Reprint 488

Recent Developments to Enhance Windshear and Turbulence Alerting at the Hong Kong International Airport

C.M. Shun, C.M. Cheng & H.G. Wai

Proceedings of the 4th International Symposium on Electronics in the Air Transport Industry, SEATI 2003,

The Institute of Electrical Engineers Hong Kong, p.46-60

RECENT DEVELOPMENTS TO ENHANCE WINDSHEAR AND TURBULENCE ALERTING AT THE HONG KONG INTERNATIONAL AIRPORT

C.M. Shun, C.M. Cheng and H.G. Wai

Hong Kong Observatory
134A Nathan Road, Kowloon, Hong Kong, China

ABSTRACT

The Hong Kong Observatory (HKO) provides windshear and turbulence alerting service to aviation users of the Hong Kong International Airport (HKIA). This paper describes two recent developments to enhance the alerting service. They are the implementation of a LIght Detection And Ranging (LIDAR) System and the uplink/downlink of meteorological information to and from aircraft.

1 Introduction

Windshear and turbulence are weather phenomena that affect aircraft operation [ICAO (1987); HKO and IFALPA (2002)]. Windshear refers to a change in the wind direction and speed for typically tens of seconds resulting in a change in the headwind, i.e. winds blowing towards an aircraft. A decrease in headwind will result in a decreased lift that will cause an aircraft to go below the intended flight path (Fig. 1). While windshear at great heights is not usually a severe hazard, windshear at low levels, e.g. on approach and departure zones, requires timely and appropriate corrective actions to ensure aircraft safety.

Turbulence is caused by rapid irregular motion of air. It brings about rapid bumps and jolts. It does not normally affect the intended flight path of an aircraft significantly (Fig. 2). In severe turbulence cases, however, abrupt changes in the altitude and attitude of the aircraft may occur, resulting in a momentary loss of control and possibly injuries to passengers and flight crew.

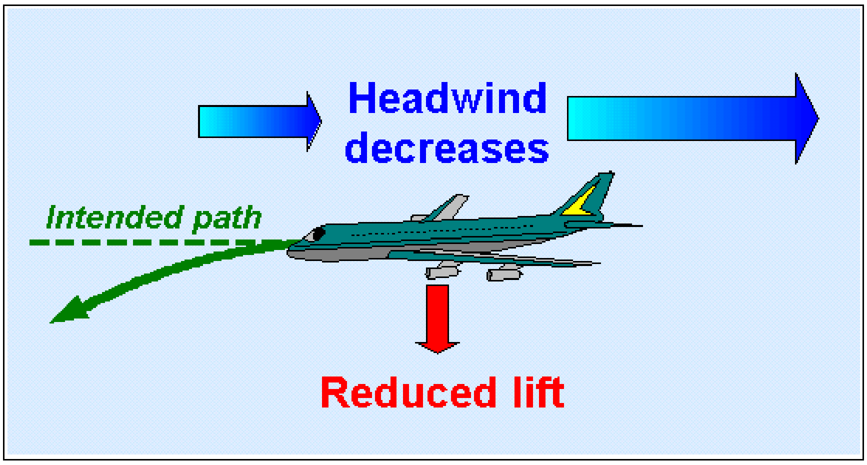


Fig. 1 Decreased headwind results in reduced lift to aircraft.

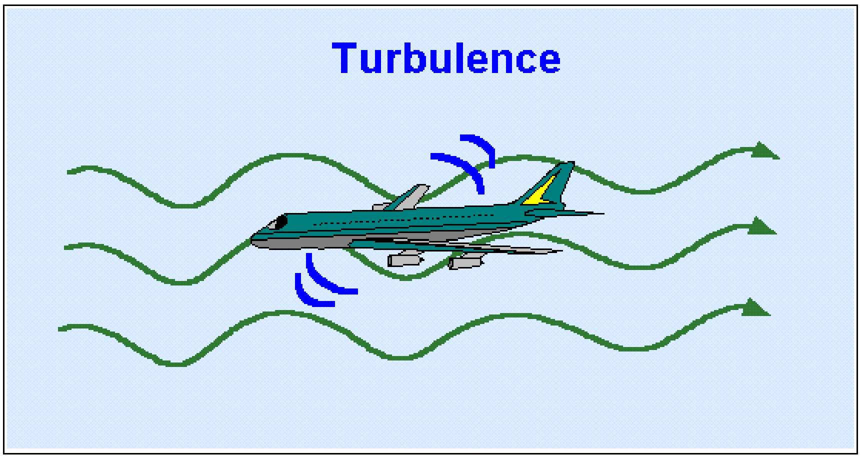


Fig. 2 Turbulence causes rapid bumps and jolts to aircraft.

Windshear and turbulence at HKIA can be caused by a wide variety of phenomena, including wind blowing across hilly terrain, thunderstorm, tropical cyclone, sea breeze and strong monsoon wind. HKO operates weather sensors to monitor windshear and turbulence conditions in and around HKIA. These include a Terminal Doppler Weather Radar (TDWR) for detecting windshear under rainy weather, a number of anemometers for measuring ground-level winds and two wind profilers for measuring winds aloft (Fig. 3). With a view to enhancing the windshear and turbulence alerting service, HKO has recently implemented a LIght Detection And Ranging (LIDAR) system, and is developing facilities for uplink/downlink of meteorological data to/from aircraft. These will be discussed in Sections 2 and 3 respectively.

