ZephIR Lidar
wind speed at light speed

ZEPHIR PERFORMANCE EVALUATION AFTER 40 MONTHS OF CONTINUOUS OPERATION

OPERATIONAL EVIDENCE OF LONG-TERM STABILITY OF ZEPHIR LIDAR PERFORMANCE

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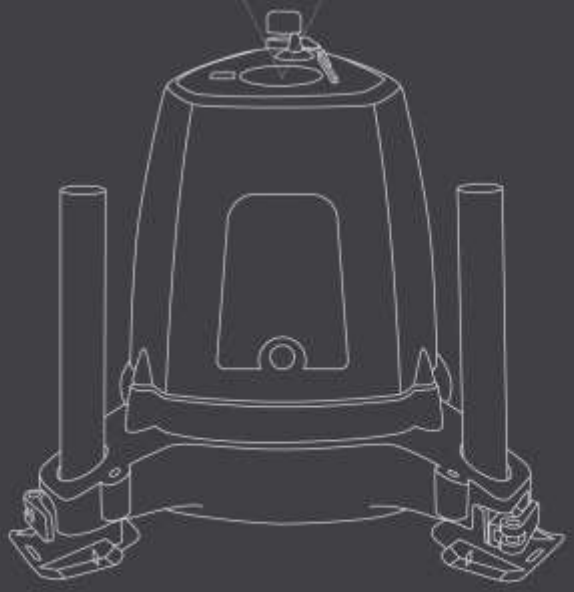

MUHAMMAD M A MANGAT

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ABSTRACT

This report demonstrates the performance of a ZephIR Continuous Wave (CW) lidar over a period of 40 months continuous operation. It examines the performance before and after the 40 month operational deployment, during which time no maintenance or servicing has been conducted on the ZephIR. Due to the inherent design of the ZephIR and its CW operation, once factory calibrated a device will not need to be recalibrated during long-term operation; however, in order to provide evidence and traceability to IEC compliant anemometry, system validations are routinely performed whenever each unit returns to base. The method employed here to evaluate the performance over time is to compare pre- and post-deployment validations of the ZephIR against a 91m IEC compliant mast at the UK's Remote Sensing Test Site (Pershore, UK) which is operated by ZephIR Lidar. From analysis of the results it is concluded that any changes in accuracy of the ZephIR over the period are insignificant and much less than 1% in wind speed; this fits well within the industry standard (IEC) requirement for accuracy which is of the order of 1.5% to 2.0% depending on wind speed for a first class, calibrated, well-mounted cup anemometer. This conclusion is consistent with the expectation from an analysis of the stability of the main factors that contribute towards the overall system calibration.

1. INTRODUCTION

The advantages of Remote Sensing Devices (RSDs) include their ease of installation and suitability for multiple campaigns, or longer-term finance-grade assessments for Energy Yield Analysis (EYA) contributing to Annual Energy Production (AEP) calculations. A drift in performance would require recalibration which would be a disadvantage to the operator in terms of inconvenience, cost and time.

ZephIR does not require re-calibration and one of the drivers of this report was to demonstrate system performance stability over time. As per IEA Wind recommendations for ground-based vertically profiling remote sensing for wind resource assessment, a periodic verification or validation for RSDs should be performed after every two years or more frequently if specified by the manufacturer [1].

ZephIR Lidar manufactures monostatic, continuous wave (CW) Doppler lidar systems, all based on the same proven core optical design. It specifies 18 months service period for its original ZephIR 175 models and 24 months service interval for ZephIR 300 models. To demonstrate the stability of the design in terms of accuracy the performance of a ZephIR 175 model has been analysed upon its return to the factory 40 months of continuous operation after first deployment.

1.1 ZephIR Lidar system

Ground-based ZephIR lidars are capable of measuring wind speeds and directions at up to 10 user-selected heights. As a vertically-scanning lidar, it interrogates each measurement height sequentially at a scan rate of 1Hz building up a wind profile up to heights of 200m. During each scan, the ZephIR collects 50 or more line-of-sight (LOS) measurements before moving to the next measuring height. Over a standard 10-minute averaging period, the lidar returns values of mean speed and direction at each height, as well as turbulence (TI) data.

1.2 ZephIR Lidar Calibration

There are four main calibrations required for ZephIR lidar systems which are performed in the factory during product manufacture and commissioning [2].

