Development of a high power Doppler Wind Lidar for measuring wind and EDR along aircraft approaches

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Abstract: Air flows in the troposphere have a major impact on air traffic safety and operations. In the framework of the European UFO project (www.ufo-wind-sensors.eu), LEOSPHERE and ONERA have developed a new high powered scanning Doppler LIDAR using an innovative powerful Erbium doped fiber laser amplifier. The performances of this prototype have been evaluated through a campaign in 2014 performed at Toulouse airport, France. In addition, specific algorithms have been developed for retrieving wind and EDR quantities along aircraft approaches and in 3D around airport. The wind and EDR measurements have been then compared to reference sensors in order to assess their accuracy.

Keywords: Coherent Wind Doppler Lidar, pulsed high power EDFA, weather dependent separations, wake vortices, wind, turbulence

1. Introduction

At airports, runway operation is the limiting factor for the overall throughput; the current ICAO standards determine for three aircraft categories the minimal distance separation between aircrafts given their wake turbulence category in order to avoid the risk of wake vortex encounter whatever the weather conditions. To renew these out-of-date and conservative regulations, many studies have focused on the better understanding of vortex behaviors with weather conditions that can only be characterized accurately by scanning Doppler lidars [1][2]. They showed that wake vortex decay varies a lot with weather conditions. In case of high turbulence, wake vortices strength will for example decay quicker. To greatly optimize aircraft distance separations, weather dependent separation regulations (WDS) are under development. Such regulations require accurate and frequent observations of winds, crosswinds and eddy dissipation rate (EDR) that have a direct impact on the lifetime of wake vortices[3][4] along approach and takeoff paths.

This is why the UFO project, entitled Ultra-Fast wind sensOrs for measuring Wind and EDR for Wake Vortex mitigation has been launched [5]. The main objectives were to develop new sensor technologies, especially a 1.5 micron fiber-based high power scanning Lidar [6] developed by LEOSPHERE and ONERA and its adapted wind and EDR retrievals algorithms. The developed LIDAR has been validated during a field campaign in April/May 2014 at Toulouse-Blagnac airport in France. The complementary and combination of the scanning Doppler lidar with a 2D electronic X-band radar from THALES as well as Aircraft wind retrievals with Mode-S EHS have been evaluated. The current paper will describe the main achievements of the project with the scanning coherent Doppler LIDAR and will compare the data availability and accuracy of such a sensor. Finally the proposed combination between the different sensors for all weather wind and turbulence observing systems at airports will be presented.

2. Lidar requirements

The next table describes the operational requirements of a lidar for the different airport applications. A lidar simulation tool [7] developed by ONERA and LEOSPHERE is used to determine technical specifications compliant with the measurement requirements. The atmosphere is assumed to be standard : Aerosol Optical Depth = 0.2 and Lidar ratio =30 . Right columns of Table 1summarize the initial guess for the laser source technical specifications to be developed in UFO in order to obtain the measurement requirements. The required mean power is up to 4W for glide path measurements.

Table 1 : Synthesis of wind and EDR measurement needs and lidar solutions

Areas of interest	Needs	Horizontal range (km)	Vertical range (km)	Spatial scale (m)	Revisit time (s)	Pulse (ns) PRF (KHz)	Energy/ pulse (µJ) Integration time (s)	Mean power (W)
Glide Path	Wind measurements along glide path	10	0,5	100	10	400 10	400 <0.25	4
	EDR measurements along glide path	10	0,5	100	600	400 10	400 <0.25	4
	3D Wind measurements along glide path	10	0,5	100	30	400 10	400 <1	4
360° View	Wind shears	7-8	0,5	200	60-180	800 10	200 <1	2
	3D Wind measurements	7-8	0,5	200	300	800 10	200 <1	2
Critical area	Wake Vortices measurements on runways	1	0,2	20	<10	200 10	200 <0.1	1
	EDR measurements cross to runways	1	0,2	30	600	200 20	200 <1	1

Leosphere is developing pulsed fiber Doppler lidars for more than 10 years, based on a technology formerly developed at ONERA. The core technology is using EDFA (Erbium Doped Fiber Amplifiers) operating around 1.55µm in the telecom C band, and an all-fiber architecture.

