

Improving Rotorcraft Flight Tests Safety and Efficiency with Real-Time Wind Mapping

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Abstract

Helicopter testing plays a critical role in ensuring their operational readiness, safety, and performance optimization. At Airbus Helicopters Flight Test Center in Donauwörth, procedures are conducted to validate helicopter performance and systems, involving maneuvers such as power reduction, recovery, and low altitude landing procedures. Traditionally, weather data for these tests was obtained from ground and tower measurements. However, this approach falls short in providing precise wind data within the helicopter's vicinity.

This paper presents efforts aimed at enhancing safety, efficiency, and performance evaluation by providing real time wind data at various altitudes proximate to helicopters during testing operations. To achieve this, the study explores different approaches, with particular focus on a commercially available ground wind LIDAR system.

The system demonstrated promising results in providing wind speed data comparable to traditional cup anemometers, although limitations in wind measurement were noted.

The findings underscore the potential of wind LIDAR to enhance the understanding of test conditions, mitigate risks associated with maneuvers, and facilitate post-test analysis for rotorcraft testing. Nevertheless, optimization of the LIDAR is necessary to improve reliability and further integration tests are needed to validate the system's compatibility for real time use with current Flight Test Instrumentation.

Key words: Rotorcraft, Testing, Instrumentation, Wind, LIDAR.

I. Introduction

Helicopter testing stands as a cornerstone in ensuring the operational readiness, safety, and optimal performance of rotorcraft. At the Airbus Helicopters Flight Test Center in Donauwörth, procedures are in place to validate various aspects of helicopter performance and systems. These procedures include maneuvers, such as power reduction, recovery, and low-altitude landing procedures, typically conducted between 10 to 60 meters above ground level. However, relying solely on ground and tower weather measurements fails to provide accurate wind data within the vicinity of the helicopter.

This challenge was addressed by proposing a solution to enhance safety, efficiency, and performance evaluation through real-time wind data mapping. Furthermore, the solution enables wind data measurement at altitudes of interest while being operable in controlled

airspace, as testing operations often extend beyond Airbus facilities

To achieve this objective, various solutions have been explored, with a focus on leveraging a commercially available ground wind LIDAR system.

The paper will outline the methodology employed to meet these objectives, discuss encountered challenges, and present achieved results. Additionally, it will explore the potential benefits and implications of this solution while offering insights into future directions for further refinement and implementation.

II. Solutions Overview

To identify potential solutions, a review of existing weather measurement technologies was conducted. This research covered both emerging solutions and established methods available on the market. The aim was to identify concepts that could feasibly address the challenge of precise weather data collection at low altitudes.

Building upon this preliminary research, multiple concepts were generated. Each concept was evaluated against a set of criteria, including accuracy, cost-effectiveness, safety, regulatory compliance, and compatibility with controlled airspace.

The following subsections presents the three main concepts that emerged from the preliminary research, highlighting their potential benefits and drawbacks.

A. Tethered aerostat

This concept employs a helium-filled balloon anchored to the ground to elevate sensor units to the desired altitudes for weather data collection. Stability is ensured by aramid cables, minimizing movement for accurate measurements. Sensor units, linked to the balloon and ground via tensioned aramid cables, consist of off-the-shelf weather sensors and wireless modules transmitting data to a base station. The base station communicates data to both the test helicopter and ground teams.

Upfront cost of such a solution is expected to be in the 8,000€ and 18,000€ price range with a maintenance cost mostly coming from the calibration and verification of sensors.

Advantages:

- Extended operational durations, lasting up to two days without frequent maintenance.
- Ability to withstand high wind speeds, thanks to the aerostat design and aramid cables.
- Compact transmitter units within the sensor modules enhance autonomy and reduce weight.

Disadvantages:

- Potential impact of wind-induced movements on measurement accuracy.
- Requirement for a clear radius around the attachment point, potentially limiting deployment (e.g., for a 60-meter flight, a 60-meter clear radius around the center attachment point is necessary).

- Regulatory challenges for flying in controlled airspace and public traffic areas.

