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Use of ground-based and nacelle-mounted lidars for power curve measurement

Wagner, Rozenn

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Use of ground-based and nacelle-mounted lidars for power curve measurement

Rozenn Wagner

rozn@dtu.dk

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Fredericia

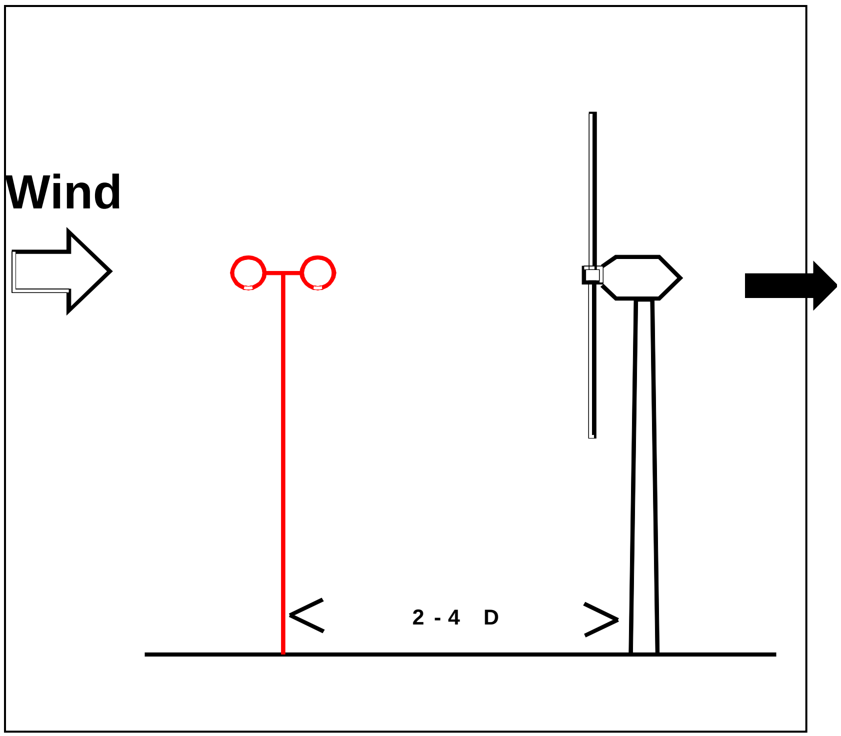
DTU Wind Energy
Department of Wind Energy

Two ways of using a lidar for power curve measurement

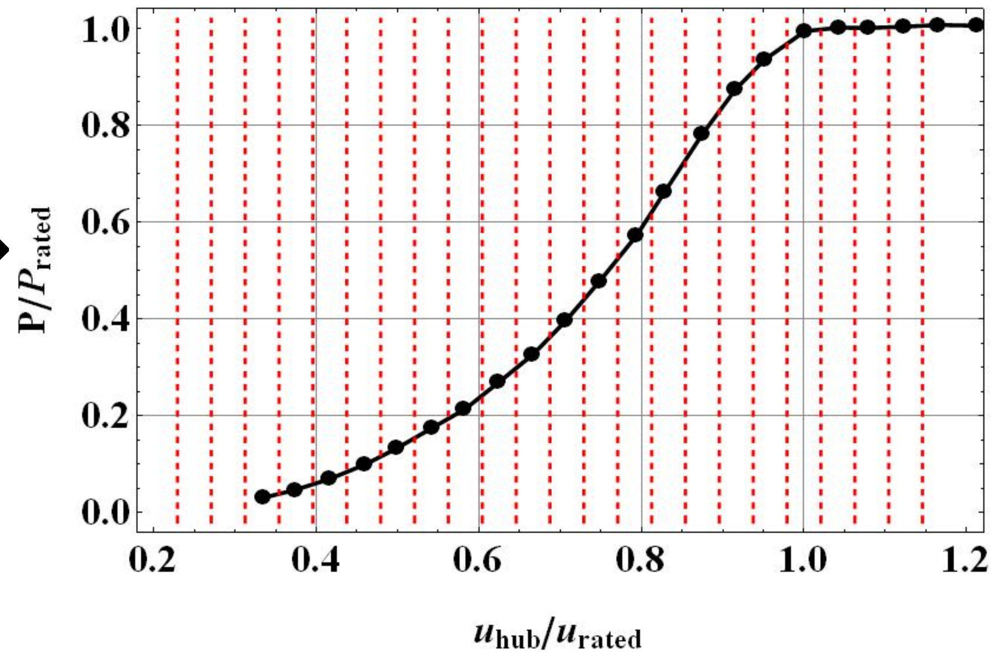
1. Ground based lidar

2. Nacelle based lidar

How is a power curve measured?

