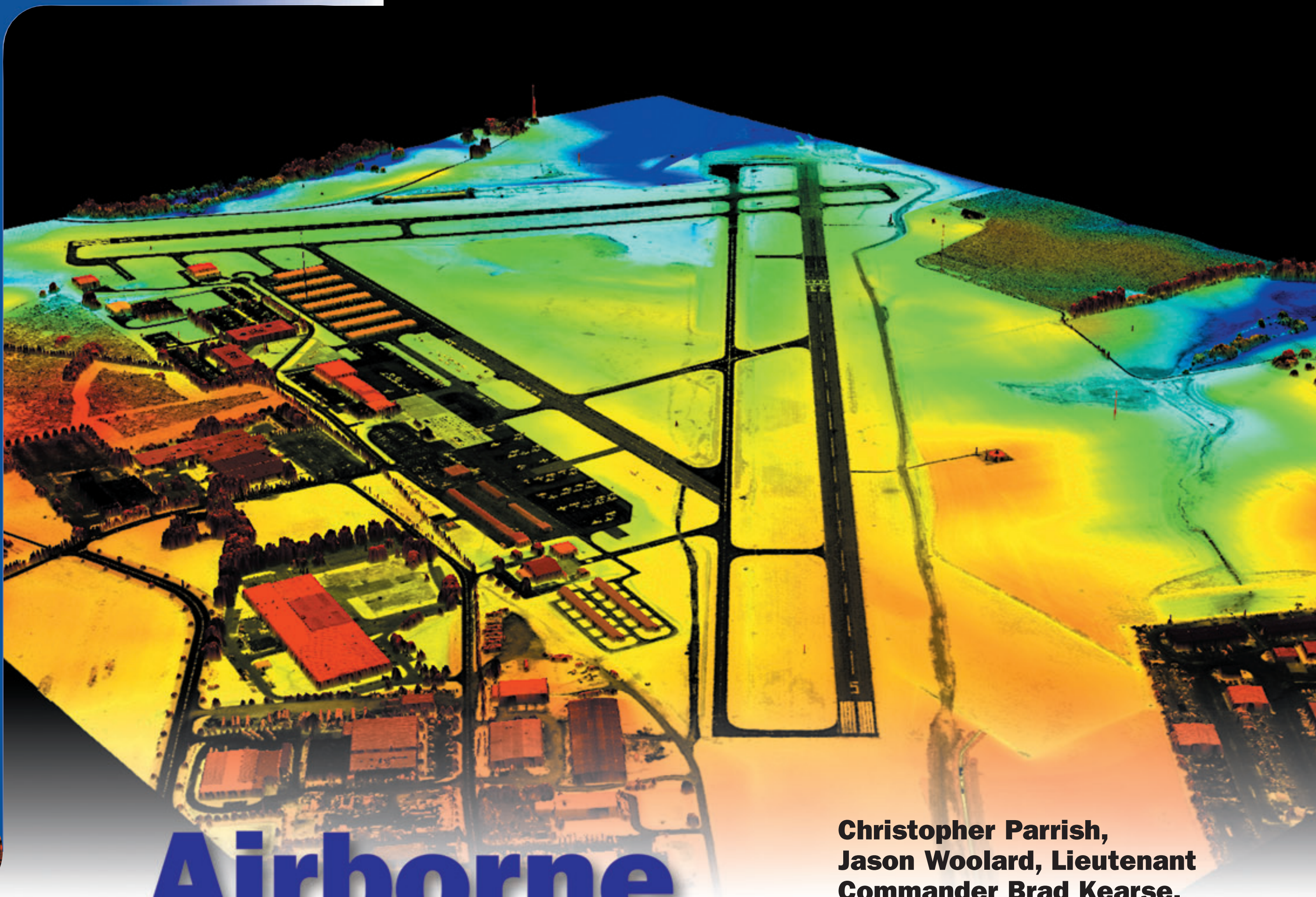

Airborne LiDAR Technology for Airspace Obstruction Mapping

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Introduction

The National Airspace System (NAS) handles more than 55,000 daily flights, which use 12,300 instrument approach procedures. These instrument approach procedures allow pilots to navigate safely into airports in reduced-visibility weather conditions by following specified flight courses, turns, and minimum altitudes. Over the past decade, the number of instrument procedures for aircrafts has grown by approximately 50%.

