PROCEDURES FOR FOD DETECTION SYSTEM PERFORMANCE ASSESSMENTS: RADAR-BASED AND DUAL SENSOR SYSTEMS

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PRESENTED FOR THE
2010 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2010

INTRODUCTION

As part of a comprehensive performance assessment of Foreign Object Debris (FOD) detection systems at civil airports, assessments of a radar system and a hybrid electro-optical and radar detection system was conducted by the Center of Excellence for Airport Technology (CEAT). The radar-based sensor was the QinetiQ *Tarsier^{TM}* FOD detection system. The hybrid sensor was the Xsight *FODetect^{TM}* FOD detection system.

The performance assessments were designed to provide a rich data resource that could assess the performance of both individual sensors and combined sensor systems. Targets included a variety of items, some with known detection characteristics, such as radar cross sectional area (RCS) for radar-based sensors and color and surface condition for electro-optical systems. Targets also had different shapes and sizes and were made of different materials to provide target characteristics that would challenge detection systems. Assessment campaigns were scheduled over a 12-month period with the intent of testing under varied weather conditions.

The performance assessment of the radar-based *Tarsier^{TM}* FOD detection system was initiated in 2004. It included a preliminary test at John F. Kennedy International Airport (JFK) in January 2005 and an assessment of an operational system from June 2007 to March 2008 on an entire runway at Providence's John F. Green International Airport (PVD).

The assessment of the Xsight *FODetect^{TM}* FOD detection system (a hybrid sensor) began in early 2008; the Xsight *FODetect^{TM}* system was installed at Boston's Logan International Airport (BOS). This installation provided partial runway coverage with a total of five sensor units. The BOS studies were initiated in June 2008 and ended in March 2009.

The overall goals of testing any FOD sensor are:

1. calibrating the FOD detection system with items of known detection characteristics and confirm sensor operation for each test campaign, providing information on system reliability and robustness;

2. determining detection performance for FOD items with different hazard potentials, considering distance from the sensor and orientation to the sensor;

3. assessing system detection of FOD items placed randomly in blind testing, providing a test of the typical detection needs of airports.

The detection capabilities of each sensor are unique to the technology being tested. The *Tarsier*™ FOD detection system is based on a radar sensor that is located on a tower set back from the runway, outside regulated safety zones. The primary sensor is a 94 GHz coherent radar. This millimeter wavelength radar is capable of detecting small targets at long distances, with a claimed smallest detection of a 10 mm (0.39 inch) metal fitting in normal operation. The primary performance criterion is detection of a target with a reflectivity of -20 dBm2 at a range of 1 km (0.62 mi) in a 16 mm per hour (0.62 inch/hour) rainfall. The radar sensor was designed to sweep along the runway length with overlapping coverage of the two scanners near the middle of the runway. A single scan required 70 to 90 seconds to complete.

Xsight's *FODetect*™ FOD detection system is based on a radar and intelligent vision sensors mounted together on a runway edge light. In the BOS installation, 5 sensors replaced edge lights for a distance of approximately 550 ft along the north west section of Runway 15R. The hybrid sensor employs a 76 GHz radar and a video camera supported by image analysis software. In the BOS configuration, each sensor scanned a rectangle approximately 200 ft long centered on the runway edge light, with a width defined by the distance from the edge line to the runway center line (approximately 75 ft).

CALIBRATION TESTING

Calibration testing consisted of using objects with defined detection characteristics. The objective of calibration testing was to determine if the system met a defined detection criterion and to confirm detection performance as the performance assessment progressed. Calibration targets for radar sensors were:

- metal cylinders of 1.5 in (3.8 cm) in diameter and 1.25 in (3.1 cm) in height with a nominal reflectivity of -20dBm,
- spheres of 2 in (5 cm) in
- targets machined from metal tubes 2 in (5 cm) in diameter by 2.5 in (6.3cm) in height with a nominal -10 dBm reflectivity and
- targets machined from metal tubes 3 in (7.6 cm) in diameter by 4.5 in (11.4 cm) in height with a nominal 0 dBm reflectivity.

Calibration targets were also selected specifically for the hybrid radar/electro-optical system. These included white, grey, and black PVC cylinders that were 1.52 in (3.81 cm) in diameter and 1.25 in (3.1 cm) in height and a metal cylinder of the same dimensions. The metal cylinders provided radar reflectivity and PVC cylinders provided a color contrast to runway backgrounds.

The arrangement of calibration targets on the runway was designed to assess the capability of the radar or electro-optical system to detect known targets at different distances from the primary sensor. For the radar-based sensor (the QinetiQ *Tarsier*™) used at PVD, the entire runway length was used for testing, and calibration targets were placed in six transects, Figure 1.

