8.7 Calculation of windshear hazard factor based on Doppler LIDAR data

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1. INTRODUCTION

In the alerting of low-level windshear at the Hong Kong International Airport (HKIA), Doppler LIDARs are used to measure the headwind profiles along the flight paths and significant headwind changes are detected automatically using an algorithm developed by the Hong Kong Observatory (HKO). This paper discusses another possible analysis method that may be applied to the LIDAR data, namely, calculation of F-factor based on the LIDAR data.

The F-factor algorithm toolset is applied to the analysis of windshear encounter at HKIA. Both flight data (from the commercial jet) and LIDAR data are analyzed for each event. The events were either strong headwind/tailwind shears or turbulence (or both). There was no microburst event, which is usually evidenced by headwind/tailwind shear and a significant downdraft. The followings summarize the findings from this work:

- correlation between aircraft winds and LIDAR winds is demonstrated;
- correlation between aircraft measured F-factor and LIDAR-based F-factor is demonstrated. Using the LIDAR headwind profile in a B-747 simulator, correlation with aircraft measured F-Factor is established. This establishes that the LIDAR headwind data can be used as the basis to calculate windshear comparable to those measured in flight;
- LIDAR-based F-factor has to be further processed in order to produce F-factor comparable to the flight measured F-factor;
- aircraft data can and should be used as the standard for performance assessment of the LIDAR as a windshear detector;
- Certain windshear events indicate the existence of both turbulence and windshear. LIDAR processing algorithms should accommodate both; and
- the B-747 simulator can be used to produce F-factor profiles from LIDAR headwind data comparable to flight data.

2. DATA ANALYSIS METHOD

A suite of algorithms and software have been developed to process flight data and perform calculations to assess and quantify turbulence and windshear disturbances. These algorithms have been verified on many different aircraft types. The algorithms have been implemented on aircraft to perform calculations in flight. The followings are some examples of parameters calculated by the algorithms:

Turbulence:

- standard deviation of loads
- 3-D winds
- EDR (both winds- and loads-based)
- TKE
- F-factor (for turbulence scales)

Windshear:

- 3-D winds
- F-factor (for windshear and microburst scales)
- flight path deviation parameters

The analysis process is summarized in Figure 1. Flight data is read in from a data file. There are often the cases that the dataset is missing some parameters (e.g. angular rates), or there may be spikes or dropouts in the data. These issues are fixed in the next step so as to provide adequate data for the remaining calculations. From these data, the turbulence and windshear parameters can be calculated. Data can be output as temporal or spatial series. Finally, the results are checked for consistency and accuracy.

A suite of processing algorithms has also been developed for application to Doppler sensors such as radars and LIDARs. These algorithms have been applied to ground-based or airborne applications and cover both turbulence and windshear. Only the windshear algorithms are covered in this paper. The LIDAR data processing sequence is illustrated in Figure 2. In the current work, velocity data from the LIDARs are used as input data. The LIDAR dataset is used to extract the winds along the runway approach path. As is often the case with LIDAR data to be used in conjunction with other data (e.g. aircraft data), spatial and temporal averaging is required. The exact averaging interval depends upon the application. For the windshear application, the extracted winds are used to calculate an F-factor. This requires differencing of the horizontal wind to produce the horizontal component of the F-factor.

For microburst windshear detection, it is necessary to identify regions where there is a horizontal divergence which is indicative of a microburst outflow. Once the divergence has been identified, the vertical component of F-factor is calculated from continuity considerations since the LIDAR cannot measure vertical velocity directly, and the total F-factor is then calculated. This F-factor is then averaged over 1-km to give the parameter (also referred to as the 1-km averaged F-factor). This averaging is the established approach for identifying and quantifying hazardous windshears from radar or

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LIDAR maps.

Also used in this study is a B-747 simulator. This is a six degree-of-freedom simulator which can fly either controls-fixed or under automatic control. The simulation can ingest spatial or temporal wind fields into the aircraft response model. These wind fields can be 1-, 2-, 3-, or 4-dimensional. They can be implemented in the aircraft model either at a single point (the center of gravity) on the aircraft, or using the 5-point approximation model to include wind gradients. The input winds can be in the form of gridded products or from other sources such as flight data or LIDAR measurements (as used herein). This simulation has been established and verified in many different applications. For this study, 1-dimensional LIDAR measured spatial series of headwinds are used in the simulation and applied to the center of gravity on the aircraft.

