CARL VON OSSIETZKY universität OLDENBURG

DoWES

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Universität Oldenburg
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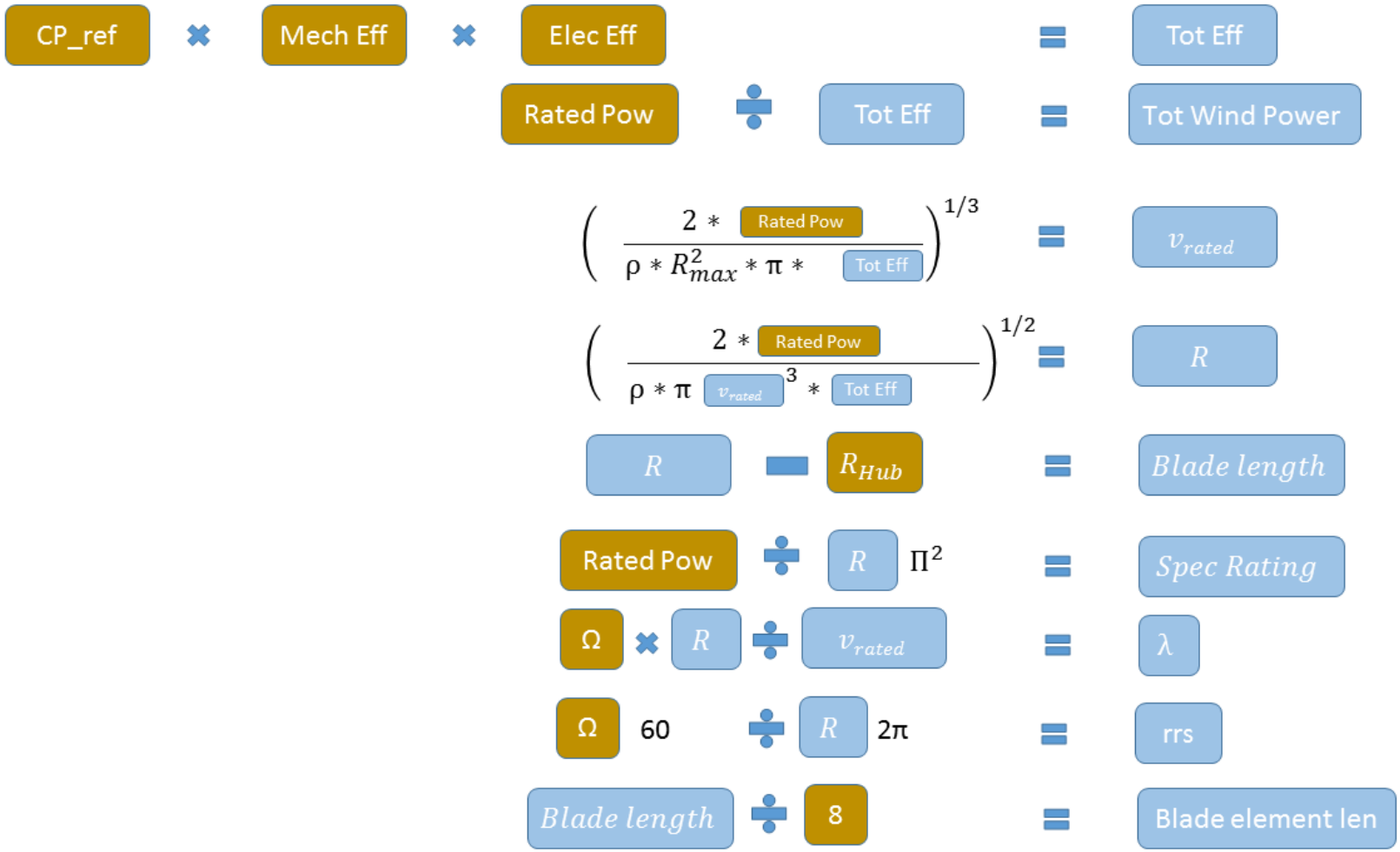
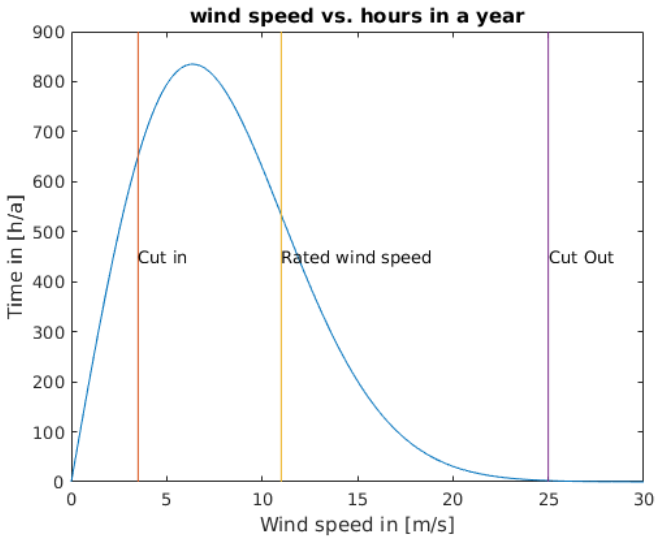
Formulas

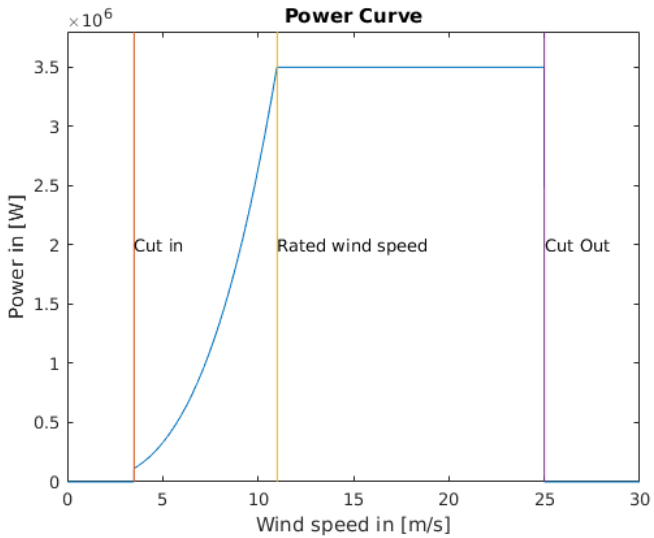

CP_ref
Mech Eff
Elec Eff
Tot Eff
Rated Pow
Tot Eff
Tot Wind Power
$\left(\frac{2 * \text{Rated Pow}}{\rho * R_{max}^2 * \pi * \text{Tot Eff}} \right)^{1/3}$
v_{rated}
$\left(\frac{2 * \text{Rated Pow}}{\rho * \pi \; v_{rated}^{\;3} * \text{Tot Eff}} \right)^{1/2}$
R
R
R_{Hub}
Blade length
Rated Pow
R
Π^2
Spec Rating
Ω
R
v_{rated}
λ
Ω
60
R
2π
rrs
Blade length
8
Blade element len

Results

Main parameters	**Unit**	**Value**
Calculate total conversion efficiency	m	0.4704
Total wind power that needs to be extracted	kW	7439.258
Rated wind speed (rounded up)	m/s	11
Rotor radius (rounded up)	m	54
Blade length (without hub)	m	52.75
Rotor area (rounded radius)	m^2	9160.884
Specific rating (design)	W/m^2	382.051
λD Design tip speed ratio	-	7.454
Rotor rated speed	rpm	14.5
Blade element length (8 elements, same length)	m	6.593

