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# Performance Assessment of a Mobile, Radar-Based Foreign Object Debris Detection System

September 2011

Final Report

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| *Center of Excellence for Airport Technology<br>Department of Civil and Environmental Engineering<br>University of Illinois at Urbana Champaign<br>205 N. Mathews, MC-250<br>Urbana, IL 61801<br><br>**Federal Aviation Administration<br>William J. Hughes Technical Center<br>Airport and Aircraft Safety Research and Development Group<br>Airport Technology Research and Development Team<br>Atlantic City International Airport, NJ 08405 | 11. Contract or Grant No. |

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16. Abstract

In 2008, the Federal Aviation Administration (FAA) Airport Technology Research and Development Team initiated research to conduct a performance assessment of the Trex Enterprises FOD Finder™, a mobile, radar-based foreign object debris (FOD) detection system. This assessment included the system's capability to detect objects of various shapes, sizes, and materials at all locations on the runway surface. The system's capability to detect FOD during both nighttime and daytime conditions, in periods of sun, rain, mist, fog, and snow was also assessed.

The FOD Finder detection system was installed at the Chicago O'Hare International Airport (ORD) in March 2009 and initially tested in July 2009. The assessment of the FOD Finder detection system at ORD was supplemented by the evaluation of two additional FOD Finder detection systems at Honolulu International Airport and the McClellan-Palomar Airport in Carlsbad, California. The performance assessment at all three airports began in May 2010 and concluded in September 2010. Researchers conducted several test sessions at each airport to assess the FOD Finder's capability to detect selected FOD items that were of various shapes, sizes, color, and material in both nighttime and daytime conditions, in periods of sun, rain, mist, fog and snow.

The FOD Finder detection system was able to detect the objects of various shapes, sizes, and materials on runway surfaces, taxiways, and aprons, and was able to perform satisfactorily in nighttime, daytime, sun, rain, mist, fog, and snow conditions, as required by FAA Advisory Circular 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment."

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|---|---|
| AC | Advisory Circular |
| AOA | Airport operations area |
| CEAT | Center of Excellence for Airport Technology |
| CRQ | McClellan-Palomar Airport |
| FAA | Federal Aviation Administration |
| FOD | Foreign object debris |
| GPS | Global positioning system |
| GUI | Graphical user interface |
| HNL | Honolulu International Airport |
| ORD | O'Hare International Airport |
| PVC | Polyvinyl chloride |
| WAAS | Wide area augmentation system |

# EXECUTIVE SUMMARY

In 2008, the Federal Aviation Administration (FAA) Airport Technology Research and Development Team initiated research to conduct a performance assessment of the Trex Enterprises FOD Finder™, a mobile, radar-based foreign object debris (FOD) detection system. In 2008, Chicago O'Hare International Airport (ORD) agreed to host the FOD Finder demonstration. The detection system was installed by Trex Enterprises at ORD in March 2009, and the FAA developed plans for a comprehensive performance assessment of the technology. Preliminary testing was conducted in March 2009 and July 2009. Mobile units were also deployed to the Honolulu International Airport in Honolulu, Hawaii and McClellan-Palomar Airport in Carlsbad, California. Installation and preliminary testing continued in 2009, and the performance assessment program was implemented in May 2010 with a test schedule intended to evaluate detection performance under typical airport operational conditions and under different environmental conditions. As part of an FAA Safety Technology Research and Development Program, research teams from the University of Illinois Center of Excellence for Airport Technology (CEAT) developed the performance assessment protocol specifically for this mobile technology and implemented testing procedures appropriate to the technology and the specific airport setting.

This report describes a performance assessment of the FOD Finder detection system. Performance requirements were based on FAA Advisory Circular (AC) 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment," which details parameters for a FOD detection system's basic functions, detection performance, and system output. An assessment of operational issues was also performed.

The FOD Finder performed according to the manufacturer's product specifications and met performance requirements identified in AC 150/5220-24. For basic functions, the FOD Finder

- provided surveillance in the airport operations area (AOA) as specified by the airport.
- detected and located single and multiple FOD items on the AOA.
- provided an alert to the user when FOD was detected.
- operated in conjunction with, and did not interfere with, airport and aircraft communication, navigation, and surveillance systems.
- operated in conjunction with, and without interference from, normal airport and aircraft operations.
- provided a data record of detected FOD, allowing for equipment calibration and maintenance and analysis of the FOD event.

In the area of detection performance, the FOD Finder

- met the requirements for location accuracy.

- met the requirements for inspection frequency.
- provided surveillance of an entire runway.
- met the specifications for clear weather, dry pavement conditions with a standard target detection rate of 100%.
- met the specifications for detection of ten categories of items required in the AC with a detection rate of 100%.
- provided alerts of FOD presence on the runway and provided location information to facilitate removal.

For system output, the CEAT tests revealed that the FOD Finder

- provided a digital data record of operations that included an alert time and date and the location of the FOD object.
- provided digital data that could be presented in a number of formats.
- provided digital data suitable for data management, which meets the needs of many airports.

## 1. INTRODUCTION.

As part of the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Program, the University of Illinois Center of Excellence for Airport Technology (CEAT) has been supporting the research and development activities of the FAA William J. Hughes Technical Center for more than 10 years. In 2004, the FAA initiated research to assess foreign object debris (FOD) detection systems used within the airport operations area (AOA). The system that is the subject of this assessment is the FOD Finder™, a mobile radar-based FOD detection system developed by Trex Enterprises. In March 2009, CEAT conducted a preliminary assessment of the FOD Finder at Chicago O'Hare International Airport (ORD). Based on the positive findings from the preliminary assessment, a second assessment was conducted in July 2009. Installation of the FOD Finder system was completed at ORD in late 2008. Testing trials, as FOD Finder systems were integrated into airport operations, were in March 2009. A performance assessment program was implemented in May 2010 with a testing schedule intended to evaluate detection performance under typical airport operational conditions and under different environmental conditions. In addition to ORD, performance assessments were also conducted at the Honolulu International Airport (HNL) and the McClellan-Palomar Airport (CRQ) in Carlsbad, California. Because the FOD Finder is a mobile technology, the performance protocols and procedures used for stationary systems were reviewed and adapted to this technology type by the CEAT research team. Test campaigns were conducted from May 2010 through September 2010.

## 2. OBJECTIVE.

The overall objective of the assessment was to determine the performance of the FOD Finder and to develop requirements and standards for FOD detection technologies. With publication of Advisory Circular (AC) 150/5220-24 [1], performance requirements were identified by the FAA. This report describes the performance of the FOD Finder and considers if the assessment data is relevant to the requirements described in the AC.

## 3. PERFORMANCE REQUIREMENTS FOR FOD DETECTION SYSTEMS.

AC 150/5220-24 established specifications, as shown in table 1, for a range of FOD detection technologies, including:

- an intelligent vision system.
- a radar-based FOD detection system.
- a hybrid vision/radar FOD detection system.
- a mobile, radar-based system, such as the FOD Finder.

The requirements in AC 150/5220-24 for a mobile, radar-based system are used in this report as a focus of the performance assessment for the FOD Finder and provide the performance criteria to which the technology should be evaluated to demonstrate compliance with the AC. The FOD items used in the tests were selected based on sensor characteristics conforming to the AC requirements for this technology.

