HONG KONG OBSERVATORY

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WINDSHEAR AND TURBULENCE ALERTING SERVICE AT THE HONG KONG INTERNATIONAL AIRPORT – A REVIEW

by

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CONTENTS

Abstract

The Hong Kong Observatory (HKO) has been operating a windshear and turbulence alerting service at the Hong Kong International Airport (HKIA) since its opening in 1998. A review was conducted to look at the performance of the windshear and turbulence alerting service and to identify ways to further improve the service.

The review was based on studies of reports of windshear and turbulence made by pilots since airport opening and on the findings made by two international meteorological experts on windshear and turbulence. The windshear and turbulence reports include those obtained in the two rounds of intensive windshear reporting exercises conducted in 2000, with the active participation of pilots, airline operators and air traffic controllers.

The international experts concluded that the existing windshear and turbulence alerting facilities were a good system and provided a solid platform for now and to build on for the future. While the windshear and turbulence alerting service could be further improved, they considered that the alerting facilities were operationally state-of-the-art. Based on the experts' recommendations and results of detailed studies conducted by HKO, a number of improvement measures were introduced and implemented. By the end of 2001, the results of the improved measures of windshear and turbulence alerting were encouraging. HKO is proceeding with other measures to further improve the service.

摘要

香港天文台自一九九八年機場啓用以來爲香港國際機場提供風切變和湍流預警服務。天文台探討了風切變及湍流預警服務的表現，並尋求進一步提升服務水平。

這次探討是依據自機場啓用以來機師提供的風切變和湍流報告，以及兩位國際風切變及湍流專家的研究結果而進行的。有關風切變和湍流報告是包括二零零零年進行的兩次加密風切變及湍流報告活動所得的報告。飛機師、航空公司及航空交通控制人員均積極參與該兩次活動。

國際專家總結出，現行用以提供風切變和湍流預警服務的設施不但是一個良好的系統，亦爲日後建立改善措施提供了根基扎實的平台。雖然風切變和湍流預警服務尚有可改進之處，他們認爲設施已達世界先進水平。就專家所提出的建議及天文台的詳細研究結果，天文台至今已引進了多項改善措施，並予以實行。截至二零零一年年底爲止，經改良的風切變及湍流預警技巧取得了令人鼓舞的成績。天文台現正進行其他的改善措施，以求進一步提升服務水準。

Figures

1. Introduction

1.1 Windshear refers to a change in the headwind or tailwind sustained for more than a few seconds, resulting in changes in the lift to an aircraft. A decreased lift will cause the aircraft to go below the intended flight path. In the presence of significant windshear, a pilot has to take corrective action to ensure safety. Turbulence is caused by rapid irregular motion of air. It brings about bumps or jolts. In severe cases, the aircraft might go momentarily out of control.

1.2 Most windshear and turbulence conditions cause no threat to aircraft in flight. However, when they occur close to the ground they may affect aircraft during landing and take-off.

1.3 Windshear and turbulence typically occur in weather conditions such as thunderstorm, tropical cyclone, cold and warm fronts, and jet (narrow band of strong wind). Near ground, sea breeze, strong monsoon wind, and winds blowing across hills can also cause windshear and turbulence.

1.4 For Hong Kong, over the three and a half years since the opening of the Hong Kong International Airport (HKIA) at Chek Lap Kok (CLK) (July 1998 to December 2001), 0.14% of all flights in and out of the airport reported significant windshear. Over the same time period, 0.04% of all flights reported significant turbulence. A majority of these events were reported in the spring months of March and April, mostly caused by winds blowing across the hills over Lantau Island (i.e. terrain-induced). See Figure 1 for the location of HKIA relative to the mountainous Lantau Island.

1.5 ICAO requires the designated meteorological authority to issue windshear alerts on reported or expected existence of windshear which could adversely affect aircraft during landing and take-off. In compliance with the ICAO requirement, the Hong Kong Observatory (HKO) as the designated meteorological authority in Hong Kong provides a windshear and turbulence alerting service for aircraft using HKIA. To run this service, HKO operates a number of wind sensors in and around the airport and a Terminal Doppler Weather Radar (TDWR) at Tai Lam Chung. The locations of the various meteorological facilities are shown in Figure 1.

1.6 HKO regularly monitors the performance of its windshear and turbulence alerting service. This report:

(a) presents the performance of the existing alerting service; and
(b) identifies areas for further improvement and reports the progress so far.

The opportunity is also taken to provide an account of common weather patterns for windshear and turbulence at the HKIA.

2. Background

2.1 The study of windshear at Chek Lap Kok (CLK) dates back to 1979. The studies conducted by HKO, then the Royal Observatory, included physical modelling studies using water tank and wind tunnel, as well as investigation flights by the Royal Hong Kong Auxiliary Air Force (now the Government Flying Service).

2.2 The results of the studies were assessed by the UK Civil Aviation Authority, closely advised by the UK Meteorological Office and the Royal Aircraft Establishment UK in the early 1980s. Such work was reviewed and, in part repeated, in the late 1980s by overseas consultants in their study of site selection of a new airport. Among other findings, the above studies concluded that the windshear and turbulence levels at CLK and the old Kai Tak airport were similar.

2.3 The consultants recommended in the early 1990s that for the proposed new airport at CLK, windshear associated with thunderstorms should be monitored by a Terminal Doppler Weather Radar (TDWR), a proven tool for monitoring microbursts (Fujita, 1978) and windshear under rainy conditions. The consultants further recommended that a system be developed to alert pilots to terrain-induced windshear.

2.4 Both of these recommendations were implemented in time for the opening of the new airport in 1998. The TDWR was installed at Tai Lam Chung strategically overlooking CLK and the surrounding areas (see Figure 1), and a computerized system for alerting terrain-induced windshear was developed by Weather Information Technologies Inc., the commercial arm of the U.S. National Center for Atmospheric Research (NCAR). The windshear and turbulence alerts thus generated are relayed by Air Traffic Control (ATC) to aircraft using HKIA.

