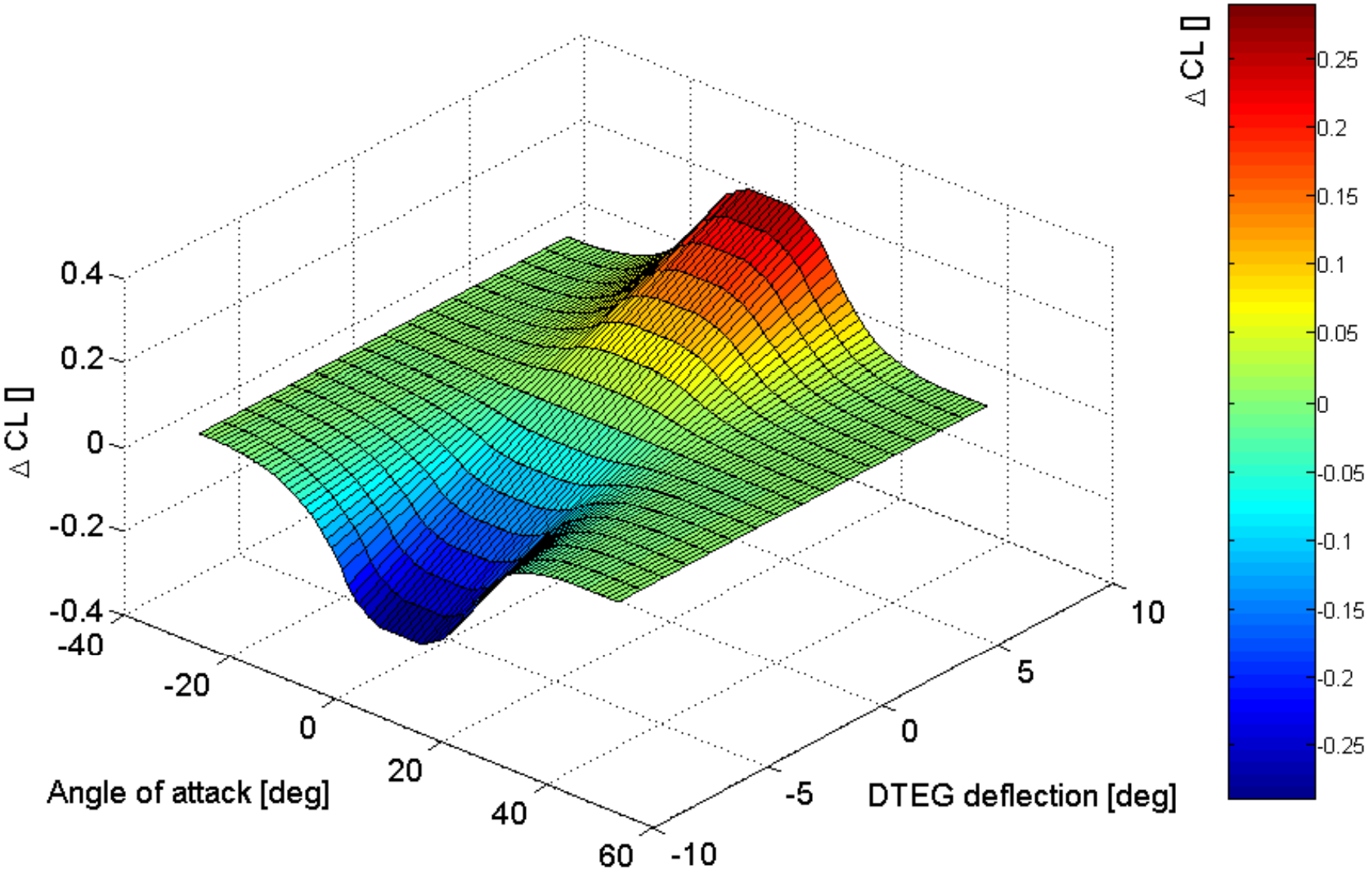


Introduction (7:8)





Introduction (8:8)



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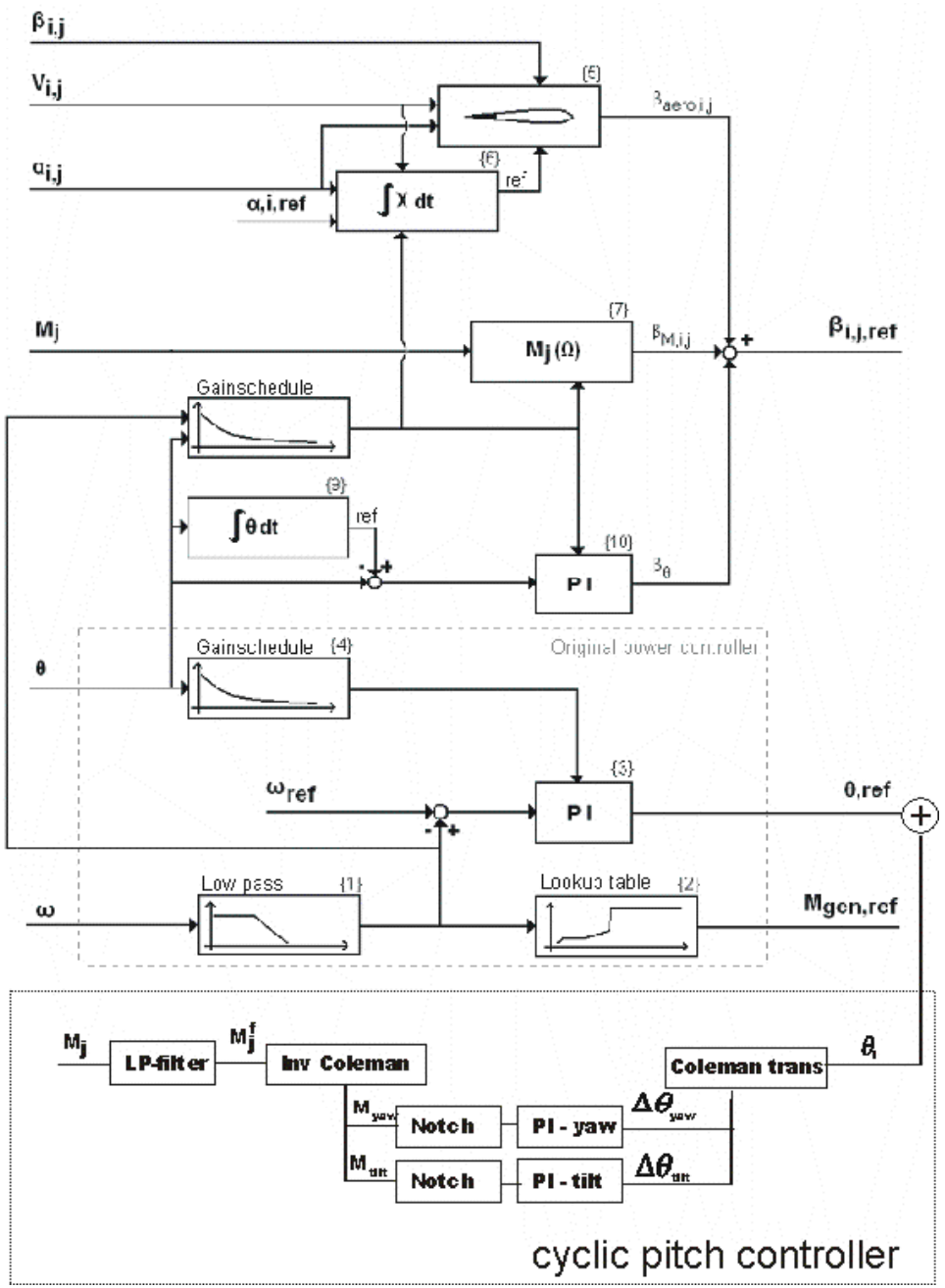
Controller (1:6)