Table 1. AC 150/5220-24 Performance Requirements

| AC Category | AC Performance Requirement for FOD Detection Systems |
|---|---|
| Basic Functions | Equipment must perform the following functions:<br>1. Provide surveillance in the AOA as specified by the airport.<br>2. Detect and locate single and multiple FOD items on the AOA.<br>3. Provide an alert to the user when FOD has been detected.<br>4. Operate in conjunction with, and not interfere with, airport and aircraft communication, navigation, and surveillance systems.<br>5. Operate in conjunction with, and without interference from, normal airport and aircraft operations (e.g., aircraft and vehicle movements).<br>6. Provide a data record of the detected FOD, allowing for equipment calibration and maintenance, and analysis of the FOD event. |
| Detection Performance: Object Detection | Systems must be able to detect the following objects (mobile systems must provide this performance at a minimum speed of 20 mph (30 km/h)):<br>1. An unpainted metal cylinder measuring 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter<br>2. A white, grey, or black sphere measuring 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball)<br>3. 90% of the following objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. One item from each category must be included in the group, and each item must measure no larger than 4 in. (10 cm) in any dimension, unless otherwise specified:<br>• a chunk of asphalt or concrete<br>• any portion of a runway light fixture (in-pavement or edge light)<br>• an adjustable crescent wrench up to 8 in. (20 cm) long<br>• a deep socket at least 2 in. (5 cm) in length<br>• a piece of rubber from an aircraft tire<br>• a distorted metal strip up to 8 in. (20 cm) in length<br>• a fuel cap (aircraft or automotive)<br>• a lug nut<br>• a hydraulic line (from aircraft or ground support equipment) up to 8 in. (20 cm) in length<br>• a white PVC pipe of 2 in. (5 cm) in diameter<br>4. Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects. |

Table 1. AC 150/5220-24 Performance Requirements (Continued)

| AC Category | AC Performance Requirement for FOD Detection Systems |
|---|---|
| Detection Performance: Location Accuracy | Systems must provide location information for a detected object that is within 16 ft (5.0 m) of the actual FOD object location.<br><br>Note: This standard is based on the average accuracy of hand-held GPS devices, which most airport operators use when retrieving detected FOD. Airport operators using nonvisual detection systems, who require greater location accuracy, can procure optional components that enable the system to have visual detection capabilities. |
| Detection Performance: Inspection Frequency | For continuous detection systems—The system must provide continuous operation from fixed sensors to allow the continuous inspection of runway surfaces during flight operations. The duration of flight operations is dependent on the airport and specified by the user.<br><br>For mobile detection systems—The system must provide a mobile operations capability to enhance mandated airport safety self-inspections (per AC 150/5200-18 [2]). The frequency of inspections is dependent on the airport and specified by the user. |
| Detection Performance: Detection Response Time | Systems must have the capability to provide rapid detection of a FOD occurrence in the area being scanned.<br><br>For continuously operating FOD detection systems designed to provide between-movement alerts, the system must provide inspection of runway surfaces between aircraft movements.<br><br>For other continuously operating FOD detection systems, the system must provide inspection updates as specified by the airport, generally within 4 minutes of a FOD occurrence. |
| Detection Performance: Surveillance Area | The airport operator will specify the desired surveillance (detection) area in the AOA requiring FOD detection. This area is generally based on the airport's FOD management plan.<br><br>The primary area of coverage is the runway; certain portions of the runway may be specified by the airport operator if full coverage is not feasible. Other areas are of less importance, with a decreasing level of priority from other paved movement areas down to nonpaved, nonmovement areas.<br><br>The manufacturer of a FOD detection system must notify the airport operator of any locations within the specified surveillance area where detection would not be possible. |

Table 1. AC 150/5220-24 Performance Requirements (Continued)

| AC Category | AC Performance Requirement for FOD Detection Systems |
|---|---|
| Detection Performance: Performance in Weather | Systems must demonstrate detection performance under clear and inclement weather conditions. Under clear weather conditions, the pavement of the AOA is expected to be dry; under inclement weather conditions, the pavement will be wet with rain, snow, or mixed precipitation.<br>1. Detect objects under rainfall or snow conditions (e.g., having a specific intensity, duration, and frequency) for a 2-year category of storm in the local region, as specified in CLIM 20, Climatology of the United States No. 20 [3]). More stringent requirements may be specified by the user.<br>2. Systems must have site-specific performance specifications that include:<br>• performance during clear weather conditions.<br>• performance during inclement weather conditions.<br>• amount of time required for the system to recover after a rain or snow storm (e.g., to return to clear-weather performance capabilities after adverse weather conditions subside, defined as when precipitation of rain or snow ends.)<br>All systems must demonstrate detection performance during daylight, nighttime, and dawn/dusk operations. |
| System Performance: Alerts and Alarms | Systems must be able to alert the system operator to the presence of FOD in scanned areas, providing airport management with enough information to assess the severity of the hazard to determine if immediate object removal is necessary.<br>• False alarms (an alert causing the airport operator to take action to remove a FOD object that does not exist) should be minimized and must not exceed:<br>- For systems with visual detection capabilities: one per day as averaged over any 90-day period.<br>- For systems without visual detection capabilities: three per day as averaged over any 90-day period.<br>Note: Some small items may be moved by wildlife or blown away before airport operators have a chance to investigate FOD alerts. |

Table 1. AC 150/5220-24 Performance Requirements (Continued)

| AC Category | AC Performance Requirement for FOD Detection Systems |
|---|---|
| System Output:<br>Detection Data | All systems must automatically provide a data record on detected FOD.<br>1. Records must contain:<br>• alert time and date<br>• location of FOD object<br>2. Capturing the following information is recommended, but not required:<br>• Description of FOD detected or retrieved (e.g., size, name, type, serial number)<br>• Time and date of FOD retrieval<br>• Time and date of disposition of alert<br>• Name of personnel detecting/investigating FOD item<br>• Image of the FOD object retrieved (if available)<br>• Chain of custody information |
| System Output:<br>Data Presentation | FOD detection data can be provided in a coordinate scheme, on maps of the airport, in an operator's console, or broadcast to mobile units. The selection of information options will be specified by the airport, consistent with airport systems operations. |
| System Output:<br>Data Management | Data collected in the FOD detection process should be digitally recorded. Data systems should have the capability to retain the data for at least 2 years after the detection event. |

GPS = Global positioning system
PVC = Polyvinyl chloride

## 4. THE FOD FINDER CHARACTERISTICS AND SPECIFICATIONS.

The FOD Finder, as shown in figure 1, is based on a millimeter-band radar mounted on a vehicle. As the vehicle moves along the length of the runway or the surface to be examined, the FOD Finder scans the surfaces in front of the vehicle. The FOD Finder is designed to scan an 80° area in front of the vehicle and approximately 650 ft (200 m) ahead of the vehicle, as shown in figure 2. Recent modifications to the FOD Finder allow scanning to the side and the rear. The FOD Finder can operate on all airport surfaces, runways, taxiways, and apron and ramp areas. Because the radar scan covers areas wider than the runway or other surfaces, system operators define a polygon that limits FOD reporting to defined surface areas. The system provides precise location information as the vehicle moves. Alerts programmed into the system warn drivers of critical airport locations to prevent runway incursions and to avoid areas where height clearances are less than the height of the vehicle with the radar. Vehicle speed can vary up to and exceeding 30 mph. Performance assessments were performed at approximately 15 mph.

Figure 1. The FOD Finder Components, Including Sensor, Control Module, and Vacuum Attachment

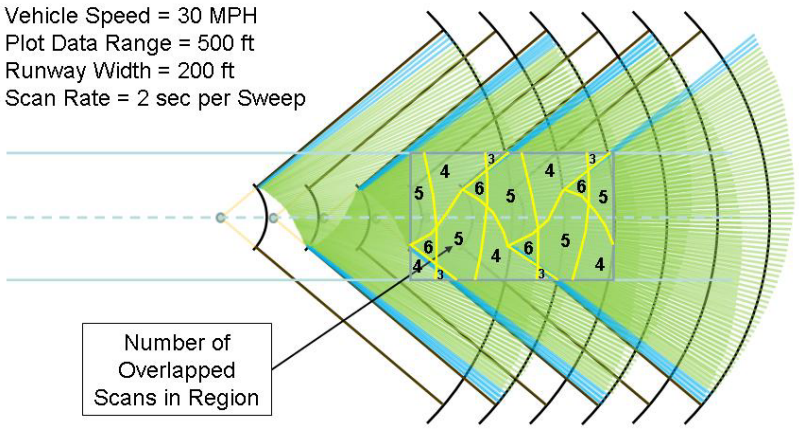


Figure 2. Scan Profile for the FOD Finder

The sensor is capable of detecting small targets under a variety of environmental conditions. The scan is directed in front of the vehicle, although scan options include a scan to the rear to confirm removal of a FOD item by the optional vacuum system, shown in figure 1. When FOD is detected, the FOD Finder operator receives an audio and visual alert. Standard operating procedures will cancel the FOD alert if the vehicle drives over the FOD item when the vacuum is operating. The operator also has the option of retrieving the FOD item. Upon retrieval, the operator has the option of photographing and cataloging the FOD item using an onboard video-capture system and a bar code printer. All detections are recorded, and an electronic report is generated following each FOD management session. Within the vehicle, a tablet PC provides operational control for the system and a moving map that updates the vehicle and FOD position in real time. The graphical user interface (GUI) uses icons to indicate the position of the vehicle, scan area, and FOD detections.

