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Wind Shear Alerting at Hong Kong International Airport

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1. INTRODUCTION

Wind shear is a sustained change in wind direction and/or speed experienced by an aircraft for more than a few seconds resulting in a change in the headwind and thus the aircraft lift. A decrease in lift will cause the aircraft to descend below its intended flight path. Wind shear is thus of greatest concern to aircraft during approach and takeoff due to its proximity to ground. A change of 15 knots or more in head- or tail-wind is considered significant wind shear, and may require timely and appropriate corrective action by the pilot.

Wind shear can be caused by a wide variety of phenomena including thunderstorms, gust fronts, warm/cold fronts, land/sea breeze, low-level jet and winds blowing across hilly terrain.

The Hong Kong Observatory, being the Meteorological Authority in Hong Kong, is responsible for the provision of wind shear and turbulence alerting service at the Hong Kong International Airport (HKIA). The Observatory installed a Windshear and Turbulence Warning System (WTWS) which comprises of a Terminal Doppler Weather Radar (TDWR) and a network of anemometers for wind shear and turbulence alerting service.

This paper describes the major effort to enhance wind shear alerting service at the HKIA since its opening in July 1998. The automation of wind shear detection using Doppler LIDAR would be described and the use of these new algorithms in terrain-induced wind shear detection demonstrated using the wind shear event on 30 Mar 2005.

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2. WIND SHEAR AT HKIA

From the pilot reports of wind shear received from the opening of HKIA in July 1998 to June 2005, about one in 500 flights in and out of the airport reported significant wind shear.

HKIA was built on reclaimed land to the north of mountainous Lantau Island which has peaks rising to nearly 1 000 m (see Figure 1). The average height of the U-shape Lin Fa Shan is around 700m while individual peaks such as Lantau Peak and Sunset Peak rises to above 900 m. The most common cause of wind shear at HKIA is by far the disruption of air flow by the hills surrounding the airport, especially in strong winds crossing Lantau Island in spring under stably stratified conditions (Lau and Shun 2000) and in uniform flow during the passage of tropical cyclones (Shun et al 2003).

As HKIA is surrounded by sea on three sides, sea breeze is another common cause of wind shear (Lee and Shun 2003). Typically a low-level convergent shear line occurs between the westerly sea breeze and the opposing prevailing winds from the east, leading to significant wind shear.

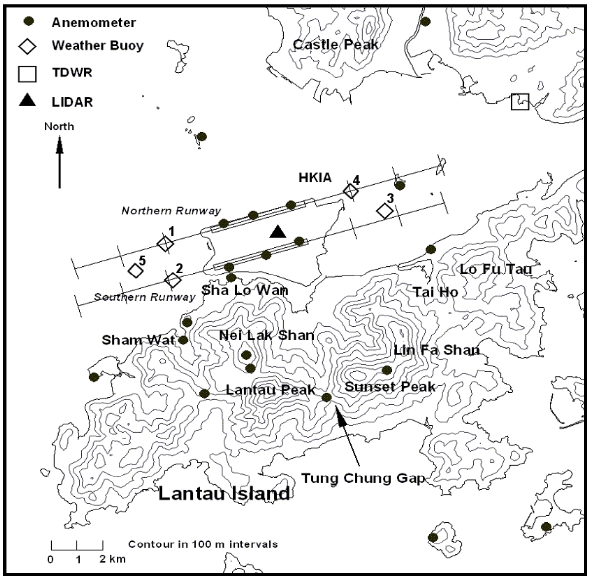

Figure 1. Map of HKIA, its approach/departure corridors and surrounding areas. Terrain contours are given in 100 m intervals.

a) TDWR and WTWS

Installed in 1996, the TDWR and the WTWS provide warnings on wind shear in rainy weather. Then a more sophisticated algorithm was developed for the TDWR to detect wind shear under clear-air conditions, but the TDWR return signals may not always be available for wind shear detection under these conditions.

b) AWARE and LIDAR

To enhance wind shear detection in dry weather, HKO has installed five strategically-located weather buoys to the west and east of the airport, several anemometers on valleys over Lantau and a pulsed Doppler LIght Detection And Ranging (LIDAR) system at the airport. The location of these facilities is indicated in Figure 1.

(i) AWARE

Since 2001, the HKO has deployed five weather buoys over the waters surrounding the airport (Chan and Yeung 2002). These weather buoys, stationed about 1 and 2 NM from the runway thresholds, helped extend the coverage of the surface anemometer network and were particularly useful in detecting wind shear caused by sea breezes. They also serve as the 'ground' truth complementing the remote-sensing equipment. Apart from wind measurements, the weather buoys also provide sea surface temperature data, important for determining the air-sea temperature difference and thus very useful for forecasting the occurrence of sea breeze.

