P4.21 PULSED DOPPLER LIDAR FOR TERMINAL AREA MONITORING OF WIND AND WAKE HAZARDS

Stephen M. Hannon *
CLR Photonics, Inc., a division of Coherent Technologies, Inc.

1. INTRODUCTION

Pulsed Doppler lidar is the infrared equivalent of pulsed Doppler radar. Instead of raindrops, however, lidars reflect off naturally-occurring dust particles (aerosols). The aerosols have negligible fall velocities and so trace the wind field nearly perfectly. Up until the mid-1990's, Doppler lidars were limited to research implementations and short-duration, human-in-the-loop deployment for a variety of atmospheric research applications. At that time, significant engineering resources were brought to bear and the first commercially available, autonomous systems were developed and fielded by the end of the decade. The WindTracer® pulsed Doppler lidar represents this tremendous leap ahead in terms of reliable, unattended, continuous operations. These advances have enabled successful long-term installations at two airports over the past three years for the purposes of windshear and turbulence alerting as well as wake vortex monitoring.

Figure 1 shows a typical configuration for ground-based wind sensing. The equipment shelter (see Figure 1) contains the Doppler lidar equipment and is the location from which the actual remote sensing takes place. The environmental equipment shelter includes the scanner, the transceiver and the signal processor. Inside the shelter, the transceiver is mounted vertically and kinematically attaches to the rooftop scanner. Laser radiation emanates from the transceiver and is directed into the atmosphere by the computer-controlled scanner. The backscattered laser radiation is collected and processed by the transceiver, control electronics, and signal processor to produce various data products. These data products are then displayed locally and/or broadcast to other locations. The environmental equipment shelter is connected to the remaining equipment locations via an Ethernet connection.

The Remote Operator Station contains the primary Doppler lidar remote control and monitoring station and is connected to the shelter via an Ethernet connection. RASP GUI stands for Real Time Advanced Signal Processor (RASP) Graphical User Interface (GUI). operations. Additional workstations can be set up to receive and display output products, and even control system. Table 1 lists the nominal transceiver parameters.

This paper presents a summary of recent development and airport installations using the 2 µm coherent Doppler lidar. Airport installations are described and sample results applicable to both windshear and wake vortex monitoring are presented.

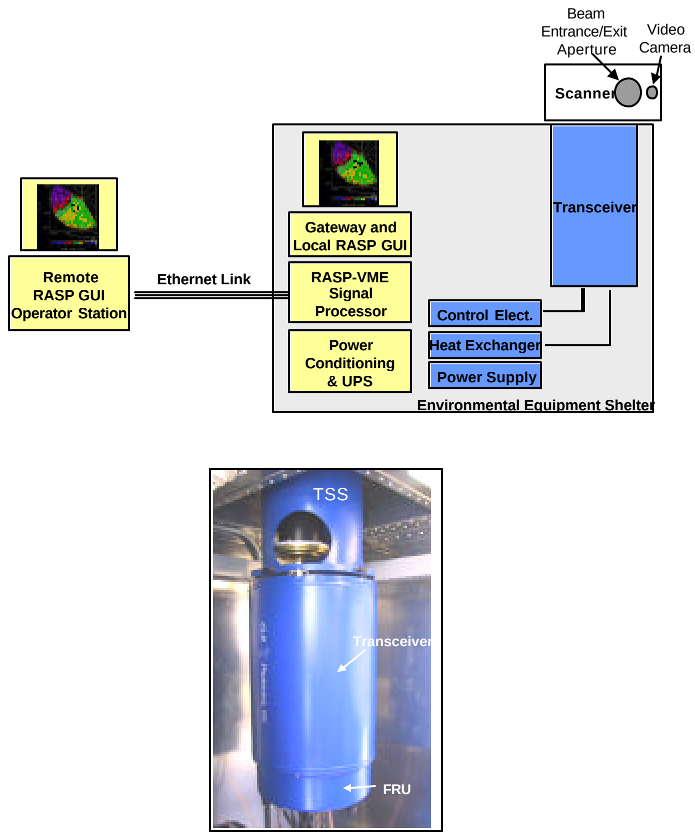

Figure 1 WindTracer® Doppler lidar system configuration showing key subsystems (above). The transceiver cylinder (below) is hung beneath the scanner and measures roughly 40 cm in diameter.