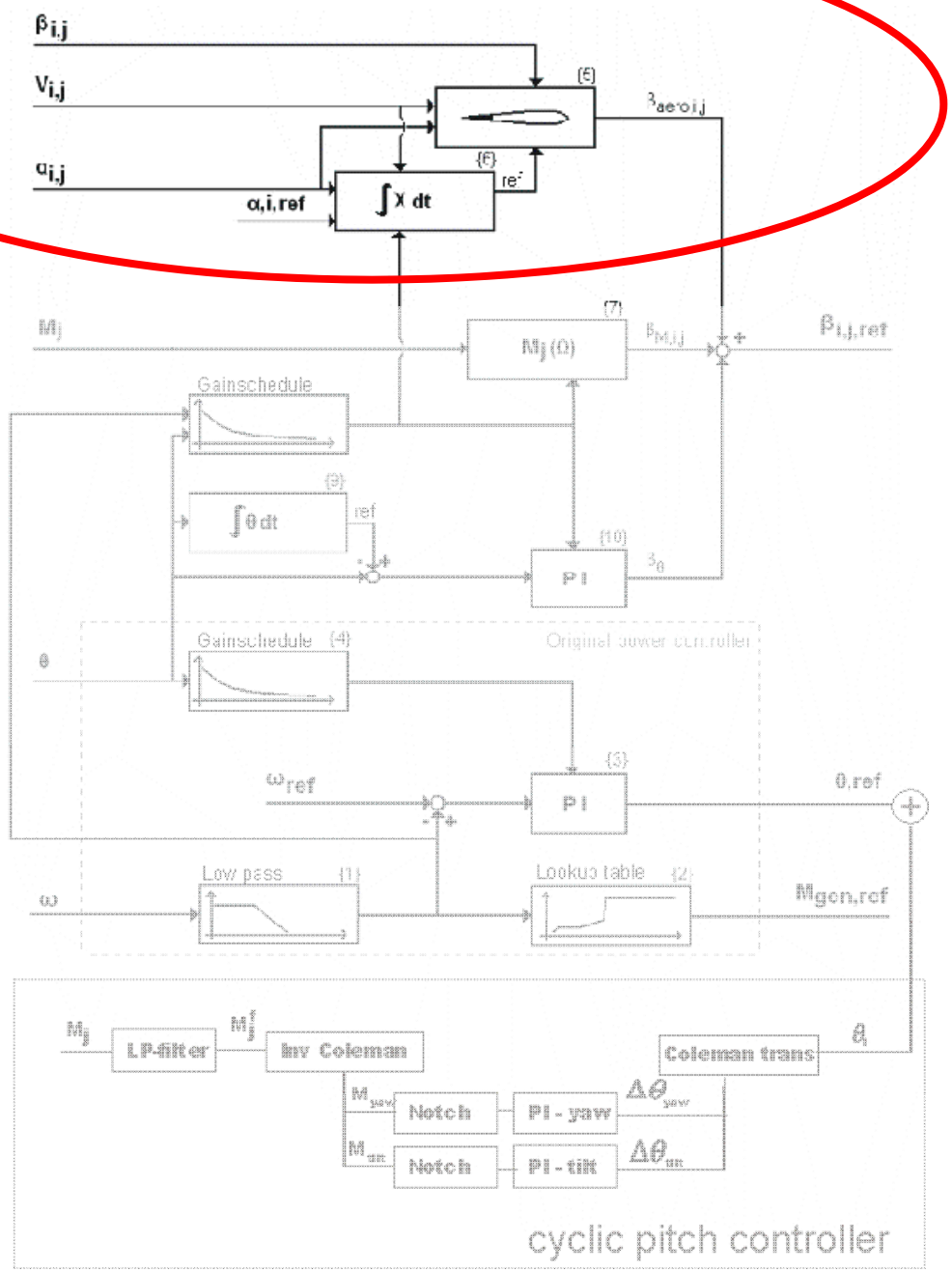


Controller (2:6)

An ”inverse” Theodorsen/Gaunaa model

Possibility to use running averages or reference AOA values. (The K_α factor)

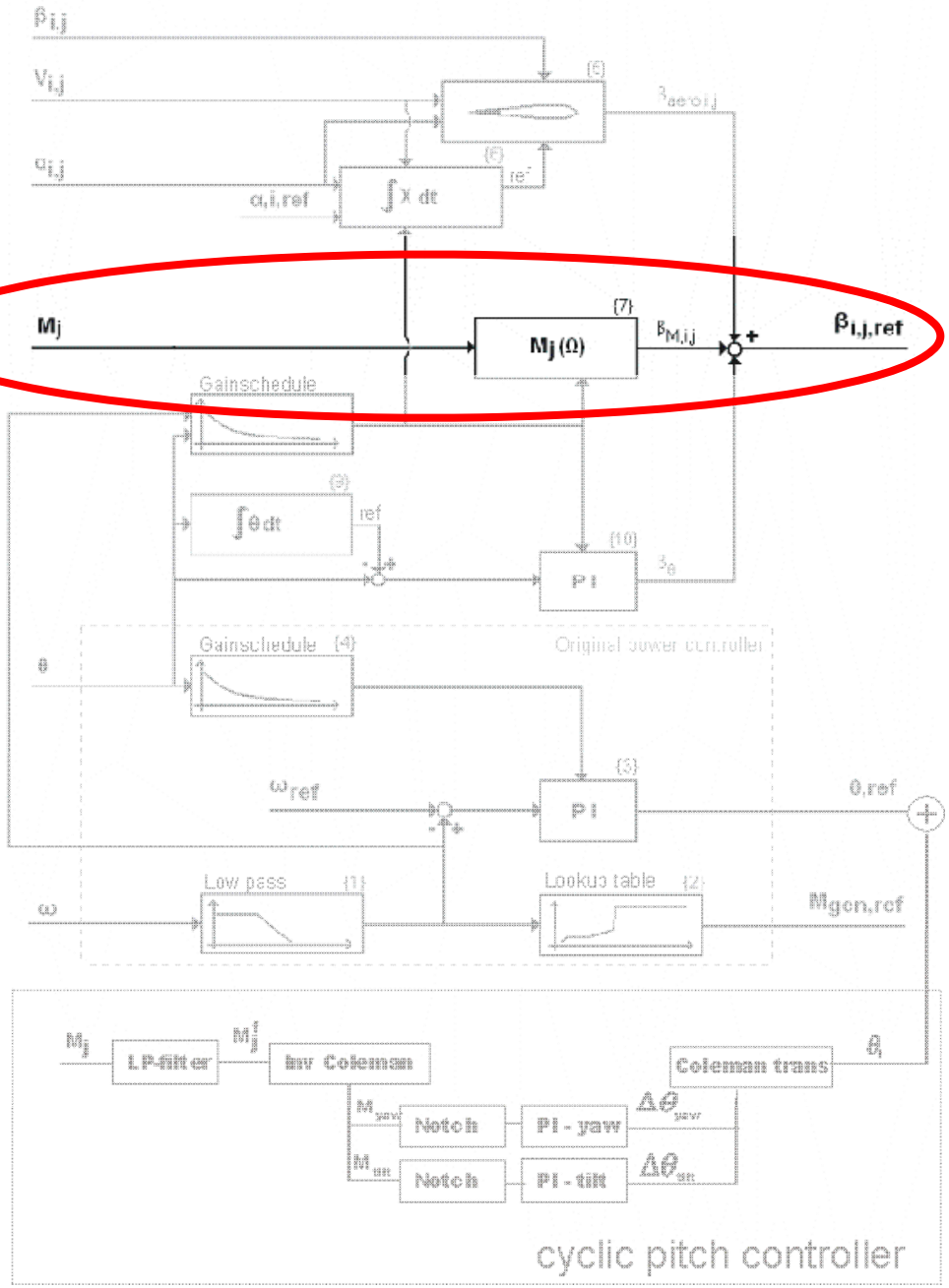
Objective: level out ”stochastic” signal AOA / Vrel