Estimation of AEP

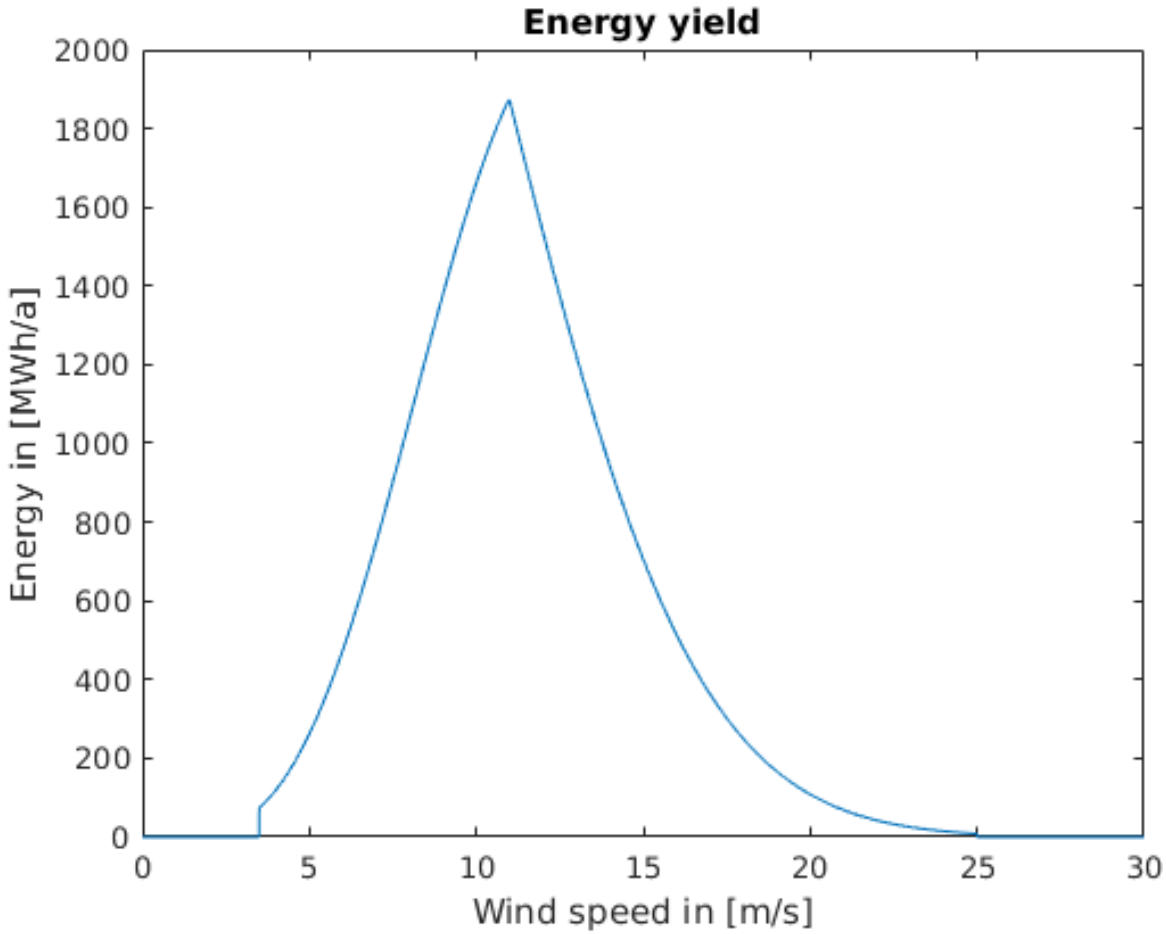




$$\text{AEP} = \sum_{v} n_v \cdot p_v$$

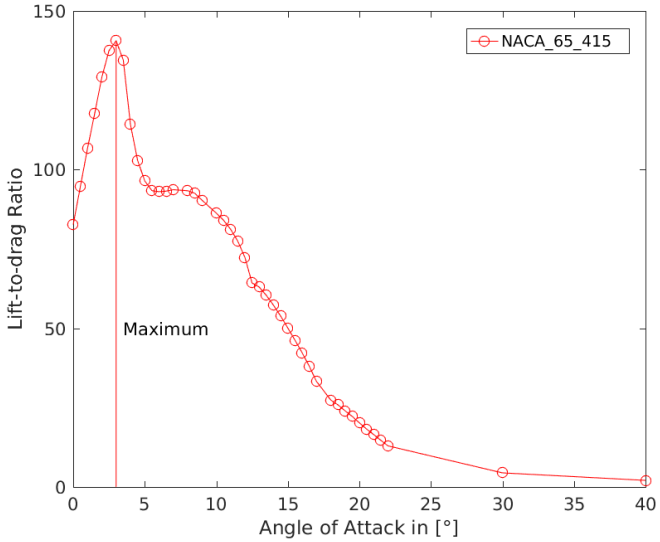
with:
n = number of hours
p = power curve
v = wind speed

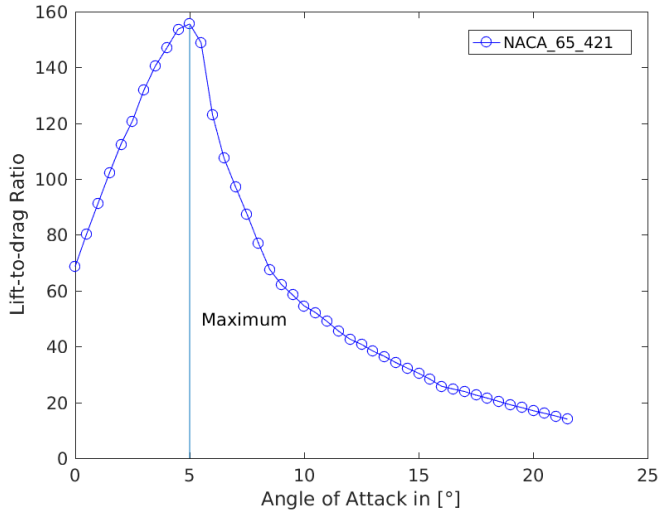
Resulting Energy yield



$$\text{AEP} = 13,49 GWh$$

Lift-to-drag ratio





NACA 65-415	α	c_l	c_d	c_m
80% method	10	1.345	0.016	0.071
lift-to-drag method	3.0	0.710	0.005	0.088
NACA 65-421	α	c_l	c_d	c_m
80% method	11	1.255	0.026	0.055
lift-to-drag method	5.0	0.952	0.006	0.092

Table : Main aerodynamic parameters

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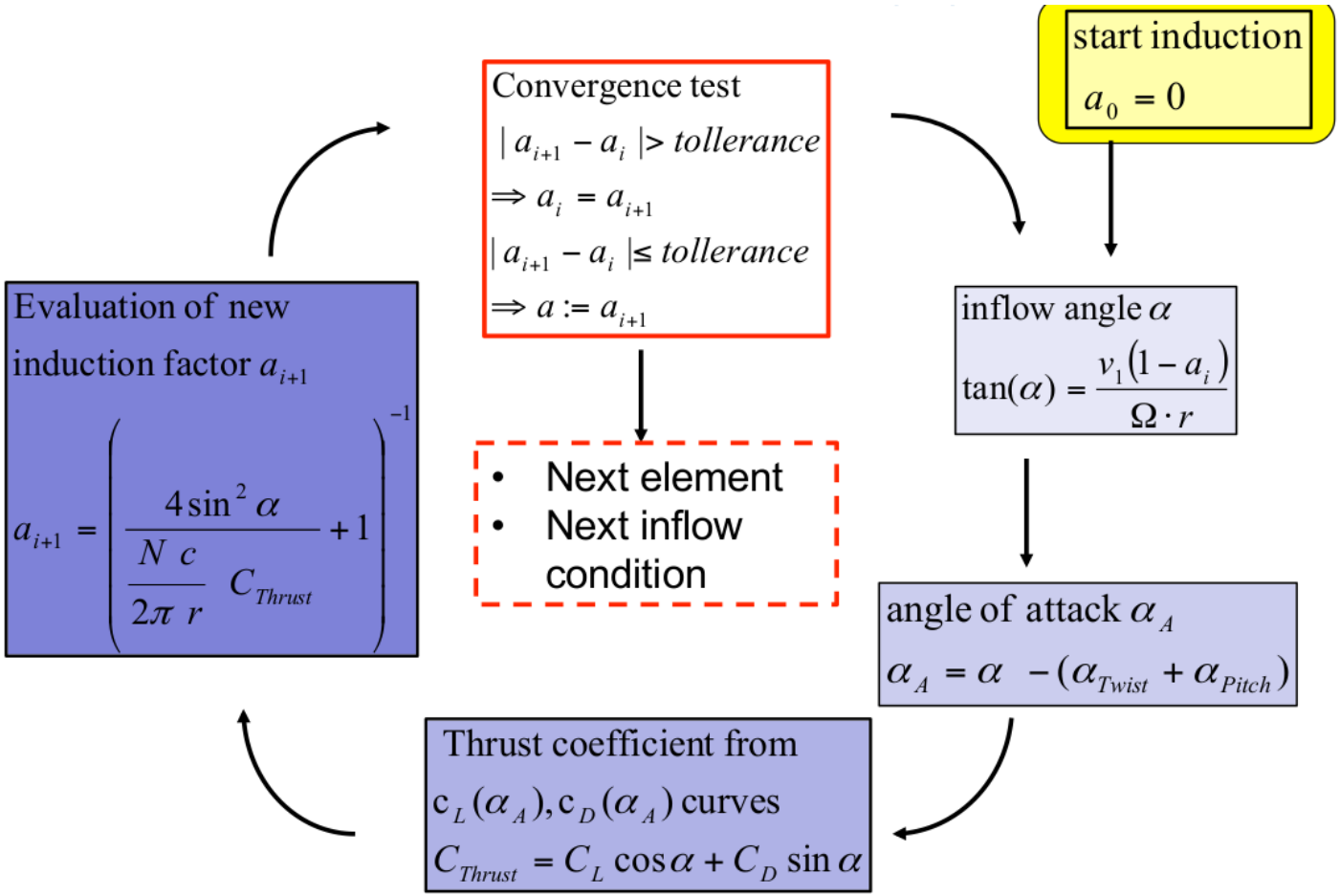
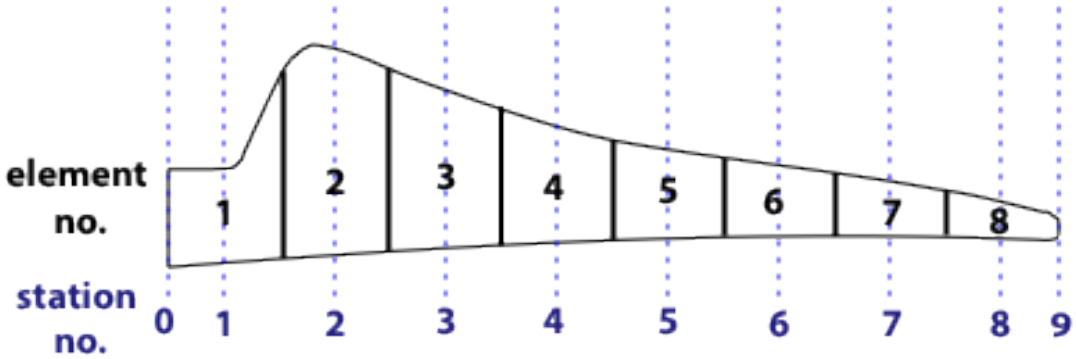
BEM algorithm

