AEROTECH RESEARCH (U.S.A.), INC.

AirSide™ Data Processing Solution

Bridging the gap between ground-based and airborne wind shear and turbulence detection

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Table of Contents

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1 Purpose

Ground-based measurements of wind shear and turbulence are used as part of a weather hazard advisory system for aircraft landing and taking off at some airports. In order to be effective, these systems must have detection capabilities comparable to the systems on board aircraft. If this is not the case, the ground-based system will be prone to false and missed detections reducing its effectiveness as a safety system.

This White Paper will:

- Illustrate constraints of the current operational system today, and how they may be addressed.
- Detail the requirements for improvements and gains that may be achieved.
- Describe and demonstrate how AeroTech's AirSide™ [1] data processing solution meets the needs and solves the problem as well as offering additional capabilities.

AirSide is designed for Doppler wind sensor manufacturers, airport meteorological providers, and aircraft operators who require greater reliability and accuracy of wind shear and turbulence warnings.

The purpose of this White Paper is to introduce AirSide to the user community, demonstrate the need it addresses, illustrate how it may be used in conjunction with measurement systems, and present the economic and safety benefits of integrating ground-based wind sensors with AirSide.

[1] AirSide™ is a trademark of AeroTech Research (U.S.A.), Inc.

2 Background

Many airports around the world are affected by severe wind shear and turbulence that can make take-off and landings difficult if not dangerous. It has been well documented that the Hong Kong International Airport is affected by wind shears and turbulence generated both by weather and the large mountain ranges nearby. Similar conditions exist at Palermo, Italy, where, on September 24, 2010, a landing A-319 encountered wind shear and touched down short of the runway. No one was injured, but the airport was closed for 42 hours. Figures 1 and 2 show the relation of high terrain relative to the runways at these airports.