Controller (3:6)

An elastic response model

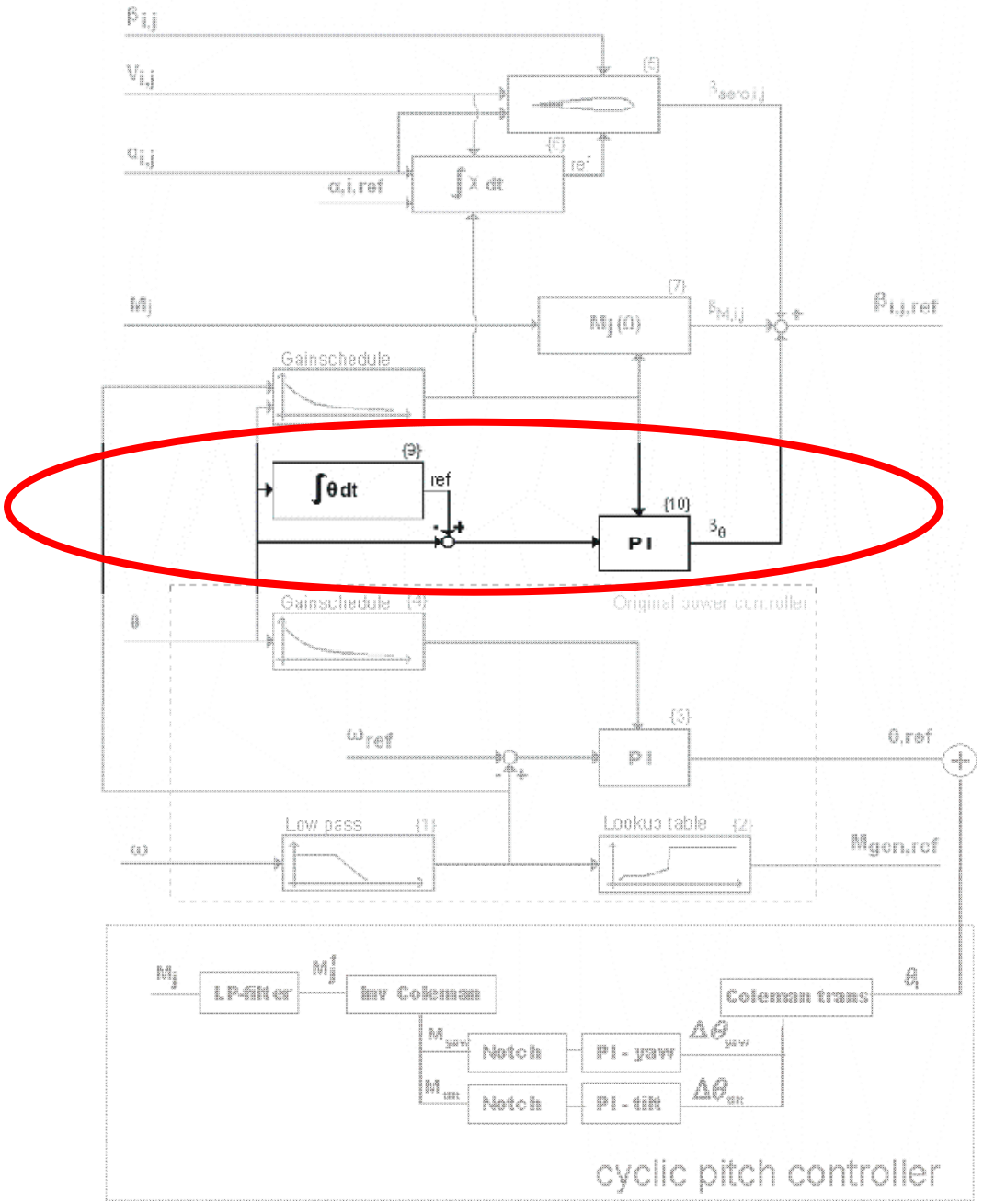
Objective: level out “deterministic” signal Mj (blade root moment)



Controller (4:6)

Pitch communication model

Objective: DTEG and blade pitch work together



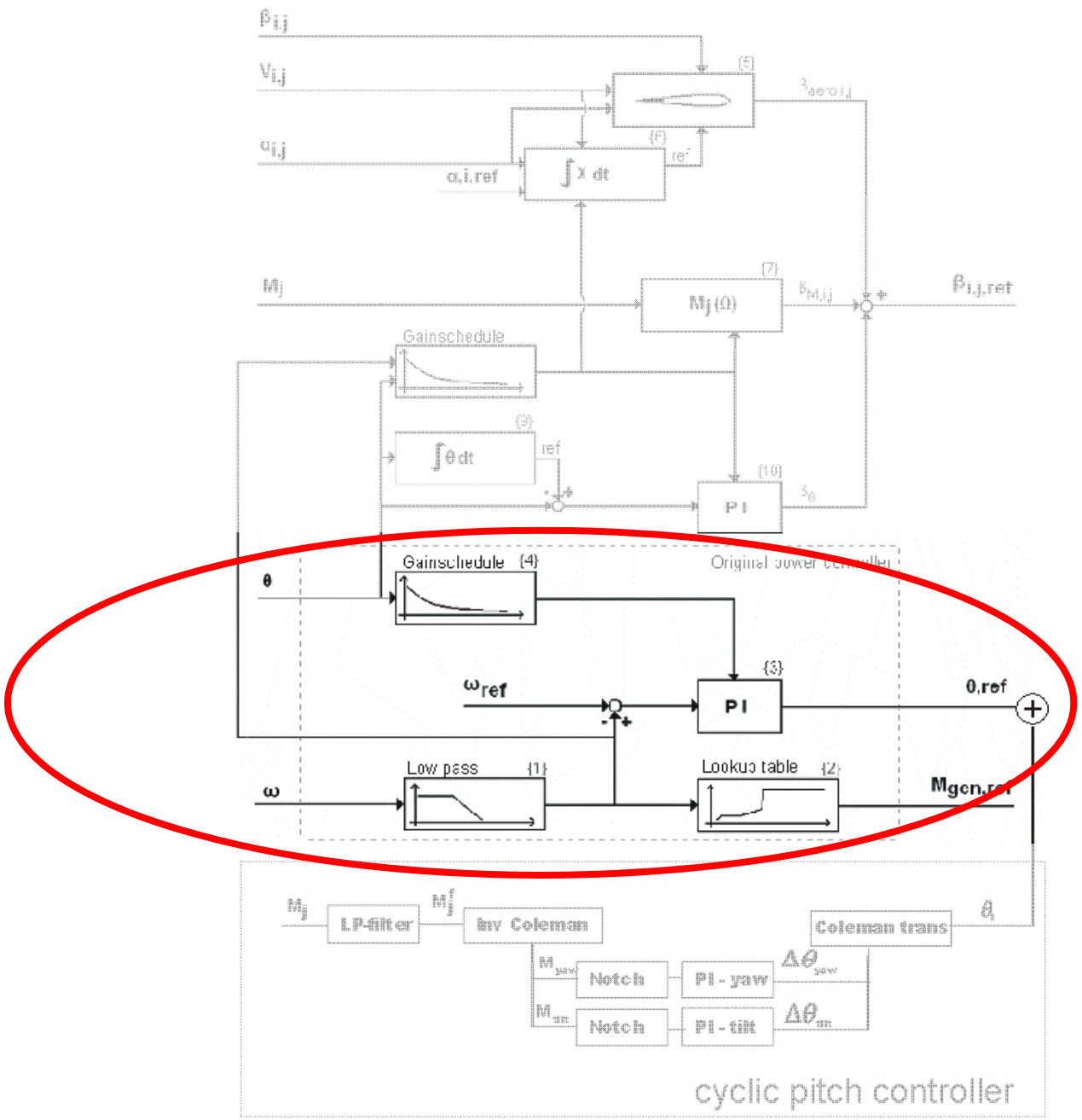
Controller (5:6)

pitch servo modeled as a 2nd order system

max pitch rate: 8 degree/sec

Power controller model:

Omega filter to remove ”free-free” oscillations



Controller (6:6)

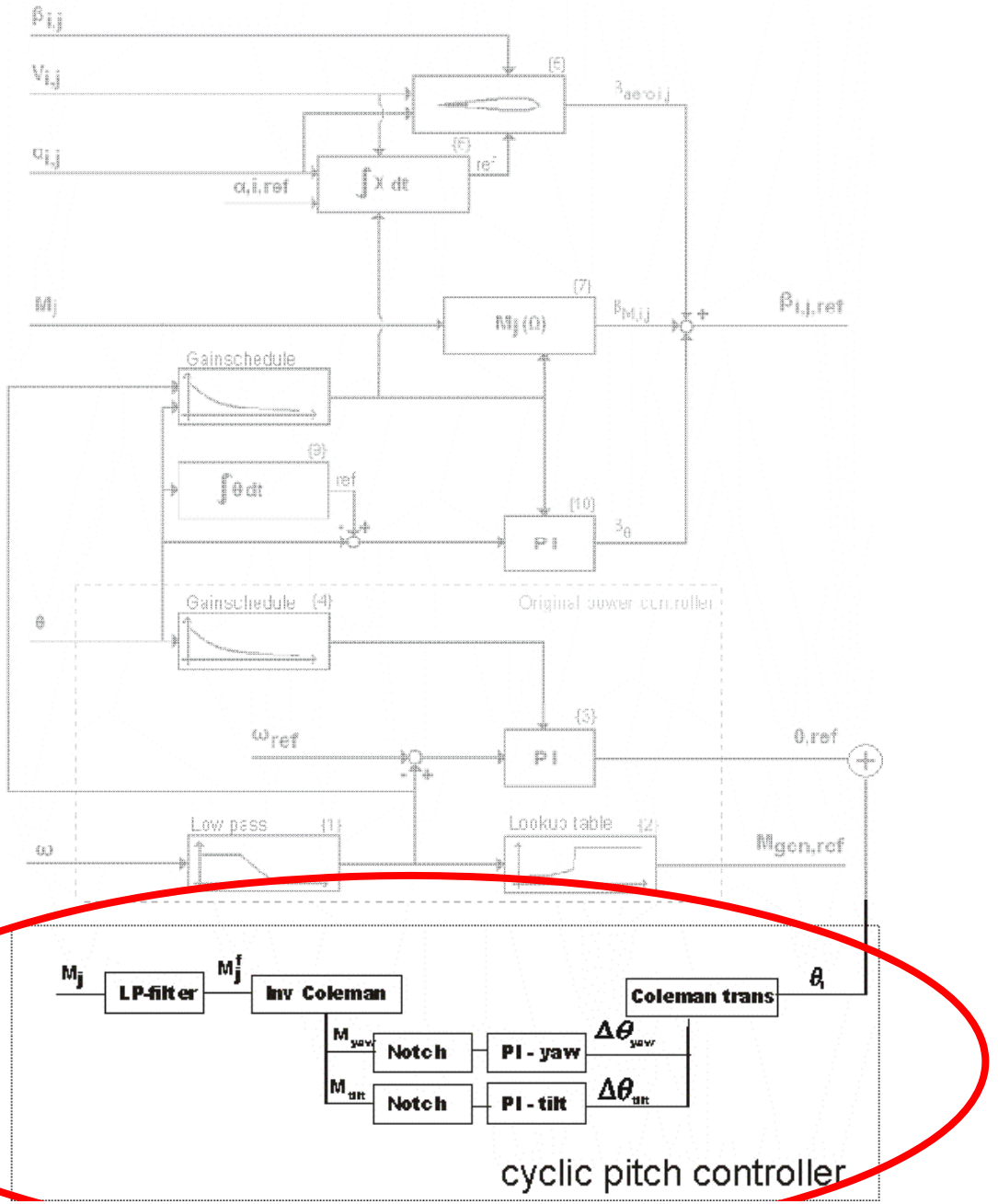
Cyclic pitch controller
Invers Coleman transformation