3. EXAMPLE OF F-FACTOR PROFILE

In this paper, only data of one flight are presented to show how the headwind profile and F-factor profile look like. The flight selected was a B-777-200 aircraft that reported a “15 – 20 knot windshear at 300 feet” prior to landing, according to the pilot report.

Figure 3 shows the along track winds from the aircraft flight data. Between 1.5 and 1 nm from the approach (where the aircraft was between 300 and 450 feet), there was a rapid increase in headwind of approximately 17 knots. This will have the effect of increasing the aircraft’s airspeed and/or raising it above the glide path – either effect could cause the aircraft to land beyond the planned touchdown point and risk a runway overrun. Although a negative F-factor constitutes a performance or energy increase, the effect may be destabilizing at this point in the approach. The resulting F-factor and its components are shown in Figure 4. Notice the peak of -0.08 at about 1.2 nm from touchdown.

The aircraft was on the approach to 07L and so data from the north runway LIDAR was used. Figure 5 shows the headwind profile from the processed LIDAR data. The LIDAR measured an increase in headwind between the runway threshold and 1 nautical mile away. The resulting F-Factor and 1-km averaged F-factor are shown in Figure 6.

The aircraft’s F-factor is compared to the LIDAR’s in Figure 7. The LIDAR 1-km averaged F-factor underestimates the strong negative F-factor measured by the aircraft. This illustrates that the 1-km average of F-factor is not suitable for this windshear condition.

The LIDAR headwind profile shown in Figure 5 is input into the B-747 simulator. The resulting F-factor is compared to the aircraft’s F-factor in Figure 8. Good correlation is seen between the two datasets, especially where there is the large headwind increase and associated negative F-factor. Please note that, in Figure 3, the distance refers to the distance away from the actual touchdown of the aircraft, whereas in Figure 5, the distance refers to the distance away from the runway threshold. The two distances have been aligned in the calculation of F-factor profiles in Figures 7 and 8.

4. DISCUSSIONS

Based on the example in Section 3 and many other examples of aircraft and LIDAR data, it is seen that:

- Correlation between aircraft winds and LIDAR winds has been demonstrated. The aircraft derived winds are seen to correlate with the LIDAR measured winds. There are some variations which may be attributed to atmospheric non-stationarity, as well as temporal and spatial differences between the aircraft and the LIDAR measurement volume.

- Correlation between aircraft measured F-factor and LIDAR-based F-factor has been demonstrated. Using LIDAR measured headwind profiles in a B-747 simulator demonstrates correlation with aircraft measured F-Factor. This establishes that the LIDAR headwind data can be used as the basis to calculate windshear comparable to that measured in flight.

- LIDAR F-factors have to be further processed in order to produce F-factors comparable to flight measured F-factors. Algorithms used for processing microburst windshear (i.e., the 1-km averaged F-factor) are neither useful nor applicable to the cases analyzed; microburst windshears are not apparent in the data analyzed. The vertical component of the F-factor is not seen to be significant in the events analyzed. Not including that component in the LIDAR F-factor calculations do not affect the results. However a processing algorithm needs to be implemented to take the “raw” (unfiltered) LIDAR F-factors and filter them in such a way as to replicate the flight data.

- Aircraft data should be used as the standard for performance assessment of the LIDAR as a windshear detector. Aircraft data, in particular wind data, F-factor and accelerometer data, should be used to fine tune the processing algorithms and refine the detection and alerting protocols. By analyzing large numbers of datasets, aircraft data can be used to establish the detection performance of the LIDAR windshear and turbulence sensor.

- The B-747 simulator can be used to produce F-factor profiles from LIDAR headwind data comparable to flight data. It has been shown to produce F-factors comparable to aircraft F-factors from the LIDAR data. The simulation is a useful tool in assessing the hazard from the LIDAR data.