Using the wind data from the weather buoys as well as the anemometers along the runways, a new wind shear detection algorithm, known as the Anemometer-based Windshear Alerting Rules-Enhanced (AWARE), has been developed to detect wind shear for each approach/departure corridor based on runway-oriented wind speed difference between anemometers in this extended network. Data filtering is in place to reduce false alarms caused by small-scale fluctuations of gusty wind.

(ii) LIDAR

Since the terrain-induced wind shear at HKIA is highly three dimensional and localized, the addition of the weather buoys alone could not provide the much-needed spatial information for detection of wind shear due to terrain. In mid-2002, a pulsed Doppler LIDAR system was installed strategically on the roof-top of the air traffic control complex near the center of the airport between the two parallel runways (see Figure 1) for wind shear monitoring. The LIDAR, operating at 2 micron wavelength, supplements the TDWR in monitoring the wind flow around HKIA in rain-free weather. At this location, the LIDAR is able to scan the approach and departure corridors of both runways. Shun and Lau (2002) provided a detailed description of the LIDAR implementation. Interesting LIDAR observations of terrain-induced phenomena downwind of Lantau were documented by Shun et al (2003, 2004).

Two LIDAR-based wind shear detection algorithms have been developed for automatic detection of wind shear. The first algorithm, is based on the shear along each radial of the LIDAR PPI scans. This Radial shear Alert Generation Algorithm (RAGA) first identifies shear segment along each radial beam. Adjacent shear segments are then clustered together to form shear features. If the total shear in Doppler radial velocity of that shear feature exceeds 15 kt (7.5 m/s) and the shear feature occurs over the area of the respective approach/departure corridors, an alert with the wind shear magnitude and location affected will be generated.

Since the LIDAR is located at the centre of the airport, its PPI scans can only intersect the flight path at a few points. For example, the 0.0-degree PPI scan align best with the arrival corridor (with nominal glide slope of 3 degrees) only at about 1 NM from the runway ends and beyond that any shear that occur would be below that of the flight path. As the terrain-induced wind shear at HKIA is very localized, the shear magnitude so detected might not agree with that of actually experienced by the aircraft. Hazard Coverage Area (HCA) has since been introduced for different PPI scans (see Figure 2) such that only shear feature that occur within the HCA would contribute toward the alert.

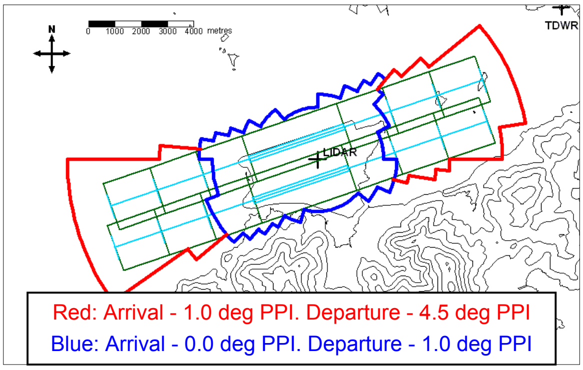

Figure 2. Diagram showing Hazard Coverage Area of PPIs at three different elevations angles, namely 0.0, 1.0 and 4.5 degrees. The ARENA boxes (the green rectangles) for the runways and approach/departure corridors are also indicated.

The second algorithm is designed to measure the headwind along the glide paths. Since the LIDAR is not situated along either of the two runways, it is not possible to obtain the glide path data by doing simple RHI scans. In order to achieve short re-visit time, rather than doing multiple PPI or RHI scans cutting across the glide paths, a new scan strategy known as the Glide Path (GP) scans were introduced. In contrast to the traditionally used PPI and RHI scans which provide data at constant elevation and azimuthal angles respectively, the elevation of the LIDAR beam varies with the azimuthal angle in the GP scans such that the LIDAR beam stays as close to the actual glide path as possible (see Figure 3).

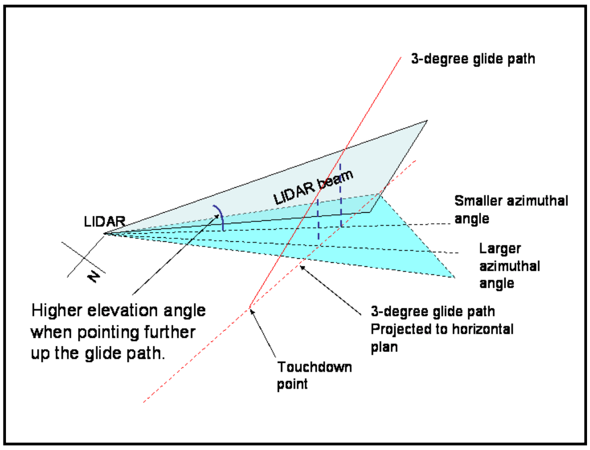

Figure 3. Diagram illustrating a LIDAR glide path (GP) scan along the 3 degree glide path of towards the western approach of the north runway.

