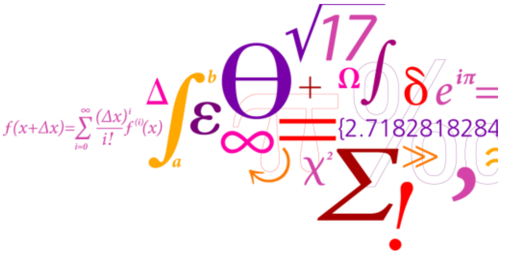
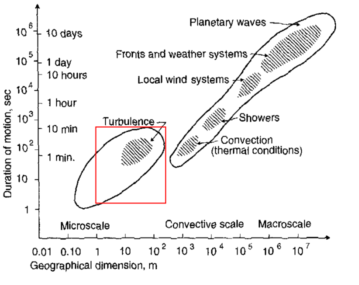
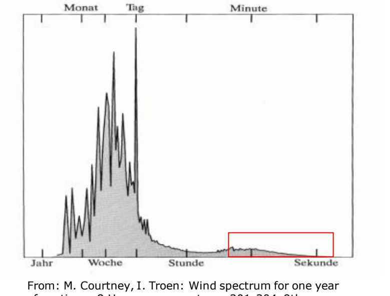
HAWC2 course

Lesson 2: Wind



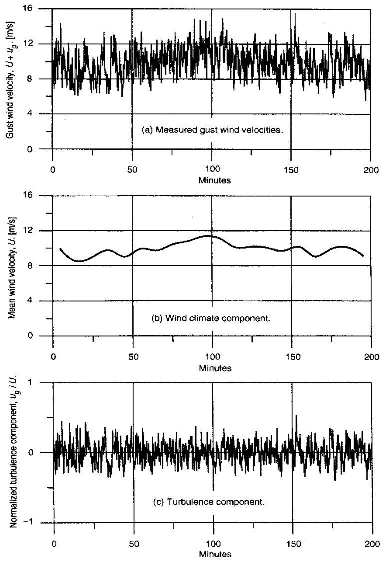
Wind systems/ scales





From: M. Courtney, I. Troen: Wind spectrum for one year of continous 8 Hz measurements. pp 301-304, 9th symposium on Turbulence and diffusion, Denmark 1990.

Mean values and turbulence



Measurement

Variation in wind with frequency content lower than 10min^{-1}

Frequency content higher than 10min^{-1}

Mean wind and turbulence

Mean wind

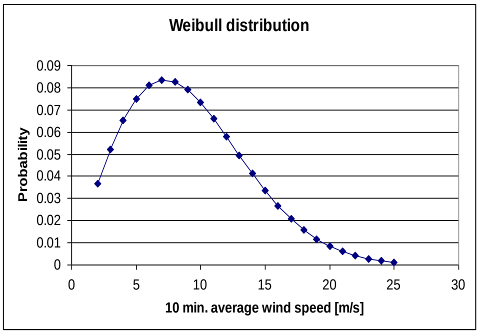
- Hub center wind speed distribution
- Wind shear
- Wind direction
- Slope of mean wind

Turbulence

- Intensity in u-direction
- Relative intensity in v- and w- directions
- Pre-calculated turbulence time series
- [std(U), mean(U), length scale, coherence]

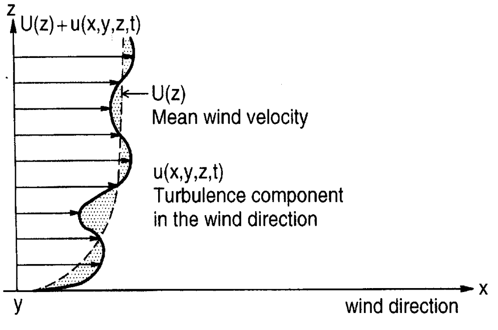
Weibull distribution of mean wind

$$P(U \le U_0) = 1 - \exp\left(-\frac{U_0}{A}\right)^k$$



$$P(U_0 \le U \le U_1) = -\exp\left(-\left(\frac{U_1}{A}\right)^k\right) + \exp\left(-\left(\frac{U_2}{A}\right)^k\right)$$