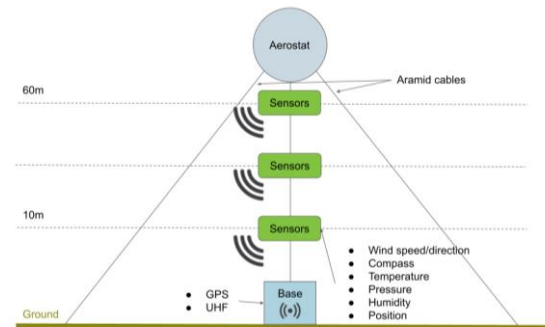


Fig. 1. Tethered aerostat concept illustration.

B. Drones

The drone-based solution shares similarities with the aerostat concept but employs drones to lift and position sensor units at specific altitudes. The drones can be either wired or wireless, each presenting its own set of advantages and challenges. To ensure accurate measurements, sensors are fixed away from the perturbations generated by the drone's blades.

Upfront cost of this solution ranges between 10,000€ and 20,000€. Ongoing maintenance costs mainly revolve around sensor calibration, verification, and drone upkeep.

Advantages:

- Easy deployment, reduced setup time.
- Portable design for effortless mobility.

Disadvantages:

- Similar challenges to aerostats.
- Maintenance concerns due to drones not being designed for extended flight durations.
- Requirement for active operator control.
- Significant increase in costs, operator needs, and space requirements for simultaneous data collection at multiple altitudes.

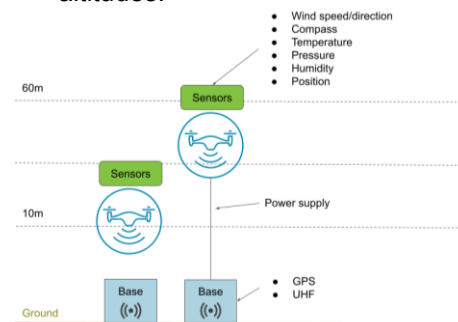


Fig. 2. Drone concepts illustration.

C. Wind LIDAR and SODAR

LIDAR (Light Detection and Ranging) and SODAR (Sonic Detection and Ranging) concepts are based on remote sensing devices that measure wind speed and direction using different techniques.

LIDAR shoots laser beams into the sky. These beams hit particles and aerosols in the air that reflect them back at the instrument. Wind speed and direction are then derived from the reflected light [1]-[4].

SODAR uses a similar principle. It transmits via speakers a short acoustic pulse into the air, then listens for return signals. By analyzing sound waves that are scattered back by temperature variations in the air the device then determines wind speed and direction [5]-[6].

Price of such a solution is expected to be in the 30,000-100,000€ price range with a maintenance cost mostly coming from periodic verification.

Advantages:

- Ground-based measurements without the need for airborne units.
- Capability to provide wind measurements at various altitudes for wind mapping.
- Measurements do not disturb airflow.

Disadvantages:

- Limited to wind speed and direction measurements.
- Potential challenges in calibrating the devices as they need to be calibrated against a multiple anemometer fixed on a mast and such installations are not widely available.
- Fog, rain and snow are reducing measurement availability and accuracy.
- Effectiveness declines with low aerosol quantity.
- SODAR emits audible sound and accuracy is reduced by environmental noise.
- LIDAR's laser can be a hazard.

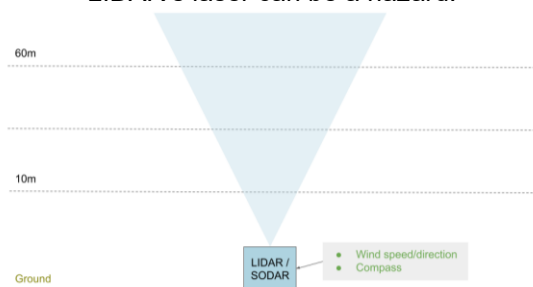


Fig. 3. LIDAR concept illustration.

III. Solution Selection

After consideration of the various concepts the LIDAR solution emerged as the preferred option.

It was chosen over other flying concepts because it presents fewer constraints in terms of regulatory compliance, logistical intricacies, and the need for additional development efforts.

Furthermore, the decision was made to opt for LIDAR over SODAR because noise generated by helicopters can interfere with SODAR measurements, leading to reduced accuracy. LIDAR's reliance on laser beams eliminates this concern.

Additionally, the noise emitted by SODAR during its operation could pose challenges not only in terms of personnel comfort and safety but also regarding its compatibility with installation in environmentally sensitive areas during campaigns, such as protected wildlife zones.

