THE PERFORMANCE ASSESSMENT OF A MOBILE FOD DETECTION SYSTEM

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INTRODUCTION

As part of a comprehensive performance assessment of Foreign Object Debris (FOD) detection systems at civil airports, the Center of Excellence for Airport Technology (CEAT) at the University of Illinois tested a mobile, radar-based detection system called the Trex Enterprises FOD FinderTM FOD Detection System.

The presence of Foreign Object Debris (FOD) on airport movement areas threatens the safe operation of aircraft; poses risks to airline crews, passengers and airport personnel; and has the potential to cause costly damage. Because FOD originates from many sources including aircraft, vehicles, pavements and fixtures, it is composed of a wide range of materials in a variety of colors, shapes and sizes. This variability complicates the detection of FOD items and challenges the development of utilitarian FOD detection systems.

The overall goal of the CEAT performance assessment is to determine the accuracy of FOD detection systems considering:

- 1. distance of the FOD object from the system's sensor
- 2. site conditions at the FOD placement site (e.g. smooth surfaces or grooved concrete and asphalt surfaces)
- 3. detection reliability with speed
- 4. detection capability under different weather conditions

Each performance assessment is designed to provide a rich data resource that assess the performance of a system under both field test and actual operating conditions. A wide array of FOD items in the airport environment are used, and the operational characteristics of a FOD detection system under typical airport operating conditions are considered. FOD targets include a variety of items, some with known characteristics, such as radar cross sectional area (RCS), shape, size, or material. Position and orientation of items are also varied. The intent of item selection and orientation is to produce unknown, or complex, challenges to detection systems that are similar to the challenges posed by the detection of "naturally occurring" FOD on runways.

Based on its experience, CEAT has found that the performance assessment protocols for each FOD detection system that is assessed must be designed to test the specific characteristics of that system. Because of the system's mobility, the FOD Finder[™] presented a particular challenge for protocol and procedure development. The FOD Finder[™] is designed to support monitoring of all airport surfaces and to assist airport personnel in their inspection routines through the use of a radar sensor located on top of a vehicle. Thus, the primary performance criterion for the FOD Finder[™] was detection of a target with a known reflectivity at a minimum speed of approximately 20 mph, and CEAT protocols and procedures were modified and expanded with this in mind.

The performance assessment of the FOD FinderTM FOD detection system is underway at several airports in the United States with the intent of testing under varied site and environmental

conditions. The performance assessment program was initiated in March of 2009 with preliminary testing at O'Hare International Airport (ORD). A second FOD Finder[™] unit is being tested and is already in daily operational use at HNL; a third unit has completed testing at the McClellan-Palomar Airport (CLD) in Carlsbad, CA. The performance assessments are being conducted by CEAT with the cooperation of Trex Enterprises and host airports. Testing campaigns for the FOD Finder[™] system will be completed based on a schedule developed by CEAT to meet the technical evaluation requirements of the FAA. Full-scale testing is expected to be completed by June 2010.

This paper discusses the development of calibration, performance, and blind test procedures necessary to conduct a science-based assessment of a mobile FOD detection system in a civil airport environment. It also gives an overview of operational assessment that has been initiated with a review of the contribution of the FODFinder[™] to operations at HNL.

THE FOD FINDER™ SYSTEM

The FOD Finder[™] is designed to supplement normal inspection activity by detecting small objects as the vehicle passes over runways, taxiways, and on apron surfaces. The system consists of a radar unit mounted on a vehicle with all control functions installed in the vehicle, as shown in Figure 1. The primary sensor is a 78 GHz solid-state, coherent, 3-dimensional radar. This millimeter wavelength radar is designed to detect small targets at a distance of approximately 150 m (500 ft) across the width of a runway or within a polygon defined in the radar system. Power is supplied by the vehicle to a radar scanner mounted on a platform on the vehicle roof. A tablet PC is controls the system, providing a graphical user interface for the system operator.



Figure 1. The FOD Finder[™] System Showing the Vehicle, the Radar Scanner Mounted on the Roof and the Tablet PC That Controls the System Installed in the Vehicle.

Because it is operated from a mobile, rather than a fixed, platform, the FOD Finder[™] system is unique among FOD detection systems and presents a particular challenge for the development

of assessment protocols and procedures. The system's mobility, along with its technical characteristics, requires a singular performance assessment approach.