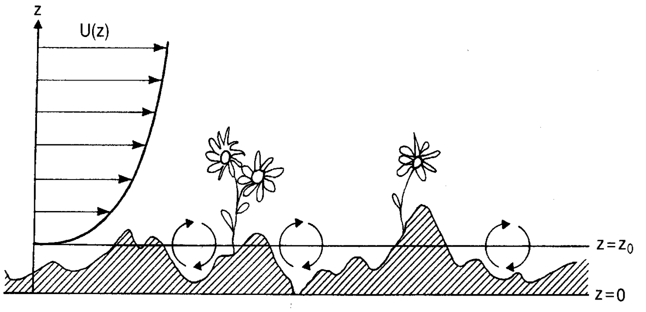
Wind profile



$$U(z) = U_{hub}\frac{\ln(z/z_0)}{\ln(z_{hub}/z_0)}$$ Logarithmic description

$$U(z) = U_{hub}(z/z_{hub})^a$$ Power law description

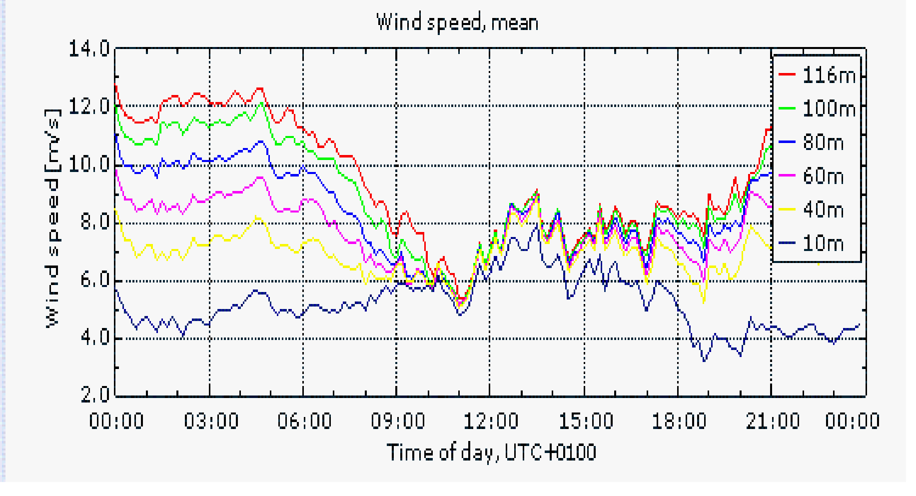
The roughness length, Z_0



- Open sea: 0.0001 m
- Open land: 0.01 m
- Farmland: 0.05 m
- Forrest, city: 0.5-1 m

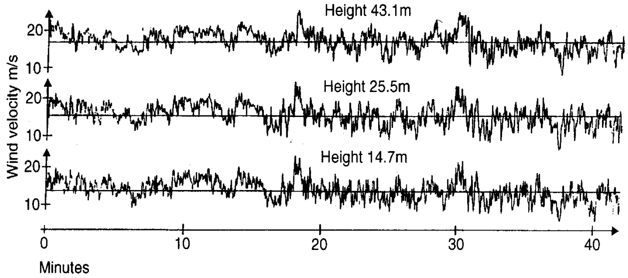
Rotors in atmospheric shear, stability

Met-mast measurements, Høvsøre



from http://veaonline.risoe.dk

Turbulence in neutral conditions



For neutral conditions:

$\sigma = \alpha u_*$ Monin-Obukhov scaling.

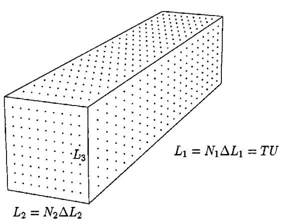
$\bar{V}(z) = \frac{u_*}{\kappa} ln(z/z_0)$, Log. Power law profile