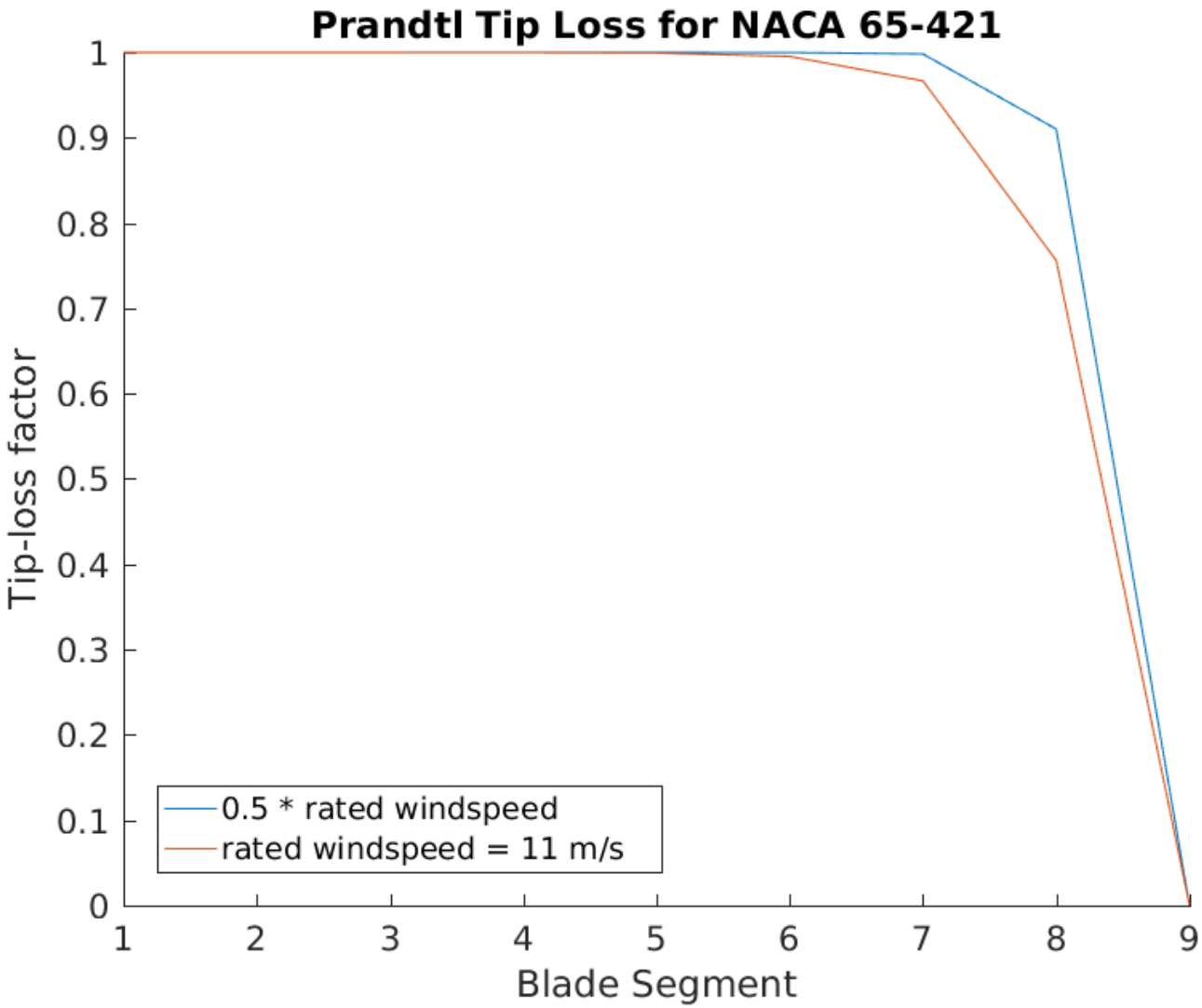


Blade design

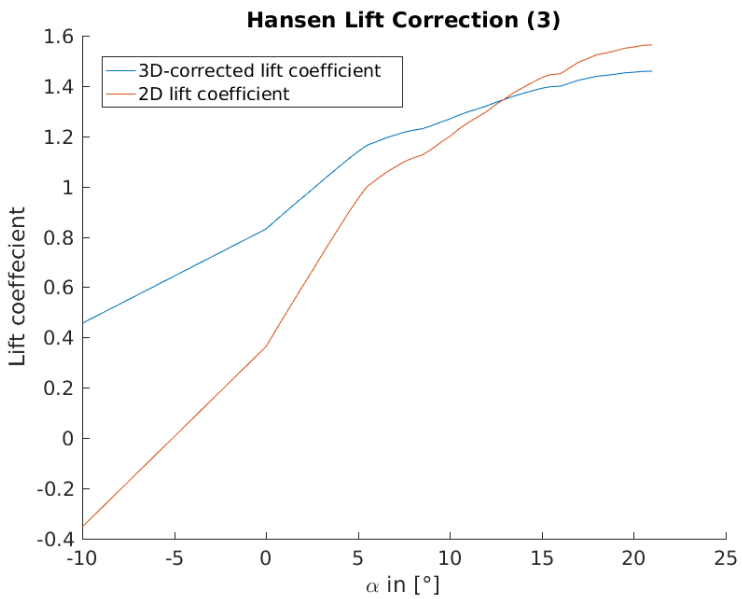


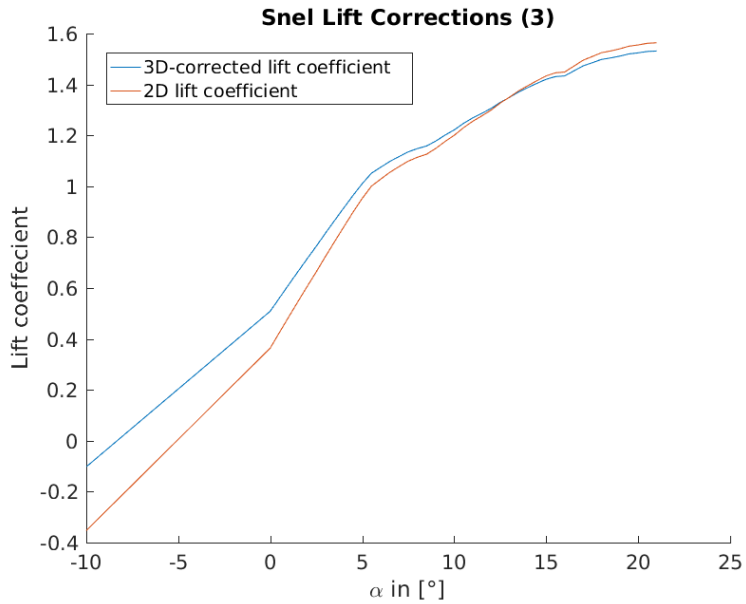
Station	1 Cylinder	2 65-421	3 65-421	4 65-421	5 65-421	6 65-415	7 65-415	8 65-415	9 65-415
Blade	3.297	9.891	16.484	23.078	29.672	36.266	42.859	49.453	52.750
Chord	6,628	5,426	3,935	3,014	2,425	1,887	1,617	1,413	1,329
Twist	27,590	11,022	3,813	0,055	-2,211	-2,715	-3,783	-4,580	-4,907