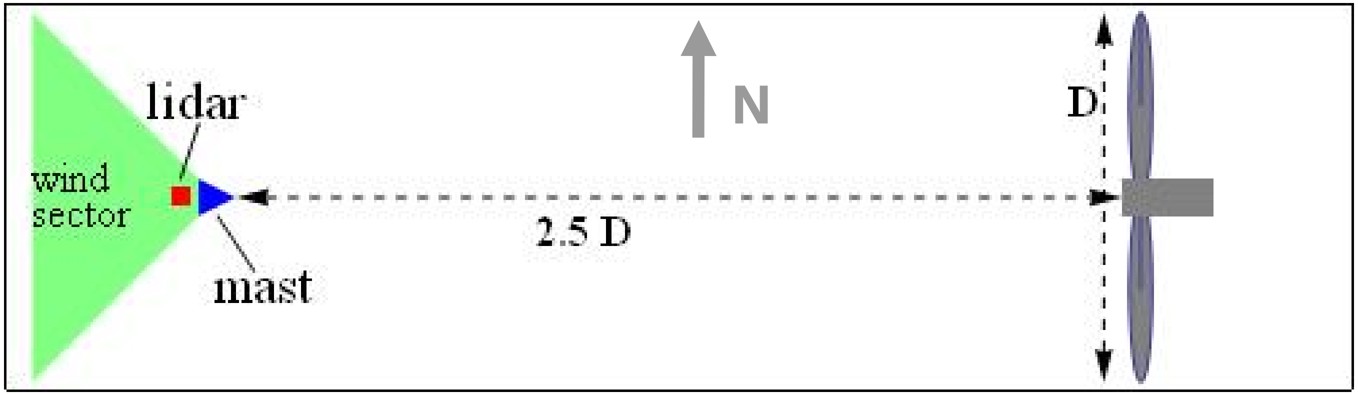


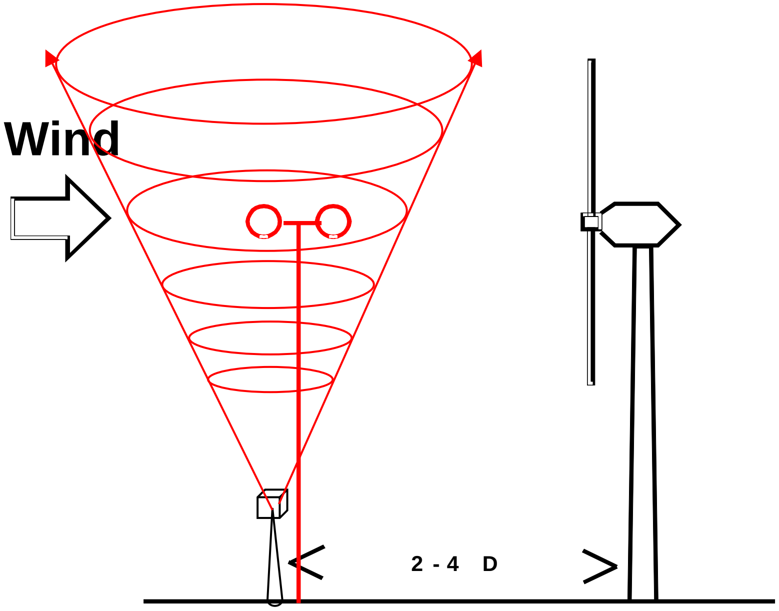
IEC standard 61400-12-1 Ed.1

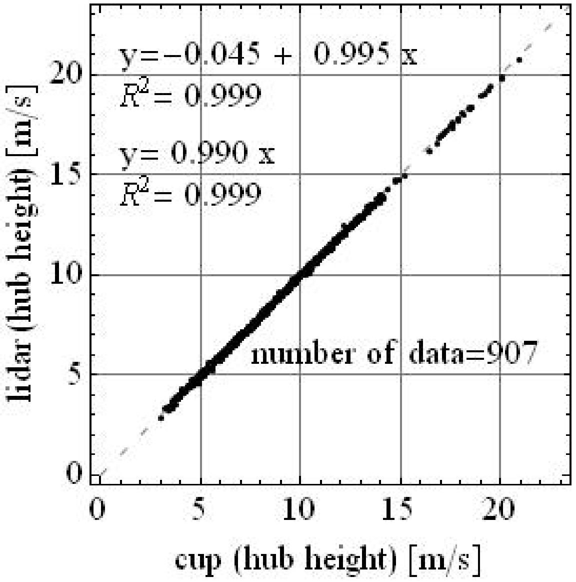


But the power curve does not only depend on the hub height wind speed;
but also on the whole wind speed profile.