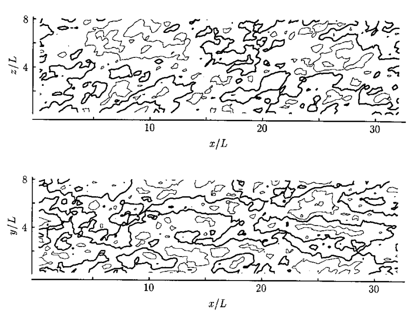
$I_{amb}(z) = \frac{\alpha\kappa}{ln(z/z_0)}$, where the von Karmans constant κ=0.4 and α~2.4

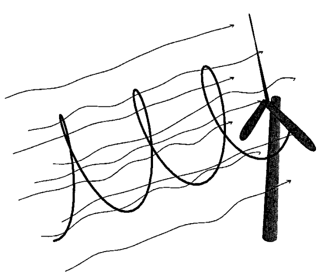
Turbulence intensity is not dependent on wind speed in neutral conditions

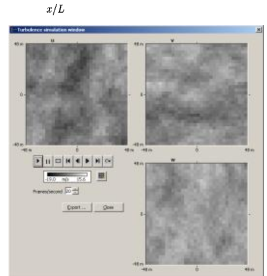
$\sigma(z) = I(z)U(z) = \frac{\alpha\kappa}{\ln\left(\frac{z_{hub}}{z_0}\right)}$ Standard deviation is constant with height in neutral conditions

Implementation of turbulence in aeroelastic models

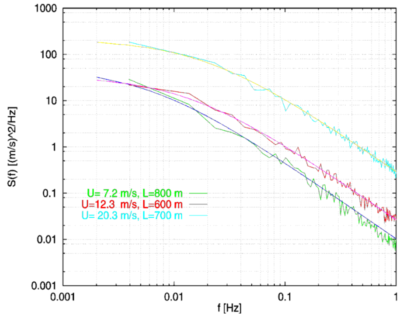


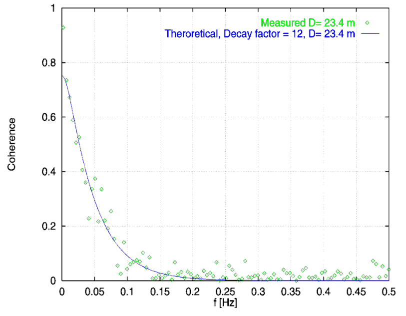






Turbulence





$$S_i(f) = \sigma_i^2 \frac{L_i/U}{(1+1.5(fL_i/U))^{5/3}}$$

Normal formulation for coherence:

$$coh(r,f) = \exp\left[-A_i\left(\frac{rf}{U}\right)\right]$$

In the IEC standard:

$$coh(r,f) = \exp\left[-12\sqrt{\left(\frac{rf}{U}\right)^2 + \left(\frac{0.12r}{L_C}\right)^2}\right]$$

3-D turbulence – typical properties

All components in the turbulence must be included (u,v,w)

$$\frac{s_v}{s_u} = 0.8 \text{ (comp. ter. : : 1.0)}$$

$$\frac{s_w}{s_u} = 0.5 \text{ (comp. ter. : : 0.8)}$$

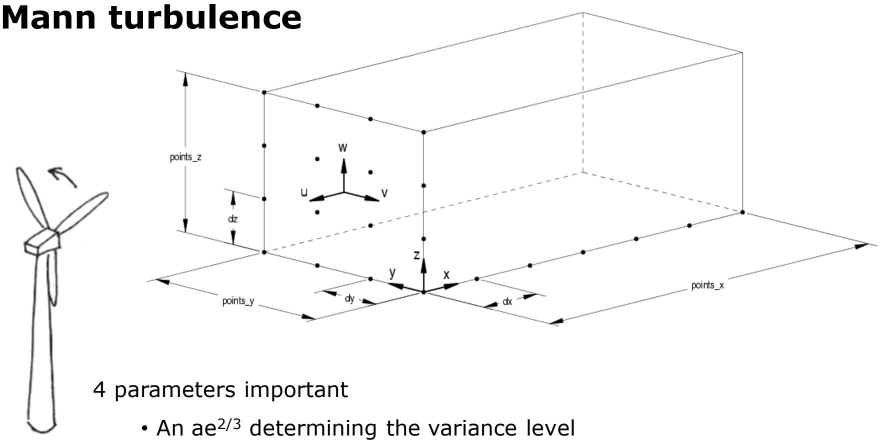
Standard deviation ratio

$$\frac{L_v}{L_u} = 0.33; \quad \frac{L_w}{L_u} = 0.25$$

Length scale ratio

When using the Mann model, these properties are given through the gamma parameter (more on this later).

