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Doppler Effect - The Glide Path Scan That Alerts for Low-level Windshear

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LIDAR airport system

DOPPLER EFFECT

The glide path scan that alerts for low-level windshear

The Doppler Light Detection And Ranging (LIDAR) systems at Hong Kong International Airport provide real-time windshear alerts for all the arriving and departing aircraft

Doppler LIDAR systems are used at Hong Kong International Airport (HKIA) for monitoring and alerting low-level windshear. They provide wind data in high spatial and temporal resolutions for capturing terrain-induced airflow disturbance in non-rainy weather, which accounts for the majority (about 70%) of the low-level windshear at the airport. Runway-specific LIDAR systems have been set up, and a special scan strategy of the laser beam – the glide-path scan – has been devised to measure the headwind profile along the flight path.

An algorithm has been developed to automatically detect significant headwind changes to be encountered by the aircraft and issue timely windshear alerts to the pilots. The LIDAR windshear alerts have a success rate of about 80% based on pilot windshear reports, and their usefulness is demonstrated here by considering a typical case of terrain-induced windshear at HKIA. Further developments of windshear and turbulence alerting services in Hong Kong are also discussed.

Low-level windshear could be hazardous to any landing or departing aircraft at the airport. It refers to sustained wind change occurring below 1,600ft or within three nautical miles of the end of the runway. In aviation meteorology, significant windshear is a headwind change of 15kts or more occurring over a distance between 400m and several kilometers. The latter (the maximum spatial scale of significant windshear) is taken as 4km in the case of microburst. Such sustained changes in the headwind could drastically reduce the lift to an aircraft, causing it to deviate from its intended flight path (HKO and IFALPA 2005). At HKIA, about one in 500 aircraft reports an encounter with significant windshear.

Seasonal disrupted windshear

The majority of the pilot windshear reports at HKIA (about 70%) are related to terrain-disrupted airflow disturbances. The airport in Hong Kong is situated in an area of complex terrain (Figure 1). To its south is the mountainous Lantau Island with peaks rising to about 1,000m above mean sea level with valleys as low as 400m in between. It is surrounded by water on the other three sides. When winds from the east through southwest climb over the terrain of Lantau Island, airflow disruptions may appear at the glide paths of HKIA. This situation occurs in the east to southeasterly flow in the spring in stable boundary layers, in strong southwest monsoon winds in the summer, and in high winds crossing the mountains during the approach of tropical cyclones.

The next most common type of low-level windshear at HKIA (about 20%) is sea breeze. It occurs in winter to spring when a westerly sea breeze sets in over the airport against the prevailing easterly wind. When an aircraft lands at HKIA from the west, it may experience a sudden increase of headwind as it flies through the sea breeze front. Under the southwest monsoonal weather in the summer, the sea breeze may also appear in the form of an easterly wind over the seas to the east of the airport.

The remaining windshear events (about 10% of the pilot reports) occur in convective weather such as gust front and microburst, and low-level jets in winter.

In order to detect low-level windshear, a suite of meteorological instruments (Figure 1) has been set up and operated by the Hong Kong Observatory (HKO) inside and around the airport. Since the opening of HKIA in mid-1998, a dense network of surface anemometers has been developed. It has undergone continuous expansion in the last 10 years or so, and now includes ground-based anemometers at the peaks and valleys

The south runway LIDAR system operating from Hong Kong International Airport

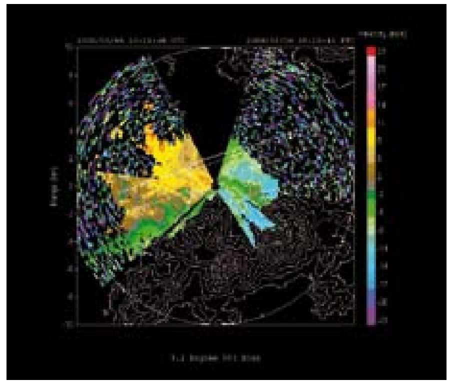


FIGURE 3: **3.2º velocity imagery from the south runway LIDAR in the morning of March 5, 2009. Blobs of reverse flow (colored in green) could be seen to the west of HKIA**

FIGURE 1: **A map showing the many meteorological instruments installed inside and around HKIA for the monitoring of low-level windshear**

of Lantau Island as well as weather buoys over the waters around the airport.