The primary performance criterion for the FOD Finder is to detect a metal cylinder that is 1 in. (2.5 cm) high with a diameter of 0.94 in. (2.4 cm). The standard target used in this performance assessment was smaller than the 1.2-in. (3.0-cm)-high and 1.5-in. (3.8-cm)-diameter cylinder specified in AC 150-5220-24.

## 5. THE FOD FINDER INSTALLATION AT CRQ, HNL, AND ORD.

The FOD Finder was installed on vehicles at three airports: CRQ, HNL, and ORD. The airport diagrams are shown in figures 3, 4, and 5, respectively.

At HNL and ORD, the FOD Finder was installed on airport operational vehicles. At CRQ, the FOD Finder was installed on a Ford 150 pick-up truck. The units at HNL and ORD were used in daily operations to support airport operations personnel. At CRQ, the FOD Finder was used as needed for tests and demonstrations.

At each airport, the FOD Finder was tested on multiple pavement types:

- At CRQ, tests were conducted on Runway 6/24. At the time of testing, the runway was being replaced, so the tests were conducted on old and new runway surfaces. Both surfaces were ungrooved asphalt.

- At HNL, Runway 8R and Taxiway RA were used. The runway was grooved; the taxiway was not.

- At ORD, Runway 27L and an apron area, referred to as the scenic pad, were used. Both ORD locations were Portland cement concrete. The scenic pad was jointed, reinforced concrete pavement that was not grooved. Runway 27L was grooved, jointed pavement.