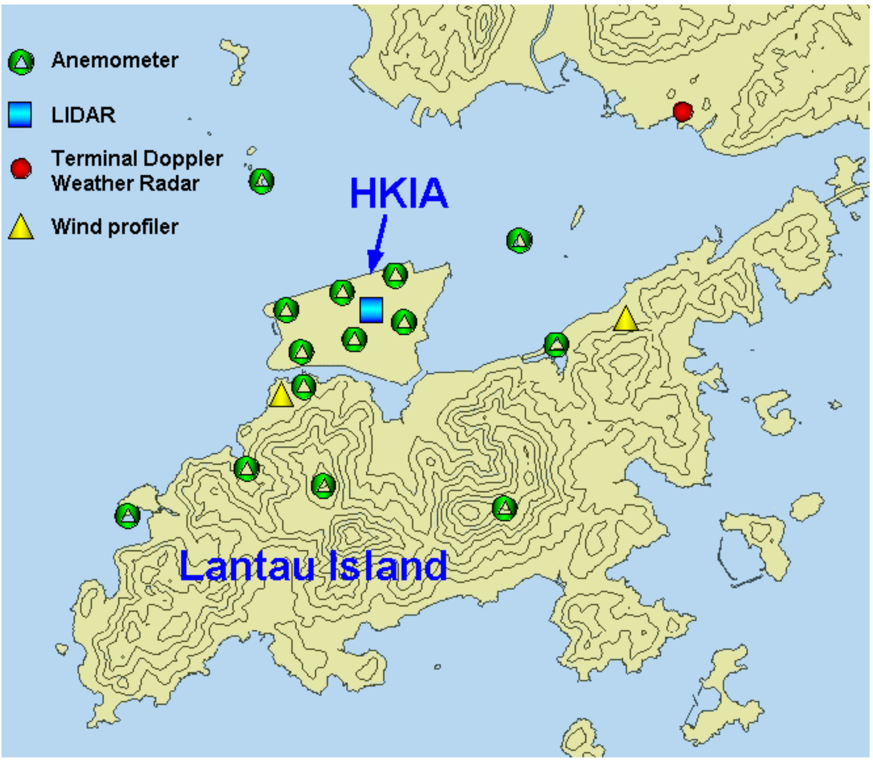


Fig. 3 Location of meteorological equipment.

2 LIDAR

Since the opening of the airport in 1998, the TDWR has been very effective in detecting windshear around HKIA in rainy weather, particularly in severe weather such as thunderstorms and tropical cyclones [Shun and Lau, 2000]. Windshear reports over the past few years, however, indicate that a majority of them occurred in rain-free weather. To enhance the detection of windshear under such rain-free conditions, a LIDAR system (Fig. 4) was installed in HKIA in mid-2002 [Shun and Lau, 2002].

2.1 Operating Principle

So how can the LIDAR system detect windshear in rain-free weather? The LIDAR operates by emitting pulses of infrared light into the atmosphere (Fig. 5). The infrared light, at 2 μm wavelength, is reflected back by dust particles or aerosols in the air. By comparing the shift in the frequency of the reflected light with that of the original emitted light, i.e. the Doppler shift, the radial component of the winds in the atmosphere can be measured. It should be noted that infrared light is easily absorbed by water droplets in precipitation, thereby limiting the performance of

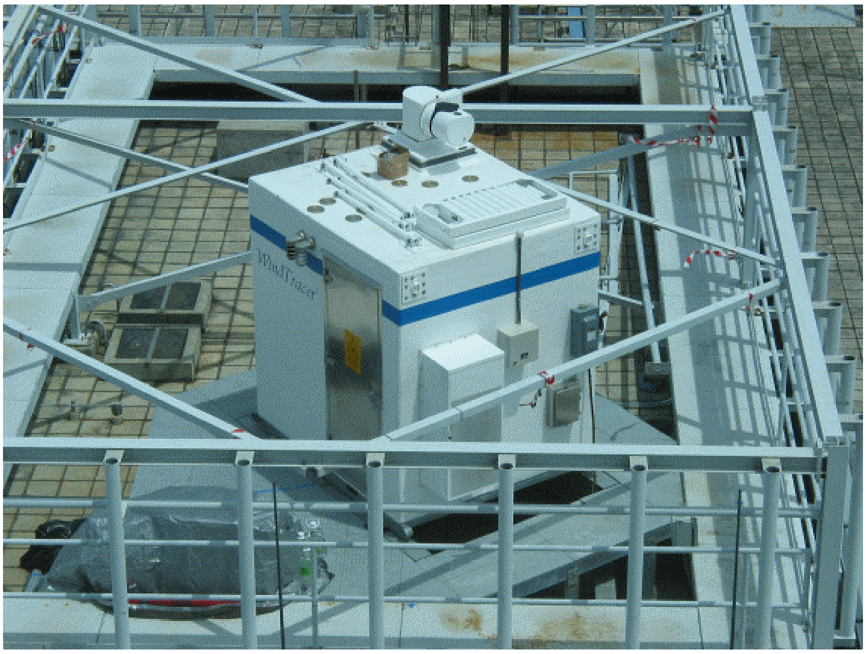


Fig.4 The Light Detection And Ranging (LIDAR) system at HKIA.