A terminal Doppler weather radar (TDWR) has also been operated for detecting gust fronts and microbursts using sophisticated algorithms. A number of radar wind profilers have been working near the flight paths to the east and west of the airport as well as on an island upstream of Lantau Island (for east to southeasterly flow) to monitor the vertical wind profiles within the boundary layer of the atmosphere. Furthermore, a microwave radiometer was recently introduced to HKIA to measure the low-level temperature and humidity changes in association with cross-mountain airflow.

Among all the meteorological instruments working at HKIA, Doppler LIDAR systems make the most direct measurements of the winds to be encountered by the landing/departing aircraft, because they scan right along the glide paths. Here, in this article we focus on the application of LIDARs for the alerting of low-level windshear in an operational environment.

Doppler LIDAR

Because the majority of low-level windshear at HKIA (terrain-disrupted airflow and sea breeze) occurs in non-rainy conditions, the Doppler LIDAR located at Hong Kong International Airport is very suitable for the detection of this type of wind change at the airport. The first LIDAR at HKIA was installed in mid-2002 on the roof of the air traffic control complex (ATCX) near the center of the airport, in order to have a good view over all the arrival runway corridors. It is still working at the airport and, to the best knowledge of the author, it is the Doppler LIDAR with the longest record of continuous operation for aviation weather alerting purposes in the world.

The LIDAR at HKIA operates with a laser beam with a wavelength of approximately 2mμ. It has a pulse repetition frequency of 500Hz and uses 50 pulses for wind averaging, i.e. a data output frequency of 10Hz. The range gate size is about 100m. Line-of-sight velocity is measured with an accuracy within 1m/s, as checked regularly in comparison with ground-based anemometer measurements.

One special aspect of the operation of a LIDAR at the airport is the laser safety issue. Through theoretical calculations, the LIDAR at HKIA is confirmed to be eye-safe when it is scanning. When the laser beam is stationary it may affect aided eyes, e.g. as seen through binoculars. A number of laser safety measures have been implemented, such as sector blanking and safety interlock; consequently, since operation of the LIDAR system at HKIA began in 2002 there has been no report of safety issues related to the laser beam.

The single LIDAR has already demonstrated its usefulness in monitoring low-level windshear and providing timely alerts to pilots. However when it was required to measure the winds over the eight runway corridors of HKIA, the data update frequency at a particular corridor was occasionally not fast enough to capture the terrain-induced airflow disturbances, which are highly transient and sporadic in nature. It was therefore planned to set up a runway-specific LIDAR. The north runway LIDAR of HKIA was installed in late 2006. In the spring of the following year, the LIDAR originally deployed at the rooftop of ATCX was moved to the south runway. The dual LIDAR operation mode – the so-called dual LIDAR Windshear Alerting System (LIWAS) – has been in use since then.

Dual LIWAS

For successful use of the LIDAR system in wind monitoring, the development of the scan strategy for the laser beam is a crucial factor. Compared with the conventional microwave radar, the 'antenna' of the LIDAR is much smaller (just a mirror with a diameter of several inches) and the scan strategy can be devised with more flexibility. At first, only the traditional plan position indicator (PPI) and range height indicator (RHI) scans were employed for the LIDAR system. The adoption of these scans amply demonstrated the capability of LIDAR for monitoring low-level windshear, but they might not capture the wind changes experienced by the aircraft, because the scanning locations were still not right at the glide paths. Therefore, glide-path scans *(Shun and Chan, 2008)* were developed and implemented for the single LIDAR system at HKIA in 2004.

The idea of a glide-path scan is to measure the headwind directly along the glide path. In PPI or RHI scans, it is required to rotate only one set of the motors of the LIDAR system: either the azimuthal or the elevation motor. With glide-path scan, both sets of motors would need to rotate at the same time so that the laser beam just slides along the flight path, which in general is an oblique line in the three-dimensional space. In dual LIWAS at HKIA, the arrival glide path is taken as a line with an elevation angle of 3º with respect to the horizon starting at the runway end, and the departure glide path is a line with an elevation angle of 6º starting at the middle of the runway. The accuracy of the glide-path scan of the LIDAR is checked by viewing the location of the aircraft relative to the laser beam through the video camera of the LIDAR.

The wind data collected along the glide path is used to construct the headwind profile to be encountered by the aircraft. Significant wind changes in the headwind profile, called windshear ramps, are then detected automatically using a sophisticated algorithm developed by the Hong Kong Observatory. Details of the algorithm can be found in *Shun and Chan (2008)*. In general, a headwind profile contains more than one windshear ramp. The detected ramps are prioritized according to the severity factor, which is related to the normalized windshear value: the change between V/H1/3, where the change V is the change in headwind and H is the corresponding ramp length.

