Windshear – Its Detection and Altering

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Abstract

Windshear is a sustained change in the wind resulting in changes in the lift to the aircraft.   Those who have flown on an aircraft might occasionally experience sudden change of altitude during the course of landing or departure.   They might be caused by windshear and the pilot would need to respond in a timely manner to ensure safety.   In other parts of the world, the microburst, a kind of severe windshear caused by thunderstorms, had brought a number of fatal aircraft accidents.   Weather information and warnings on windshear are thus very important to aircraft operation and safety.

In this paper, we will explain how windshear can affect aircraft operation, and the weather conditions which might lead to windshear over the Hong Kong International Airport at Chek Lap Kok.   These include terrain-disrupted flow, microburst, gust front, sea breeze and low-level jet.   We will talk about the technologies now employed by the Hong Kong Observatory for windshear alerting, including the world first automatic LIDAR (LIght Detection And Ranging) windshear alerting system for detection of windshear in rain-free conditions, the sophisticated Terminal Doppler Weather Radar system for detection of microburst and windshear in rainy conditions and the introduction of weather buoys for monitoring of sea breezes. Furthermore, we will discuss how the combination of science, technologies and user education contribute to the enhancement of aviation safety in Hong Kong.

1.   Introduction

Windshear refers to a sustained change of headwind (or tailwind) an aircraft encountered during its flight journey.   A significant increase/decrease of headwind would increase/decrease the lifting force (or simply the lift) which an aircraft would experience, subsequently causing the aircraft to fly above or below its intended flight path.   Under significant windshear condition, pilot might experience difficulties in controlling the aircraft and would require timely and appropriate corrective actions to

ensure aircraft safety. A survey conducted by the International Civil Aviation Organization (ICAO 2005) showed that between 1964-1983, low level (below 1,500 feet altitude) windshear has caused at least 28 large transport aircraft accidents/incidents in the world that together resulted in over 500 fatalities and 200 injuries. Windshear has once been cited as one of the major killers in aviation. Since then, the aviation community including government agencies, aerospace industry, pilot associations and ICAO developed a number of research and training programs aiming at improving the understanding of windshear and promoting the awareness among the pilots (e.g. FAA 1988). Though there has been a marked reduction since then in the number of aircraft accidents/incidents in which windshear was cited a contributing factor, windshear is still considered as a hazard for aviation, especially when the windshear occurs at low level during an aircraft's takeoff and landing phases.

The Hong Kong International Airport (HKIA) is situated on a reclaimed island (Chek Lap Kok) surrounded by waters. To its south and north are high mountains with heights ranging from 400m to 950m above sea level. Apart from the usual windshear events due to convective weather occurred worldwide, a number of windshear events are rather unique locally, e.g. sea breeze front and terrain-induced windshear. Among all the aircrafts landing and takeoff at the HKIA in the past seven years (1998 – 2005), about 1 in 500 pilots reported significant windshear (i.e. headwind change of 15 kt or more). A majority of these events were reported in spring, particularly in the month of March and April. To assist pilots to prepare for landing or takeoff at HKIA under windshear conditions, the Hong Kong Observatory (HKO) has been operating a world-class Windshear and Turbulence Warning System (WTWS) since the opening of the airport in 1998 to alert pilots of significant windshear over and in the vicinity of HKIA. It has continuously been enhanced, with the latest achievement being the implementation of the world's first LIDAR (LIght Detection And Ranging) Windshear Alerting System (LIWAS). The aviation weather forecaster of the Observatory based on objective methods and meteorological assessment also issues warnings of windshear for broadcast to aircraft-in-flight via the Automatic Terminal Information Service (ATIS) of the airport.

As an aside discussion, rapid fluctuations of the headwind or tailwind encountered by an aircraft for less than a few seconds are referred to as turbulence, whereas a sustained change of the headwind or tailwind for more than a few seconds is defined as windshear. In severe turbulence cases, abrupt changes in the altitude and attitude of an aircraft, causing it temporarily out of control, could occur but in general turbulence only brings bumps or jolts and would not normally affect the intended flight-path significantly and is therefore not discussed here.

In this paper, we briefly talk about how windshear will affect the performance of an aircraft.   We then discuss what the major weather conditions would lead to significant windshear over HKIA.   We also talk about the technical details of HKO's WTWS and show how it is used to detect and alert the pilots of windshear.   Finally, we discuss about how WTWS, air traffic control (ATC) personnel and pilots, can join hands together to ensure aircraft safety at HKIA.

2.   Aircraft performance and windshear

An aircraft flies in the air by utilizing the lifting force exerted on its wings. The magnitude of the lift F_L can be expressed as:

$$F_L = \frac{1}{2} C_L \rho S V_a^{\,2}$$
(1)

where ρ is the air density, V_a the true air speed of the aircraft, S the cross-sectional area of the wings and C_L the lift coefficient (Tritton 1995).   The change of the lift (relative to the aircraft) as an aircraft flies into a windshear region can be shown to be (Fujita 1985):

$$\frac{\Delta F_L}{F_L} = -\frac{2}{V_a} \Delta u + \frac{k}{V_G} \Delta w$$
(2)

where Δu and Δw are respectively the change of the horizontal and vertical wind components, V_G the aircraft ground speed and k a parameter dependent on the lift coefficient and the attitude (technically speaking, the angle of attack) of the aircraft.