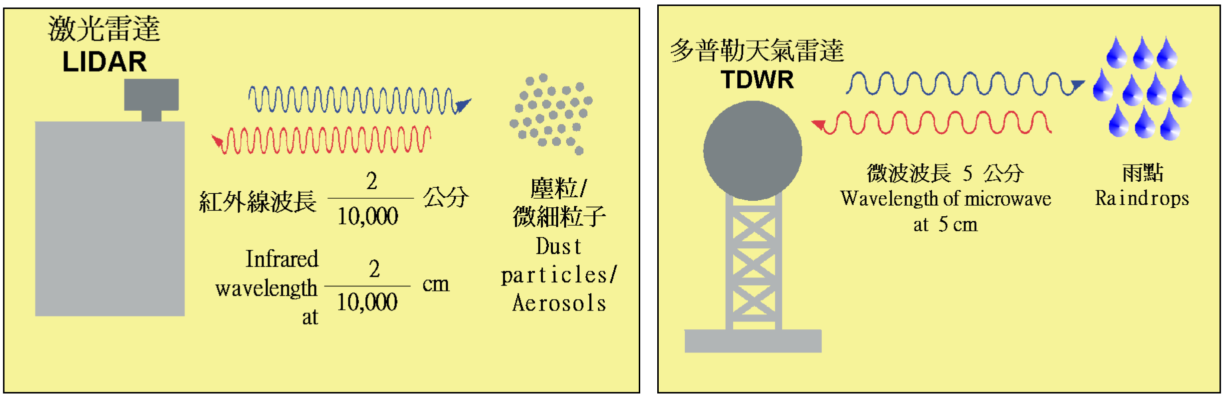


Fig. 5 Principle of operation of LIDAR and TDWR.

LIDAR in rainy weather. In contrast, instead of infrared light, the TDWR emits microwave at 5 cm wavelength, which is reflected back by rain droplets in the air (Fig. 5). As such, TDWR performs very well in rainy weather. Thus, the LIDAR and the TDWR complement one another – one works best in fine weather, the other in rainy weather.

2.2 Location and Mode of Operation

The LIDAR system was strategically placed on the roof-top of the Air Traffic Control Complex between the two parallel runways in HKIA [Shun and Lau 2002]. See Fig. 3 for location of the LIDAR. At this location, it overlooks the flight departure and approach corridors of both runways (Fig. 6). It can be configured to perform surveillance scans at different elevation angles. For trial operation, the LIDAR is set to scan at three elevation angles between 1 degree and 4.5 degrees to enable the monitoring of wind conditions out to three nautical miles (5.6 kilometres) from the respective runway thresholds. LIDAR data are collected automatically and are updated once every two minutes.

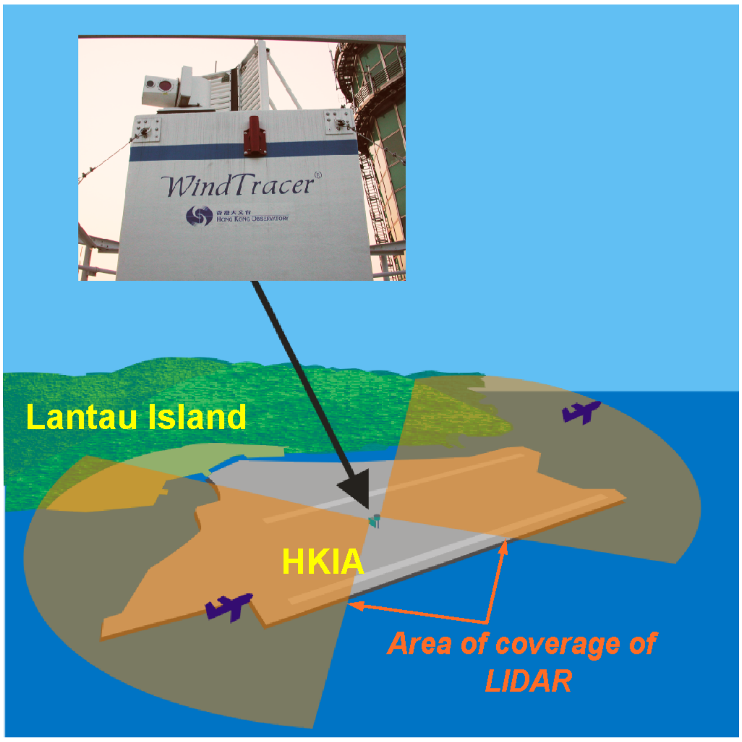
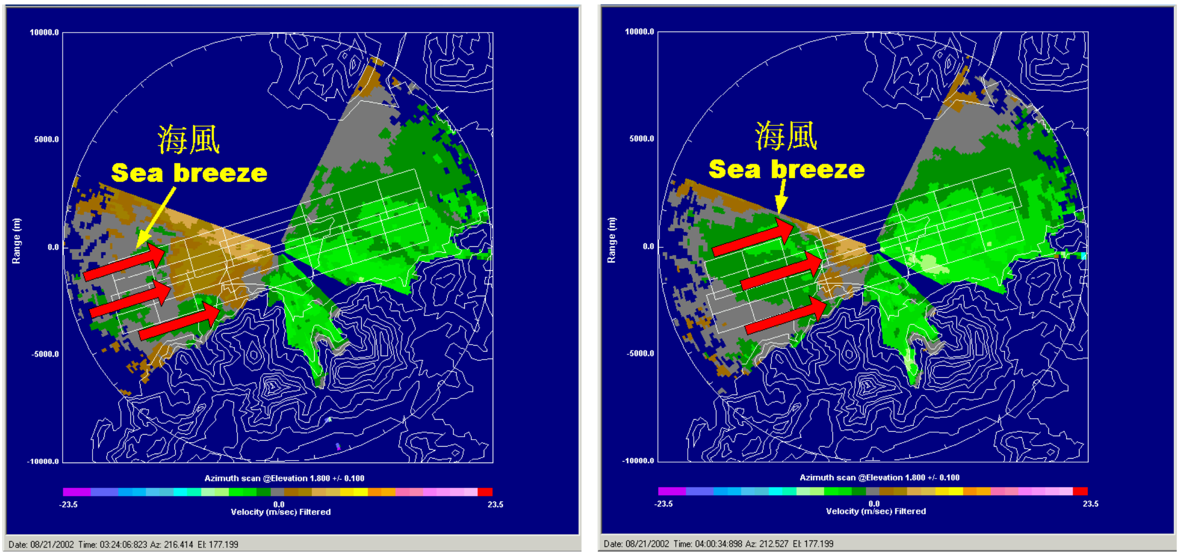


Fig. 6 Area of coverage of LIDAR.

