Invitation to the 2013 "Blind test 3" Workshop
Two in-line wind turbines with spanwise offset

Per-Åge Krogstad and Lars Sætran
Department of Energy and Process Engineering, NTNU, Trondheim, Norway

This note describes the third blind test case organized by NOWITECH and NORCOWE. The first blind test, BT1, was organized in Bergen, in October 2011, and attracted around 40 participants with 11 sets of predictions being submitted. For that blind test the geometry of a model turbine was made available and the participants were asked to predict its performance and the wake development from the turbine down to 5 diameters. The results from the BT1 have been reported in [1].

For the next blind test, held in Trondheim, in October 2012, the test complexity was increased by adding a second turbine behind the first. The main task in BT2 was to predict the performance of the downstream turbine which is affected by the wake developing behind the first turbine. The participants were also asked to predict the flow in the wake behind the second turbine. Obviously, this is a more complicated test case than BT1 and requires more computer resources to be performed properly. Despite this, results were submitted by 9 different participants showing good agreement with the measurements. A documentation of the results will be presented at the ICOWES2013 meeting in Copenhagen, Denmark, 17-19 June 2013 [2].

In this third blind test, BT3, we have chosen to increase the complexity slightly again. We use the same turbines, positioned with the same streamwise separation, but shifted slightly sideways so that the wake from the first turbine only hits part of the rotor plane of the downstream turbine. In this way the second turbine will experience a non-symmetrical load and the dynamics of the forces is expected to become more serious. Also, the wake development behind the second turbine is going to be highly non-axisymmetric. This test case is performed both in a virtually turbulence free, uniform flow environment, and with a turbulent flow. In the latter case a grid has been used to produce again a uniform inflow, but with about 10% turbulence intensity at the location of the first turbine.

For those who submitted results for BT2, but are unable to cope with the additional complexity of the asymmetry in the present case, we will also provide data for the BT2 setup performed in the turbulent environment described above.

Again we invite you to submit predictions for this test case and participate in a two-day workshop to be held in Bergen, tentatively scheduled for early December 2013. Here the results from the predictions will be discussed and a comparison with measurements will be presented.

1 Test case definitions

In the following we provide information about how to set up the test case. Depending on whether your computational model assumes axisymmetric flow and uses a rotating frame of reference, or computes a rotating rotor in a fixed environment, you may want to use the exact tunnel dimensions or convert the cross section to an equivalent circular cylinder in order to account for possible blockage effects and wall boundary layers.

We also provide full details of the model geometry. A CAD file that describes one blade mounted on one third of the nacelle is available. Alternatively you can build your own geometry from tables containing definitions of the airfoil, as well as the chord length and twist as function of the radius. The information needed is described in the following sections.

1.1 The models

A picture of the models in the wind tunnel is shown in Figure 1. Both turbines have three bladed upstream rotors, with the same blade geometry, but a slightly different rotor diameter, due to some differences in nacelle diameters. The blades were machined in aluminum and have a NREL S826 airfoil section from root to tip. (See Somers [3] for full airfoil documentation.)

Figure 1: Model in the wind tunnel

Figure 2 gives the dimensions of the two turbines and shows that the models have slightly different tower and nacelle layouts. *Also note that the tower heights given in the figure show their physical dimensions to the fixing points and not the actual height as operated in the wind tunnel.* These heights will be specified further down. The turbine operated upstream will in the following be refered to as T_1, while T_2 will be the downstream one. The two turbines are positioned at a streamwise separation of $3D$, where D is defined as $0.894\ m$. This is the diameter of the rotor of the downstream turbine T_2.

The tower of turbine T_1 is a cylinder with a constant diameter of $0.11\ m$, while for T_2 the rotor sits on top of a stepped tower consisting of 4 cylinders of different diameters. This is the same turbine that was used in BT1. The nacelle of turbine T_1 is a circular cylinder of $D_{T_1}^{nac} = 0.13\ m$ diameter. The nacelle of T_2 is also circular but with a diameter of $D_{T_2}^{nac} = 0.09\ m$. The rotor diameter of T_1 is $D_{T_1} = 0.944\ m$, while $D_{T_2} = 0.894\ m$. Both turbines are driven by a belt transmission connected to a 0.37 kW asynchronous motor located under the tunnel floor, controlled by a Micromaster 440 Siemens frequency converter. Turbine T_1 has the belt mounted inside the tower, while for T_2 the tower is too slender to allow this, so the belt runs behind the turbine tower.

