Design of Wind Energy Systems

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CIP Tutorial 05
Hints for wind fields and wake modelling

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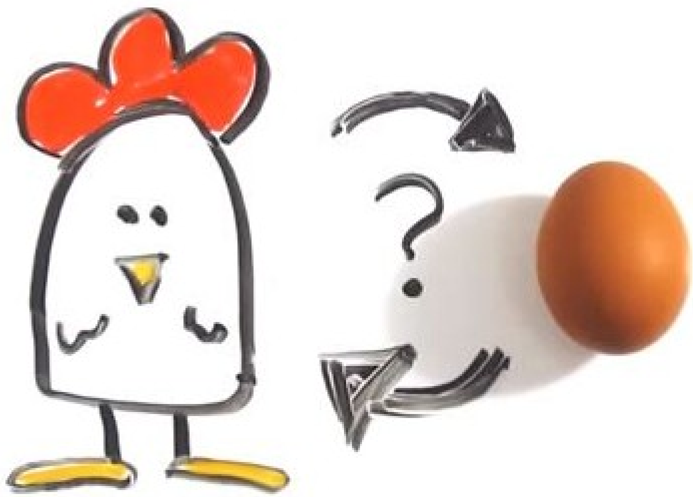
ForWind – Wind Energy Systems

Topics

- Some concepts for wind field generation
- Wind fields – TurbSim
- Summary

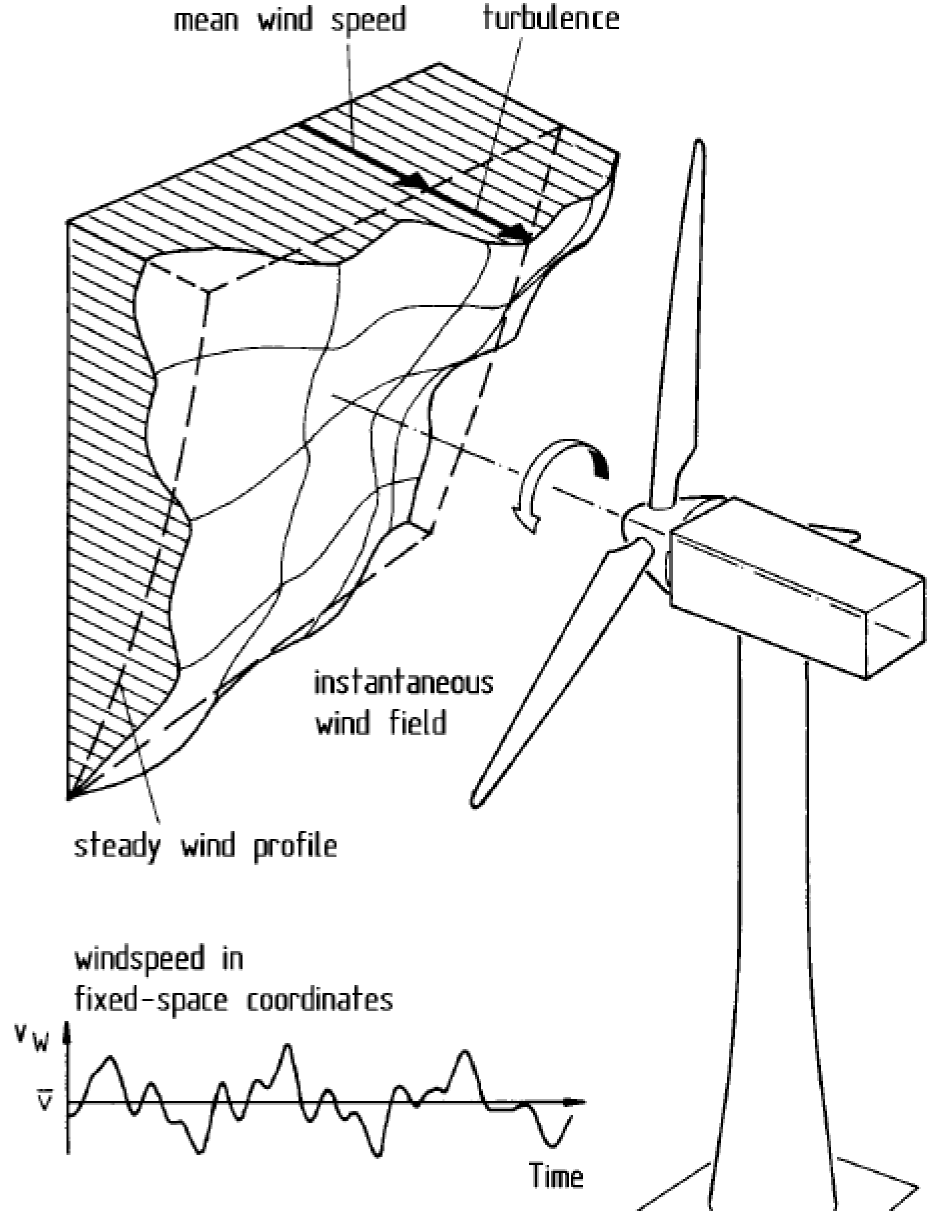
Some concepts for wind field generation

- Where do we start?