Notch filter

PI on yaw and tilt

Coleman transformation

additional pitch angle output



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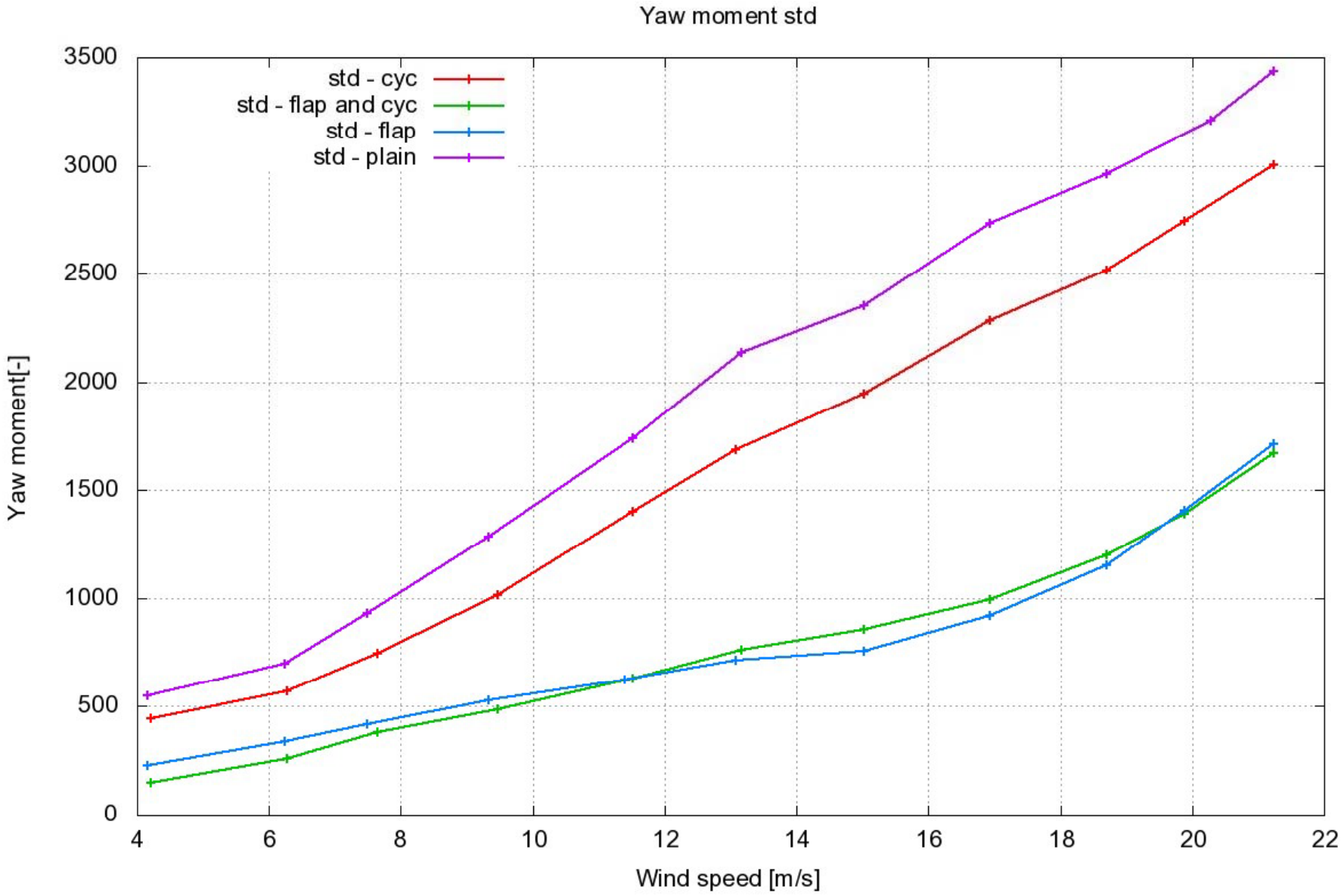
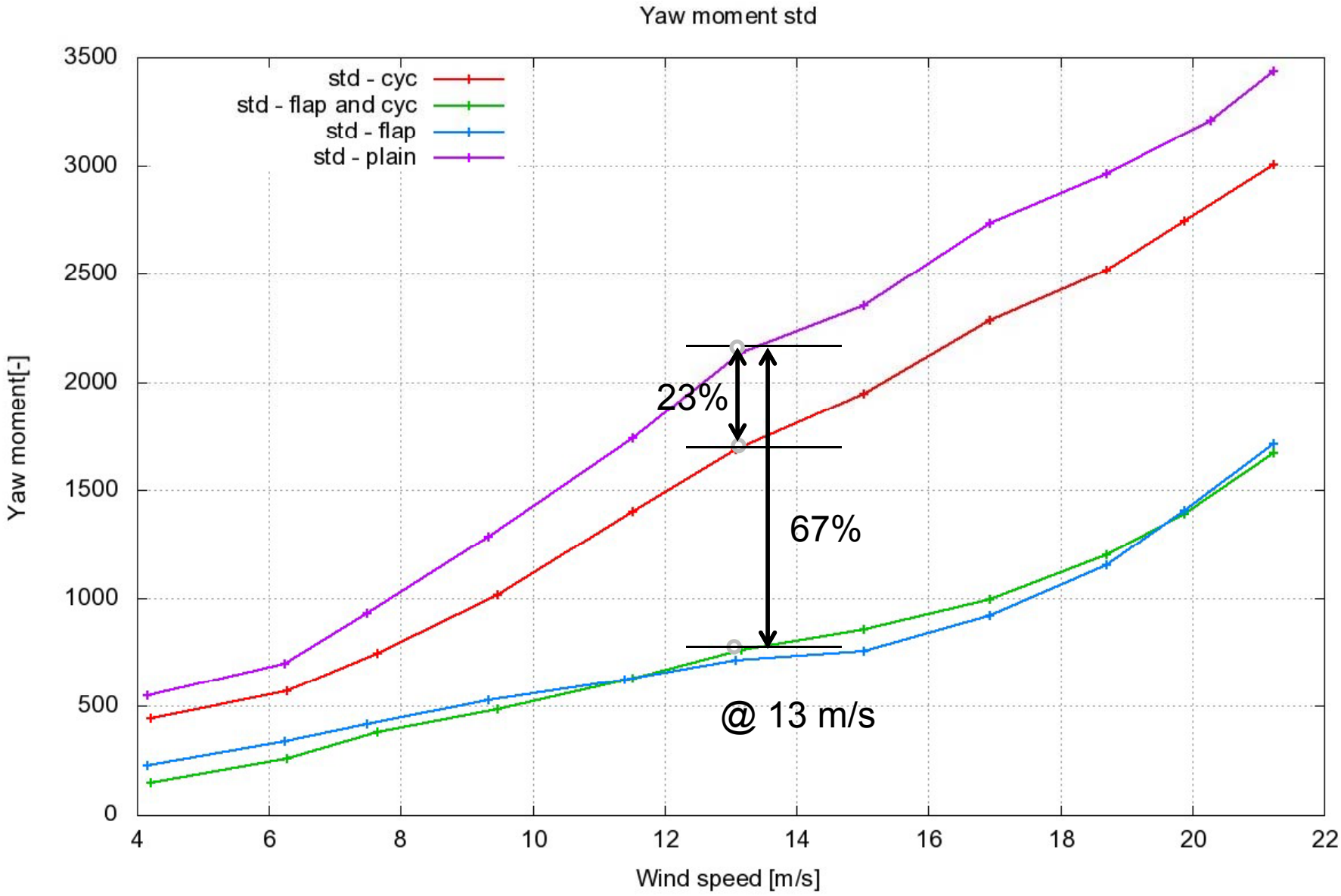
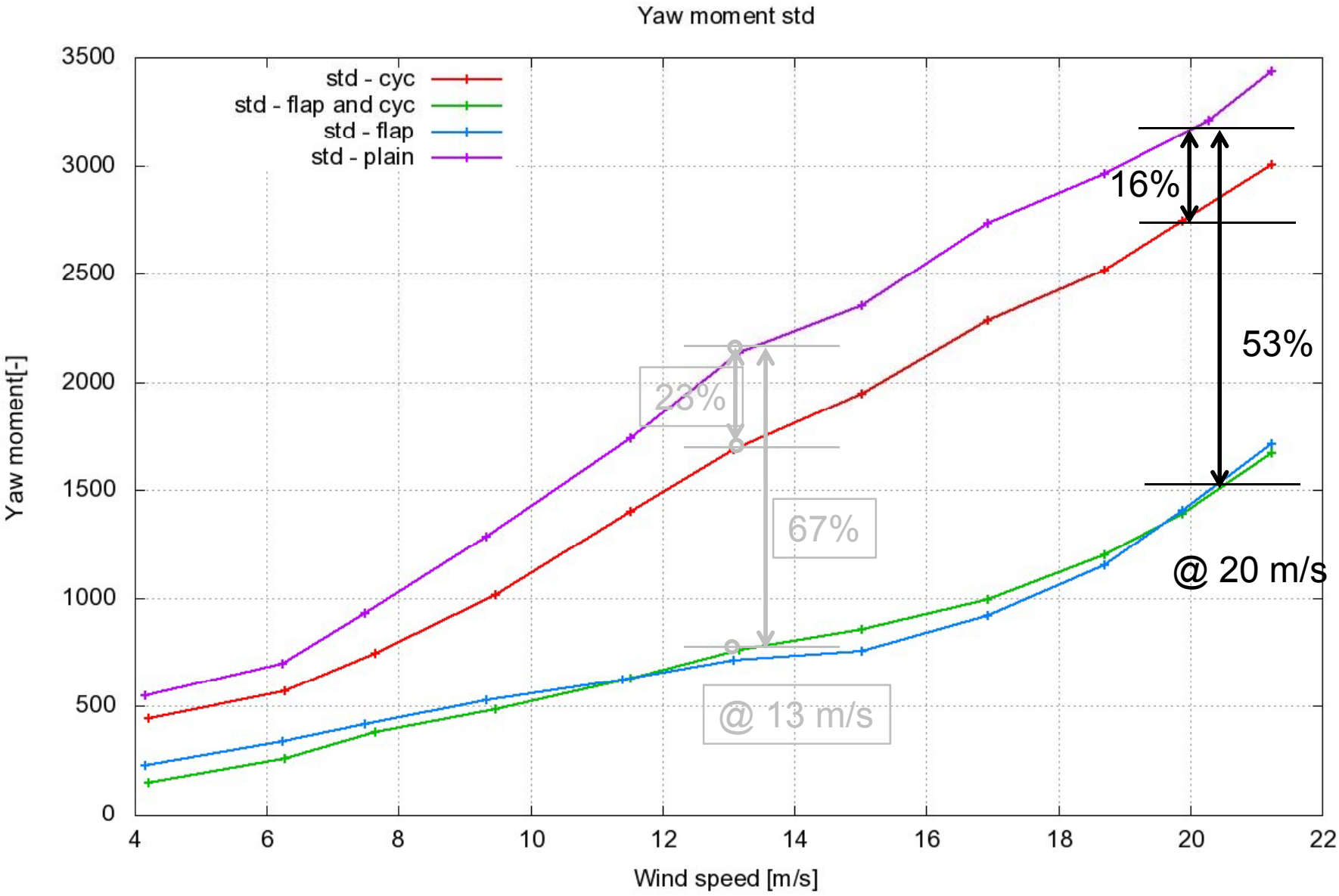
Results (1:6)