GENERAL TEST PROCEDURES

The standard CEAT performance assessment includes a field-test campaign followed by an operation assessment of an installed system. All CEAT performance assessments address issues such as FOD item size, distance from the sensor, and the speed of sensor movement under a variety of weather and pavement surface conditions. Typically, both field-test campaigns and operational assessments involve:

- calibration/inter-calibration testing,
- performance testing, and
- blind testing

To fully test the unique characteristics of the FOD FinderTM, this approach was expanded to include a single-FOD-item array test. Further, because the effective operation of the FOD FinderTM requires that the operator and the technology work in concert at all times that the system is being used, the operational assessment became, in part, an integral part of the field test campaign. FOD items used in the testing of the FOD Finder[™] technology were selected to meet the specific needs of the system, and the testing campaigns were designed to comprehensively test this technology. FOD Finder[™] calibration targets were selected to provide radar reflectivity consistent with the system's radar frequency. For example, the -20 dBm^2 cylinder used in other CEAT FOD detection performance assessments was used. Trex Enterprises suggested the use of a standard AA battery as an item with known reflectivity that also could be considered a real FOD item on an airport. The selection of a standard calibration item awaits Trex Enterprises selection based on AC 150-5220-24, which allows vendors to specify targets. The standard array of performance items used in CEAT testing, as shown in Table 1, was supplemented with a lug nut that has a reflectivity consistent with the calibration target. This standard lug nut was used at multiple locations in the test area to provide additional performance information on detection of typical FOD items at different speeds. Blind test items were also selected from the CEAT FOD collection.

FOD Item*	Expected Hazard	Frequency of Occurrence	
1. Small piece of concrete	High	Common	
2. Standard lug nut from	High	Common	
service vehicle			
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 –	Moderate	Based on construction	
galvanized nails or		activity	
sheetrock screws			
12. Runway infrastructure	High	Uncommon	
part – piece of runway light			
or signage			
13. Small fasteners	Moderate	Common	
14. Metal strip	High	Uncommon	
15. Fiberglass door	Moderate	Common	
* Items selected based on			
consultation with James			
Stephan of Delta Airlines			
based on his studies of FOD			
items common on runways.			

Table 1. Proposed FOD Items for Detection Performance Testing.

General test procedures were developed to accommodate the operational mode of the FOD FinderTM. Design of testing was related to scan characteristics of the system, as shown in Figure 2. The nominal specifications include a sweep angle of 75 degrees with a 4 second left-to-right cycle time. The effective range of the FOD FinderTM is approximately 35 m (100 ft) on either side of the unit and 175 m (580 ft) in front of the unit. Design speed is 30 mph. The FOD FinderTM system uses a differential GPS to determine position on the airport, and detection is limited to detection rectangles set for the airport. In addition to detection rectangles, the system has alerts to prevent runway incursions and to prevent damage to the radar sensor as the vehicle passes under obstructions. For airport testing, it was assumed that the FOD FinderTM would be used for operations that focused on critical airport surfaces designated by airport personnel. At a minimum, all campaigns are designed to involve FOD item placement on a runway, taxiway, or apron surface.



Figure 2. FOD Finder Scan Profile Based on Standard Speed and Radar Settings.

To ensure that the assessment of the FOD Finder[™] is science-based, all experimental procedures have been standardized. First, a rectangle approximately 150 m (500 ft) long and 60 m (200 ft wide) is established on a runway, taxiway, or apron surface. At the four corners of this rectangle, standard 15 cm (6 inch) radar reflectors (Figure 3) are placed at each corner. Standard 5 cm (2 inch) radar reflectors (Figure 4) are placed at approximately 30 m (100 ft) intervals along the long dimension of the rectangle. Small radar reflectors are also placed at the midpoint of the end lines of the rectangle. To accommodate the bidirectional passage of the FOD Finder[™] vehicle through the rectangle, two corner reflectors are placed back-to-back at each location to provide uniform targets for the radar (Figure 5). This placement of strongly reflecting radar targets assists in the analysis and interpretation of all test item placements and assures that the area covered will be consistent from campaign to campaign.



Figure 3. Six-Inch Corner Reflector Used as a Standard Large Target.



Figure 4. Two-Inch Corner Reflector Used as a Standard Small Target.



Figure 5. Large and Small Corner Reflectors Showing Back-to-Back Orientation..