Mann turbulence



4 parameters important

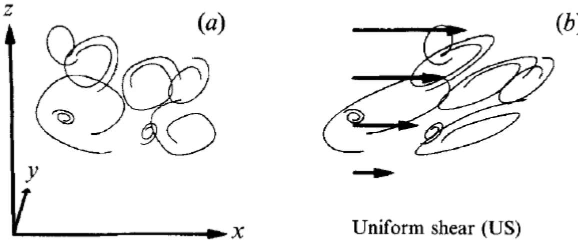
- An $ae^{2/3}$ determining the variance level
- A length scale frequency with most energy
- A gamma parameter
- High frequency compensation. (Should the point value represent local vector, or average value for the cell volume)?

Mann turbulence

- The turbulence level is in the Mann model obtained through an $\alpha\varepsilon^{2/3}$ parameter in the isotropic energy spectrum (Von Karman).

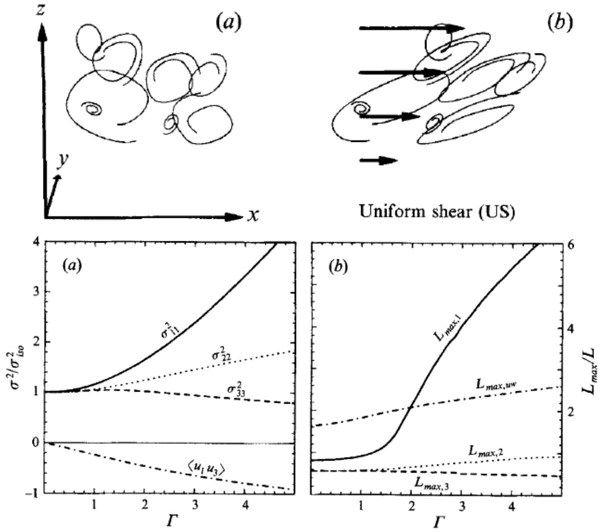
$$E(k) = \alpha\varepsilon^{\frac{2}{3}} L^{\frac{5}{3}} \frac{(Lk)^4}{(1+(Lk)^2)^{\frac{17}{6}}},$$

- The spectrum is affected by sheared inflow which modifies the low frequent content and the turbulence level. Γ is a parameter describing the level of shear. Γ=3.9 correspond to normal conditions.



J. Mann. The spatial structure of neutral atmospheric surface-layer turbulence. J. Fluid Mech. (1994), vol. 273, pp. 141-168

Turbulence properties as function of Γ



Turbulence scaling

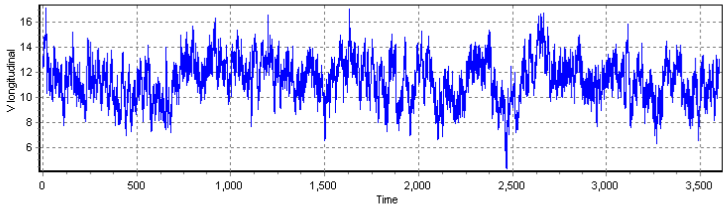
- Since it is problematic to predict the correct $\alpha\varepsilon^{2/3}$ value to get the requested turbulence level is is much more easy and pratically usefull to rescale the turbulence field (which is done automatically inside HAWC2).
  - Turbulence field in the center of the box is read and actual variance level found.
  - A scaling factor compensated for difference in variance level is found

$$SF = \sqrt{\frac{var_{target}}{var}}$$

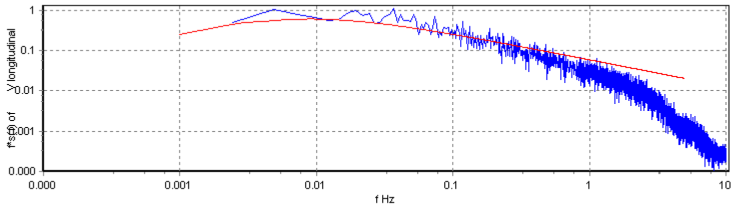
  - This is multiplied to the wind field in u,v and w direction

