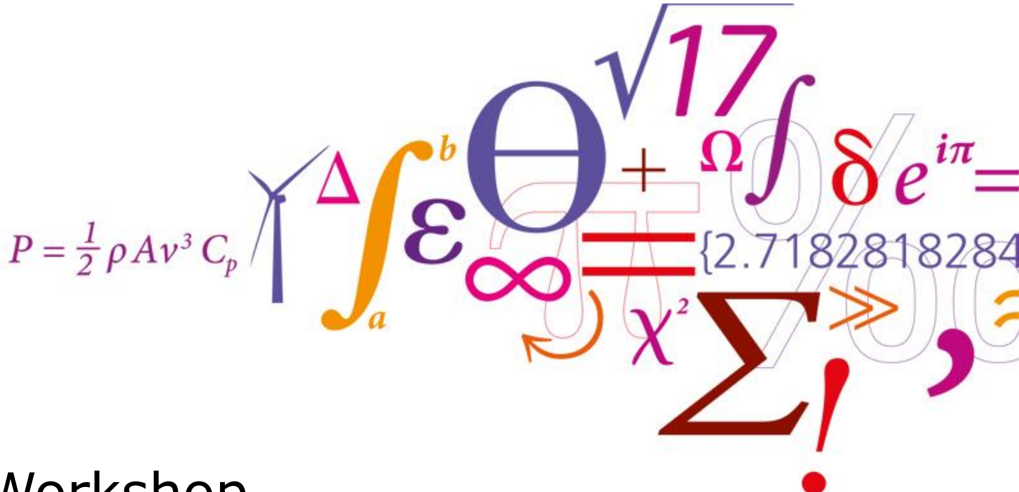
Why are lidars so uncertain?

Why are ~~lidars~~ cups so uncertain?



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EWEA Resource Asessment Workshop,
Helsinki, June 2, 2015

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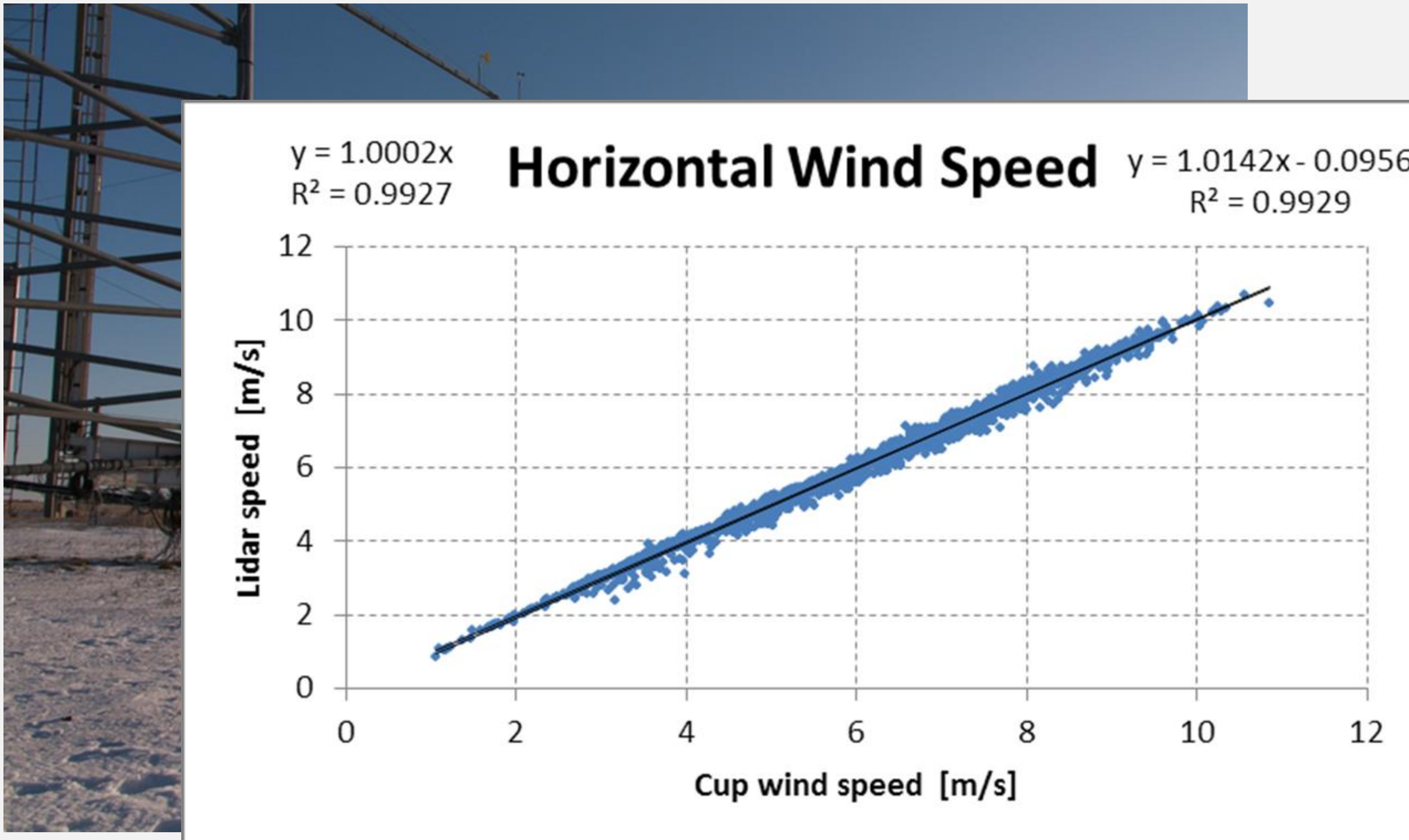
Summary