2. SYSTEM DEVELOPMENTS

Over the past decade, CTI has dedicated more than 300 person years toward the development of robust Doppler lidar systems. Our initial focus was to achieve an autonomous operation capability such that these unique sensors can be deployed in an unattended fashion in operational environments. Subsequent to those activities, software developments have focused on automated windshear alerting and more robust wake vortex monitoring. Key advances are briefly summarized below.

* *Corresponding author address*: Stephen M. Hannon, CLR Photonics, Inc., Louisville, CO 80027; e-mail: steve.hannon@ctilidar.com

Table 1 Nominal WindTracer® Specifications

Parameter	Value
Laser Material	Tm:LuAG
Wavelength	2022.5 nm
Average Power	1 Watt
Pulse Energy	2 mJ
Pulse Repetition Frequency	500 Hz
Pulsewidth	400 ns
Aperture Diameter	10 cm
Cooling	Air cooled Heat Exchanger

2.1. Autonomous Operation

The transceiver is the primary subsystem and includes the transmit laser and associated transmit/receive and beam expansion optics as well as the photodetector(s). Through the use of very low coefficient of thermal expansion materials for the mounts and a graphite composite structure for the optical bench, a wide ambient operating range is achieved without need for a re-circulating chiller (liquid to air heat exchanger only). The custom electronic cards incorporate built-in-test capability for automatic logging of system status and errors. The control electronics affect automatic and safe power up and power down of the transceiver—a necessity for autonomous operation.

The transceiver employs an end-pumped transmit laser configuration which utilizes long-lifetime continuous wave (CW) pump diodes. The one Watt average power unit has extremely good beam quality and robust mode matching optics such that very high signal to noise efficiency is achieved and maintained. Typical horizontal measurement ranges are 8-10 km for the 10 cm aperture diameter sensor.

With the core transceiver subsystem improved in a significant way, the next critical subsystem element required for autonomous operation is the data system and associated software. Configuration files establish the various system parameters for a particular measurement. The configuration files are then executed according to user-defined schedules that enable the user to achieve hands-off, long-term operation while meeting a broad range of measurement objectives. The graphical user interface can be remotely located and connected to the equipment shelter through land lines or radio frequency modem links. Therefore, the sensor can be installed and controlled, and the data displayed and re-broadcast, many miles away inside the operations center. When permitted for a particular installation, remote control of the system can be accomplished. This includes full power-down and power-up of the system as well as accessing a range of remote diagnostic information.

2.2. Field Serviceability

A key requirement for the systems, especially those installed in remote locations, is to maximize the degree of field serviceability. Improved field serviceability of the transceiver has been afforded by the recent addition of two key field replaceable units (FRUs): the pulsed laser pump diode and the master oscillator. Both of these devices are fiber-coupled and are accessible outside of the transceiver pressure vessel. This means that in the case of a component failure, these devices can be safely replaced in the field by appropriately trained staff. In addition, because the pump diodes associated with these modules have a finite lifetime, they can be replaced during scheduled maintenance visits with minimum system down time.

2.3. Graphical Situation Display for Automated Alerting

The primary means by which WindTracer® data has been utilized for wind hazard alerting is through the human interpretation of raw radial velocity displays. This is performed by a forecast meteorologist or similarly trained individual and is the way the WindTracer® data is used operationally today at the Hong Kong International Airport, for example. Automated alerting is needed at Hong Kong and elsewhere for the WindTracer® operational benefits to be maximized. Recently, CTI has worked with SIGMET, Inc. and has developed a wind hazard situation display that is based on their IRIS software package. The IRIS Terminal Doppler Weather Radar (TDWR) suite provides the type of microburst, windshear and gust front detection that is needed for automated alerting.

The general processing flow is shown in Figure 2. The WindTracer® base data processing feeds a data pipe that is ingested by the IRIS software and then displayed on a workstation display. A sample output from that display is given in Figure 3. Here, a gust front is detected and indicated by both a line and an ellipse overlay.

A virtual ribbon display output is also produced by companion software. It utilizes nomenclature and formatting similar to that used in TDWR ribbon displays.

