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Wind Shear and Turbulence Alerting at Hong Kong International Airport

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Wind shear and turbulence alerting at Hong Kong International Airport

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Introduction

Hong Kong International Airport (HKIA) was built on reclaimed land to the north of mountainous Lantau Island, which has peaks rising to nearly 1 000 m adjacent to valleys as low as 400 m. Figure 1 illustrates the location of HKIA relative to this rugged terrain. To the north-east of HKIA are a number of smaller hills with peaks rising to 600 m. In this hilly, coastal environment, a wide variety of weather phenomena can cause low-level wind shear and turbulence. From the opening of HKIA in July 1998 to the end of 2003, about one in 500 flights in and out of the airport reported significant wind shear. Over the same period, around one in 2 000 flights reported significant turbulence.

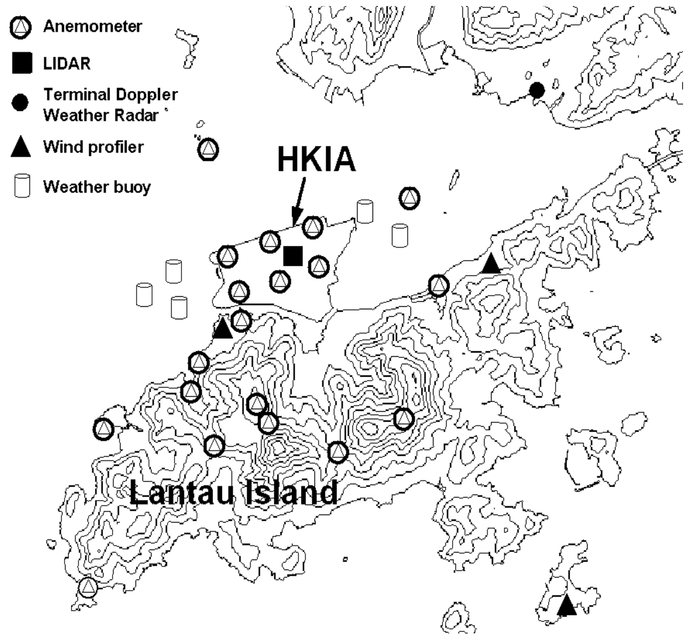

Figure 1 — Map of HKIA and the surrounding area, with 100-metre terrain contours

Wind shear is a sustained change (i.e. lasting more than a few seconds as experienced by aircraft) in wind direction and/or speed, resulting in a change in aircraft lift. A decrease in lift will cause the aircraft to descend below the intended flight path. A change of 15 knots or more in head- or tail-wind is considered significant wind shear, which may require timely and appropriate corrective action by the pilot.

Turbulence is caused by rapid, irregular motion of the air. It brings about bumps or jolts, but does not normally influence the intended flight path of an aircraft to a large extent. However, in severe turbulence, abrupt changes in the altitude and attitude of an aircraft may occur and the pilot may momentarily lose control of the aircraft. For reporting and alerting purposes, moderate or severe turbulence is considered significant.

Typical weather scenarios

There are a number of meteorological causes for wind shear and turbulence at HKIA. The most common one is the disruption of the flow of air by the hills surrounding the airport. Thunderstorms are another cause—occurring at HKIA on an average of 37 days a year—because they can bring microbursts and gust fronts. Sea breezes also cause wind shear [1]. Typically, a low-level convergent shear line occurs between the westerly sea breeze and opposing background winds from the east (Figure 2). Yet another cause, albeit the least frequent, is the low-level jet in winter [2]—a narrow band of strong north-easterly winds in the lower atmosphere causing a headwind gain to an aircraft entering the jet and vice versa. The headwind changes are more notable for departing aircraft than those on approach because of the steeper gradient of the departure flight path.