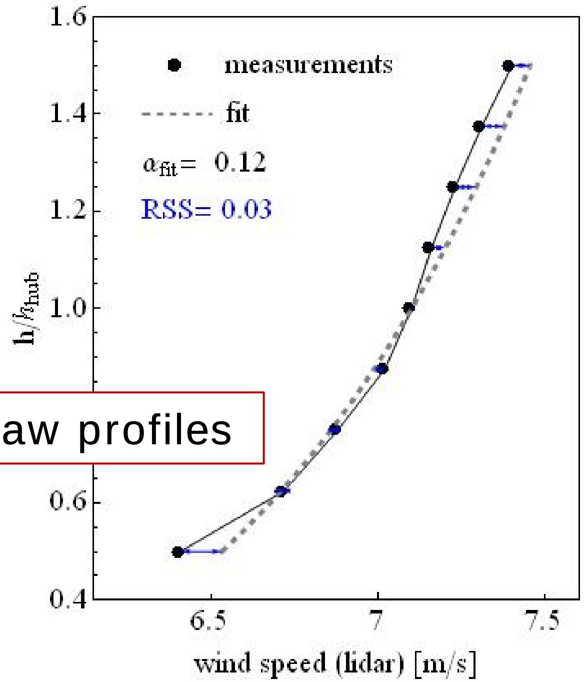
Measurement setup



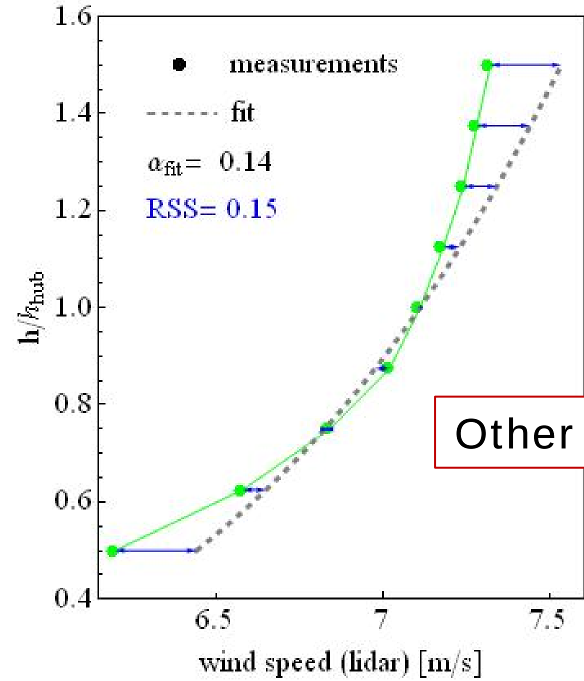




Profiles classification



Power law profiles



Other profiles

$$u_{fit}(z) = u_{hub}^{m} \left(\frac{z}{z_{hub}} \right)^{\alpha_{fit}}$$

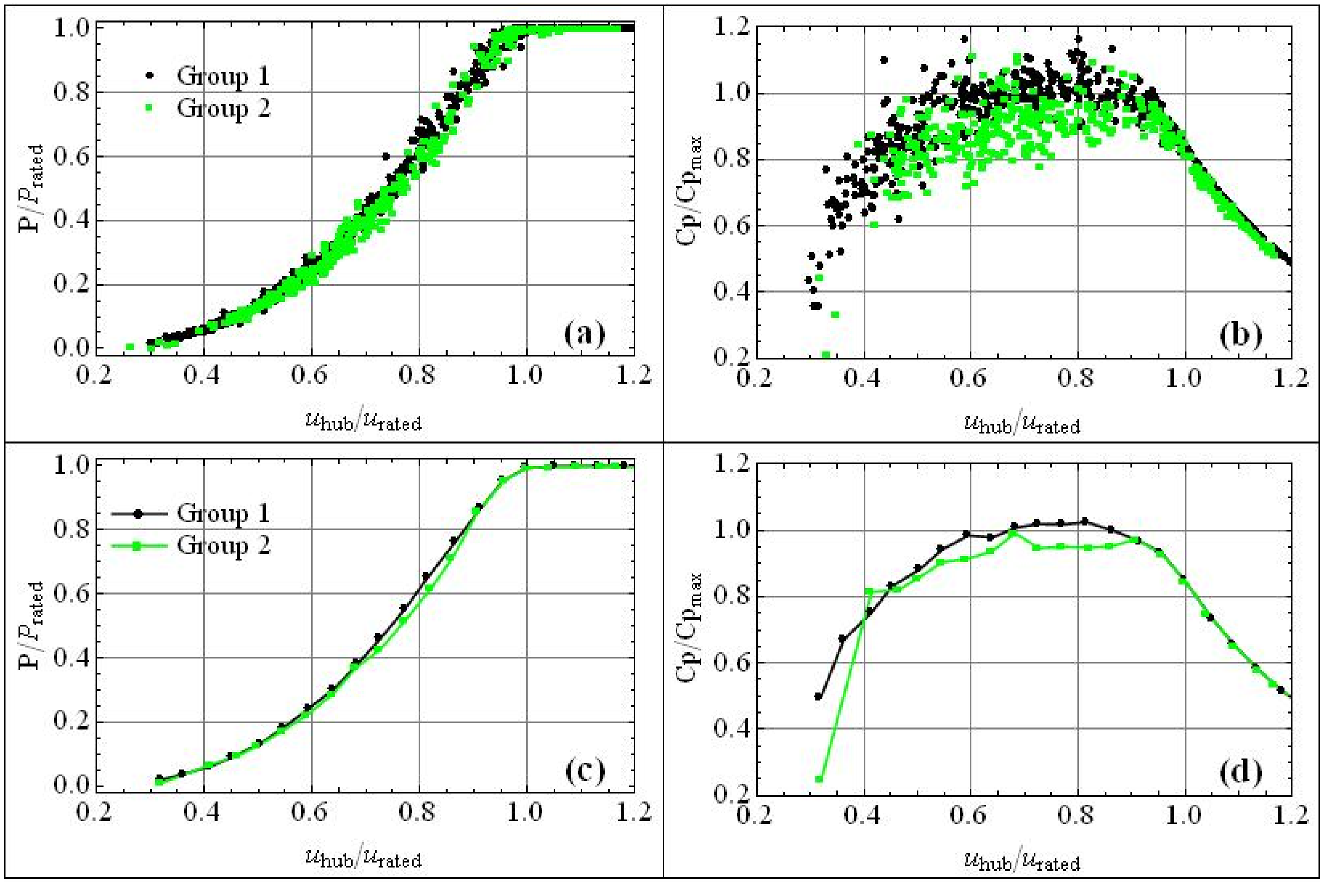