According to Eq. (2), as an aircraft flies into a region with horizontal wind drop and/or downdraft, lift will decrease, causing the aircraft to fly below the original flight-path (Fig.1).   This losing of altitude could become very dangerous during an aircraft's landing and takeoff phases. This is normally called "headwind
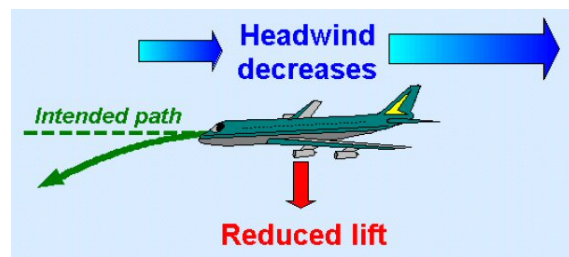

Fig.1 Due to the decreased headwind in a sinking shear case, the lift will be reduced and subsequently the aircraft would fly below its intended flight path.

loss" or "sinking shear" scenario.   Conversely, when an aircraft encounters horizontal wind increase and/or updraft, the lift will increase, causing the aircraft to fly above the original flight path.   This is called a "headwind gain" or "lifting shear" scenario.   Though not seems to be as critical as the headwind loss scenario, the headwind gain scenario could still cause trouble to the pilot during an aircraft's

landing as the aircraft could be caused to fly above the approaching glide-path, hence missing the touch down zone and have to make a go-around (Figs.2a-2d). During windshear situation, a pilot needs to respond in a timely manner to carry out corrective measures so as to ensure aircraft safety.
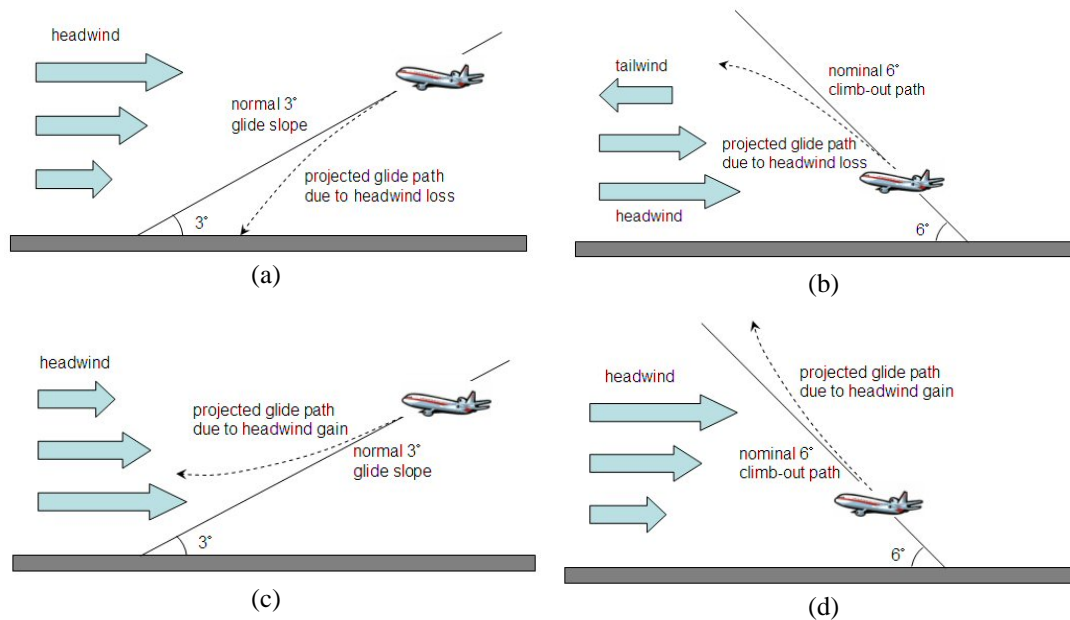

Fig.2   Windshear effects on aircraft landing or takeoff from an airport: (a) headwind loss during landing, (b) headwind loss during takeoff, (c) headwind gain during landing, and (d) headwind gain during takeoff.   (adapted from ICAO 2005).

3.   Local Weather Leading to Windshear over HKIA

Windshear can be caused by a wide variety of atmospheric phenomena. The five typical causes of windshear at HKIA are: winds blowing across terrain (terrain-induced), sea breeze, gust front (thunderstorm-related), microburst (thunderstorm-related), and low level jet.

3.1 Terrain-induced windshear

Winds flow across a high obstacle would be disrupted, causing wind speed and direction changes in the lee side (i.e. downwind) of the obstacle.   When winds of 15 knots or higher blow across the hills on Lantau from the east, southeast, south and southwest, windshear may occur near the airport (Fig.3a).   Furthermore, high winds may come from the northwest through northeast sectors across the hills over the northwestern part of the New Territories to affect HKIA (Fig.3c).   On windy occasions such as the approach of a tropical cyclone (Shun *et al.* 2003), air streams of

high wind speed may emerge from the mountain gaps. Lying between these high-speed air streams are air streams of lower wind speed which could be traced back to the flow over the mountain peaks. Hence, as an aircraft approach or depart from HKIA, it may traverse through alternating high-speed and low-speed air streams, leading to headwind losses (sinking shear) and gains (lifting shear) at different locations along the approach and departure corridors (Fig.4a). When the aircraft flies from a low-speed air stream to a high-speed air stream, it may experience a large headwind gain, leading to a lift of the aircraft. These lifting/sinking shears occur irrespective of whether there is accompanying precipitation or not.
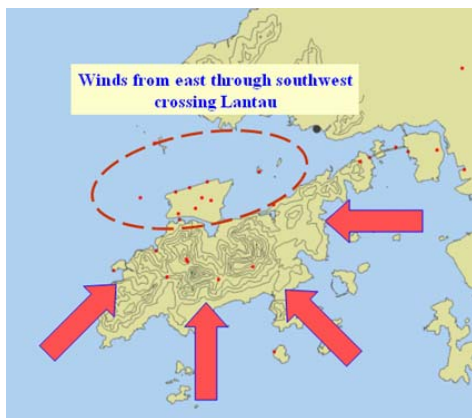

Fig.3a Terrain-induced windshear case due to wind flow disturbed by Lantau Island.
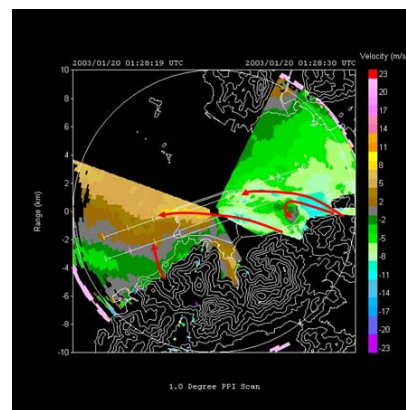

Fig.3b LIDAR radial velocity image showing the complex wind flow behind the Lantau Island.