Yaw moment std
std - cyc
std - flap and cyc
std - flap
std - plain
Yaw moment[-]
Wind speed [m/s]
0
500
1000
1500
2000
2500
3000
3500
4
6
8
10
12
14
16
18
20
22

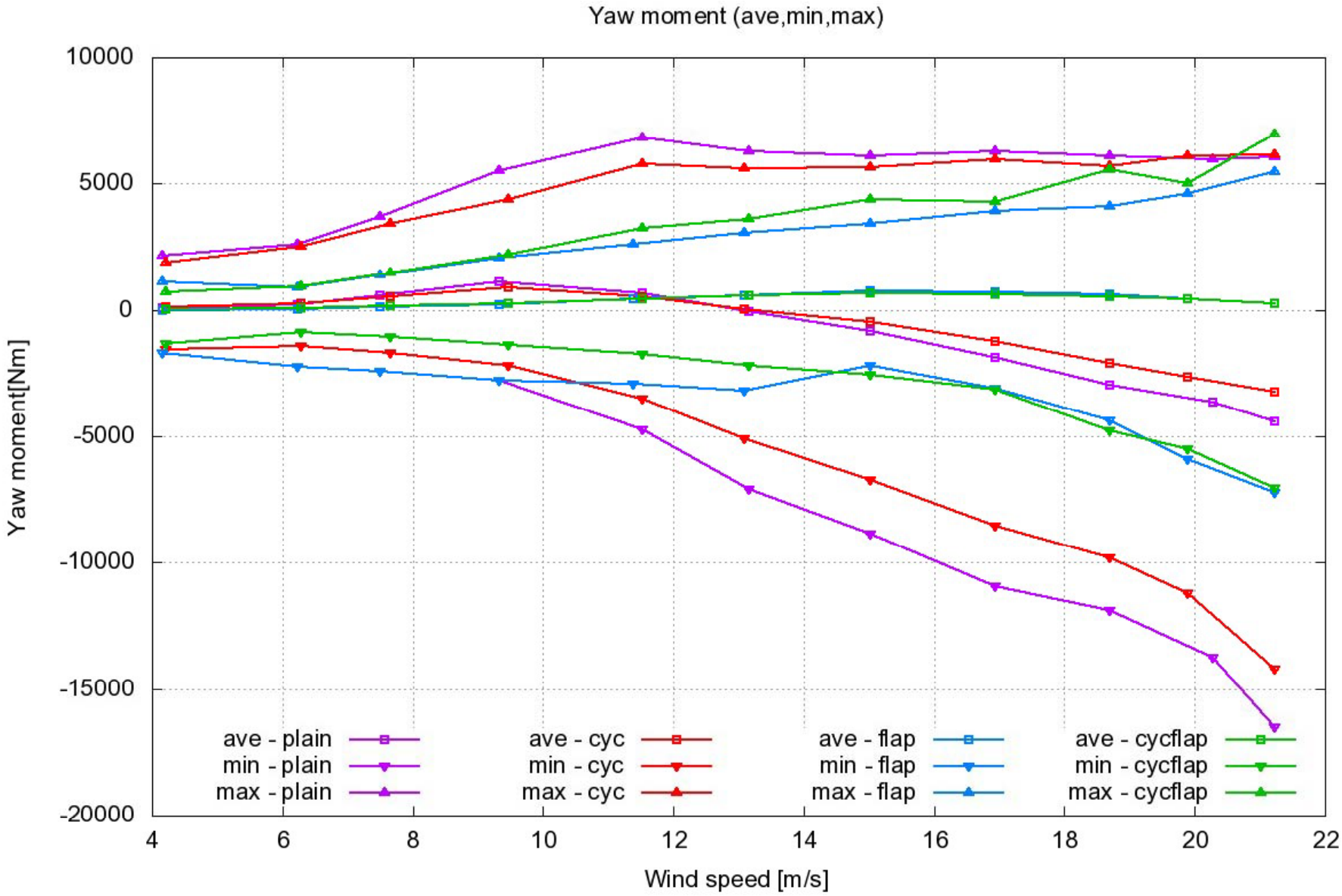
Results (1:6)


Yaw moment std
std - cyc
std - flap and cyc
std - flap
std - plain
Yaw moment[-]
Wind speed [m/s]
23%
67%
@ 13 m/s
0
500
1000
1500
2000
2500
3000
3500
4
6
8
10
12
14
16
18
20
22

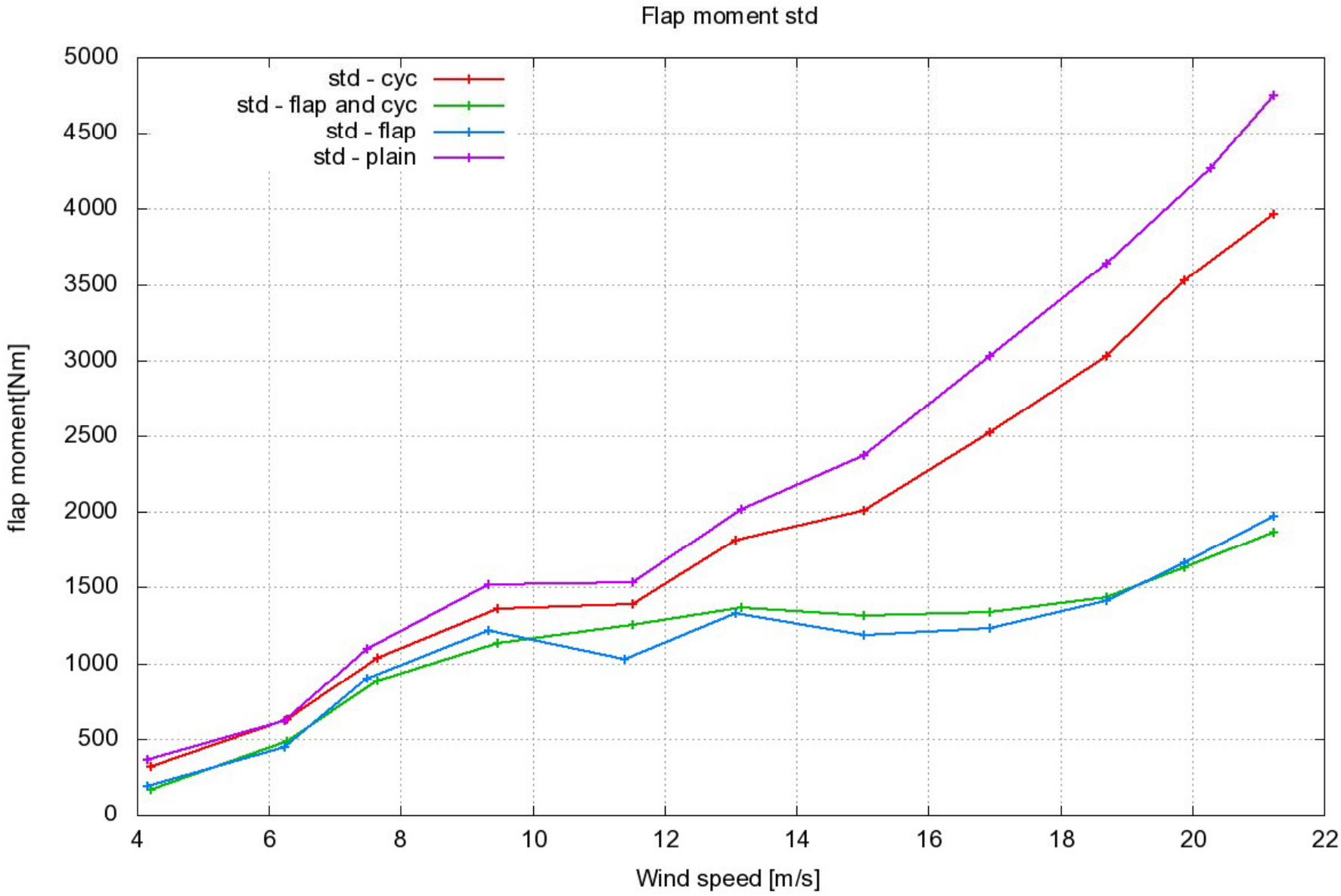
Results (1:6)


