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Universität Oldenburg  
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- 1 Selection of Main Parameters
- 2 Rotor design, BEM
- 3 Control and characteristic curves
- 4 Tower design, modal analysis
- 5 External conditions
- 6 Fatigue load analysis
- 7 Extreme load analysis

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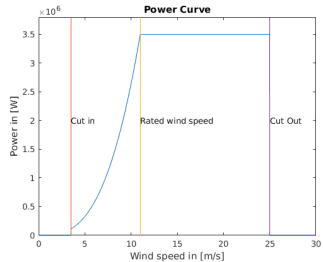
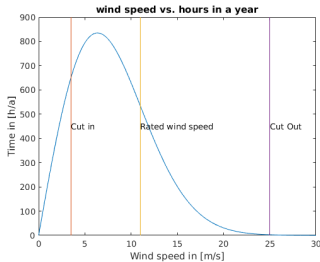
# Formulas

$$\begin{aligned}
 & \text{CP}_{\text{ref}} \times \text{Mech Eff} \times \text{Elec Eff} = \text{Tot Eff} \\
 & \text{Rated Pow} \div \text{Tot Eff} = \text{Tot Wind Power} \\
 & \left( \frac{2 * \text{Rated Pow}}{\rho * R_{\text{max}}^2 * \pi * \text{Tot Eff}} \right)^{1/3} = v_{\text{rated}} \\
 & \left( \frac{2 * \text{Rated Pow}}{\rho * \pi * v_{\text{rated}}^3 * \text{Tot Eff}} \right)^{1/2} = R \\
 & R - R_{\text{Hub}} = \text{Blade length} \\
 & \text{Rated Pow} \div R^3 \pi^2 = \text{Spec Rating} \\
 & \Omega \times R \div v_{\text{rated}} = \lambda \\
 & \Omega \cdot 60 \div R \cdot 2\pi = \text{rrs} \\
 & \text{Blade length} \div 8 = \text{Blade element len}
 \end{aligned}$$

# 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
$\lambda D$ 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



$$AEP = \sum_v n_v \cdot p_v$$

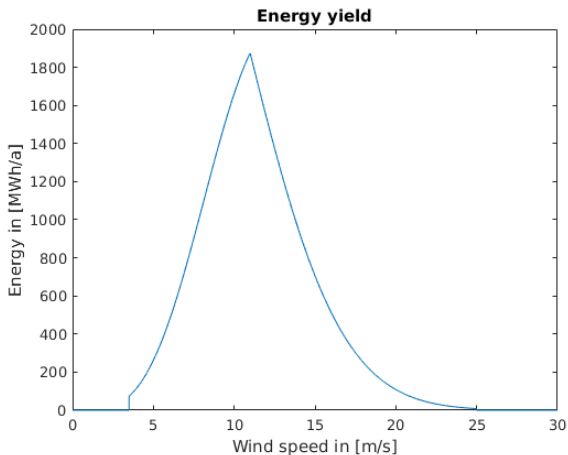
with:

$n$  = number of hours

$p$  = power curve

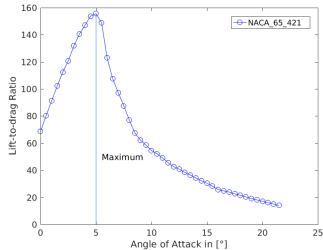
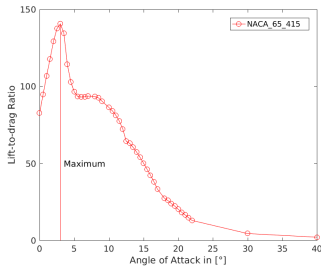
$v$  = wind speed

# Resulting Energy yield



$$AEP = 13,49 GWh$$

# Lift-to-drag ratio



NACA 65-415	$\alpha$	$C_l$	$C_d$	$C_m$
80% method	10	1.345	0.016	0.071
lift-to-drag method	3.0	0.710	0.005	0.088
NACA 65-421	$\alpha$	$C_l$	$C_d$	$C_m$
80% method	11	1.255	0.026	0.055
lift-to-drag method	5.0	0.952	0.006	0.092

