Task 41 Meeting Firenze 2024

Turbulence research

Mark Runacres

FLOW research group, Vrije Universiteit Brussel, Belgium

27 May 2024

Agenda

What I had in mind

- Why are we interested in turbulence?
- Quick recap of what we wrote in the proposal.
- Update on standards maintenance committee MT-2 (‘small wind turbines’) and relevant work. Formulate specific advice that we can pass on to MT-2 under the present revision. Some of this will come back this afternoon.
- Classification of turbulence *beyond TI*. What do we need to know? What do we have?
- Buildings and other obstacles (Pablo Ouro, Beatriz Ramos, Luis Cano, Mark Kelly). Preparation of WP1A-3 on obstacles: what do we plan to do and who will contribute?
- Coupling with other work packages, in particular WP1B

Recap of work package WP1A

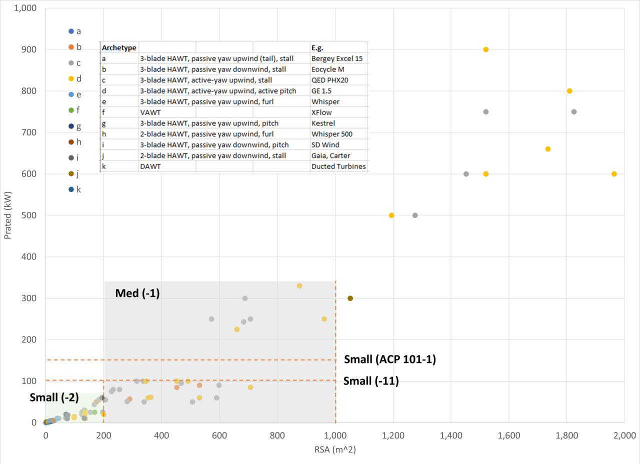
- WP1A-1: Data mining (by Dec 2023)
- WP1A-2: Classification and pattern recognition (by Dec 2024)
- WP1A-3: Characterising the local environment with respect to obstacles (by Dec 2025)
- WP1A-4: Dissemination

Research to inform standards

- Which standards are we considering?
  An important standard for us to inform is IEC 61400-2 which is currently under revision. This is done by a so-called maintenance committee, in this case MT-2, under TC 88 which is the IEC technical committee for wind energy

Report on MT-2 activities

Small wind turbine sizes



Archetype		E.g.
a	3-blade HAWT, passive yaw upwind (tail), stall	Bergey Excel 15
b	3-blade HAWT, passive yaw downwind, stall	Eocycle M
c	3-blade HAWT, active-yaw upwind, stall	QED PHX20
d	3-blade HAWT, active-yaw upwind, active pitch	GE 1.5
e	3-blade HAWT, passive yaw upwind, furl	Whisper
f	VAWT	XFlow
g	3-blade HAWT, passive yaw upwind, pitch	Kestrel
h	2-blade HAWT, passive yaw upwind, furl	Whisper 500
i	3-blade HAWT, passive yaw downwind, pitch	SD Wind
j	2-blade HAWT, passive yaw downwind, stall	Gaia, Carter
k	DAWT	Ducted Turbines

Figure: Small wind sizes and archetypes

Proposed scope extension

- New scope extension after feedback from national TC88 Committees
- Extension to cover rotor swept area up to 1200 m^2 was majority accepted via TC88.
- Work is also progressing through a number of sub-committees
- A tiered approach is proposed for dealing with the plethora of SWTs, following recommendations from Task 41.
  Also connects to US standards (AWEA 9.1 and ACP SWT-1).
  Break points for when simplified load model can be relied upon.

Normal turbulence model

- There is an inconsistency in the way in which the normal turbulence models used in 61400-2 and 61400-1 define the longitudinal wind speed standard deviation
- Ray Byrne has spotted this inconsistency and suggested a way to harmonise the two definitions

Averaging times

- There is a suggestion within MT-2 to reduce the record length for a velocity bin in duration testing from 10 minutes to 1 minute
- Care should be taken about how turbulence intensity is computed. See separate presentation Mark Runacres

Back to turbulence

What do we mean by turbulence?

- Turbulence characteristic by stochastic fluctuations around the mean, eddies at different scales and efficient mixing
- Time-scale of fluctuations: faster than a few minutes
- Fluctuations in all fluid variables, focus is mostly on fluctuations of wind velocity vector (so changes in wind speed and direction)

What's so special about distributed wind?

- On average, lower tower heights $\rightarrow$ higher level of turbulence
- Closer to end user $\rightarrow$ closer to obstacles
- Generally smaller turbines, often fixed speed /stall control, and passive yaw (tail fins)
- So although we don't want to equate distributed wind ('behind the meter') with small wind, it's probably fair to say that distributed wind energy is predominantly generated by smallish wind turbines.

Data sets

- There is a wealth of available data, if we are happy with 10-min averaged cup anemometry and record lengths of a few years (or less)
- Not so many high-frequency measurements, but we have a few sets and probably enough to work with. Data set around 2 TB at present. So time to analyse.
- Very rare to have concurrent wind data and turbine performance data (for distributed wind)

Data sets (cont.)