Using the LIDAR data points closest to the glide path, a headwind profile is constructed for each glide path. The algorithm, GLIde path shear alert Generation Algorithm or GLYGA, is then used to identify significant wind shear features. Adapted from the Peakspotter Program by Jones and Haynes (1984), which was adopted by Woodfield (1983) for identification of wind shear from aircraft flight data recorder (FDR) data, GLYGA picks up wind shear feature if the headwind change over the ramp length over which the wind speed change occurs exceeds a predefined threshold, i.e. $\Delta V \,/\, L^{1/3}$ > threshold, where .ΔV = headwind change and L = ramp length. Wind shear features with ramp lengths between 400 m and 4 000 m detected by GLYGA with the headwind change exceeding predefined threshold will trigger an alert for the glide path concerned. While GLYGA better measures the shear along the glide path, due to its 1-dimensional perspective, it is more difficult to detect nearby features which may move in sideway and affect the glide path between successive scans. More details on RAGA and GLYGA can be found in Choy et al (2004).

4. WIND SHEAR CASE ON 30 MAR 2005

A trough lingered over mainland China to the north of Hong Kong by the end of Mar 2005. Locally, the easterlies started to strengthen overnight on 29 Mar bringing some rain and much cooler weather to Hong Kong. Aloft, around 400 – 600 m, was a low-level southeasterly jet with a maximum of close to 16 ms^{-1}. As a result of the cooler surface easterlies, a strong inversion (4.7°C) existed between 559 – 924 m at 00 UTC 30 Mar (Local time = UTC + 8 H). Under this strongly stratified condition, 45 aircraft reported wind shear on approach to and departure from HKIA between 00 and 03 UTC. One pilot reported 35 KT (18 ms^{-1}) gain at about 300 ft (100 m) on approach to HKIA and conducted a go-around at around 0032 UTC.

As on-board aircraft data from the above flight was not available to the Observatory, the current study was made using data from another flight arriving at 0049 UTC. The pilot reported 20 KT (10 ms^{-1}) gain and loss at about 500 ft (~150 m) on approach to the north runway from the west. The aircraft observed winds were basically southeasterlies as it descended from 1 500 ft (~460 m) to 1 080 ft (~330 m) amsl (Figure 4). The winds then varied significantly, first veering to southwest which resulted in some tailwind and then northeast as the wind speed dropped markedly to below 10 KT (5 ms^{-1}). As the plane continued its descent, between 650 ft (~200 m) and 550 ft (~170 m), the wind direction stayed southeast but the wind speed increased rapidly from around

20 KT (10 ms^{-1}) to a maximum of 35 KT (18 ms^{-1}) before dropping back to 15 KT (7.7 ms^{-1}) again. The headwind change derived from the on-board wind measurement when the plane descended from ~850 ft (260 m) to ~550 ft (170 m) was 25 KT (12.9 ms^{-1}) gain followed by 18 KT (9.3 ms^{-1}) loss.

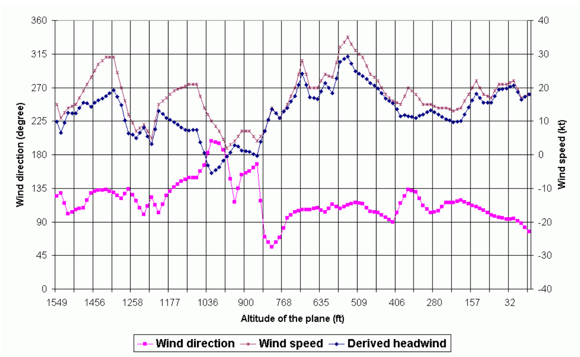

Figure 4. On-board flight data from an aircraft arriving HKIA at 0049 UTC on 30 Mar 2005 and the derived headwind profile.

Based on the 00 UTC ascent, if we take the Brunt-Väisälä frequency N ~ 0.017 s^{-1} which is the average value between 100 – 1000 m, h ~ 934 m (height of Lantau Peak, see Figure 1), we obtain $Nh/U_0 \geq 1$ (since U_0, the upstream flow is less than 16 ms^{-1}) which suggests gravity wave breaking and the formation of wake to the lee of the mountain.