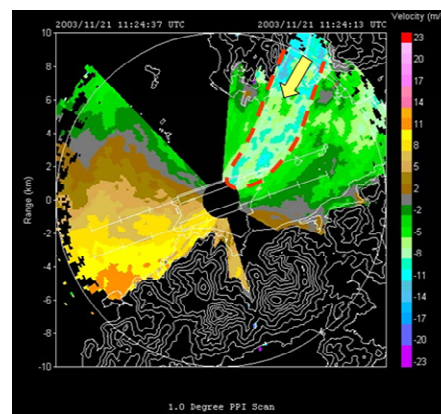Fig.3c Terrain-induced windshear due to wind flow disturbed by mountains to the northeast of HKIA.

Fig.3d LIDAR radial velocity image showing the complex wind flow behind the mountains to the northeast of HKIA.

Besides alternative high and low wind speed regions, the cross mountain flow may also generate even complicated localized flows such as horizontal vortices, vertical rotors or hydraulic jumps (ICAO 2005). These features may bring significant windshear to HKIA and affect aircraft safety. Terrain-induced windshear could occur almost all-year round with the most frequent occurrence in spring.
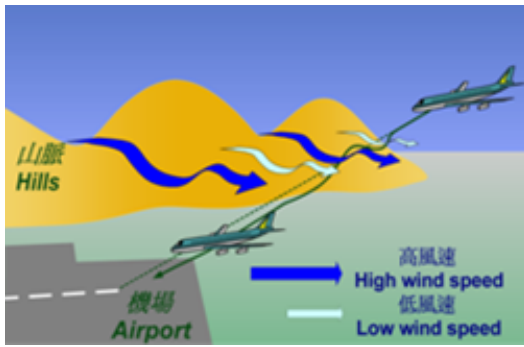
Fig.4a The regions lying to the lee side of the mountain peaks will have low speed wind but those areas behind the mountain troughs will have gap flow of high wind speed.
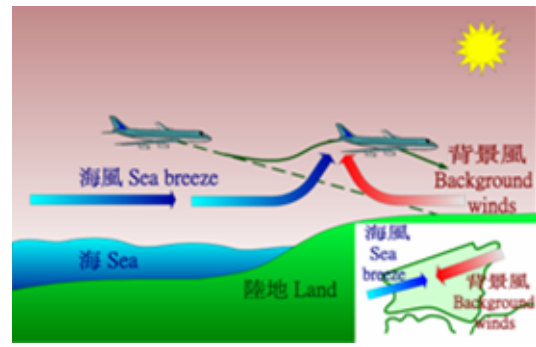

Fig.4b An aircraft may encounter windshear over the region where the sea breeze meets the prevailing/background wind.
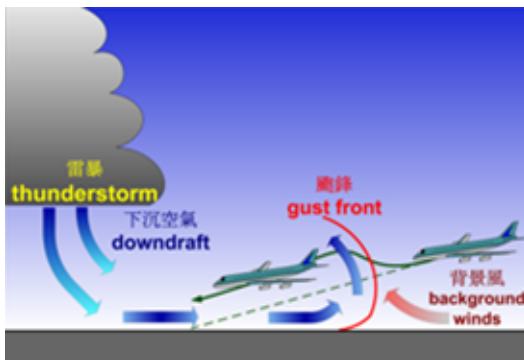

Fig.4c A gust front may cause an aircraft to deviate from the original flight path.
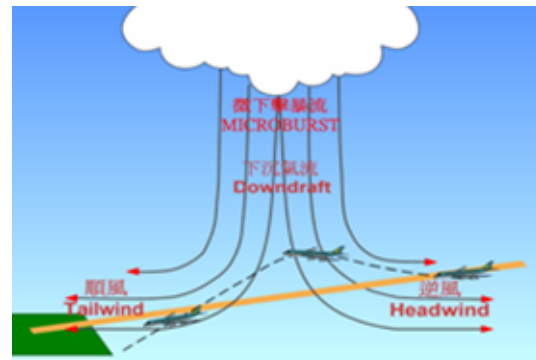

Fig.4d A microburst may cause an aircraft to deviate from the original flight path.
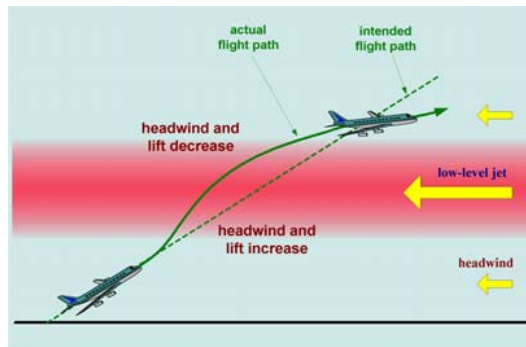

Fig.4e Windshear due to the low level jet.

3.2 Sea breeze windshear

As HKIA is built on an island, daytime heating may trigger convection over the landmass and subsequently the formation of sea breeze blowing towards the aerodrome from the surrounding waters (Lee and Shun 2003). Sea breeze usually develops under fine weather and light wind conditions. At HKIA, the onset of sea breeze is typically characterized by winds turning westerly over the western part of the airport. With prevailing easterly winds blowing in the background, significant

windshear in the form of headwind gain to an aircraft may develop along the runways (Fig.4b). While not frequent, windshear of 20 knots or greater associated with sea breeze may occur under background easterly winds of 10 knots or higher. Such a weather setup occurs more in winter and spring.

3.3 Gust front windshear

A severe thunderstorm is normally associated with intense convection which might subsequently bring violent downdraft and heavy rain to the areas affected. The descending air is cool and dense, and spreads out on hitting the ground. The leading edge of the cool air is called the gust front. Once formed, gust fronts can move great distances. Some might also last long after the parent storm dissipates. Aircraft flying across a gust front may normally encounter increased headwind and lift (Fig.4c). Thunderstorms could form almost everywhere nearby HKIA and therefore gust front could affect the airport nearly in all directions. As it is associated with thunderstorm, gust front normally occurs during the rainy season.