2.5 As the system for detecting terrain-induced windshear was developed before airport opening, the HKO was mindful of the need to verify its performance and enhance it with the benefit of windshear information offered by commercial flights using HKIA. Shortly after airport opening, the algorithms for alerting windshear and turbulence were improved in the light of occasional reports received from pilots.

3. Conduct of performance review of the windshear and turbulence alerting service

3.1 In order to conduct an objective review of performance of the windshear and turbulence alerting service, a record of the presence or absence of windshear and turbulence as experienced by aircraft landing at or taking off from HKIA is required. According to international practice, a pilot reports windshear and turbulence when they are encountered and when in his/her opinion they may affect other aircraft. As such, windshear and turbulence encountered may at times go unreported, especially when windshear and turbulence alerts are already in effect. From airport opening (July 1998) to February 2000, a total of 552 pilot reports were received, representing a mere 0.2% of the total number of landings and take-offs at HKIA. This creates some difficulties in verifying the performance of the windshear and turbulence alerting service.

3.2 To improve the situation, the HKO has over the past years repeatedly appealed to pilots to make reports whenever they encounter windshear or turbulence. A windshear reporting form was developed jointly with the aviation community and the Civil Aviation Department (CAD) in 1998. The form has subsequently been simplified in 2000 to make the pilot's task easier. In addition, ATC also assists in passing pilots' verbal reports of windshear and turbulence to HKO.

3.3 To obtain a fuller picture of the windshear situation at HKIA, the HKO launched two intensive reporting exercises — during 1 – 31 March 2000 and 14 August – 17 September 2000 respectively. These were conducted with active participation by airline operators, pilots and ATC. The time periods were chosen to coincide with: (a) the spring season when terrain-induced windshear is believed to be most frequent; and (b) the rain and typhoon season when thunderstorms and high winds often occur. During the exercises, pilots were requested to file a report irrespective of whether they had encountered windshear or not. This enabled a comprehensive review of the performance of HKO's windshear alerting service. Altogether, HKO received nearly 10,000 reports from pilots, representing one-third of all flights during the two intensive reporting exercises.

3.4 Furthermore, two international meteorological experts, one from New Zealand and the other one from the United States of America, were specially appointed by the HKO in July 2000 to provide independent advice in respect of the performance of the existing windshear and turbulence alerting facilities and service for the HKIA and future development strategy. The work included a review of the scientific studies of windshear at CLK conducted from 1979 to 1997. This was followed by a visit to Hong Kong from 27 July to 7 August 2000 to review the facilities, a meeting with representatives from airlines and CAD, as well as a review of notable windshear events reported since airport opening.

4. Findings of the review

4.1 Of the nearly 10,000 reports received from pilots during the intensive reporting exercises in 2000, there were about 350 reports of windshear (i.e. 15 knots or more) inside the alerting area covered by HKO's windshear and turbulence alerting service. Of these, slightly over 300 reports were received during the first exercise (1 – 31 March 2000), six times that of the second exercise (14 August – 17 September 2000). This is largely consistent with the pattern observed in 1999, i.e. a majority of windshear events at HKIA occur in springtime.

4.2 Immediately after the intensive reporting exercises, HKO evaluated the performance of its windshear alerting service against reports received from pilots during the exercises. A windshear alert is considered to be accurate if an alert had been issued when windshear was encountered or if an alert had not been issued when no windshear was encountered. The service was found to be accurate about 85% of the time. HKO's windshear alerts were capable of alerting about 50% of all windshear events (15 knots or more) reported by pilots. It was also found that the TDWR by virtue of its design was generally satisfactory in detecting windshear under rainy weather, and that a majority of pilot windshear reports not covered by HKO's windshear alerts were associated with non-rainy weather.

4.3 The difficulties in accurately alerting windshear and turbulence, which are transient and sporadic in nature (especially when they are induced by terrain), are amply illustrated by reports made by pilots on 17 March 2000, when strong winds blew across Lantau from the south. Around midday that day, reports received from pilots making consecutive landings over a half-hour period show that half of the aircraft reported encounter of windshear while the other half did not. In particular, the pilot of one aircraft reported a 15-knot windshear loss (i.e. decrease in lift), followed within a time interval of two minutes by another reporting a 25-29 knot gain (i.e. increase in lift). [Note: windshear of 15 knots or above is commonly regarded as 'significant'; windshear of 30 knots or more is 'severe'.] Amazingly, the pilot of an ensuing aircraft two minutes later reported no windshear at all, and this was followed by yet another report of 15-knot gain. Because of the transient and sporadic nature of windshear, this example is also illustrative of some pilots' perception of false alarm by the windshear alerting service (because they did not experience windshear), even when windshear is indeed occurring.

4.4 During the two reporting exercises, there were about half as many reports of turbulence as that of windshear. Overall, the HKO's turbulence alerts were accurate over 90% of the time. [Note: a turbulence alert is considered to be accurate if an alert had been issued when turbulence was encountered or if an alert had not been issued when no turbulence was encountered.]

4.5 After detailed studies, the experts concluded that the windshear and turbulence alerting facilities at HKIA were a good system and provided a solid platform for now and to build on for the future, and HKO's work had usefully supplemented them. Although HKO's windshear and turbulence alerting service to users could be improved, it was their belief that the facilities at HKIA were as good as any operational system in the world. They strongly supported the efforts to improve the alerting service that HKO had undertaken and planned to undertake.

4.6 The experts further made a number of recommendations, ranging from short, medium to long-term depending on the extent of work involved. Their recommendations are, in essence, as follows: -

(a) to enhance communication with users operationally;
(b) to provide more information to users for better understanding of the windshear and turbulence phenomena;
(c) to add wind sensors in and around HKIA and Lantau;
(d) to implement automatic transmission of onboard weather observations from aircraft to ground and of various weather products from ground to aircraft;
(e) to continue and extend work on improving weather monitoring under non-rainy conditions; and
(f) to further improve the windshear alerting techniques.

