Assignment #1:

This assignment deals with applying the BEM algorithm and learn the basic operation of a variable speed pitch regulated wind turbine. All aerodynamic and structural data are available for the DTU 10 MW virtual experimental wind turbine in the report "Description of the DTU 10 MW Reference Wind Turbine", DTU Wind Energy Report-I-0092. Have a look in this report and read section 3, where you can find tables and Figures that can be used when validating your code.

Overall data for the DTU 10 MW WT:

Rotor radius R= 89.17 m
Number of blades 3
Rated electrical power 10 MW
Cut in wind speed 4
m/s
Cut out wind speed 25
m/s Air density ρ=1.225
kg/m^3

The blade is described with following table, where the first column indicates the radial distance from the rotational axis and columns 2 and 3 are the corresponding chord length and twist angle. The fourth column indicates the airfoil used by specifying the thickness to chord ratio measured in per cent.

r [m]	c [m]	β [deg]	t/c [%]
2,80	5,38	14,50	100,00
11,00	5,45	14,43	86,05
16,87	5,87	12,55	61,10
22,96	6,18	8,89	43,04
32,31	6,02	6,38	32,42
41,57	5,42	4,67	27,81
50,41	4,70	2,89	25,32
58,53	4,00	1,21	24,26
65,75	3,40	-0,13	24,10
71,97	2,91	-1,11	24,10
77,19	2,54	-1,86	24,10
78,71	2,43	-2,08	24,10
80,14	2,33	-2,28	24,10
82,71	2,13	-2,64	24,10
84,93	1,90	-2,95	24,10
86,83	1,63	-3,18	24,10
88,45	1,18	-3,36	24,10
89,17	0,60	-3,43	24,10

The airfoils used along the blades are FFA-W3-xxx, where the last three digits indicate the thickness of the airfoil as the thickness to chord ratio t/c. E.g. the FFA-W3-241 has a thickness to chord ratio of 24.1 %.

Airfoil data, $C_l(\alpha)$ and $C_d(\alpha)$ for six airfoils are provided: cylinder.txt, FFA-W-600.txt, FFA-W-480.txt, FFA-W-360.txt, FFA-W-301.txt and FFA-W-241.txt. A cylinder has a thickness to chord ratio of 100%. When estimating the local lift and drag coefficients at the various radial positions one must interpolate in both angle of attack and the thickness to chord ratio.

BEM Tip: **Avoid placing the last blade element too close to the tip since this can give numerical problems caused by Prandtl's tip loss correction. However, when integrating the loads to determine the total thrust and torque an element should be placed at the tip and the loads put 0 N/m.**

Q#1 Compute the highest obtainable power coefficient, Cp,max(λmax, θp,max), and the corresponding values of the tip speed ratio and pitch angle, λmax and θmax . Try both equations (1) and (2) as described on the course slides for the momentum equation and compare the two solutions. Make and discuss contour plots Cp(λ,θp) and C_T(λ,θp).

$$\frac{C_T}{F} = \begin{cases} 4a(1-a) & a \le 0.33 \\ 4a(1-\frac{1}{4}(5-3a)a) & a > 0.33 \end{cases} \qquad (1)$$

$$a = 0.246 \cdot \frac{C_T}{F} + 0.0586 \cdot (\frac{C_T}{F})^2 + 0.0883 \cdot (\frac{C_T}{F})^3 \qquad (2)$$

Tip: The optimum pitch lies between -4 and 3 degrees and the optimum tip speed ratio between 5 and 10.

Q#2 Imagine that we want the turbine to run at the maximum $C_p = C_{p,max}$ all the way to rated power P_{mech}=10.64 MW. What is the rated wind speed, $V_{o,rated}$ and the maximum rotational speed needed, ω_{max}. Also plot $\omega(V_o)$.

Q#3 To limit the power at high wind speeds one can pitch the blades.
Compute the pitch setting, $\theta_p(V_o)$ between cut-in and cut-out wind speed when the mechanical power is limited to 10.64 MW and the rotational speed to ω_{max}. Do this for both pitching toward feather and stall. Plot and comment power $P(V_o)$, pitch $\theta_p(V_o)$ and thrust, $T(V_o)$ for botch pitch strategies. Also plot the corresponding non-dimensional coefficients $C_p(V_o)$ and $C_T(V_o)$

Q#4 Run the Ashes program and compare the aerodynamic loads with your own BEM code for Vo=5, 9, 11, and 20 m/s. Try and explain the source of any differences you may see.

Q#5 Compute the annual energy production for the pitch regulated wind turbine erected at a site with following Weibull parameters, A=9 m/s and k=1.9. How much energy is lost if the wind turbine is stopped at V_o=20 m/s instead of 25 m/s, and why could that in some cases be a good idea.