3.4 Microburst windshear

Microburst is the most violent form of downdraft from a thunderstorm. It is characterized by an intense and localized descent of cool air, causing a sudden outflow of horizontal winds above the ground with a typical horizontal extent of a few kilometres (Fujita 1985). An intense microburst could induce damaging winds as high as 75m/s. When an aircraft flies through a microburst, it may first encounter an increasing headwind and lift, then a downdraft from above, followed by an increasing tailwind and sink (Fig.4d). Microburst is considered as one of the most damaging weather to air transport. More than 500 fatalities in aircraft accidents in USA have been attributed to microburst since 1970 (Fujita et al., 1990). When microburst is observed/detected/reported over an airport, most pilots would not take off or make a landing to ensure safety.

Depending on the development stage of a thunderstorm, its motion and relative distance with respect to the flight-path of the aircraft, the windshear associated with a microburst could show different characteristics compared to the conventional one, i.e. headwind gain and lift preceding a downdraft followed by headwind loss and sink. A microburst could be asymmetric which has winds on one side stronger than the other side. In certain cases, the column of downdraft from a microburst could hit the ground at an angle rather than vertically downward. Hence, as an aircraft flies through a microburst, it may encounter windshear differently.

3.5 Low-level jet windshear

A low-level jet is a narrow band of strong winds in the lower atmosphere. Windshear arising from a low-level jet is relatively infrequent in HKIA (Lau and Chan 2000).   When an aircraft departing from the airport ascends and enters the jet, it will experience increasing headwind and lift.   As it departs the jet, however, the headwind and lift would drop again (Fig.4e).   By virtue of its flying usually against the prevailing wind, a landing aircraft passing through a jet will also encounter the same sequence of headwind changes.   However, since a landing aircraft usually descends on a small gradient (i.e. 3 degrees glide-path) than a departing aircraft, the extent of headwind changes it would experience is generally less than that for a departing aircraft.

Statistically speaking, most of the windshear cases occurred at HKIA are caused by the winds blowing across the mountains surrounding the airport.   Based on pilot report statistics, terrain-induced windshear accounts for about 70% of all the windshear reports received.   The 2nd most prominent windshear type is the sea breeze which accounts for roughly 20% of all the windshear events.   The gust front, microburst and low-level jet induced windshear in total account for the rest of the 10% of the reported events.   These statistics would however be considered as indicative information since, for example, pilots tend to avoid landing/takeoff during thunderstorm and so the frequency of gust front and microburst is probably underestimated.
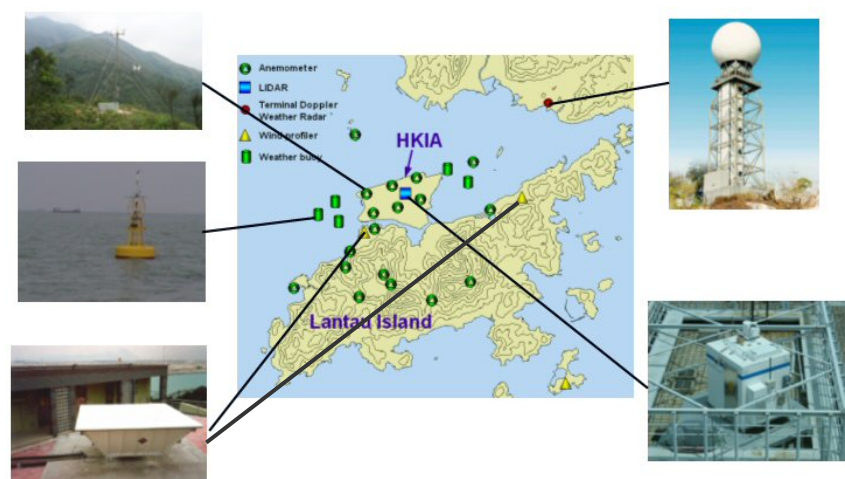

Fig.5   The HKO has implemented a comprehensive meteorological monitoring system over and around the HKIA for detecting windshear conditions to support the airport operations.

4   The HKO Windshear Detection System

In order to monitor and detect the windshear conditions over HKIA, the Observatory implemented one of the most comprehensive and sophisticated windshear and turbulence warning systems in the world to provide timely alerting service for all arriving and departing flights.   The system is composed of a number of state-of-the-art weather sensors including: a Terminal Doppler weather radar (TDWR), a suite of wind sensors consisting of a number of land-based anemometers and strategically distributed weather buoys over the waters around the airport island, a number of wind profilers, and a pulsed Doppler LIDAR (Fig.5).

4.1 Terminal Doppler Weather Radar (TDWR)

A Terminal Doppler Weather Radar emitted pulsed microwave of 5cm wavelength out to the air to detect any raindrop, ice, snow, grauple or hail (which are known as hydrometeors) formed in the atmosphere (Fig.6a) (Fujita *et al*. 1990, Rinehart 2004). Through analyzing the intensity and the frequency shift (due to the Doppler effect) of the reflected wave, a TDWR can calculate the concentration and the movement of the
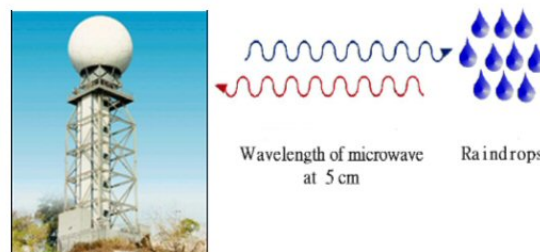