Prandtl tip losses



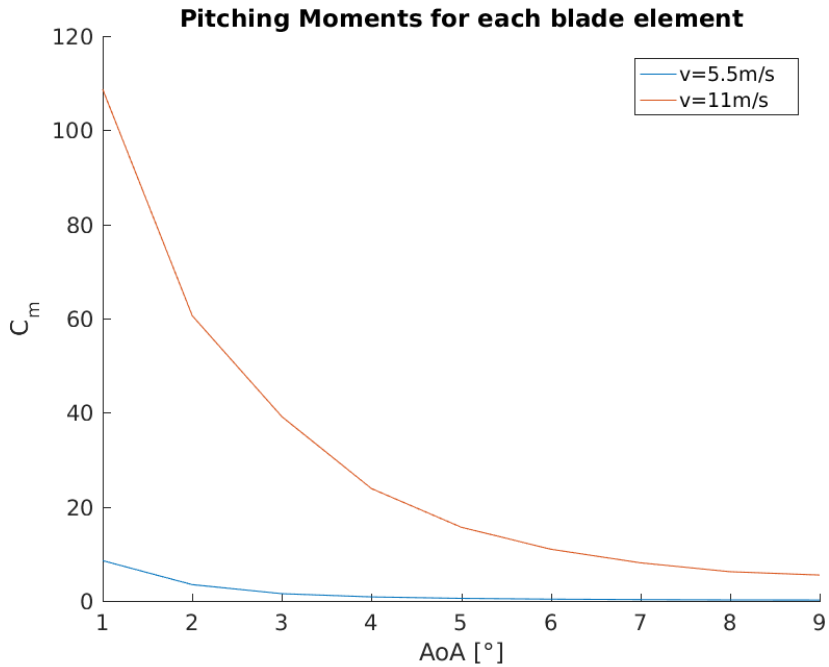
Hansen and Snel 3d correction





Pitching moment

$$M = C_m \cdot A \cdot c \cdot \rho \cdot v^2 \cdot 0.5$$



Result by summing up the sections along the blade

$$M(5.5m/s) = 15.881Nm$$
$$M(11m/s) = 278.705Nm$$

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WT_Perf

```
-----  Turbine Data  ----------------------------------------------------------
 3                    NumBlade:                  Number of blades.
35.95                 RotorRad:                  Rotor radius [length].
 1.2                  HubRad:                    Hub radius [length or div by rad
-3.0                  PreCone:                   Precone angle, positive downwind
 5.0                  Tilt:                      Shaft tilt [deg].
 0.0                  Yaw:                       Yaw error [deg].
70.0                  HubHt:                     Hub height [length or div by rad
 8                    NumSeg:                    Number of blade segments (entire
   RElm    Twist    Chord   AFfile  PrntElem
3.421875         29.36987577     5.070530343     1       FALSE