2.4. Enhanced Wake Vortex Monitoring

A substantial number of enhancements have been implemented to the WindTracer® wake vortex detection and tracking software modules (Hannon and Thomson, 1997). The driving force behind these developments has been the long-term research data gathering at St. Louis International Airport. These involve enhanced ability to detect and track vortices in the vicinity of hills, trees and other ground obstructions. This is especially important at St. Louis where the primary area of interest is within a few thousand feet of the runway threshold, where rolling terrain and trees provide strong zero Doppler signal returns that can hamper the ability to track nearby vortices.

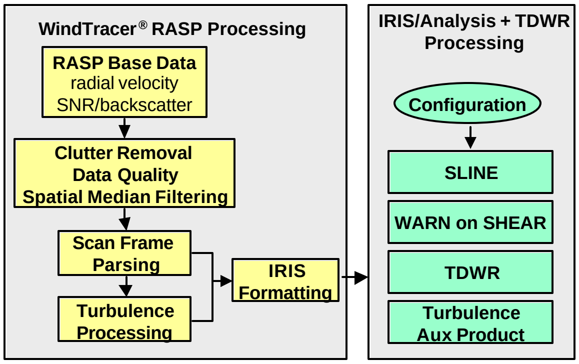

Figure 2 Block diagram of processing flow for wind hazard situation display product generation.

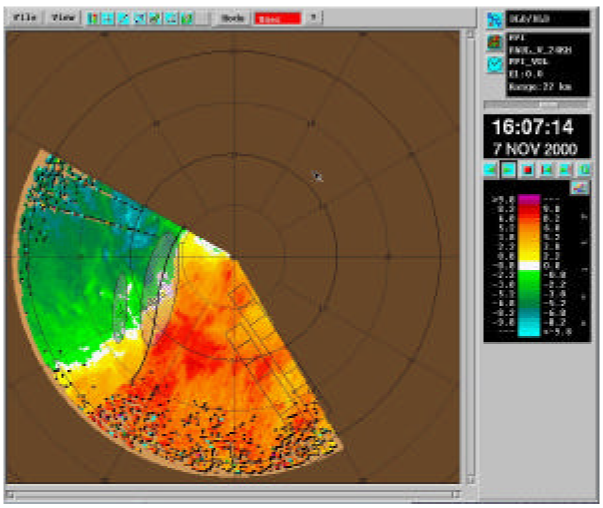

Figure 3 Sample plan position indicator (PPI) display of measured radial velocity. The velocity data is color-coded with positive velocities defined as away from the lidar. A shear line algorithm is applied to the data and icons indicate the location of the gust front relative to the airport approach and departure corridors.

3. HONG KONG INTERNATIONAL AIRPORT: WIND HAZARD MONITORING

In June 2002, a WindTracer® Doppler lidar was installed at the Hong Kong International Airport. This represents the first such permanent installation in the world. The WindTracer® is providing airport forecasters high resolution images of the windshear and turbulence environment at the airport.

The Hong Kong International Airport is located next to a large mountainous island (Lantau Island) which sometimes causes windshear and turbulence, especially when the wind blows over the mountain and toward the airport. Other wind hazards arise due to frontal passages (including gust fronts) and sea breezes. These wind conditions are potentially hazardous to landing and departing aircraft. Much of the time, these hazardous wind conditions occur in clear air such that the existing TDWR at the airport is hard-pressed to provide reliable alerting of the wind hazards. Anemometer stations are also installed at the airport but they only give wind information at specific points close to the ground. The newly installed WindTracer® Doppler lidar generates a clear air view of the winds over wide areas along and near the approach and departure corridors and so naturally covers the areas that the radar and anemometers miss.

A photograph of the Air Traffic Control Complex is shown below. The site, on the top of a large building near the center of the airport, affords excellent viewing of the approach and departure corridors on either end of the airport. At this point, the lidar system has logged over 18,000 operating hours since its installation.

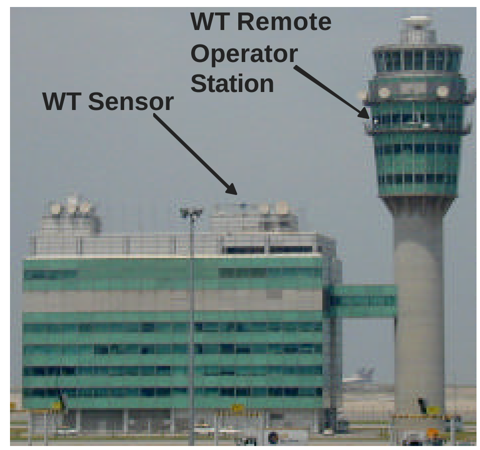

Figure 4 Photograph of the Hong Kong Air Traffic Control Tower facility.

