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Located in an area susceptible to wind shear and turbulence, the Hong Kong Observatory continues to refine techniques for detecting these phenomena and providing timely alerts to aircraft approaching or departing Hong Kong International Airport.

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SINCE the opening of the Hong Kong International Airport (HKIA) nearly five years ago, about 1 in 600 flights in and out of the airport has reported significant wind shear. Over the same period, around 1 in 2,400 flights has reported significant turbulence.

Hong Kong International Airport was built on reclaimed land to the north of the mountainous Lantau Island, which has peaks rising to nearly 1,000 metres (3,281 ft) adjacent to valleys as low as 400 metres (1,312 ft). *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 metres (1,969 ft). In this hilly, coastal environment, a wide variety of weather phenomena can cause wind shear and turbulence.

Wind shear is a sustained change (i.e. lasting more than a few seconds) 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 headwind or tailwind is considered significant wind shear which may require timely and appropriate corrective action by the pilot.

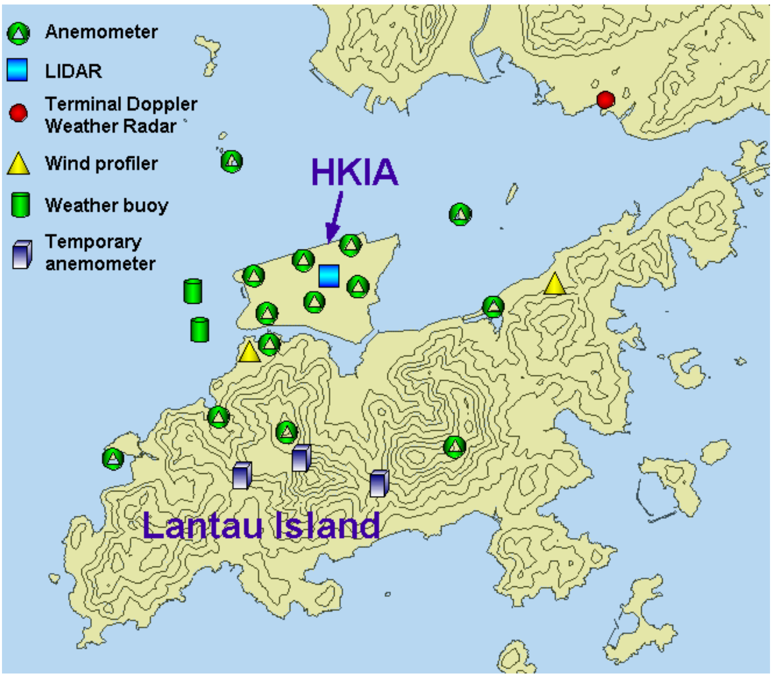

Figure 1. Map of HKIA and the surrounding area, with 100-metre terrain contours.

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 scenarios

There are a number of reasons for wind shear and turbulence at Hong Kong International Airport. The most common is windy conditions, where the hills surrounding the airport disrupt the flow of air. Thunderstorms are another cause — occurring at HKIA on an average of 37 days a year — because they can lead to gust fronts and microbursts, with associated wind shear and turbulence. Sea breezes also cause wind shear and turbulence. Typically, a low-level convergent shear occurs between westerly sea breezes and the opposing background winds from the east. Yet another cause, albeit the least frequent, is a low-level jet — a narrow band of strong winds in the lower atmosphere causing a headwind gain to an aircraft entering the jet and vice-versa. The headwind changes are more significant 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 is caused by air flowing across hilly terrain, especially strong winds at Lantau Island in the spring and during the passage of tropical cyclones. Information obtained from pilot reports and high-resolution weather radar observations at HKIA has shed light on the characteristics of terrain-induced wind shear and turbulence.

On windy occasions such as the passage of a tropical cyclone, streams of high-speed air were observed by weather radar to emerge from valleys. Lying between these fast air streams are lower speed air streams downwind of the peaks. Aircraft traversing these alternating high- and low-speed air streams 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 2*.