4.7 HKO immediately acted on the above recommendations. The work done and improvements achieved are covered in Section 6.

5. Common weather patterns for windshear and turbulence at the Hong Kong International Airport

5.1 Since airport opening in 1998, HKO conducted detailed studies of windshear and turbulence reports made by pilots, including those in the intensive windshear reporting exercises in 2000. The studies indicate that by far the most common windshear and turbulence events at the airport are related to winds blowing across hills (i.e. terrain-induced), including strong winds associated with the passage of tropical cyclone. For the other reports, most of them are associated with thunderstorm and sea breeze. Though relatively infrequent, there have also been windshear and turbulence events associated with jet in the lower atmosphere. A brief account of these weather patterns is given in the following.

Wind blowing across hills

5.2 As HKIA is located to the north of the mountainous Lantau Island, when winds from the east, southeast, south and southwest blows across the hills on the island, the wind pattern on the other side of the hills may become disturbed, causing localized windshear and turbulence near the airport. When winds come from the northwest through northeast sectors, Castle Peak to the north of HKIA can also cause windshear near HKIA, though much less frequently.

5.3 The Terminal Doppler Weather Radar (TDWR) monitors the wind pattern over the airport by measuring winds in the radial direction, i.e. along the direction of the radar beam. A windshear case associated with Typhoon Maggie on 8 June 1999 is illustrated in Figure 2, which is a snapshot taken at 02:56 H (local time) of the radial winds on an inclined plane at 0.6° elevation angle from the radar site. At that moment, Maggie was departing from Hong Kong and some 140 kilometres to its west. Automatic weather stations on Lantau Island reported strong southerly wind over the hills. On the lee side of the hills, there were a number of streaks of high wind (indicated by blue arrows in Figure 2), with velocities of around 20 ms^{-1} (39 knots) and maximum reaching 24-26 ms^{-1} (47-51 knots). In between the high-speed streaks were low-speed streaks (indicated by the green arrows in Figure 2) with velocities of just a few metres per second. The large difference in winds across these adjacent high-speed and low-speed streaks resulted in significant windshear and turbulence over the airport. Quite a number of aircraft reported having encountered windshear and turbulence on that occasion. A detailed account of TDWR observations of the wind pattern over the airport during the passage of tropical cyclones is reported in Shun and Lau (2000). Another terrain-induced windshear case typical in springtime was also studied in detail and results are presented in Lau and Shun (2000).

5.4 In lighter winds and when the lower atmosphere is stable (a weather condition that suppresses air motion in the vertical direction), the winds may flow around the hills and may also cause windshear over the airport (Figure 3).

Thunderstorm

5.5 Severe thunderstorms are associated with intense convection, often resulting in violent descent of air, or downdraft, and heavy rain. The descending air is cool and dense, and tends to spread out on hitting the ground. The leading edge of the cool air, called the gust front, often produces abrupt changes in the wind (Figure 4), or windshear, for an approaching aircraft.

5.6 The most violent form of downdraft from a thunderstorm is called the microburst (Fujita, 1978). An aircraft flying through a microburst would experience a sequence of rapid wind changes, namely headwind (wind blowing towards the aircraft), downdraft (wind blowing from above), then followed by tailwind (wind blowing from behind). Such rapid wind changes are hazardous to aircraft landing and taking off the airport (Figure 5).

5.7 Figure 6 presents a radar pattern for a microburst affecting the airport at 15:37 H on 3 September 1999. The microburst was located just to the southwest of the radar site. It can be inferred from the picture that the downdraft from the microburst partly spread towards the radar (in green colour) and partly away from it (in yellow and brown). An aircraft traversing the microburst near that time reported a significant loss of headwind. The strong winds moving away from the radar met up with the background southwesterly wind, forming a gust front (red curve in Figure 6).

Sea breeze

5.8 Unlike thunderstorms, sea breeze usually develops under fine weather. With sunshine, the land surface heats up faster than the sea surface. As the air above the land surface warms up and rises, the cooler maritime air moves onshore, forming a sea breeze (Figure 7). Convergence of air occurs when the sea breeze and the background wind blow in opposite directions.

5.9 At HKIA, the onset of sea breeze is typically characterized by winds turning to westerly over the western part of the airport (Cheng, 1999). With prevailing easterly wind blowing in the background, significant wind changes, or windshear, may develop along the runways (inset of Figure 7) (Cheng, 2002). Turbulence may also occur in a sea breeze.

Low-level jet

5.10 A jet in the lower atmosphere manifests itself as a narrow band of strong winds (Figure 8). It occurs once in a while during the cool months when the winter monsoon prevails over Hong Kong. When an aircraft departing from the airport ascends and enters the jet, it would experience increasing headwind (lift). As it departs the jet, however, the headwind would decrease (sink). This sequence of increase and decrease in headwind can sometimes be mistaken to be an encounter with microburst. However, a microburst is associated with rainy weather, whereas it is not necessarily so for a jet. A detailed account of windshear events associated with a low-level jet can be found in Lau and Chan (2000).

5.11 By virtue of its flying normally against the prevailing wind near an airport, 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 gentler path than a departing aircraft, the rate of headwind change it would experience is generally less than that for a departing aircraft.

6. Improvement work and achievements

6.1 After the studies by the international experts in July 2000, HKO immediately acted on their recommendations. As of end of 2001, all the required work is either in progress or has already been completed.

6.2 During 2001, communication with users in the operational environment has improved considerably. This was achieved through close co-operation with CAD's air traffic controllers, resulting in more interaction with pilots both in the communication of HKO's windshear and turbulence alerts to the pilots as well as in their reporting of windshear and turbulence encountered. This has enabled more effective monitoring of windshear and turbulence.

6.3 In providing information to users for better understanding of the windshear and turbulence phenomena, apart from updating the relevant aeronautical information publications for aviation users, HKO produced a pamphlet on windshear and turbulence for the public as well as for members of the aviation community. Soft copy of this pamphlet and additional information on the windshear and turbulence alerting facilities and service are made available on HKO's internet website. Technical updates on windshear and turbulence at HKIA are also disseminated through HKO's regular liaison meetings with airline operators and newsletters on aviation weather services, and promulgated helpfully by the Hong Kong Airline Pilots Association (HKALPA).