2.3 Applications

In a matter of two months since its installation in mid-2002, the LIDAR has already captured some interesting cases. Figure 7 illustrates an example of sea breeze as observed by the LIDAR on 21 August 2002. Sea breeze at the HKIA usually approaches from the west and has been known to cause windshear to approaching and departing aircraft (Fig. 8). At 11:24 a.m. that morning, the LIDAR image (Fig. 7a) revealed that approaching from the west, the sea breeze appeared some 2 nautical miles to the west of the northern runway and about 1/2 nautical mile to the west of the southern runway. It is indicated by red arrows and the associated velocities are represented in green to gray colours in Fig. 7a. At this location, the LIDAR measured a headwind difference, i.e. windshear, of about 10 kt. Half an hour later, the sea breeze advanced eastward to the western end of both runways (Fig. 7b). At the same time, the windshear determined from the LIDAR rose to about 15 kt.

This agreed well with windshear of 15 kt reported by an aircraft landing on the northern runway from the west at that time. This shows the ability of the LIDAR to detect in advance the onset of sea breeze and the ensuing windshear – in the present case as much as an hour before detection by anemometers on the airfield. In effect, under fine weather, the LIDAR is capable of considerably extending the range of detection of windshear at the airport.



(a) 11:24 a.m. *(b) 12:01 p.m.*

Fig. 7 Approach of sea breeze (indicated by red arrows, in green to gray colours) to HKIA from (a) 11:24 a.m. to (b) 12:01 p.m. on 21 August 2002.

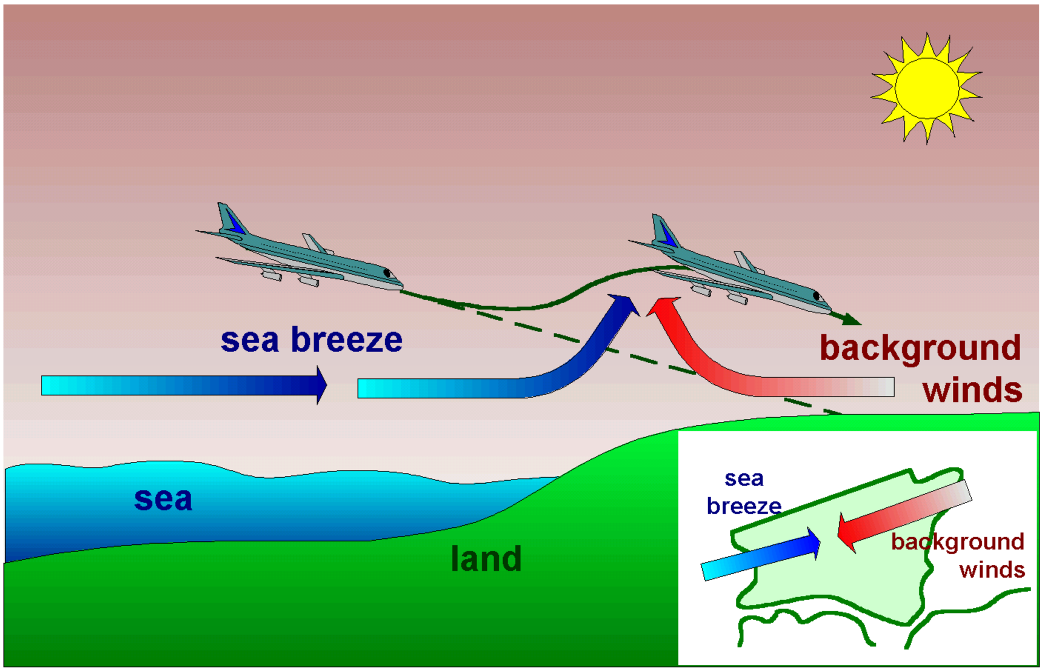


Fig. 8 Sea breeze at HKIA.

While the LIDAR is unable to measure winds within a rain area, it can still be useful in detecting windshear ahead of approaching thunderstorms. This is possible by virtue of the nature of thunderstorms. In mature thunderstorms, there is usually violent downdraft (descending flow of air) accompanying the rain. The descending air, being cool and dense, spreads out on hitting the ground. The leading edge of the cool air is called the gust front (Fig. 9). Aircraft flying across a gust front may encounter increased headwind and hence increased lift. Very often, the cool air near the gust front is dry enough to be detectable by the LIDAR. Figure 10 shows an example of gust front ahead of a severe thunderstorm approaching the HKIA from the northeast at about 4 p.m. on 10 September 2002. The northeasterly winds arising from the downdraft of the thunderstorm as detected by the LIDAR were indicated by a blue arrow. A gust front was discernible, as marked by a red curve in Figure 10. The change in headwind across the gust front was found to be about 20-27 kt. This agreed with a windshear report of 25 kt from an aircraft that landed on the northern runway from the east about 10 minutes later, by which time the gust front had moved over to the runways. This example illustrates the usefulness of the LIDAR in detecting windshear events ahead of severe weather.

