Fulcrum 3D
precision sensing

Fulcrum3D Sodar | technical note

inflow angle measurements using Sodar

inflow angles and wind farm performance

Accurate understanding of inflow angles is essential to good wind farm design.

Wind turbine yield calculations generally assume horizontal wind flows moving through the turbine swept area.

Any inflow angle present has the effect of reducing the turbine swept area, or conversely, reducing the horizontal wind component. If wind flows are not horizontal, and if this is not corrected for, actual energy yields will be less than predicted.

Equally importantly, non-horizontal wind flows put increasing torsional effects on wind turbines which can impact the operational life of wind turbines.

Both impacts materially affect the commercial performance of a wind farm. Accordingly, measuring inflow angles is an important part of good wind farm design.

complex terrain

In complex terrain, non-horizontal wind flows are prevalent, driven both by terrain and thermal effects. Horizontal wind flows are pushed upwards by uneven (rising) terrain, affecting wind turbines normally located at the top of ridgelines.

Likewise, it is more common in complex terrain to experience thermal pooling of cooler air, and diurnal effects as air warms and cools through the day. The bidirectional nature of these flows introduces both positive and negative inflow angles.

It is also likely that inflow angles will differ through time of year, wind speed and wind direction, making it very difficult to carry out any kind of corrections.

Inflow angles in excess of 15 degrees are not uncommon in complex terrain. Such large inflow angles can be material to project economics.

simple terrain

As accurate 3D measurement systems become more commonplace, it is becoming increasingly apparent that even “simple terrain” sites can be affected by significant inflow angles.

Rather than being introduced by terrain effects, in simple terrain non-horizontal wind components are more commonly driven by thermal activity.

While the cause is somewhat different, and the direct effects typically lower, the combined effect with errors introduced by cup anemometers mean inflow angle assessment is important in flat terrain sites as well.

cup anemometer response to inflow angles

Cup anemometers introduce measurement errors whenever inflow angles are present.

Cup anemometers are designed to be mounted horizontally to measure horizontal wind flows. For this reason, anemometer calibrations are carried out with the anemometer mounted horizontally in a wind tunnel.

When anemometers measure non-horizontal wind flows, the expected relationship for an “ideal” anemometer is a cosine response to the inflow angle, representing the horizontal component in the wind (see Annex J IEC 61400-12-1:2005). The horizontal component of the wind should always be at or less than the total wind speed.

However, anemometer cup and body shapes affect anemometer measurements of wind flows which are not horizontal. Accordingly, they do not follow the cosine response of an “ideal” anemometer. Anemometers are often tested in a wind tunnel with a pre-defined anemometer tilt to determine their actual response with respect to inflow angle, and a response curve determined for each anemometer type.

A sample of response curves from widely used instruments is outlined below. Each response curve also indicates the cosine response indicating the ideal response to various inflow angles.

It is clear that over a typical range of wind flow angles the response of each anemometer varies widely, with a number of errors introduced:

- Over speeding, where the measured wind speed is greater than the actual wind speed
- Asymmetrical response, where positive or negative inflow angles have unequal response characteristics
- Unequal response with respect to wind speed, with difference wind speeds presenting different errors for the same apparent inflow angle

Within the range of typical inflow angles, wind speed measurement **errors in excess of 10% can occur** based on inflow angles alone. The presence of any level of inflow angle is likely to add at least 1% error to wind speed measurements.

This can occur both on flat terrain and complex terrain.

In theory, these response curves could be used to correct for the inflow angles. However, the inflow angle time series data is simply not available to correct measured wind speeds for this anemometer characteristic as inflow angles are rarely measured in practice.

The Fulcrum3D Sodar provides inflow measurements at each measurement height allowing met masts to be corrected as well as other benefits.

typical anemometer response curves[1]