6.4 During 2001, HKO implemented temporary wind sensors and commenced measurement at three locations on Lantau. A fourth sensor was put on trial over the waters west of HKIA for advance detection of sea breezes giving rise to potential windshear. Measurements made by the temporary sensors are being studied to determine their values in further improving the windshear and turbulence alerting techniques, before considering their permanent establishment.

6.5 To measure the weather aloft, HKO enlisted the assistance of the Government Flying Service (GFS). During 2000 and 2001, GFS' fixed-wing aircraft made a number of flights in and around HKIA, taking valuable measurements using on-board weather sensors. HKO also enlisted the service of commercial aircraft in this endeavour. Modern commercial aircraft are equipped to measure such weather elements as wind, temperature and/or turbulence. The availability of such 'in-situ' data is very important for HKO to further improve the windshear and turbulence alerting service. In return, HKO is planning to develop weather products for transmission to aircraft in flight, including graphical displays of windshear and turbulence alerts, so that the pilot can have ready access to such information.

6.6 To improve windshear monitoring under non-rainy weather, HKO placed an order for a LIght Detection And Ranging (LIDAR) system in 2001. To be installed at the airport in 2002, the LIDAR will scan the atmosphere to determine wind conditions above HKIA under clear air or non-rainy conditions. It will be put on trial from 2002 to 2005, during which HKO will carry out data collection, feasibility assessment, technique development and operational evaluation. The LIDAR is expected to usefully complement the TDWR which is designed to detect windshear associated with rainy weather including thunderstorms.

6.7 Based on the study results described in Section 5 above, HKO further developed improved windshear alerting techniques and implemented them in 2001. Development of these improved windshear alerting techniques followed a systematic approach and was largely similar for the different weather conditions. Since the majority of the windshear events occurred in the spring months of March and April, the methodology for development of the improved windshear alerting techniques for spring is outlined, step by step, below:-

(a) Data from various weather equipment operated by the HKO were studied. These include:

(i) wind observations from the TDWR;
(ii) vertical wind profiles from wind profilers (vertically-pointing Doppler radars) at Sha Lo Wan and Siu Ho Wan (see Figure 1 for their locations);
(iii) wind and temperature profiles from the upper-air sounding system at King's Park, some 25 km east of HKIA; and
(iv) wind information from a network of anemometers over and around HKIA (see Figure 1 for their locations);

(b) To better understand the actual weather conditions experienced by the aircraft during the encounter of significant windshear, on-board flight data available from commercial aircraft and the Government Flying Service for specific events were analyzed;

(c) Pilot reports of significant windshear, including those received during the intensive reporting exercises in 2000, were collated to form a chronological database of actual windshear conditions at HKIA. The database contains both positive and negative windshear reports (i.e. occurrence and non-occurrence, respectively), with detailed information on time, location and magnitude of the windshear events;

(d) Detailed case studies (based on weather data described in (a) and (b)) of windshear reports made by pilots of aircraft landing at or taking off from HKIA during the spring months of March and April indicate that a large majority of these reports were associated with wind blowing across the hills over Lantau Island. Under such weather situations, three weather factors favourable to occurrence of windshear at HKIA were identified. These factors were: (i) a large difference between the winds on hilltops and at HKIA, (ii) strong wind blowing across hills on Lantau; and (iii) a stable lower atmosphere. These factors were then quantified by parameters, which included the prevailing wind direction and speed, horizontal and vertical differences of winds at different locations, and vertical temperature profile of the atmosphere;

(e) The parameters described above were suitably combined to form equations and decision flow charts for alerting windshear in spring when winds were blowing across the hills over Lantau Island. The equations and the flow charts were then tried out for optimal performance by maximizing the number of successful alerts and minimizing false alarms on the basis of pilot reports of significant windshear received during the intensive reporting exercise in March 2000;

(f) Threshold figures were established for these factors, and the optimal equations and flow chart adopted. Figure 9 shows schematically a decision flow chart incorporating the improved windshear alerting techniques for spring; and

(g) Finally, the improved techniques were independently tested by applying them to windshear reports received outside the intensive reporting exercise period, specifically March and April 1999 and April 2000. Upon confirming the improvement in performance, the techniques were implemented in early 2001.

6.8 As of the end of 2001, results with the improved techniques have been encouraging, with 80% of windshear reports successfully covered. This contrasts with a previous figure of 50% (para. 4.2 above).

7. Conclusion

7.1 A review of the windshear and turbulence alerting service at HKIA has been conducted. The review was based upon detailed studies by HKO on windshear and turbulence reports made by pilots, including those made in the two intensive windshear reporting exercises in 2000, and the findings of international meteorological experts. As part of their findings, the experts concluded that the existing windshear and turbulence alerting facilities were a good system and provide a solid platform for now and to build on for the future, and HKO's work on windshear alerting had usefully supplemented them. While the windshear and turbulence alerting service could be further improved, the experts considered that the facilities were as good as any operational system in the world. The limitations in accurately alerting windshear and turbulence in view of their sporadic and transient nature are also noted.

7.2 HKO had studied in detail the reports of windshear and turbulence by pilots including those made during the intensive windshear reporting exercises in 2000. On the basis of these studies and the experts' recommendations, HKO implemented in 2001 a number of improvements to its windshear and turbulence alerting service including enhanced communication with and more information for users, implementation of facilities for better windshear and turbulence monitoring, and the introduction of improved windshear alerting techniques. As of the end of 2001, the results obtained with the improved techniques have been encouraging. HKO will continue the improvement efforts.

Acknowledgement

The Hong Kong Observatory (HKO) gratefully acknowledges the support of pilots, airline operators, Civil Aviation Department and Government Flying Service in respect of windshear and turbulence reports from flights in and out of the Hong Kong International Airport. Cathay Pacific Airways Ltd kindly provided flight data used in the windshear case studies for the purpose of enhancing flight safety. Dr. C.M. Cheng helpfully contributed towards the preparation of Section 5.