As part of its precise positioning activities, the National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS) supports the NAS and instrument procedure development by managing the Aeronautical Survey Program in accordance with a series of interagency agreements with the Federal Aviation Administration (FAA). The National Spatial Reference

System (NSRS), defined and managed by NGS, is a consistent national coordinate system that specifies latitude, longitude, height, and orientation throughout the nation. The NSRS provides the basis for accurately geolocating features that penetrate FAA obstruction identification surfaces. The obstruction identification surfaces are imaginary three-dimensional surfaces enveloping the airport and approach paths, and any object, such as a tree, building, or tower, that sticks up above these surfaces is termed an airport "obstruction."

Specifications for airport obstruction surveys are contained in FAA No. 405, *Standards for Aeronautical Surveys and Related Products* (U.S. Department of Transportation, 1996). In order to meet the accuracy standards in FAA No. 405 and maintain a system of checks and balances, both field and photogrammetric surveys are currently utilized. The accuracy and reliability with which airport features can be geolocated using photogrammetric methods, which rely on georeferenced stereoscopic aerial photography, have been well documented over the past several decades. The field surveys are critical in identifying and positioning manmade and natural objects that are not readily visible in the photography, such as smaller towers, transmission lines, whip antennas, and trees without canopies. The FAA uses the source data provided by NGS to develop instrument approach and departure procedures and determine maximum takeoff weights for civil aircraft in the NAS.

Over the past fifty years, NGS has conducted thousands of airport surveys. Even though the current method of conducting these surveys will still play an important role in obstruction surveying, research into new remote sensing technologies is beginning to take hold. The flexibility of using remote sensing could help to meet the higher demand for obstruction survey data, create digital databases compatible with other FAA and National Aeronautics and Space Administration (NASA) initiatives, and adapt to the varying requirements of different airports.

In cooperation with academic, government, and private industry partners, NGS has investigated the use of LiDAR (an acronym for Light Detection And Ranging) for the collection of obstructions and terrain databases over the past three years. LiDAR is an active remote sensing technology that uses laser ranges and airborne GPS and inertial measurement unit (IMU) data to generate high-resolution elevation datasets. LiDAR holds much promise as a potential means of collecting accurate data for aeronautical databases. By applying LiDAR to airport obstruction surveys, NGS' goal is to investigate the capability to obtain obstruction data meeting an accuracy of 20 feet vertical and 50 feet horizontal for all obstructions. The FAA sets these requirements for nonprecision instrument approach procedure development. Our secondary objective is to explore the capability to deliver final LiDAR obstruction data sets to the FAA to be used for approach procedure development. In this paper, we present the results of the most recent phase of this research.

Figure 1 *Custom sensor mount used in the 2002 study. This mount allows the lidar sensor head to be tilted between zero (nadir) and 40° forward. Here, the sensor head is shown in the 20° forward tilt position. The survey aircraft is a Cessna Skymaster.*

Background

In 2001, NGS collaborated with the FAA, the University of Florida (UF), and Optech, Inc. on the first phase of research into the application of LiDAR in airport obstruction surveys. We collected data in the approaches to Gainesville Regional Airport in Gainesville, Florida using two LiDAR systems: an Optech Airborne Laser Terrain Mapper (ALTM) 2033 in a NOAA Cessna Citation and an Optech ALTM 2010 in a UF Cessna Skymaster. We then compared the LiDAR data against field-surveyed obstruction data collected by an NGS field crew using GPS and conventional survey methods. Although the 2001 study provided much valuable information, the results were relatively disappointing; at best, only 94% of the field-surveyed obstructions were detected using the LiDAR systems. In particular, several poles, antennas, and other small-diameter obstructions were not detected with the LiDAR systems.

In the second phase of our research, completed in 2002, we focused on determining the best configuration of a LiDAR system for detecting obstructions. Specifically, we investigated the effects of varying the following parameters: flying height, tilt (or "forward look") angle of the sensor, laser beam divergence, scan angle, and pulse repetition frequency (PRF). Optech manufactured a custom sensor mount that allowed the LiDAR sensor head to be tilted up to 40° forward of nadir (**Figure 1**). The three best configurations all resulted in 100% detection of the field-surveyed obstructions. The best configuration used a 20° tilt angle, narrow beam divergence, and a flying height of 750 meters. All fourteen configurations used a scan angle of ±15°, a scan frequency of 53 hertz, a PRF of 50 kilohertz, and a flying speed of approximately 110 knots.

