"Blind test" Workshop
Calculations for a modell wind turbine

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Abstract

As part of the activities on wind turbine technology organized by NOWITECH / NOR-COWE we would like to invite you to participate in a so-called "Blind test" workshop. The main purpose of the workshop is to validate the performance of current wind turbine performance and wake predictions methods. The organizers of the workshop provide the geometry of a model wind turbine that has been extensively tested in the large wind tunnel of the Dept. Energy and Process Engineering, NTNU. Using only the geometric information, research groups who have a suitable computer code are invited to compute the performance of the turbine for a set of predefined operating conditions. The output from the predictions will be processed and compared with the experimentally obtained data by the organizers. The participants will then come together at a workshop in Bergen, tentatively scheduled for October 2011, to discuss the results and try to sort out recommendations for successful predictions etc.

We hope that the results may be published in a suitable journal afterwards.

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1 Test case definisions

In the following we provide information about how to set up the test case. You need to specify the wind tunnel environment as well as the turbine geometry. 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.

We also provide full details of the model geometry. You may want to download a CAD file that describes one blade mounted on one third of the nacelle, or you can build your own geometry from tables containing definitions of the airfoil as well as its chord length and twist as function of the radius.

The choice depends on your computational codes and personal preferences. In any case the information needed is described in the following sections.

1.1 The model

A picture of the model in the wind tunnel is shown in Figure 1. As may be seen from the photo the turbine has 3 blades and the rotor sits on top of a stepped tower consisting of 4 cylinders of different diameters.

The geometry of the tower and nacelle, with its dimensions, are shown in Figure 2. The nacelle is also circular with a diameter of d = 90mm. It has an almost semi spherical hub cover at the front. Its deviation form a sphere is small as indicated in the figure, 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.

The rotor diameter is D = 0.894m and the centre of the rotor is located Y = 0.817m above the floor level.