Terrain-induced wind shear

Most wind shear and turbulence at HKIA are caused by air flowing across hilly terrain, especially strong winds crossing Lantau Island in spring and during the passage of tropical cyclones. Pilot reports and high-resolution weather radar observations at HKIA

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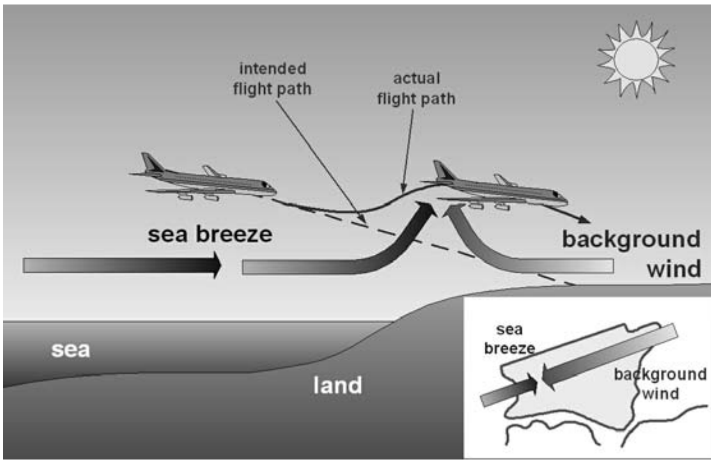

Figure 2 — A sea breeze can bring wind shear due to its convergence with the background wind.

have shed light on the characteristics of terrain-induced wind shear and turbulence [3].

On windy occasions, such as the passage of a tropical cyclone, streaks of high-speed air were observed by weather radar to emerge from valleys of Lantau. Lying between these high-speed streaks are lower speed streaks downwind of the peaks. Aircraft traversing these alternating high- and low-speed streaks may encounter headwind losses and gains at different locations along the approach and departure paths. A schematic diagram illustrating the observed phenomena in relation to the terrain is shown in Figure 3.

When an aircraft moves from a high-speed streak to a low-speed one, it may experience a large headwind loss resulting in loss of lift. This sink occurs whether there is precipitation or not. The sequence of a headwind gain followed by a loss may sometimes resemble the classic pattern of a microburst. In wet conditions, such as those accompanying tropical cyclones, this pattern has misled some pilots into thinking that the terrain-induced wind shear was associated with a microburst. Pilots would anticipate that the wind shear would diminish as the precipitation moved away, only to discover that the terrain-induced wind shear still persisted in the latter part of the flight.

Terrain-induced wind shear and turbulence events are also found to be transient and sporadic. This is best illustrated by the wind shear that occurred on 17 March 2000, when strong south-easterly winds blew across Lantau Island. Reports from pilots making consecutive landings on the same runway over a half-hour period around midday show that half the flights experienced wind shear. One aircraft reported a 15-knot loss, followed, within the space of two minutes, by another reporting a 25-29 knot gain. Amazingly, an aircraft two minutes later reported no wind shear at all, followed by yet another report of a 15-knot gain. In other words, even though weather conditions may remain broadly similar, some aircraft encounter wind shear or turbulence while others do not.

Wind shear and turbulence alerting

The Hong Kong Observatory (HKO) provides aviation weather services for HKIA, including a wind-shear and turbulence-alerting service for arriving and departing flights. Weather sensors for monitoring wind-shear and turbulence conditions in and around HKIA include a terminal Doppler weather radar (TDWR) and a network of anemometers and wind profilers (see Figure 1 for the location of these sensors).

A wind-shear and turbulence-warning system (WTWS) equipped with a suite of wind shear and turbulence detection algorithms processes data from these weather sensors on a minute-to-minute basis. The system automatically integrates wind-shear alerts generated by the TDWR and wind-shear and turbulence alerts generated by WTWS algorithms into consolidated alerts for relay to pilots by air traffic controllers.

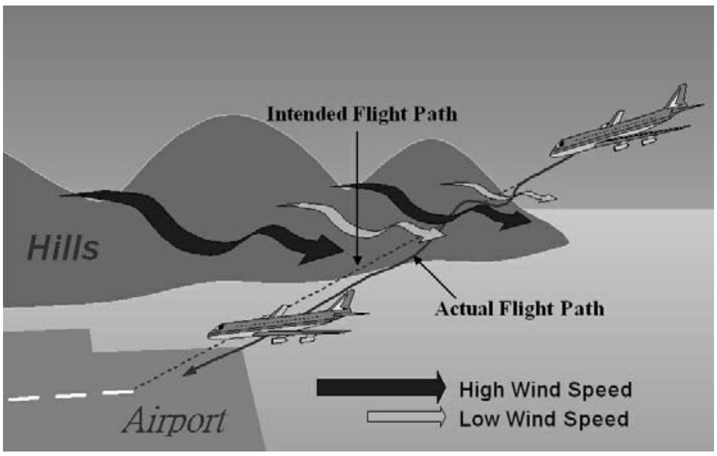

Figure 3 — The most common cause of wind shear at KHIA is the terrain-induced airflow pattern.