References

1.	Cheng, C.M.	1999	"Characteristics of sea breezes at Chek Lap Kok", Technical Note No. 96, Hong Kong Observatory, 23 pp.
2.	Cheng, C.M.	2002	"Sea-breeze induced windshear at Chek Lap Kok, Hong Kong", Hong Kong Observatory (to be published as technical note).
3.	Fujita, T.T.	1978	"Manual of downburst identification for project NIMROD", University of Chicago, SMRP Research Paper No. 156, 104 pp.
4.	Lau, S.Y. and S.T. Chan	2000	"Case study of a windshear caused by a low-level jet (14 December 1998)", Technical Note No. 101, Hong Kong Observatory, 26 pp.
5.	Lau, S.Y. and C.M. Shun	2000	"Observation of terrain-induced windshear around Hong Kong International Airport under stably stratified condition", *Preprints, 9th Conference on Mountain Meteorology*, Colorado, U.S.A., August 2000, 93-98.
6.	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, 42-53.

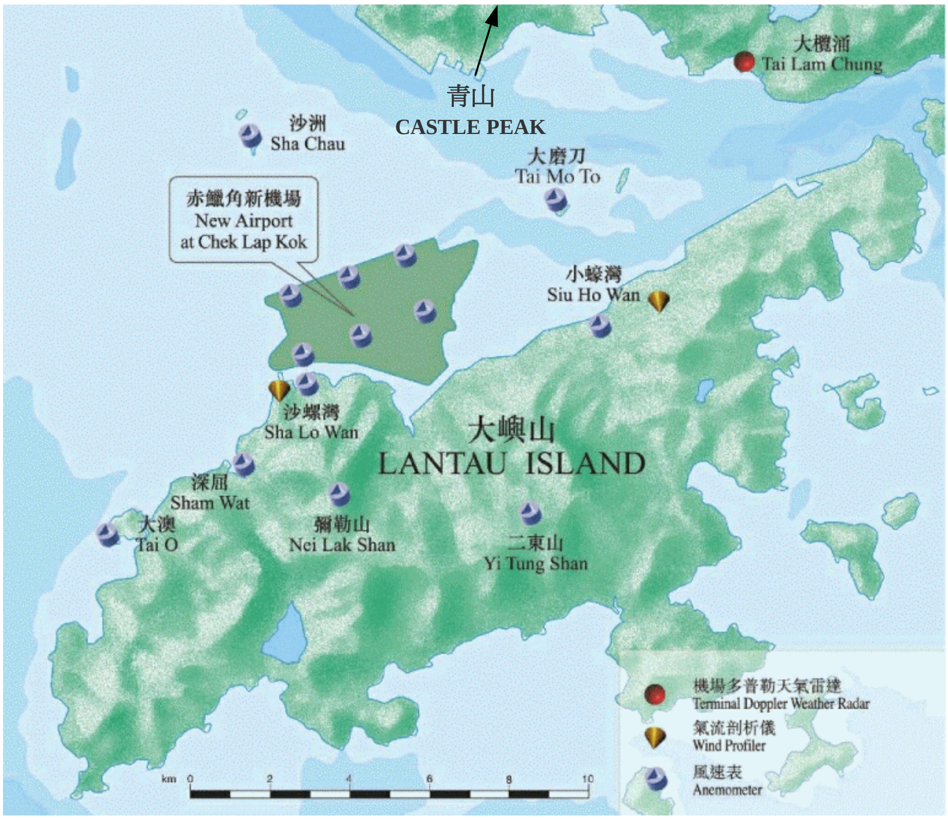

Figure 1 Location of weather sensors in support of the windshear and turbulence alerting service.

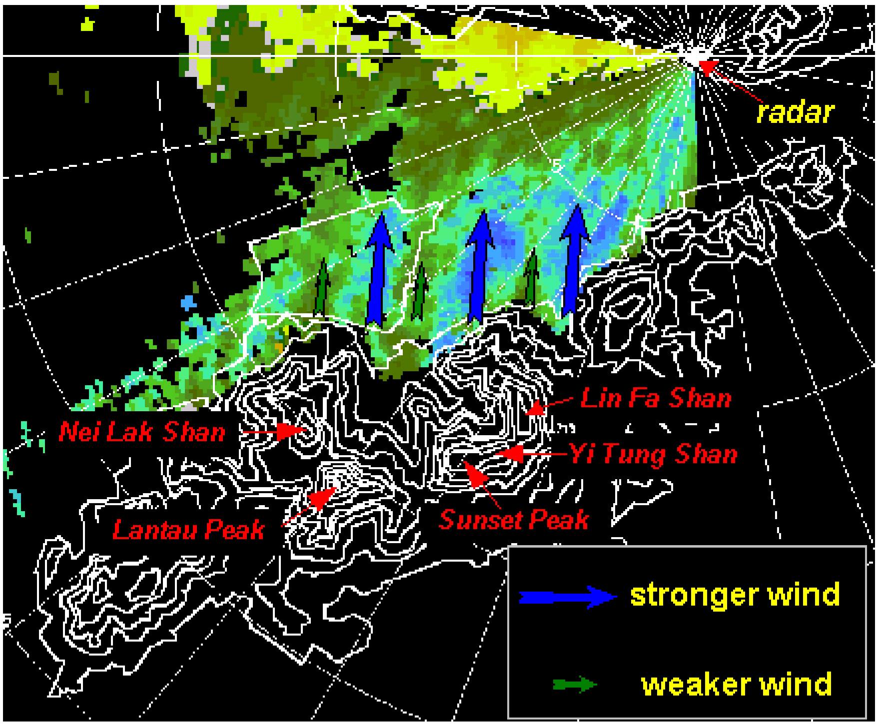

Figure 2 Radar picture of radial winds at 0.6° elevation angle at 02:56 H on 8 June 1999.