Turbulent wind

- Wind is unevenly distributed over the rotor area
- As wind varies over time, so does the aerodynamic loads and the structural response
- Probability distributions relate time to wind speed
- Load cases define conditions to be simulated
- To estimate structural loads a statistical approach is followed



Hau, 2005

Probability distribution

- Weibull distribution, where Rayleigh distribution is a special case
- Rayleigh can be assumed to be a “usual” frequency distribution
- The probability distribution helps to estimate:
  - annual energy production
  - structural loads

Wind classes & normal turbulence model

- Standard IEC 61400 defines the following wind classes:

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

Where:
Vref – reference wind speed (50y)
Iref – turbulence intensity at 15m/s

- The normal turbulence model (NTM) is defined as follows :

$$\sigma_1 = I_{ref}\left(0{,}75V_{hub} + b\right); \quad b = 5{,}6\ \mathrm{m/s}$$

Where:
σ1 – std. dev. of ambient turbulence at a given wind speed at hub height

Wake modelling – Frandsen

- The effective turbulence accounts for the increase of turbulence due to wakes, and it can be used to estimate structural loads (IEC 61400)

$$I_{\text{eff}} = \frac{\hat{\sigma}_{\text{eff}}}{V_{\text{hub}}} = \frac{1}{V_{\text{hub}}}\left[(1 - N\,p_{\text{w}})\hat{\sigma}^{m} + p_{\text{w}}\sum_{i=1}^{N}\hat{\sigma}_{\text{T}}^{m}(d_i)\right]^{\frac{1}{m}}$$

Note: it does not account for mean wind speed reduction, and:

$$\hat{\sigma}_{\text{T}} = \sqrt{\frac{0{,}9V_{\text{hub}}^2}{(1{,}5 + 0{,}3d_{\text{i}}\sqrt{V_{\text{hub}}/c})^2} + \hat{\sigma}^2}$$

- N – number of neighboring wind turbines (N = 1)
- p_w – probability of wind direction (assume uniform case: pw = 0.06)
- σ – standard deviation of ambient turbulence (σ_1 in NTM)
- d_i – distance to neighboring wind turbine (di = 4 or 8)
- c – constant value (c = 1 m/s)
- m – Wöhler slope from SN-curve (m = 4 for steel, m = 10 for fiber glass)

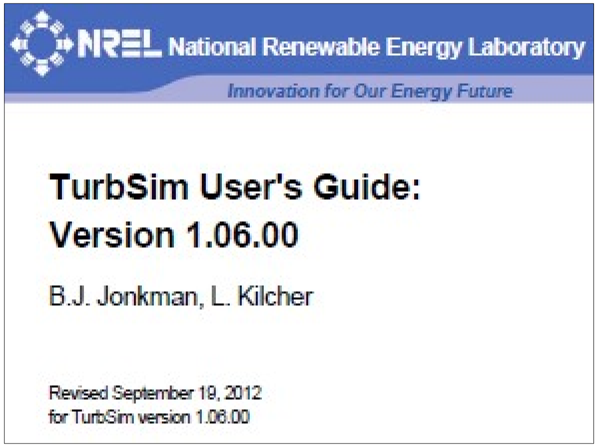
Power production & faults

- Faults can be related to failure of control functions or the electrical system
- Some failures of the turbine have to be considered in the simulations to guarantee structural integrity
- In tutorial 05 no faults are taken into account

[http://www.snopes.com/photos/accident/windmill.asp]

Wind fields – TurbSim

- Overview
- Test case
- Wind field


NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

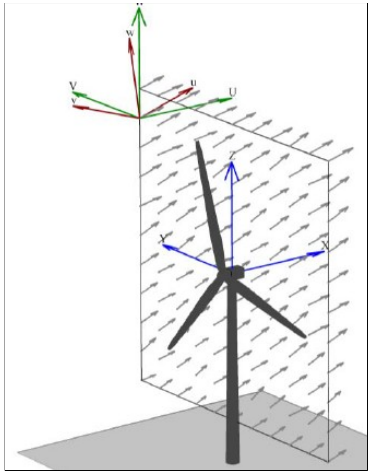
TurbSim User's Guide:
Version 1.06.00

B.J. Jonkman, L. Kilcher

Revised September 19, 2012
for TurbSim version 1.06.00

Overview – TurbSim

- Numerical simulation of 3 wind vectors
- Wind is presented in a rectangular grid
- Includes Kaimal & von Karman spectral models
- Output can be used as input to AeroDyn, FAST, GH Bladed & MSC ADAMS