- Velocity
- Focus range
- Sensitivity
- Cone angle

Velocity Calibration

LOS velocity of ZephIR lidars depend on the measured Doppler frequency, v_D, and the laser wavelength only. Stable wavelength and frequency scaling ensures velocity calibration is extremely robust.

Focus Range

Focus range of a ZephIR lidar is calibrated by pointing it at a calibrated moving target located at a known precise distance away.

Sensitivity

Sensitivity (signal to noise ratio), is measured close to the theoretical limit from using a uniform moving target.

Cone Angle

Scan cone angle is calibrated by comparing the speed returned by the lidar and that of moving belt.

Once a ZephIR has undergone the factory calibration and test procedure it needs no further calibration and its accuracy shall remain stable for the duration of operation. ZephIR systems are only placed next to an IEC compliant mast for validation purposes and they are not calibrated to that mast unlike some other RSDs.

1.3 Test Site

The test was conducted at the UK's Remote Sensing Test Site (Pershore, UK) operated by ZephIR Lidar. The site comprises of an IEC-compliant [3] 91m tall mast. The mast has four pairs of anemometers at 20m, 45m, 70m and 91m and two direction vanes at 88m and 43m. One of the anemometers at 91m is a Metek USA 1 sonic anemometer. All cup anemometers are classified as Class A. Mast shadow filters are applied for the highest two heights based on direction from the 88m vane and lower two heights based on direction from the 43m vane.

The terrain at the site is relatively benign with sparse low growing vegetation. A full analysis of the site has been undertaken [4].

1.4 Performance Verification

Test procedures and performance verification criteria for the validation of ZephIR units at the Pershore test site have been devised in collaboration with DNV-GL, and are as follows:

Set up

i. Unit should be situated within 10m from the base of the mast [5]
ii. The difference of measurement height of the ZephIR and cup anemometer not exceeding 2m.

Criteria

iii. Forced-fit gradients of the 10-minute horizontal wind speeds (calm filter applied: > 3 m/s)
iv. The gradients are within 2% of unity and $R^2 > 0.97$.
v. A minimum of 400 valid comparable measurements are required.

2. RESULTS

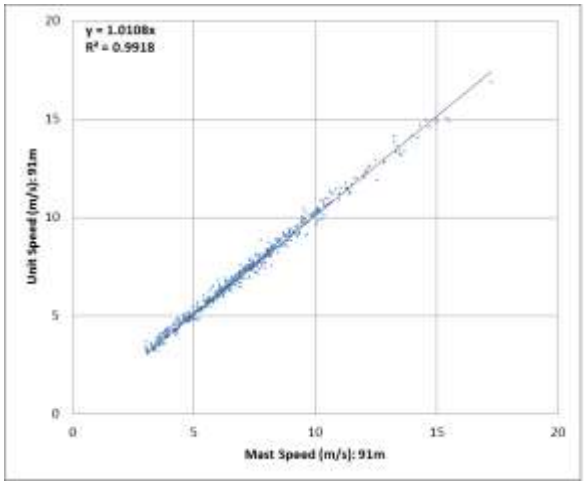
A standard ZephIR 175 has been used for this test. Following delivery to site in September 2010 it was deployed continuously, acquiring wind profile data until February 2014. Due to operational constraints associated with the specific deployment, it was not possible to recover the device for inspection and service within the recommended service interval. As such, given the length of time that the ZephIR had been operated outside of its recommended service interval, it was decided that a post campaign validation would be beneficial.