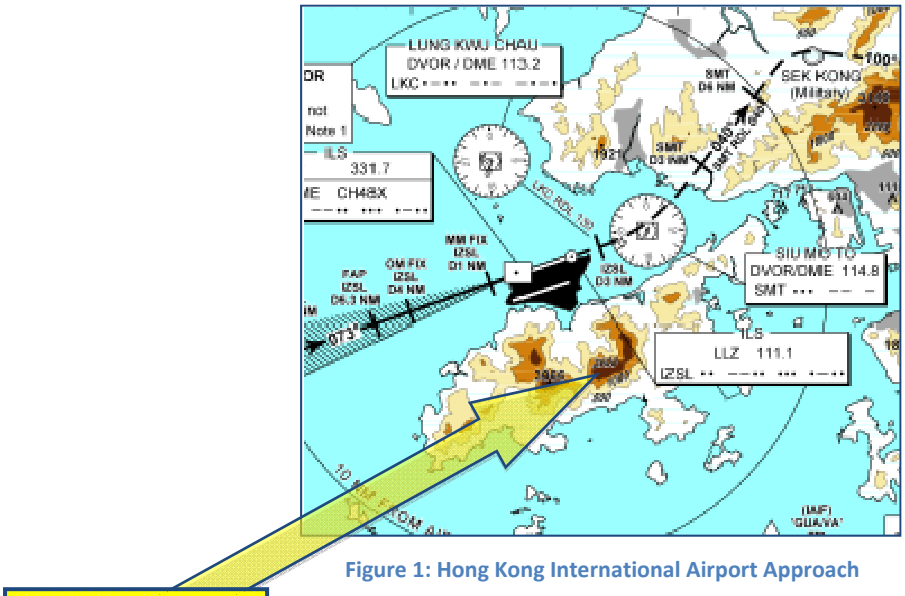

Figure 1: Hong Kong International Airport Approach

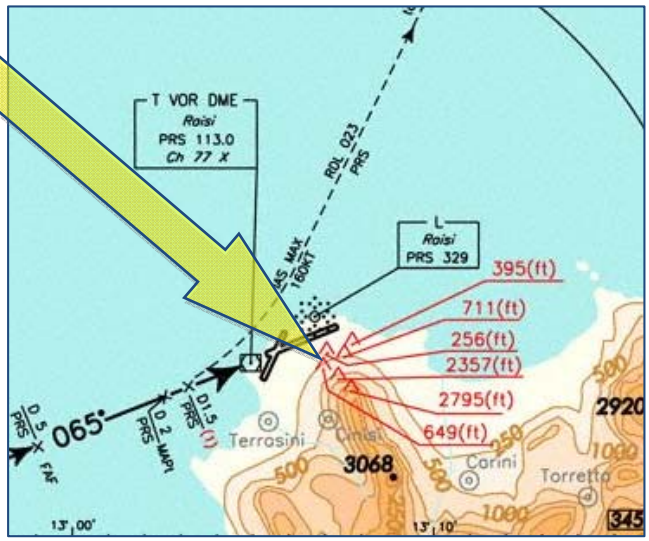

Figure 2: Palermo Airport Approach

Both Hong Kong and Palermo airports have installed advanced ground-based detection systems that detect and warn of wind shear or turbulence conditions on arrival and departure. More airports around the world are equipping with similar systems. The warnings are based on wind speed measurements over a volume of the atmosphere, and are made by such instruments as Doppler radars, and Laser radars (also known as lidars). However, for reasons described later in this White Paper, creating warnings based solely on wind speed measurements (and their gradients) may lead to inaccurate and unreliable hazard assessments.

2.1 The Operational Problem Today

The following is a sequence of events describing the situation today in which a ground-based system produces alerts of wind shears that turn out to be non-hazardous:

STEP 1. Ground-based systems detect winds and wind gradients along the approach to the arrival runway. The intent is to give pilots awareness of wind shear and turbulence hazards in advance of encountering them so that they are prepared to react to a warning in the cockpit. With this advance knowledge, pilots may take such precautions as carrying additional airspeed, or higher thrust settings.

STEP 2. Wind data from ground-based system is processed and hazards diagnosed. Warnings are disseminated to arriving aircraft.

STEP 3. Arriving aircraft experience little or no disturbance on the approach. Although there may have been wind variations detected by the ground-based system, they were not strong enough to have an impact on flight. These warnings are perceived by pilots as false detections – even though the sensors did detect wind variations. These false warnings may be referred to as “nuisance” alerts. If this happens too often, pilots’ confidence in the system will be eroded, and the effectiveness of the system’s warning capability reduced. This could be particularly serious when a significant event is detected and the subsequent warnings are not heeded.

A similar situation can occur for aircraft taking-off. Pilots, expecting a wind shear on take-off and climb-out may use higher than normal thrust settings. An engine failure at high power setting on climb-out may result in reduced controllability margins, and the higher thrust setting also has the consequence of increasing the “wear and tear” on the engines.

Operators of major international airports such as Hong Kong or Palermo have to maximize traffic throughput (landings and take-offs) while maintaining safe operations. Airports prone to hazardous wind conditions, due to nearby terrain for example, need

advanced wind detection systems in order to ensure safe operations. It is a matter of safety – the consequences of an accident can be disastrous.

A wind shear detection system susceptible to high error rates will be of reduced value to an airport operator, and therefore the purchase and installation of such a system will be a less attractive business proposition.[2]

2.2 How Wind Shear and Turbulence Affect Aircraft

Before we identify what is needed to mitigate this issue, it is necessary to understand how wind variations affect an aircraft taking off and landing.

An aircraft experiencing wind changes, referred to as **wind shear**, on landing or take-off can experience significant deviations in airspeed and altitude. Airspeed may increase or decrease (bringing the aircraft close to stalling speed), and the aircraft may rise or sink above the prescribed flight path.

Rapid variations in wind speed, known as **turbulence**, can make the aircraft difficult to control, be very uncomfortable to the occupants, and, in extreme cases may result in a hard landing or a missed approach.

An aircraft's response to wind shear and turbulence depends on its type. A small commuter aircraft will respond quite differently than a larger wide-body aircraft. It is therefore ***crucial*** to account for the aircraft response characteristics in detecting and quantifying hazards in wind measurements.

Another important consideration is that modern aircraft are equipped with systems that detect wind shear, which will alert the pilot to a wind shear hazard and, in severe cases, direct the pilot to abandon the approach, or "go-around". Warnings from ground-based systems augment the advance warning from a few seconds to several minutes. While ground-based systems cannot direct the pilot to go-around, they can **advise** the pilot to be aware of the possibility of a wind shear and a subsequent alert from the on board systems. In order for this advisory capability of the ground systems to be meaningful and fit in with onboard system detections, there needs to be a compatibility between the two processing techniques and performance.

2.3 The Need for Improved Processing

In order to maximize the effectiveness of ground based warning systems there is a need for a system that:

[2] It is important to note that, in assessing a sensor's performance, all detection systems produce a finite number of nuisance alerts, and all detection systems will miss some alerts. A system that produces too many of either one of these errors will quickly erode the confidence the pilots have in the warnings. The key is in minimizing the errors to within acceptable standards.