- Lidar calibrations against cup anemometers
  - Have a high reference uncertainty
  - Vary quite a bit (±1%)
- The high reference uncertainty is entirely due to the cup (calibration, classification and mounting)
- A lot of the variation is probably also due to the cup
- Observation:
  - Most of the lidar uncertainty ís actually due to the cup
- Remedy:
  - Apply good metrology and modern technology to significantly reduce cup anemometer (and thereby lidar) uncertainty.

Lidar calibrations



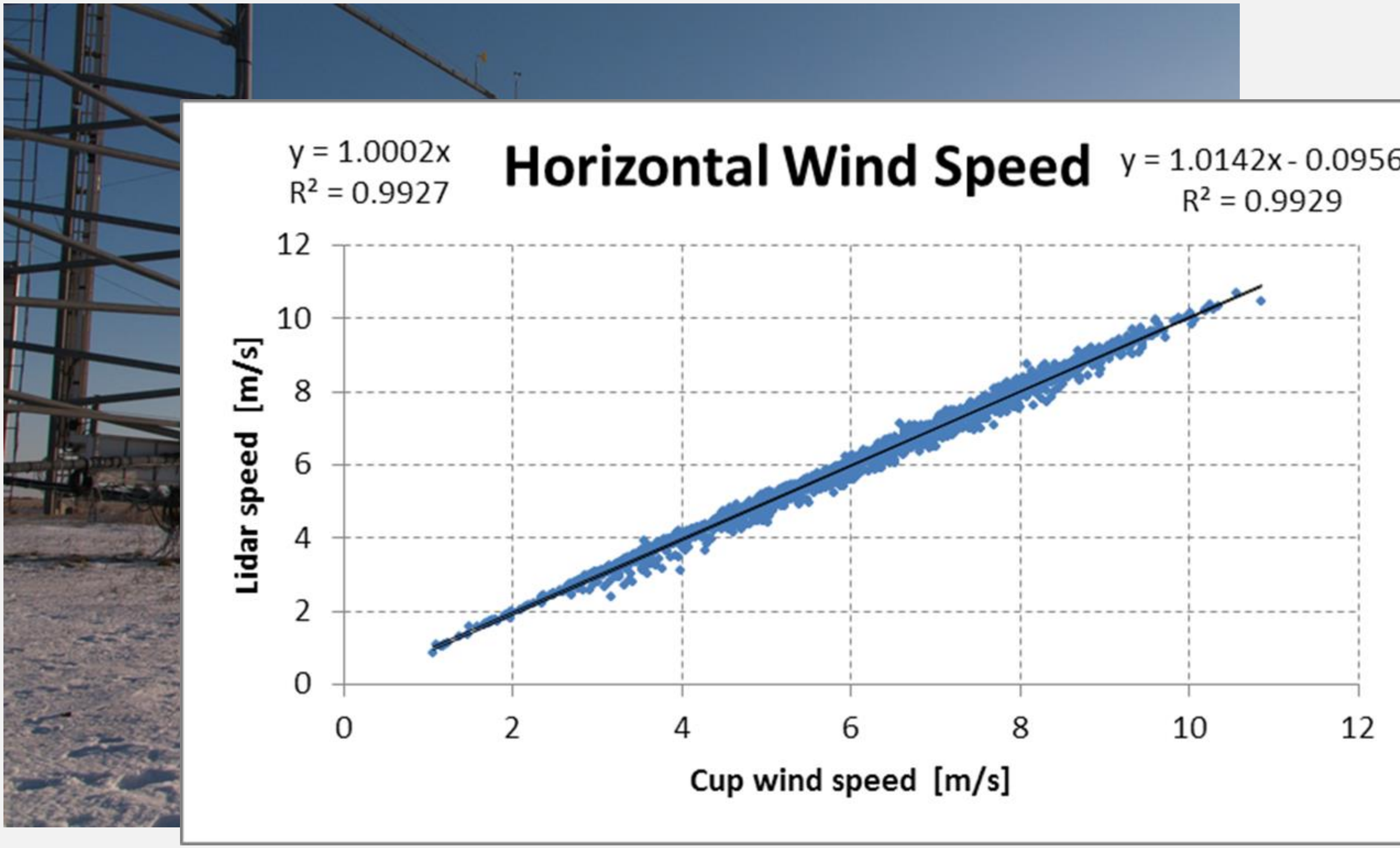
Lidar calibrations – Black and white

FACT:
Lidars DO NOT measure horizontal wind speed directly

- A 'black box' calibration makes a direct calibration between the horizontal wind speed reported by the lidar and a reference cup anemometer wind speed.
  - This tests both the lidar and the validity of the calibration site to achieve the homogeneity the lidar is assuming

- A 'white box' calibration determines the accuracy of the inputs to the lidar's reconstruction algorithm – LOS speeds, ranges and angles. The uncertainty of the reconstructed horizontal speed can then be inferred.
  - This is very useful when it is not really possible to find the necessary homogeneity for the calibration.

Ground-based lidar – Black box



Nacelle lidar – white box - geometry

Nacelle lidar – white box – LOS speed

More on this..

PO.026

Generic calibration procedures and results for nacelle-based profiling lidars

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Abstract

In power performance testing, it has been demonstrated that the effects of wind speed and direction variations over the rotor disk can no longer be neglected for large wind turbines [1]. A new generation of commercial nacelle-based lidars is now available, offering wind profiling capabilities. The use of profiling nacelle lidars to assess power performance could remove the need to erect expensive meteorology masts, especially offshore.

Developing standard procedures for power curves using lidars requires to assess lidars measurement uncertainty that is provided by a calibration. Based on the calibration results from two lidars, the Avent 5-beam Demonstrator and the Zephir Dual Mode (ZDM), we present a **generic methodology to calibrate profiling nacelle lidars**.