Turbine T_2 has an almost semi spherical hub cover at the front. Its deviation from a sphere is small but if the exact geometry is deemed necessary, it may be obtained from the organizers as a table in an Excel file. In the CAD file mentioned above, the correct shape is of course included. At the rear, the cap is again formed from a sphere, slightly offset and with a somewhat larger diameter, as indicated in the figure.

Turbine T_1 has a slightly pointed hub cover. The dimensions are documented in Figure 2(b); a CAD file and an excel file may also be downloaded for this turbine too.

With respect to the centre line, the upstream turbine is offset 0.20 m to the $LEFT$ when seen from the direction of the incoming wind, while the downstrem turbine is offset 0.20 m to the $RIGHT$. This gives a total spanwise shift between the two turbines of 0.40 m or close to one rotor radius. Both turbines rotate in the counter-clockwise direction when viewed from the front.

1.2 The blade geometry

The blades use the NREL S826 airfoil along the entire span. The normalized coordinates for the profile are given in Section 2. We also include a table of chord length and twist angle as function of the radius, which you will find in Section 3. Combined, this information allows you to define the blade geometry.

For your convenience, we supply a CAD file containing a 120 degrees segment of the nacelle of turbine T_2 with one blade mounted in the correct position. We also supply the 3D CAD files of both complete turbines.

The CAD files may be downloaded from
http://www.ivt.ntnu.no/ept/downloads/workshop2013.
The login details are:
User: Workshop2013
Password: Turbine

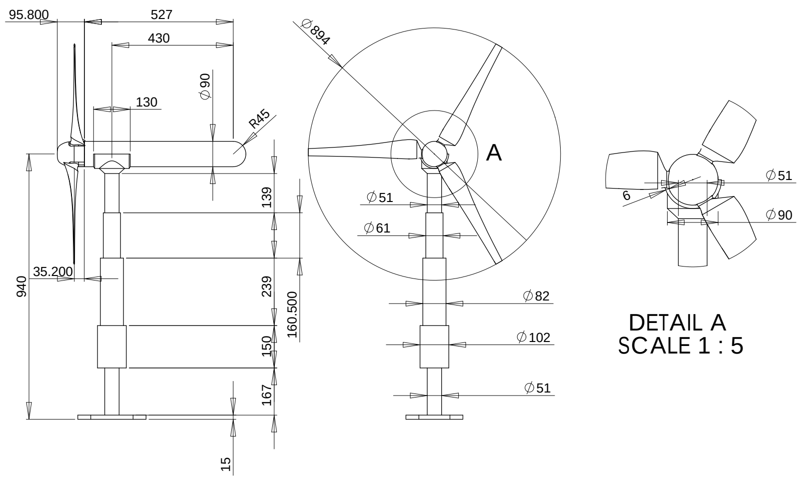
1.3 The test environment

The model turbines were tested in a closed return wind tunnel. It has a test section which is 2.71m wide and 11.14m long. The tunnel has a flexible roof which has been adjusted for zero pressure gradient. The tunnel heights are given in Table 1.

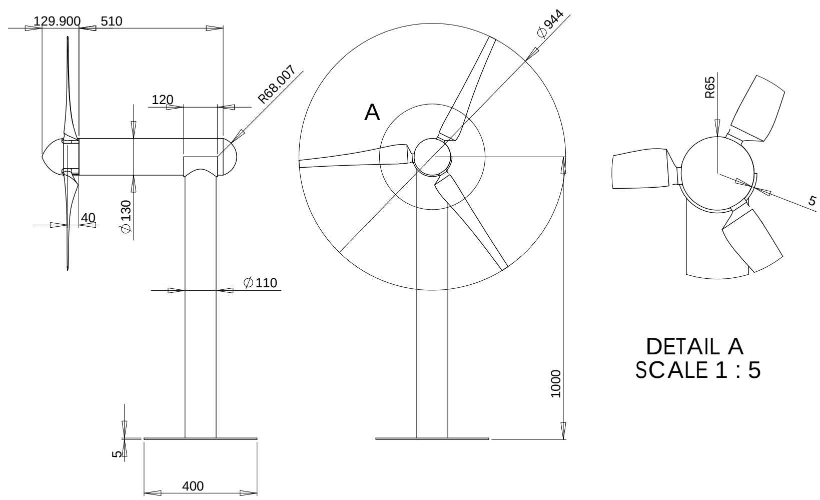
X (m)	Height (m)
0.000	1.801
2.810	1.801
5.621	1.813
8.435	1.842
11.150	1.851