Figure 1. Locations of Calibration Transects at PVD.

For the hybrid system (the Xsight *FODetect*^{TM}) used at BOS, ten sensors were installed along approximately 600 ft (280 m) of runway; five sensors were installed on each side of the runway. The middle three sensors on each side of the runway were used for performance assessments. Targets were placed on the corners of a rectangle that was approximately 150 ft (45 m) in length centered on the middle sensor. The width of the rectangle was approximately 70 ft (21m) wide as defined by the distance between the runway edge and center lines. A target for the hybrid system consisted of a group of 4 cylinders that included white, grey, and black PVC cylinders and a metal cylinder. Target orientation varied based on position. To assess system performance, targets were also placed in additional positions, Figure 2, that included placements 30 ft (10 m) beyond the rectangle edge.

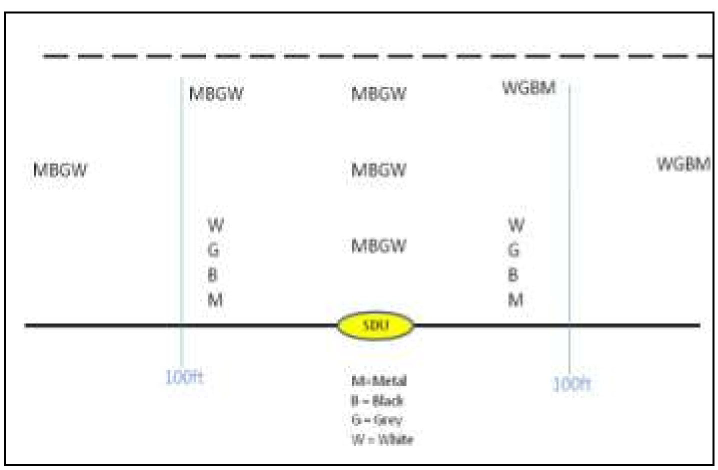

Figure 2. The Location of Calibration Targets at BOS.

PERFORMANCE TESTING

Performance testing was conducted to assess the detection of a range of common FOD items that were selected to present different hazard potentials and frequency of occurrence in aircraft movement areas, Table 1. Unlike calibration targets the performance targets were not selected based on sensor type. Items were selected to provide a standard set of targets that could be used with all FOD detection system performance assessments.

Table 1.
Standard FOD Items Used in Performance Assessments.

FOD Item[a]	Expected Hazard	Frequency of Occurrence
1. Small Piece of Concrete	High	Common
2. Standard Lug Nut From Service Vehicle	High	Common
3. Roller Bearing	High	Common
4. Chunk of Rubber	Low	Common
5. Mechanics Wrench	High	Common
6. Fuel Cap	High	Common
7. Cotter Key	Moderate	Common
8. Plastic Bottle/Bottle Cap	Low	Common
9. Strapping Material	Moderate	Common
10. Expansion Joint Material	Low	Common
11. Construction Material–Galvanized Nails or Sheetrock Screws	Moderate	Based on Construction Activity
12. Runway Infrastructure Part–Piece of Runway Light or Signage	High	Uncommon
13. Small Fasteners	Moderate	Common
14. Metal Strip	High	Uncommon
15. Fiberglass Door	Moderate	Common
16. Asphalt Chunk	High	Common

[a]Items were selected based on consultation with James Stephan of Delta Airlines based on his studies of FOD items common on runways.

For radar testing at both PVD and BOS, an array was marked on the runway with a UV paint that was near background color yet fluoresced under UV light for night time testing. At PVD the arrays were coordinated with calibration transects producing a 5 item by 5 item array, Figure 3. The distance between items in the array was approximately 25 ft (7.5 m). Only 23 targets were placed on the array because of the location of permanent runway lighting. In test campaigns, calibration targets were placed in 5 positions in the array, and FOD targets were placed in the remaining positions. The placement of individual FOD items at all transects was consistent for each campaign, with positions selected on a campaign-specific randomization scheme. During the performance testing, items were placed in the array and detection performance recorded. After detection, items with a long axis were rotated 45 degrees and detection was again recorded. A complete campaign consisted of targets rotated through 8 cardinal points of the compass