A primary goal in the latest phase of our research was to demonstrate the capability to perform a complete end-to-end obstruction survey using LiDAR and, thus, begin the transition from pure research to implementation. Using the knowledge gained from the 2002 study, we aimed to deliver a final LiDAR-derived obstruction data set to the FAA for use in instrument approach procedure development.

Experiment

In September 2003, NGS conducted an airborne LiDAR survey of the new Area Navigation Approach (ANA) Obstruction Identification Surfaces (OIS) for Stafford Regional Airport in Stafford, Virginia and Frederick Municipal Airport in Frederick, Maryland. Based on the findings from the previous phases of our research, we determined that the best sensor configuration for airport obstruction mapping consisted of one sensor mounted in the nadir position and one mounted with a 20° forward look angle. This dual sensor configuration provided strong geometry (horizontal and vertical spacing of laser points on vertical features) and radiometry (detected laser return signal) for mapping airport obstructions.

From September 8 through 11, 2003, two Optech ALTM 2050 LiDAR sensors were flown onboard a NOAA Twin Otter aircraft. The sensors collected data simultaneously at a PRF of 50 kilohertz from an altitude of 750 meters above ground level. The survey ground speed was 60 meters per second with a scan angle of +/- 16° and a scan frequency of 31 hertz. Each project consisted of nine flight lines over the airport and its approaches. The flight times for each mission were just over one hour and generated more than 450 million x,y,z data points. The flights were successful, resulting in high resolution data sets for the airports and surrounding areas (**Figure 2**).

The ground survey field portion of the experiment provided data critical to the analysis of LiDAR data for airport obstruction mapping. An NGS field party surveyed both the Stafford and Frederick airports using conventional survey techniques to provide horizontal and vertical positional information for 50 objects at the Stafford airport and 91 objects at the Frederick airport. A wide variety of objects was surveyed ranging from trees to light poles and buildings.

Analysis and Results

To determine how well obstructions were detected and geolocated using the LiDAR systems, we compared the LiDAR data against the field-surveyed obstruction data. The algorithm used to perform the comparison involved creating a virtual cylinder around each field-surveyed obstruction and searching for LiDAR points within the cylinder. The radius of the search cylinder was set to 3 meters and the maximum elevation difference to 6 meters, based on the applicable specifications contained in FAA Order 8260.19C, *Flight Procedures and Airspace* (U.S. Department of Transportation, 1993). If no LiDAR points were found within the search cylinder, our software reported the obstruction to be "not detected." If multiple LiDAR points were found in the cylinder, the software selected the point closest to the field-surveyed point as a "match" and used it in computing the obstruction geolocation accuracy achieved with the LiDAR systems.

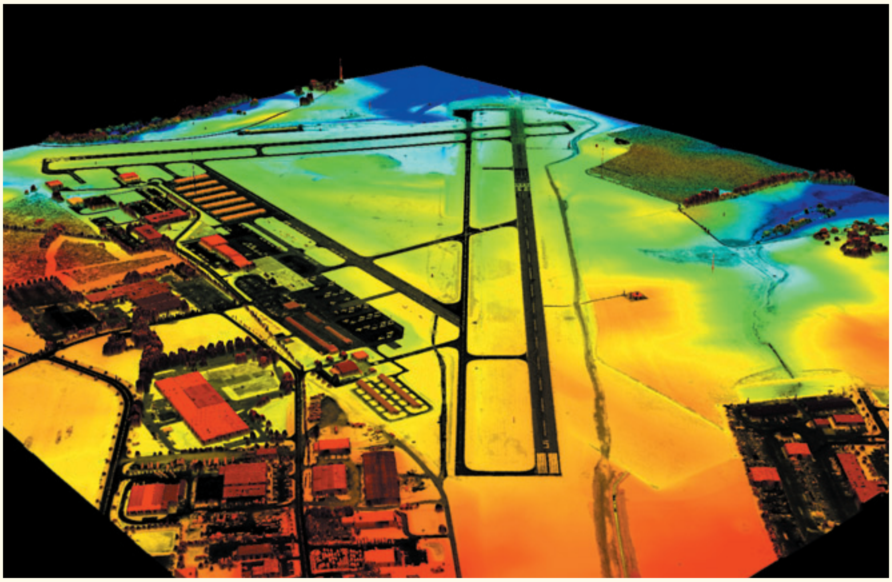

Figure 2 *A color-ramped LiDAR intensity image draped over the LiDAR digital surface model for Frederick Municipal Airport.*

In **Table 1**, we show the final results of the obstruction detection analysis. The combination of sensors resulted in 100% detection of the field-surveyed obstructions at both the Stafford and Frederick airports. The vertical accuracy (root mean square error) is also quite good for both airports: 1.12 meters for Stafford and 0.69 meters for Frederick.