Table 1: Height of test section as function of distance from the inlet

At the inlet to the empty test section the flow is uniform across the cross section to within $\pm 1\%$, except for the thin region of wall boundary layers, and the turbulence intensity was been measured to be 0.24%. The conventional model which relates the dissipation rate of turbulent kinetic energy, ϵ, to the streamwise velocity fluctuation, u, and the streamwise



(a) Downstream Turbine, T_2



(b) Upstream Turbine, T_1

Figure 2: T_1 and T_2, tower and nacelle dimensions

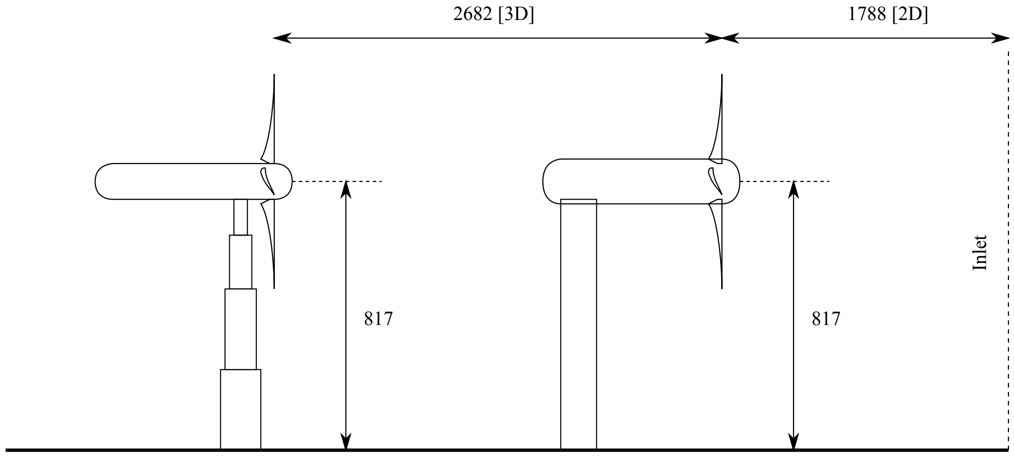


Figure 3: Wind tunnel placement of the turbines

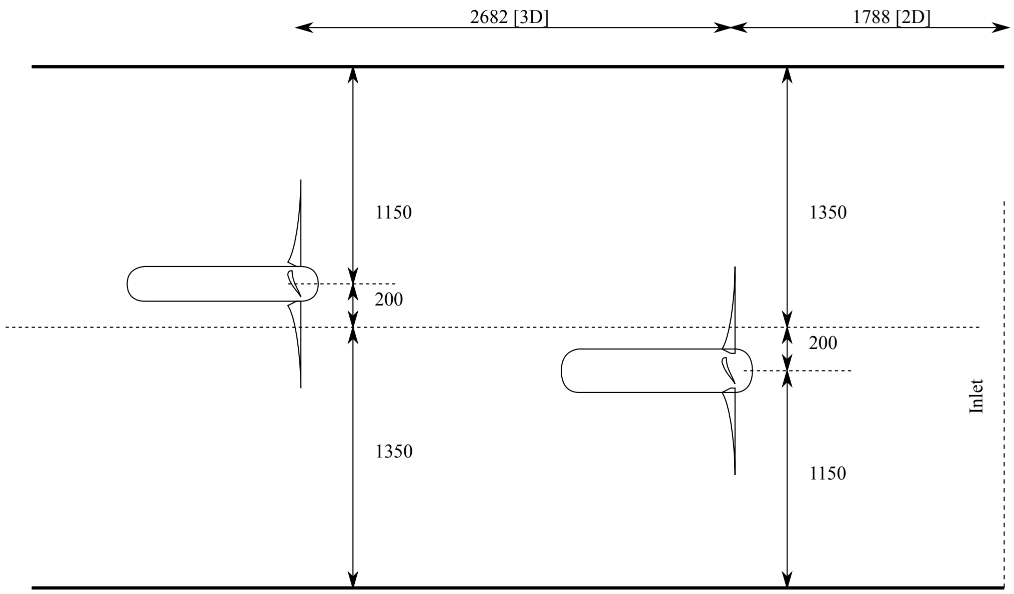


Figure 4: Wind tunnel test section seen from above

integral length scale, L_{uu}, is given by

$$\epsilon = \frac{3}{2} A \frac{u^3}{L_{uu}}. \tag{1}$$

Using $\frac{3}{2}A \approx 1$ (taken from Krogstad & Davidson, [4]) the integral length in the streamwise direction at the test section inlet was calculated from measurements of u and ϵ to be $L_{uu} = 0.035$ m. (Note that this length is virtually identical to the length scale obtained by integrating the streamwise auto correlation function normally specified. However, this integral quantity is experimentally much harder to measure correctly and was therefore not used here.) At the position where the rotor centre for the first turbine is located ($x/D = 2$), the length scale has grown slightly. The measurements here gave $L_{uu} = 0.045$ m and the turbulence intensity was 0.22%. Over the area swept by the rotor, the mean velocity in the empty tunnel was found to be uniform to within ±0.5%.