Example at 11.4m/s, u-dir

Wind speed at hub height [m/s]

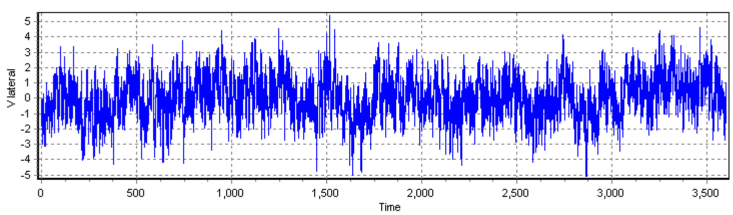


Power spectra f S(f) of wsp at hub height and Kaimal target spectrum [m/s]

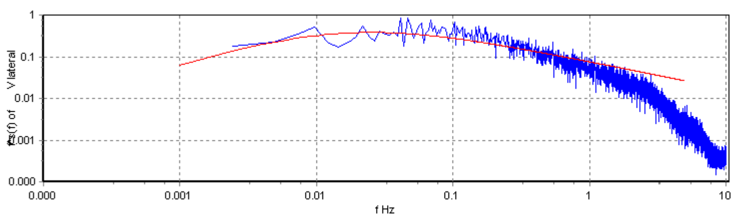


Wind at 11.4m/s, v-dir

Wind speed at hub height [m/s]

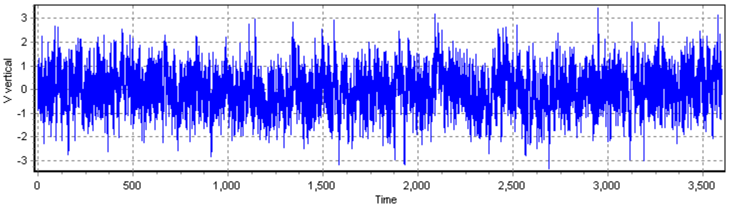


Power spectra f S(f) of wsp at hub height and Kaimal target spectrum [m/s]

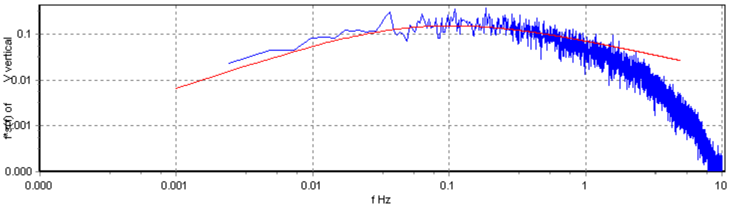


Wind at 11.4m/s, w-dir

Wind speed at hub height [m/s]



Power spectra f S(f) of wsp at hub height and Kaimal target spectrum [m/s]



HAWC – wind input

```
begin wind ;
  density                1.225 ;
  wsp                    4   ;
  tint                   0.15 ;
  horizontal_input       1     ;           0=false, 1=true
  windfield_rotations    0.0  0.0  0.0 ;    yaw, tilt, rotation
  center_pos0            0.0 0.0 -123.0 ;
  shear_format           3  0.2  ;0=none,1=constant,2=log,3=power,4=linear
  turb_format            1     ;  0=none, 1=mann,2=flex
  tower_shadow_method    1     ;  0=none, 1=potential flow, 2=jet, 3=pot2, 4=jet2
;  scale_time_start       0 ;
;  wind_ramp_factor   0.0 40.0 0.5 1.0 ;    t0, t1, f0, f1
;
;  wind_ramp_abs   50.0 50.1 0.0 1.0 ;       t0, t1, V0, V1
;  wind_ramp_abs   80.0 80.1 0.0 1.0 ;
;
  begin mann;
    create_turb_parameters 29.4 1.0 3.9 1025 1.0 ;      L, alfaeps,gamma,seed, highfrq compensation
    filename_u    ./turb/114s1u.bin ;
    filename_v    ./turb/114s1v.bin ;
    filename_w    ./turb/114s1w.bin ;
    box_dim_u    8192 2.0508 ;
    box_dim_v    32 3.125;
    box_dim_w    32 3.125;
  end mann;
;
  begin tower_shadow_potential;
    tower_offset 0.0 ;
    nsec  2;
    radius      0.0   6.0 ;
    radius    -120.0  2.0 ;
  end tower_shadow_potential;
end wind;
;
```

If these files exist, new files will not be created!