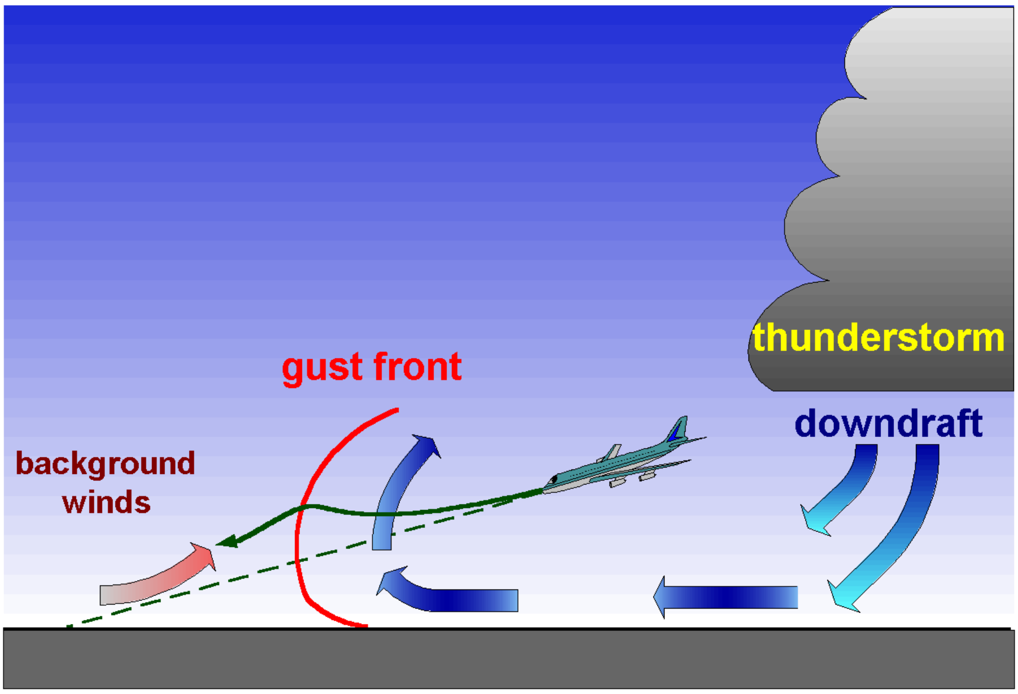


Fig. 9 Gust front forms ahead of thunderstorm.

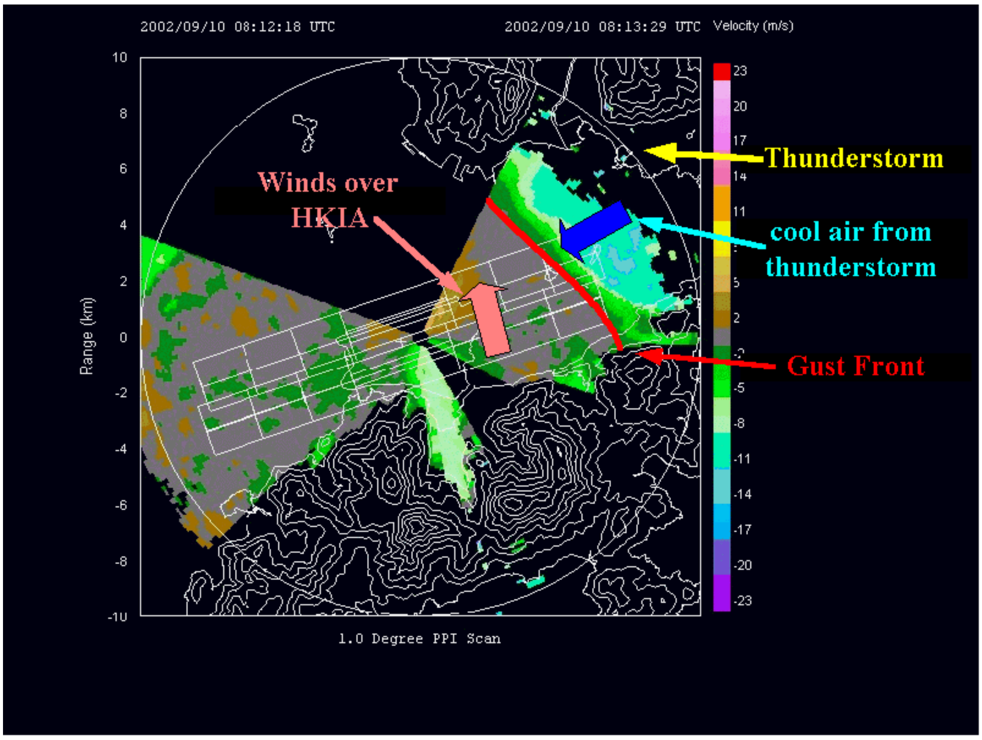


Fig. 10 The LIDAR detected a gust front ahead of an approaching thunderstorm at around 4 p.m. on 10 September 2002.

3 Uplink/Downlink of Meteorological Data

Prompt transmission of the latest weather information and alerts to aircraft is essential to their safe landing and taking off at the airport. At present, the weather information is transmitted to an aircraft in two ways, both by means of voice transmission:

(a) conversation between pilot and air traffic controller by radio; and

(b) broadcast on the Automatic Terminal Information System (ATIS) of the Civil Aviation Department of Hong Kong (CAD), which continuously disseminates such vital information as updated airfield conditions, meteorological reports and navigational aids serviceability information to aircraft departing from or arriving at HKIA.

With recent advances in telecommunications technology, it is increasingly viable for the digital transmission of weather information directly to the cockpit. It is also possible for direct transmission of meteorological data collected on-board aircraft to the meteorological office. The benefit of these so-called uplink/downlink capabilities (Fig. 11) is described below.