When an aircraft moves from a high-speed air stream 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 headwind gain followed by headwind loss may sometimes resemble the classic pattern of a microburst. In wet conditions such as those accompanying tropical

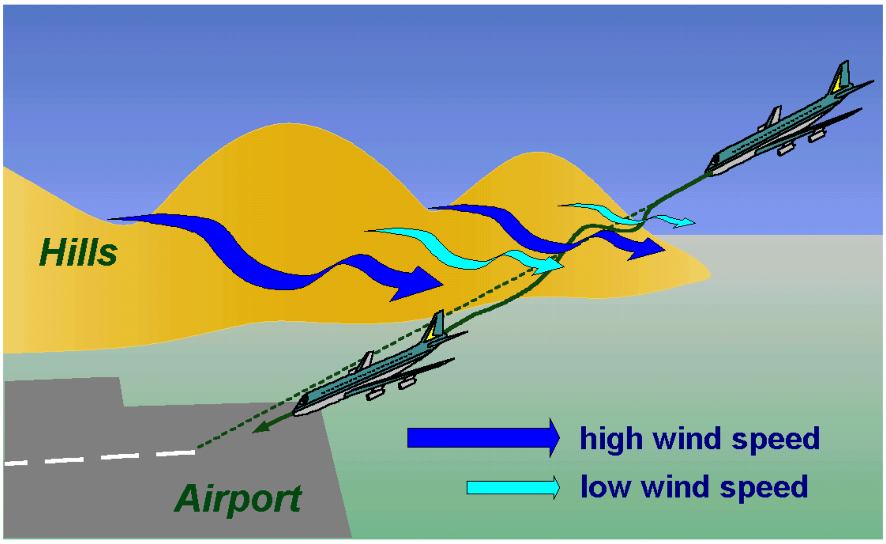

Figure 2. The most common cause of wind shear at HKIA is the terrain-induced air flow pattern.

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 condition would diminish as the precipitation moved away or eased off, only to discover that 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 mid-day show that half of the flights experienced wind shear. One aircraft reported a 15-knot headwind loss, followed within the space of two minutes by another reporting a 25 to 29 knot headwind gain. Amazingly, an aircraft two minutes later reported no wind shear at all, followed by yet another report of a 15-knot headwind 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 suite of wind sensors consisting of a number of anemometers and two wind profilers (see *Figure 1* for the location of these sensors).

Weather sensors for monitoring wind shear and turbulence conditions in and around Hong Kong International Airport include a terminal Doppler weather radar.

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. 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.

The Hong Kong Observatory aviation forecaster issues wind shear alerts to supplement the automatic WTWS alerts. The forecaster does this by referring to information from the weather sensors and utilizing techniques developed through studies of pilot reports of wind shear and associated weather patterns. These techniques are being progressively automated and integrated into the WTWS following their verification based on actual flight data and wind shear reports by pilots. Actual pilot reports of wind shear or turbulence received in a timely manner by HKO also trigger forecaster alerts. The forecaster alerts are broadcast on the automatic terminal information system (ATIS).

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

Alerts for turbulence are based on the same intensity thresholds as those adopted by ICAO for automatic aircraft turbulence reporting. They are issued with reference to heavy category aircraft such as the Boeing 747-400. Turbulence alerts are classified into two levels: "moderate turbulence" and "severe turbulence". This is based on a quantity called the eddy dissipation rate.

Improved wind shear alerting techniques. To obtain a more complete picture of the wind shear situation at HKIA, the Hong Kong Observatory launched two month-long intensive reporting exercises with active participation by airlines, pilots and air traffic controllers. One of these exercises was timed to coincide with the spring season when terrain-induced wind shear is believed to be 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 file a 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 the Hong Kong Observatory 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 deemed important in the occurrence of wind shear were quantified according to meteorological parameters, including the prevailing wind direction and speed, horizontal and vertical differences of winds at different locations, and vertical temperature profile of the atmosphere. These parameters were judiciously combined to form equations and decision flow charts 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 flow charts were adopted.

After independently testing the alerting techniques in 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 percent of wind shear reports in 2002 were successfully covered by Hong Kong Observatory's wind shear alerts. This contrasts with a previous figure of around 50 percent for 2000. The false alarm rate has also been decreasing.