The large-mode-area (LMA) fibers enable high peak power generation. The average power exceeds several watts and high pulse repetition frequency (PRF) efficiently compensates the relative low pulse energy. Moreover, the MOPA architecture flexibility in terms of pulse duration allows fulfilling a large variety of requirements, enabling the design of high spatial resolution or long range systems. This is particularly recommended for lidar systems addressing several ATM needs.

In fiber lasers, peak power is limited by non-linear effects. In highly coherent emission, the most limiting effect is the Stimulated Brillouin Scattering (SBS) [8]. To overcome these limitations in the UFO project, LMA fibers are used. By decreasing the power spatial density, the output peak power can be increased up to 250W.

However, this is not enough if both long range and high range resolution are required. In this case, high pulse energy and short pulse duration are needed, leading to high peak power requirement. In the frame of UFO, a new original architecture patented by ONERA is tested for the first time on a Doppler lidar, yielding a significant increase in the available peak power, around 400W. Experimental developments confirm that this technology is able to provide 4W of mean power, enough as for the performance requirements [8]. A commercial Windcube400S is used as a basis. The EDFA is replaced by the new EDFA prototype and an air conditioner is added to warranty good reliability during the Toulouse spring campaign. More than 10km range is demonstrated with 3,2W and an integration time of 0,16s.

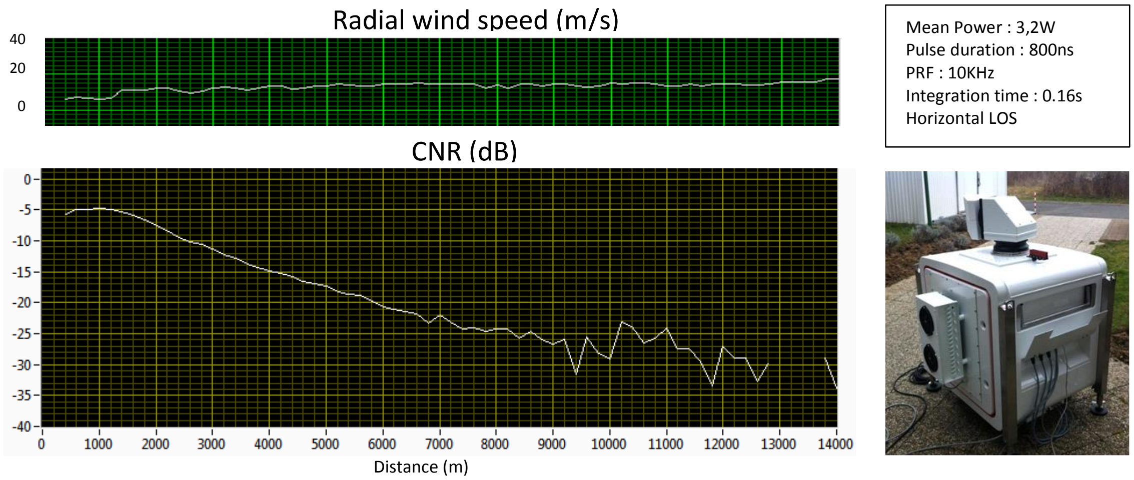

Figure 1 : Performance validation of new long range UFO lidar

3. Algorithms and methods for measuring wind and turbulence

The first objective of the scanning lidar is to provide headwinds, crosswinds and turbulence at several points along the glide path to adjust weather dependent separations. The second objective consists in providing horizontal wind speeds and directions every 500 meters horizontally and up to an altitude of 500m for being assimilated into weather forecast models and improving their forecasts. To retrieve wind speed components both along the approaches and in 3D around the airport, a specific algorithm based on the coupling of the volume velocity processing (VVP) and a single value decomposition (SVD) has been developed [8]. This algorithm has then been tested during two months to retrieve wind speeds and directions at one point 1.6km away where an anemometer is located. The retrieved wind measurements are compared to the measurements of the anemometer [10]. The accuracy of the ten minutes averaged horizontal wind computed by the algorithm compared to the anemometer is 0.06 m/s and the correlation factor is 98%.