TurbSim wind field & coordinates system

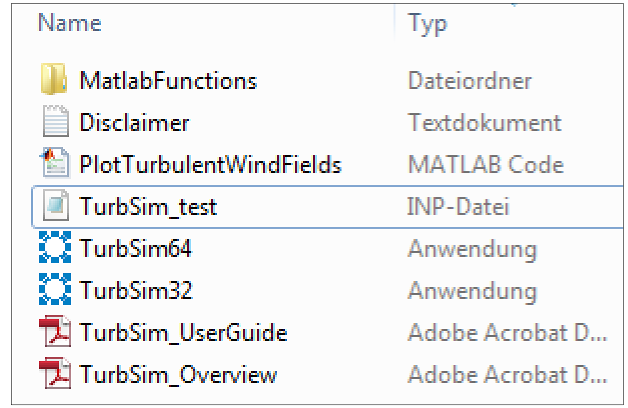
```
TurbSim input test file. Valid for TurbSim v1.06.00, 23-Jun
To be use in DOWES class (SS2014)
---------Runtime Options-----------------------------------
2318573              RandSeed1        - First random seed  (-
RANLUX               RandSeed2        - Second random seed (-
False                WrBHHTP          - Output hub-height tur
False                WrFHHTP          - Output hub-height tur
False                WrADHH           - Output hub-height tim
False                WrADFF           - Output full-field tim
True                 WrBLFF           - Output full-field tim
False                WrADTWR          - Output tower time-ser
False                WrFMTFF          - Output full-field tim
False                WrACT            - Output coherent turbu
True                 Clockwise        - Clockwise rotation lo
 0                   ScaleIEC         - Scale IEC turbulence

--------Turbine/Model Specifications-----------------------
11                   NumGrid_Z        - Vertical grid-point m
11                   NumGrid_Y        - Horizontal grid-point
0.01                 TimeStep         - Time step [seconds]
630                  AnalysisTime     - Length of analysis ti
630                  UsableTime       - Usable length of outp
80                   HubHt            - Hub height [m] (shoul
110                  GridHeight       - Grid height [m]
110                  GridWidth        - Grid width [m] (shoul
0                    VFlowAng         - Vertical mean flow (u
0                    HFlowAng         - Horizontal mean flow

--------Meteorological Boundary Conditions-----------------
"IECKAI"             TurbModel        - Turbulence model ("IE
"1-ED3"              IECstandard      - Number of IEC 61400-x
"B"                  IECturbc         - IEC turbulence charac
```

TurbSim input file

Test case – TurbSim (1/2)

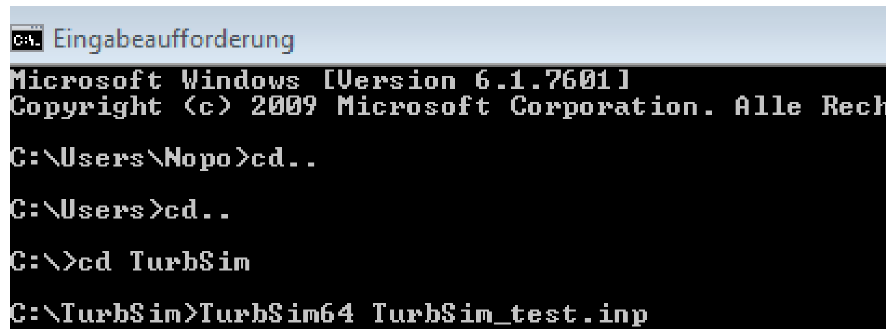
1. Unpack zip folder as C:\ TurbSim
2. Explore folder; it contains:
   - TurbSim64.exe (or *32 bits)
   - TurbSim_test.inp – test input file
   - Turbsim _UserGuide/_Overview
   - Disclaimer & FAQ text files
   - PlotTurbulentWindFields.m – matlab script to plot wind field
   - Folder with used matlab functions
3. In DOS, run in correct folder:
   - **TurbSim64 TurbSim_test.inp**