7.765625         14.20925825     4.459489198     1       FALSE
12.109375        6.823436492     3.384116952     1       FALSE
16.453125        2.753876508     2.650669029     1       FALSE
20.796875        0.230641975     2.160752278     2       FALSE
25.140625        -1.473157945    1.815959346     2       FALSE
29.484375        -2.69646261     1.563239845     2       FALSE
33.828125        -3.615679163    1.370923606     2       FALSE
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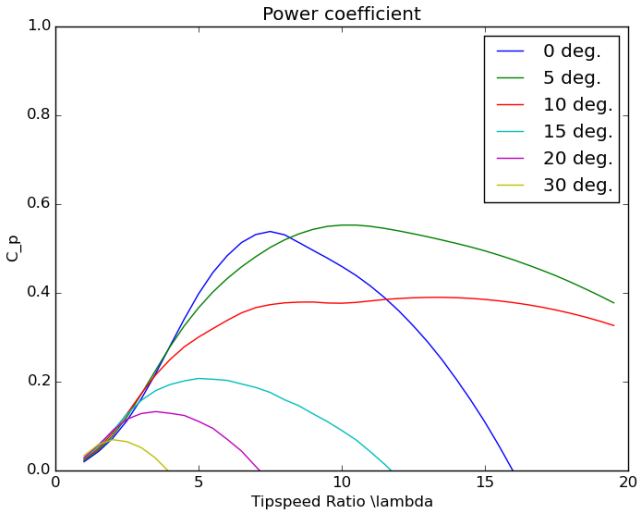
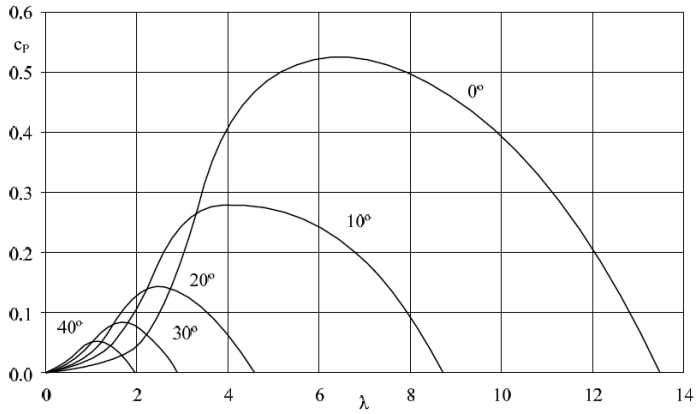
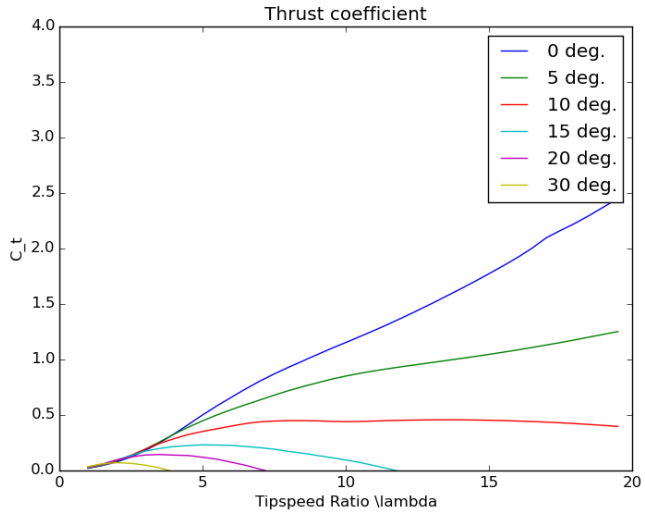
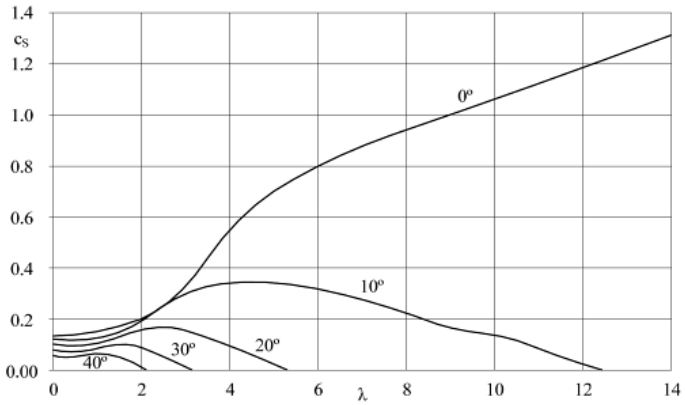
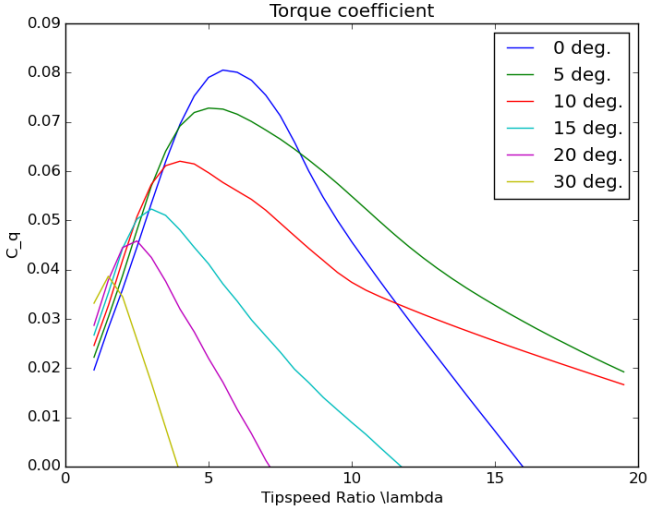
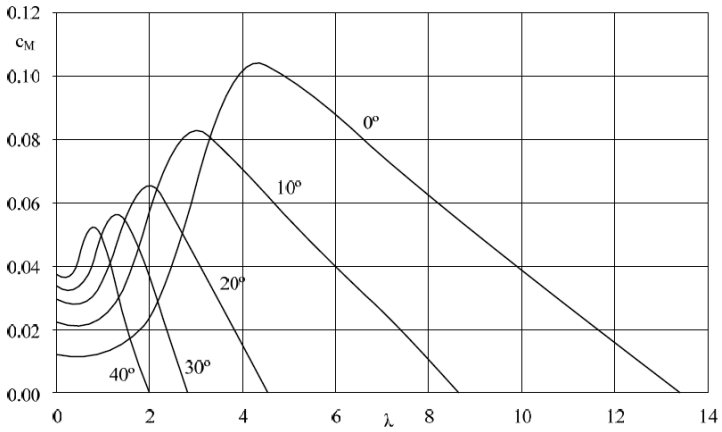





Thrust coefficient
0 deg.
5 deg.
10 deg.
15 deg.
20 deg.
30 deg.
C_t
Tipspeed Ratio \lambda


c_S
0°
10°
20°
30°
40°
λ


Torque coefficient
0 deg.
5 deg.
10 deg.
15 deg.
20 deg.
30 deg.
C_q
Tipspeed Ratio \lambda


c_M
0°
10°
20°
30°
40°
λ

How does the wind turbine operate below and above rated wind speed?