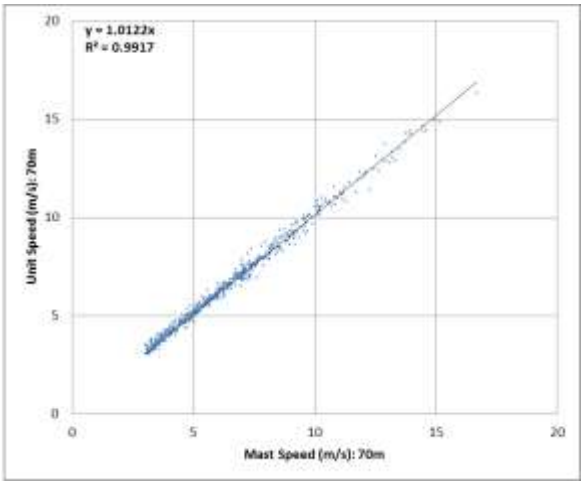
2.1 Pre-Deployment test

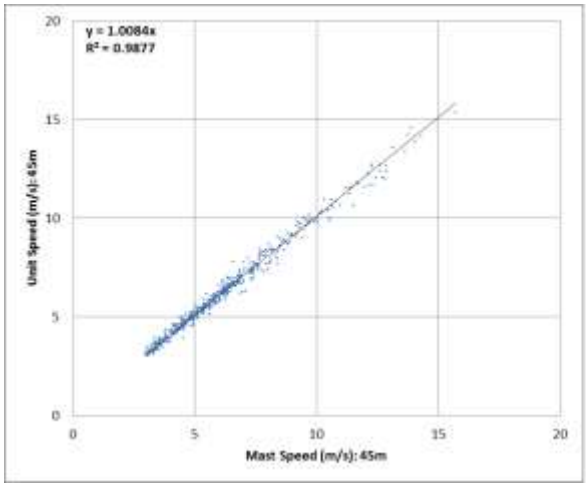
Pre-deployment period refers to the unit's initial validation against the reference mast post manufacture and factory calibration. This took place in Aug 2010, immediately following production of the unit. The results of comparing lidar and mast 10-minute speed values are shown in table below.

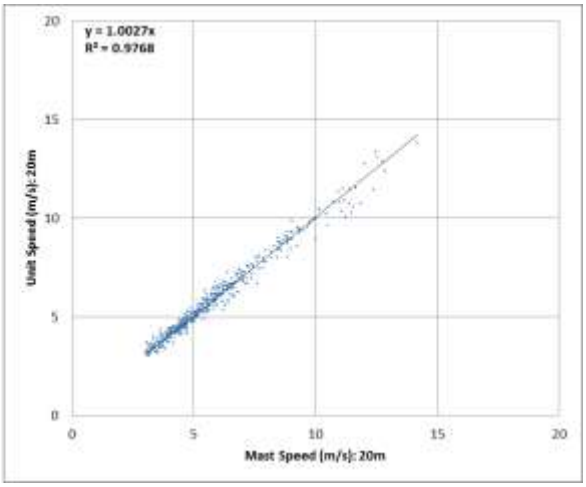
Height[m]	Gradient	R^2
91	1.0108	0.9918
70	1.0122	0.9917
45	1.0084	0.9877
20	1.0027	0.9768

Correlation plots at all four heights are shown below:







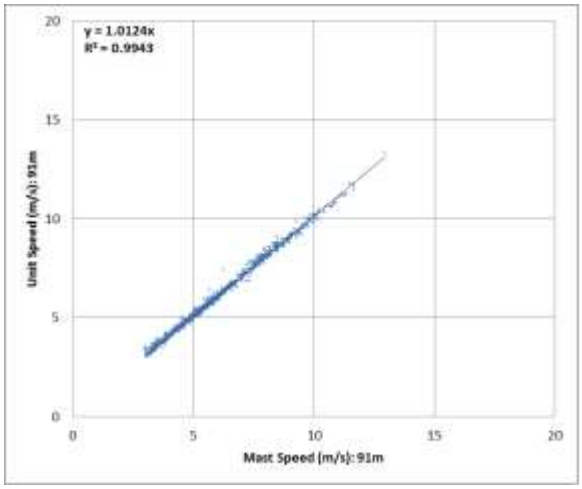


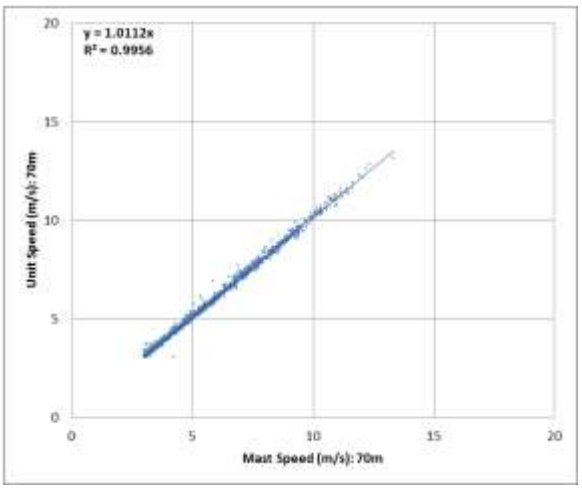
2.2 Post-Deployment test

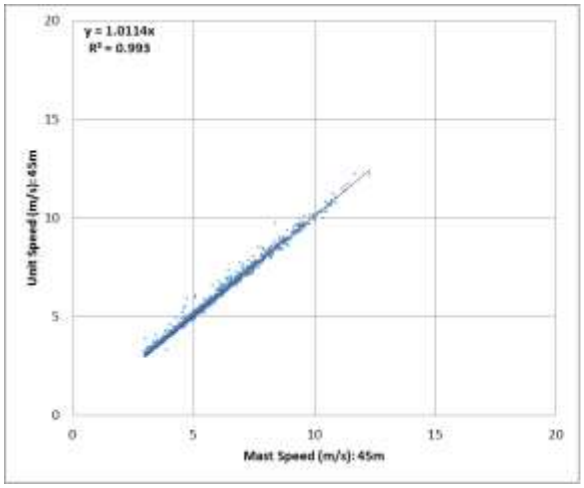
Post-deployment refers to the period of validation following the return of the unit to ZephIR after 40 months of continuous operation.

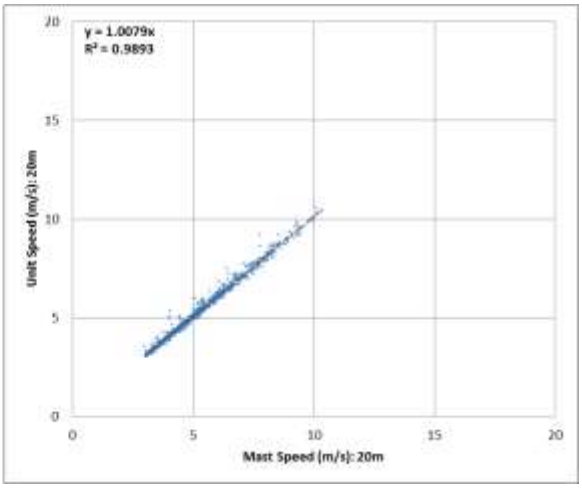
Height	Gradient	R^2
91	1.0124	0.9943
70	1.0112	0.9956
45	1.0114	0.993
20	1.0079	0.9893

Correlation plots at all four heights are shown below:









The gradients of the plots indicate the accuracy of the unit. Comparison of the gradients for the pre- and post-deployment tests shows an impressive level of consistency, with any differences much smaller than 1%. This includes the possible contributions from differing atmospheric conditions during the two test periods, which took place at different times of the year. In addition, during this period, the mast was re-instrumented in accordance with IEC guidelines [3].

3. CONCLUSION

A ZephIR lidar has returned to the UK Remote Sensing Test Site (Pershore, UK), with an IEC compliant mast for post deployment performance validation, after 40 months continuous operation. Correlation results from both validations against a meteorological mast fulfil the ZephIR performance verification criteria, as agreed with DNV-GL. Results also confirm that there is no noticeable drift in performance between the two correlations implying that the initial factory calibrations performed have remained stable. Whilst it is not recommended to operate ZephIR devices well beyond their recommended service interval as this will eventually increase the risk of unit malfunction, this report does provide evidence of the stability of ZephIR's calibration process.

The uncompromised long-term performance of ZephIR lidars is a consequence of their robust Continuous Wave design based on proven telecomms components. Alternative lidar designs typically demand a 'back-to-base' service interval of just 12 months, which may impact any commercial deployment. ZephIR is provided, as standard, with a 24 month warranty during which time a service is not required.

4. REFERENCES

[1] IEA Wind Recommended Practice 15.Ground-Based, Vertically-Profiling Remote Sensing for Wind Resource Assessment, First Edition, January 2013.

[2] T Rutherford et. al., *Lidar Calibration and Performance Validation Process,* Natural Power, AWEA 2012.

[3] IEC 61400-12-1 International Standard. *Part 12-1 : Power performance measurements of electricity producing wind turbines.* Edition 1.0 2005-12, International Electrotechnical Commission.

[4] W. Barker et. al., *Lidar Turbulence Measurements for Wind Farm Energy Yield Analysis*, Natural Power/ ZephIR Ltd., EWEA 2013.

[5] *Guidelines for siting of ZephIR and comparison against a meteorological mast,* ZephIR Lidar best practice guidance document, 2014