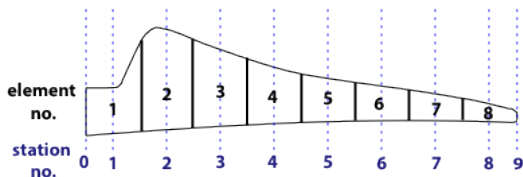
Table : Main aerodynamic parameters



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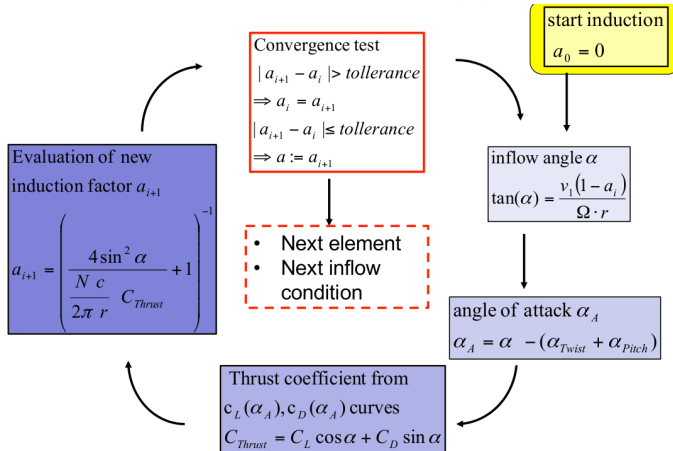
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# Blade design

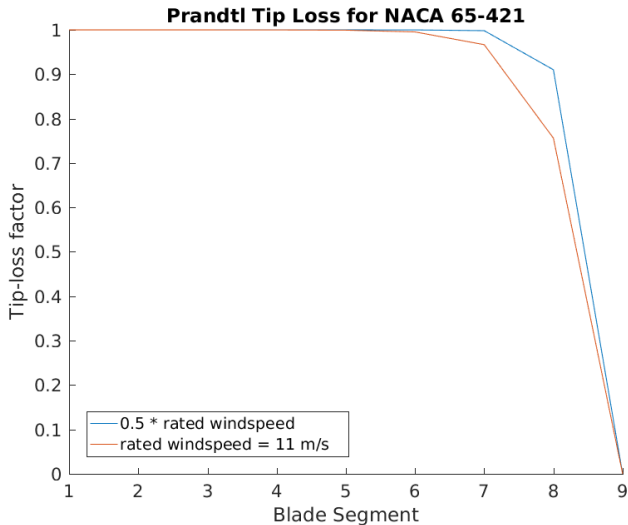


Station	1	2	3	4	5	6	7	8	9
	Cylinder	65-421	65-421	65-421	65-421	65-415	65-415	65-415	65-415
Blade	3.297	9.891	16.484	23.078	29.672	36.266	42.859	49.453	52.750
Chord	6,628	5,426	3,935	3,014	2,425	1,887	1,617	1,413	1,329
Twist	27,590	11,022	3,813	0,055	-2,211	-2,715	-3,783	-4,580	-4,907

# BEM algorithm

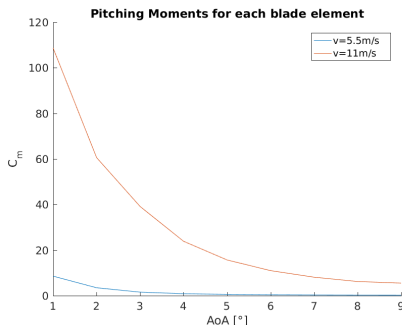


# Prandtl tip losses



# 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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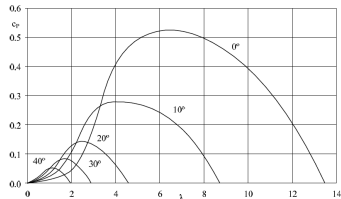
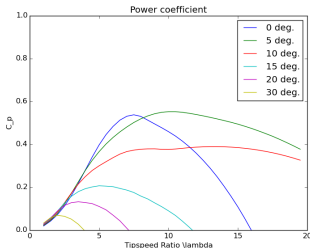
# WT\_Perf