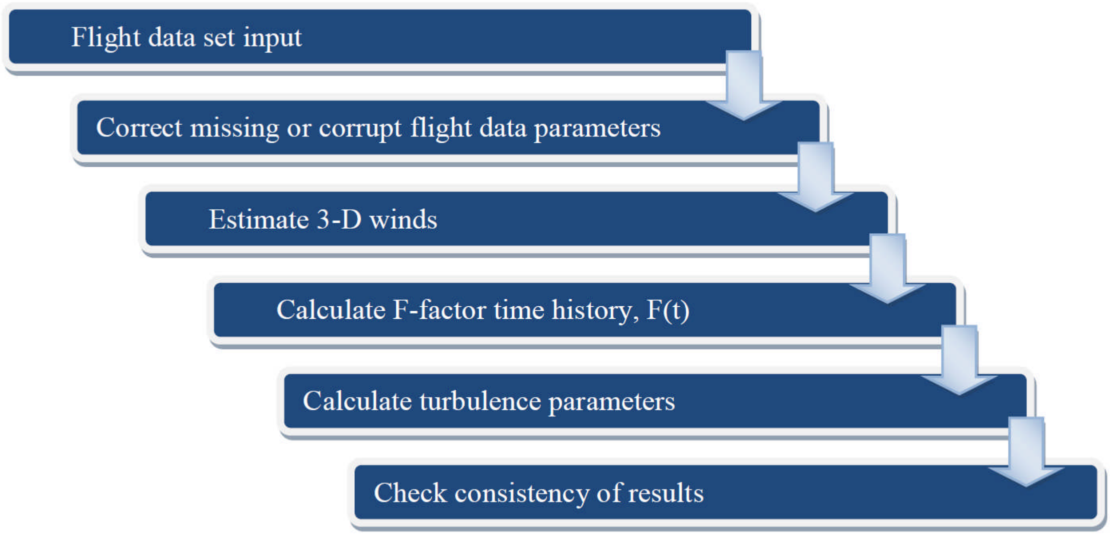

Figure 1: Flight Data Processing

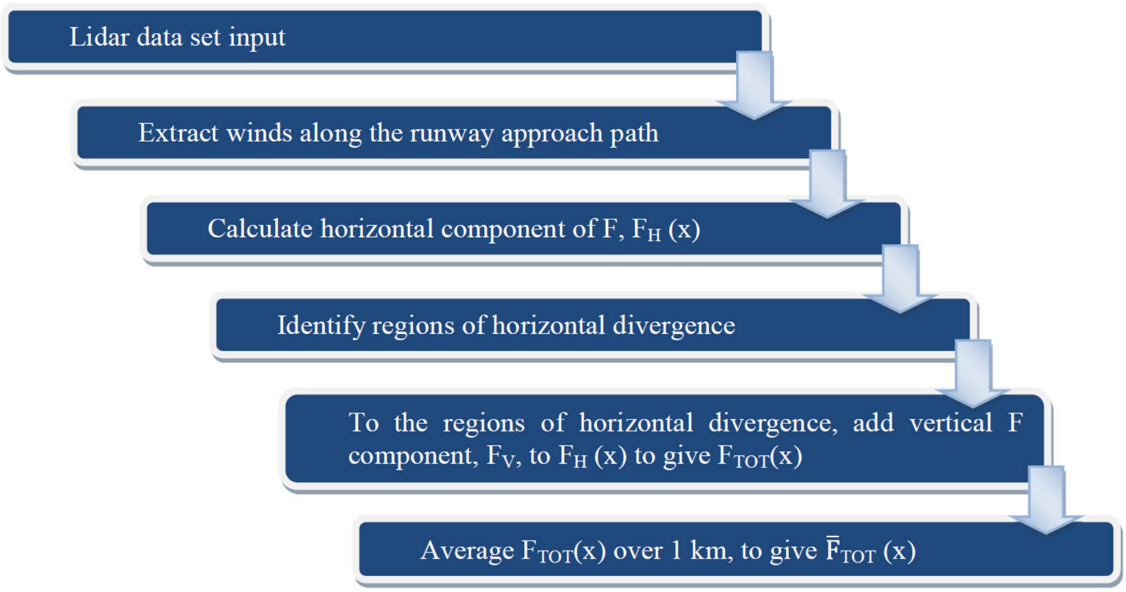