- Whether or not we need more data depends on what we want to do with the data in the next phase of the WP. This is something I would like to discuss today.

The effect of turbulence on a wind turbine's power production

Effects

- Higher energy content: positive effect
- Turbulent fluctuations of wind direction: negative effect
- Slower transition to rated power: negative effect

These effects are superimposed in a non-trivial way.

Turbulence is also not independent of wind shear and veer.

How do we quantify these effects on performance?

- Power given by

$$P = \frac{1}{2}\rho C_P(\lambda) A u^3$$

- If we wish to include unsteady misalignment of rotor and incoming wind we can adapt this expression and write

$$P = \frac{1}{2}\rho C_P A u^3 (\cos\gamma)^p$$

  with γ angle between wind velocity vector and rotor normal
- There's debate about which value for p to use. Does anyone know of measurements on smallish wind turbines that pertain to this question?
- Let's take $p = 3$ as this is what actuator-disc and BEMT predict.

How do we quantify these effects on performance? (cont.)

- Let's use Reynolds decomposition to separate turbulent fluctuations from the more slowly varying underlying function

$$u = \overline{u} + u'$$
$$\gamma = \overline{\gamma} + \gamma'$$

How do we quantify these effects on performance? (cont.)

- Fill this in in expression for power, take first order Taylor expansion and time average. We then have

$$\overline{P} = \frac{1}{2}\rho C_P A \overline{u}^3 \left[1 + 3\left(\frac{\sigma_u}{\overline{u}}\right)^2\right] \left[1 - \frac{\overline{\gamma}}{2} - \frac{\sigma_\gamma^2}{2}\right]^3$$

which simplifies to

$$\overline{P} = \frac{1}{2}\rho C_P A \overline{u}^3 \left[1 + 3 I_u^2\right] \left[1 - \frac{\sigma_\gamma^2}{2}\right]^3$$

if we assume $\overline{\gamma} = 0$ and use the definition of the streamwise turbulence intensity $I_u = \sigma_u / \overline{u}$.

Effect of turbulence near rated wind speed

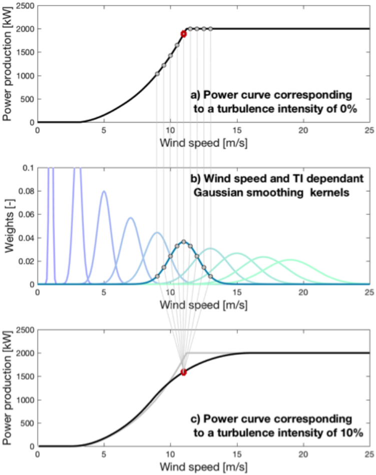


Figure: Effect of turbulence near rated wind speed. Figure from Saint-Drenan et al. 2020 DOI: 10.1016/j.renene.2020.04.123

Effect of turbulence near rated wind speed (cont.)

What do we need to know?

- Going back to

$$\overline{P} = \frac{1}{2}\rho C_P A \overline{u}^3 \left[1 + 3I_u^2\right] \left[1 - \frac{\sigma_\gamma^2}{2}\right]^3$$

we see that the performance is affected by turbulence through the turbulence intensity I_u and the variance σ_γ^2 of the misalignment.

What do we need to know? (cont.)

- Turbulence intensity is a characteristic of the wind. Arguably the most important and relevant turbulence metric for wind energy

What do we need to know? (cont.)

- σ_γ^2 does not only depend on the wind.
  - Of course it is affected by the turbulent fluctuations in wind directions,
  - but also by the yawing behaviour of the turbine. If the yawing response of the turbine is immediate and perfect (unlikely), then $\sigma_\gamma^2 = 0$
  - This is one point where WP1A and WP1B connect
  - Other turbulence characteristics play a role in rotor aerodynamics and may affect performance

The effect of turbulence on loads

Wind speed fluctuations

- Varying loads on blades $\rightarrow$ fatigue
- Blade loads are transmitted to the drivetrain and other components

Wind direction fluctuations

- Also creates fatigue
- Also transmitted to drive train
- Yawing causes gyroscopic loads (David Wood)

Turbulence intensity

What more may we need than TI?

- Changes of wind direction
- How important are shear and veer for distributed wind? (Not strictly turbulence metrics, but related to turbulence)
- All wind characteristics exhibit strong diurnal variations and seasonality. This is also the case for TI and, in some cases, the power spectral density.
- Turbulence length scales
- Coherent turbulent kinetic energy. See Neil Kelley. Coherent structures related to shear instability. But also obstacles are expected to create coherent structures in their wake.
- What else?

Points to return to

- What advice do we give about reference speed of 15 m/s?
- Which advice should we transmit to MT-2 about 1' averaging?
- Which turbulence metrics should we calculate for the data that we have?
- What does WP1B need from WP1A? IMO the characterisation of turbulence from WP1a should be relevant to WP1b.