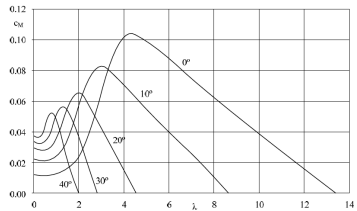
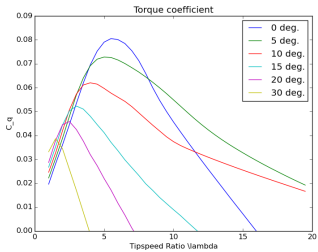
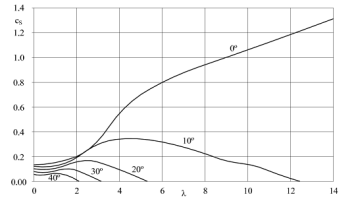
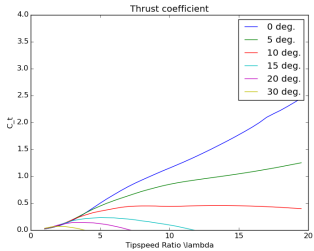
```

----- 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

```







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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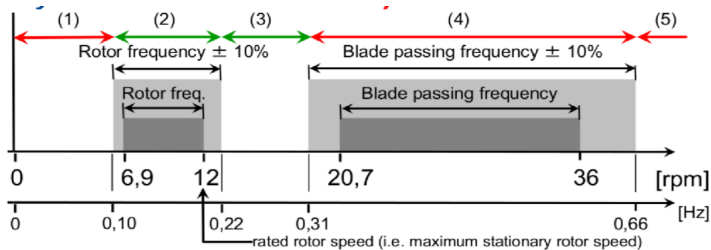
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# Tower eigenfrequency

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

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

Design range: Classical soft-stiff design



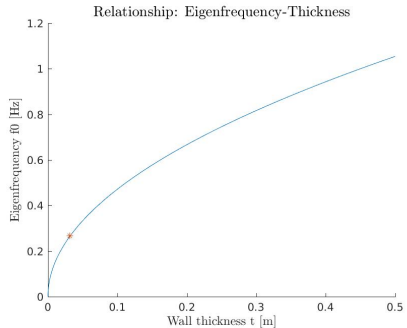
# Wall thickness

Can be obtained from the eigenfrequency and some other parameters

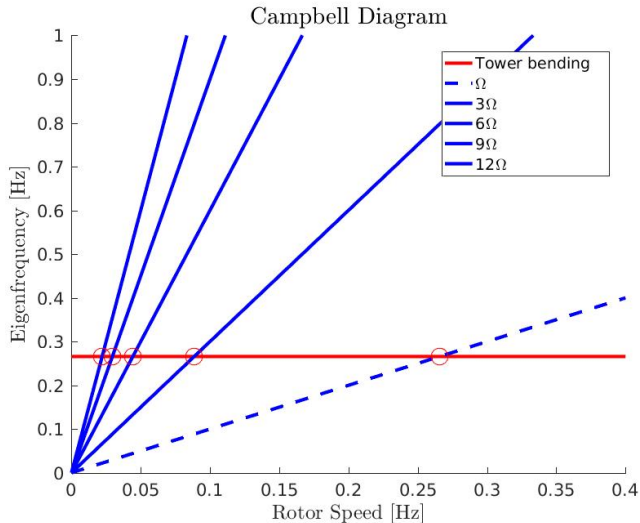
$$f_o \cdot 2\pi = \sqrt{\frac{3E\pi D^3 t}{l38(m_{top} + 0.25\rho\pi Dtl)}}$$

With fsolve:  $t = 0.0318m$

Costs: ca 195870Euro



# Campbell diagram



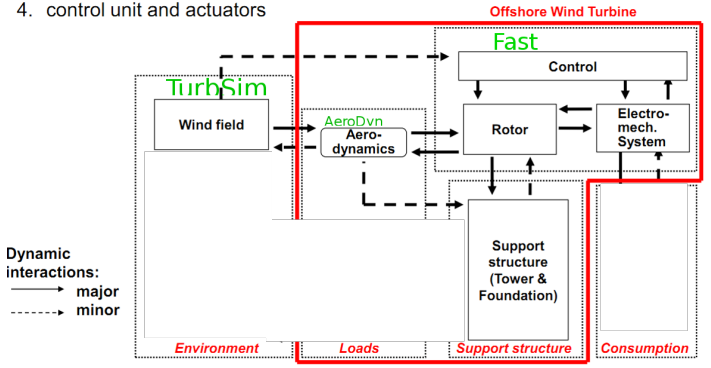


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# Software during the design process