For characterizing the atmospheric turbulence, Eddy Dissipation Rate (EDR) was chosen. An algorithm based on the estimation of the structure function [11] has been implemented based on the combination of spatial and time data averaging. In order to test the EDR algorithm, a tool has been developed in order to simulate a 2D Von Karman turbulent wind field with a given EDR level. This tool is based on Monin and Yaglom formalism [12].

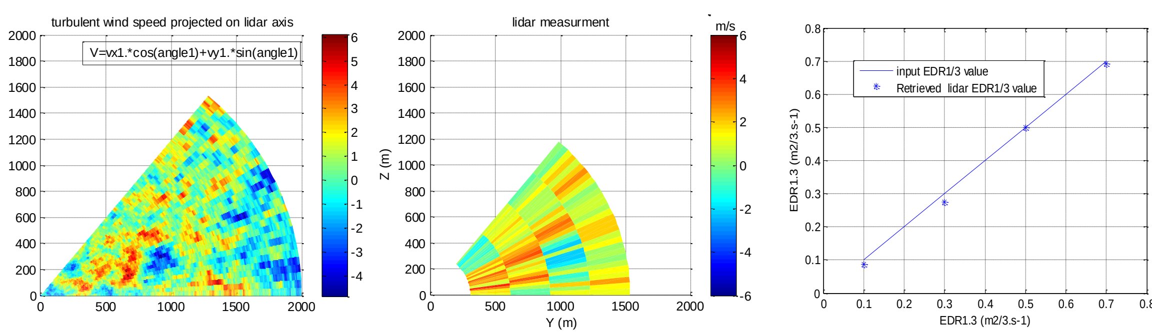

Figure 2. Left: Turbulent wind field realizations with an EDR=0.74 m2.s-3. Middle: lidar simulated measurements. Right: Correlation of EDR retrievals for different EDR values.

Figure 2 shows an example of turbulent wind field realization, over a field of 2000 m by 2000m, and its projection on the lidar axis for a given EDR level and turbulence scale L0. The EDR retrievals are in good agreement with the expected EDR values.

4. Results

The high power laser scanning WINDCUBE LIDAR has been deployed at Toulouse-Blagnac airport and configured in order to perform wind and EDR measurements every kilometer along the glide path in less than one minute and 3D wind retrievals around the airport in 5min.Typical accumulation times of 0.16s were used per line of sight. During the trial, the LIDAR has been continuously measuring up to an averaged range of 8km which could vary with weather conditions. The 3D wind retrievals were provided in order to have access to the horizontal wind fields in 3D. They have been validated against a lidar profiler located at 3km from the airport. The glide path wind retrievals provided the profiles of headwinds and crosswinds along the approaches. This information can be useful for adjusting in real time distance separation in the final approach in weather dependent separation concepts since the wind below 500m can change in direction and intensity. The accuracy of glide path winds was evaluated in comparison to the in-situ wind measurements performed by a research aircraft from TUB University. The obtained accuracy of the glide path wind retrievals with LIDAR is 0.4 m/s and its dispersion 0.5 m/s compared to the research aircraft.