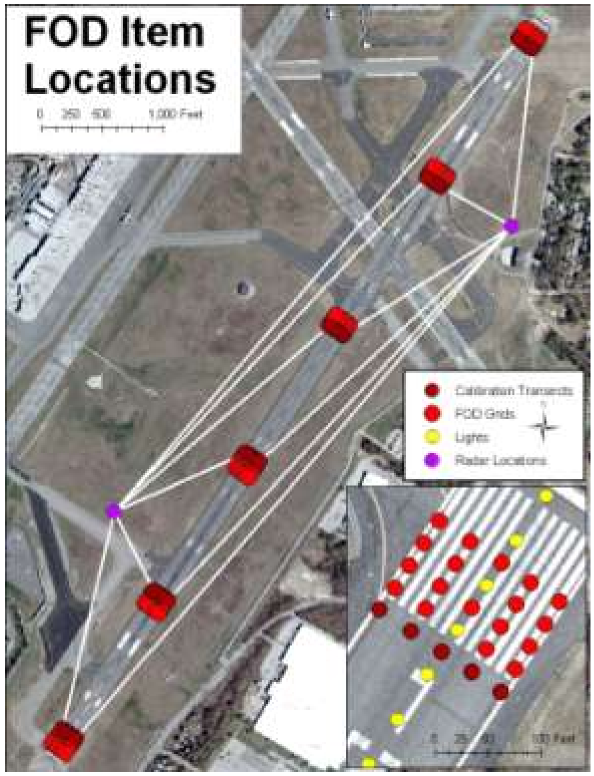

Figure 3. Location of FOD Arrays at PVD.

For hybrid system testing at BOS, a mid-line was established in the testing rectangle that was centered on the middle sensor, Figure 4. Five identical FOD items were placed at equal distances across the centerline of the rectangle; four calibration items were along the centerline boundary of the rectangle.

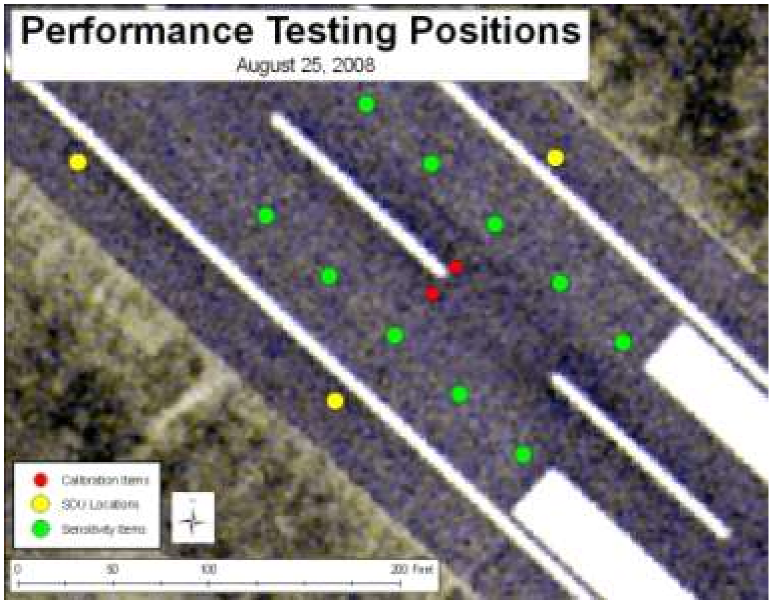

Figure 4. Performance Testing Positions at BOS.

At both locations, a differential GPS survey, accurate to millimeters in the X/Y plane, was used to establish the location of targets placed during calibration and performance testing. The GPS location was then used to compare the latitude and longitude for each target provided by the *Tarsier*™ radar and the *FODetect*^{TM}.

BLIND TESTING

The blind testing used actual FOD items collected from runways that were donated by airports or items selected to provide a range of possible FOD item categories reported by airports. CEAT has developed a collection of over 100 FOD items that have been measured, photographed, and numbered. From this inventory of actual FOD items, 30 items were selected at random for use in each test campaign. In addition to the random selection of items, the location for placement was randomly selected, and larger FOD items were dropped so that final position was also randomly determined. In each blind test, a series of placements were executed with multiple items used in each placement. Following a detection opportunity, items were cleared and new items placed until 30 items were tested. An example of the selection of FOD items used in a test campaign is provided in Figure 7.

Figure 5. Blind Testing Grid at PVD Showing Longitudinal and Lateral Areas Selected for FOD Placement.