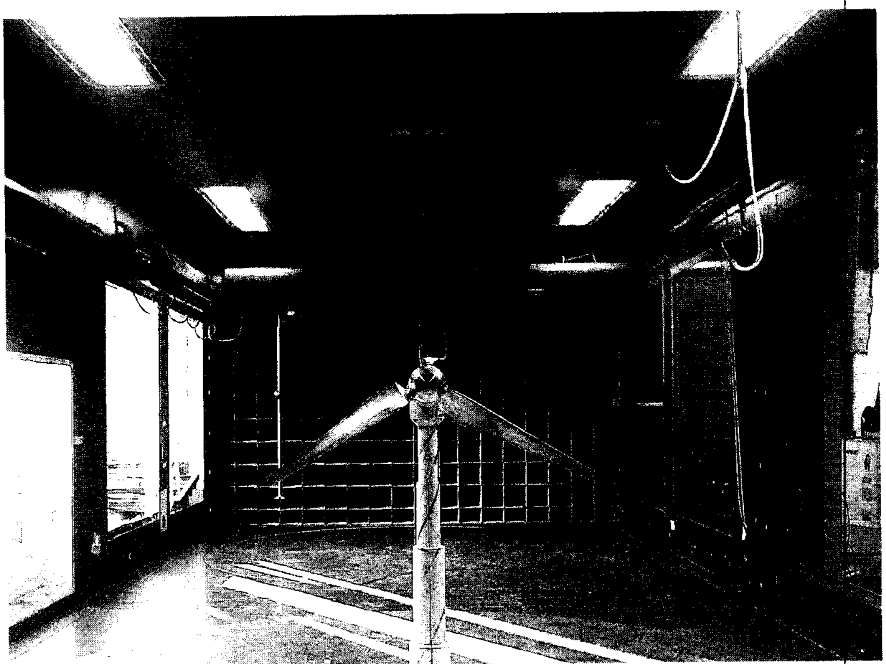

Figure 1: Model in the wind tunnel

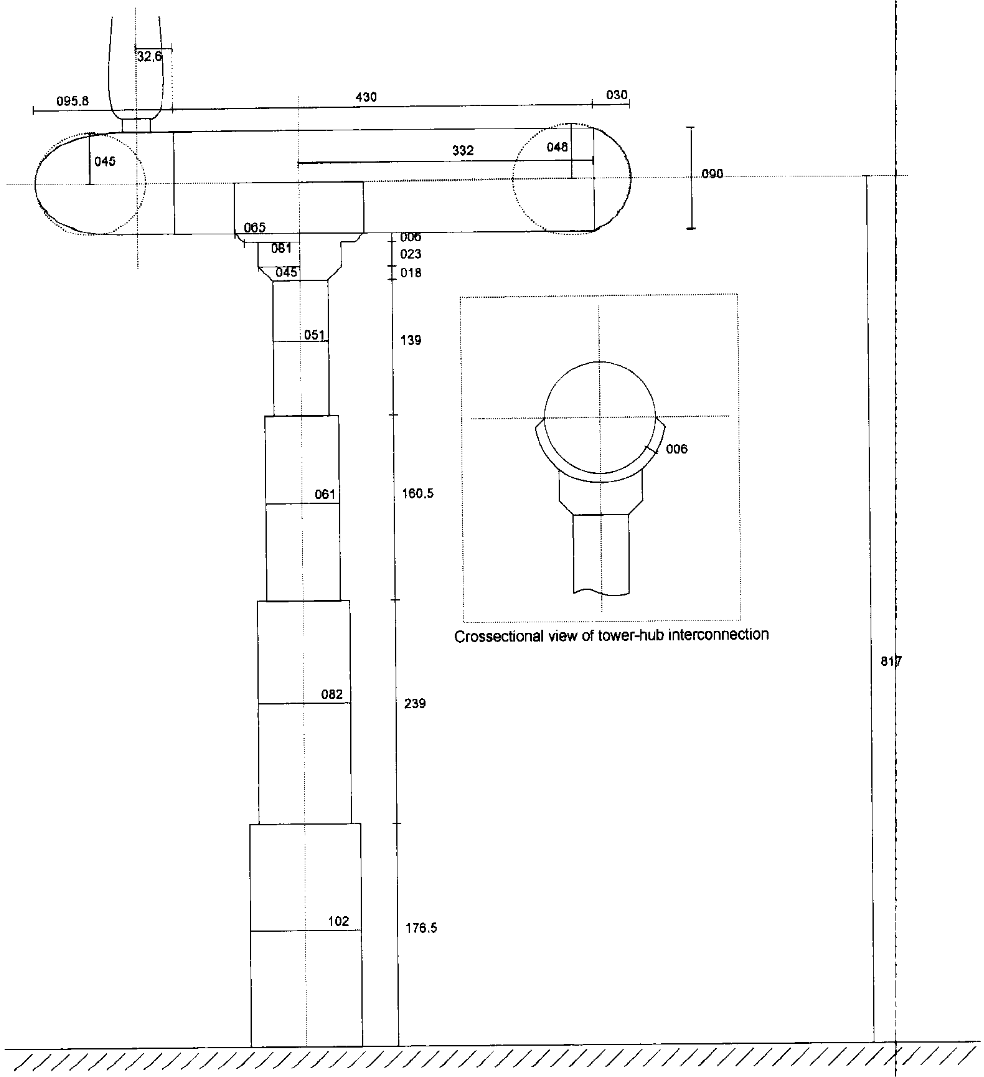

Figure 2: Tower and nacelle dimensions

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'll find in Section 3. Together this information allows you to define the blade geometry. However, for your convenience we also supply a CAD file containing a 120 degrees segment of the nacelle with one blade mounted in the correct position. This is shown in Figure 6.

The CAD file may be downloaded from

http://www.ivt.ntnu.no/ept/downloads/workshop2011.

The login details are:
User: Workshop2011
Password: TurbinS826

1.3 The test environment

The model turbine was tested in a tunnel which has a test section which is 2.71m wide and 11.15m long. The tunnel has a flexible roof which has been adjusted for zero pressure gradient at a bulk tunnel speed of $U \approx 14$m/s. The tunnel heights are given in table 1.