$$RSS = \sum_i \left(u_{fit}(z_i) - u_i^m \right)^2$$

RSS<0.1

RSS>0.1

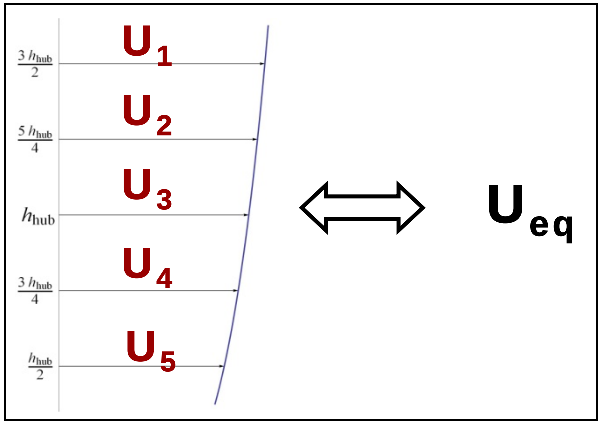
Categorisation of profiles for demonstration of shear effect

Standard power curve



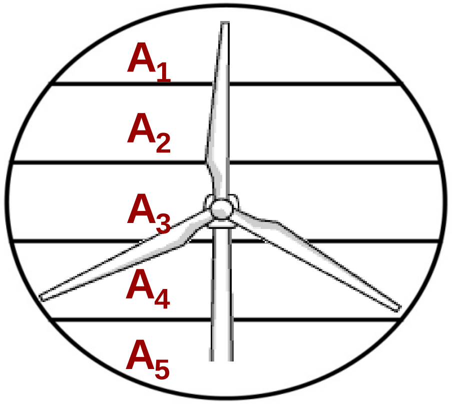
Two groups of profiles result in 2 different power curves.