Fig.6a A TDWR utilizes microwave of 5 cm wavelength and the Doppler principle to detect the intensity and movement of raindrops and ice particles in the air.
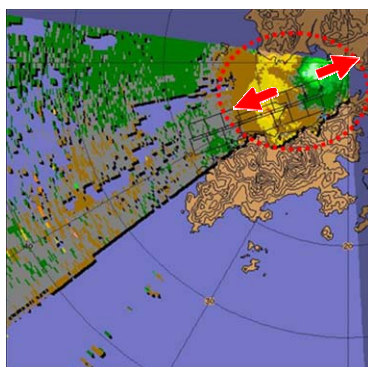

Fig.6b   A microburst case as detected by TDWR. In the figure the "warm" colours (i.e. brown, yellow and pink) represent radial velocity away from the radar whereas the "cool" colours (i.e. green, blue and purple) represent radial velocity towards the radar.
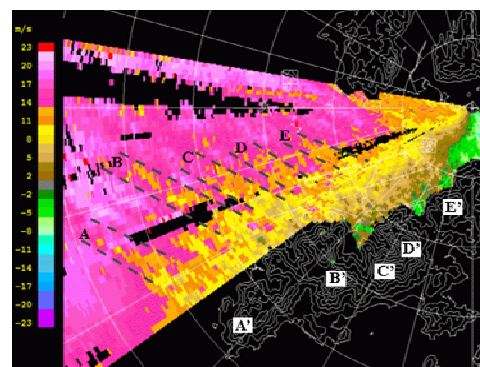
Fig.6c   Terrain-induced windshear as detected by TDWR during the approach of a Severe Tropical Cyclone (Hagupit, 11 Sep 2002). Shown are some alternating high (in pink) and low (in yellow) wind speed regions.

hydrometeors under monitoring. The HKO TDWR was purposely built to serve the terminal area of the airport. Its mission is to detect windshear and microburst associated with convective storms so as to enhance the safety of aircraft landing and takeoff from HKIA. The radar is strategically located at Tai Lam Chung, about 12km northeast of HKIA so that it has a clear view of the runways, airport approach and departure zones (Fig.5). Figures 6b and 6c show some windshear cases detected by TDWR.

4.2 Anemometer network

The Observatory operates a number of land-based automatic weather stations over the Chek Lap Kok Island and the surrounding areas to measure the winds around the airport (Fig.5). The remote stations on mountain tops and outlying islands are solar-powered and send the wind data back to the airport using radio links in real-time. Wind-powered generators have also been installed at a few remote stations to provide power during prolonged cloudy condition. Meanwhile, five weather buoys are also deployed in waters off the HKIA. A weather buoy consists of an automatic weather station mounted on a 3-metre diameter buoy. The weather buoy measures weather elements including wind, air pressure, temperature and humidity, and transmits them by radio links to the airport in real-time. It requires very little power and operates on solar power.

The buoy supplements the land-based weather stations by providing timely weather information over the data-sparse waters. Such information is particularly useful in estimating windshear over that area. Since the implementation of the buoys, they have enabled more timely issuance of windshear alerts to aircraft in sea-breeze situations, sometimes up to 15 to 30 minutes earlier.

4.3 Wind Profilers

A wind profiler is basically a vertically pointing Doppler weather radar. It can measure the winds at different heights above the ground through analyzing the UHF/VHF radio wave reflected from the small eddies in the atmosphere. With one wind profiler located at Sha Lo Wan and another one at Siu Ho Wan (Fig.5), the winds over the approach and departure areas of the airport are detected. Wind profiler data are updated every 10 minutes.

4.4 LIght Ranging and Detection (LIDAR)

Though the TDWR is very effective in detecting windshear under rainy conditions, it is not as effective under clear-air conditions due to the absence of hydrometeors as reflector for microwave. To further enhance windshear detection in dry weather, the Observatory has implemented a pulsed Doppler LIDAR system at the
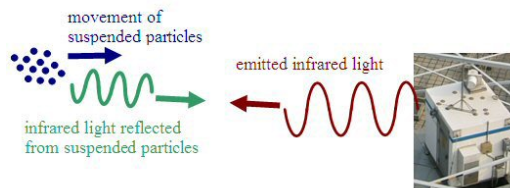

Fig.7a   A LIDAR uses an infrared laser beam with a wavelength of 2 μm to measure the wind by tracking the movement of suspended particles in the air. It works best in fine and rain-free conditions.
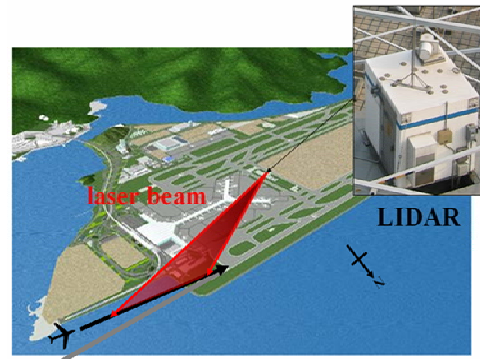

Fig.7b   LIWAS glide-path scanning strategy for windshear detection over HKIA.

airport since mid-2002. The LIDAR system is strategically placed on the roof-top of the Air Traffic Control Complex between the two parallel runways for scanning the approach and departure corridors of both runways. Operating on a principle similar to that of TDWR, LIDAR emits eye-safe laser pulses of wavelength of 2μm for detecting the movement of tiny particles (known as aerosols) in clear-air to obtain the wind speed and direction aloft (Fig.7a). It is configured to perform sector scans at
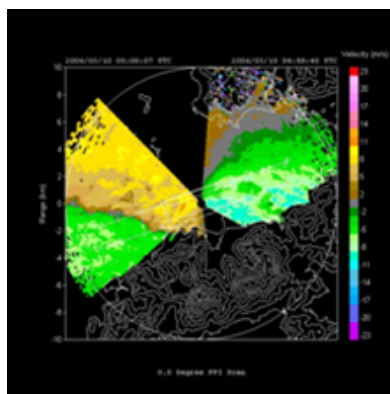