Yaw moment std
std - cyc
std - flap and cyc
std - flap
std - plain
Yaw moment[-]
Wind speed [m/s]
3500
3000
2500
2000
1500
1000
500
0
4
6
8
10
12
14
16
18
20
22
16%
53%
@ 20 m/s
23%
67%
@ 13 m/s

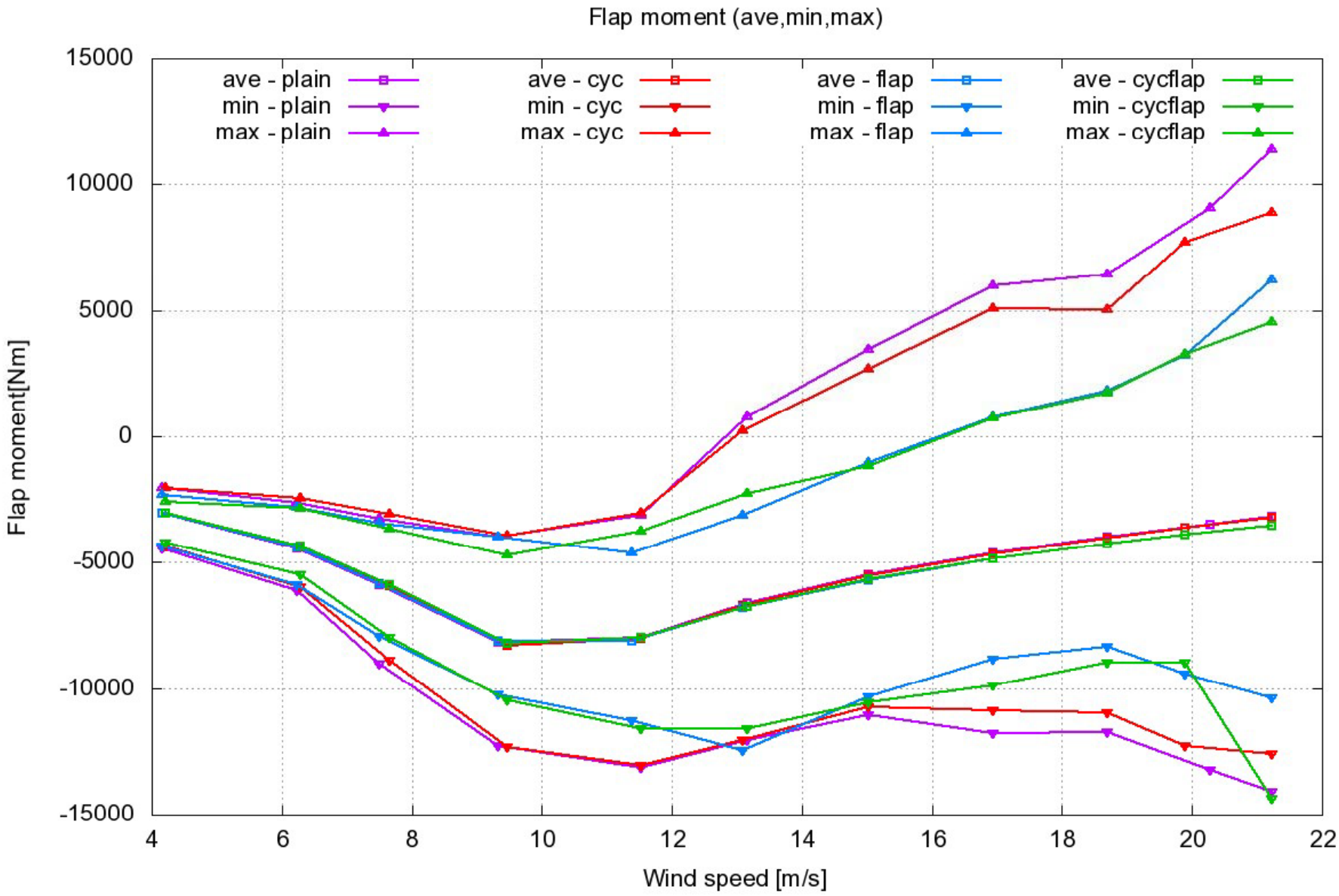
Results (2:6)


Yaw moment (ave,min,max)
Yaw moment[Nm]
Wind speed [m/s]
10000
5000
0
-5000
-10000
-15000
-20000
4
6
8
10
12
14
16
18
20
22
ave - plain
min - plain
max - plain
ave - cyc
min - cyc
max - cyc
ave - flap
min - flap
max - flap
ave - cycflap
min - cycflap
max - cycflap