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

X (m)	Height (m)
0.000	1.801
1.281	1.801
5.621	1.813
8.435	1.842
11.150	1.851

At the inlet to the test section the flow is uniform across the cross section to within ±1% and the turbulence intensity has been measured to be 0.3%. Over the area swept by the rotor, the inlet flow is uniform to within ±0.5%

The model is located on the centre line with its rotor plane located at $X = 3.66$m from the test section entrance, as shown in Figure 3.

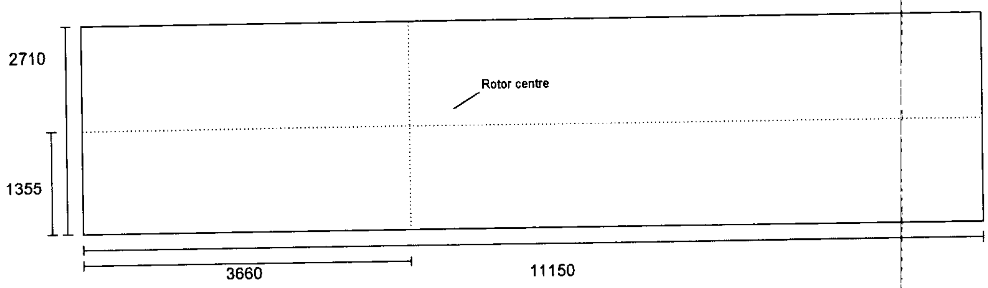

Figure 3: Wind tunnel test section seen from above

2 Definition coordinates for NREL S826

The definitions of the NREL airfoil used for the blade may be found in Somers [1] and is shown in Figure 4. 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. If you are using a Blade Element Momentum method, you may need to generate data for the operational Re of the model turbine. You can do this e.g. by using the program package called $XFOIL$, see Drela [2].

Table 2 contains a list of the normalized coordinates for the airfoil.

3 Chord and Twist data

Table 3 contains a list of the airfoil chord length and twist angle as function of 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 by setting the twist angle to 120 degrees.

Table 2: Coordinates for the NREL S826 airfoil

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		

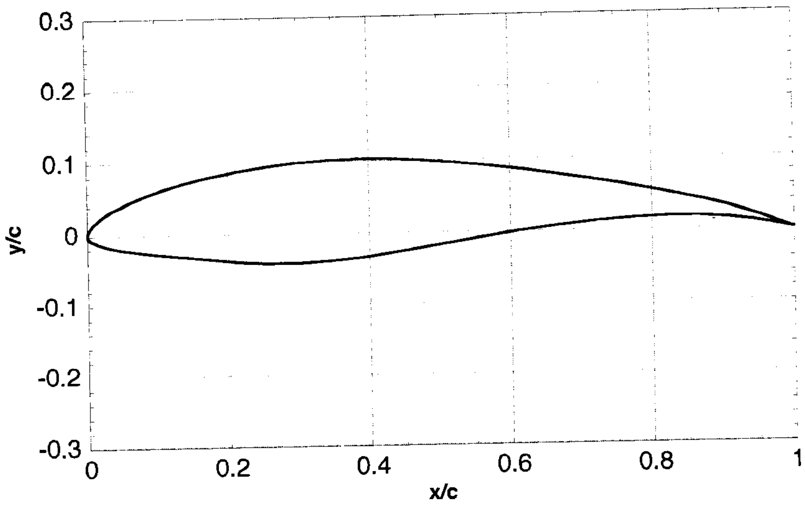

Figure 4: Shape of the NREL S628 airfoil

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 5(a) and 5(b).

Figure 5: Blade a) seen in the plane of rotation and b) in the axial direction.

Finally we show the blade mounted on the hub in Figure 6.

Table 3: Definitions of chord length and twist angle as function of blade radius.

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

4 Computation output

We expect calculations from various groups using a range of prediction methods. Some may want to use Blade Element Momentum methods, some rely on Actuator disk or Actuator line theories and some will use full three-dimensional CFD methods. Therefore the amount of output that may be generated will depend very much on the method applied. We have therefore specified different types of output to be generated. The "Mandatory output" specified in Section 4.1 is considered a minimum to be able to participate. It consists of the overall performance of the turbine and may be generated by e.g. a BEM method.