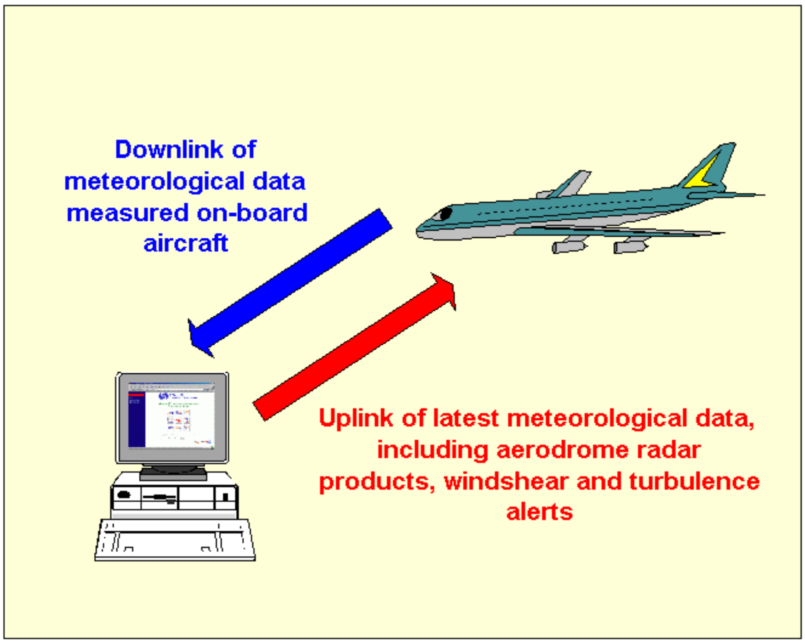


Fig. 11 Uplink/Downlink of meteorological data.

3.1 Benefit

Modern telecommunications technology has enabled transmission of information at greater speed and larger data volume than before. Facilities that take advantage of modern telecommunications technology for uplink and downlink of meteorological data are emerging, offering great potential in improving the aviation weather services, especially in the vicinity of the terminal area. The benefits may include the following:

(i) *Timeliness of weather information*

Weather information such as weather forecast and windshear and turbulence alerts can be automatically transmitted to the cockpit directly, thereby greatly minimizing the time delay for the pilot to obtain the latest weather information. This is particularly of value when warnings of severe weather, such as windshear and turbulence, are issued. With wider bandwidth in telecommunications, it is possible for up-to-the-minute weather information to be made available to aircraft throughout the course of take-off, in-flight and landing.

(ii) *Accuracy of weather information*

By means of digital telecommunications, weather information can be transmitted to the aircraft without human intervention. This can reduce possible errors, albeit rare, in message handling and in verbal communication.

(iii) *Provision of more weather products to aircraft*

The wider bandwidth of telecommunications will enable transmission of data not only in text but also in graphical form. A wider variety of useful weather products can be considered for uplink to the aircraft. These include: (a) aerodrome weather observation and forecast for local aerodrome as well as international aerodromes all over the world; (b) windshear and turbulence alerts; (c) weather products from terminal weather radar (Fig. 12); (d) weather satellite pictures. With such weather information at hand, pilot will have a better appreciation of the weather conditions during the entire course of flight.

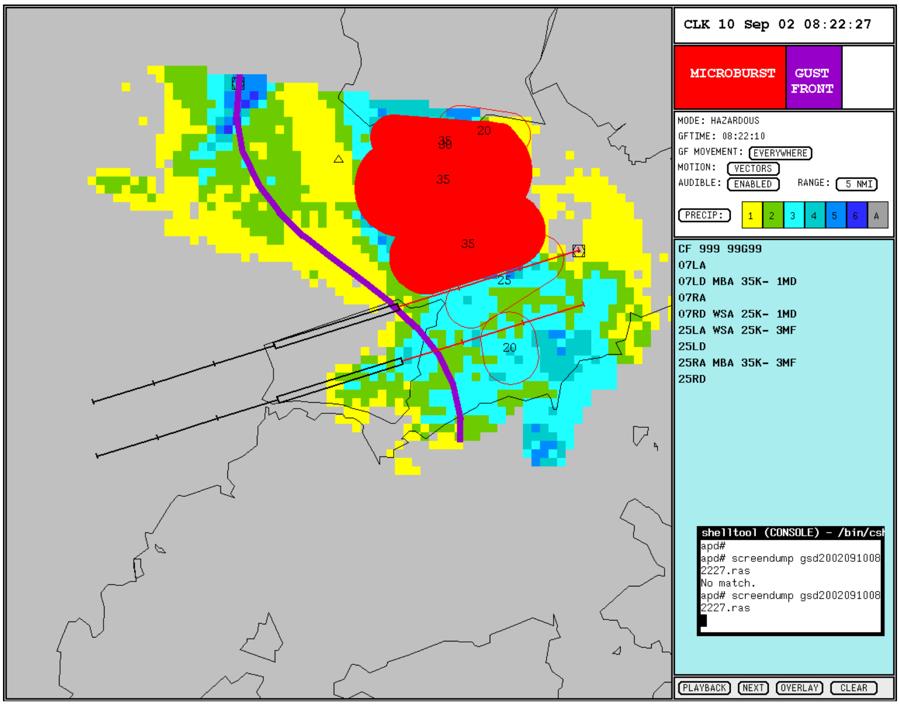


Fig. 12 Sample product from terminal weather radar. The areas in 'band-aid' shape represent locations with a headwind loss of over 30 kt. The purple line represents a gust front arising from thunderstorm and an increase of headwind of 15 kt or more can be expected across this gust front.