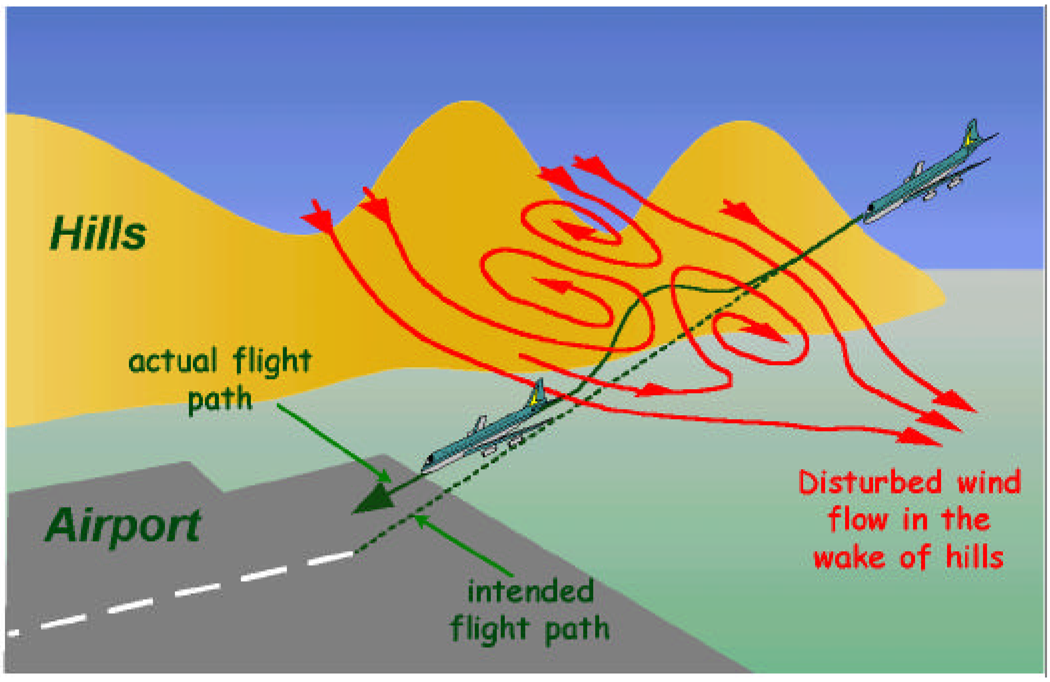

Figure 3 Disturbed wind flow in the wake of hills, as simulated by a computer model.

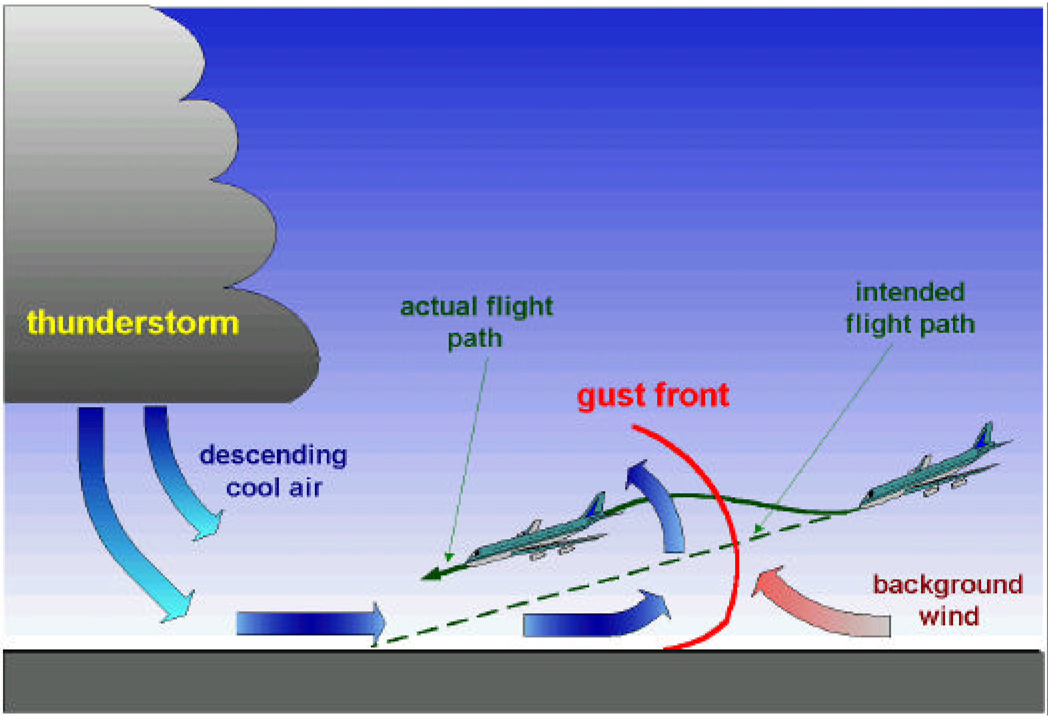

Figure 4 Effect of a gust front on an approaching aircraft.