At the location of the second turbine the turbulence intensity was measured to be 0.23% and the integral length scale was $L_{uu} = 0.053$ m.

Figure 5: Models and turbulence grid

In order to include the effects of atmospheric turbulence, measurements were also performed using a large scale grid at the entrance to the test section. (See Figure 5.) The grid mesh size was $M = 0.240$ m, which at the position of the upstream turbine, T_1, gave a turbulence intensity of 10.0%. The length scale here was estimated from equation (1) to be $L_{uu} = 0.065$ m. This is a turbulent flow where the kinetic energy is decaying with the distance from the grid. Initially there are significant spanwise variations in the flow, but by the time the flow reaches the position of the first turbine, the mean velocity was virtually independent of the spanwise coordinates and was found to be uniform to within ±0.65%. Similarly, the turbulence intensity was constant to within ±0.9%.

Since there are no significant spanwise variations in the flow, the kinetic energy dies out slowly downstream. As the flow reaches the position of the second turbine, the turbulence intensity in the empty tunnel has dropped to 4.8% with a streamwise integral length scale of $L_{uu} = 0.100$ m.

Both turbines have the same rotor axis height above the wind tunnel floor, $h = 0.817\ m$ (see figure 3). However, unlike in the BT2 test case, the turbines are not mounted at the spanwise centre line. Seen from the inlet to the test section, turbine T_1 is shifted 0.2 m towards the left, while turbine T_2 is shifted the same amount to the right, giving a total spanwise shift between the two turbines of $\Delta z = 0.4\ m$ (see figure 4). This shift, which is slightly less than the rotor radius, was estimated to give a wake that interact with the downstream turbine rotor over close to half of its area.

All measurements were taken with a bulk velocity at the test section inlet equal to $U_\infty = 10.0\ m/s$.

2 Definitions for NREL S826

The definitions of the NREL S826 airfoil used for the blade may be found in Somers [3] and the airfoil is shown in Figure 6. Table 2 contains a list of the normalized coordinates for the airfoil. Somers specifies the geometry, as well as estimated performance characteristics, such as lift and drag coefficients, for a range of full scale operating Reynolds numbers. Unfortunately, these are computed for much higher Re than the ones applicable in the model tests.

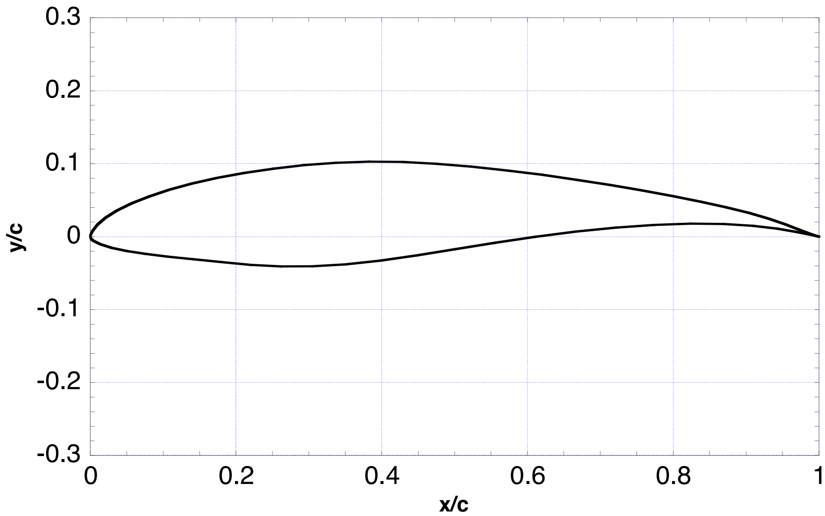


Figure 6: Shape of the NREL S628 airfoil

For the first two blind tests, the participants were asked to estimate the performance data for S826 themselves. When the predictions were analyzed and compared, we have seen that part of the scatter in the results may be traced back to the fact that different groups have generated quite different estimates for the lift and drag coefficients. In order to reduce the uncertainty for the current blind test, we have decided to provide a standard set of C_L and C_D coefficients that the participants should use for all operating conditions. In this way it is hoped to remove some of the variability in the predictions, possibly at the expense of introducing some systematic differences between the predictions and the measurements.