Rotor equivalent wind speed (REWS)



Concept:

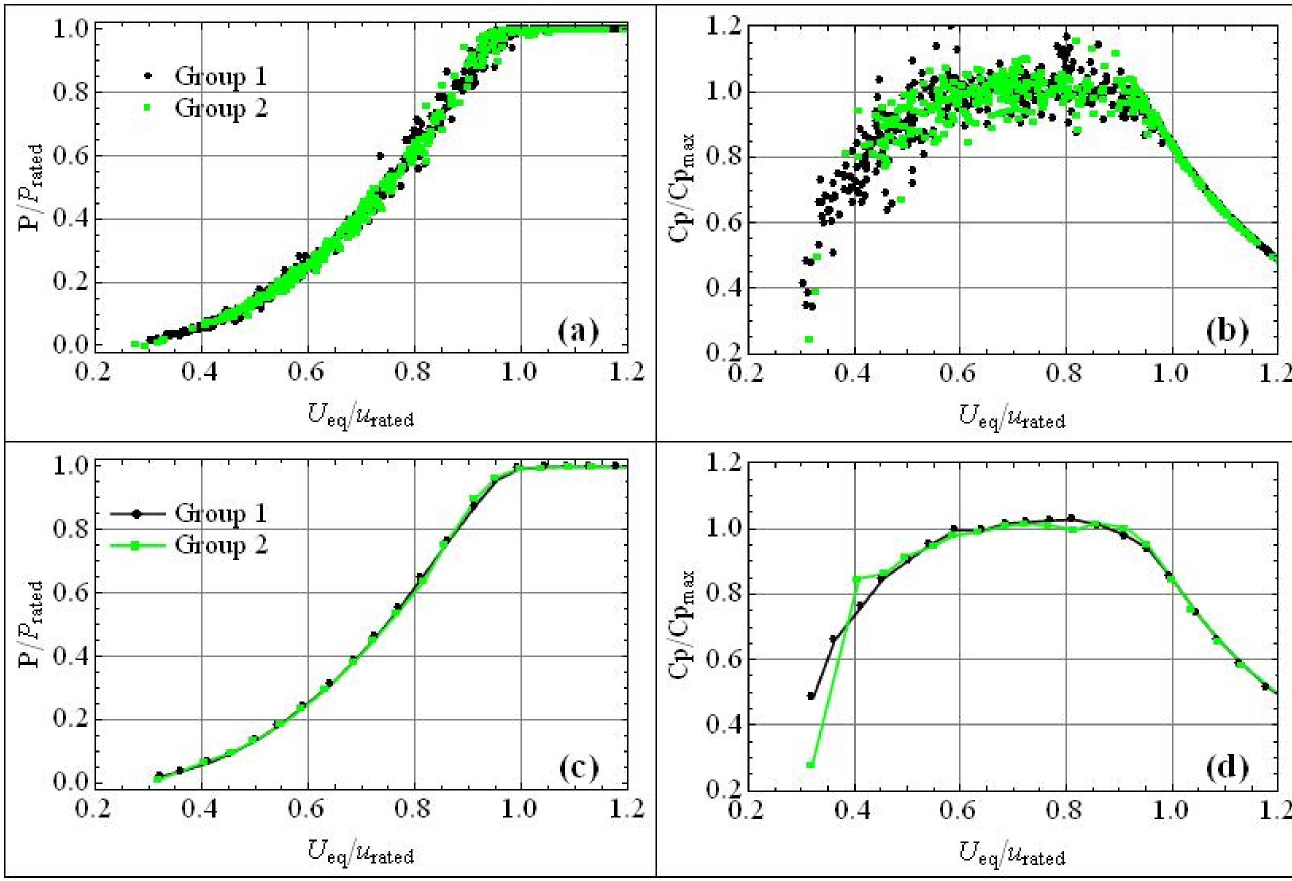
One wind speed representative of the whole wind speed profile in front of the wind turbine rotor in term of power production



Definition:

$$U_{KE} = \left(\frac{1}{A} \int_{-R}^{R} u(z)^3 c(z) dz \right)^{1/3} \approx \left(\sum_{i=1}^{N} u_i^3 \frac{A_i}{A} \right)^{1/3}$$

Power curve with REWS



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→Similar power curves are obtained for both groups of profiles

Wagner et al., *Accounting for the wind speed shear in wind turbine power performance measurement*, Wind Energ. 2011; 14:993–1004. doi: 10.1002/we.509

IEC 61400-12-1 Ed.2 CDV

Status: CDV to be released soon

1) Shear measurement must be included
   → either add uncertainty for the unknown shear

   → or use the rotor equivalent wind speed
   With wind speed measurements at minimum 3 different heights including one height above hub height.

IEC 61400-12-1 Ed.2 CDV

Status: CDV to be released soon

1) Shear measurement must be included
   → either add uncertainty for the unknown shear

   → or use the rotor equivalent wind speed
   With wind speed measurements at minimum 3 different heights including one height above hub height.