Objectives

The objectives of this work are to:

1) Develop generic calibration procedures, i.e. applicable to any type of nacelle-based lidar irrespective of their type (pulsed or continuous-wave) and design.
2) Apply the calibration procedures to both the 5-beam Demonstrator and the ZDM lidars. (see pictures below)
3) Provide calibrated lidars, since both are to be installed on nacelles of wind turbines during measurements campaigns (see www.unitte.dk), which goal is to develop procedures to assess power performance that could be applied in any type of terrain (flat or complex, onshore or offshore).

Pictures of the 5-beam Demonstrator (left) and the Zephir Dual Mode (right), during their calibration at DTU Wind Energy test site, Høvsøre, DK

The fundamental reason for developing calibration procedures is to **assign uncertainties to lidars wind measurements**. Commercial applications of lidars, e.g. power performance testing or resource assessment, demand the estimation of measurement uncertainties.

Metrology standards [2] define a calibration as a 3-step process:

- **Establishing a relation** between the measurand and reference quantity value;
- **Uncertainties measurand** = uncertainties on reference + calibration process ;
- Apply the calibration relation to preserve **traceability** in the measurement chain.

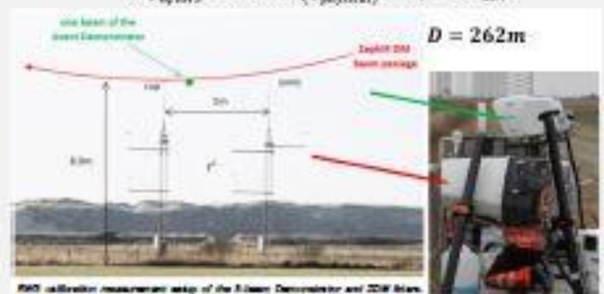
Calibration procedure principles

A lidar probes the wind by emitting light through a laser beam. Aerosols contained

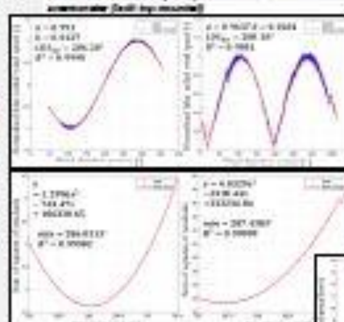
White box calibration steps, setup and results

The data required for the RWS calibration are time-averaged of: calibrated measurements of horizontal wind speed (HWS) and direction (θ); lidar RWS and beam inclination $\varphi_{physical}$. These data enable a reference equivalent RWS to be obtained by projecting the HWS onto the LOS direction (LOS_{dir}):

$$Ref_{eq\,RWS} = HWS \cdot \cos(\varphi_{physical}) \cdot \cos(\theta - LOS_{dir})$$



RWS calibration measurement setup of the 5-beam Demonstrator and ZDM lidars. The HWS is measured by a cup anemometer and the wind direction by a vane.

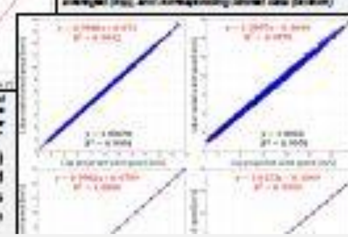


LOS direction evaluation: 5-beam Demonstrator (left) and ZDM (right) lidars. Top: cosine and rectified cosine response to wind direction respectively. Bottom: fine evaluation by use of a "Residual Sum of Squares process"

The **LOS direction is estimated** by:

1. Fitting the lidar response to the wind direction.
2. Linear regressions between the RWS and $Ref_{eq\,RWS}$ using different projection angles are performed, and the RSS are reported. The accurate LOS direction corresponds to the minimum of the fitted parabola.

Calibration relation results: 5-beam Demonstrator (left) and ZDM (right) lidars. Linear regressions on "raw" (10-min averaged (top), and corresponding binned data (bottom)



The calibration results (binned data) show consistent gains in the forced regression with an error of less than 0.9% for both the ZDM and the

Lidar uncertainty from the calibration

(per bin, according to Annex L)

$$U_{\mathrm{lidar}} = \sqrt{U_{ref}^2 + \Delta V^2 + \frac{\sigma_{lidar}^2}{N} + \sigma_{dev}^2}$$

Lidar uncertainty

Reference uncertainty

mean deviation

”uncertainty” of mean in bin (?)