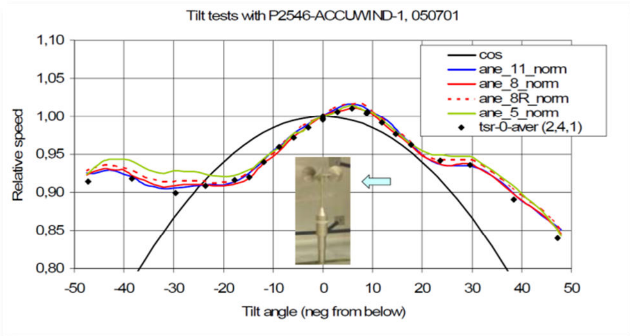


Figure 1 - Angular Response Windsensor P2546

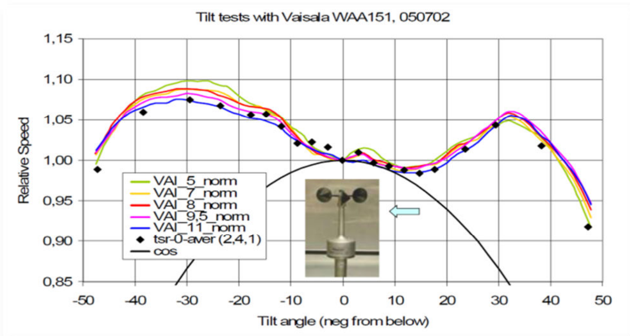


Figure 2 - Angular Response Vaisala WAA151

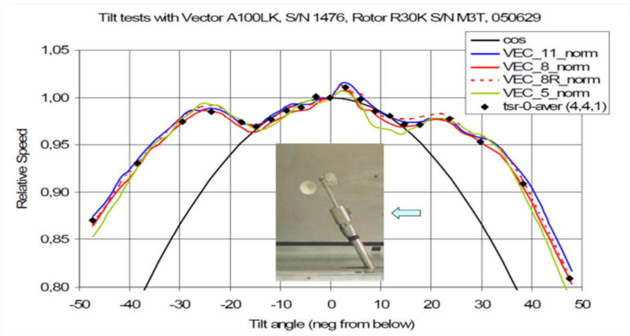


Figure 3 - Angular Response Vector A100LK

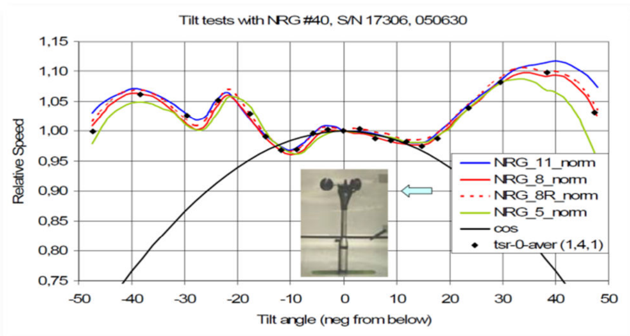


Figure 4 - Angular Response NRG #40

[1] ACCUWIND – Classification of Five Cup Anemometers According to IEC61400-12-1, Risø National Laboratory, 2006

measuring inflow angle with a Fulcrum3D Sodar

how it works

The Fulcrum3D Sodar emits a sound pulse (a chirping sound) approximately every 2 seconds. This sound pulse is scattered by thermal turbulence in the atmosphere, and some of the signal is scattered back towards the unit. The returned signal is recorded and divided into time slices which correlate to 10m height bins.

The Fulcrum3D Sodar analyses the Doppler Shift in the returned signal in each height bin to determine the 3 dimensional wind vector for further analysis.

direct measurement of inflow angles

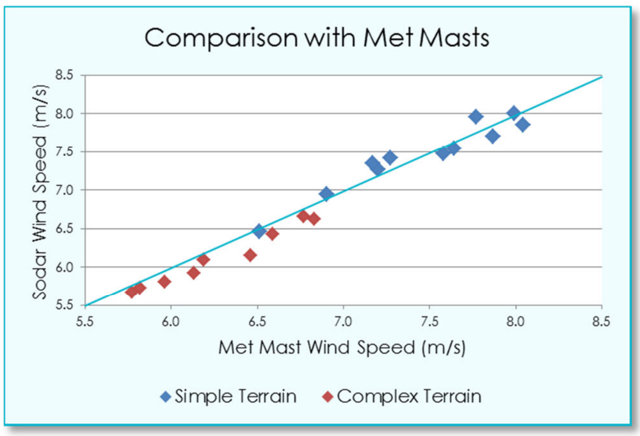
The 3D wind vector is resolved into its various components to provide conventional horizontal wind speed, horizontal wind direction, vertical inflow angle and/or vertical wind speed. The Fulcrum3D Sodar provides a 10 minute time series of inflow angles in each height bin, with coincident wind speed and direction data to allow comparison.

By providing inflow angles at each height bin, the Fulcrum3D Sodar allows analysis at varying heights across the turbine to consider actual inflow angles at hub height, and right across the swept area. For example, in complex terrain, inflow angles are seen to vary with height depending on the speed and direction of the wind and the shape of the incoming terrain.

proven performance

The Fulcrum3D Sodar has been independently verified by a range of internationally recognised wind energy experts, confirming that the Sodar is measuring wind speeds to a high degree of accuracy.

To date, Sodars performance has been verified through a variety of tests in different climates, topography, locations and elevations, including in both simple and complex terrain.



Fulcrum3D Sodar | simply better

Who is Fulcrum3D?

Fulcrum3D combines the strengths of Fulcrum Energy's firsthand renewable energy project experience with the specialist technical design and manufacturing expertise of Orang-utan Engineering.

The result is unique technology designed specifically to support the renewable energy sector.

Our range of remote sensing products includes:

- Wind monitoring using our compact beam Sodar
- Integrated noise / weather monitoring
- Solar resource monitoring
- Cloud tracking and cloud monitoring systems

Our technology platform is based on a robust telemetry system, designed for maintenance free operation in remote environments.

All data is available for web download via our *Flightdeck* portal. Additional data tools are also available via *Flightdeck*.

We look forward to providing you with great Australian technology supported by first class service and support.