- ✓ Ingests wind measurements from ground-based measurement systems such as radars or lidars.
- ✓ Processes wind measurements to calculate wind shear and turbulence hazards accounting for aircraft response characteristics, and closely mirrors processing done by airborne detection systems.
- ✓ Identifies, locates, and quantifies wind shear and turbulence hazards, and produces meaningful information on the hazard.
- ✓ Issues advisory information to pilots.

As mentioned above, ground-based systems can increase the advance warning of wind shear or turbulence for pilots. In order for this to work well, any discrepancies between the ground-based and airborne systems should be minimized. To be of greatest value, a ground-based measurement system's performance should approach that of an airborne system in terms of false and missed detections.[3]

Another important requirement is the need to get the necessary information to the people who need it - pilots and controllers – quickly and accurately. This is a two-step process:

The hazard region must be identified and its location and severity quantified. If the severity is above a preset level then;

An advisory must be issued to pilots and controllers; e.g., "*severe wind shear 3 nm from threshold*." The form of this advisory depends on media available for presentation. Controllers may have the capability of viewing this information on a graphical display, whereas pilots may not have this option, and may only be able to receive information aurally. During the busy periods of take-off and landing, getting this information to the pilot in a form that is useful can be a challenge. If this advisory message short, reliable, and accurate, this problem is greatly mitigated. In the future, graphical displays and improved data communications will allow this information to be displayed in the cockpit quickly and clearly.

Having identified the key requirements, we can now proceed to describe how they are incorporated into the AirSide processing solution.

[3] Performance requirements for airborne systems are described in FAA Technical Standards Orders C-63 and C-117.

3 The AirSide™ Data Processing Solution

The AirSide processing solution is designed to meet all of the above needs in an integrated package. Not only does it contain algorithms, processes, and logic to enhance ground-based systems' wind measurements, it provides that ability to ingest flight data and compare what the aircraft experienced to what was measured on the ground – thereby demonstrating and enhancing the ground-based system's effectiveness.

AirSide was developed using AeroTech's unique integrated weather/aircraft simulation toolset, and is described below.

3.1 System Description

The components of the AirSide processing solution are depicted in Figure 3. Each of the numbered boxes is described below.

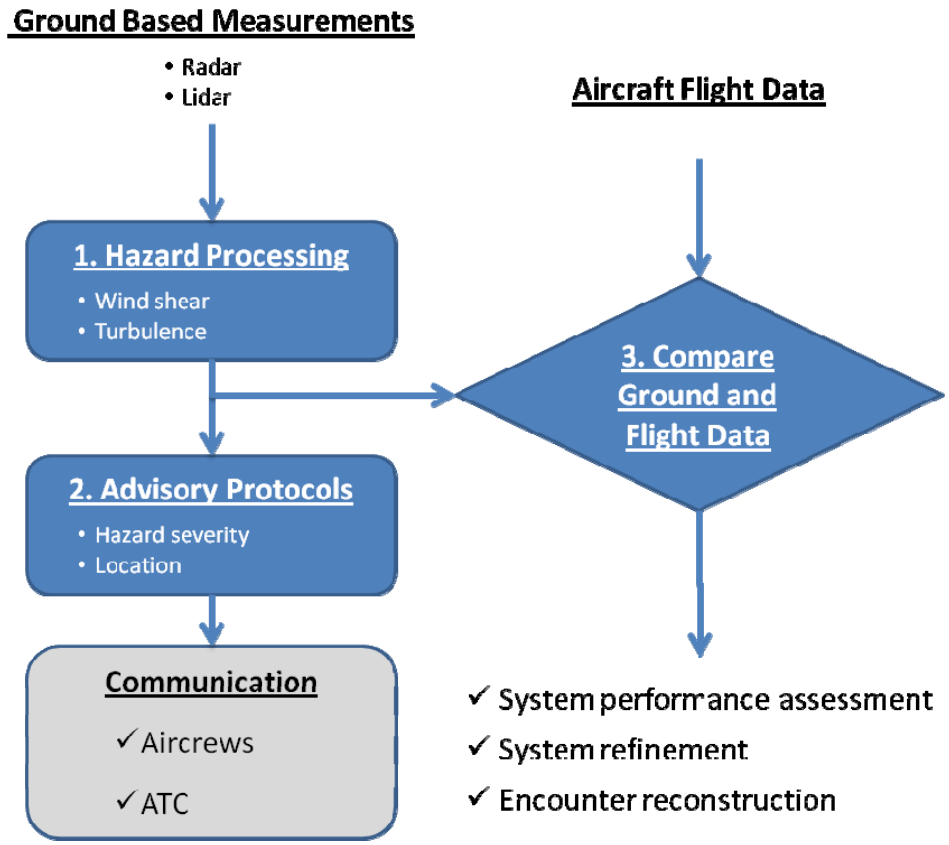

Figure 3: AirSide™ Data Processing Solution

The first step is to receive wind measurement data from the radar or lidar sensors. AirSide is designed to integrate with these ground-based systems. For turbulence, AirSide can also process TKE and EDR measurements.