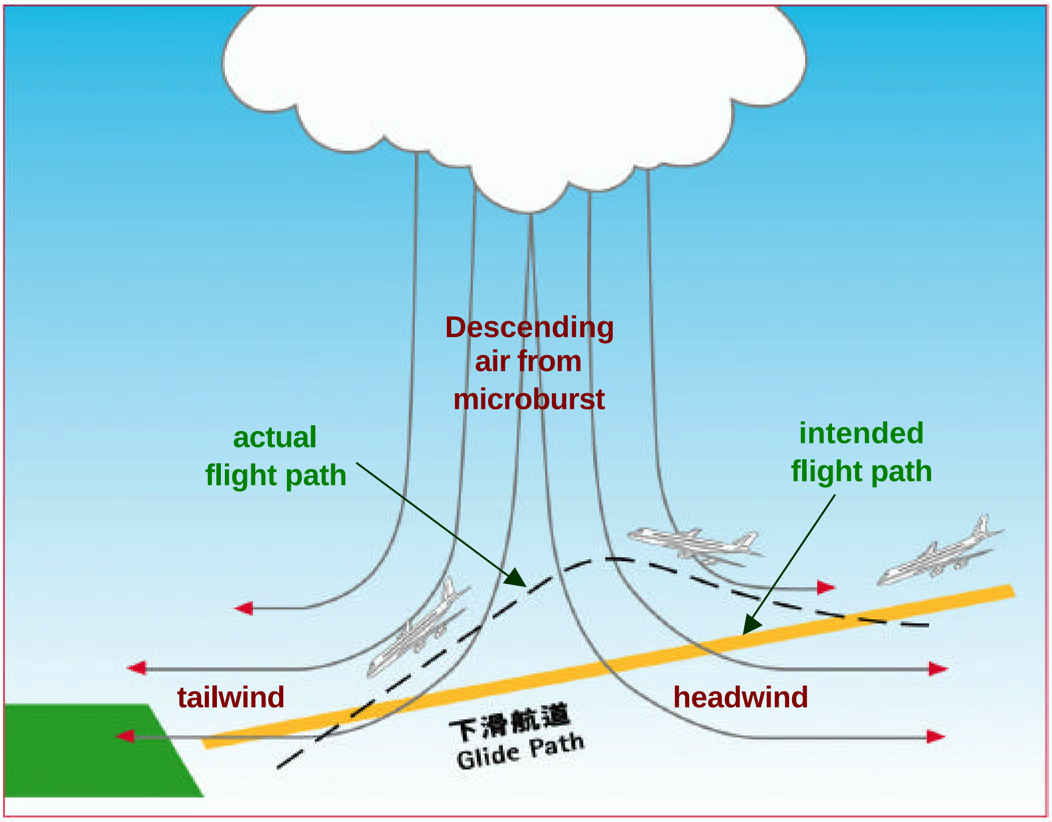

Figure 5 Effect of a microburst on an approaching aircraft.

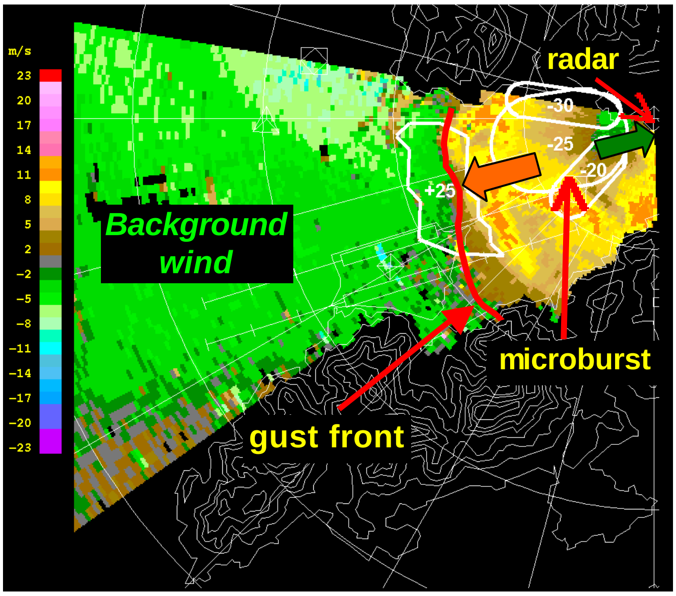

Figure 6 Radar picture of radial winds at 0.6° elevation angle at 15:37 H on 3 September 1999.

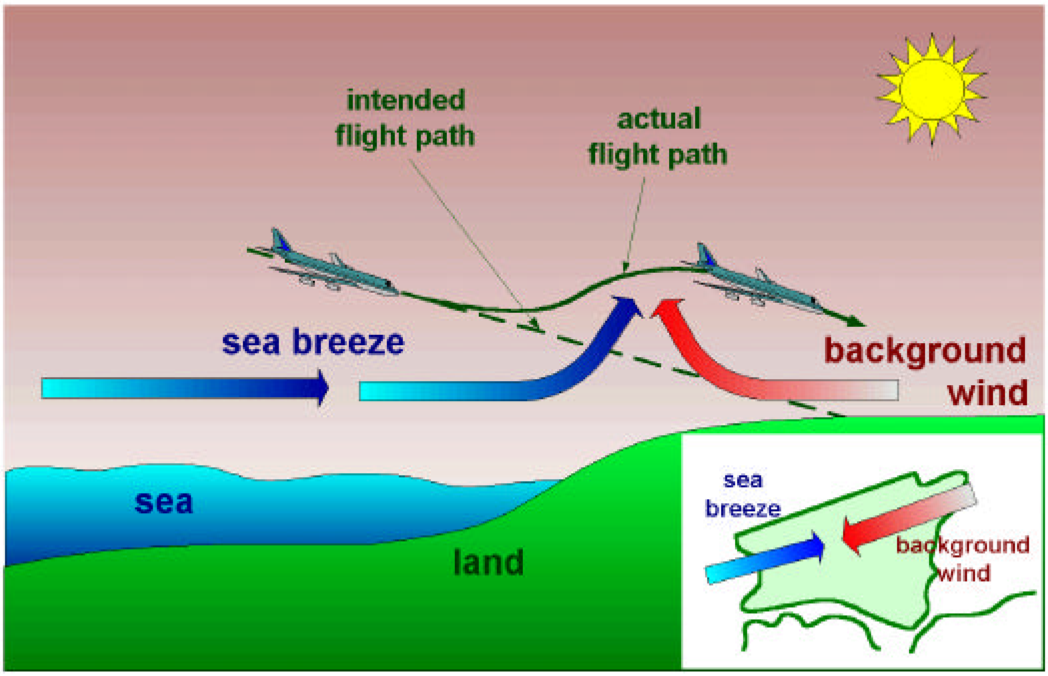

Figure 7 Effect of a sea breeze on an approaching aircraft.