(iv) *Availability of meteorological data from aircraft*

Through telecommunications links, meteorological data collected onboard aircraft can be made available to the meteorological office. Such meteorological data represents the weather that an aircraft encounters first-hand. The data collected during the departing or landing phase of the aircraft is of particular importance because it can indicate the occurrence of windshear and/or turbulence on the ascent/descent path, and is very useful to windshear and turbulence alerting and in warning the following aircraft.

Data collected by aircraft can usefully supplement conventional weather observations, especially over data sparse oceanic areas. Such data provide valuable input to weather prediction models operated by many weather services in the world. Studies reveal that aircraft meteorological data has positive impact on the performance of weather prediction models, resulting in better forecast for aviation in general.

3.2 Uplink/Downlink Facilities

A number of facilities for uplink of meteorological information to aircraft have emerged in recent years. They include: the Datalink Automatic Terminal Information Service (D-ATIS) and Datalink VOLMET service (D-VOLMET). Both services were introduced by CAD in Hong Kong in 2001. They enable the pilot to more efficiently acquire knowledge of the latest runway weather conditions at HKIA and other operational meteorological information of Hong Kong. This includes, among others, the windshear and turbulence alerts issued for the HKIA. Other means of uplinking information are being explored and developed. It is expected that with the availability of wider bandwidth in telecommunications, more facilities will be developed for communicating a greater variety of useful weather products to the aircraft.

In respect of downlink of meteorological data, there are a number of applications currently available (Fig. 13):

(i) Automatic Dependent Surveillance (ADS) datalink;

(ii) Controller-Pilot Data Link Communications (CPDLC) datalink; and

(iii) Aircraft Meteorological Data Relay (AMDAR).

ADS and CPDLC are air traffic management datalink applications under the auspices of the International Civil Aviation Organization (ICAO). Primarily used for aircraft surveillance and air-ground communication, they are also capable of transmitting aircraft weather reports. In 2000-2001, HKO conducted trials with CAD in receiving automatic weather reports from aircraft overflying the South China Sea [Wai, 2002]. The trials demonstrated the capability of automatic reception of aircraft weather data via ADS and CPDLC.

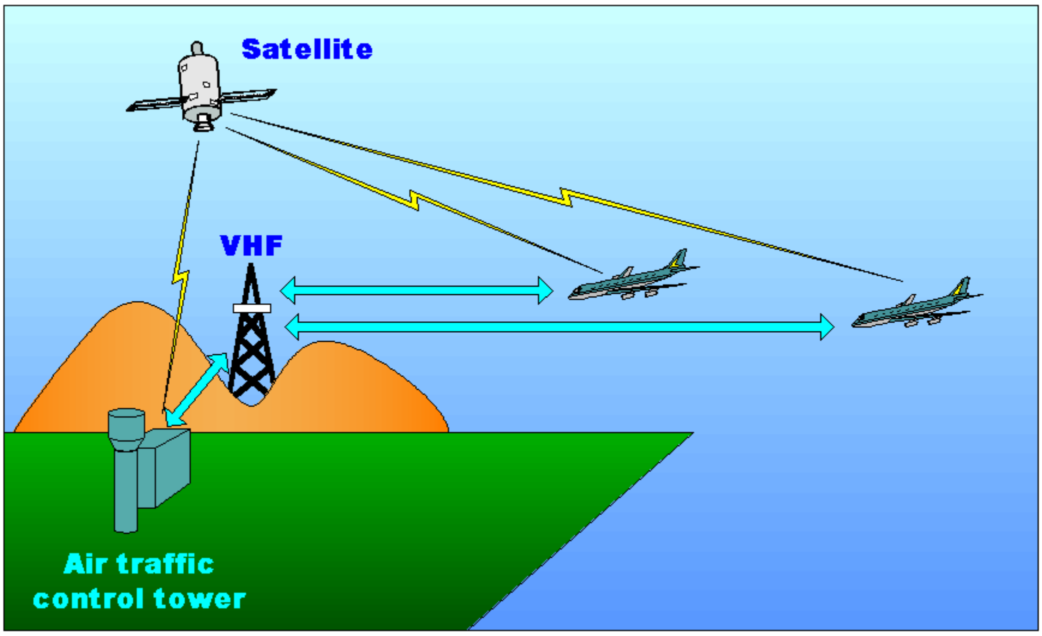


Fig. 13 Downlink of meteorological data via ADS/CPDLC datalinks and AMDAR.

Operating since the late 1990s, AMDAR is an aircraft weather observation programme under the auspices of the World Meteorological Organization (WMO). With the appropriate software installed on the aircraft computer, reports of winds, temperatures and turbulence can be downlinked automatically at pre-configured time intervals (during en-route phase) or height intervals (during ascent/descent phase). This provides a cost-effective means of obtaining meteorological data from aircraft. HKO started the implementation of an AMDAR programme in 2000 [Shun, 2002], when arrangement was made with overseas meteorological offices to collect meteorological reports downlinked from Australian and US aircraft landing at and taking off from HKIA. At present, over 7000 ascent/descent reports on average are received a day. HKO has also arranged with a local airline to conduct trial data collection with a view to further advancing the AMDAR programme for Hong Kong.