2) Allows the use of lidars/sodars to measure the wind speed profile, in flat terrain.
   → the lidar/sodar must be calibrated prior to power curve measurement campign (to assess uncertainties)
   → used with a control mast during the power curve measurement

Summary ground based lidars

Ground based lidars can provide accurate **wind speed profile measurements** all the way to the tip height:

→Lower scatter→ lower uncertainty

→More repeatable power curve → better AEP estimation

IEC 61400-12-1 Ed.2 will allow:

- Rotor equivalent wind speed power curve
- The use of lidars/sodars for power curve measurement

IEA Task 32 about lidars (2012-2015)

Aim at recommended practices for the use of lidars in various applications

→WP 3.1 Exchange about experience about power curve measurement according to IEC 61400-12-1 Ed.2

→WP 2.4 Use of lidars (wind profiles)for resource assessment

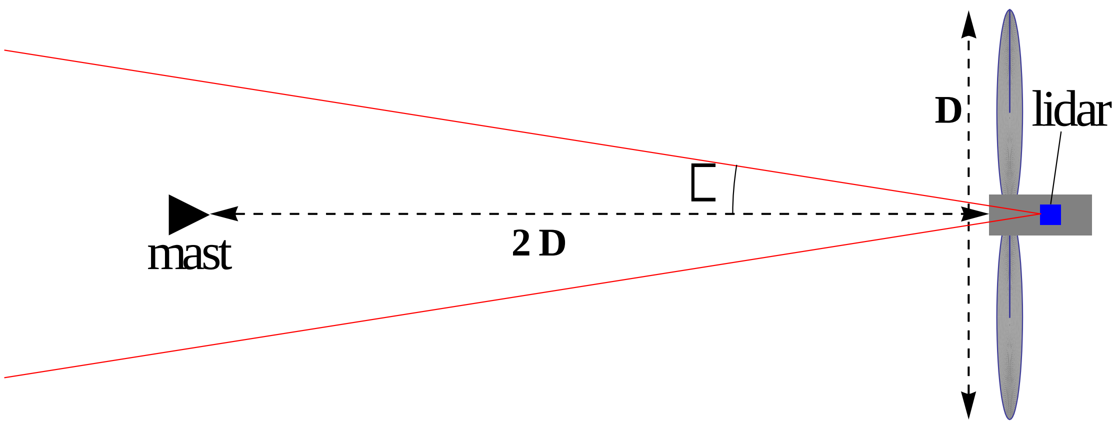
Nacelle mounted lidar

EUDP Project:
"Nacelle lidar for power performance measurement"
2010-2012

<u>Project partners:</u>

DTU
DONG Energy
Avent Lidar
Siemens Wind power

How does it work?



-2 lines of sight

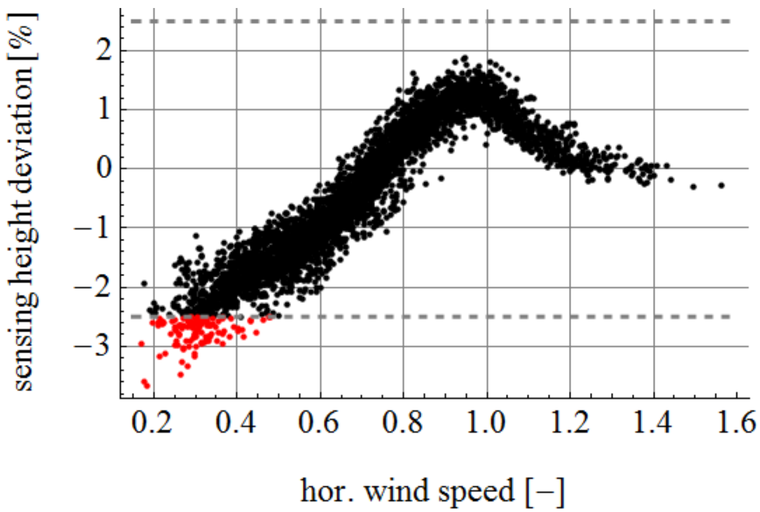
-Half opening angles: 15°

-Measures radial speeds and reconstructs horizontal wind speed vector

-Assumes vertical component to be null

-Assumes horizontal homogeneity!