## 4. control unit and actuators



# Turbulence intensity

Free stream (NTM)

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

$$I = \sigma / v_{hub}$$

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

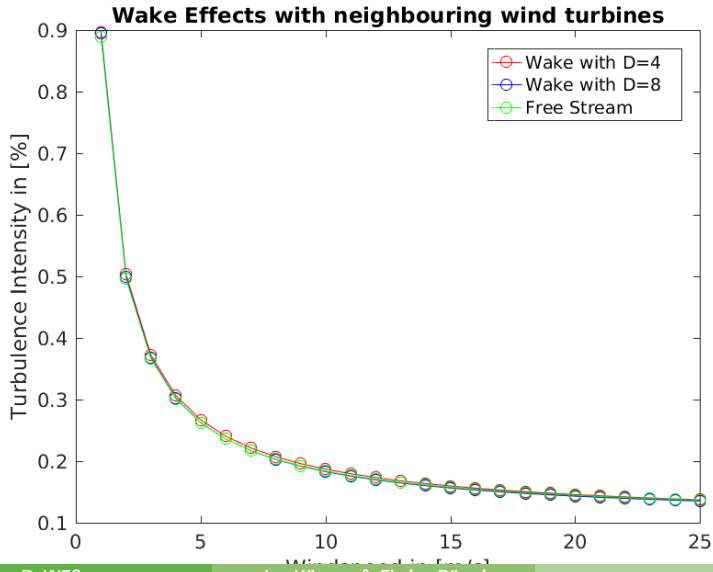
## Wakes (Frandsen model)

$$\sigma_T = \sqrt{\frac{0.9v_{hub}^2}{1.5 + 0.3d_i\sqrt{V_{hub}/c}}} + \sigma$$

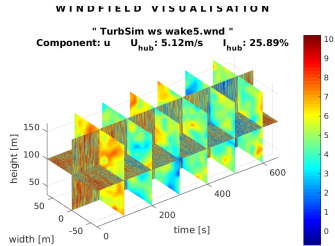
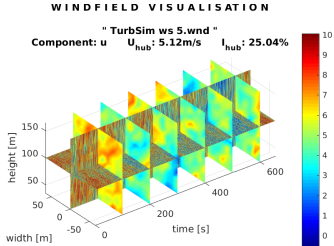
$$I = ((1 - Np_w)\sigma^m + p_w * \sum_{i=1}^N \sigma_T^m(d_i))^{1/m} \frac{1}{V_{hub}}$$

v	5m/s	10m/s	15m/s	25m/s
4 · d	0.2667	0.1867	0.1594	0.1370
8 · d	0.2621	0.1827	0.1562	0.1349

# Comparison



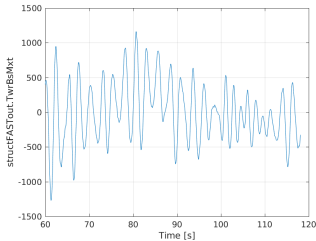
# Windfields



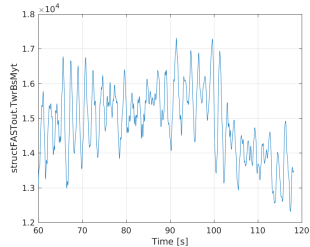
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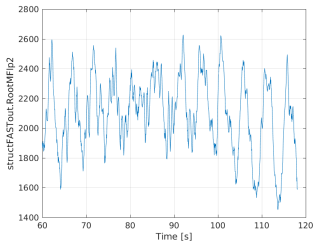
# Bending moments