Standard deviation of the deviation

I am not convinced that these terms are correct, but it doesn’t change the main argument of this presentation.

Lidar uncertainty from the calibration

- Typical sizes (m/s) at 10 m/s (standard uncertainty)

$$\mathrm{U_{lidar}} = \sqrt{U_{ref}^2 + \Delta V^2 + \frac{\sigma_{lidar}^2}{N} + \sigma_{dev}^2}$$

0.17

0.15²

0.05²

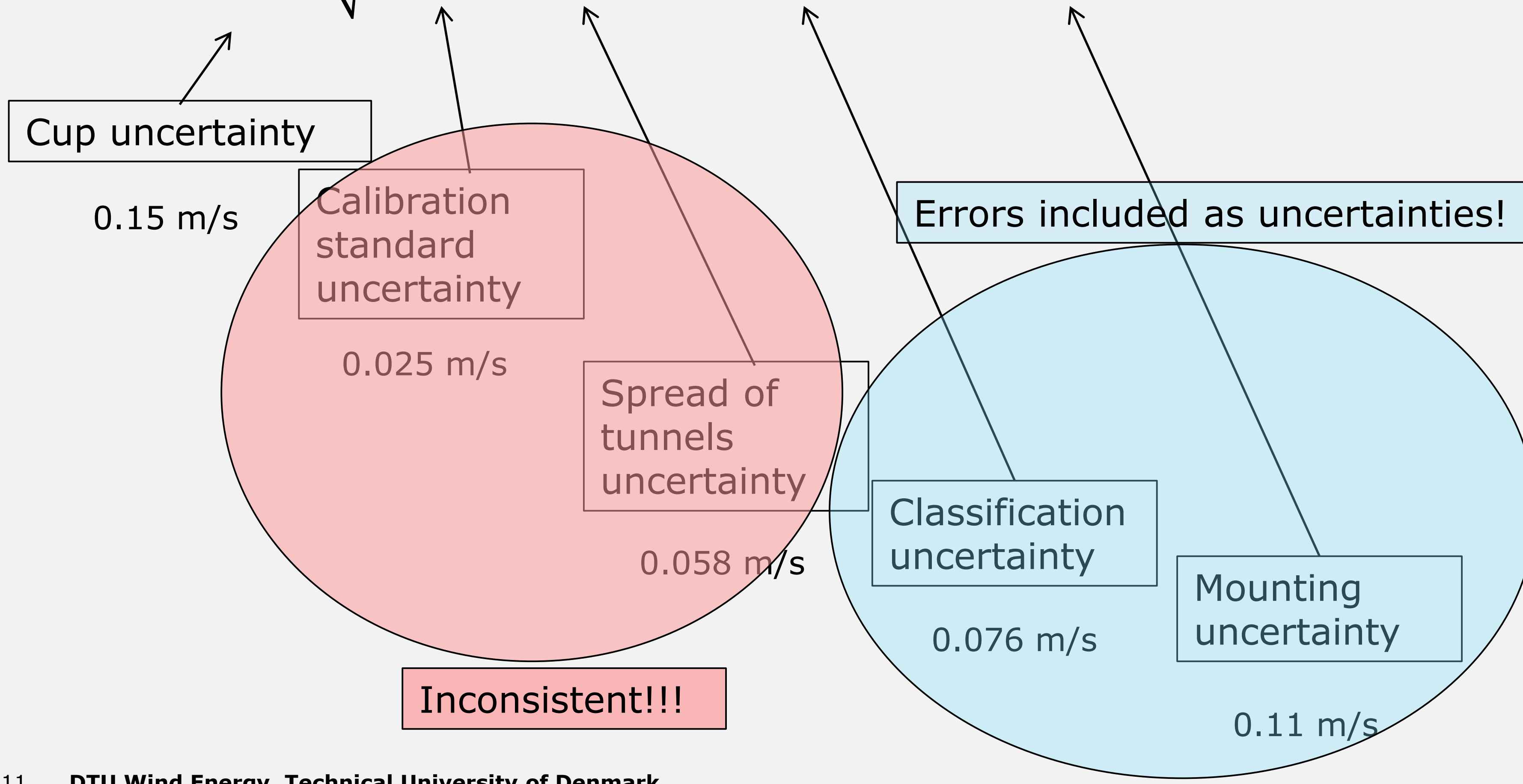
0.02²

0.07²

The reference cup contributes most of the uncertainty.

Where does the reference cup uncertainty come from? (typical values for 10 m/s)

$$U_{ref} = \sqrt{U_{cal}^2 + U_{tunnel}^2 + U_{operational}^2 + U_{mounting}^2}$$