Based on observations made by the weather sensors, the WTWS issues alerts for possible wind shear and turbulence occurring within three nautical miles of the runway thresholds. Alerts for wind shear are classified into two levels: a "microburst alert" for a runway-oriented wind-speed loss of 30 knots or greater accompanied by precipitation, and a "wind shear alert" for a runway-oriented wind speed loss of 15-29 knots or gain of 15 knots or more.

Alerts for turbulence are based on the same intensity thresholds as those internationally adopted for automatic aircraft turbulence reporting. These are generated by a turbulence algorithm which is primarily based on wind measurements of surface and hilltop anemometers. Turbulence alerts are classified into two levels: "moderate turbulence" and "severe turbulence", with reference to heavy category aircraft such as the Boeing 747-400. This is based on a quantity called the eddy dissipation rate.

Wind-shear and turbulence alerts, supplemented by the forecaster's assessment and actual pilot reports, are also broadcast on the automatic terminal information service (ATIS) to help pilots prepare for their take-off or landing in advance.

Improved alerting techniques

To obtain a more complete picture of the wind-shear situation at HKIA, HKO launched two month-long intensive reporting exercises in 2000 with the active participation of airlines, pilots and air-traffic controllers. One of these exercises was timed to coincide with the spring season, when terrain-induced wind shear is most frequent, and the other during the rainy season, when typhoons, severe storms and high winds often occur.

During the exercises, pilots were requested to report whether they had encountered wind shear or not. Altogether, HKO received nearly 10 000 reports from pilots, representing one-third of all flights during the two intensive reporting exercises. This allowed HKO to conduct a comprehensive review of the performance of the wind-shear alerting service and also permitted further development of wind- shear alerting techniques.

Improved wind-shear alerting techniques were developed, using a systematic approach. Pilot reports of wind shear, including those received during the intensive reporting exercises, were collated to form a chronological database of actual wind shear conditions. Data from the various weather sensors and on-board flight data obtained from commercial aircraft were analysed for the wind-shear cases.

Factors including prevailing wind direction and speed, horizontal and vertical differences of winds at different locations, and vertical temperature profile of the atmosphere are deemed important in the occurrence of wind shear. These parameters were judiciously combined to form equations and decision flowcharts for issuing wind-shear alerts under different weather scenarios. The equations and flow charts were then tested for optimal performance by maximizing the number of successful alerts and minimizing false alarms on the basis of the pilot wind-shear reports received during the intensive reporting exercises. In this manner, threshold figures were established for the relevant meteorological parameters and optimal equations and flowcharts were adopted.

After independently testing the alerting techniques with reference to pilot wind-shear reports received outside the intensive reporting exercises, thereby confirming improved performance, the new techniques were implemented in early 2001 with encouraging results. Over 85 per cent of wind-shear reports in 2002 were successfully covered by HKO's wind-shear alerts.

The performance of the turbulence-alerting service was also reviewed based on pilot reports received during the two intensive reporting exercises, when there were about half as many reports of turbulence as of wind shear. Overall, HKO's turbulence alerts were accurate over 90 per cent of the time.

New developments

To enhance wind-shear detection in dry weather, HKO has implemented several new facilities in the past couple of years. These include five strategically located weather buoys to the east and west 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. The weather buoys have proved to be very effective in extending the coverage of the surface anemometer network in detecting wind shear caused by sea breezes, gust fronts and low-level shear lines induced by terrain. A new algorithm, known as the Anemometer-based Windshear Alerting Rules–Enhanced (AWARE), has been developed in-house 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 also in place to reduce false alarms caused by small-scale (turbulence) fluctuations of gusty winds. With the endorsement of stakeholders (i.e. airlines, pilots, air- traffic controllers, civil aviation authority) and considering the better performance of AWARE over the Low-Level Wind Shear Alert System (LLWAS), AWARE replaced

LLWAS of the WTWS in the first half of 2004.