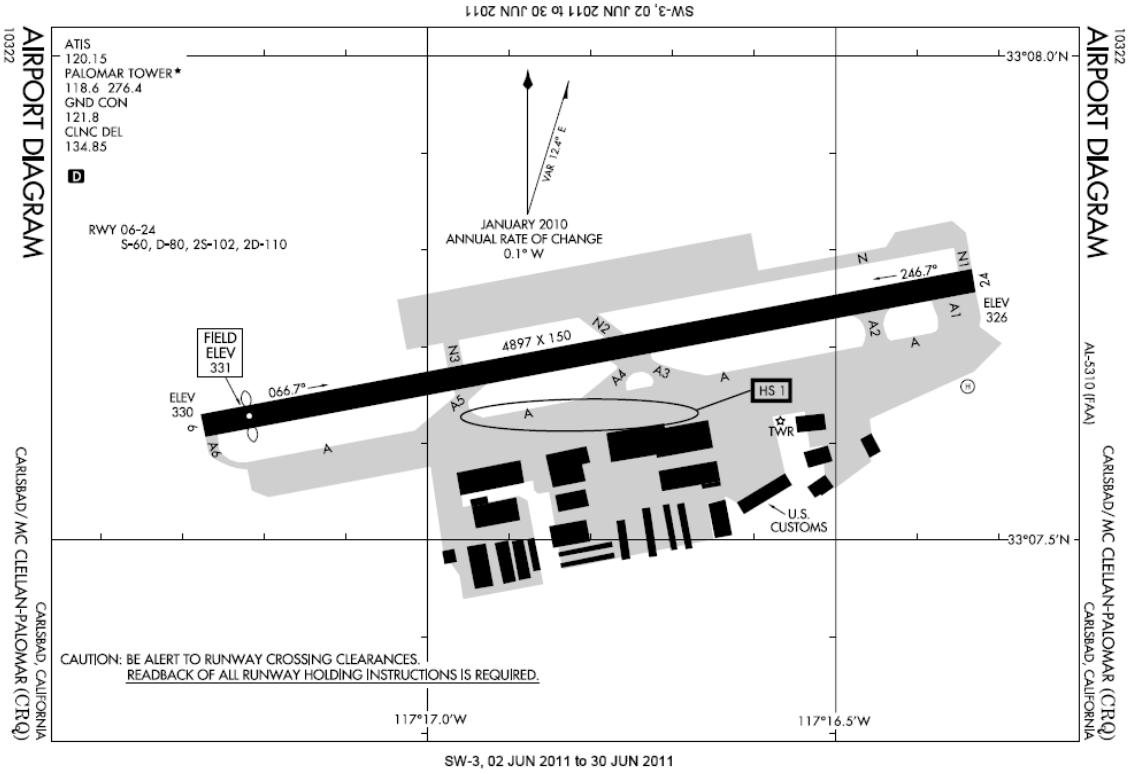


Figure 3. Airport Diagram of CRQ

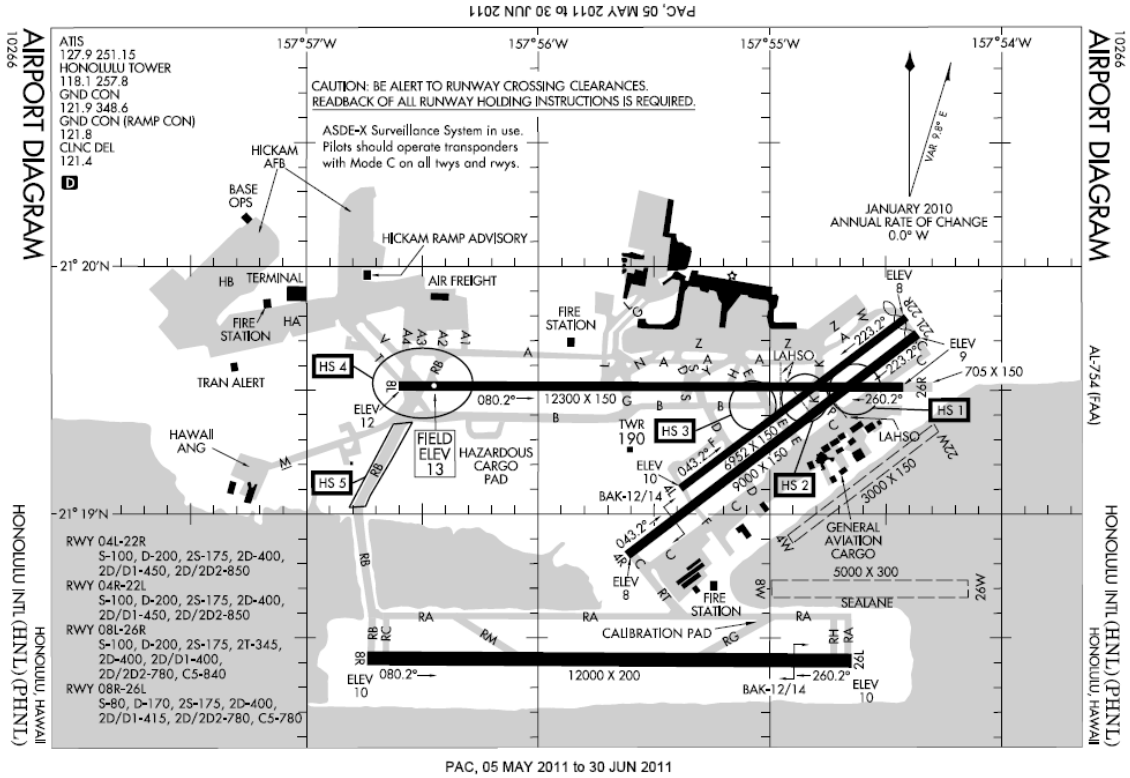


Figure 4. Airport Diagram of HNL

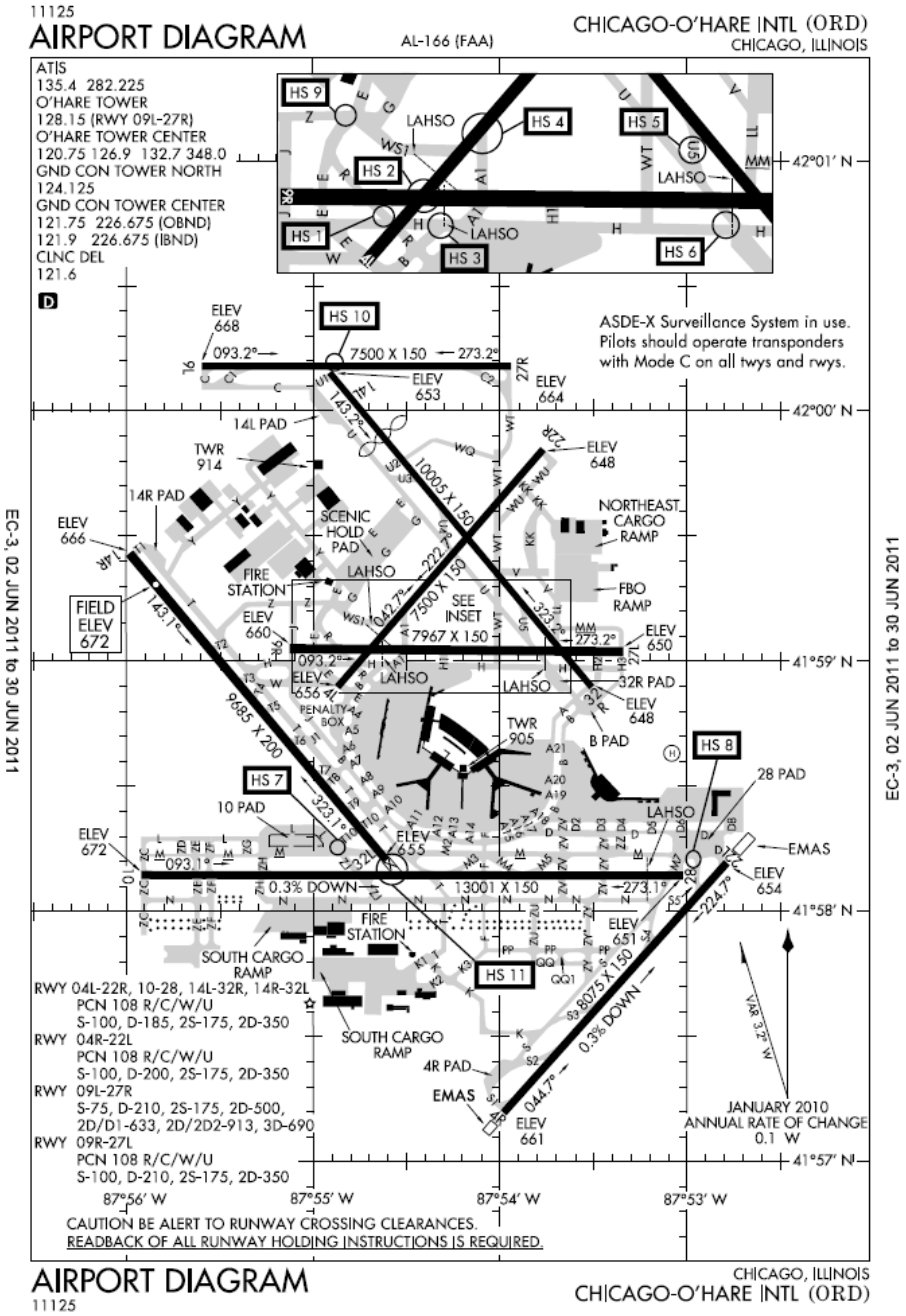


Figure 5. Airport Diagram of ORD

## 6. THE FOD FINDER ASSESSMENT PROTOCOLS.

### 6.1 THE FOD TEST ITEMS.

To meet AC 150/5220-24 performance requirements, detection of an unpainted metal cylinder measuring 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter and white, grey, or black spheres measuring 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball) were required. The long-term test program used a standard technology-specific FOD item, which was smaller than the

target required in AC 150/5220-24. The target used in this assessment was a metal cylinder that was 1 in. (2.5 cm) high with a diameter of 0.94 in. (2.4 cm), as shown in figure 6. Targets were placed in a 500- by 100-ft (152- by 30-m) rectangle on the airport surface. A target grid, consisting of three lines of five targets, was located in the rectangle. One line was placed along the center line of the rectangle, and two lines were located 25 ft (8 m) to each side of the center line, as shown in figure 7.

Figure 6. Standard Targets Used to Assess the FOD Finder

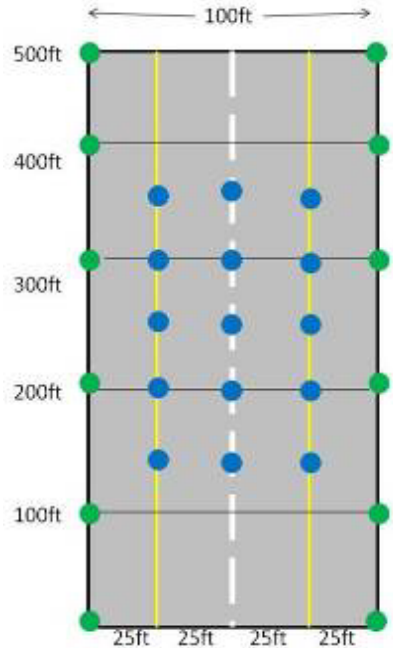


Figure 7. Characteristics of the Test Rectangle (The green dots indicate the radar reflector positions and the blue dots indicate the standard target locations.)

## 6.2 RUNWAY AND TAXIWAY TEST PROCEDURES.

The assessment procedures were designed to test sensor performance on different airport surfaces, including taxiways, apron areas, and runways, and under different environmental conditions. Tape measures were used to establish a test rectangle with a nominal dimension of 500 ft (152 m) long by 100 ft (30 m) wide on the selected surface.

To position the vehicle prior to each detection run, a starting point located 500 ft (152 m) from the rectangle was marked with cones. Cones and large corner reflectors, as shown in figures 8 and 9, were placed at the four corners of the rectangle. Small corner reflectors, as shown in figure 10, were placed every 100 ft (30 m) along the length of the rectangle. The reflectors provided a detection reference for the FOD target tests. FOD targets were placed in the rectangle on a test grid defined by the center line of the rectangle (see figure 7).

Figure 8. Cones and Large Corner Reflector Marking Front-Left Corner of the Test Rectangle

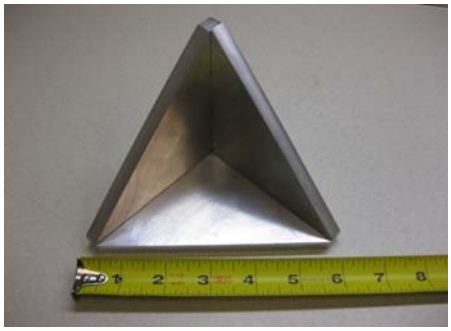

Figure 9. Large (6-in.) Corner Reflector Used to Define Test Rectangle Corners


Figure 10. Small (1.5-in.) Corner Reflector Used to Mark 100-ft Increments on the Long Axis of the Test Rectangle

The FOD Finder vehicle was driven through the test rectangle between the outer edge of the test rectangle and the test grid at a speed of approximately 15 mph. The distance from target to sensor varied continuously as the vehicle moved through the rectangle. A complete test included a pass in each direction through the rectangle. Following the two passes, detections were verified and data recorded.