Figure 2: Lidar Data Processing

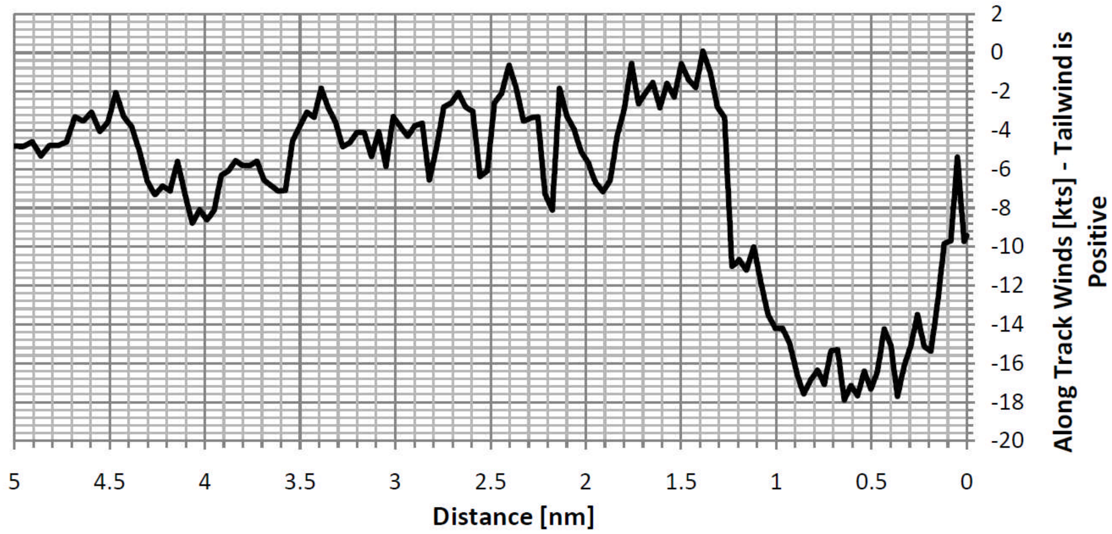

Figure 3 Aircraft along-track winds (distance from the actual touchdown)