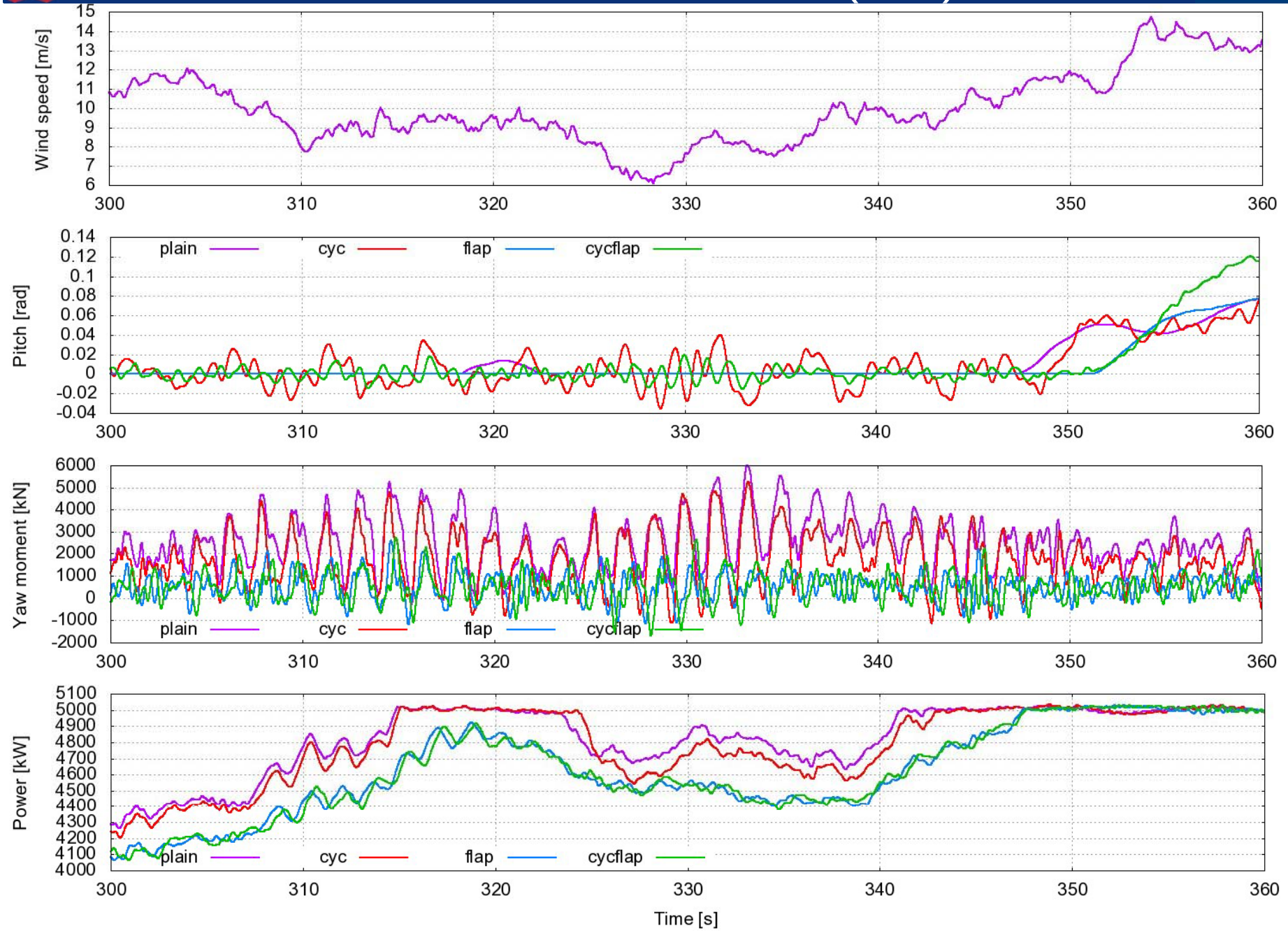
Results (3:6)


Flap moment std
std - cyc
std - flap and cyc
std - flap
std - plain
flap moment[Nm]
Wind speed [m/s]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
4
6
8
10
12
14
16
18
20
22

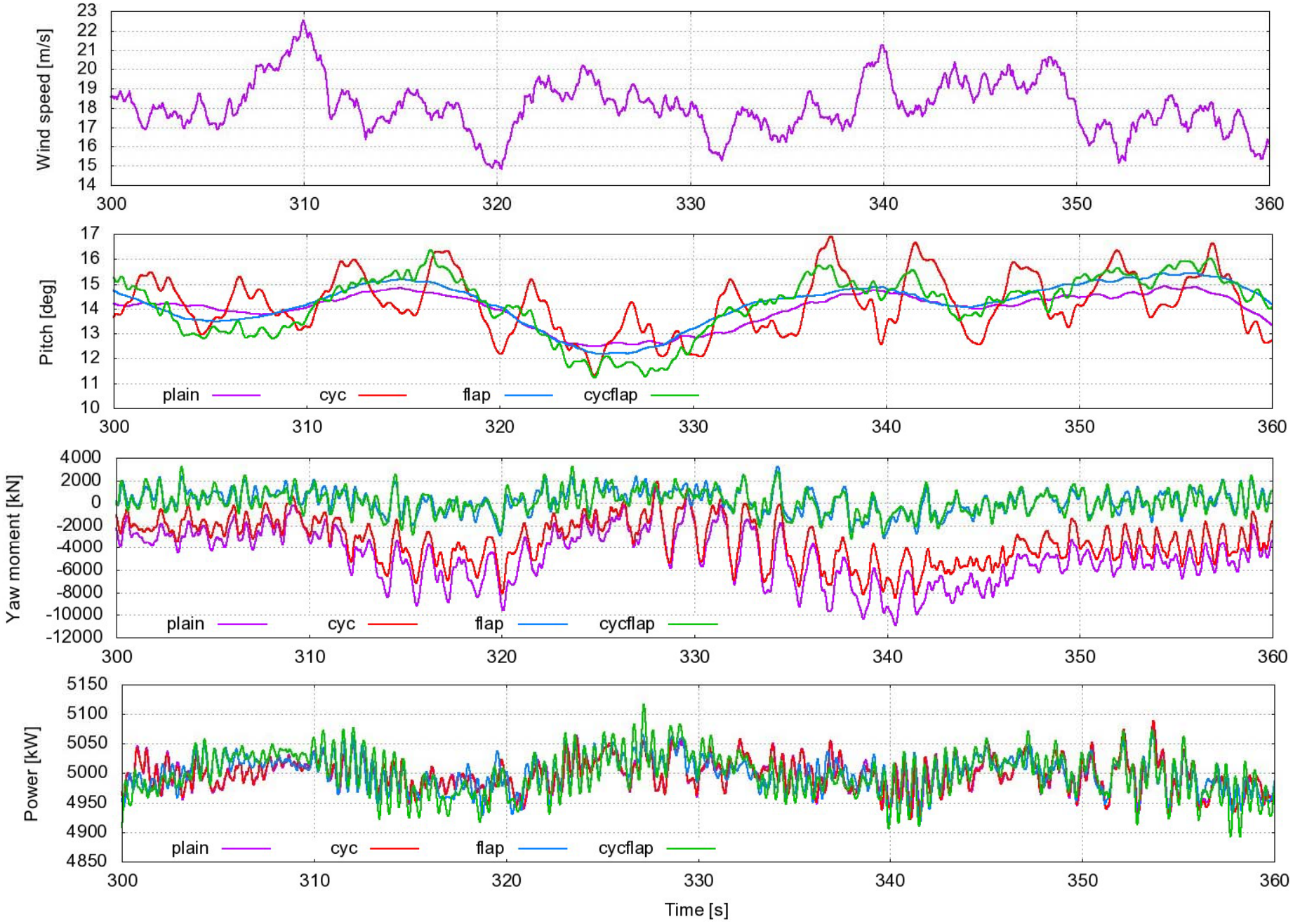
Results (4:6)


Flap moment (ave,min,max)
ave - plain
min - plain
max - plain
ave - cyc
min - cyc
max - cyc
ave - flap
min - flap
max - flap
ave - cycflap
min - cycflap
max - cycflap
Flap moment[Nm]
15000
10000
5000
0
-5000
-10000
-15000
4
6
8
10
12
14
16
18
20
22
Wind speed [m/s]

<13 m/s> results (5:6)



<19 m/s> results (6:6)



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Conclusion

-The flaps with a +/-8 degree angle range seem to be able to eliminate almost all of the 30 degree yaw error

-Controllers needs to be integrated to see full potential

- Power production should be a part of the

-Tuning of controllers is very time consuming

Future work...

A “real” turbine

Acoustic noise reduction

Power production

Position of DTEG

Extreme directional change in wind direction

Dimension of DTEG

Main shaft (fatigue)

Extreme wind conditions (gusts)

Yaw misalignment

Tilting moment

Blade flapwise, extreme (bending, buckling)

Hardware in the loop

Offshore

Blade edgewise (fatigue)

Floating turbines

Yaw system (extreme)

Tower welding (fatigue)

Stand still

Main bearing (fatigue)

Negative wind shears

Lightning

CFD

Gear (fatigue)

Wind farm issues

Monte Carlo simulations

Sensor dynamics/hysteresis

IEC Load case

Pitch regulation

Sensor delay

Signal noise

Two bladed turbine

Stability

Foundation (extreme)

Emergency shut down