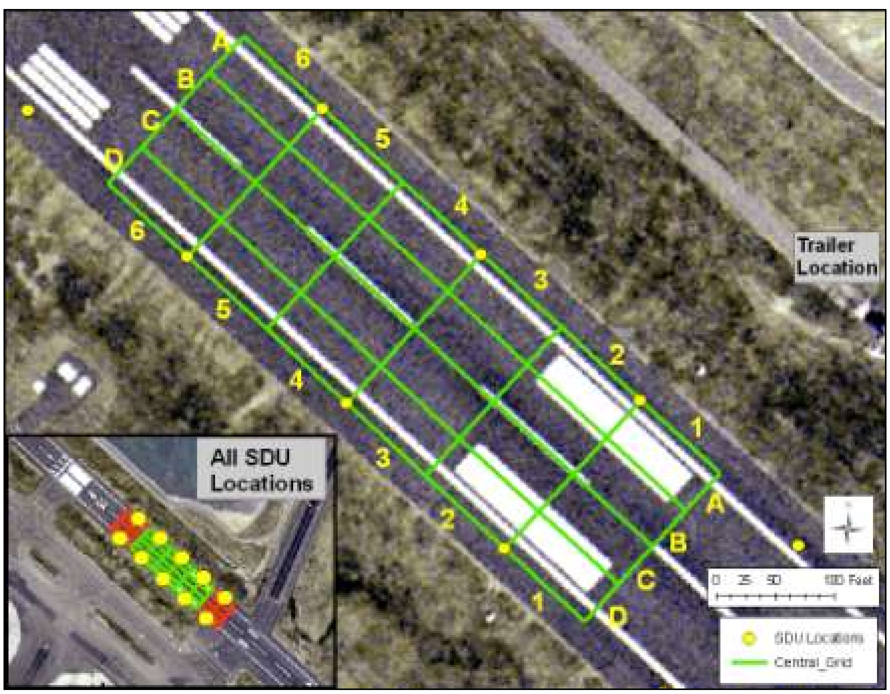

Figure 6. Blind Testing Grid at BOS.

Figure 7. Group of Blind FOD Items.

INCLEMENT WEATHER TESTING

An objective of the performance assessment program was to assess detection capabilities for all sensors under variable weather conditions. Initial scheduling anticipated some inclement weather conditions during a year-long assessment, but weather-event timing and issues associated with airport operations under snow emergency conditions played a major role in determining testing opportunities. Further, testing protocols for the hybrid system placed an additional criterion of testing under different lighting conditions important to visual detection. The result was implementation of an opportunistic assessment strategy and acceptance of the limits involved in inclement weather assessments. A primary limit was that sampling would be impossible during an event. The strategy adopted was to conduct testing as soon as possible after an event, when airport operations had returned to near-normal.

At PVD, during the October 2007 campaign, calibration transects were deployed in a light drizzle, which was followed by a high intensity rain squall that moved across the runway from south to north. This event provided a dynamic period in which to assess system performance. At BOS, testing occurred during one light rain event that coincided with dusk testing, which meant that lighting conditions changed during the rain event.

Assessments were conducted under snow conditions at both PVD and BOS. At PVD, the radar operated in a winter-operations mode where detections were limited to "between the edge lines" to avoid edge areas where snow removal was not as efficient. Assessments occurred during two snow events. On January 24, 2008, snow flurries with no measurable accumulation occurred. On February 12, 2008, a measurable snowfall occurred; it changed to sleet on February

13, 2008. Testing was limited by runway clearance needs which only allowed the placement of calibration targets at runway transects if they were followed by immediate retrieval. On February 12, 2008, after the snow had changed to sleet and plowing had taken place (1:40 am), UIUC personnel set out cylinders as targets at transects 1–4 only.

At BOS, on January 7, 2009, an event included rain, freezing rain, freezing drizzle, mist, ice pellets and snow. The NOAA weather station at BOS reported 1.1 in of snow and a total of 1.17 in of wet precipitation. On January 10, 0.7 in of snow and 0.05 in of wet accumulation were reported for BOS. On January 11, snow, fog, mist and haze were noted at BOS by the NOAA weather station. A total of 4.8 in of snow fell on January 11 and a total of 0.35 in of wet accumulation. On January 12, 2009, trace amounts of snowfall continued in the morning. During this extended winter weather event, testing was completed on January 8, 9, and 13. Testing was also completed after a snow event that occurred on January 29 and 30.

SUMMARY

A performance assessment of a radar FOD detection system and a hybrid electro-optical FOD detection system took place at PVD and BOS, respectively. The assessments followed a protocol established by CEAT that includes calibration, performance testing and blind testing. -Calibration items used for performance assessments were selected based on stated performance claimed by detection-system developers. Calibration testing procedures on the runways were also related to sensor characteristics and performance parameters identified by system developers. Although the actual testing procedures adopted for each system were developed based on specific system characteristics, the protocols for performance assessments are consistent for all FOD detection system types.