In the assessment, the FOD Finder was operated in normal mode. In this mode, all detections were shown on the console screen, alerts were provided, and the target location was recorded. Following each test, a report was generated. The report included a map showing the FOD detections and tables of detections identified by latitude and longitude. This report was also broadcast to mobile devices immediately after test completion.

### 6.3 PERFORMANCE ASSESSMENT METHODS.

Final assessment procedures were developed to accommodate the specific capabilities of the FOD Finder. Because the FOD Finder can be used on all airport surfaces, assessments were designed to provide test campaigns on a variety of surfaces, with an emphasis on runways. In total, six runway test campaigns were completed, two at each airport: CRQ, HNL, and ORD. Multiple test campaigns were completed on the airport taxiway and apron areas, as appropriate. The FOD Finder can be adjusted to different surfaces by altering a threshold, or sensitivity, setting. For these assessments, the sensitivity of the FOD Finder was changed based on surface conditions and preliminary tests. The sensitivity levels used in these assessments varied between 21 and 28, with 50% of the tests set at 25 and 33% of the tests set at 22. The sensitivity value was established based on preliminary testing at each site, and the setting was kept constant for each test campaign.

#### 6.3.1 Targets.

The targets used in the final performance assessment were selected and provided by Trex Enterprises, which conformed to the target selection criteria set forth in AC 150/5220-24 for the type of sensor technology being used for detection. CEAT used these same targets for all assessments, as called for in their performance assessment procedures. The target selected and used in the performance assessments was smaller than the minimum target size specified in the AC.

#### 6.3.2 Test Methods.

Test procedures were standardized for all performance assessment test campaigns. When possible, the test area was cleared of any FOD prior to the test. At ORD, the scenic pad was swept or jet blowers were used to clear any FOD from the area. At other locations, the test area was not cleared, but the FOD Finder was used to identify and remove any FOD. For each test, standard targets were placed in the grid in the test rectangle. Detection passes were made, maintaining a speed of 15 mph.

#### 6.3.3 Location Accuracy.

AC 150/5220-24 contains detailed specifications for the location accuracy of FOD detection systems, describing how accurate the FOD detection system must be in determining the location

of a FOD item that it detects. Typically during the performance assessment, CEAT uses a small hand-held, wide area augmentation system (WAAS)-enabled global positioning system (GPS) with a nominal accuracy of 8 to 15 ft (2.4 to 4.5 m) to compare the location data reported by the hand-held unit to the location data reported by the FOD detection system's GPS to calculate the location accuracy of the system. For this performance assessment, however, CEAT elected to use the FOD Finder's highly accurate differential GPS to determine the position of the FOD items, and then compared the reported location data to the location indicated on the hand-held unit. This allowed CEAT to verify and report the location accuracy of the FOD Finder with greater precision.

## 7. THE FOD FINDER PERFORMANCE ASSESSMENT RESULTS AND DISCUSSION.

### 7.1 SUMMARY OF STANDARD TARGET DETECTION.

The test results for the FOD Finder standard target under dry pavement conditions for all test campaigns are presented in tables 2 and 3.

Table 2. Detection of Standard Targets at Selected Airports

| Site | Number of Targets | Number of Detections | Percentage of Detections |
|---|---|---|---|
| CRQ | 45 | 45 | 100 |
| ORD | 60 | 60 | 100 |
| HNL | 90 | 90 | 100 |
| Total | 195 | 195 | 100 |

Table 3. Detection of Standard Targets on Different Airport Surfaces

| Surface | Number of Targets | Number of Detections | Percentage of Detections |
|---|---|---|---|
| Off Runway | 75 | 75 | 100 |
| Runway | 120 | 120 | 100 |
| Total | 195 | 195 | 100 |

### 7.2 LOCATION ACCURACY.

The FOD Finder uses a differential GPS system, which has a higher location accuracy than the WAAS-enabled hand-held unit used by CEAT, to record target locations. During the tests at CRQ, the detection locations determined by the FOD Finder varied between 2 and 13 ft (0.6 and 4 m) from the location provided by the hand-held GPS. At ORD, on the scenic pad and the runway, the FOD Finder detections varied between 2 and 12 ft (0.6 and 3.7 m). At HNL, accuracy for runway and taxiway detections varied between 1.5 and 12.5 ft (0.5 and 3.8 m). CEAT location accuracy measurements are comparable to expected GPS location accuracy listed in AC 150/5220-24.

## 7.3 DETECTION UNDER VARIABLE WEATHER CONDITIONS.

To capture different pavement and weather conditions, the performance assessment program was planned at multiple locations. However, during the planned test campaigns, only dry pavement conditions were present. Pavements were initially wet during one ORD test campaign, but dried before the tests were conducted. At HNL, tests were conducted with a light rain/mist falling, but the pavements were not wet.

During preliminary tests in at ORD in March 2009, the FOD Finder was used in winter weather conditions during the early stages of a snow event. Conditions included a light rain that changed to freezing rain followed by snow. The FOD Finder was operated in conditions that varied from wet pavement, through standing water/ice, to accumulating snow. Although no standard tests were conducted during this event, detection performance was observed. During the changing weather conditions, the FOD Finder continued to detect FOD items. In one instance, snow was piled over a metal cylinder, and the cylinder was detected.

## 8. DETECTION OF STANDARD FOD ITEMS AS REQUIRED BY AC 150/5220-24.

The specifications and criteria provided in AC 150/5220-24 include the requirement that the FOD detection system manufacturer demonstrate detection performance with targets that simulate actual FOD items. As specified in the AC, the FOD detection system should detect 90% of the following group of objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. (Note: one item from each category must be included in the group and each item must measure no more than 4 in. (10 cm) in height, width, or length, unless otherwise specified.)

- A chunk of asphalt or concrete
- Any portion of a runway light fixture (in-pavement or edge light)
- An adjustable crescent wrench up to 8 in. (20 cm) in length
- A deep socket at least 2 in. (5 cm) in length
- A piece of rubber from an aircraft tire
- A distorted metal strip up to 8 in. (20 cm) in length
- A fuel cap (aircraft or automotive)
- A lug nut
- A hydraulic line (from aircraft or ground support equipment) up to 8 in. (20 cm) in length)

- A white polyvinyl chloride (PVC) pipe 2 in. (5 cm) in diameter

- Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects

The manufacturer selected a group of targets and provided them to CEAT for testing, as shown in figure 11. As part of this assessment, CEAT observed the placement of 10 items in a rectangle approximately 100 by 100 ft (30 by 30 m). The FOD Finder demonstrated that it was able to detect 100% of the FOD items. CEAT also confirmed that the FOD items were placed no more than 10 ft (3 m) from each other and confirmed that these items were detected.

Figure 11. Items Selected to Meet AC Detection Requirements

## 9. THE FOD FINDER ASSESSMENT BASED ON AC 150/5220-24 REQUIREMENTS.

CEAT performance assessment of the FOD Finder at ORD was based on specifications/criteria provided in AC 150/5220-24. The AC lists specifications for basic functions, detection performance, and system output. Based on data collected during the performance assessment, table 4 summarizes FOD Finder performance as it relates to AC 150/5220-24. Sections 9.1 through 9.3 provide a narrative analysis of the FOD Finder's conformance to the AC performance specifications.