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- below rated wind speed it is still possible to achieve a high power coefficient c_p for 9 m/s is 0.544

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- if the wind speed is higher than the rated wind speed the power coefficient drops significantly

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- below rated wind speed it is still possible to achieve a high power coefficient c_p for 9 m/s is 0.544
- if the wind speed is higher than the rated wind speed the power coefficient drops significantly
- Constant TSR leads to a high power coefficient

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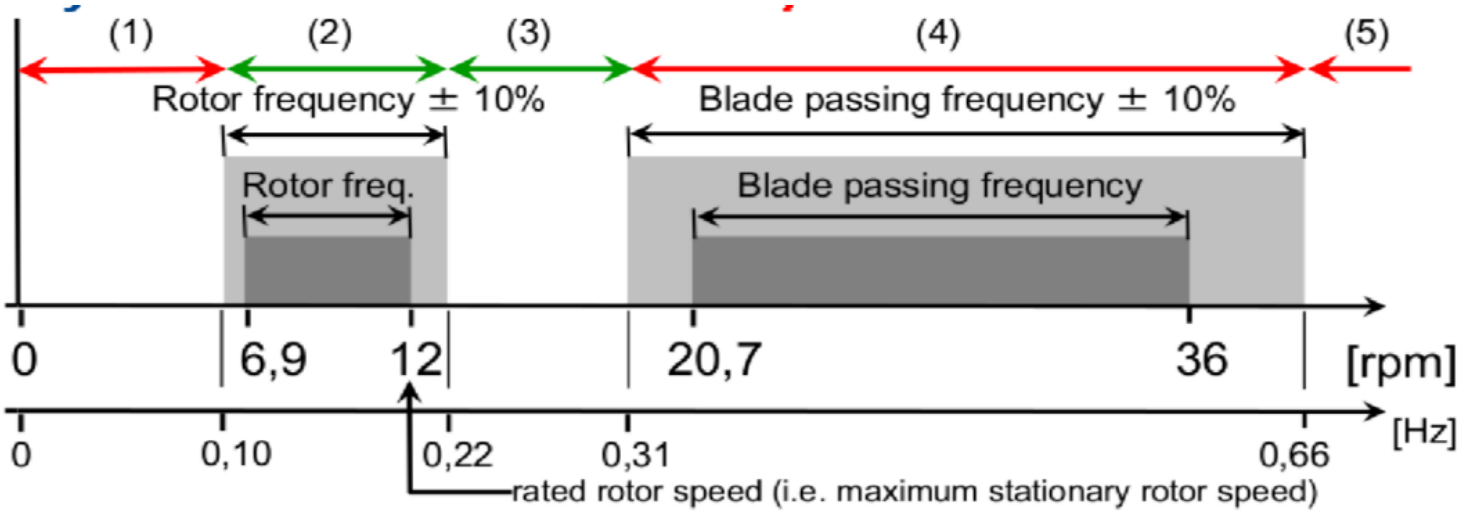
Tower eigenfrequency

Adding a 10% safety margin to the rotor rated speed which represents the maximum stationary rotor speed:

$$f_o = \Omega_{rated} \cdot 1.1 = \frac{14.5}{60} Hz \cdot 1.1 = 0.2658 Hz$$

Design range: Classical soft-stiff design

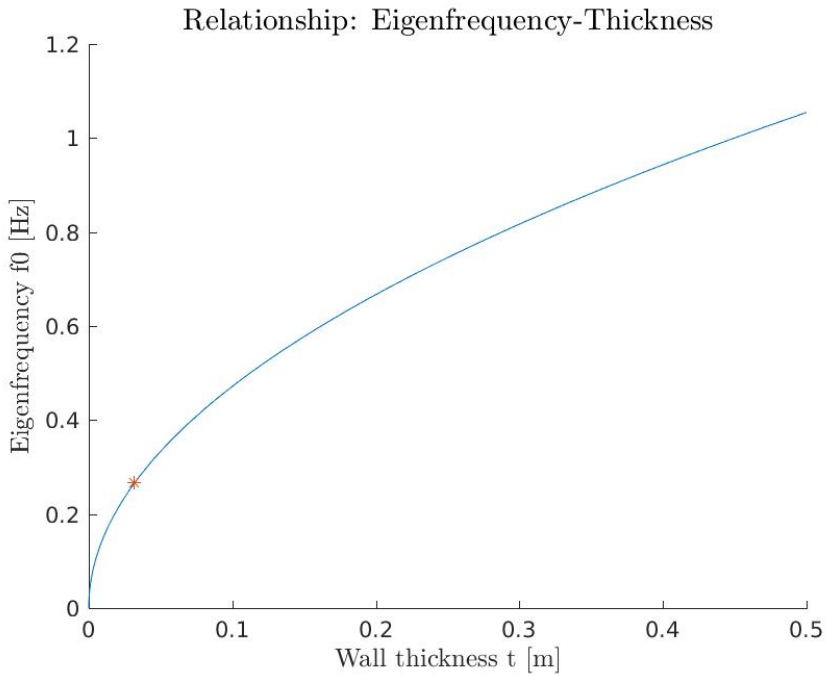


Wall thickness

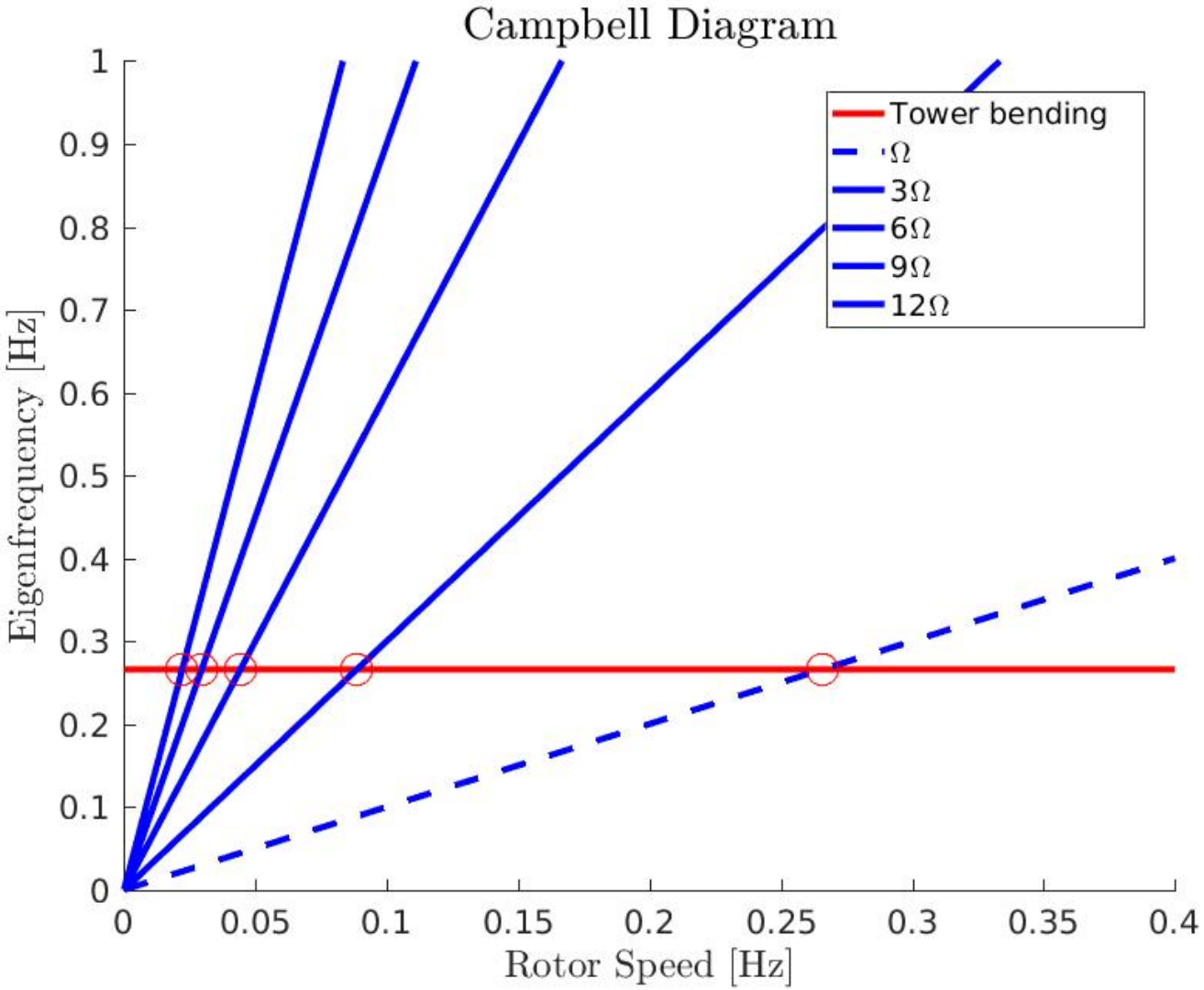
Can be obtained from the eigenfrequency and some other parameters