The data to be used is given in Table 3. Note that this set is given for one Reynolds number only ($Re = 10^5$). This corresponds to the Re obtained at the blade tip at the design operating condition, i.e. at a tip speed ratio of 6. Obviously this will be somewhat incorrect for the inner part of the blade, but the effects on the performance data at the design condition have been seen to be small. More severe are the changes as the tip speed ratio varies over about one order of magnitude, from the deep stall condition up to the run-away tip speed ratio. However, the T_1 turbine is always operated at the design condition, and the performance of the downstream turbine, T_2, is likely to be so much affected by the wake from T_1, that the Re-effects on C_L and C_D are likely to be small.

In figure 7 the data from Table 3 are compared with 2D measurements on the S826 performed at DTU, Denmark, [5] and at METUWIND, Turkey. The XFOIL data in Table 3 are seen to fall between the measurements, capturing the trends from the METUWIND at the normal operating modes, but being closer to the DTU data at extremely high angles of attack. Measurements for $Re = 1.0 \times 10^5$ are shown, but more data are available from both the DTU, Denmark, and the METUWIND, Turkey measurement campaigns.

x/c	y/c (upper surface)	x/c	y/c (lower surface)
0.0000	0.0000	0.0000	0.0000
0.00018000	0.0015900	0.00021000	-0.0014600
0.0025500	0.0074800	0.00093000	-0.0027400
0.0095400	0.016380	0.0021600	-0.0040300
0.020880	0.025960	0.0036700	-0.0052500
0.036510	0.035800	0.013670	-0.010350
0.056360	0.045620	0.029200	-0.015180
0.080260	0.055190	0.049980	-0.019600
0.10801	0.064340	0.075800	-0.023620
0.13934	0.072880	0.10637	-0.027290
0.17395	0.080680	0.14133	-0.030910
0.21146	0.087580	0.17965	-0.034860
0.25149	0.093430	0.21987	-0.038550
0.29361	0.098070	0.26153	-0.040640
0.33736	0.10133	0.30497	-0.040510
0.38228	0.10294	0.35027	-0.037940
0.42820	0.10249	0.39779	-0.032800
0.47526	0.10005	0.44785	-0.025630
0.52324	0.096070	0.50032	-0.017200
0.57161	0.090940	0.55484	-0.0084100
0.61980	0.084890	0.61055	-0.0001500
0.66724	0.078160	0.66644	0.0069900
0.71333	0.070950	0.72142	0.012540
0.75749	0.063410	0.77434	0.016210
0.79915	0.055720	0.82409	0.017840
0.83778	0.047980	0.86953	0.017410
0.87287	0.040290	0.90945	0.014980
0.90391	0.032620	0.94257	0.011130
0.93072	0.024790	0.96813	0.0068900
0.95355	0.016950	0.98604	0.0032400
0.97251	0.0098200	0.99655	0.0008400
0.98719	0.0043100	1.0000	0.0000
0.99668	0.0010300		
1.0000	0.0000		

Table 2: Coordinates for the NREL S826 airfoil

α	C_L	C_D	C_L/C_D	α	C_L	C_D	C_L/C_D
-40.0	-0.96710	0.39968	-2.4197	3.00	0.82540	0.023250	35.501
-35.0	-0.87580	0.36549	-2.3962	4.00	0.91800	0.024420	37.592
-30.0	-0.75170	0.32383	-2.3213	5.00	1.0019	0.025880	38.713
-25.0	-0.60080	0.27557	-2.1802	6.00	1.0783	0.027800	38.788
-20.0	-0.43470	0.22170	-1.9608	7.00	1.1469	0.030290	37.864
-18.0	-0.36800	0.19869	-1.8521	8.00	1.2060	0.033540	35.957
-16.0	-0.30430	0.17474	-1.7414	9.00	1.2550	0.037850	33.157
-14.0	-0.24910	0.14843	-1.6782	10.0	1.2929	0.043660	29.613
-12.0	-0.20180	0.12244	-1.6482	11.0	1.3320	0.049960	26.661
-11.0	-0.18650	0.10792	-1.7281	12.0	1.3509	0.059220	22.812
-10.0	-0.18110	0.091970	-1.9691	13.0	1.3718	0.069050	19.867
-9.00	-0.19240	0.073190	-2.6288	14.0	1.3784	0.081720	16.867
-8.00	-0.25200	0.054460	-4.6272	15.0	1.3638	0.098800	13.804
-7.00	-0.23440	0.038600	-6.0725	16.0	1.3431	0.11883	11.303
-6.00	-0.14360	0.029050	-4.9432	18.0	1.2563	0.17904	7.0169
-5.00	-0.049500	0.023940	-2.0677	20.0	1.1940	0.26157	4.5647
-4.00	0.071400	0.021820	3.2722	22.0	1.2493	0.29458	4.2410
-3.00	0.18800	0.021090	8.9142	25.0	1.3379	0.33390	4.0069
-2.00	0.30260	0.020730	14.597	30.0	1.4702	0.38800	3.7892
-1.00	0.41360	0.020770	19.913	34.0	1.5519	0.42331	3.6661
0.00	0.52200	0.021040	24.810	40.0	0.96620	0.63129	1.5305
1.00	0.62690	0.021530	29.118	50.0	0.84970	0.73405	1.1576
2.00	0.72880	0.022220	32.799				