2



TurbSim folder

3

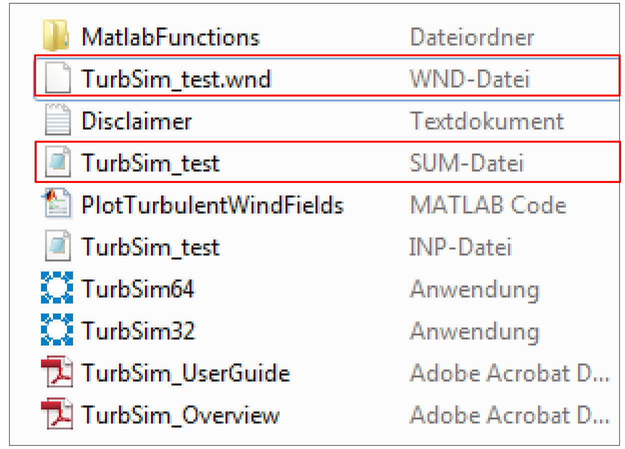


Turbsim commands in DOS

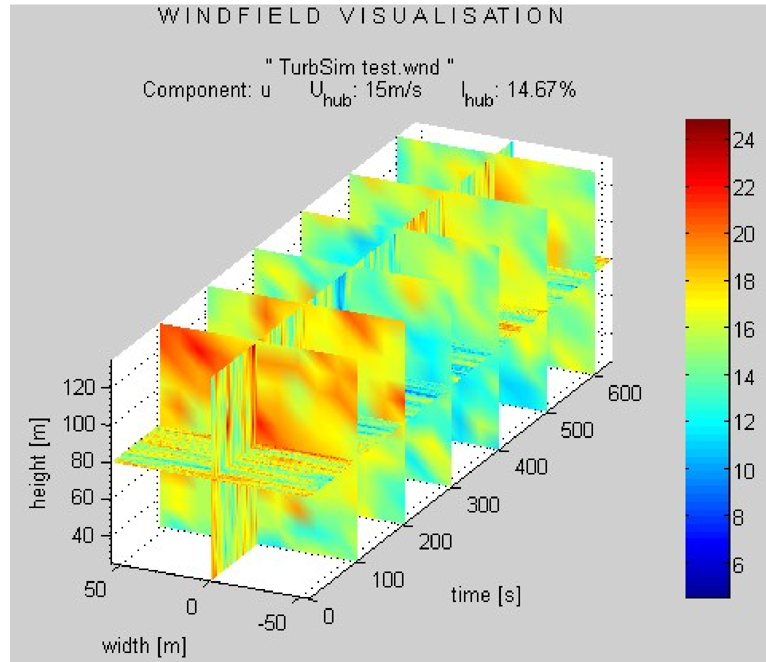
Test case – TurbSim (2/2)

4. Review results in folder: 4
   - TurbSim_test.sum – summary file
   - TurbSim_test.wnd – output file
5. Review the results: 5
   - Run matlab script “PlotTurbulentWindFields” & select output file

Note: Use TurbSim_UserGuide.pdf to know how to change inputs



TurbSim folder with results



TurbSim wind field visualization with Matlab

Wind field – TurbSim

1. Comment 2-lines header for traceability: "color", user & date
2. Update turbine values
   - HubHt – hub height
   - GridHeight/Width – grid size
3. Update meteo. conditions:
   - IECturbc – turb. intensity (%) at reference wind speed
   - RefHt – height of reference wind speed (equal to HubHt)
   - URef – reference wind speed
   - PLExp – power law exponent

1

```
TurbSim input test file. Valid for TurbSim v1.06.00, 23-Jun-2014
To be use in DOWES class (SS2014)
```

2

```
--------Turbine/Model Specifications-----------------------
11                   NumGrid_Z          - Vertical grid-point matrix dim
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0.01                 TimeStep           - Time step [seconds]
630                  AnalysisTime       - Length of analysis time series
630                  UsableTime         - Usable length of output time s
80                   HubHt              - Hub height [m] (should be > 0.
110                  GridHeight         - Grid height [m]
110                  GridWidth          - Grid width [m] (should be >= 2
0                    VFlowAng           - Vertical mean flow (uptilt) ar
0                    HFlowAng           - Horizontal mean flow (skew) ar
```

3

```
--------Meteorological Boundary Conditions-------------------
"IECKAI"             TurbModel          - Turbulence model ("IECKAI"=Kai
"1-ED3"              IECstandard        - Number of IEC 61400-x standarc
"B"                  IECturbc           - IEC turbulence characteristic
"NTM"                IEC_WindType       - IEC turbulence type ("NTM"=nor
default              ETMc               - IEC Extreme Turbulence Model "
"PL"                 WindProfileType    - Wind profile type ("JET";"LOG"
80                   RefHt              - Height of the reference wind s
15.0                 URef               - Mean (total) wind speed at the
default              ZJetMax            - Jet height [m] (used only for
0.11                 PLExp              - Power law exponent [-] (or "de
0.03                 Z0                 - Surface roughness length [m] (
```

Note: use „IECKAI" to model Kaimal spectrum according to IEC Standard

Summary / Conclusion

- We discussed some concepts related to the importance of turbulent wind fields
- We described the concept of effective turbulence according to Frandsen
- We generated turbulent wind fields with help of “TurbSim”