Table 4. Summary of FOD Finder Performance Related to AC 150/5220-24 Requirements

| AC Category and Performance Requirement | CEAT Findings |
|---|---|
| Basic Functions | |
| 1. Provide surveillance in the AOA as specified by the airport. | Met AC specification with the capability of detecting FOD on runway, taxiway, apron, and ramp areas. |
| 2. Detect and locate single and multiple FOD items on the AOA. | Detected and located single and multiple FOD items in detection zones. |

Table 4. Summary of FOD Finder Performance Related to AC 150/5220-24 Requirements (Continued)

| AC Category and Performance Requirement | CEAT Findings |
|---|---|
| Basic Functions (Continued) | |
| 3. Provide an alert to the user when FOD has been detected. | Provided visible and audible alerts. |
| 4. Operate in conjunction with, and not interfere with, airport and aircraft communication, navigation, and surveillance systems. | Currently in operation at HNL and ORD with no interference reported. Operations at CRQ had no reported interference. |
| 5. Operate in conjunction with, and without interference from, normal airport and aircraft operations (e.g., aircraft and vehicle movements). | Operated successfully at HNL, CRQ, and ORD with no interference reported. |
| 6. Provide a data record of detected FOD, allowing for equipment calibration and maintenance, and for analysis of the FOD event. | Full data record for period of operation provided; equipment was calibrated and maintained; multiple FOD events recorded. |
| Detection Performance: Object Detection | |
| 1. An unpainted metal cylinder measuring 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter. | Detected this target. The standard target used in the FOD Finder tests was smaller, measuring 1 in. (2.5 cm) high and 0.94 in. (2.4 cm) in diameter. Detection rate was 100% |
| 2. A white, grey, or black sphere measuring 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball). | Detected this target. |
| 3. Detect 90% of the following group of objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. One item from each category must be included in the group, and each item must measure no larger than 4 in. (10 cm) in any dimension unless otherwise specified:<br>• A chunk of asphalt or concrete<br>• Any portion of a runway light fixture (in-pavement or edge light)<br>• An adjustable crescent wrench up to 8 in. (20 cm) long<br>• A deep socket at least 2 in. (5 cm) in length<br>• A piece of rubber from an aircraft tire<br>• A distorted metal strip up to 8 in. (20 cm) in length<br>• Fuel cap (aircraft or automotive)<br>• Lug nut<br>• Hydraulic line (from aircraft or ground support equipment) up to 8 in. (20 cm) in length<br>• A white PVC pipe 2 in. (5 cm) in diameter | Detected 100% of the items placed in a 100- by 100-ft (30- by 30-m) square. |

Table 4. Summary of FOD Finder Performance Related to AC 150/5220-24 Requirements (Continued)

| AC Category and Performance Requirement | CEAT Findings |
|---|---|
| Basic Functions (Continued) | |
| 4. Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects. | Met AC specification. |
| Detection Performance: Location Accuracy | |
| Systems must provide location information for a detected object that is within 16 ft (5.0 m) of the actual FOD object location. | Met AC requirement for average accuracy. |
| Detection Performance: Inspection Frequency | |
| Continuous Detection Systems. The system must provide continuous operation from fixed sensors to allow the continuous inspection of runway surfaces during flight operations. The duration of flight operations is dependent on the airport and specified by the user.<br><br>Mobile Detection Systems. The system must provide a mobile operations capability to enhance mandated airport safety self-inspections (per AC 150/5200-18). The frequency of inspections is dependent on the airport and specified by the user. | Met AC specification. |
| Detection Performance: Detection Response Time | |
| For continuously operating FOD detection systems designed to provide between-movement alerts, the system must provide inspection of runway surfaces between aircraft movements.<br><br>For other continuously operating FOD detection systems, the system must provide inspection updates as specified by the airport, generally within 4 minutes of a FOD occurrence. | Not applicable for mobile unit. |
| Detection Performance: Surveillance Area | |
| The primary area of coverage is the runway; certain portions of the runway may be specified by the airport operator if full coverage is not feasible. Other areas are of lesser importance, with a decreasing level of priority from other paved movement areas down to nonpaved, nonmovement areas.<br><br>The manufacturer of a FOD detection system must notify the airport operator of any locations within the specified surveillance area where detection would not be possible. | Manufacturer provided coverage of runways, taxiways, and other pavement surfaces, meeting AC requirement.<br><br>The FOD Finder has the capability of including or excluding areas in the scan from which FOD items will be reported. |

Table 4. Summary of FOD Finder Performance Related to AC 150/5220-24 Requirements (Continued)

| AC Category and Performance Requirement | CEAT Findings |
|---|---|
| Detection Performance: Performance in Weather | |
| 1. Detect objects under rain or snow conditions (e.g., having a specific intensity, duration, and frequency) for a 2-year category of storm in the local region, as specified in CLIM 20, Climatology of the United States No. 20. More stringent requirements may be specified by the user.<br>2. Systems must have site-specific performance specifications that include:<br>• performance during clear weather conditions<br>• performance during inclement weather conditions<br>• amount of time required for the system to recover after a rain or snow storm (e.g., to return to clear-weather performance capabilities after adverse weather conditions subside, defined as when precipitation of rain or snow ends.<br>3. All systems must demonstrate detection performance during daylight, nighttime, and dawn/dusk operations. | Tests were conducted under very light rainfall, but the tests did not produce results for specific frequency events, as required in this criterion.<br>• Met requirements for clear weather conditions<br>• Tests were conducted during a rain event with no appreciable reduction of detection capability<br>• System remained operational during and after snowfall event, as required<br>Met AC specification. |
| Detection Performance: Alerts and Alarms | |
| False alarms (an alert causing the airport operator to take action to remove a FOD object that does not exist) should be minimized and must not exceed:<br>• for systems with visual detection capabilities, one per day, as averaged over any 90-day period<br>• for systems without visual detection capabilities, three per day, as averaged over any 90-day period.<br>Note: Small items may be moved by wildlife or blown away before airport operators have a chance to investigate FOD alerts. | The FOD Finder notifies an operator of a possible FOD item, allowing rapid assessment of the alert and formulation of an action plan. In this operational mode, false alarms are minimized.<br>Assessment did not incorporate operational analysis to determine conformance to specification. |

Table 4. Summary of FOD Finder Performance Related to AC 150/5220-24 Requirements (Continued)

| AC Category and Performance Requirement | CEAT Findings |
|---|---|
| System Output: Data Detection | |
| 1. Records must contain:<br>• Alert time and date<br>• Location of FOD object<br>2. Capturing the following information is recommended, but not required:<br>• Description of FOD detected or retrieved (e.g., size, name, type, serial number)<br>• Time and date of FOD retrieval<br>• Time and date of disposition of alert<br>• Name of personnel detecting/investigating FOD item<br>• Image of the FOD object retrieved (if available)<br>• Chain of custody information | Met AC specification.<br><br>System supports photographic records with a report providing all recommended information. |
| System Output: Data Presentation | |
| FOD detection data can be provided in a coordinate scheme, on maps of the airport, in an operator's console, or broadcast to mobile devices. The selection of information options will be specified by the airport, consistent with airport systems operations. | Met AC specification. |
| System Output: Data Management | |
| Data collected in the FOD detection process should be digitally recorded. Data systems should have the capability to retain the data for at least 2 years after the detection event. | Met AC specification. |

## 9.1 BASIC FUNCTIONS.

### 9.1.1 Provide Surveillance in the AOA as Specified by the Airport.

The FOD Finder was installed at ORD, HNL, and CRQ and provided surveillance of all airport surfaces specified by the user. Surfaces included runways, taxiways, and apron areas. This surveillance met the requirements of the airport for this technology demonstration.

### 9.1.2 Detect and Locate Single and Multiple FOD Items on the AOA.

The FOD Finder was able to consistently locate single and multiple FOD items on the AOA under a variety of test conditions during the CEAT performance assessment. The detection rate was 100%.

9.1.3 Provide an Alert to the User When FOD has Been Detected.

The FOD Finder provided visual and audible alerts of the detected FOD inside the vehicle. The FOD Finder GUI provided a phased alert with probable targets identified in one color, which shifted to red as the targets were confirmed. The alert strategy related the FOD targets to the vehicle's position, guiding the operator to the location of the FOD items. More recent versions of the FOD Finder have a vacuum system mounted on the vehicle so the vehicle can quickly retrieve the identified FOD. In addition to vehicle alerts, information on FOD detections was immediately sent to various management staff via mobile devices, as specified by each airport.

9.1.4 Operate in Conjunction With, and Not Interfere With, Airport and Aircraft Communication, Navigation, and Surveillance Systems.

Operation of the FOD Finder occurred with no interference to aircraft communication, navigation, or surveillance technologies. Through the normal FAA 7460 application process, radio frequency issues were reviewed, and installation and operation of the FOD Finder followed normal FAA and the Federal Communications Commission approval processes.