$$f_0 \cdot 2\pi = \sqrt{\frac{3E\pi D^3 t}{l^3 8(m_{top} + 0.25\rho\pi Dtl)}}$$

With fsolve: $t = 0.0318m$



Campbell diagram



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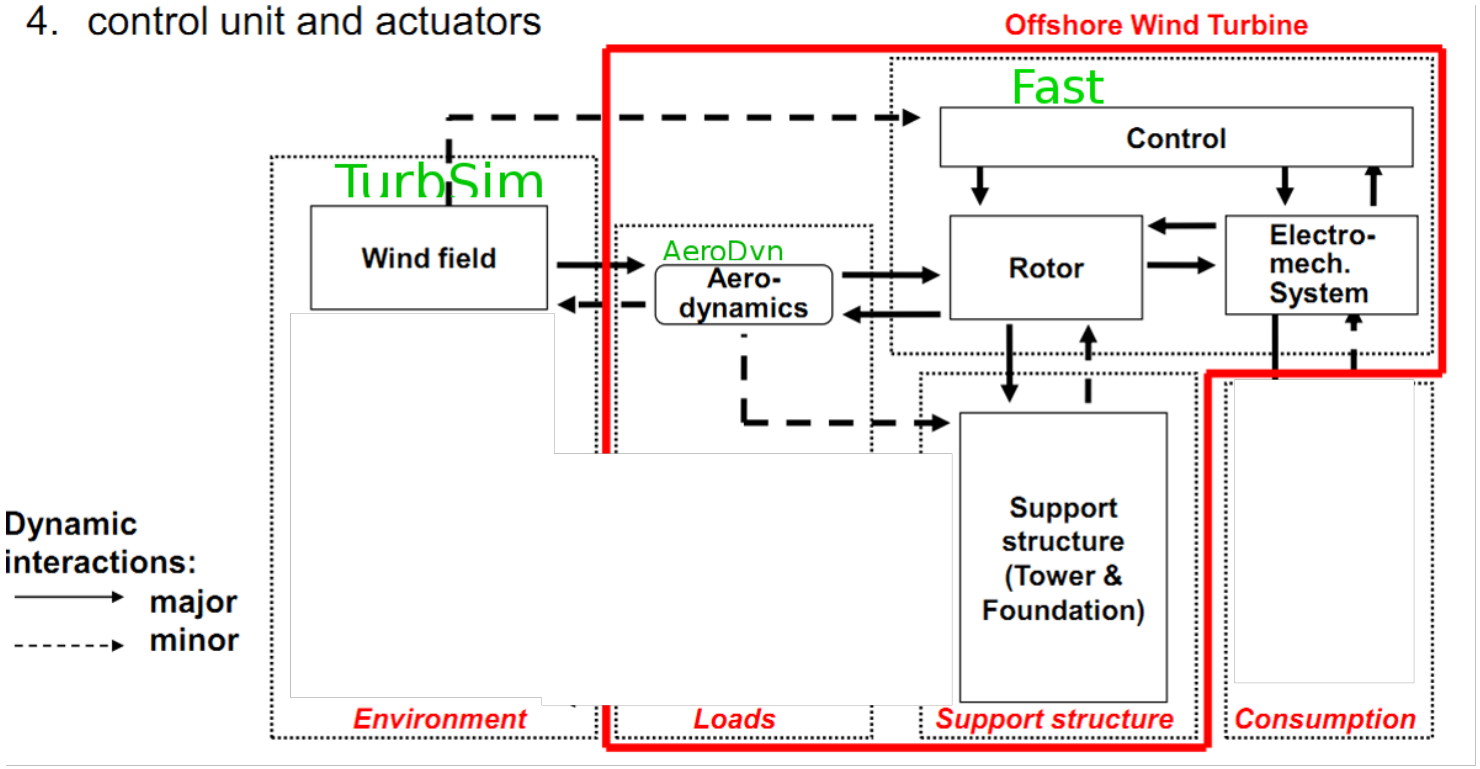
Software during the design process



Turbulence intensity

Free stream (NTM)

$$\sigma = I_{ref} * (0.75 * v_{hub} + 5.6 m/s)$$
$$I = \sigma / v_{hub}$$

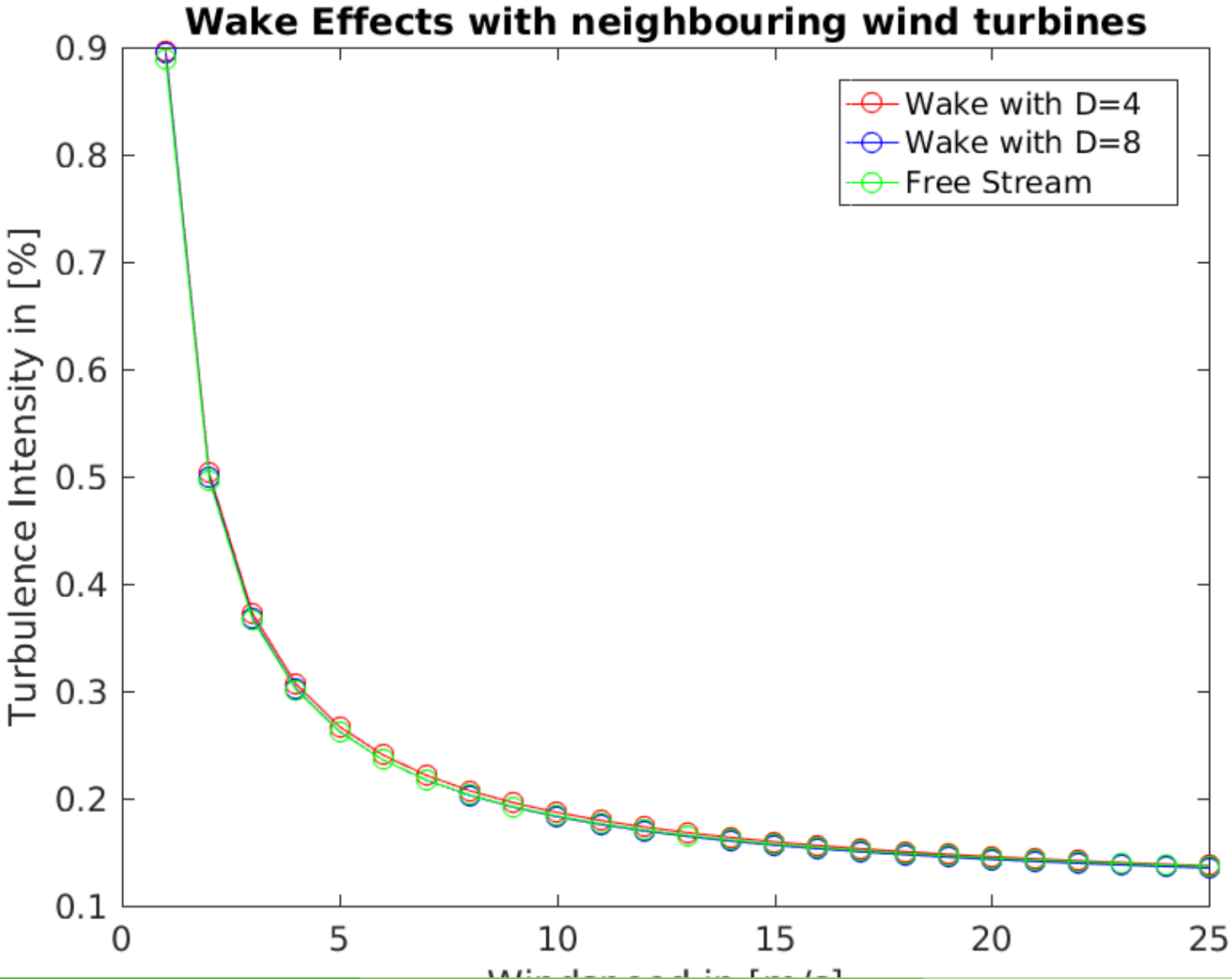
v	$5 m/s$	$10 m/s$	$15 m/s$	$25 m/s$
I	0.2618	0.1834	0.1573	0.1364
Operational condition	partial	partial	full	full

Wakes (Frandsen model)

$$\sigma = I_{ref} * (0.75 * v_{hub} + 5.6 m/s)$$
$$I = \sigma / v_{hub}$$

v	$5 m/s$	$10 m/s$	$15 m/s$	$25 m/s$
$\mathbf{4 \cdot d}$	0.2667	0.1867	0.1594	0.1370
$\mathbf{8 \cdot d}$	0.2621	0.1827	0.1562	0.1349

Comparison


Wake Effects with neighbouring wind turbines
Wake with D=4
Wake with D=8
Free Stream
Turbulence Intensity in [%]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25

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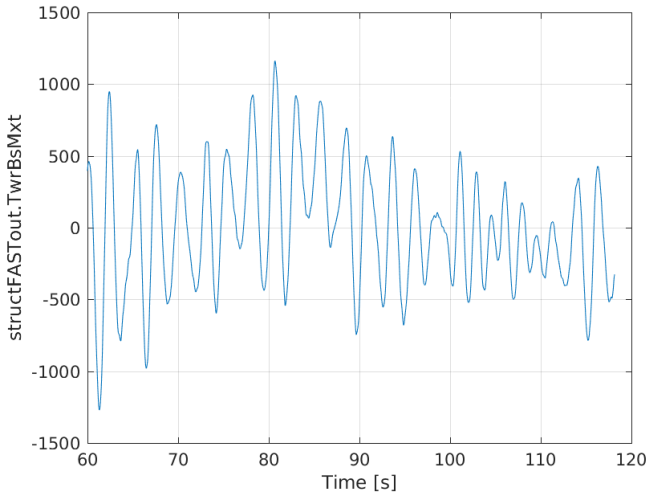
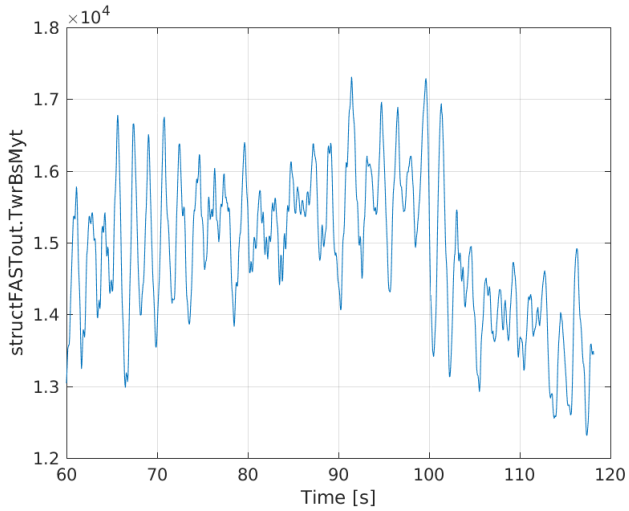