Summing up so far:

- Most of the lidar uncertainty comes from the cup

- Most of the cup uncertainty comes from
  - Tunnel uncertainty
  - Operational uncertainty
  - Mounting uncertainty

We believe that new technology and better metrology can considerably reduce all 3 of these items!

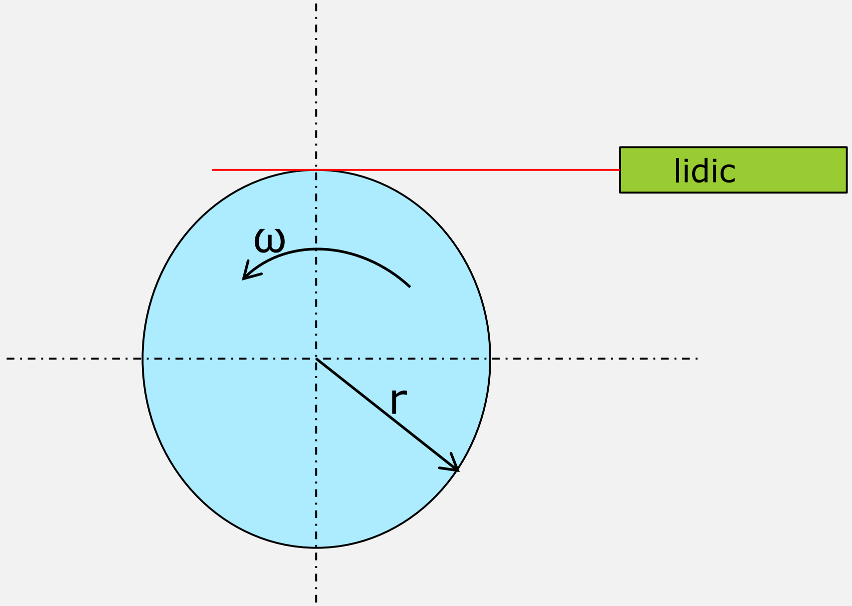
The new technolgy is ?

LIDAR!

More specifically, short range CW lidars (LIDICS) calibrated using the same principle as LDA (rotating wheel).

Lidar line-of-sight (LOS) speeds:

- Are inherently very accurate
- For short range, CW devices the radial speed can be traceably calibrated to high accuracy