Even though your method may be capable of predicting the power and trust coefficients correctly, there is no guarantee that it has reproduced the flow field and load distributions on the blades satisfactorily. To find out more about this we ask for some extra output about the blade load distributions, if your method is capable of supplying this. For those who generate data also for the downstream flow field, we ask you to provide some optional output to find out how well the near wake development is predicted.

4.1 Mandatory output

The operating conditions for the turbine should be set to a wind speed of $U_{ref} = 10.0\text{m/s}$ and air density of $\rho = 1.2\text{kg/m}^3$. The design tip speed ratio was $\lambda = \Omega R/U_{ref} = 6$. ($\Omega$ is the angular speed of rotation and R is the rotor radius.) This will give a rotor tip Reynolds number at the design point of $Re_c = \lambda U_{ref} c_{tip}/\nu = 103600$, where c_{tip} is the tip chord length and ν is the kinematic viscosity of air.

All participants are required to provide the following output:

1. A table of power coefficients, $C_P = \frac{2P}{\rho U_{ref}^3 A}$, where P is the power extracted from the wind and A is the rotor swept area ($A = \pi D^2/4$). The table should be made as function of the tip speed ratio, λ, from $\lambda = 1$ to 12, preferably in increments of $\Delta\lambda = 1$. If you decide to use a larger increment you should at least produce results for $\lambda =$ 3, 4, 6, 9 and 12.

2. A table of thrust coefficients, $C_T = \frac{2T}{\rho U_{ref}^2 A}$, where T is the force acting on the rotorplane the direction of the wind. Data should be provided for the same operating conditions as specified for C_P.

3. Documentation that the solution is grid independent.

4. A 2 pages maximum 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.

If your method is primarily calculating the wake and use the above data as input, you must specify how you have obtained the data (from a simplified calculation, from colleagues etc.).

4.2 Additional output

If your method is capable of providing more detailed output, we ask you to provide as many of the following outputs as possible:

1. The normalized blade load distribution in the streamwise direction, $C_{Fx}(r) = \oint (C_{pres}\mathbf{n} \cdot \mathbf{i})\, d(S/c)$. Here $C_{Fx}(r)$ is the normalized load force, which is a function of the radial position, r/D, c is the local chord length at radius r, C_{pres} is the pressure coefficient distribution around the blade at a constant r, $\mathbf{n}$ is the unit normal vector of the blade and $\mathbf{i}$ is the unit vector in the streamwise direction. S is the path of integration to be taken around the blade at constant radii. The load distribution should be given from the innermost station of the blade where the airfoil S628 is used ($r = 0.055\text{m}$) to the tip. The data should be provided for tip speed ratios of $\lambda = 3$, 6 and 10.

2. The corresponding normalized blade load distribution in the tangential direction, $C_{Fz}(r) = \oint (C_{pres}\mathbf{n} \cdot \mathbf{t})\, d(S/c)$. $\mathbf{t}$ is the unit vector in the azimuthal direction. The data should be provided for tip speed ratios of $\lambda = 3$, 6 and 10.

3. The normalized mean velocity defect, $(U_{ref} - U)/U_{ref}$, along a horizontal and a vertical diagonal through the wake centre at positions $X/D = 1$, 3 and 5. U is the time averaged velocity component in the streamwise direction. The data should be provided for tip speed ratios of $\lambda = 3$, 6 and 10.

4. The normalized turbulent kinetic energy, k/U_{ref}^2, along a horizontal and a vertical diagonal through the wake centre at positions $X/D = 1$, 3 and 5. The turbulent kinetic energy is defined as $\frac{1}{2}\left(u_x^2 + u_r^2 + u_\theta^2\right)$ in a cylindrical coordinate system, or you

may use a corresponding approximation. The data should be provided for tip speed ratios of $\lambda = 3$, 6 and 10.

(Note. No measurements will be available for items 1 and 2, but a comparisom between methods is deemed interesting.)

References

[1] Somers, D.M., The S825 and S826 Airfoils. *National Renewable Energy Laboratory* 2005; NREL/SR-500-36344.

[2] Drela, M., Xfoil v. 6.97.
http://web.mit.edu/drela/Public/web/xfoil/