Fig.8a   LIDAR detection of a sea breeze front (the gray line) to the west of the runway thresholds around 1:00p.m. on 10 Mar 2006. Winds blowing away from the LIDAR are highlighted with blown/yellow/orange colour while those towards the LIDAR are highlighted in green colour.
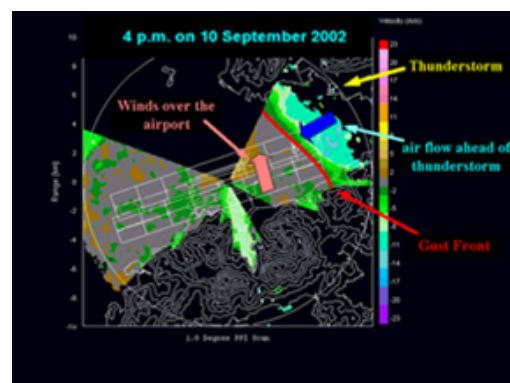

Fig.8b   LIDAR detection of a gust front emerging from a thunderstorm located to the northeast of HKIA.

several different elevation angles to monitor the wind conditions out to about 3 nautical miles (1 nautical mile = 1.86 km) from the respective runway thresholds.

The LIDAR is configured to scan towards the landing and takeoff glide-paths over HKIA.   A software is also developed for automatic identification of significant windshear along the glide-paths (see Section 4.5.3).   LIDAR data are collected automatically and are updated about once every two minutes.

Figures 3b, 3d show two examples showing the terrain-induced windshear conditions around HKIA as detected by LIDAR.   Figure 8a shows another example associated with the onset of sea breezes.   These examples demonstrate that LIDAR is rather effective in detecting windshear under dry weather environment.   Although the LIDAR works best in fine weather, it is also able to capture terrain-induced windshear 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 windshear (Shun 2003).   Figure 8b also shows that LIDAR could be used to detect the movement of a gust front originated from the downburst of a thunderstorm.   In short, the LIDAR has demonstrated its capability of detecting windshear 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 or low cloud.   The LIDAR has proved useful in supplementing the TDWR in windshear detection for a much wider range of weather conditions.

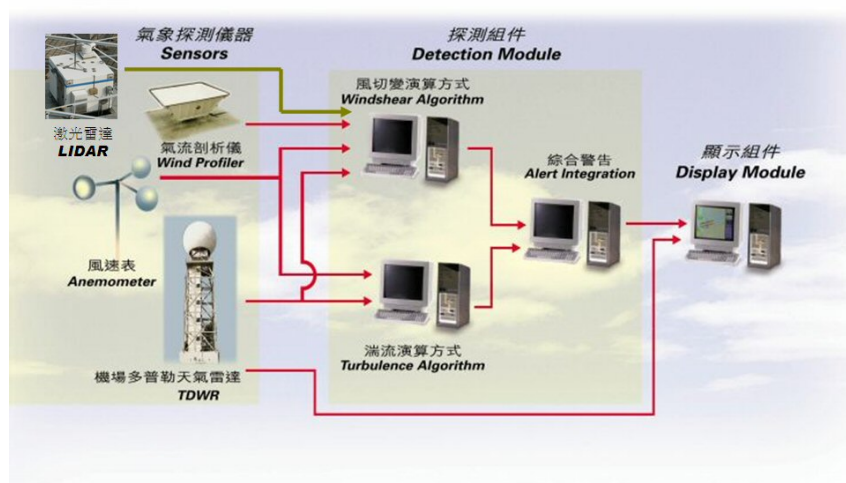4.5 Windshear and Turbulence Warning System

Fig.9   The HKO WTWS Windshear and Turbulence Warning System

To assist pilots to prepare for landing or takeoff at HKIA under windshear conditions, the Observatory has been operating a world-class Windshear and Turbulence Warning System (WTWS) since the opening of the airport in 1998 to alert pilots of significant low-level windshear and turbulence (Fig.9) (Shun 2003, Shun 2004). It has continuously been enhanced, with the latest achievement being the implementation of the world's first LIDAR Windshear Alerting System (LIWAS). WTWS is equipped with a suite of windshear and turbulence detection algorithms for processing data received from the above mentioned weather sensors. It is composed of a number of sophisticated algorithms for automatically detecting low-level windshear over the aerodrome and its vicinity, under clear-air and rainy conditions. In particular, three algorithms are described below.

4.5.1 AWARE

An anemometer based windshear detection algorithm called AWARE (Anemometer-based Windshear Alerting Rules – Enhanced) has been developed by the Observatory and launched for operation in mid-2004. Based on wind readings at the runway anemometers, Tai Mo To and the weather buoys, AWARE seeks every ten seconds headwind changes along the two runways. It has been demonstrated to

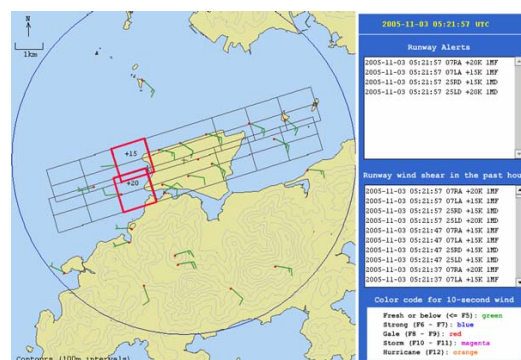Fig.10 Sample product of AWARE. It successfully detected a sea breeze front lying to the west of both the south and north runways.

be rather effective in detecting boundary layer windshear caused by sea breeze (Fig.10).

4.5.2 TDWR

The TDWR is equipped with a computerized algorithm for automatically detecting severe weather systems under rainy conditions around HKIA. It makes use of a variety of methods to minimize undesirable radar return from the ground and moving targets such as birds, aircraft and automobiles, etc. over and in the vicinity of HKIA. It is particularly designed for detecting the thunderstorm-induced windshear phenomena including microburst and gust front mentioned in Section 3 above. A typical microburst or gust front has quite distinctive wind patterns in the form of

difference in wind speed from one side of the weather feature to the other side as revealed by the radar's Doppler velocity (Fig.6b). The HKO TDWR is equipped with a sophisticated software for detecting the presence of such wind patterns. Once detected, it will generate alert automatically for attendance of air traffic controllers. TDWR is a well-proven technology for detecting microburst and gust front at a number of international airports (Merritt 1987). The TDWR is able to provide an updated alert as fast as a minute or less under thunderstorm weather conditions.