The total length of the box should correspond to the simulation length (subtracted the time for initial transients)

$$\mathrm{wsp} = \frac{N_x \, \Delta x}{t_{stop} - t_0}$$

Generation of very large Turbulence Fields

An example:

Wind speed 11.4m/s

Simulation length 3600s

Fieldsize in meters
41040, 200, 150

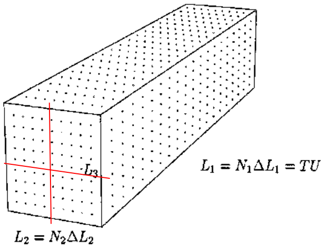
No of points in each direction
32768, 64, 32

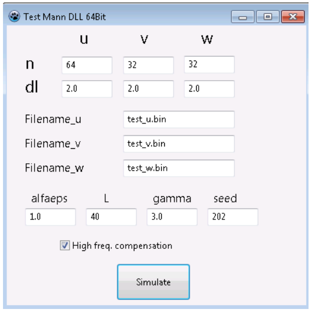
dL1, dL2, dL3
1.252m, 3.125m, 4.68m

dt 0.109s

Memory consumption
3x4x4x32768x64x32=3.2GByte

This cannot be addressed on WIN32. => A new 64 bit application have been made.





Stability

Until a turbulence model with a buoyancy term is included, the way to model turbulence for different stability class may be through the Mann model using modified parameters

Very Unstable:	$L_M = 105.1$, $\Gamma = 2.1$	Very Stable:	$L_M = 10.0$, $\Gamma = 2.7$
Unstable:	$L_M = 80$, $\Gamma = 2.44$	Stable:	$L_M = 15.4$, $\Gamma = 2.7$
Near Unstable:	$L_M = 60.7$, $\Gamma = 2.8$	Near Stable:	$L_M = 28.0$, $\Gamma = 2.8$

Example:

Unstable afternoon

Neutral:

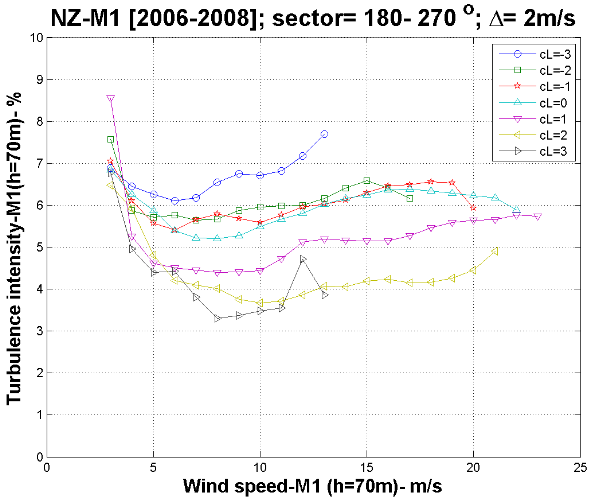
$$L_M = 38$$
$$\Gamma = 2.7$$

Example

Stable night

Stability

Remember the turbulence level is varying with the stability class!