The calibrated lidics can be used for

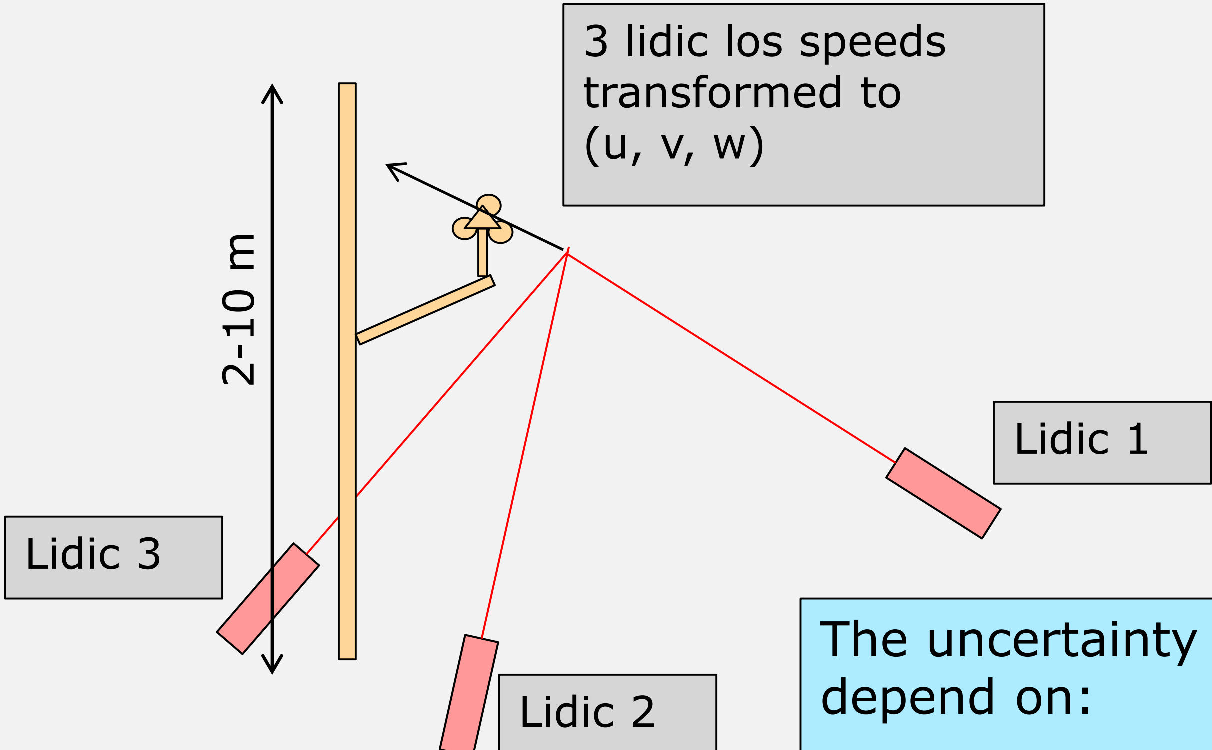
- Measuring more accurately in wind tunnels
  - This will hopefully nearly eliminate the *‘tunnel’ uncertainty*

- Performing free-air calibrations
  - Can corroborate the improved wind tunnel calibrations

- Performing free-air classification tests
  - Will provide real cup sensitivity characteristics (T and ti) that can be used to **correct** cups (maybe in real-time) and significantly reduce the class (*operational uncertainty*)

- Measuring the flow distortion around a mast and cup combination
  - Will provide robust corrections and thereby significantly reduce the *mounting uncertainty*

Measuring in the free-air using 3 lidics



The uncertainty of (u, v, w) will depend on:

- the los speed uncertainty
- the lidic geometry
- the range accuracy

DTU is committed to reducing cup anemometer uncertainty

- It is part of our 4 year plan (reduction of cup anemometer uncertainty by 1%)
- We are already seeking funding to achieve this
- Applies to sonics as well

Conclusion

- Lidar uncertainty is dominated by the reference cup anemometer uncertainty.

- Cup anemometer uncertainty can be improved by:
  - Solving the tunnel blockage calibration issues

  - Measuring and correcting for sensitivities instead of just including them as uncertainties (Smartcups)

  - Measuring and correcting for mounting effects, with much reduced mounting uncertainty as a consequence.

- We can use precision calibrated, short range, continuous wave lidars (LIDICS) to achieve this.

- These improvements will reduce cup anemometer, sonic and consequently lidar uncertainty

Thanks and any questions?

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