4.5.3 LIWAS

The LIWAS utilizes: (a) LIDAR scans towards the landing and takeoff flight paths to measure the winds to be experienced by aircraft (Fig.7b), and (b) a sophisticated software developed by the Observatory for identifying significant windshear on the glide-paths and for issuing windshear alerts automatically. The automatic LIWAS windshear alerts, available on a minute-to-minute basis, have been fed in real-time into the WTWS for relay to aircraft via air traffic controllers since December 2005. Figure 11 shows a sample product of LIWAS indicating the wind profiles along the glide-paths of the 8 runway corridors of HKIA.
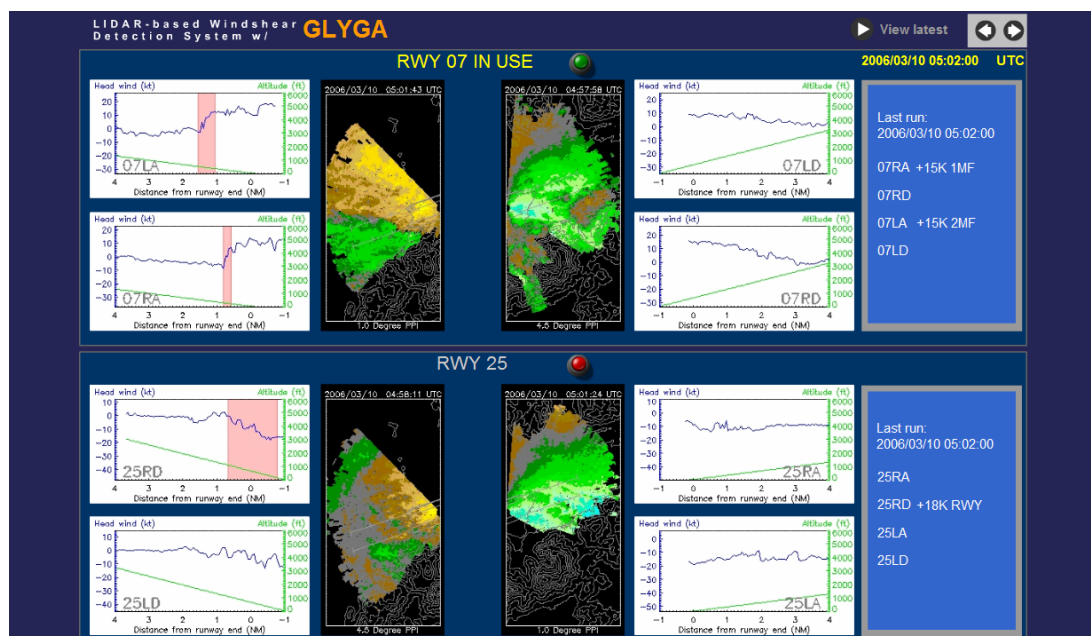
Fig.11 The Observatory developed the first algorithm in the world to detect windshear automatically based on the LIDAR wind data collected along the flight path (right figure). Brown/yellow/orange colour shows wind blowing away from the LIDAR while green colour towards the LIDAR.

In short, the Observatory's WTWS is the world first windshear alerting system to utilize LIDAR and weather buoys, in addition to the sate-of-the-art TDWR and

conventional anemometer network, covering both rainy and dry weather conditions. (Fahey 2006)

5   Windshear Alerting Services

The WTWS automatically integrates microburst and windshear alerts generated by the TDWR and windshear alerts generated by AWARE, LIWAS, and other algorithms into consolidated alerts for relay to pilots by air traffic controllers. Aircraft operated at HKIA are alerted of low-level windshear in two ways:

- Windshear alerts passed by air traffic controllers -
  Alerts of windshear within 3 nautical miles of the runway thresholds generated automatically by the WTWS are passed to aircraft via ATC.
- Windshear warnings broadcast on Automatic Terminal Information Service -
  Warnings of windshear issued by the Aviation Forecaster are broadcast to aircraft on Voice-ATIS and D-ATIS (Digital ATIS).
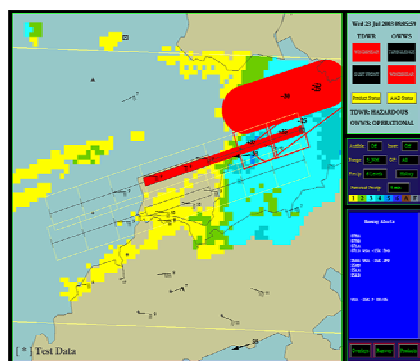

Fig.12a The WTWS Graphical Situation Display installed at the Airport Control Tower showing the windshear and turbulence alerts over various runway corridors at HKIA. Red hollow circle or ellipse – windshear alert generated by TDWR.   Red-filled circle or ellipse – microburst alert generated by TDWR. Red hollow rectangular shape – windshear alert generated by AWARE.

Fig.12b The WTWS Alphanumeric Alert Display installed at the Airport Control Tower showing the windshear and turbulence alerts over various runway corridors at HKIA.

Alerts for windshear are classified into two levels: "Microburst Alert" and "Windshear Alert".   Windshear with runway-oriented wind speed loss of 30 knots or greater and accompanied by precipitation are referred to as Microburst Alert.   This is automatically generated by the TDWR.   Windshear with runway-oriented wind speed loss or gain of 15 knots or greater (except microburst) are referred to as Windshear Alert.   The Microburst or Windshear Alert passed by ATC includes the

intensity and type of alert (i.e. microburst or windshear), the magnitude of the runway orientated wind speed difference and the location (final approach or departure area as appropriate).   Both graphical and textual alerts are provided simultaneously (Figs.12a, 12b).   Besides, all aircrafts which encounter significant windshear are requested to report the event to the ATC Tower and the Observatory.   These reported events together with the WTWS detected windshear alerts would then be relayed via ATC Tower to the following aircraft to alert them of the latest windshear conditions.