1. Hazard Processing

The data are processed into the wind shear and turbulence hazard metrics scaled for aircraft response using AeroTech's patented algorithms and technologies.

2. Advisory Protocols

Hazardous regions are located and quantified, indicating regions where the aircraft's energy will be rapidly increased or decreased, and/or where strong accelerations due to turbulence will be encountered. In each case, AirSide calculates the severity of the impact to the aircraft. AirSide combines hazard location and severity into a concise information message through a set of rules called **"Advisory Protocols."**

This information is transmitted to Air Traffic Control and aircrews. Communication may be verbal, textual, or, in the future, graphical (depending on installation infrastructure). In all cases the information must be provided in a timely and understandable manner, and in a way that does not increase the workload of the aircrews. This is a key component to the successful implementation.

3. Compare Ground and Flight Data

For post-flight analysis, AirSide also ingests flight data recorded on aircraft that flew through the same region measured by the ground-based sensor. AirSide uses the aircraft data to calculate the same metrics that are calculated in Box 1.

The processed aircraft and ground-based sensor data are compared to quantify the detection performance of the ground-based sensor compared to what was actually experienced by the aircraft. By using AirSide in this way, the sensor's end-to-end processing can be optimized to achieve the detection performance required. This unique capability makes AirSide an important tool in maximizing the overall ground-based system's performance.

3.2 The Operational Scenario with AirSide™

Clearly the successful application of AirSide requires integration with systems and infrastructures in place at the airport. When fully integrated, the scenario described in Section 2.1 will proceed as follows:

STEP 1. Ground based systems detect winds and wind gradients along the approach to the arrival runway. As stated in earlier, the intent is to give pilots awareness of wind shear and turbulence hazards in advance of encountering them.

STEP 2. AirSide processing is applied to the measured wind fields and detects regions of significant energy loss/gain in addition to significant turbulence.

STEP 3. The AirSide Hazard Protocols convert these detections to concise text messages and disseminates these to aircraft and ATC.

STEP 4. Aircraft on arrival carry extra airspeed in order to provide additional safety margin over airspeed fluctuations. On encountering the wind shears, on-board systems detect the encountered wind shear and direct the pilot to abandon the approach and go-around. The pilot's confidence in the AirSide - generated warnings helps the pilot anticipate this warning and take necessary action.

STEP 5. Pilots in aircraft not yet on final approach, on receiving this hazard information, can decide whether to delay their landing or divert until conditions improve.

3.3 Demonstration of AirSide Appied to an Actual Event[4]

Lidar wind data along the approach to a runway at Hong Kong International Airport was processed by AirSide into a wind shear severity parameter, F-factor. The result is shown as the red line in Figure 4. From these data, AirSide detection identified an affected region of a significant energy loss followed by energy gain between 1½ and 2½ nautical miles from touchdown. Such a variation can lead to significant departures from a stabilized approach. This identified region is the basis for a wind shear advisory for ATC and other arriving traffic.

