AIRPORT LOW-LEVEL WIND SHEAR LIDAR OBSERVATION AT BEIJING CAPITAL INTERNATIONAL AIRPORT

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ABSTRACT

Ocean University of China lidar team operated a pulse coherent Doppler lidar (PCDL) for the low level wind shear monitoring at the Beijing Capital International Airport (BCIA) in 2015. The experiment configuration, observation modes is presented. A case study shows that the low level wind shear events at the southern end of 18R/36L runway were mainly caused by the trees and buildings along the glide path under strong northwest wind conditions.

1. INTRODUCTION

Low-level wind shear is a sharply change in wind speed or wind direction in space within 2000 feet at height. Wind shear can be broken into vertical and horizontal components, with horizontal wind shear occurring near fronts and near the coast, and vertical wind shear typically near the ground surface [[1]]. Wind shear can cause disastrous aircraft accidents by affecting aircraft airspeed during take-off and landing phases [2]. There were 33 accidents caused by turbulence encounter, covering 18 percent of the total numbers of accidents between 2014 and 2015 [3, 4]. Effective wind shear alarm systems are needed to guarantee the safety of civil aviation.

The PCDL systems have been proved to be a useful tool that can capture the small size characteristic of wind, turbulence, wake vortices, and so forth [5-8]. The PCDL is one of the most accurate optical sensing techniques by transmitting a laser beam into the atmosphere and detecting the radial backscattered signal by aerosol particles [9]. The radial velocity (Line of sight velocity, LOS) could get by analyzing the Doppler shift in the frequency of the backscattered signal [10, 11]. The LOS velocity is the component of the air motion along the laser beam, thus the wind field information could be induced [11].

Due to the variable types of low-level wind shear and its uncertainty of location and quick evolution, low-level wind shear detection requires high spatial and temporal resolution that could only be achieved by operating a PCDL. OUC's PCDL is the modified version based on a commercial WindPrint S4000 Doppler wind lidar from Seaglet Environmental Technology. The pulsed 1550 nm fiber laser source is based on the MOPA architecture with a large core fiber and excellent beam quality (M^2=1.2), whose pulsed energy is 150 μJ with a pulse repetition rate of 10 kHz and an adjustable pulse length of 100 ns to 400 ns (200 ns in this study). The software of PCDL also includes a real time display of the radial wind velocity and wind profiles production. The measurement range of the PCDL system is ± 50 m/s, while the speed measurement accuracy is 0.1 m/s. The scanner and detection range of 3000 m (4000 m at a proper aerosol concentration) enable the PCDL system to capture the wind shear occurring far away from the PCDL. The Fast Fourier Transform (FFT) spectral estimates are processed with FPGA (Field Programmable Gate Array) in real time. All these design of the PCDL system make it stable, reliable and high-integrated. The detailed specifications of the PCDL system are listed in the Table 1.

Table 1 Specifications of the pulsed coherent Doppler lidar

Qualification	Specification
Spatial Resolution (Transverse)*	< 5 m @ specified range
Radial Spatial Resolution	30 m
Measurement Range**	90 to 4000 m
LOS Velocity Update Rate	4 Hz
Wind Profile Update Rate	1 min
PPI Scan Speed	20°s^{-1}(max)
Scanner Positioning Accuracy	0.1°
Velocity Measurement Range	± 50 m/s
Resolution of Velocity	0.3 m/s
Wavelength	1.5 μm
Pulse Energy	150 μJ
Pulse Duration	200 ns
Pulse Repetition Frequency	10 kHz

* *Depending on the laser beam positioning accuracy.*

** *Weather condition related*

The OUC Lidar team operated the PCDL for low level wind shear study at BCIA in 2015. We have developed and carried out several low level wind shear observation campaigns to capture the wind shear events from the radial velocity measurement in PPI (Plane Position Indicator) at low elevation angles and wind profiles in 5-DBS (Doppler Beam Swing) mode.