Figure 5 WindTracer® Remote Operator Station (right) adjacent to a TDWR display (left) in the HKO's Airport Meteorological Office.

An important distinguishing characteristic of Doppler lidar is that its narrow beam produces negligible sidelobe clutter. Clutter is a problem for microwave radar because it can cause false or misleading signals. In contrast, Doppler lidar works especially well when scanning very near the ground or in the vicinity of a hillside.

The customer for the WindTracer® in Hong Kong is the Hong Kong Observatory (HKO). The HKO is one of the world's leading meteorological organizations and forecasts weather and issues warnings on weather-related hazards at the airport and within a designated airspace over the northern part of the South China Sea. To enhance the safety of aircraft landing at and taking off from the HKIA, the HKO issues alerts of low-level windshear and turbulence. A TDWR, a network of over 20 anemometers, two wind profilers, and now the pulsed Doppler lidar, are used to assist in the detection and warning of windshear and turbulence.

The WindTracer® data is currently being used by aviation weather observers and forecasters to augment the existing sensor suite in an evaluation mode. A sample data snapshot is shown in Figure 6. The runways and alerting areas are shown in the map overlay. The control tower blocks the beam to the north. Current developments include automating the detection and alerting algorithms and integrating them with the HKO's existing alerting system. Once operationally implemented, HKIA will have the most sophisticated, and robust, windshear and turbulence alerting system in the world. Additional information about the Hong Kong Doppler lidar is available (e.g., Shun, 2003; Chan and Mok, 2004).

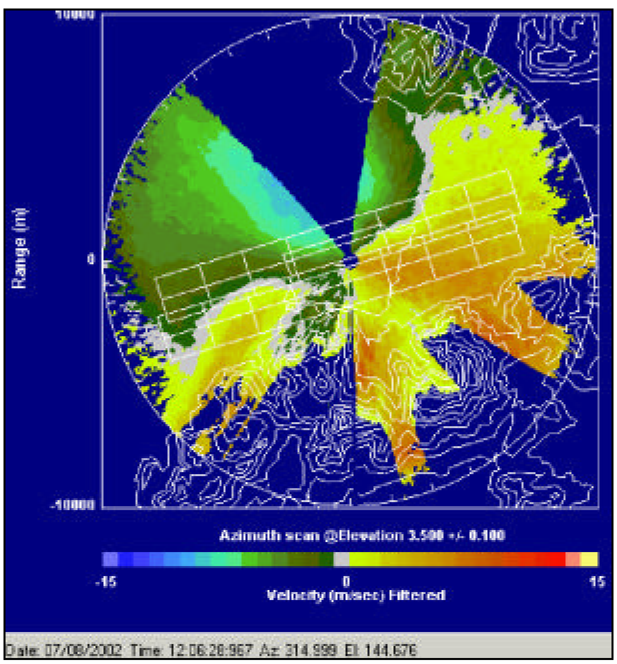

Figure 6 Sample PPI display of measured radial velocity with an overlay of the airport alerting area and nearby Lantau Island. Flow is out of the NNW.

4. DENVER INTERNATIONAL AIRPORT: WAKE AND WIND MONITORING

In August and September of 2003, a WindTracer® pulsed Doppler lidar was installed north of Denver International Airport (DEN). The primary purpose for this deployment was to monitor the wakes of arriving aircraft onto runway 16L. In addition, the system conducted wind surveillance scans on a regular basis.

4.1. Glide Slope Wake Vortex Monitoring

The DEN Wake Acoustic Test was sponsored by NASA and had as its objective the collection of acoustic (sound) signature data from wakes of landing aircraft in an effort to characterize these signatures for a variety of aircraft types in various conditions. The role of the pulsed lidar was to provide 'ground truth' position information to aid in the characterization activities. Much of this data was collected with the lidar tracking the vortices in the more traditional transverse viewing geometry. Here, the lidar scans vertically at a fixed azimuth. The scan plane intersects the aircraft flight path perpendicular to its direction of travel (Hannon and Thomson, 1997). Analysis of the acoustic signature data is expected to appear in published reports and papers over the next year or two.