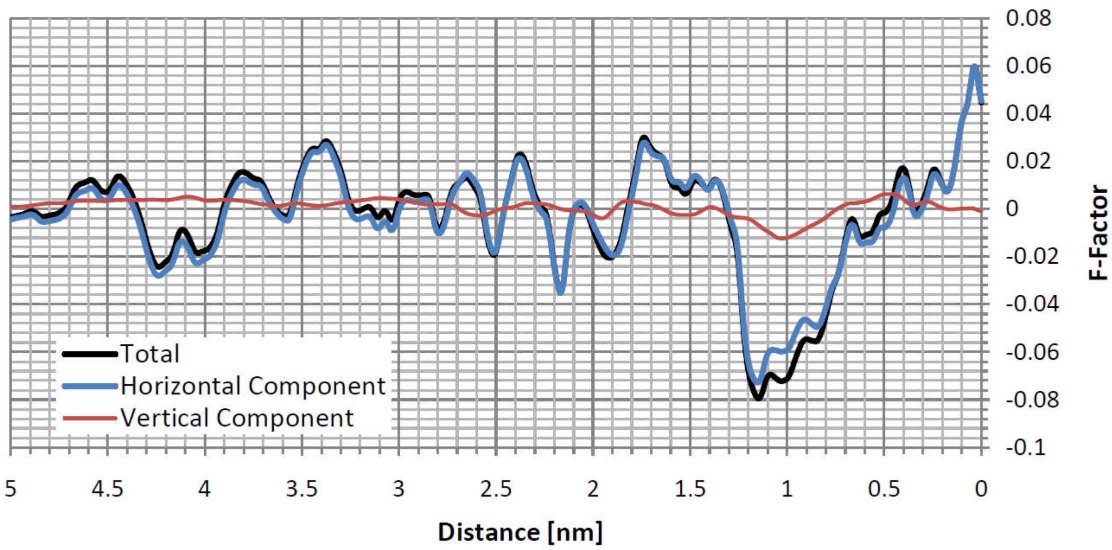

Figure 4: F-factor component comparison for the aircraft

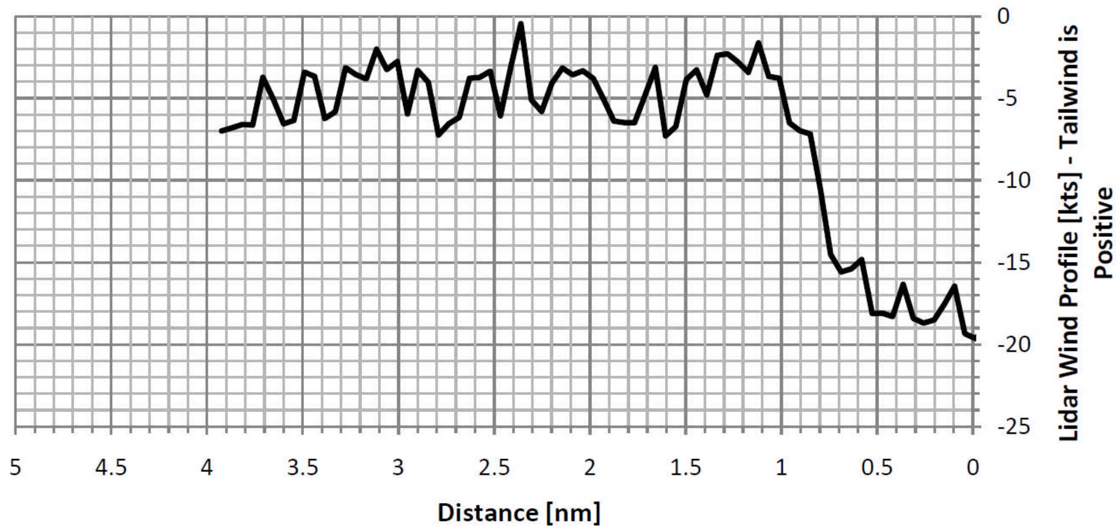

Figure 5: LIDAR headwind profile (distance from runway threshold)