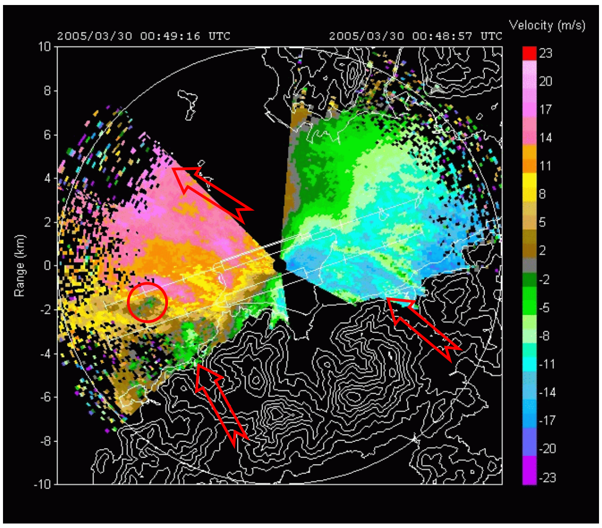

Figure 5. LIDAR 1.0 degree PPI scan taken at around 0049 UTC on 30 March 2005.

Figure 5 shows the radial velocity from the LIDAR 1.0° PPI scan. The reverse flow (~ -7.6 ms^{-1}) downwind of Nei Lak Shan (NLS) (see Figure 1 for location) extended northward and came very close to the flight path of the north runway at around 2 NM. This was well captured by the anemometer on Buoy 5. At around the same time, Buoy 5 (see Figure 1 for location) also recorded a sudden rise in temperature of 2.7°C, from 18.4°C to 21.1°C, within 30 minutes. Temperature at HKIA, however, had not recorded a similar rise and was only 18.4°C at the time.

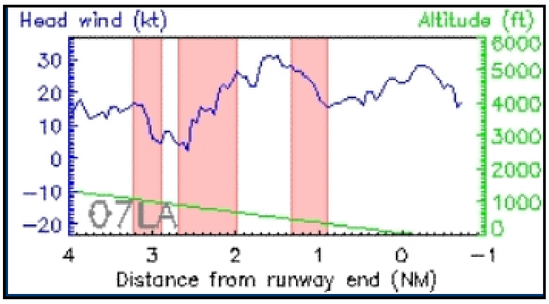

Figure 6. Output from GLYGA for 07L arrival corridor at 0050 UTC on 30 Mar 2005. Note the close resemblance in shape of this composed profile with the headwind profile derived from flight data in Figure 4.

Between 1 to 2 NM, the radial velocity was much higher at around +17.8 ms^{-1}. Further down the flight path near 1 NM, the radial velocity reduced back to +9.6 ms^{-1}. These LIDAR observations agree very well with the wind speed changes observed by the on-board flight data.

Both GLYGA and RAGA were able to capture the strong shear (see Figures 6 and 7). The variations in headwind, as shown in the GLYGA display (Figure 6), resembles closely to that observed on-board (Figure 4). The magnitude as detected by the GLYGA, 24 KT (12.3 ms^{-1}) gain, also agrees very well with what was observed on-board the aircraft. The alert given by the RAGA was somewhat higher, a 35 KT (18.0 ms^{-1}) at 3 NM. However, close analysis of the RAGA shows that the shear segment generating the alert was caused by the reverse flow near 2NM which did not actually intersect the glide path.

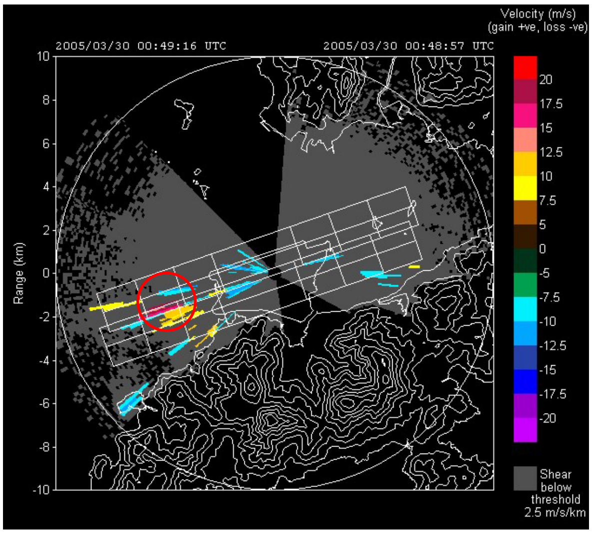

Figure 7. Output from RAGA for the arrival corridors at around 0050 UTC on 30 Mar 2005. Significant radial shear segments, up to 17.5 ms^{-1} were detected between 1 to 2 NM from the runway end of the 07L arrival corridor.

5. CONCLUSION

In the past couple of years, the LIDAR has demonstrated its capability in operational wind shear alerting under clear-air conditions. As the 30 Mar 2005 case showed, the LIDAR observations agreed very well with the on-board wind measurements. Both LIDAR-based wind shear detection algorithms were able to detect the shear though the magnitudes were somewhat different due to the design of the algorithms. Work is underway to refine the LIDAR based algorithms and integrate them with the existing WTWS for automatic wind shear alerting.

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