Installed in mid-2002, the pulsed Doppler LIDAR system is strategically placed on the roof-top of the air traffic control (ATC) complex between the two parallel runways (Figure 4). At this location, the LIDAR is able to scan the approach and departure corridors of both runways. Operating on a principle similar to that of Doppler weather radar, albeit at a much shorter wavelength (2 micrometres compared with a few centimetres for weather radar), the LIDAR is capable of receiving return signals from aerosols in clear air. It is currently configured to perform sector scans at several different elevation angles, as well as a number of vertical scans to enable the monitoring of wind conditions out to about three nautical miles from the respective runway thresholds. LIDAR data are collected automatically and are typically updated once every two minutes.

Figure 4 — Lifting he LIDAR onto the roof-top of the Air Traffic Control complex at HKIA

Since its installation, the LIDAR has captured many interesting wind-shear events in clear air and facilitated the monitoring of wind shear by the forecasters. While the LIDAR works best in fine weather, it also captured terrain-induced wind shear and turbulence during the passage of tropical cyclones, both before rain approached and after it subsided. An example of this was the passage of severe tropical storm *Hagupit* on 11 September 2002, during which a number of aircraft had to go around on account of wind shear and turbulence.

Figure 5 shows the LIDAR Doppler radial velocity from a low-elevation scan when one of the aircraft conducted a go-around to avoid a wind shear encounter. In the figure the "warm" colours (i.e. brown, yellow and pink) represent radial velocity away from the LIDAR whereas the "cool" colours (i.e. green, blue and purple) represent radial velocity towards the LIDAR. Over the approaches to the west of the airport, alternating high-speed and low-speed airstreams similar to those illustrated in Figure 3 can be seen.

Scientific studies are ongoing to identify LIDAR signatures of terrain-induced wind shear in the spring season when a majority of wind-shear events are reported. Terrain-induced flow patterns like the lee wave (see Figure 6 for an example), hydraulic jump [4], velocity streak, shear line and vortex shedding have been identified. New forecasting guidelines have been formulated based on these findings to facilitate the aviation forecaster to issue runway-corridor specific wind-shear alerts based on wind flow patterns revealed by the LIDAR.

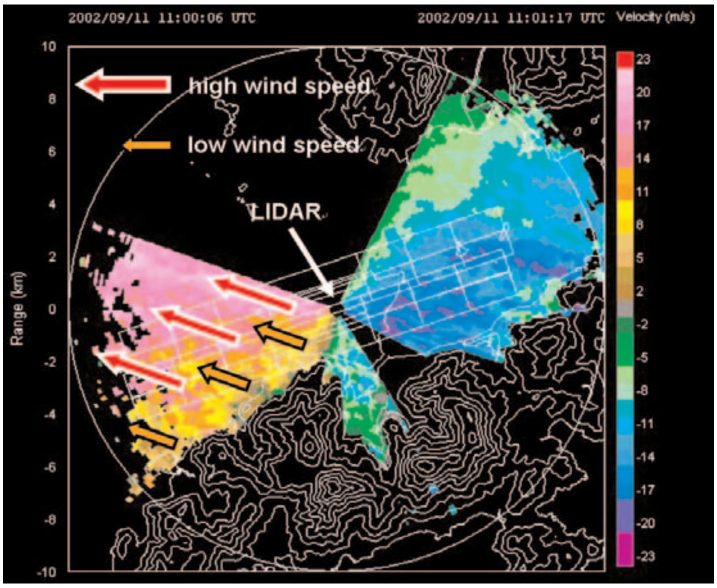

Figure 5 — LIDAR Doppler radial velocity pattern from a 1.0° elevation scan, revealing the presence of high- and low-speed streaks downwind of rugged terrain