For the study of wind shear occurring along the glide path, the PCDL was configured at the south ending of the 36L/18R runway as Figure 1 shows. Taking the 3° incidence angle of aircraft landing path into consideration, a stepwise PPI scanning pattern was performed in the field wind shear observation campaign to reveal the wind that aircrafts would encounter. The detailed designs of the glide path PPI scan are shown in Table 2.

Table 2 Scanning patterns along the glide path

No	Elevation angle	Azimuthal angle
1	3°	207° to 219°
2	2°	219° to 231°
3	1°	231° to 243°
4	0°	243° to 260°

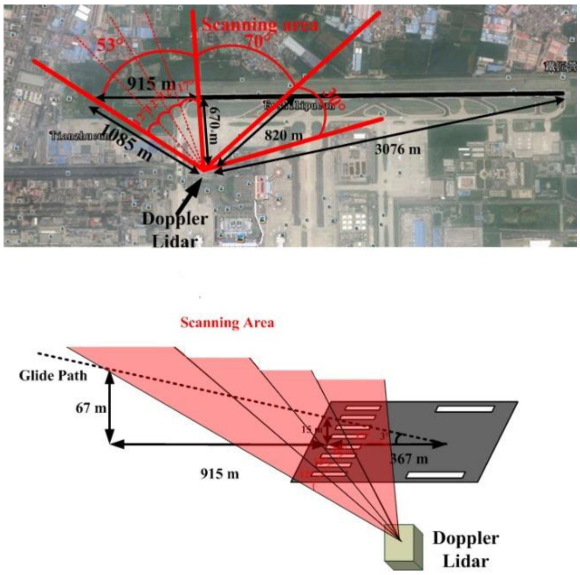

Figure 1 Location and scanning strategies of PCDL that configured at BCIA.

2. RESULTS

Wind speed profiles are effective tools to illustrate the wind speed varying with height, thus it is useful to identify the wind shear occurring at different height. We illustrated 1-min averaged wind profiles generated between 13:39 and 15:32 on Dec 15th into one figure to identify the vertical wind shear as Figure 2 shows.

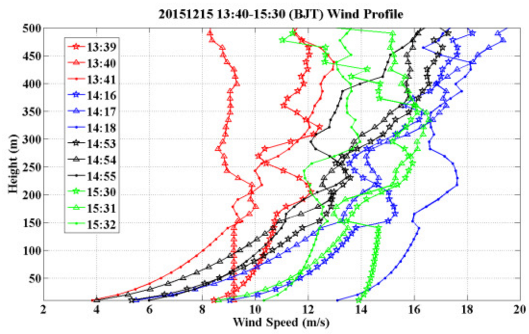

Figure 2 Wind speed profiles measured by PCDL at BCIA on Dec 15th, 2015.

Due to the influence of surface manufactures, the wind speed profiles are not perfectly match with the exponential wind profile,

$$V(h) = V_0(\frac{h}{h_0})^{\partial}, \qquad (1)$$

where h is the altitude of measurement volume of PCDL, V_0 is the wind speed at the altitude of h_0 and ∂ is the Hellmann index which is related to the surface roughness and the stability of Prandtl layer. We extended the wind profiles from 10 m above ground to 500 m by taking the two lower measured points and wind profile equation (1) into consideration.

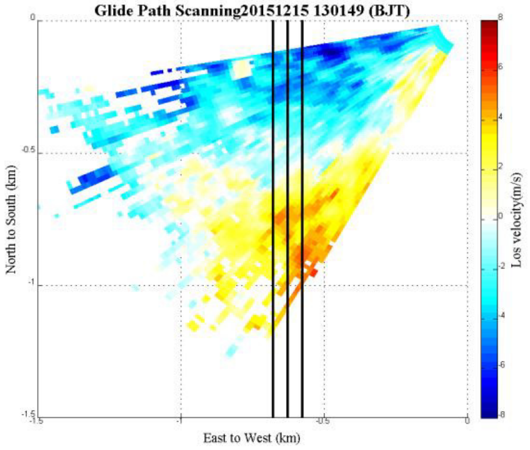

Figure 3 Glide path scanning of 36L/18R runway at BCIA on Dec 15th, 2015.