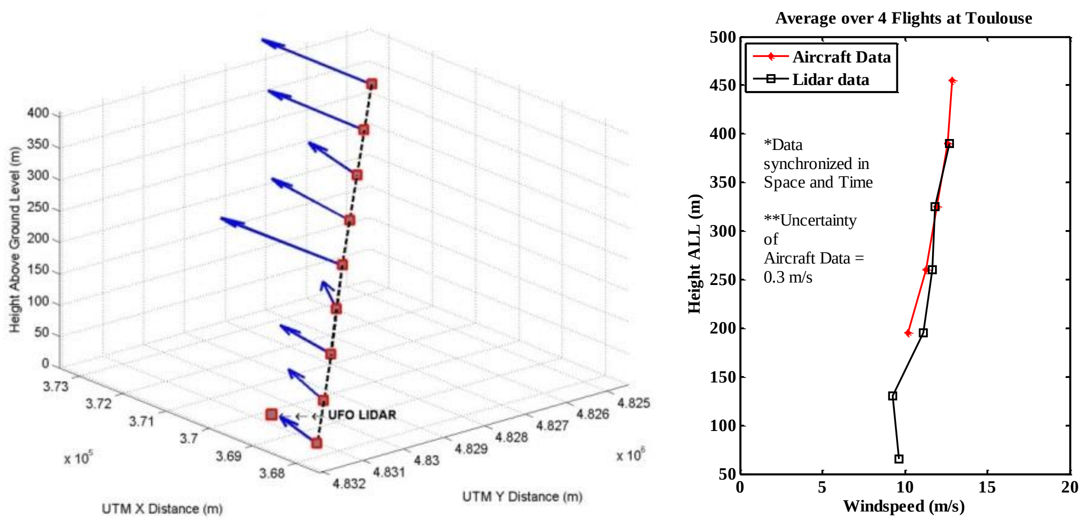

Figure 3. Headwinds and crosswinds retrievals along 10km glide path (left) and comparison of retrieved glide path winds of LIDAR with wind measurements of research aircraft (right)

The EDR retrieval algorithm has been applied on Lidar data collected at Toulouse-Blagnac airport. Examples of the 24th April 2014 are shown on Figure 3 for a set of PPI scans (PPI with elevations from 2° to 45° and azimuth 47° to 293°), as a function of time, and for different altitudes. Results show that EDR is generally higher at lowest altitudes near the surface layer as expected. Strong variations of EDR with time have also been observed within the hour of the day due to changes in cloud coverage and solar irradiance.

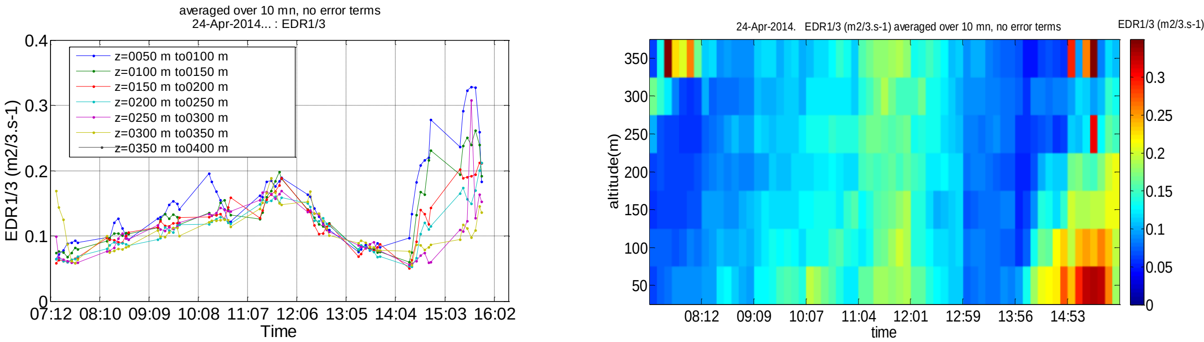

Figure 4. April 24th 2014. Left: EDR as a function of time for different altitudes – Right: evolution of EDR in color scale displayed versus time (horizontal axis) and altitude (vertical axis)

5. Conclusions and perspectives

Future concepts of weather dependent separations will require high accurate measurements of wind and turbulence (EDR) in the vicinity of airports at high resolution and frequency. A next generation high power LIDAR based on fiber technology has been developed in the UFO project to retrieve the quantities of interest respectively under clear air (visibility) and rainy (rain rate) conditions. The obtained performances of the lidar are in agreement with the requirements, ie. the capability to measure up to 10km with an accumulation time less than 0.2s and the accuracy better than 0.5m/s for retrieving glide path and 3D winds.

During the project, the combination of lidar and radar has been studied in regards to weather conditions to ensure the development of an all-weather wake vortex advisory system. On a longer term perspective, wake turbulence problematic strengthen the demands for on-board advisory systems of wake vortex or even clear air turbulence. For these applications, airborne UV LIDARs, IR LIDARs and RADARs are still under study.

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