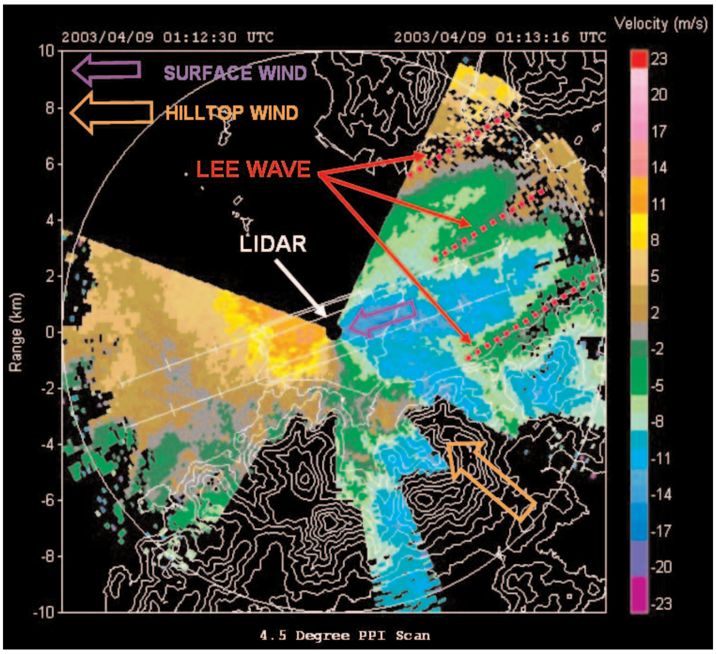

Figure 6 — LIDAR Doppler radial velocity pattern from a 4.5° elevation scan, revealing the presence of a lee-wave pattern to the east of the airport. An aircraft departing towards the east a few minutes later reported a loss of 15 knots at a height of about 520 m.

To summarize, the LIDAR has demonstrated its capability in detecting wind shear in clear air when the laser beam is not attenuated or blocked by precipitation and water droplets. The LIDAR has proved useful in supplementing the TDWR in wind-shear detection for a much wider range of weather conditions. In 2003, with the use of the additional data from the weather buoys and the LIDAR by the aviation forecasters, the hit rate of HKO's wind-shear alerts reached 95 per cent, with the false alarm rate on a continual decreasing trend.

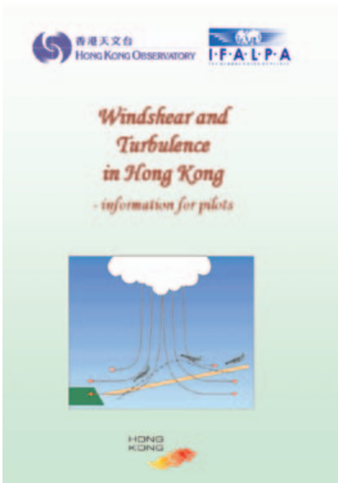

Figure 7 — Joint HKO/IFALPA booklet on wind shear and turbulence in Hong Kong

Future work

Pilots' reports and high-resolution weather-radar observations in the past few years have helped HKO improve understanding of the characteristics of terrain-induced wind shear. To promulgate this knowledge and experience, HKO conducts regular briefings and prepares information material for airlines, pilots and air-traffic controllers. An example is a booklet prepared jointly by HKO and the International Federation of Air Line Pilots' Associations (IFALPA) on wind shear and turbulence in Hong Kong, which is available in hard copy and on the Internet (http://www.hko.gov.hk/aviat/articles/WS-turb-booklet-web-ver.PDF). The booklet will be kept up to date to incorporate new knowledge about wind shear and latest changes to operational alerting.

In the past couple of years, the LIDAR has demonstrated its capability in operational wind-shear alerting under clear-air conditions. Scientific analyses of its data have improved our understanding of the wind-shear phenomena at HKIA. The HKO aviation forecaster is already making use of LIDAR data in operational wind-shear alerting. Automatic wind-shear alerting algorithms are being developed with the objective of integrating the LIDAR with the WTWS to further enhance the overall wind-shear alerting service for the airport. Research is also being conducted to explore the use of the LIDAR data in supplementing the existing anemometer based algorithm for turbulence detection.

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