Measurement height uncertainty



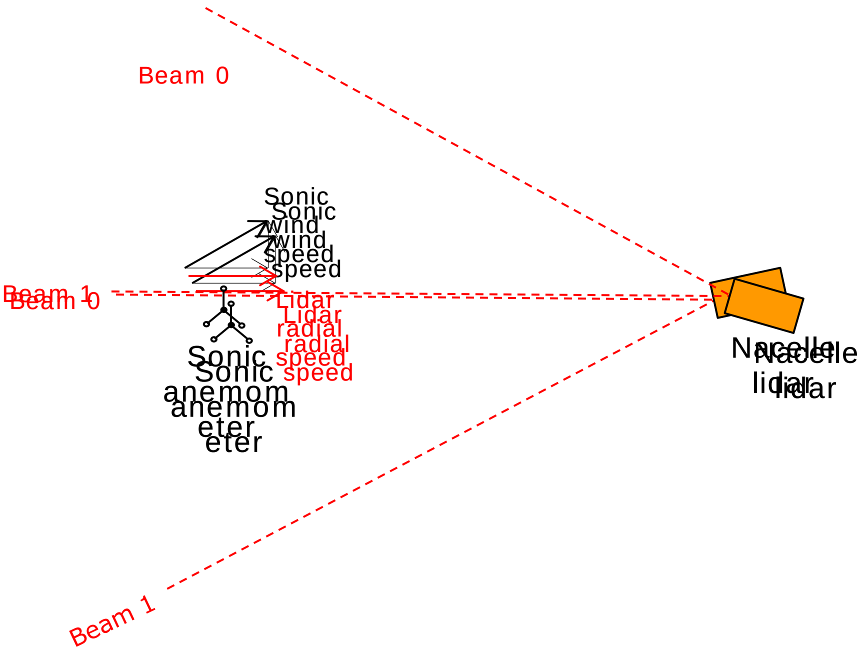
The measurement height varies due to the nacelle tilting.

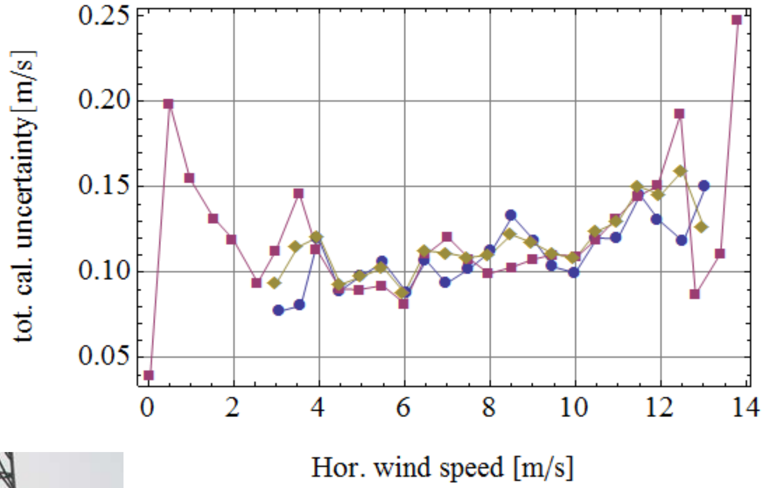
1. Lidar pre-tilted to account for:
   - the actual height of the lidar optical head above hub height
   - the backward tilt of the turbine whilst in operation

2. Extra uncertainty must be added to the wind speed bins for which the measurements took place outside the range hub height +/-2.5%.