Subsequent to the test, CTI collected 'glide slope viewing' data for aircraft on approach to both 16L and 16R. Here, a pair of horizontal scan planes was used to scan from the lidar location down toward the threshold of the runway of interest, some 9000 feet from the lidar. This viewing geometry provides several advantages relative to sensor siting for typical airports located within urban environments.

A sample glide slope viewing spectral width data set is shown in Figure 7. The upper panel set shows the passage of a B737 aircraft and the initial indication of a spectral width signature. As time advances, the middle panel set shows the elongated signature as the wake descends through the scan plane. The lower panel sets shows the signature as it begins to disintegrate, nearly 90 seconds after passage. These types of signatures were consistently produced by each aircraft and appear to offer an alternate, reliable means of detecting and tracking wakes. Ongoing developments are focused on producing automated tracking algorithms for this very purpose.

4.2. Wind Hazard Surveillance

The DEN wind hazard data is being jointly analyzed by MIT Lincoln Laboratory and CTI. During the two-month deployment, several sample windshear cases were observed by the pulsed lidar. Comparisons are now being conducted with Low Level Windshear Alert System (LLWAS) data as well as NexRAD data. In addition, MIT Lincoln Laboratory algorithms will be applied to selected cases to evaluate their ability to be easily adapted to effectively process lidar data.

A sample DEN pulsed lidar windshear data snapshot is shown in Figure 8. Here, the shear associated with a frontal passage is evident in the radial wind display.

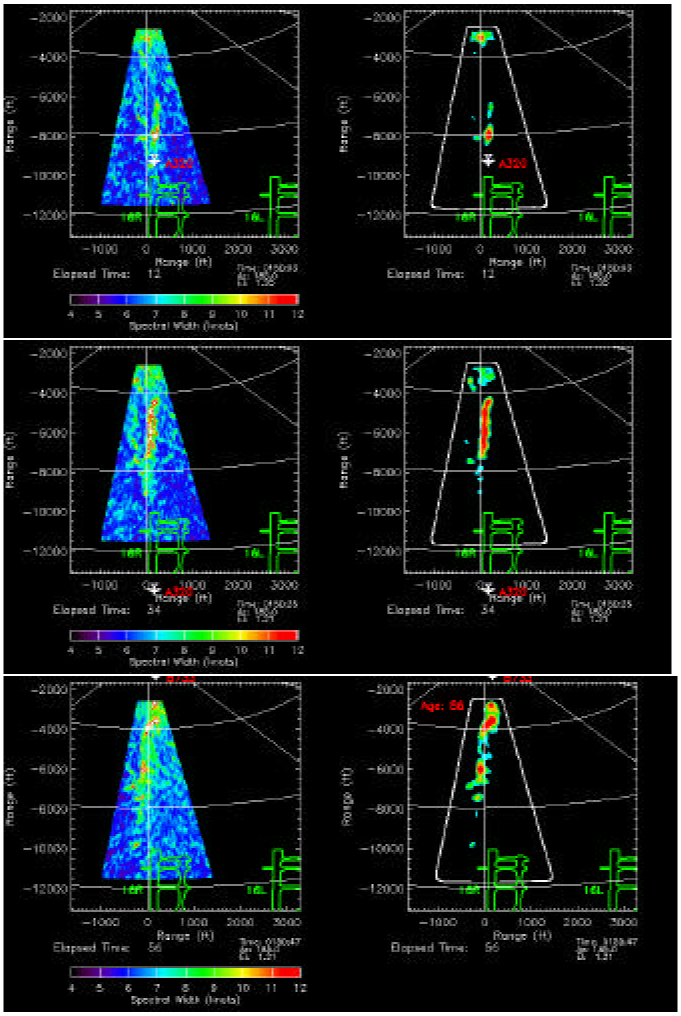

Figure 7 Sample glide slope viewing example from DEN. Snapshots from three scans are provided. Each two-panel display shows the estimated spectral width on the left and a thresholded version of the spectral width on the right. The panels are plan views of the approach corridor to runway 16R at DEN.