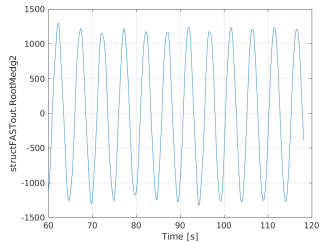
**Tower side-to-side bending moments**



**Tower fore-aft bending moments**



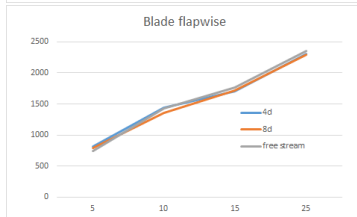
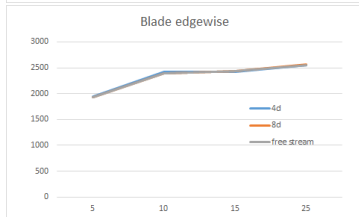
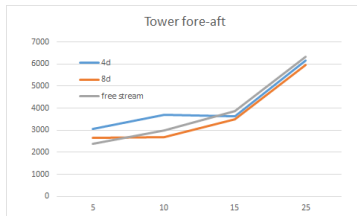
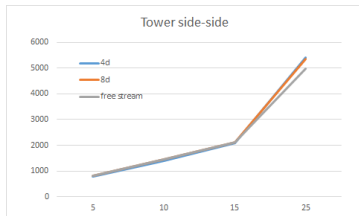
**Blade flapwise bending moments**



**Blade edgewise fore-aft bending moments**



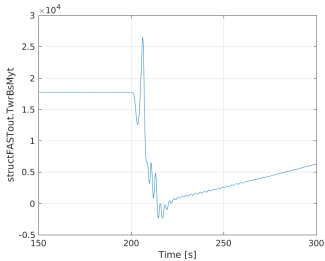
# Comparison of DELs (free stream vs wake)



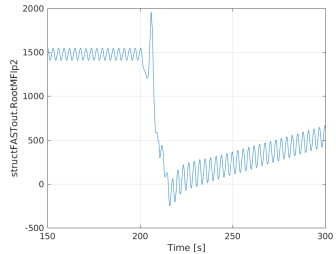
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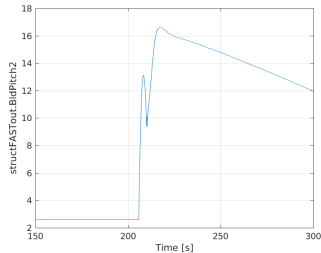
# Loadcase 2.3



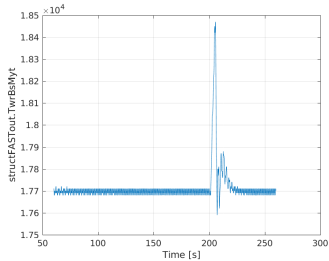
Tower fore-aft for EOG<sub>50</sub>



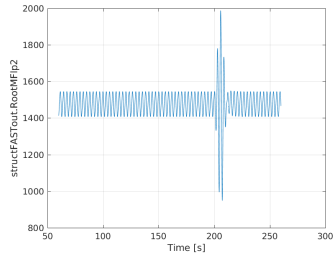
Blade flapwise for EOG<sub>50</sub>



# Loadcase 1.5



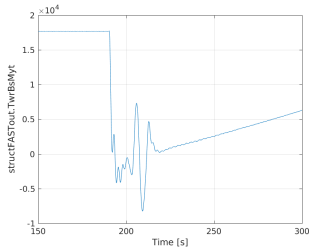
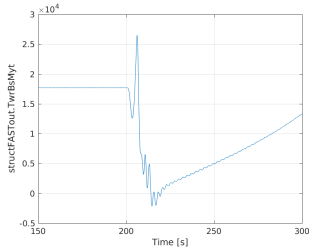
Tower fore-aft for EWS



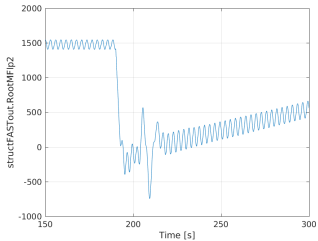
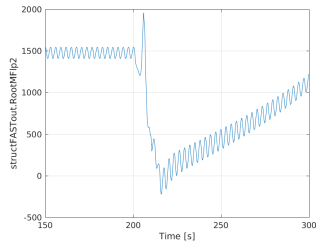
Blade flapwise for EWS

# Modified brakes and failure timing 2.3

## Tower fore-aft



## Blade flapwise



Thanks!