IV. Wind LIDAR Market Overview

The wind LIDAR market offers a diverse range of solutions tailored to various industries, with over 30 commercially available products identified in our research. These solutions span a spectrum of functionalities and price points, with vertical scan versions typically averaging around 70,000€.

In the evaluation process, the selection was narrowed down to three vertical scan wind LIDAR devices, of which one was tested. Other products were mainly excluded due to their inability to measure at the required minimum altitude of 10 meters and within the required temperature range. This limitation is largely attributed to the predominant focus of these devices on serving the needs of the renewable energy sector, offshore platforms, and airports.

V. Wind LIDAR Risks

To ensure safety of the use of the LIDAR system, a risk assessment was conducted.

Three main risks were identified and a risk assessment matrix was employed to evaluate the overall risk level of each identified risk by combining likelihood and severity.

Based on this assessment, it was determined that with the implementation mitigation strategies, the risks could be effectively managed.

For instance, the possibility of measurement errors posing significant risks during testing was identified. To address this, procedures such as periodic verification, pre-operation checks, and

automated cross-verification with ground and tower measurements could be implemented.

Moreover, although the risk of the LIDAR laser damaging devices like aircraft rangefinders is very low, precautions are necessary. Hence, implementing a laser shutdown when not in use and taking steps to prevent aircraft from entering the laser's path could be implemented.

Additionally, laser beams can be harmful to the eyes if observed directly with magnifying devices. Even though this situation is improbable, mitigation steps like placing eye hazard warning signs on the device and its surroundings, along with implementing physical barriers such as fencing to prevent unauthorized access to the laser observation area are best practice.

VI. External Studies on Selected LIDAR

To gauge the performance of the considered wind LIDAR, an evaluation was conducted, first considering external studies.

In one study [7], the LIDAR was deployed alongside a mast for a seven-week period. Data collection occurred at various heights, including 20m, 45m, 70m, and 91m. The analysis generated scatter plots that demonstrated the correlation between the LIDAR measurements and the mast data. The results showed deviations remaining within 2% of class 1 anemometry instruments across all measured heights.

In another study [8], conducted by a renewable energy consultancy group in a calibrated wind tunnel, the LIDAR showed an average deviation of 0.4% compared to a Pitot tube across speeds ranging from 5m/s to 75 m/s.

VII. Internal Study

In addition to external assessments, a study based on field data provided by the LIDAR's manufacturer and data gathered during a test of the LIDAR system at Airbus Helicopters Donauwörth was conducted to confirm its performance.

The data provided by the manufacturer compares LIDAR measurements against measurements from a guyed lattice anemometer mast. The test provides wind measurements at a 1Hz measuring rate. Measurements are done on different heights, leading to a measurement at a given height approximately every 20 seconds. Complete data was only provided for the 91m measuring height. However, this setup has limitations as the references had an accuracy of 0.2%, while the targeted accuracy for the LIDAR was 0.5%. Consequently, the Test Accuracy Ratio (TAR)

[10] for this study was 2.5, signifying that the reference standard's accuracy was 2.5 times greater than the targeted accuracy of the LIDAR.

Data gathered during tests on Airbus site were compared to measurements provided by an ultrasonic anemometer installed on Airbus Donauwörth heliport tower. However, conditions for comparison were not ideal due to installation constraints. It was tried to find the best compromise in positioning of the unit, but turbulence caused by the surrounding buildings and air traffic had an influence on the LIDAR system. There were also slight height and alignment offsets between the reference and the LIDAR. Different filtering methods were developed to compensate for noise induced by testing conditions.

Measurements were done at a fixed height of 10m and a sampling rate of 1Hz. Compared to the manufacturer test, this leads to more data points per time at the given height.

This sampling rate was chosen to answer real-time data requirements for flight testing. The wind industry in comparison mainly uses 10-minute averages.

Tests performed by the LIDAR manufacturer and Airbus both measured data in a timespan of approximately two months.

VIII. Internal Study Methodology

Stochastic evaluation methods (e.g., linear regression plots) were used to compare the LIDAR with the references. Measurements also were visualized over longer time periods, to further validate in which scenarios deviations occur. The manufacturer provides data analysis for the test performed against the guyed lattice anemometer mast. These are used for comparison to analysis conducted by Airbus Helicopters, to validate the precision of the measurement unit.

Data from tests on Airbus site required additional filtering and averaging methods to compensate for errors caused by the unfavorable testing conditions. Data otherwise would be too noisy and could not match the test data of the manufacturer, performed under scientific conditions.