[4] Data presented courtesy of Mr. P. W. Chan of the Hong Kong Observatory

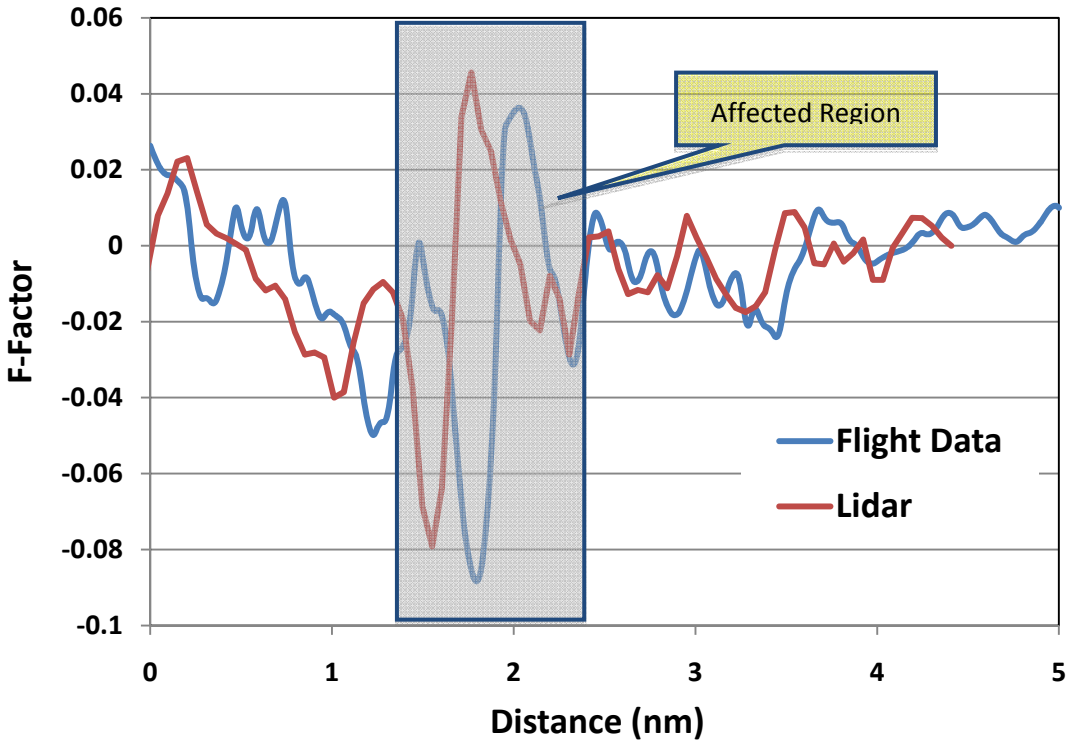

Figure 4: AirSide Performance from Flight Data and Lidar Data

Flight data from an arriving aircraft was also processed By AirSide and is shown in Figure 4 as the blue line. Clearly the aircraft experienced the shear detected by the lidar. The slight difference in position between the lidar and aircraft events is likely due to the wind shear moving with the prevailing wind between the lidar measurement and the aircraft's encounter.

Performing the above analysis for a large number of events allows the statistical quantification of performance of the ground-based system and is a very important tool in demonstrating the performance and value of a ground-based system.

Unfortunately in the above case, the lidar data was not suitable to be processed into turbulence. However, if the data were available, AirSide would perform a similar process for turbulence.

3.4 The Total Solution

Designed for Doppler wind sensor manufacturers, airport meteorological providers, and aircraft operators who require greater reliability and accuracy of wind shear and turbulence warnings, AirSide is a processing tool that uses wind sensor data, in conjunction with AeroTech's patented technologies, to produce enhanced hazard warnings with comparable performance to airborne systems. Unlike systems that base hazard detection solely on wind measurements, AirSide, integrated into a ground-based warning system, yields a reliable and very versatile solution to an important problem.

4 Summary

Many modern airports are equipping with advanced ground-based wind shear and turbulence detection systems in order to provide pilots with as much warning as possible of hazardous conditions for arriving and departing aircraft. Since airport performance and safety relies on these systems, it is very important that warnings from these systems are as reliable as possible.

The integration of the AirSide processing solution with ground-based wind shear and turbulence detection systems will:

- ✓ Enhance the value of the ground-based measurement system to airport operators,
- ✓ Enhance the value of the total system to aircraft operators, controllers and pilots,
- ✓ Ensure safe and efficient operation of the airport under challenging wind shear and turbulence conditions, and
- ✓ More fully integrate lidar and radar systems into a **total** solution.

In addition, AirSide's unique capability to compare aircraft and sensor data allows the optimization of sensor processing, and the demonstration of the detection performance. Both of these abilities are key in demonstrating the value of a ground-based system to an airport operator or other customer.

AirSide processing of lidar data has already been shown to correctly detect and quantify hazards corroborated by aircraft data.

5 About AeroTech Research

AeroTech Research has been a leader in the field of atmospheric hazard detection and avoidance since 1994. AeroTech's proprietary technologies detect and report turbulence, wind shear, and wake vortex hazards and are protected by patents and patents pending. AeroTech's real-time Turbulence Auto-PIREP System (TAPS®) [5] automates traditional pilot reports (PIREPs), increasing pilot and ground controller awareness of turbulence hazards. TAPS has been deployed on over 180 commercial aircraft. AeroTech has several other systems for atmospheric hazard detection and avoidance; many are developed in conjunction with NASA and FAA for Next Generation (NextGen) Airspace development programs. AeroTech is based in Newport News, Virginia, U.S.A.

[5] TAPS® is a registered trademark of AeroTech Research (U.S.A.), Inc.

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