We have captured the existence of small-size airflow disturbances embedded in the prevailing wind with high spatial resolution by operating step-wise PPI scan mode as Figure 3 shows. The red and blue colors indicate positive (away from lidar) and negative (towards lidar) movement, respectively, of the atmospheric particles along the laser beam. These airflow disturbances are generally small scale with serval hundred meters at horizontal dimensions and difficulty to be captured by DBS mode. There are three black lines in Figure 3, the center one is the extended centerlines of the runway and the other two are located at about 50 m to both side of the extended centerline to take into consideration the uncertainty with the flight path of the aircraft. By checking the series of PPI scans, the airflow disturbances move along glide path with the background wind flowing over the runway corridor. They are believed to arise from disruption of the northerly airflow by the buildings above the ground surface.

For illustrating the transient and sporadic nature of the low level wind shear along the glide path, we construct the headwind profiles through the step-wise PPI scan as Figure 4 shows. The duration of a PPI scan over the runway corridor is about 30 s.

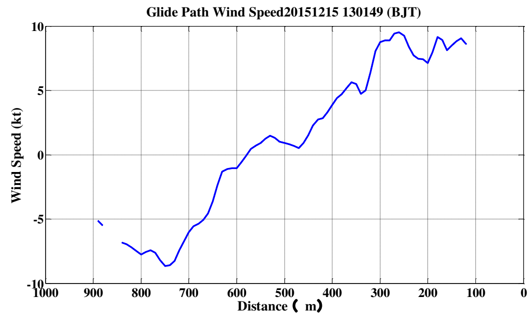

Figure 4 Wind speed profiles measured by PCDL at BCIA on Dec 15th, 2015.

Woodfield and Woods defined a severity factor I of wind shear as

$$I = (\frac{dV}{dt})(\frac{\Delta V}{V_{app}})^2 = \frac{1}{V_{app}}\left|\frac{\Delta V}{R^{1/3}}\right|^3, \qquad (2)$$

where $\Delta V/R^{1/3}$ is the rate of change of wind speed, ΔV is the total change of wind, V_{app} means the normal approach speed of the aircraft and R represents the ramp length.

The value of the severity factor I is 0.08 with respect to the headwind speed reduced 18 kt within 500 m. The cubic root of severity factor is used to classify the turbulence alerts into two levels: “moderate turbulence (0.3~0.5)” and “severe turbulence (>0.5)”. The value in this study is 0.44, a moderate turbulence.

The reliability of algorithms have been proved by wind shear reports from the crew and the airport terminal control office. According to the pilot’s report, there is wind shear event at 13:01, 15th December, 2015. The pilots have to overshoot to ensure safety.

3. DISCUSSION AND CONCLUSIONS

The PCDL is proved to be an effective remoting tool to detect the low-level wind shear under dry conditions. It is possible to capture the wind shear events with different observation modes. From the field wind shear observation campaign at BCIA, we developed algorithms to identify the wind shear and turbulence.

The method to extend the height of wind profiles with calculating the Hellmann index needs to be improved by taking surface roughness into account. Also, wind speed retrieved from the PPI scan data is related to the intercept angle between the laser beam pointing direction and the prevailing wind. When the scanning azimuthal angles are nearly correspond with or nearly opposite to the prevailing wind, the LOS wind speeds are nearly equal to the real wind speed. However, when it is nearly perpendicular to the primary wind direction, the LOS wind speed is a project component of the wind vector. If the angle of intercept is larger than 30 degrees, the radial wind data would not be utilized to construct the headwind profiles considering the increasing underestimation of the headwind component as the across angle increases.

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