Filters like the wind directional and wind velocity filter remove data based on an average of the data provided by LIDAR and Tower.

For some evaluations only data without air traffic was used (weekends, nights).

The LIDAR used during the manufacturer and Airbus site tests can show a 180° offset in

directional measurements. This is a known issue, which will be removed in future LIDAR hardware versions. A filter using the tower reference data is used to remove the faulty data. Data are considered as faulty if the direction difference between tower and LIDAR is greater than 90° .

Turbulence is filtered out using turbulence intensity calculations. Average and standard deviation of wind speed in a 10-minute interval are used to get a percentage value indicating the intensity of turbulence [11]. The method is often used in the wind power industry. Data with intensity values bigger than a given intensity threshold is removed.

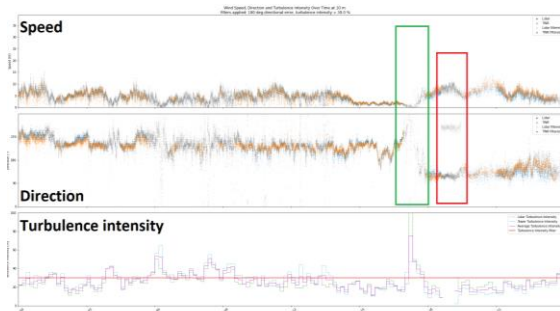


Fig. 4. Time plot of wind speed and direction as well as turbulence intensity. Example: one day on Airbus site.

Figure 4 shows an example of a visualization over time of the raw data. Data that was removed by the 180° filter (red) and the turbulence filter (green) can be seen. Removed data is visualized in gray tones. The bottom plot shows the turbulence intensity and its threshold.

A 30 second running average is used to smoothen the 1Hz measurements. This method is often used when working with real-time wind measurement applications. A vectorial based average method is used, separating the wind vector in x and y parts to be averaged. The averages then are transformed back in speed and direction components (polar coordinates). This considers the circular nature of the data.

Filters were not always used. The result section will state which ones were used.

IX. Results Manufacturer Data

The manufacturer tests have less noise caused by the environment. The analysis at Airbus Helicopters therefore mostly applied no additional filters except the 180° shift correction. The manufacturer applied filters to remove data collected in the shadow of the guyed lattice mast. The mast provides multiple reference measurements at different heights. Filters were applied by the manufacturer, removing data

where the reference measurements had too big discrepancies. [11]

A. Wind speed

The manufacturer test data showed good correlation of wind speed measurements. The visualizations over time suggested a good correlation. To check this, a linear regression was performed.

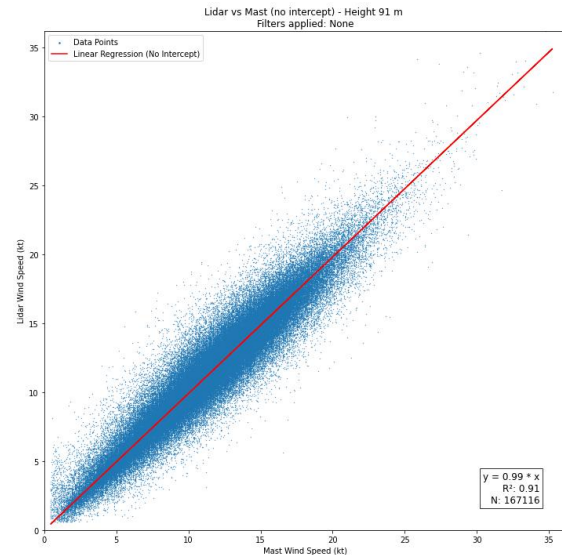


Fig. 5. Linear regression of wind speed at 91 m (manufacturer data).

Figure 5 shows the result of a linear regression forced through the origin without applying any filters. The result confirms the good correlation between Mast measurements and Lidar measurements with a slope of 0.99 and a r squared value of 0.91. A linear regression was also performed by the manufacturer, leading to the same results. The manufacturer gets a slope of 0.99 and a r squared value of 0.909 [8]. Given the data from the manufacturer test, both analyses confirmed the good correlation between the measurement methods.

B. Wind direction

For the direction, a linear regression was performed, with the same settings the manufacturer used. Meaning the direction data was shifted to consider the circular nature of it, allowing for linear regression. Data with velocity less than 4 m/s was filtered, as direction is poorly defined for low-speed data. The 180° shifts are also filtered.

