Application of a Ground-Based Doppler LIDAR to Automatic Windshear Alerting

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A Doppler Light Detection And Ranging (LIDAR) system has been operated by the Hong Kong Observatory (HKO) for weather monitoring at the Hong Kong International Airport (HKIA) since 2002. Runway-dedicated LIDARs were deployed at the airport in late 2006. In the past 6 years or so, a number of aviation weather applications of the LIDAR have been developed by HKO to improve aviation safety. This paper aims to summarize the latest developments in the major application area of the LIDAR systems in HKIA, namely, automatic windshear alerting. The future development work for this application is also discussed.

Nomenclature

$H$ = ramp length
$S$ = windshear severity factor
$t$ = time
$V$ = wind speed
$\Delta V$ = change in wind
$V_{app}$ = normal approach speed of the aircraft

I. Introduction

The first Doppler LIDAR at HKIA was installed in 2002 to improve the alerting of windshear in clear air conditions, which accounts for the majority (about 90%) of windshear at low level (below 1.600 feet) in Hong Kong. It is still operating at HKIA and is the LIDAR system with the longest lifetime in the world working in an operational environment for aviation weather alerting. The technical specifications of the LIDAR could be found in Ref. 1. It has a measurement range of around 10 km with a range resolution of about 100 m. Based on the radial wind velocity from the LIDAR, HKO has developed an automatic LIDAR Windshear Alerting System (LIWAS), the first of its kind in the world. LIWAS has been put into operation since December 2005 and found to provide crucial windshear information in alerting the pilots. To improve windshear alerting, runway-specific LIDAR was deployed at HKIA in late 2006. Each of the two parallel runways of HKIA is served by a dedicated LIDAR installed nearby the respective runway, viz. the north-runway LIDAR providing windshear alerts for the north runway, and the south-runway LIDAR providing alerts for the south runway. The locations of these LIDAR systems are shown in Fig.1.

At present, LIWAS provides windshear alerts to all the four arrival runway corridors and one departure runway corridor of HKIA (locations in Fig. 1). This paper summarizes the latest developments of LIWAS, namely, the major features of the windshear detection algorithm, the performance statistics of the runway-specific LIDARs in capturing the pilot windshear reports, and the inconsistency of pilot windshear reporting as revealed in the LIDAR and Quick Access Recorder (QAR) data of the aircraft. The future developments of LIDAR application in windshear alerting are also discussed.

II. LIWAS

With the deployment of the runway-specific LIDARs, the laser beam from each LIDAR system is well aligned with the orientation of the respective runway. The radial wind velocity measured by the LIDAR along the glide paths could be used to represent the headwind to be encountered by the aircraft. Significant changes of the
headwind profile measured by the LIDAR are detected automatically by LIWAS for the issuance of low-level windshear alerts to pilots via the Air Traffic Control (ATC).

In order to measure the winds along the glide paths, HKO invents a special scanning strategy of the LIDAR, namely, the glide-path scan. This kind of scan involves the orchestrated motion of the elevation and azimuthal motors of the LIDAR scanner to collect the wind data along the glide paths, which are slanted straight lines in the sky. A schematic diagram of the glide-path scan is given in Fig. 2. The glide-path scan is different from the convectional scans of LIDAR and weather radar, which only involve either elevation motion (vertical scan, or the so-called Range-Height Indicator scan) or azimuthal motion (surveillance scan, or the so-called Plan-Position Indicator scan). The glide-path for a arrival runway corridor is taken to be a straight line with 3-degree elevation from the horizon starting at the end of the respective runway, whereas the one for a departure runway corridor is taken to be a line with 6-degree elevation starting from the middle of the runway. If the angle between the laser beam and the runway orientation is greater than 30 degrees, the radial velocity measured by the LIDAR is not regarded as having good representation of the headwind to be encountered by the aircraft and it would not be included in the construction of the headwind profile. With the deployment of the runway-specific LIDAR, the revisit time of the laser beam over a particular runway corridor is in the order of 1 to 2 minutes.

A significant wind change in the headwind profile is called a windshear ramp. In general, a headwind profile contains more than one windshear ramp. The detected ramps are prioritized according to the severity factor $S$:

$$S = \left( \frac{dV}{dt} \right) \frac{\Delta V}{V_{app}} = \left( \frac{\Delta V}{H^{1/3}} \right) V_{app} \cdot \frac{1}{V_{app}}.$$  \hspace{1cm} (1)

The primary parameter turned out to be the normalized windshear value $\Delta V/H^{1/3}$ (Ref. 2).

LIWAS generates a windshear alert automatically when a windshear ramp with $\Delta V$ exceeding the alert threshold is detected. The LIWAS alert is ingested into the Windshear and Turbulence Warning System (WTWS) operated by HKO to provide windshear alerts to ATC for relay via voice communications to the pilots. WTWS also integrates alerts from the other windshear detection systems/algorithms, including alerts from the Terminal Doppler Weather Radar (TDWR) and alerts generated by an anemometer-based windshear algorithm developed by HKO. The integration is carried out based on an alert prioritization scheme which considers the significance of the event and credibility of the respective system issuing the alert. After the integration, one single windshear alert will be generated for each runway corridor.

### III. Performance

The performance statistics of LIWAS over the five runway corridors in use within the period mid-March to September 2008 (covering the main windshear seasons of spring and summer) are given in Table 1. Discounting the time during which the LIDAR’s measurement range was significantly reduced in heavy rain (which was more frequent within the period than in normal years), the hit rate of pilot windshear reports by LIWAS is in the region of 73 – 86%. This result is considered to be satisfactory and consistent with the performance anticipated in the development of the algorithm.