5. ST. LOUIS INTERNATIONAL AIRPORT: WAKE VORTEX MONITORING

In March of 2003, a WindTracer® pulsed Doppler lidar was installed adjacent to St. Louis International Airport (STL). This system was installed near the western end of the airport and is monitoring wake vortices and winds in support of the joint FAA/NASA Wake Turbulence Research Program (WTRP). The goal of the WTRP is to develop capacity-enhancing procedures that can be implemented in the next 3-7 years (Lang et al., 2003; Fiduccia et al., 2004).

Wakes of aircraft landing onto runways 12L and 12R are measured by the lidar within five different vertical scan planes: 31 degrees azimuth, 50 degrees, 75 degrees and 86 degrees (all azimuths measured relative to true north). The data are being analyzed by staff at the Department of Transportation Volpe Center as well as other WTRP staff.

A second pulsed lidar was installed at STL in August 2004. This system will initially focus on wind and wake monitoring from a location between the two runways. Glide slope viewing, similar to that demonstrated at DEN, will be implemented to provide more comprehensive coverage of the approach corridor. Volpe Center has also installed several other wake and wind sensors in St. Louis, including a pair of windlines and three sodars. Figure 9 shows the instrument layout at STL.

6. SUMMARY

CLR has made significant improvements in its solid-state 2 µm pulsed Doppler lidar systems over the past decade. For the past two years, one of our Doppler lidars has been operating at the Hong-Kong International Airport for windshear and turbulence detection. Another dedicated unit has been installed for more than a year at the St. Louis International Airport for FAA-sponsored, long-term wake vortex monitoring. These installations demonstrate significantly different means by which the same technology can benefit airport operations.

Going forward, system developments will focus on enhancing windshear and turbulence automated alerting algorithms. The permanent system installations provide a wealth of case study data that will be exploited to develop and evaluate the performance of these algorithms. Wake vortex software developments will focus on both transverse and glide slope viewing geometries. The initial goal of the wake vortex work is more robust research database generation. These developments can then lead to future operational algorithms that would enable lidar use within a tiered sensor network to safely enhance airport capacity and efficiency.

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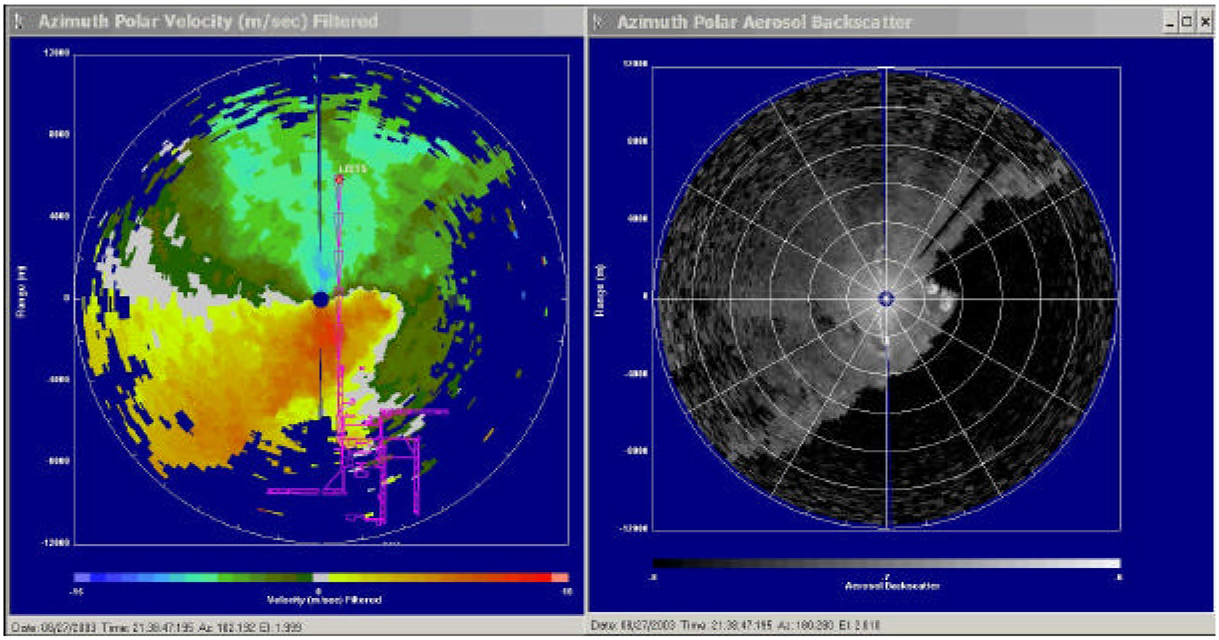