Table 3: Lift and drag coefficients calculated for $Re = 1.0 \times 10^5$ using XFOIL.

If you are insisting on using lift and drag data at the correct Re as it varies with radial position and turbine operating conditions, you will need to generate your own data tables. You can do this e.g. by using the program package called $XFOIL$, see Drela [6] or obtain the complete measurement data sets directly from DTU or METUWIND. (Contact information will be provided upon request.) It is important that you inform us about how the information is obtained if you do not use the data provided here.

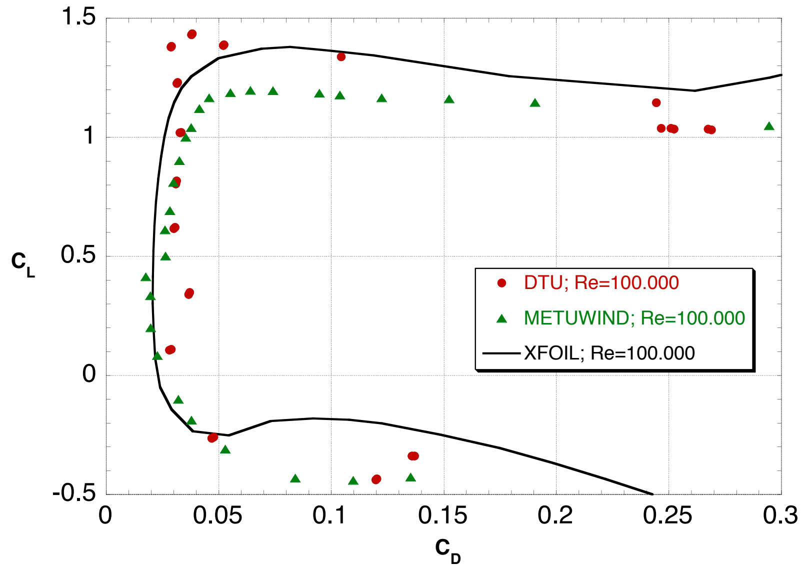
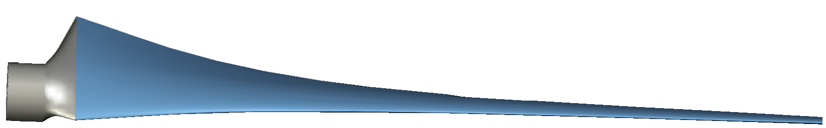


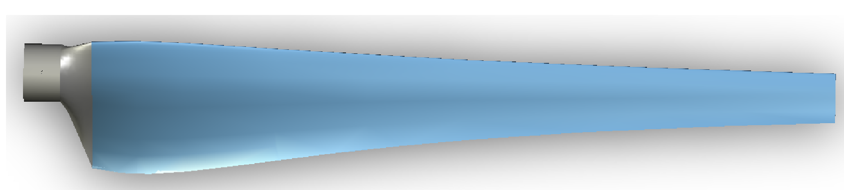
Figure 7: Comparison between data from Table 3 and measurements by DTU, Denmark, [5] and METUWIND, Turkey

3 Chord and Twist data

Table 4 contains a list of the airfoil chord length and twist angle as function of the radius. (The twist angle is measured with respect to the rotor plane.) Please note that for the first 3 coordinate sets the geometry consists of a circular cylinder used to fix the blade to the hub. Therefore a major part of this section is located inside the hub when defining the rotor geometry. This section has been identified in the table by setting the twist angle to 120 degrees. Between the last circular section and the first NREL profile, a linear transition region has been added to give a smooth change of shape. The blade is shown in Figure 8.