LIWAS generates a windshear alert automatically when a windshear ramp with the change V exceeding the alert threshold is detected. The LIWAS alert is ingested into the Windshear and Turbulence Warning System (WTWS) operated by HKO to provide comprehensive windshear alerts to air traffic controllers for relay via voice communications to the pilots. WTWS also integrates alerts from the other windshear detection systems/algorithms, including alerts from TDWR and those generated by anemometer-based windshear algorithms developed by HKO. The integration is carried out based on an alert prioritization scheme that considers the significance of the event and the credibility of the respective system issuing the alert. After the integration, one single windshear alert will be generated for each runway corridor.

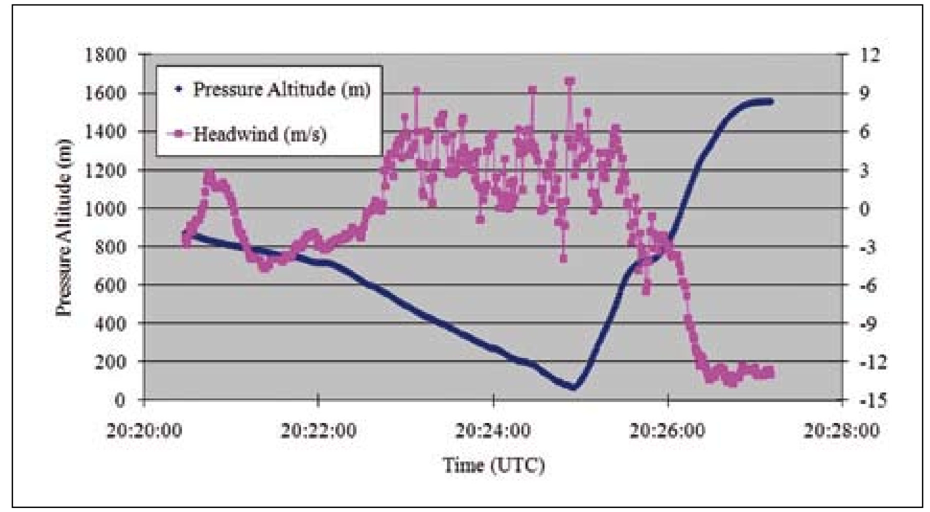


FIGURE 4: **Headwind and pressure altitude measured at an aircraft which had a missed approach due to significant windshear in the morning of March 5, 2009**

"The LIDAR at HKIA operates with a laser beam with a wavelength of approximately two microns"

Case study

In general, LIWAS captures about 75-80% of the pilot windshear reports. Here is an example showing the performance of LIWAS. This case occurred in the early morning of March 5, 2009 and was typical for terrain-induced airflow disturbances at HKIA. From the LIDAR's velocity imagery (Figure 3), east to southeasterly airflow prevailed in the airport area. However, there were blobs of reverse flow, each having a size of several hundred meters, appearing to the west of the airport, probably arising from the disruption of cross-mountain airflow by Lantau terrain.

An aircraft landing at the south runway of HKIA from the west had to conduct a missed approach due to encounter of significant windshear. The headwind measured on board the aircraft is shown in Figure 4, and significant changes of the headwind could be seen. Such wind changes were also successfully captured by the LIDAR (Figure 5). In fact multiple windshear ramps with headwind gains and losses have been detected by the LIDAR, and timely windshear alerts have been issued and relayed to the pilot on many previous occasions.

Future developments

Work is going on at HKO to develop a turbulence detection algorithm based on the LIDAR data. It has been shown that calculation of eddy dissipation rate (EDR) from LIDAR's radial velocity data could capture the mechanical turbulence at HKIA in association with cross-mountain airflow.