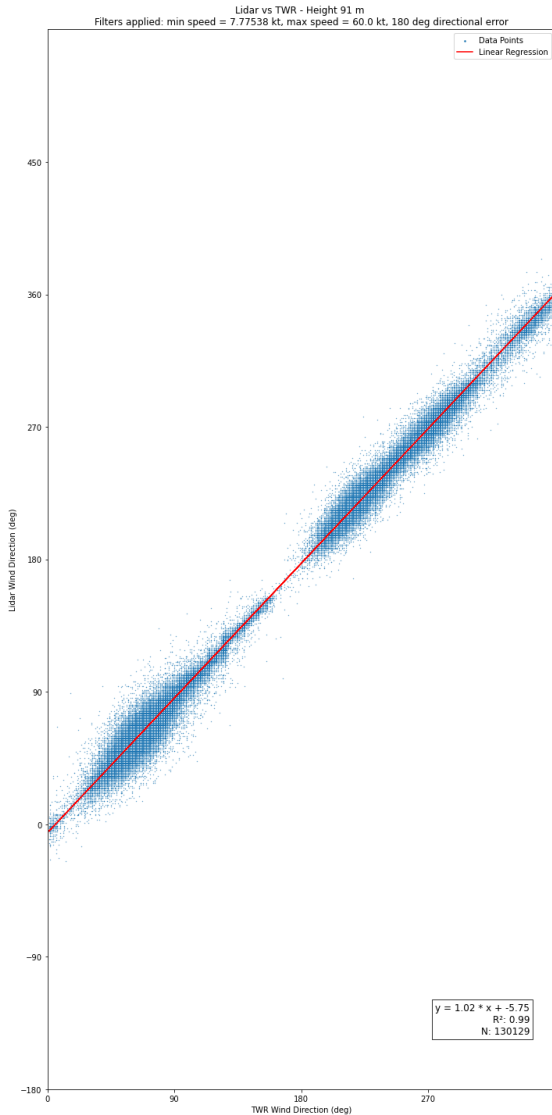


Fig. 6. Linear regression of wind direction at 91 m with filter (manufacturer data).

Figure 6 shows the results. Similar to the manufacturer plots, the line was not forced through the origin. The resulting line is almost exactly the same as with the analysis of the manufacturer. The result indicates very good correlation with a r squared value of 0.99. This is also similar to the manufacturer with a r squared value of 0.995 [8]. The line shows a slight offset from the origin by -5.75.

X. Results Donauwörth Data

A. Raw wind speed data

Section VII showed the issues with the tests in Donauwörth and explained differences to the manufacturer test. Section VIII showed different approaches in filtering to compensate for the imperfections. The necessity of the filters will be illustrated in this section. Tests in Donauwörth were all measured at a height of 10 m. For performance comparison the 20 m

measurement of the manufacturers test will be used. [8]

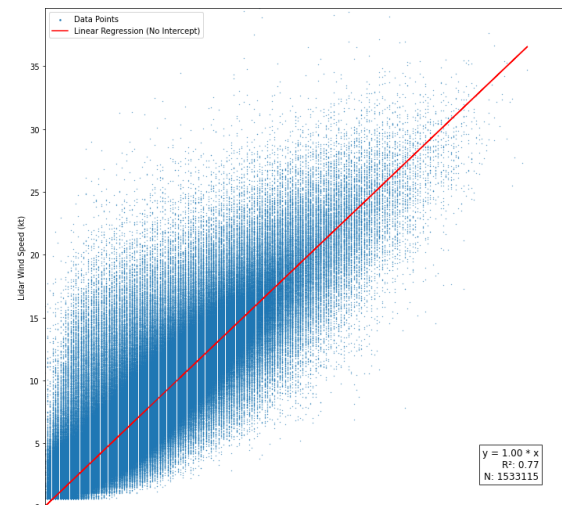


Fig. 7. Linear regression of wind speed at 10 m on Airbus site.

Figure 7 shows the linear regression result for wind speed in Donauwörth without applying any filters. The raw data leads to a slope of 0.99 and an r squared value of 0.77. The lowest measurement available of the manufacturer tests is at 20 m. The resultant slope of that measurement is 0.999 and the r squared value 0.881 [8]. The low correlation of the Donauwörth test indicates the need for filtering, allowing for less noisy data analysis.