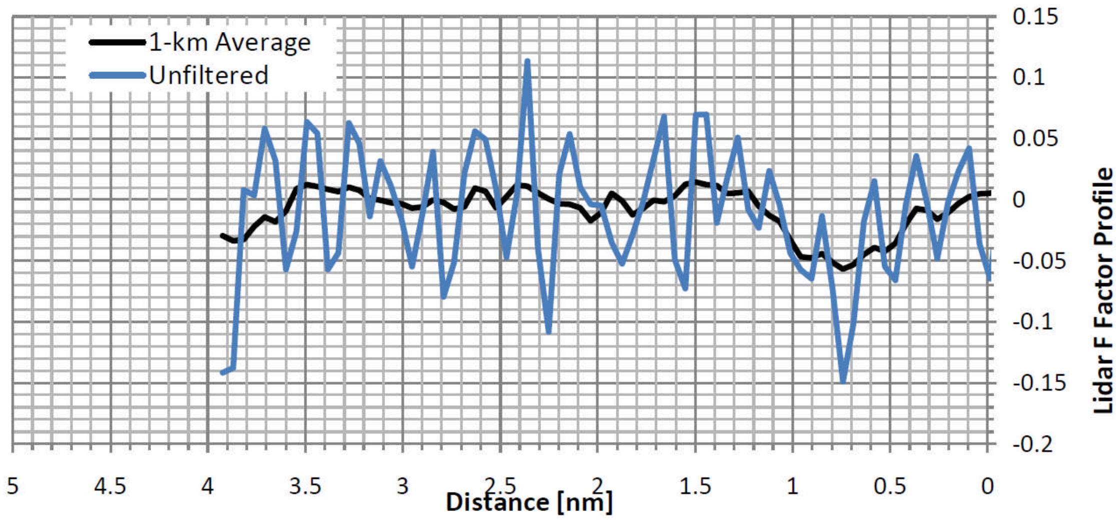

Figure 6: Unfiltered and 1-km averaged F-factor from LIDAR headwind profile

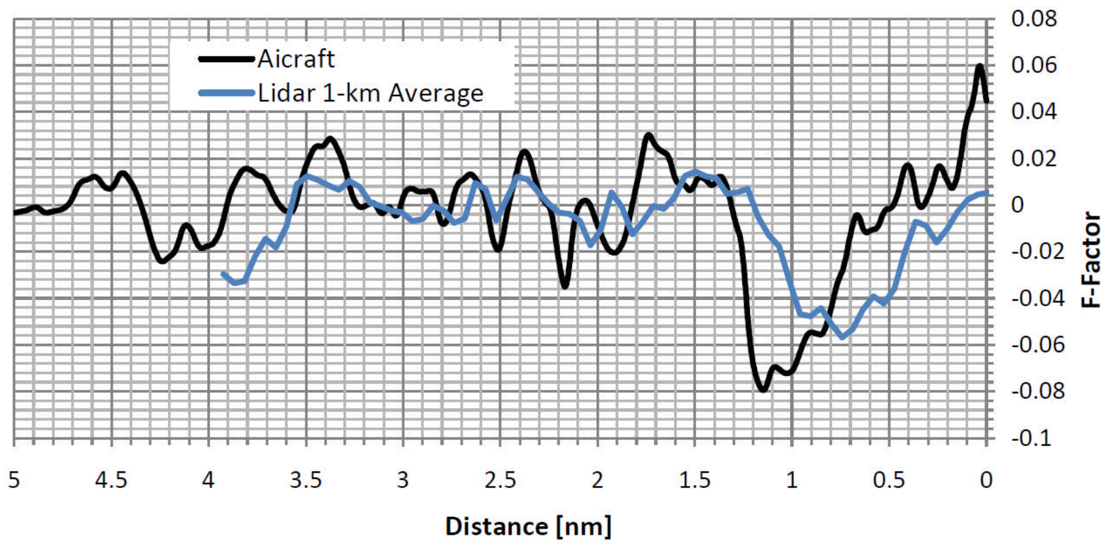

Figure 7: Aircraft and LIDAR F-factor comparison

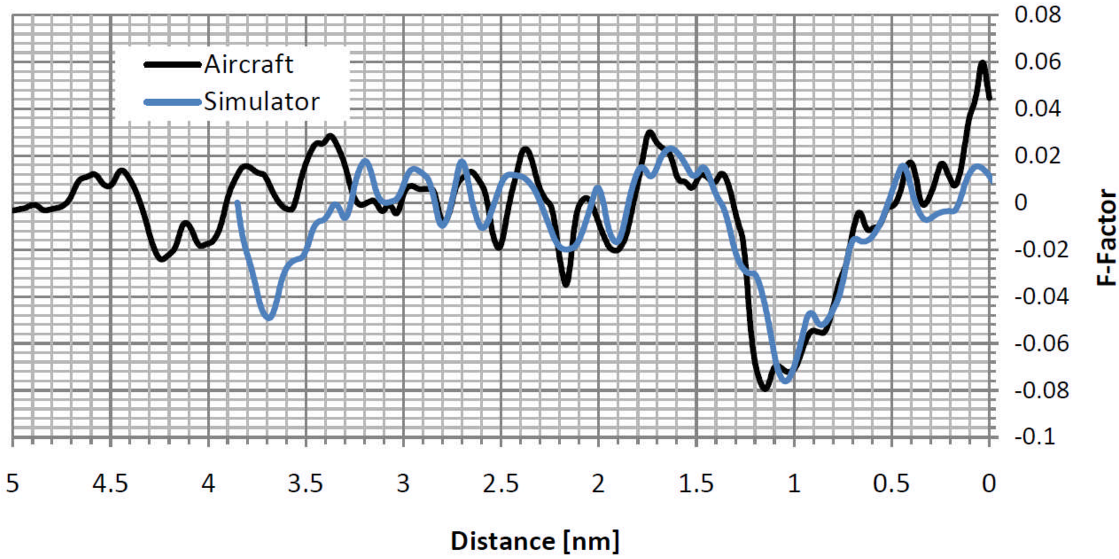

Figure 8: Aircraft and simulator F-factor comparison