3.3 Applications of Aircraft Meteorological Data

Meteorological data collected during the departing or the landing phase of an aircraft is very useful because it provides useful information on the occurrence of windshear and/or turbulence nearby the airport. Figure 14 shows meteorological data taken by an aircraft landing at HKIA on 10 April 2002. From the data, two significant windshear events can be identified - one at about 2.4 nautical miles (Event A) and the other at about 0.8 nautical mile from touch down (Event B). Event A was associated with an increase in headwind (winds towards an aircraft) of over 15 knots while event B was associated with decreased headwind of more than 15 knots. This demonstrates that aircraft meteorological data with the necessary resolution is capable of capturing windshear events. This however is also an ideal world as currently aircraft are only downlinking at 300 ft resolution, i.e. not at the high resolution shown in Fig. 14. The real-time or near real-time availability of aircraft meteorological data with relatively high resolution is being explored with a view to further enhance the windshear alerting service.

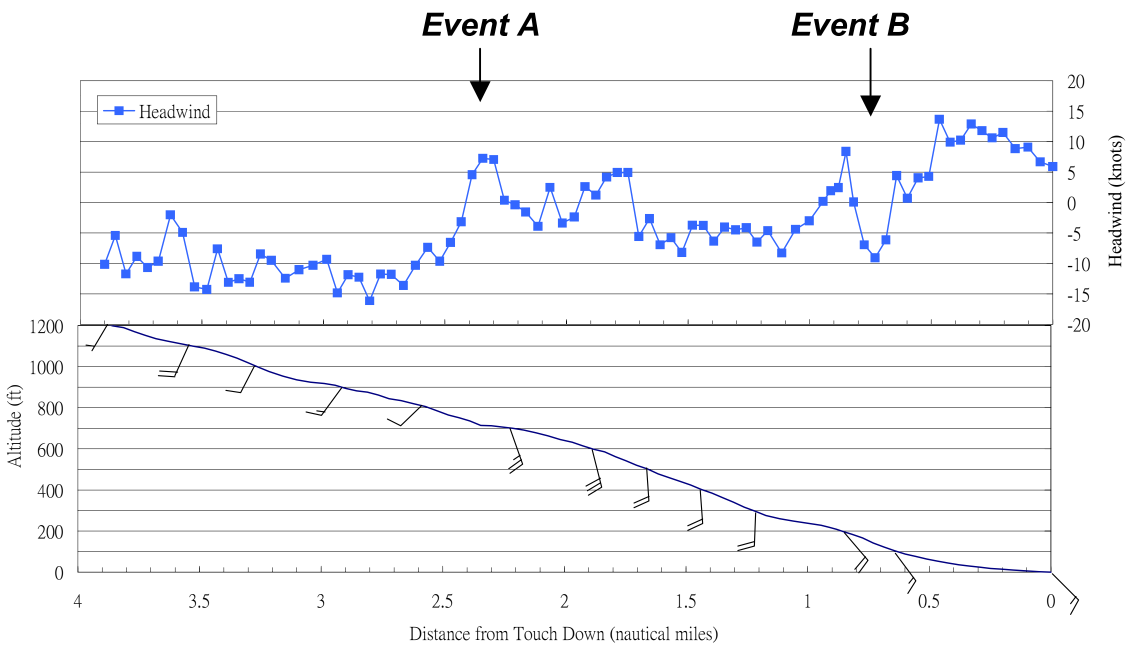


Fig. 14 Winds recorded on an aircraft landing at HKIA on 10 April 2002. The data indicated two significant windshear events with headwind change of over 15 knots.

4 Conclusion

With a view to enhancing the windshear and turbulence alerting service in Hong Kong, two developments have taken place recently. The LIDAR, which was installed in mid-2002, is now put into operational trial. HKO will collect the data over a period of time for analysis with a view to establishing and optimizing the functionality of the system. Preliminary analysis of the data indicates its usefulness in capturing windshear events under rain-free conditions. The LIDAR is expected to become fully operational in 2005.

Uplink/downlink of meteorological information to/from aircraft offers a useful means of transmitting real-time meteorological data, particularly windshear and turbulence information, to and from aircraft in flight. Development of new data links will enable more meteorological products, including windshear and turbulence alerts, satellite pictures, terminal weather radar products, as well as the latest weather forecast and warnings, to be transmitted to the aircraft. The possibility of aircraft transmitting meteorological data at higher resolution than present is being explored with a view to further enhance the windshear alerting service.

References

Hong Kong Observatory (HKO) and International Air Line Pilots' Association (IFALPA), 2002: 'Windshear and Turbulence in Hong Kong – information for pilots' (http://www.weather.gov.hk/aviat/articles/WS-turb-booklet-web-ver.pdf).

International Civil Aviation Organization (ICAO), 1987: 'Wind Shear', Circular 186-AN/122.

Shun, C.M., 2002: 'Collection and Applications of AMDAR Data in Hong Kong, China', Twelfth Session of the WMO Commission for Aeronautical Meteorology. Montreal, Canada, 16-20 September 2002.

Shun, C.M. and S.Y. Lau, 2000: 'Terminal Doppler Weather Radar (TDWR) Observation of Atmospheric Flow over Complex Terrain during Tropical Cyclone Passages', Proc. SPIE: Microwave Remote Sensing of the Atmosphere and Environment II, October 2000.

Shun, C.M. and S.Y. Lau, 2002: 'Implementation of a Doppler Light Detection And Ranging (LIDAR) System for the Hong Kong International Airport', 10th Conference on Aviation, Range and Aerospace Meteorology of the American Meteorological Society (AMS), Portland, Oregon, USA, 13-16 May 2002.

Wai, H.G., 2002: 'Development in respect of uplink/downlink of OPMET information in Hong Kong, China', ICAO Meteorology Divisional Meeting/Twelfth Session of the WMO Commission for Aeronautical Meteorology. Montreal, Canada, 9-27 September 2002.