B. Wind speed

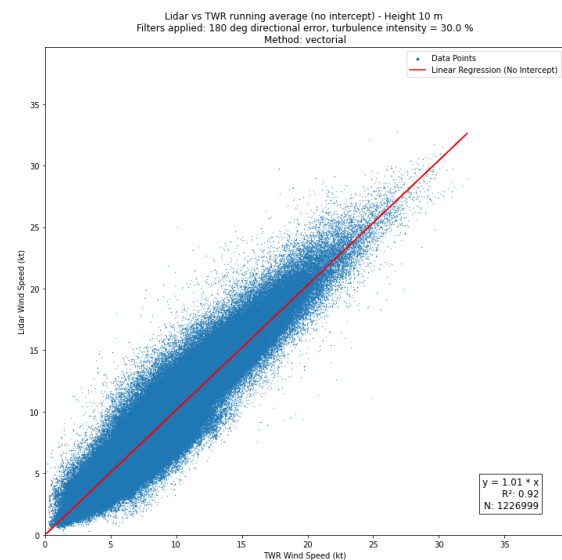


Fig. 8. Linear regression of filtered wind speed at 10 m on Airbus site.

The turbulence intensity filter in combination with the 180° shift filter and the 30 second running average allowed for better data analysis. The turbulence intensity filter was set to filter intensities bigger than 30%.

Figure 8 shows the linear regression after applying these filters. This results in a slope of 1.01 and a r squared value of 0.92. The plot allows for comparison with figure 6 that applied no filtering. The filters applied are meant to improve the data quality and remove any noise. At the same time, they should not be a method to embellish the results. For this reason, only these few filters were applied, which are commonly used in the wind industry.

C. Wind direction

A linear regression analysis for wind direction at a height of 20 meters was not performed by the manufacturer, rendering direct comparison impossible. To address this, modifications were made to the regression approach to align more closely with the method used for evaluating wind speed.

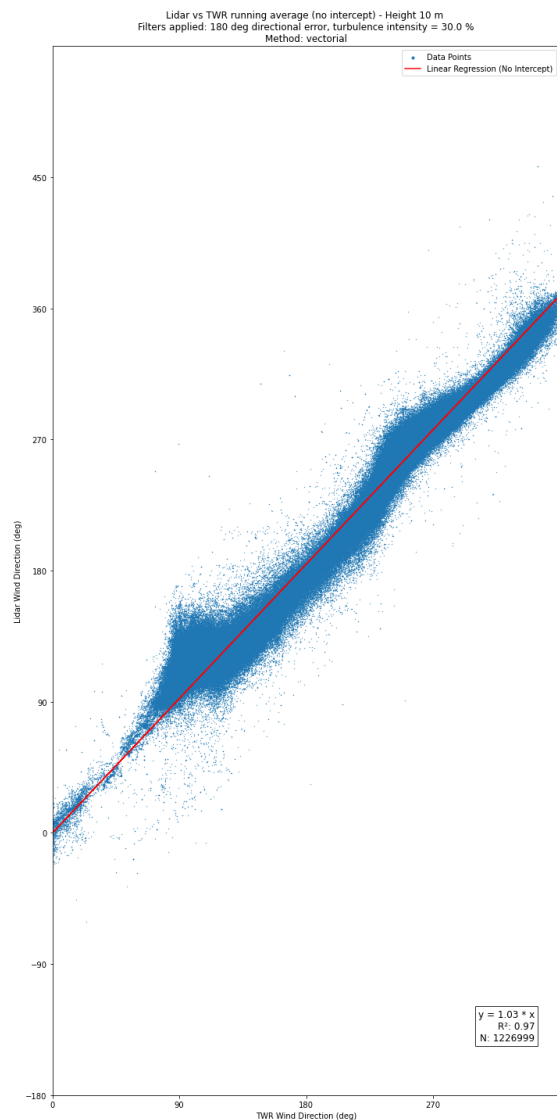


Fig. 9. Linear regression of filtered wind direction at 10 m on Airbus site.

Without any filters, the wind direction plots exhibited similar noise levels to those observed

in the speed plots. To mitigate this noise, a 30-second running average, a turbulence intensity filter with a 30% threshold, and a 180° directional filter were applied. The linear regression was forced through the origin.