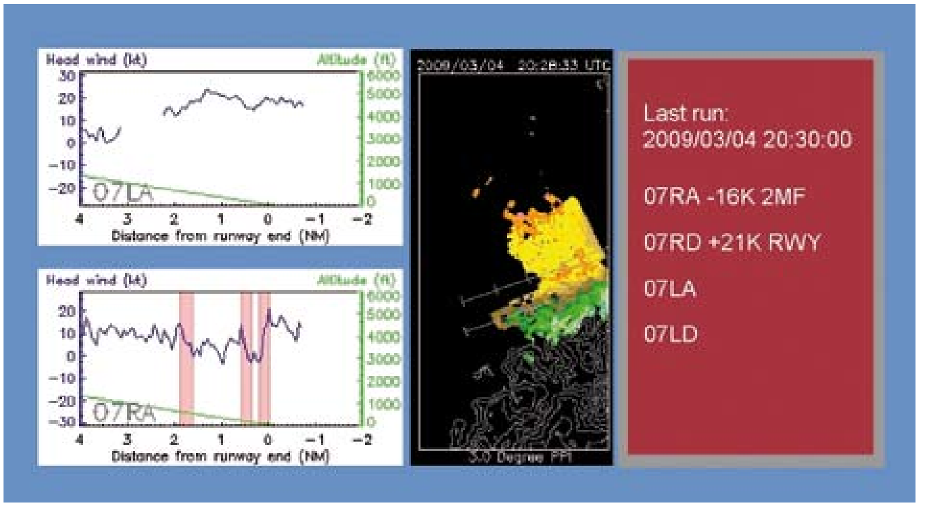


FIGURE 5: **Headwind profile measured by the south runway LIDAR over the runway corridor 07RA (arrival at the south runway of HKIA from the west), with the significant windshear ramps highlighted in red**

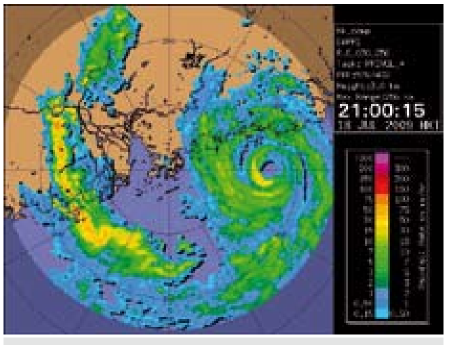
However such EDR computation, based on the so-called ‘structure function approach’, requires quite a lot of computing resources in order to implement the algorithm in real time. An alternative is to use the spectrum width data from the LIDAR. To this end it has been planned to upgrade the signal processors of the LIDAR systems at HKIA in order to obtain high-quality spectrum width data for EDR computation.

Apart from turbulence associated with mountains, the effect of buildings at the airport on the low-level winds is also of great concern at HKIA. A preliminary field study was carried out in the summer of 2009 to use a short-range, high-resolution LIDAR (with a spatial resolution of 30m) for detecting wind fluctuations associated with a building along a glide path of HKIA. This kind of LIDAR provides radial velocity map and 2D wind field as well as EDR distribution. Further study will be conducted to find out how to use this LIDAR to issue low-level wind alerts.

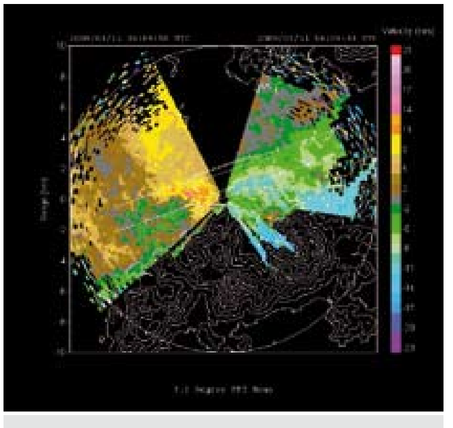
Windshear algorithms

The windshear algorithms developed so far at HKIA are mainly based on pilot reports, which are prone to pilots’ subjective perception of the wind changes. An objective windshear/turbulence database is being built up by processing quick access recorder (QAR) data of the transport category commercial jets using a sophisticated aerodynamic model of the aircraft *(Haverdings and Chan, 2009)*. The meteorological measuring system of a fixed-wing aircraft from the Government Flying Service in Hong Kong has now also been technically upgraded to conduct windshear and turbulence research flights.

The first operational LIDAR-based windshear alerting system has been developed in Hong Kong to provide real-time alerts for all the arriving and departing aircraft at HKIA. It is based on a specially devised scanning strategy of the LIDAR, namely the glide-path scan to measure the headwind profile to be encountered by the aircraft. Significant wind changes in the headwind profile are detected automatically for issuing windshear alerts to the pilots. The algorithm captures about 80% of the pilot windshear reports.



Radar image of greater HKIA area



Another 3.2° velocity LIDAR image from the south

As well as windshear and turbulence, meteorological studies in other areas have also been carried out by HKO in order to enhance the provision of aviation weather services. For instance work is ongoing about the ‘now-casting’ of lightning and short-term forecasting of thunderstorms at the Pearl River Delta area, because intense convective weather could have a considerable impact on the operation of the aircraft. Collaborative studies with other meteorological institutes around the world are also being pursued to enhance the provision of weather forecasts for the terminal area. ◗

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