The performance of the turbulence alerting service was also reviewed based on pilot reports received during the two intensive reporting exercises. During the exercises there were about half as many reports of turbulence as of wind shear. Overall, the Hong Kong Observatory's turbulence alerts were accurate over 90 percent of the time.

New developments

To enhance wind shear detection in dry weather, the Hong Kong Observatory has implemented several new experimental facilities. These include two weather buoys stationed about 1 NM to the west of the parallel runway thresholds, several temporary 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. While data from these new facilities are still being analysed, results so far show promise. For instance, 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.

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. 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 to enable the monitoring of wind conditions out to about 3 NM from the respective runway thresholds. LIDAR data are collected automatically and are updated about once every two minutes.

Over a period of several months, the LIDAR has already captured some interesting wind shear events occurring in fine weather conditions, such as those associated with the onset of sea breezes. Although the LIDAR works best in fine weather, it did capture terrain-induced wind shear during the passage of tropical cyclones, both before the 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.

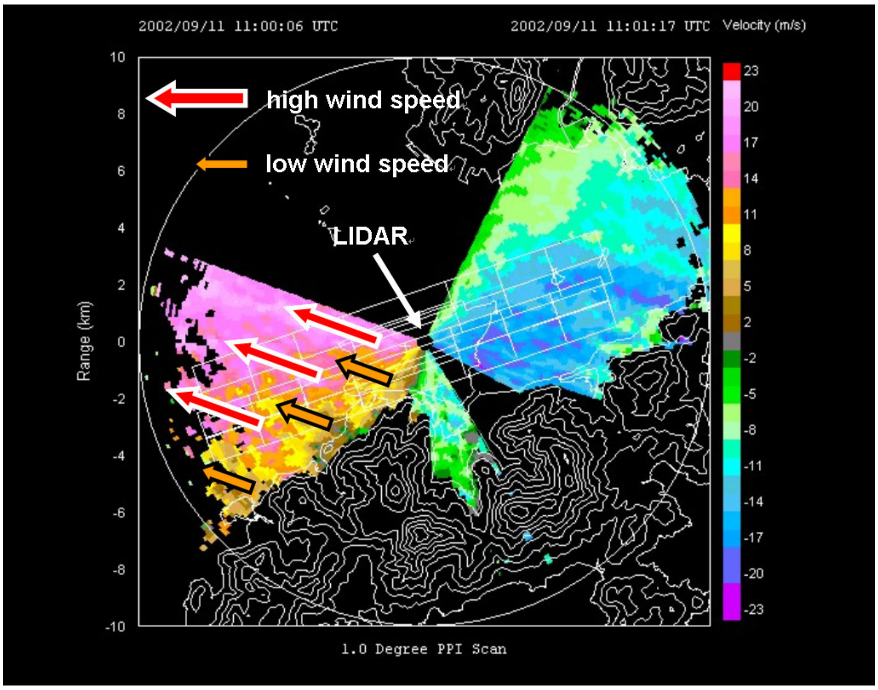

Figure 3. Hong Kong Observatory LIDAR Doppler radial velocity pattern from a low-elevation scan, revealing the presence of high- and low-speed air streams downwind of rugged terrain.

Figure 3 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 air streams similar to those illustrated in Figure 2 can be seen. To summarize, the LIDAR has demonstrated a potential for detecting wind shear not only in fine weather but also under pre-rain and post-rain conditions, when the laser beam is not attenuated or blocked by precipitation. The LIDAR has proved useful in supplementing the TDWR in wind shear detection for a much wider range of weather conditions.

Future work

Pilot reports and high-resolution weather radar observations in the past few years have helped the Hong Kong Observatory to improve the understanding of the characteristics of terrain-induced wind shear. To promulgate this knowledge and experience, the observatory conducts regular briefings and prepares information material for pilots, air transport operators 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).

As for the LIDAR implementation, the Hong Kong Observatory will continue data collection and analysis for a long enough period to establish and optimize the functions of the system. Observations so far are encouraging, and the HKO aviation forecaster is already making use of LIDAR data in day-to-day preparation of aerodrome forecasts and in the issuance of wind shear alerts. There are plans to integrate the LIDAR with the existing weather facilities to further enhance the overall wind shear alerting service for the airport.

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