### IV. Inconsistency in pilot windshear reports

The internationally-recognized length-scale of windshear is between 400 m and 4 km. Onboard windshear warning systems as well as ground-based alerting systems are designed based on this range of scale. The upper limit of the scale (4 km) was based on microburst studies by Professor Theodore Fujita back in the 1980s. The lower limit (400 m) was related to rapid fluctuations of the wind: wind changes over even smaller distances are regarded as turbulence, instead of sustained changes of the wind (viz. windshear) typically lasting at least a few seconds of the flight time.

However, studies of null reports from pilots together with weather data at HKIA have revealed that pilots tend not to report, or report less frequently, for windshear with length-scale near the higher end of the above range, i.e. between 3 and 4 km. Hence in this study, these larger-scale windshear events, or so-called “long ramp” or “gentle windshear” events, are first examined. Meteorologically, these gentle windshear events are often observed in spring-time at HKIA, when surface easterly winds prevail in the airport area. Quite often, the winds gradually veer with altitude to southeasterly and thus the headwind encountered by aircraft on approach from the west to HKIA would gradually increase on descent. From examples (Fig. 3 and 4) in which the QAR headwind data are compared against the pilot reports, it is apparent that different pilots could have different perception about the shear effects of very similar gentle windshear events. For the two cases in Fig. 3, the pilots reported headwind gains of 15 knots...
between 900 – 1,000 feet RA and 600 – 700 feet RA respectively, which are generally consistent with the QAR data. On the other hand, for the gentle windshear events of similar magnitude as revealed in the QAR data in Fig. 4, the pilots gave null windshear reports. It is interesting to note that, in the pilot reports of significant windshear and null windshear, there was a mix of Airbus and Boeing aircraft and thus the reporting did not appear to be related to the aircraft type.

The LIDAR’s headwind profiles are also plotted in Fig. 3 and 4 alongside the headwind profiles obtained from the QAR data. It could be seen that both datasets are generally consistent with each other. The significant wind changes as determined from the QAR data are all successfully captured by the LIDAR windshear alerts. The windshear alerts should get four “hits” based on the QAR data. However, based on the pilot windshear reports, there were only two “hits” for the cases in Fig. 3 and two “false alarms” for the two cases in Fig. 4.

The inconsistency of pilot windshear reports is not only observed for “long” or “gentle” windshear ramps. It is found to occur for shorter and more abrupt changes of the headwind as well. Details could be found in Ref. 3.

V. Ongoing developments

At the original location near the middle of the airport island (Figure 1), the south-runway LIDAR, which was the first LIDAR installed at HKIA in 2002 and relocated to the south runway in 2006, subscribed too large angles with respect to the middle of the south runway of HKIA and as such there was limited data coverage over the commonly used departure runway corridor 07RD (location in Fig. 1) for the development of windshear detection algorithm. Ongoing developments of LIWAS include the collection of more pilot windshear reports and LIDAR data on this runway corridor to refine the algorithm for capturing windshear encountered by departing flights. The LIWAS algorithm would also be fine-tuned so that the significant headwind changes detected by the algorithm are better aligned with the windshear perceived by the pilots, though there would be subjectivity factor in the pilot perception of windshear to be sought out as discussed above. One possible approach is that the “long” and gentle windshear ramp would not be considered in the automatic generation of windshear alerts within LIWAS.

Another area of development is to study the feasibility of using a dedicated short-range LIDAR to improve the measurement of low-level winds, which may also be disrupted by man-made structures on and near the airfield, and thus the detection of windshear and/or turbulence near the touchdown areas. A possible place to test the concept is the arrival runway corridor to the east of the north runway of HKIA (25RA, location in Fig. 1), where there are a number of buildings near the final mile of the runway corridor before touchdown. A LIDAR with a smaller measurement range of about 2 km but a higher spatial resolution of about 30 m would be deployed. It would scan continuously over the final mile and touchdown zone of 25RA, with a more frequent data update rate of a couple of tens of seconds.

VI. Conclusion

LIWAS, an automatic windshear alerting algorithm, has been developed and put into operational use at HKIA. It is based on the novel glide-path scans of the LIDAR systems invented by HKO. Significant wind changes in the headwind profiles are automatically detected based on a windshear severity factor. At times when the LIDAR has reasonable measurement ranges (i.e. not in heavy rain conditions), the hit rate of pilot windshear reports by LIWAS could be up to 84%. The objective headwind data provided by the LIDARs are generally consistent with the QAR data as recorded on the aircraft despite the spatial and temporal variability of the two datasets, and they point to the inconsistency of the pilot reports in similar windshear conditions due to the subjective perception of the wind changes by the pilots. LIWAS is under on-going developments and there is work in the pipeline to deploy a short-range LIDAR providing wind data in higher spatial and temporal resolutions to improve the measurement of low-level winds for enhancing flight safety.

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References


American Institute of Aeronautics and Astronautics
Table 1. Performance of LIWAS between 12 March and 30 September 2008 (discarding the period when the LIDAR’s measurement range was limited by heavy rain).
Figure 1. Locations of the two LIDARs at HKIA and the nomenclature of the runway corridors. Height contours are in 100 m.

Figure 2. Schematic diagram of the Glide-path Scan.
Figure 3. The headwind profiles from the QAR data and the LIDAR data in two examples of successful hits by LIWAS of pilot reports of gentle windshear.
Figure 4. The headwind profiles from the QAR data and the LIDAR data in two examples of false alarm cases of LIWAS in gentle windshear.