Our next step in the obstruction detection analysis entailed examining the LiDAR data visually using Terrasolid Ltd. TerraScan software. **Figure 3** shows a photo of one of the field surveyed obstructions at Frederick (a light pole in the runway 5 approach) and a profile

Airport	Data Set	Percent of Obstructions Detected	RMSE (m)	Acuracy at 95% CL (m)	Average # of Pts in Search Cylinder
Stafford	20 deg tilt	100	1.32	2.58	59
Stafford	Nadir	100	1.20	2.36	62
Stafford	Combined	100	1.12	2.19	122
Frederick	20 deg tilt	99	0.76	1.50	38
Frederick	Nadir	100	0.77	1.50	48
Frederick	Combined	100	0.69	1.34	87

Table 1 *Final results of the automated obstruction detection analysis. Using the dual-system approach, we achieved 100% obstruction detection at both Frederick and Stafford. The vertical RMSEs are also encouraging. The last column lists the average number of LiDAR data points found in the virtual search cylinder around each field-surveyed obstruction.*

Figure 3 *Photo of a light pole, one of the field-surveyed obstructions in the runway 5 approach at Frederick Municipal Airport. Bottom: a profile view of the corresponding LiDAR data points. The red dots represent the LiDAR data points from the tilted sensor, while the white dots represent the LiDAR data points from the nadir-pointing sensor. The green dot denotes the field-surveyed location.*

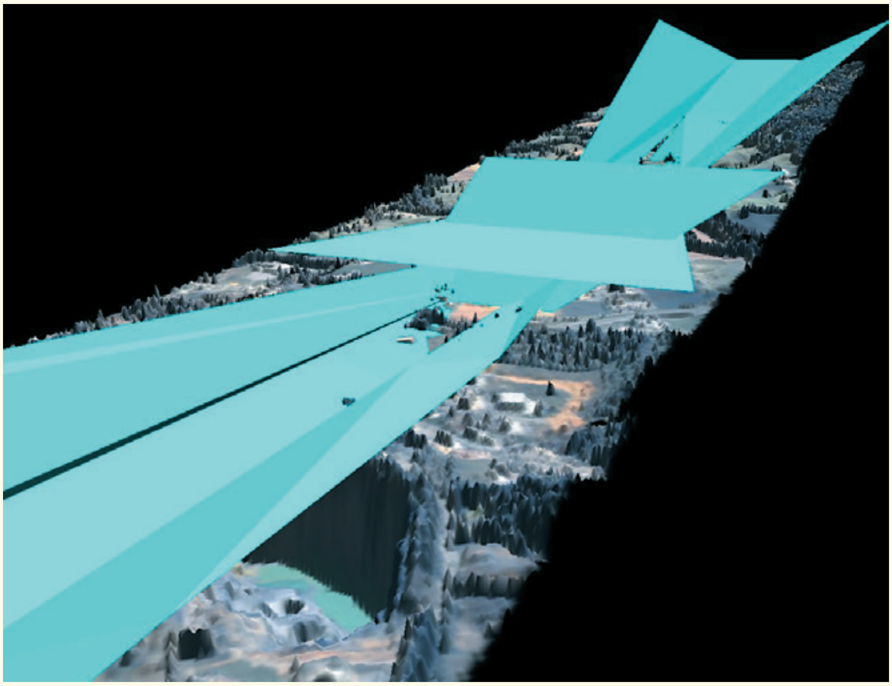

Figure 4 *A visual method of analyzing the LiDAR data against the obstruction identification surfaces (OIS) using ERDAS Imagine software. Features sticking up through the blue-colored OIS are obstructions. Custom software developed at NGS permits a precise mathematical analysis to supplement the visual analysis.*

view of the corresponding LiDAR data points. The red dots represent LiDAR points from the tilted sensor, while the white dots denote LiDAR points from the nadir-pointing sensor.