In all testing campaigns, three lines along the length of the rectangle at the rectangle center and at one-half the distance to the edge line of the rectangle are established by marking spots with UV paint, as shown in Figure 6. Five items are placed at equal distances starting at 30m (100 ft) and ending at 120m (400 ft). The three lines allow replicates of calibration items and three performance items to be placed for detection testing. Detection testing is initiated with vehicle movement at approximately 150 m (500 ft) from the test rectangle, a point at which the vehicle establishes a constant speed and is passing down the center of the test rectangle. The vehicle is then turned around and the maneuver is repeated in the opposite direction and at the same speed down the center of the test rectangle. Detections are recorded after each pass and screen captures of detections are stored for analysis. Testing continues with the same items, with the vehicle passing to over the right and left lines of items in both directions. In this protocol, detection from both directions is assessed, and detection on the center line and to each side of the radar is also assessed. Multiple items placed in a line provide for detection from multiple angles as the vehicle passes over or near the items on the runway. For blind testing, the test rectangle is divided into a grid of 30 m x 30 m (100 ft x 100 ft) squares. In the grid, each square is numbered. Blind test FOD items are selected randomly from the CEAT FOD collection (Table 1) and items are placed in randomly selected grid areas. For blind testing, it is anticipated that only a single pass will be used for item detection, although multiple passes may be used to provide additional information on FOD item assessment.



Figure 6. Reflector and Target Positions in the Test Rectangle.

In all calibration and performance testing, the test area is first sterilized of FOD (e.g. using a FOD blanket, sweeping, or jet air treatment). Targets are then be placed for testing with multiple vehicle passes made through the test rectangle during each campaign.

FOD FINDERTM CALIBRATION TESTING

As part of the quality assurance plan, a radar calibration, or inter-calibration, exercise will be completed at the beginning of each test campaign to provide data on detection effectiveness from both time-to-time and location-to-location, particularly when different FOD Finder[™] units are used in assessments. After polygon verification, calibration targets are placed on positions in the test rectangle. A total of 15 calibration targets are used with multiple passes of the vehicle providing detection information. Calibration testing is conducted at the initiation of each test campaign and may be repeated under different weather and runway surface conditions, thus providing a basis for assessment of performance under different environmental conditions. The targets used in this testing are approved by Trex Enterprises. Test locations will be established on runways, a taxiway and a pad, where the position of the vehicle and target locations will be verified using direct measurement.

Calibration testing will consider target placement to assure a scan sweep (2 sec) of the target placement area and support data post-processing to identify the time of first detection in relation to vehicle and target positions. At least two speeds will be tested, 20 mph and 30 mph. A complete data set will include passage in each direction over each line of calibration items in the rectangle.

Location Accuracy

CEAT will use a differential GPS survey system to confirm the position of target placement locations. This will assist in determination of the accuracy of system reports of FOD locations as compared to positions reported in the FOD FinderTM system.

FOD ITEM DETECTION PERFORMANCE TESTING

The FOD item performance testing will use the CEAT performance test items, Table 1. In the performance tests, replicate performance items are placed at five locations along the long axis test rectangle, as shown in Figure 6. In this procedure, three different performance items will be used in each test sequence. In each test sequence, the FOD FinderTM equipped vehicle will make 2 (one up and one back) passes for each set of FOD items at a constant speed of 30 mph. This procedure will require a total of six passes for each test sequence with a pass up and down using each item line as the line of passage of the vehicle. The angle of detection will be assessed based on the position of vehicle passage.

The performance testing will also utilize a single item in a grid in the test polygon. The preferred items are lug nuts. In this testing, an array of 15 lug nuts are used in a grid defined by the positions marked in the rectangle. The FOD Finder[™] equipped vehicle passes through the target array along the centerline, making a pass in each direction at a constant speed of 30 mph.

BLIND FOD ITEM DETECTION TESTING

Blind testing will be conducted using an array of FOD items collected from airports and other targets typical of common FOD. In general, the blind testing considers metallic and non-metallic FOD types, size ranges from small to large, and may include living materials. As many as 50 FOD items may be available for blind testing. The general procedure for blind testing is development of random placement locations for the FOD items in relation to sensor/system detectors. Multiple targets are placed on the runway at the same time. Each blind test program will involve a minimum of 30 items.

OPERATIONAL ASSESSMENT

As part of CEAT's overall performance assessment program, an operational assessment is conducted for each FOD detection technology that is tested. Because the FOD Finder[™] system is already in daily operational use at HLN, CEAT's operational analysis has been initiated parallel to the field test campaign with a review of the contribution of the FOD Finder[™] to HLN operations.