(a)



(b)

Figure 8: Blade a) seen in the plane of rotation and b) in the axial direction.

r (m)	c (m)	ϕ (deg)
0.0075000	0.013500	120.00
0.022500	0.013500	120.00
0.049000	0.013500	120.00
0.055000	0.049500	38.000
0.067500	0.081433	37.055
0.082500	0.080111	32.544
0.097500	0.077012	28.677
0.11250	0.073126	25.262
0.12750	0.069008	22.430
0.14250	0.064952	19.988
0.15750	0.061102	18.034
0.17250	0.057520	16.349
0.18750	0.054223	14.663
0.20250	0.051204	13.067
0.21750	0.048447	11.829
0.23250	0.045931	10.753
0.24750	0.043632	9.8177
0.26250	0.041529	8.8827
0.27750	0.039601	7.9877
0.29250	0.037831	7.2527
0.30750	0.036201	6.5650
0.32250	0.034697	5.9187
0.33750	0.033306	5.3045
0.35250	0.032017	4.7185
0.36750	0.030819	4.1316
0.38250	0.029704	3.5439
0.39750	0.028664	2.9433
0.41250	0.027691	2.2185
0.42750	0.026780	1.0970
0.44250	0.025926	-0.7167

Table 4: Definitions of chord length and twist angle as function of blade radius.

4 Operating Conditions

This test consists of three operating configurations for which the computational output may be submitted. For all cases the first turbine is located at $x = 1.788\ m$ measured from the inlet to the test section, which corresponds to a distance of $2D$. The streamwise separation between the turbines is $3D$, or $\Delta x = 2.682\ m$. The blade pitch angle is always set at $\beta = 0°$.

4.1 Test case A

In this case the flow environment is the one described in section 1.3 for the empty tunnel, i.e. at a uniform inflow velocity of $U_\infty = 10.0\ m/s$ and a turbulence intensity of 0.24%. The upstream turbine (T_1) is operated at its design condition:

$$\lambda = \Omega R / U_\infty = 6. \tag{2}$$

For this condition the performance envelope of the **DOWNSTREAM TURBINE** should be computed, i.e. C_P and C_T over the range of λ where $C_P > 0$. Information about the dynamics of the rotor load in the form of the ratios of the standard deviation to the mean rotor torque (100% $\sigma_M/\overline{M}$, where M is the rotor torque) may also be submitted.

Furthermore, the wake development behind T_2 should be documented when the downstream turbine is operated at $\lambda = 3.5$, 4.75 and 8. Profiles along a horizontal line at the elevation of the centre of the turbine hubs ($y = 0.817$ m) should be provided at $\Delta x/D = 1$ and 3.

4.2 Test case B

For these measurements the large scale grid was placed at the entrance to the test section. In these calculations the turbulence intensity at the position of the upstream turbine, T_1, should be adjusted to be 10.0%. Again the performance envelope of the **DOWNSTREAM TURBINE** should be computed, i.e. C_P and C_T over the range of λ where $C_P > 0$. Information about the dynamic rotor loads are also welcome.

Again we request the participants to document the wake development behind T_2 when this turbine is operated at $\lambda = 3.5$, 4.75 and 8.0. Documentation of the profiles along a horizontal line at the elevation of the centre of the turbine hubs should again be provided at $\Delta x/D = 1$ and 3.

4.3 Test case C

We also provide a test case for those who can only handle turbines aligned in the streamwise direction, e.g. due to assumptions of axi-symmetry. This will also be an easy case to complete for those who participated in BT2 and would like to see the effects of background turbulence. Using the BT2 test case description, plots comparing C_P and C_T with and without the turbulence generating grid should be submitted.

For this case we ask for profiles at $\Delta x/D = 1$ and 3, but with the T_2 turbine operating at the same conditions used in BT2, i.e. $\lambda = 2.5$, 4.0 and 7.0.

See http://www.ivt.ntnu.no/ept/downloads/workshop2012 for the BT2 test case description.
The login details are:
User: Workshop2012
Password: TurbinS826

5 Computation output

The main aim of this blind test is to find out how well the performance of a turbine that is partially exposed to a uniform flow and partially to a turbulent wake may be predicted. Therefore the main outputs are the C_P and C_T curves of the downstream turbine.