Based on these analyses, we concluded that the dual-sensor approach is important for the following reasons:

- By using two systems, we essentially double the PRF and, hence, the density of the LiDAR point cloud, improving the probability of obstruction detection.
- The two systems complement each other in that the tilted sensor provides better geometry (laser points that "walk up" the face of a vertical object), while the nadir-pointing system yields higher return signal strength from small obstructions.
- The dual system assists in distinguishing between "false returns" (*i.e.*, unwanted returns caused by atmospheric particles, birds, electronic noise, etc.) and real features (*e.g.*, the top of a power pole) in that it is unlikely that the same false point would be detected by both systems. Our next step was to analyze the LiDAR data against the OIS. **Figure 4** shows a visual method of performing the OIS analysis using ERDAS Imagine software. In this perspective view, penetrating features in the LiDAR data can be clearly seen sticking up through the OIS. We also used custom software developed at NGS, which automatically locates all obstructing points in the LiDAR data and precisely computes the penetrations. Next, NGS analysts attributed the LiDAR-derived obstruction data according to feature type (*e.g.*, tree, pole, antenna, etc.) This was performed by overlaying the LiDAR obstruction data on stereo imagery using BAE softcopy photogrammetry software, SOCET SET (**Figure 5**). We then created final LiDAR-derived obstruction data sets for both airports.

Conclusions

Through the research conducted over the past three years, we have gained a tremendous amount of knowledge regarding the application of LiDAR in airport obstruction surveying. The following are among the more important lessons learned:

- Proper configuration of the LiDAR system and proper choice of mission parameters are critical to detecting a high percentage of the obstructions at an airport.
- A combination of nadir-pointing and tilted sensors is advantageous in that it yields strong geometry and radiometry, while also assisting in distinguishing between real features and false returns.
- The sensitivity of the receiver is an important criterion in obstruction detection in that it determines the minimum detectable return signal strength.

This knowledge has allowed us to successfully complete end-to-end obstruction surveys at Frederick Municipal Airport and Stafford Regional Airport. Most significantly, we have demonstrated the capability to deliver final LiDAR obstruction data sets to the FAA and the FAA has used these data to develop instrument approach procedures. The total time from data acquisition to approach procedure development was just three months, illustrating a significant time savings over conventional survey methods.

Despite the relative success of the most recent research project, much work remains to be done. NGS is currently working on a standards and specifications document for conducting airport obstruction surveys using LiDAR, which will cover system configuration, calibration, mission planning, and other topics. These standards could be used by NGS, the FAA, and individual airports in contracting for LiDAR surveys. In addition, NGS is currently working with the FAA on the requirements for new instrument approach procedure development software that will take full advantage of LiDAR data. Through these initiatives, the use of LiDAR in airport surveying is likely to increase markedly in the near future.

Acknowledgments

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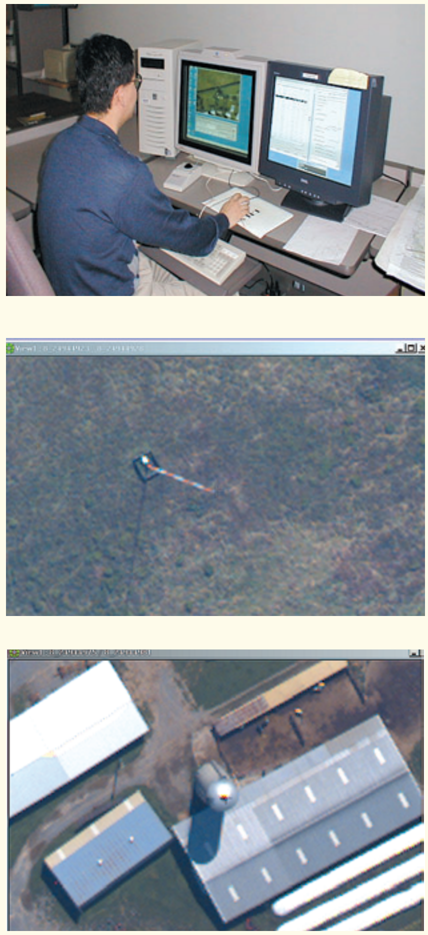

Figure 5 *Attributing the LiDAR-derived obstructions by overlaying them on stereo imagery using BAE SOCET SET software. The middle image shows a LiDAR data point on an antenna, while the bottom image shows a LiDAR data point on a silo.*

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