Lidar calibration

Individual calibrations of the two line-of-sight (radial) wind speeds



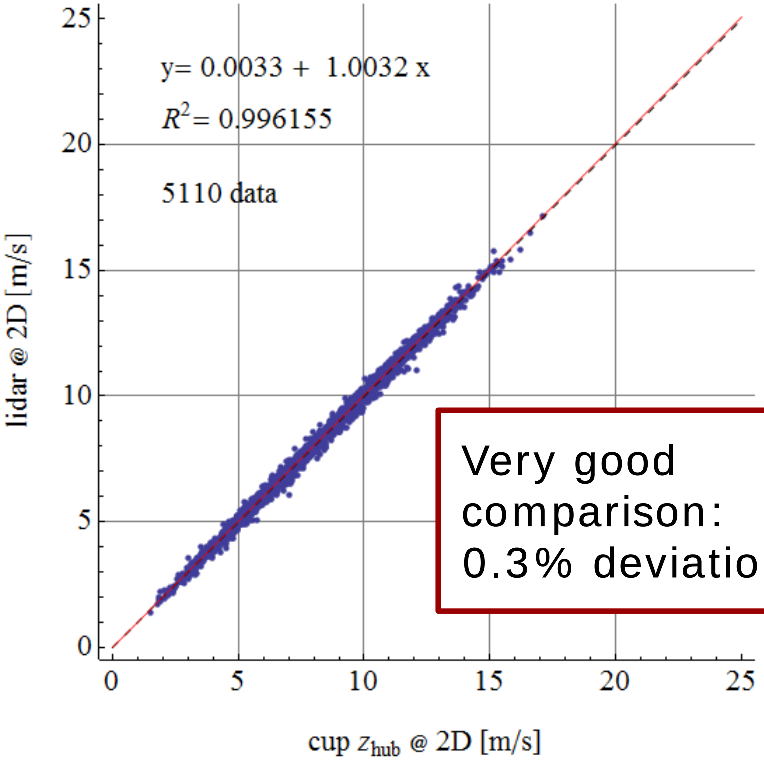


The lidar should be calibrated for traceability and uncertainty estimation.

Ten minute mean horizontal wind speed

DONG Energy power station, Avedøre, South West of Copenhagen

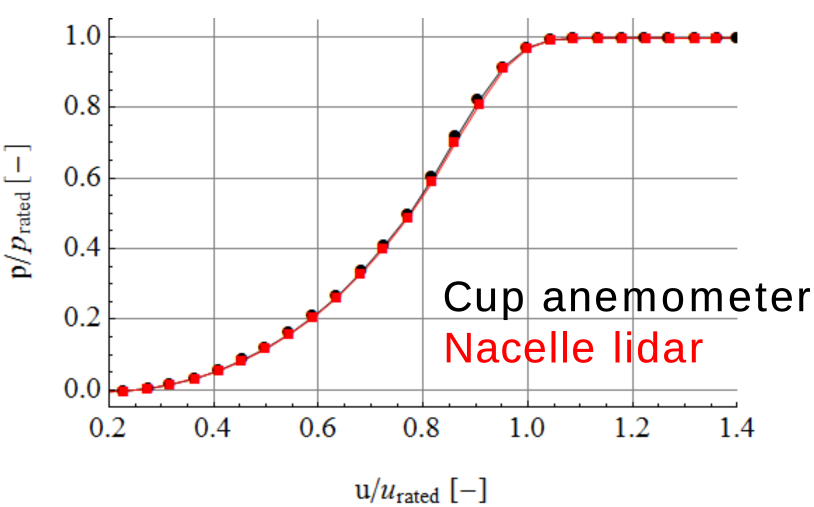
Comparison of lidar and cup anemometer 10-minute data



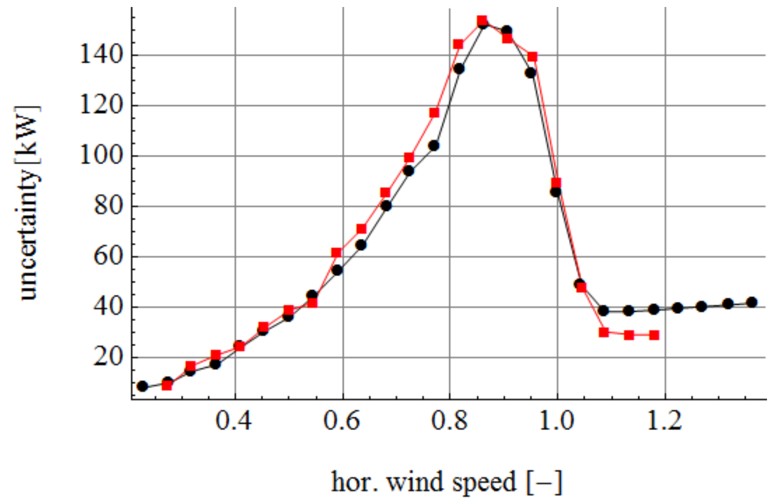
Very good comparison: 0.3% deviation

Comparison of the power curves at 2D

Bin-averaged power curves



Power curve uncertainty



	Mast top cup	Lidar
AEP for 8m/s	100%	99.4%

Very similar power curves and slightly higher uncertainty.

Summary nacelle mounted lidar

- Very **promising technology** for power curve verification, especially offshore.
- Nacelle lidar mean horizontal wind speed compares very well with the cup anemometer in front of the rotor.
- Challenges: measurement height uncertainty and calibration

DTU developed:

- Procedure to measure a power curve with a two-beam nacelle lidar
  (Wagner et al., **DTU Wind Energy E-0016**, 2013)
- Methods to calibrate a two-beam nacelle lidar
  (M. Courtney, **DTU Wind Energy E-0020** , 2013)

IEA Task 32 about lidars (2012-2015)

→WP 3.3 Power curve measurement with nacelle mounted lidars

→WP 1.3 Calibration of nacelle lidars

Thank you for your attention

rozn@dtu.dk