9.1.5 Operate in Conjunction With, and Without Interference From, Normal Airport and Aircraft Operations.

During the performance assessment, the FOD Finder was operated without interference from normal airport and aircraft operations. Detection algorithms in the system differentiated between stationary and moving targets, and no false alarms were associated with vehicles or aircraft. The FOD Finder also operated with no interference to airport operations. At ORD, the FOD Finder was used to conduct taxiway inspections when the taxiway was in use, often following aircraft.

9.1.6 Provide a Data Record of Detected FOD, Allowing for Equipment Calibration and Maintenance, and Analysis of the FOD Event.

During the performance assessment, the FOD Finder demonstrated its capability to provide a digital record of all calibration adjustments that were made to the system, all maintenance activity performed on the system, and all system-generated FOD alerts that were associated with the detection of FOD items.

9.2 DETECTION PERFORMANCE.

9.2.1 Object Detection.

The FOD Finder detected the unpainted metal cylinder and the white, grey, and black spheres. The FOD Finder was also able to consistently detect an unpainted metal cylinder measuring 1 in. (2.5 cm) high and 0.94 in. (2.4 cm) in diameter, which was smaller than the target specified in the AC and had a radar reflectivity of less than -20 $DBm^2$, as specified in the AC.

A test conducted by the manufacturer was observed by CEAT. The items selected from the ten categories of FOD listed in the AC were placed in a test rectangle. These items were detected by

the FOD Finder using the system's normal operational mode. CEAT also observed tests that detected FOD items less than 10 ft (3 m) from each other.

9.2.2 Location Accuracy.

The FOD Finder provided location information that, when compared to location acquired from a hand-held GPS, was well within AC specifications. CEAT elected to use the FOD Finder's highly accurate differential GPS to determine the position of the FOD items, and then compared the reported location data to the location indicated on the hand-held unit. As expected, the location information provided by the FOD Finder had greater accuracy than the location data provided by the hand-held GPS and was used to determine the system's accuracy. CEAT was able to confirm that the FOD Finder system's location accuracy performance met the AC 150/5220-24 requirement that the detected object be within 16 ft (5.0 m) of the actual FOD object location.

9.2.3 Inspection Frequency.

Because the FOD Finder is a mobile system, the inspection frequency is defined by airport operations personnel. This meets the requirements of AC 150/5220-24 for mobile systems.

9.2.4 Detection Response Time.

The FOD Finder provided rapid detection and alerts to detected standard targets. In general, detection response time was related to vehicle speed as the targets entered the scan area of the FOD Finder. Detection response was regularly observed to be between 1 and 5 seconds.

9.2.5 Surveillance Area.

The FOD Finder provided coverage of taxiways, runways, and apron areas at HNL, ORD, and CRQ. Only one FOD Finder unit was used at each airport.

9.2.6 Performance in Weather.

The FOD Finder was only assessed during dry pavement conditions, although some precipitation was present during two test campaigns. Performance was observed during a snow event, and the FOD Finder consistently detected FOD items that were present on wet pavement and covered by liquid precipitation and snow.

The FOD Finder met AC 150/5220-24 performance requirements for clear weather, dry pavement conditions with a 100% detection rate for all standard targets.

9.2.7 Alerts and Alarms.

The FOD Finder provided alerts of FOD presence on the runway and indicated the location of detected FOD on an airfield map. Moving displays allowed the operators to locate the FOD position in relation to the vehicle and to rapidly determine the FOD hazard.

The design of the FOD Finder incorporates the capability to confirm the hazard of an alert and immediately recover hazardous FOD items. In this operational mode, false alarms were minimized, if not eliminated.

## 9.3 SYSTEM OUTPUT.

### 9.3.1 Detection Data.

The FOD Finder provided a digital data record of operations that included the alert time and date and the location of the FOD object.

### 9.3.2 Data Presentation.

The FOD Finder provided video and digital data that could be presented in a number of formats. The basic GUI provided an aerial photograph of the area surrounding the FOD Finder, which moved in real-time with the vehicle. The detected FOD items were shown on the photographs as red and yellow dots. In addition to specific locations of detected FOD contained in the digital record, the GUI provided a visual representation of the FOD location.

### 9.3.3 Data Management.

The FOD Finder provided digital data that is suitable for data management, which meets the needs of many airports.

## 10. OPERATIONAL ANALYSIS.

CEAT did not conduct a comprehensive operational analysis of the FOD Finder, but CEAT did observe the operation of the FOD Finder at ORD and reviewed the data management for HNL. At ORD, the FOD Finder regularly supplements operator inspections of runway surfaces. The FOD Finder was used on taxiways, aprons, and ramp areas. Video and photographic tools were used in the ramp areas to document site conditions, which could be shared with airport tenants.

At HNL, the FOD Finder is used to supplement regular inspections made by airport personnel. Because the system operates remotely on the airport, the unit is equipped with a communications capability that allows the manufacturer to provide remote technical support of the unit and allows the inspection results to be reported in real time. The inspection results can be distributed through multiple methods, including email, text, etc.

Chapter 6 of AC 150/5210-24 [4], provides airports with information on the importance of collecting data and conducting analysis on the types of FOD that are being found at their airport. The FOD Finder data management software application supports this suggestion by providing the user an easy to use interface that supports data collection, data analysis, and support for a FOD reporting system. While conducting the performance assessments, CEAT was able to briefly evaluate the FOD Finder's data management tool and provide the following observations.

Figure 12 provides an example of an airport diagram that is generated by the FOD Finder system showing the location of FOD items that were detected during an inspection. Figure 13 is an illustration of the report generated by the FOD Finder showing the results of a typical airfield inspection report in tabular form. This report is available immediately for the vehicle operator in the vehicle and is also sent via email to a user-defined distribution list at the completion of a scheduled inspection.

The diagram of the airport shown in figure 12 provides a key for all locations on the airport. This map is provided with each inspection report to assist in report interpretation by those less familiar with the airport configuration. The inspection report was designed to provide critical metadata relating to the inspection (e.g., time, inspector, etc.). The graphical presentation was developed to assist in rapid interpretation of results. Color coding provides information on daylight and darkness, the period of the inspection, and locations where FOD was reported (red areas). This report, readily accessible on a variety of hand-held devices, supports rapid distribution of information from the inspection reports.