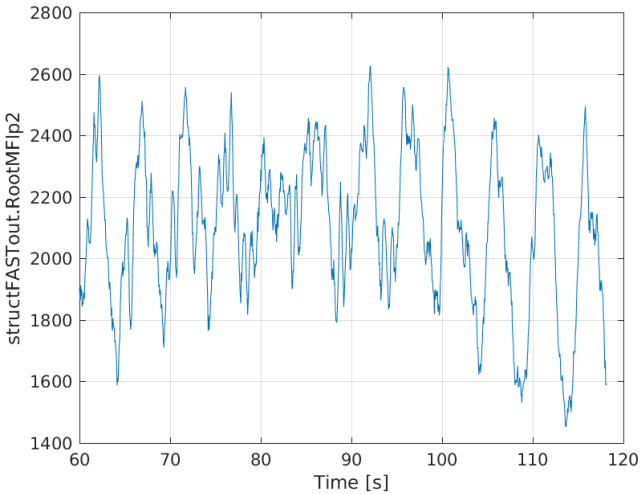
Bending moments



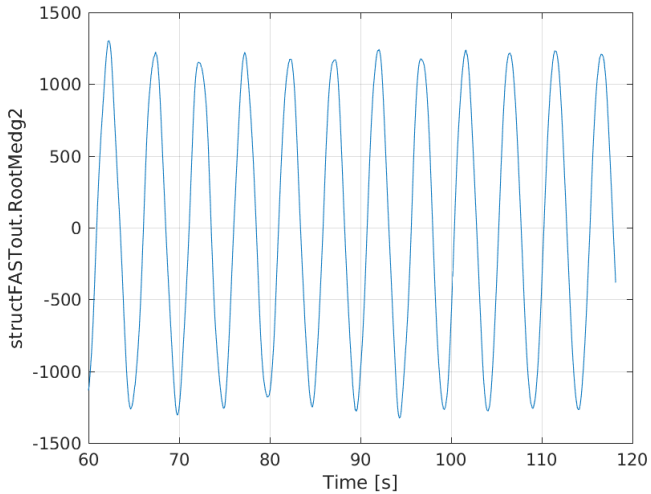
Tower side-to-side bending moments



Tower fore-aft bending moments

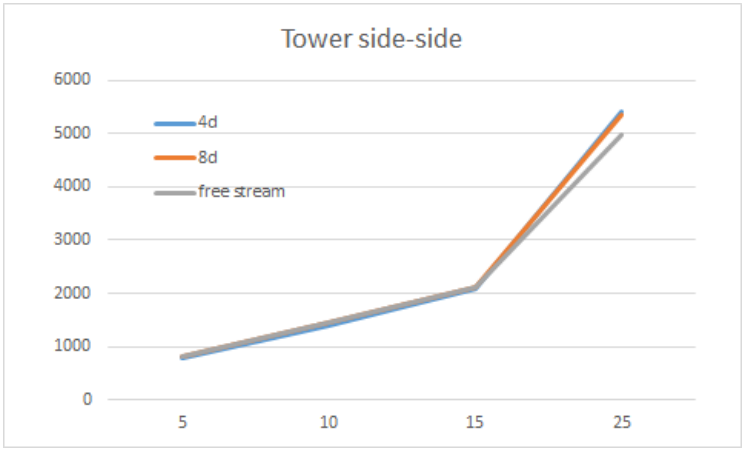


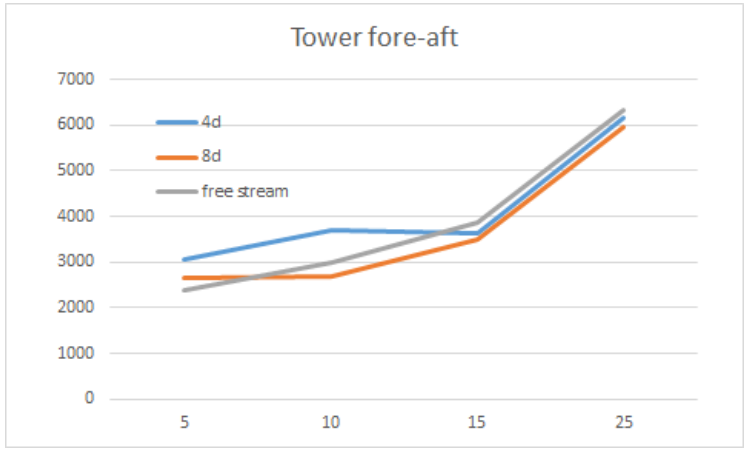
Blade flapwise bending moments

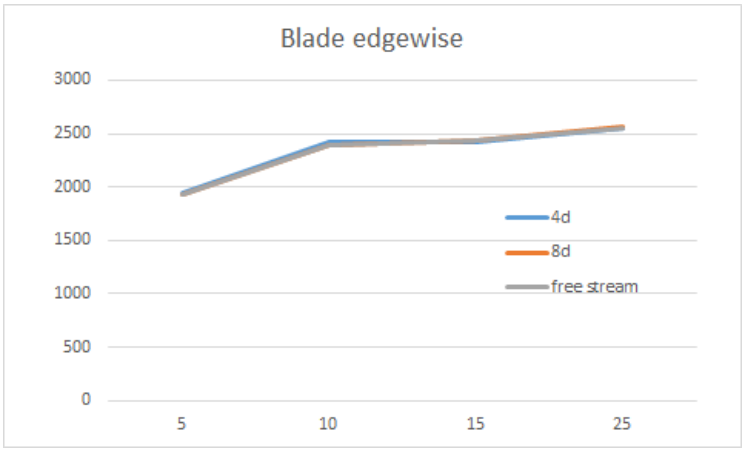


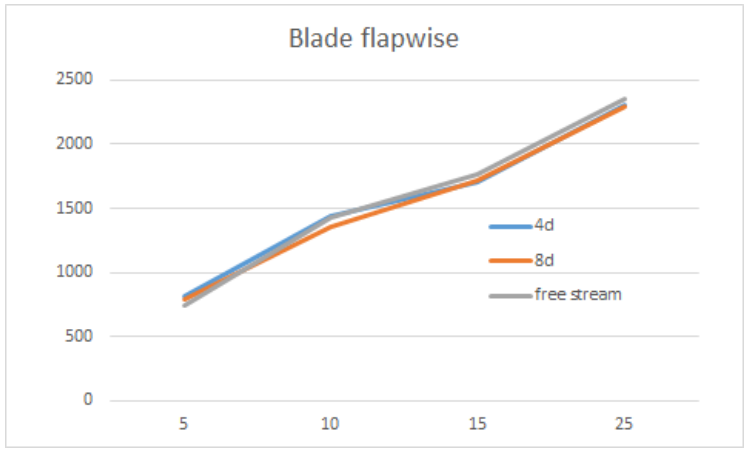
Blade edgewise fore-aft bending moments

Comparison of DELs (free stream vs wake)









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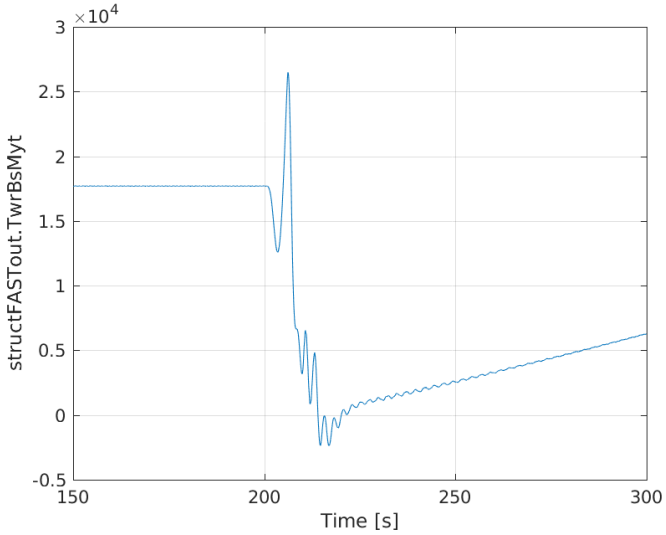
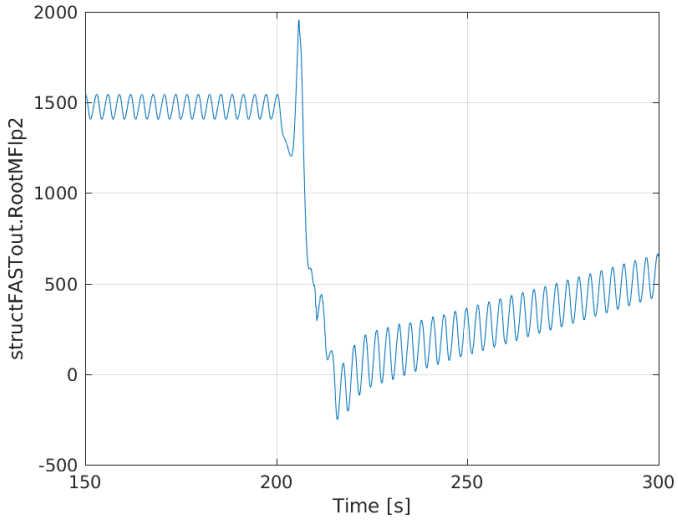
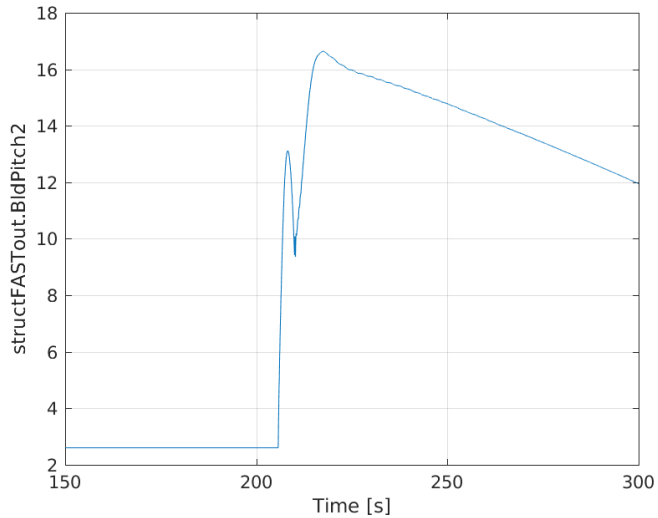
Loadcase 2.3



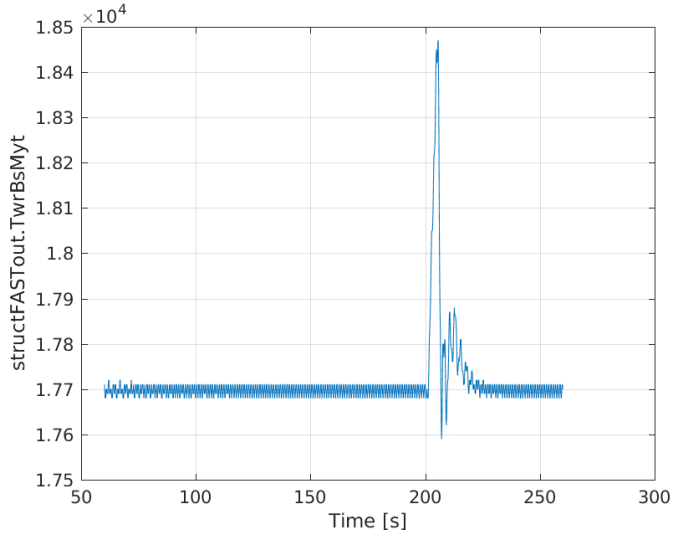
Tower fore-aft for EOG_50



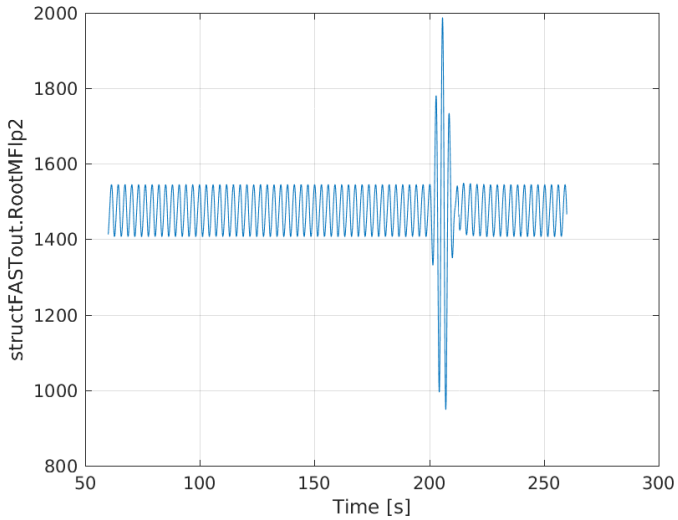
Blade flapwise for EOG_50



Loadcase 1.5



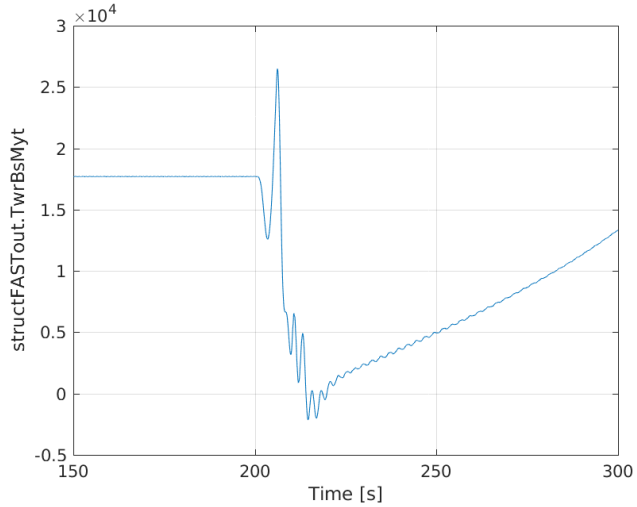
Tower fore-aft for EWS

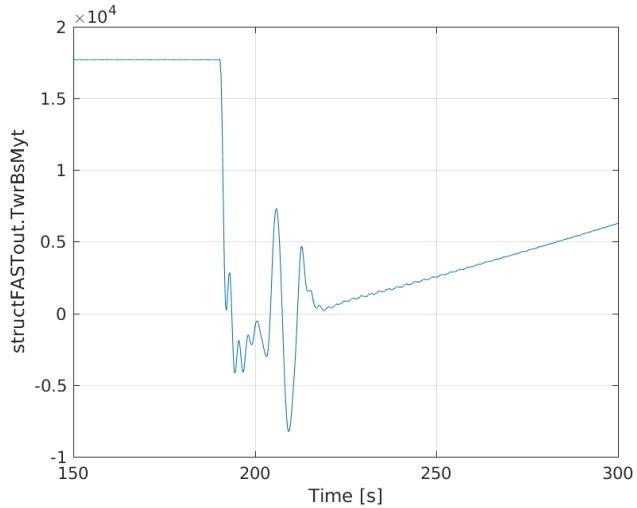


Blade flapwise for EWS

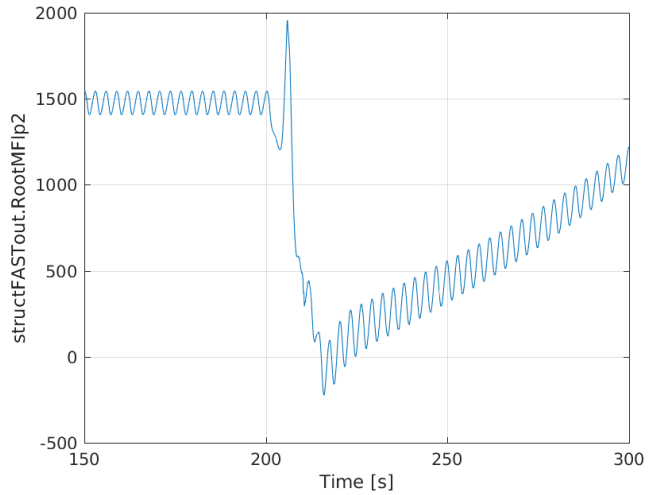
Modified brakes and failure timing 2.3

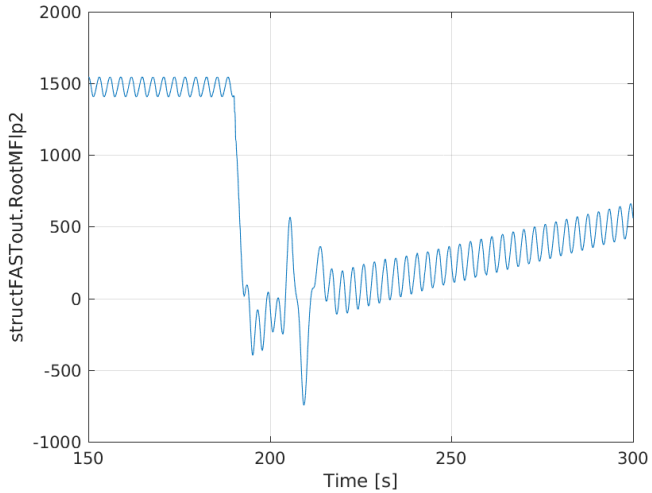
Tower fore-aft





Blade flapwise





Thanks!