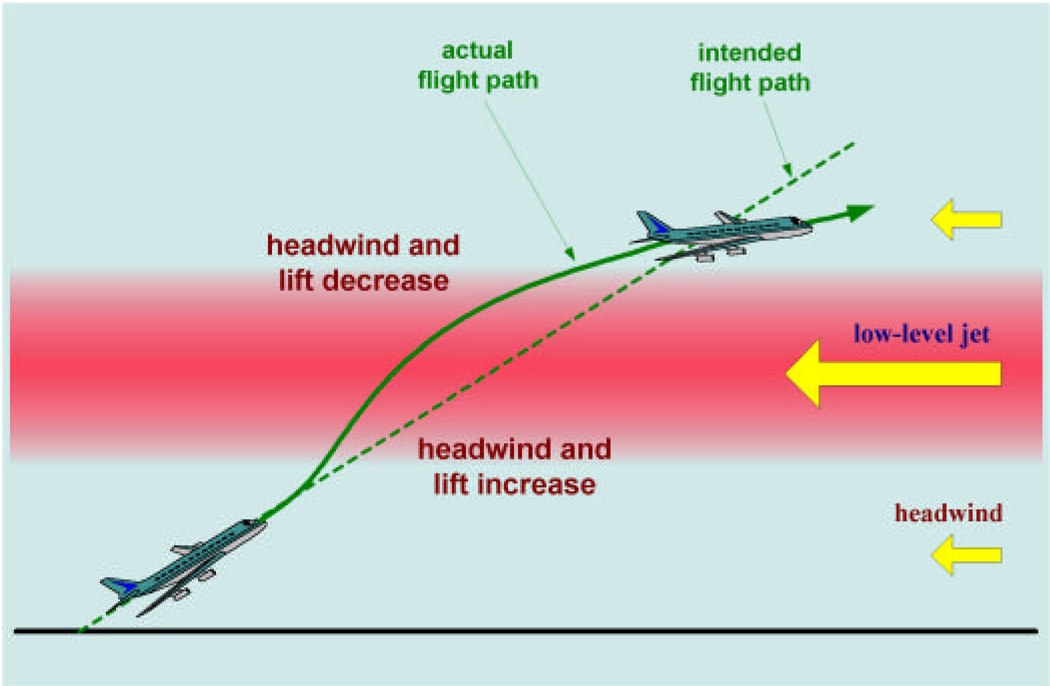

Figure 8 Effect of a low-level jet on a departing aircraft.

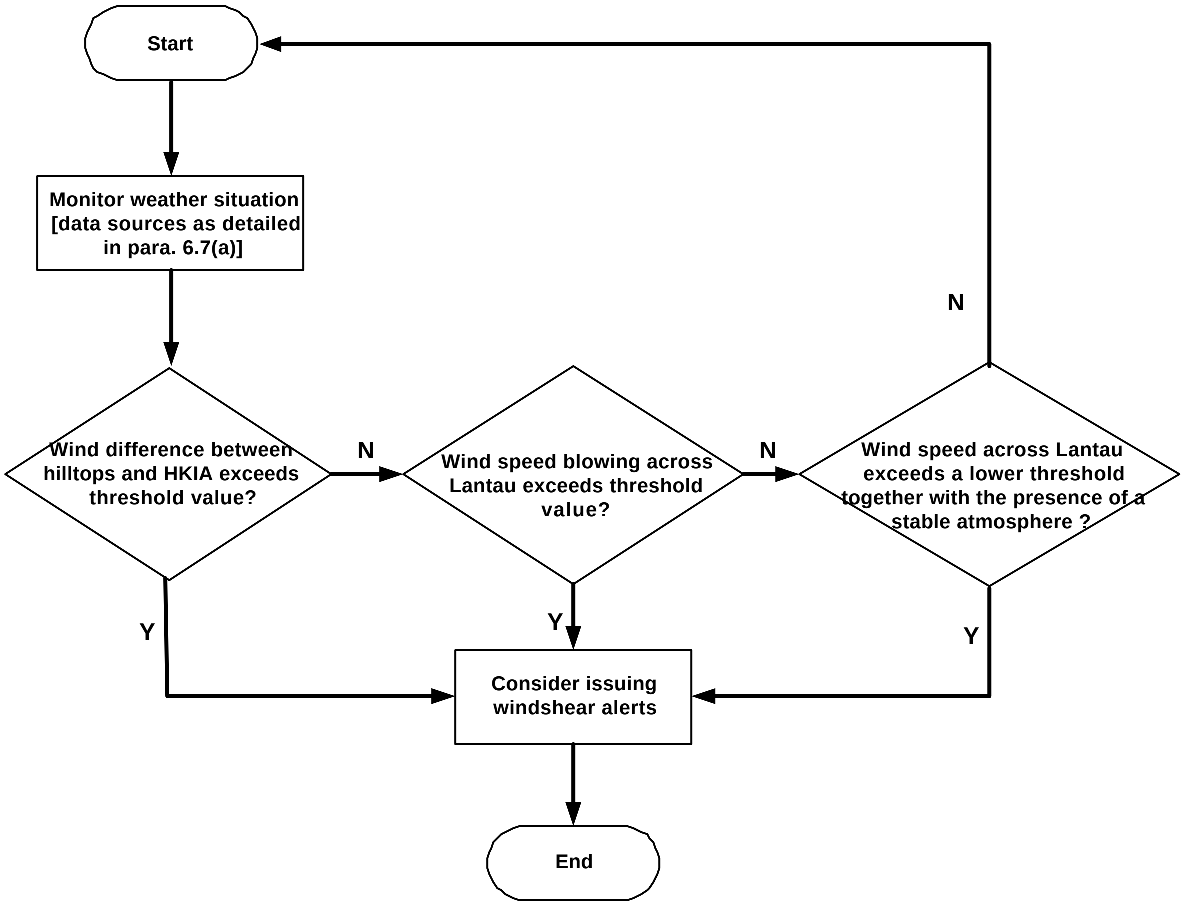

Figure 9 Schematic decision flow chart for windshear alerting in spring when winds are blowing across the hills on Lantau.