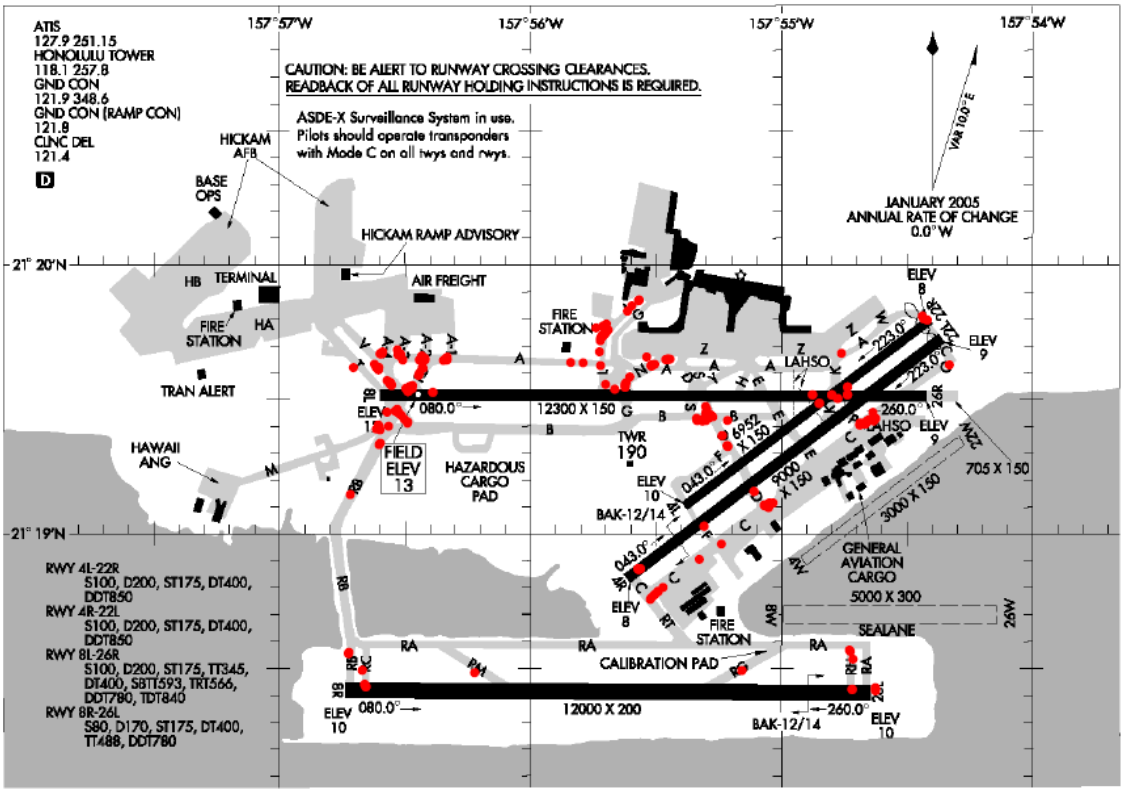


Figure 12. Airport Map Providing Information on Runway, Taxiway, and Other HNL Airport Surfaces

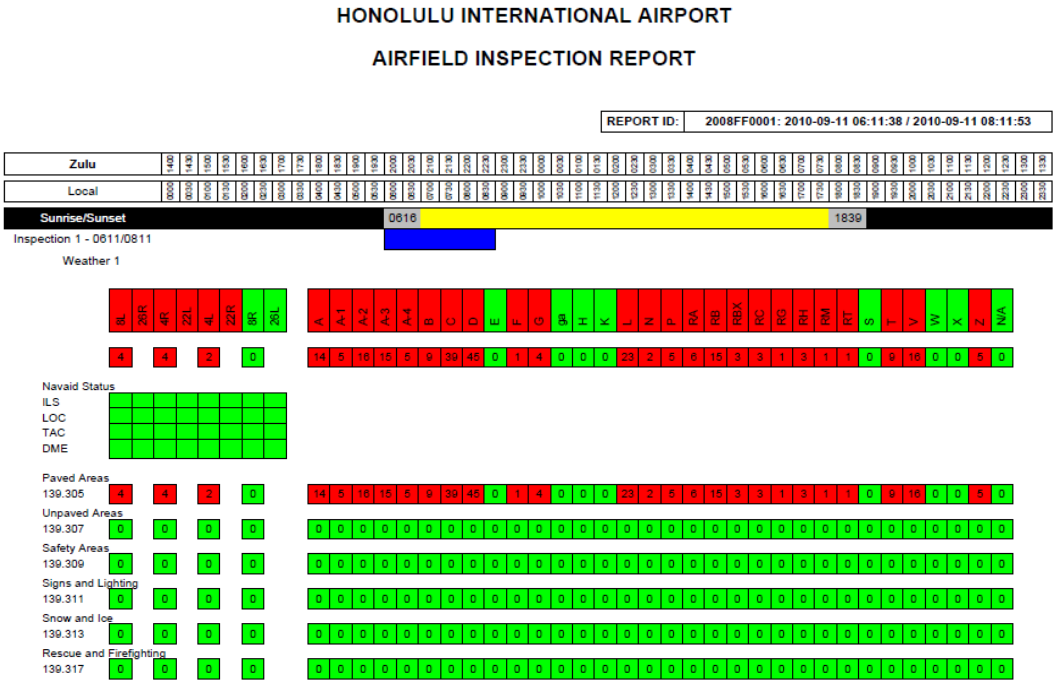


Figure 13. Inspection Report Providing Color-Coded Results of Inspection Report

In addition to the color-coded information, tabular inspection data is also provided that lists detected FOD items and provides detailed information on FOD location (figure 14). The FOD Finder can also consolidate information and provide detailed report summaries of inspection results. These summaries are particularly responsive to the requirements of Section 6 of AC 150/5210-24.

| ID | Latitude | Longitude | Location |
|---|---|---|---|
| phnl00022010032218220 3 | 21° 19' 22.9872" N | 157° 56' 23.0244" W | B |
| phnl00022010032218090 3 | 21° 19' 6.8052" N | 157° 55' 4.8972" W | D |
| phnl00022010032218090 5 | 21° 19' 7.0068" N | 157° 55' 5.2860" W | D |
| phnl00022010032218364 5 | 21° 19' 19.8372" N | 157° 55' 13.6884" W | D |
| phnl00022010032218364 7 | 21° 19' 19.8552" N | 157° 55' 13.7460" W | D |
| phnl00022010032218364 9 | 21° 19' 19.8660" N | 157° 55' 13.7856" W | D |
| phnl00022010032218367 9 | 21° 19' 19.8696" N | 157° 55' 13.6956" W | D |
| phnl00022010032218368 0 | 21° 19' 19.8912" N | 157° 55' 13.7460" W | D |
| phnl00022010032218368 1 | 21° 19' 19.9092" N | 157° 55' 13.7748" W | D |
| phnl00022010032218368 2 | 21° 19' 19.9128" N | 157° 55' 13.8180" W | D |
| phnl00022010032218070 3 | 21° 18' 59.0436" N | 157° 55' 17.2920" W | F |
| phnl00022010032218330 7 | 21° 19' 12.5220" N | 157° 55' 23.8800" W | F |
| phnl00022010032218360 5 | 21° 19' 17.5872" N | 157° 55' 15.5172" W | F |
| phnl00022010032218360 6 | 21° 19' 17.5800" N | 157° 55' 15.4812" W | F |
| phnl00022010032218360 7 | 21° 19' 17.5584" N | 157° 55' 15.4524" W | F |
| phnl00022010032218360 8 | 21° 19' 17.5368" N | 157° 55' 15.4236" W | F |
| phnl00022010032218440 3 | 21° 19' 25.8024" N | 157° 56' 34.2420" W | M |
| phnl00022010032218010 1 | 21° 18' 31.7376" N | 157° 54' 42.8040" W | RH |
| phnl00022010032218410 1 | 21° 19' 25.3308" N | 157° 56' 29.9364" W | T |
| phnl00022010032218410 2 | 21° 19' 25.3020" N | 157° 56' 29.9616" W | T |
| phnl00022010032218411 3 | 21° 19' 25.4352" N | 157° 56' 30.1368" W | T |
| phnl00022010032218411 4 | 21° 19' 25.4604" N | 157° 56' 30.1020" W | T |

Figure 14. Example of Tabular Inspection Data That Provides Location Information for Detected FOD

## 11. SUMMARY.

The Foreign Object Debris (FOD) Finder™ Detection System was operated at O'Hare International Airport, Honolulu International Airport, and McClellan-Palomar Airport. A performance assessment program consisting of calibration/intercalibration, performance, and blind tests, as well as an operational evaluation was initiated in March 2009 and completed in September 2010. In this performance assessment, test campaigns were completed under different weather conditions on different pavement surfaces at different airports. The FOD Finder performed according to product specifications and met performance requirements identified in Advisory Circular (AC) 150/5220-24. Additionally, FOD Finder data management supports Section 6 of AC 150/5210-24, specifically addressing issues of data collection and data analysis and providing support for a FOD reporting system.

## 12. REFERENCES.

1. AC 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment," September 30, 2009.

2. AC 150/5200-18, "Airport Safety Self-Inspection," April 23, 2004.

3. National Climatic Data Center, "Climatology of the United States No. 20 (CLIM20)," U.S. Department of Commerce, 1971-2000. http://www.ncdc.noaa.gov/oa/documentlibrary/pdf/eis/clim20eis.pdf

4. AC 150/5210-24, "Foreign Object Debris (FOD) Management," September 30, 2010.