Figure 8 Sample PPI display of measured radial velocity (left) and aerosol backscatter (right) at DEN on 27 August 2003. The 2.0 degree elevation angle tilt is shown. The radial velocity display is color-coded with positive velocity defined away from the lidar. The front is also clearly visible in the aerosol backscatter display, extending along a line running from the southwest to the northeast and advancing toward the southeast.

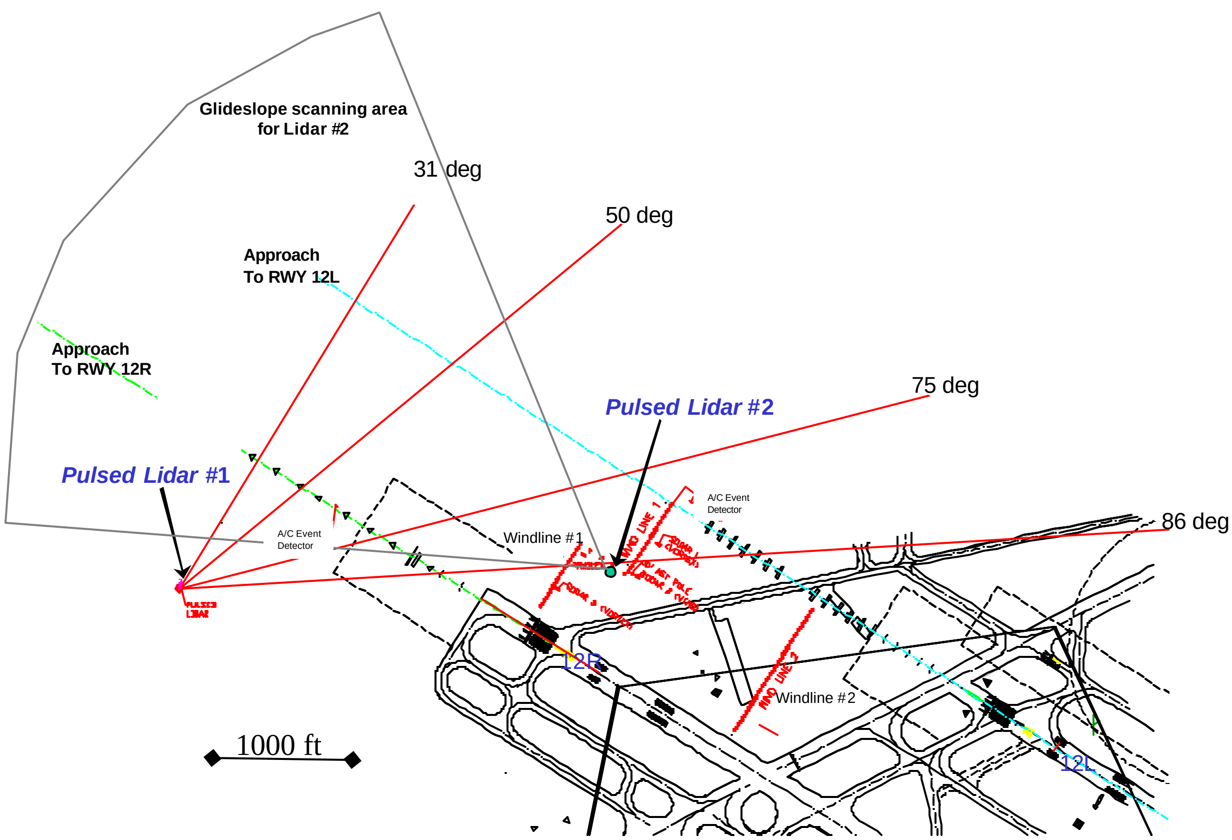

Figure 9 Instrument layout at St. Louis International Airport for wake and wind monitoring.