Using pilot reports, the Observatory has been monitoring the performance of the windshear alerting services.   The accuracy of WTWS on windshear detection has been continuously improving since its operation in 1998 (Fig.13).   In the past three consecutive years, over 90% of the windshear events reported at HKIA were successfully

Fig.13   The POD (Probability of Detection) of HKO Windshear Alert and Warning Service.

covered by windshear alerts/warnings issued by the Observatory.   Those undetected were of moderate intensity or very transient.   The majority (almost 70%) was captured by LIWAS.   The rest was captured by TDWR, AWARE and the forecaster. Meanwhile, the false alarm ratio has also been decreasing, indicating that the skill of the WTWS has been improving continuously.

Experience indicates that most of the local windshear events are caused by the winds disrupted by the mountains near HKIA, including winds associated with the passage of tropical cyclones and strong monsoon.   The LIDAR has also shown that windshear is sporadic and transient (HKO/IFALPA 2005).   In other words, a wind speed loss/gain sequence experienced by an aircraft may be experienced rather differently by the subsequent aircraft.   Some aircraft may experience windshear and/or turbulence, while others do not, even though the weather conditions are broadly the same.   In this connection, HKO works closely with the Civil Aviation Department in coordinating the provision of windshear alerting services at HKIA. HKO and CAD, together with GFS, International Federation of Air Line Pilots' Associations (IFALPA), International Federation of Air Traffic Controllers' Associations (IFATCA) and airline representatives hold regular meetings to review the windshear service and discuss further enhancements.   Meanwhile, the Observatory has continuously requested pilots to report via ATC of any windshear

encountered. The Observatory also continuously acquires on-board flight data from aircraft arriving/departing HKIA for post-analysis to enhance the understanding of windshear causes for fine-tuning the alerting algorithms. Furthermore, the Observatory, together with IFALPA has published a booklet to promulgate the knowledge of local windshear among aviation community and to encourage pilots to provide feedbacks to the Observatory (HKO/IFALPA 2005). In short, the collaboration among the Observatory and the users has been proved to be important for continuously improvement of the windshear alerting services at HKIA.

6   Future Development

In consideration of the demonstrated performance of the LIDAR in operational windshear alerting in non-rainy conditions, another LIDAR is being acquired at HKIA. This second LIDAR, scheduled for installation in early 2007, will serve as the back up to the existing LIDAR. It will also provide improved coverage over the northern runway over which most of the landing approaches are made. Meanwhile, performance evaluation is underway to refine the LIWAS algorithms. Research is also being conducted to explore the use of the LIDAR data for turbulence detection. In this connection, a plan for upgrading a fixed-wing aircraft of GFS to provide meteorological measurements for enhancing the turbulence alerting methods of WTWS is being explored. The weather data collected by the aircraft could also be used for continuous improvement of the windshear alerting methods.

To enhance the provision of windshear and turbulence information to pilots, HKO is actively looking into the feasibility of uplink of real-time windshear and turbulence information to the cockpit. Prototype windshear and turbulence products in graphical format are being developed for future uplink applications.

References

1. FAA, 1998: *Pilot Windshear Guide* (1988). Federal Aviation Administration, Advisory Circular No. 00-54.
2. Fahey, T.H. III, C.M. Shun, A. VanGerpen, J. Asano & T. Nguyen, 2006: Low Altitude Wind Windshear Hazards: Ground Based Detection and Commercial Aviation User Needs. *Proceed. 12th Conf. on Aviation, Range, & Aerospace Meteor., AMS, Atlanta, GA, USA*.
3. Fujita, T.T. and J. MacCarthy, 1990: The application of weather radar to aviation meteorology, in *Radar in Meteorology*, D. Atlas ed. Amer. Meteor. Soc., Boston.
4. Fujita, T.T., 1985: *The Downburst – Microburst and Macroburst*. Satellite and Mesometeorology Research Project (SMRP) Research Paper No. 210, National

Technical Information Service.

5. HKO/IFALPA, 2005: *Windshear and Turbulence in Hong Kong – Information for Pilots*, 2nd ed, Hong Kong Observatory. (available at http://www.weather.gov.hk/aviat/articles/WS-turb-booklet-web-ver.PDF.)

6. ICAO, 2005: *Manual on Low-level Windshear and Turbulence* (2005). International Civil Aviation Organization CAO DOC 9817.

7. Lau, S.Y. & S.T. Chan, 2000: Case Study of a Windshear Caused by Low-level Jet, *Hong Kong Observatory Technical Note No.101*.

8. Lee, O.S.M. & C.M. Shun, 2003: Observation of sea breeze interactions at and near Hong Kong International Airport. *Meteor. Appl.,* **10**, pp 1-9.

9. Merritt, M.W., 1987: Automatic detection of microburst windshear for terminal Doppler weather radar, P. Janota ed. *Digital Image Processing and Visual Communications Technologies in Meteorology, SPIE* **846**, Society Photo Optical.

10. Rinehart, R.E., 2004: *Radar for Meteorologists*. 4th ed. Rinehart Publications, USA.

11. Shun, C.M., 2003: Ongoing research in Hong Kong has led to improved windshear and turbulence alerts, *International Civil Aviation Organization (ICAO) Journal*, **58**, No.2.

12. Shun, C.M., 2004. Windshear and turbulence alerting at Hong Kong International Airport, *WMO Bulletin*, **53**, No.4.

13. Shun, C.M., S.Y. Lau & O.S.M. Lee, 2003. Terminal Doppler Weather Radar observation of atmospheric flow over complex terrain during Tropical Cyclone passages. *J. Appl. Meteor.*, **42**, pp. 1697-1710.

14. Tritton, D.J., 1995. *Physical Fluid Dynamics*, 2nd ed., Oxford University Press.