Figure 9 depicts the resulting plot with a slope of 1.03 and an r squared value of 0.97. These correlation values are good and similar to the results obtained for the manufacturer's data at other heights.

XI. Conclusion and Perspectives

Despite suboptimal testing conditions and the use of filters to compensate for this limitation during trials on Airbus site, results show the capability of the LIDAR to provide wind speed and direction with an accuracy comparable with traditional anemometers.

These findings corroborate manufacturer tests which were conducted under more controlled conditions and showed a strong correlation with anemometers without filters.

However, the current hardware exhibits an issue with direction determination, where the direction can temporarily shift by 180°. This makes the current hardware unsuitable for real-time applications.

The manufacturer has acknowledged this issue and plans to address it in future hardware iterations. Consequently, faulty data was removed during analysis. Future tests with the updated hardware are necessary and should be conducted under more controlled conditions. Additionally, new testing scenarios will be performed as in our study only one scenario with measurements at a height of 10m was considered.

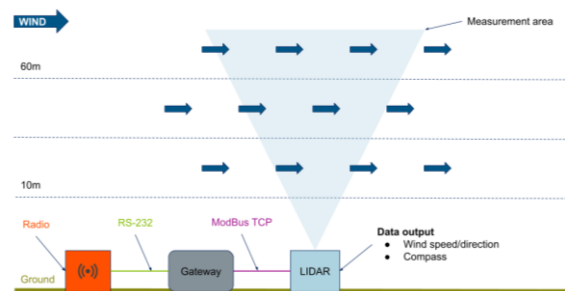


Fig. 10. Diagram of envisioned architecture for Wind LIDAR data stream during Flight Test.

Lastly, the flight test use case requires further integration of the hardware in the instrumentation architecture, e.g., for real-time display of the measured values in the cockpit of the aircraft in using an adequate RF link as depicted Figure 10.

As an extension of this first use case, a multiplication of the ground unit on the test site

can provide a matrix view of the wind conditions around the test aircraft. A relevant network architecture on the ground shall support the data transfer for control and measurement.

References

- [1] Liu, Zhengliang, et al. "A Review of Progress and Applications of Pulsed Doppler Wind LiDARs." *Remote Sensing*, vol. 11, no. 21, 2019, p. 2522, <https://doi.org/10.3390/rs11212522>.
- [2] E. Simley, L. Pao, K. Neil, B. Jonkman, Bonnie, R. Frehlich. LIDAR Wind Speed Measurements of Evolving Wind Fields, 50th AIAA Aerospace Sciences Meeting, July 2012; doi: 10.2514/6.2012-656.
- [3] Shangguan, Mingjia, et al. "Doppler Wind Lidar from UV to NIR: A Review with Case Study Examples." *Frontiers in Remote Sensing*, vol. 2, 2022, <https://doi.org/10.3389/frsen.2021.787111>.
- [4] N.D. Kelley, B.J. Jonkman, and G.N. Scott. "Comparing Pulsed Doppler LIDAR with SODAR and Direct Measurements for Wind Assessment." *Nrel.gov*, July 2007, <https://www.nrel.gov/docs/fy07osti/41792.pdf>.
- [5] Muradyan, P., and R. Coulter. "Sonic Detection and Ranging (SODAR) Wind Profiler Instrument Handbook." *Arm.gov*, https://www.arm.gov/publications/tech_reports/handbooks/sodar_handbook.pdf.
- [6] Nappo, Carmen J. "Sodar" *International Geophysics*, Elsevier, 2012, pp. 231–278.
- [7] Power, Natural. Natural Power's ZephIR Wind Lidar Demonstrates World-first Matched Performance in High-performance Wind Tunnel. Aug. 2011.
- [8] ZXlidars. Comparisons Between ZX 300 Lidar and A Reference Mast Using 1Hz Data. 19 April 2024.
- [9] ZXlidars. UK Remote Sensing Test Site: 91 m Mast Specification. 21 December 2017.
- [10] Mimbs, Scott M. "Measurement Decision Risk - the Importance of Definitions'." *Nasa.gov*, <https://ntrs.nasa.gov/api/citations/20130012508/downloads/20130012508.pdf>.
- [11] Morales, A., Wächter, M. and Peinke, J. (2012), Characterization of wind turbulence by higher-order statistics. *Wind Energ.*, 15: 391-406. <https://doi.org/10.1002/we.478>