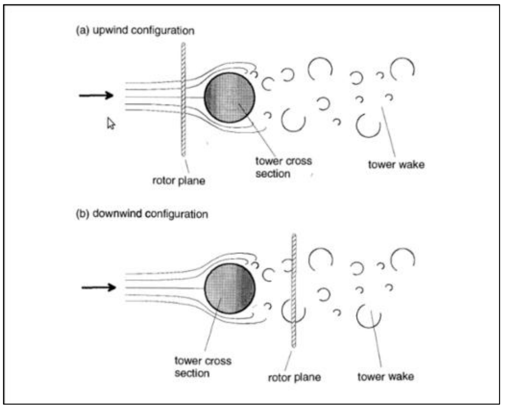


Tower shadow effects is also part of the wind module

- And so are wake effects from neighboring wind turbines, but this will be presented in a separate lecture

Tower influence modelling in HAWC2

- models for both an upstream and a downstream position of the rotor is implemented



Tower influence modelling - upstream

Flow model based on the potential flow solution around a cylinder

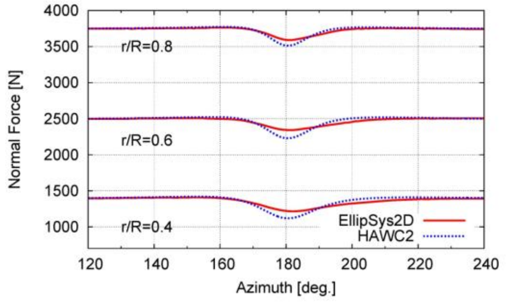


Figure 23. Comparison of HAWC2 and EllipSys2D normal force coefficients as function of blade azimuth for the upwind configuration of the UPWIND turbine at the three radial sections.

Tower influence modelling - downstreamam

Flow model based on the boundary
solution for a jet into a flow at rest

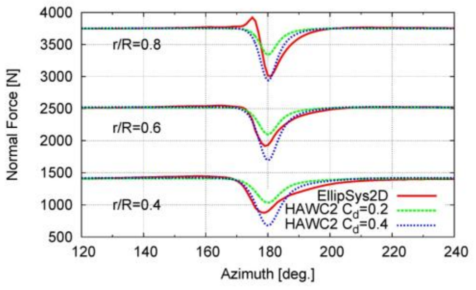


Figure 24. Comparison of HAWC2 and EllipSys2D normal force coefficients as function of blade azimuth for the downwind configuration of the UPWIND turbine at the three radial sections.

Tower influence modelling - downstream

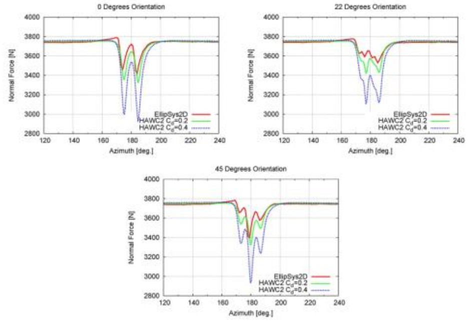


Figure 25. Comparison of HAWC2 and EllipSys2D normal force coefficients as function of blade azimuth for the four leg tower configuration for the three tower orientations.

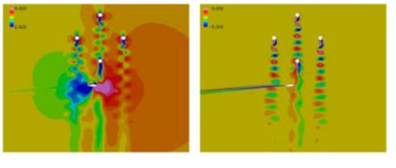


Figure 22. Snapshot of axial velocity and vorticity for the four leg configuration for the 80% radius blade section at 45 degrees orientation to the tower.

HAWC – wind input

```
begin wind ;
  density                1.225 ;
  wsp                    4  ;
  tint                   0.15 ;
  horizontal_input       1     ;            0=false, 1=true
  windfield_rotations    0.0  0.0  0.0 ;    yaw, tilt, rotation
  center_pos0            0.0 0.0 -123.0 ;
  shear_format           3  0.2  ;0=none,1=constant,2=log,3=power,4=linear
  turb_format            1     ;  0=none, 1=mann,2=flex
  tower_shadow_method    1     ;  0=none, 1=potential flow, 2=jet, 3=pot2, 4=jet2
;
  begin tower_shadow_potential;
    tower_offset 0.0 ;
    nsec  2;
    radius      0.0   6.0 ;      z, radius
    radius    -120.0  2.0 ;
  end tower_shadow_potential;
;
  begin tower_shadow_jet;
    tower_offset 0.0 ;
    nsec  2;
    radius      0.0   6.0   1.0 ;  z, radius, Cd
    radius    -120.0  2.0   1.0;
  end tower_shadow_potential;
end wind;
;
```