The operating conditions for the turbines should be set to a free stream velocity of $U_\infty = 10.0\ m/s$ and air density of $\rho = 1.2kg/m^3$. The same reference velocity should be used for both turbines when scaling the output, even though the downstream turbine will experience a different reference velocity than the first due to the presence of the upstream turbine. A data template will be provided to ensure that data from all participants can be presented in the same way.

The design tip speed ratio for both T_1 and T_2 was $\lambda = \Omega R/U_\infty = 6$. This will give a Reynolds number at the design point of $Re_c = \lambda U_\infty c_{tip}/\nu \approx 10^5$, where c_{tip} is the tip chord length and ν is the kinematic viscosity of air.

Test case A: Low turbulence free stream

The participants are requested to provide the following output:

1. The power coefficient, $C_P = \frac{2P}{\rho U_\infty^3 A}$ and thrust coefficient, $C_T = \frac{2T}{\rho U_\infty^2 A}$ at $\lambda = 6$, for the **UPSTREAM** turbine. Here P is the power extracted from the wind, T is the force acting on the rotor plane in the direction of the wind and A is the rotor swept area ($A = \pi D^2/4$). Please note that the drag of the tower and nacelle should *NOT* be included in C_T!

2. The power coefficient, $C_P = \frac{2P}{\rho U_\infty^3 A}$ and thrust coefficient, $C_T = \frac{2T}{\rho U_\infty^2 A}$, for the **DOWNSTREAM** turbine from $\lambda = 1$ to the run-away value of λ, i.e. where the turbine power coefficient becomes zero. Again the drag of the tower and nacelle must *NOT* be included in C_T.

3. The non-dimensional streamwise mean velociy, U/U_∞, along a horizontal diagonal through the extension of the rotor axes at positions $X/D = 1$ and 3 from the downstream turbine rotor when T_2 is operated at $\lambda = 3.5$, 4.75 and 8.0.

4. The normalized turbulent kinetic energy, $k^* = \frac{k}{U_\infty^2}$, along the same diagonals. (The turbulent kinetic energy is defined as $k = \frac{1}{2}\left(u_x^2 + u_r^2 + u_\theta^2\right)$ in a cylindrical coordinate system, or you may use a corresponding approximation.)

5. A description of the method you are using which gives sufficient information to allow us to classify your method in order to group the results according to methods.

Test case B: High turbulence free stream

The same output as requested for Test case A should be provided for Test case B:

1. The power coefficient, $C_P = \frac{2P}{\rho U_\infty^3 A}$ and thrust coefficient, $C_T = \frac{2T}{\rho U_\infty^2 A}$ at $\lambda = 6$, for the **UPSTREAM** turbine. The drag of the tower and nacelle should not be included in C_T.

2. The power coefficient, $C_P = \frac{2P}{\rho U_\infty^3 A}$ and thrust coefficient, $C_T = \frac{2T}{\rho U_\infty^2 A}$, for the **DOWNSTREAM** turbine from $\lambda = 1$ to the run-away value of λ. The drag of the tower and nacelle should not be included in C_T.

3. The non-dimensional streamwise mean velociy, U/U_∞, along a horizontal diagonal through the extension of the rotor axes at positions $X/D = 1$ and 3 from the downstream turbine rotor when T_2 is operated at $\lambda = 3.5$, 4.75 and 8.0.

4. The normalized turbulent kinetic energy, $k^* = \frac{k}{U_\infty^2}$, along the same diagonals.

Test case C: In-line turbines

1. The power coefficient, $C_P = \frac{2P}{\rho U_\infty^3 A}$ and thrust coefficient, $C_T = \frac{2T}{\rho U_\infty^2 A}$ at $\lambda = 6$, for the **UPSTREAM** turbine. The drag of the tower and nacelle should not be included in C_T.

2. The power coefficient, $C_P = \frac{2P}{\rho U_\infty^3 A}$ and thrust coefficient, $C_T = \frac{2T}{\rho U_\infty^2 A}$, for the **DOWNSTREAM** turbine from $\lambda = 1$ to the run-away value of λ both for the non-turbulent and high turbulence operations. The drag of the tower and nacelle should not be included in C_T.

3. The non-dimensional streamwise mean velociy, U/U_∞, along a horizontal diagonal through the extension of the rotor axes at positions $X/D = 1$ and 3 from the downstream turbine rotor when T_2 is operated at $\lambda = 2.5$, 4.0 and 7.0.

4. The normalized turbulent kinetic energy, $k^* = \frac{k}{U_\infty^2}$, along the same diagonals.

An Excel data template specifying the output format will be made available at the Blind test 3 web page before the data submission is due.

References

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