At HNL, the FOD FinderTM is used primarily to supplement regular inspections made by airport personnel. A FOD FinderTM system has been installed on a HNL vehicle, and the existing installation features a capability for rapid report generation and distribution. Although the system operates on remote airport locations, Trex Enterprises has equipped each unit with a communications capability that allows remote support of the unit and facilitates rapid reporting of inspection results. Distribution is possible through multiple channels, including email. To provide an operational example of detection system, Trex Enterprises supplied a typical

inspection report that is sent by email at the completion of a scheduled inspection. Figures 7 and 8 illustrate that reporting.

One element of the report is a map of the airport providing a key for all locations on the airport, Figure 7. This map is provided with each report to assist in inspection report interpretation.



Figure 7. Map of HNL Providing Information on Runway, Taxiway, and Other Airport Surfaces. This Map Provides a Key for Inspection Report Interpretation.

The inspection report, Figure 8, has been designed to provide critical metadata relating to the inspection (e.g. time, inspector, etc). In addition, the recorded detection data, Table 2, provides detailed information on FOD location and other characteristics. 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 inspection reports.



Honolulu International Airport Airfield Inspection Report

Figure 8. Inspection Report for HNL Providing Color Coded Results of Inspection Results.

ID	Latitude	Longitude	Location
phni000220100322182203	21" 19' 22.9872" N	157* 56' 23.0244" W	В
phni000220100322180903	21" 19' 6.8052" N	157* 55' 4.8972" W	D
phni000220100322180905	21* 19' 7.0066" N	157* 55' 5.2860" W	D
phni000220100322183645	21* 19' 19.8372' N	157* 55' 13.6884" W	D
phni000220100322183647	21" 19' 19.8552" N	157* 55' 13.7460' W	D
phni000220100322183649	21* 19' 19.8650" N	157* 55' 13.7856' W	D
phni000220100322183679	21* 19' 19.8696" N	157* 55' 13.6956" W	D
phni000220100322183680	21" 19' 19.8912" N	157* 55' 13.7460' W	D
phni000220100322183681	21" 19' 19.9092" N	157* 55' 13.7748' W	D
phni000220100322183682	21" 19' 19.9126" N	157* 55' 13.8180" W	D
phni000220100322180703	21* 18' 59.0436' N	157* 55' 17.2920' W	S.F.
phni000220100322183307	21* 19' 12.5220' N	157* 55' 23.8800' W	F
phni000220100322183605	21" 19' 17.5872' N	157* 55' 15.5172" W	F
phni000220100322183606	21* 19' 17.5800" N	157* 55' 15.4812" W	F
phni000220100322183607	21* 19' 17.5584" N	157* 55' 15.4524" W	F
phni000220100322183608	21" 19' 17.5366" N	157* 55' 15.4236' W	F
phni000220100322184403	21" 19' 25.8024" N	157* 56' 34 2420" W	м
phni000220100322180101	21° 18' 31.7376" N	157* 54' 42.8040" W	RH
phni000220100322184101	21" 19' 25.3306" N	157* 56' 29.9364" W	т
phni000220100322184102	21" 19' 25.3020" N	157* 56' 29.9616' W	Т
phni000220100322184113	21" 19' 25.4352" N	157* 56' 30.1308" W	т
phni000220100322184114	21* 19' 25.4604" N	157* 56' 30.1020" W	т

Table 2. An example of the tabular inspection data providing location information for detected FOD

In addition to the color coded information, a table of detections is also provided, Table 2, listing the items detected and location. In addition to these inspection reports, the FOD FinderTM system can consolidate information and provide detailed report summaries of inspection results.

Although performance assessments of the FOD FinderTM FOD detection system are note complete, Trex Enterprises has demonstrated the availability of an advanced FOD detection technology and an innovative data management system consistent with the requirements for detection system output specified in Advisory Circular 150/5220-24. CEAT performance assessments of the FOD FinderTM will continue and operational capabilities will be a particular focus of this assessment considering the fundamental of technology and operations in this system.

CONCLUSIONS

The FOD Finder[™] FOD detection system provides a new paradigm in FOD detection technologies–the mobile system. This mobility has challenged the CEAT performance assessment program to develop calibration, performance, and blind test procedures for this unique radar technology. The protocols developed by CEAT have been adapted to FOD Finder[™] system characteristics and support a science-based assessment of system performance in an airport environment. Performance assessments continue at ORD and the CEAT performance assessment program for the FOD Finder[™] is supported by operational activities at HNL.