AN/FSY-3: Space Fence System
Overview of User Interface and Conjunction Assessment Study

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Information in this presentation has been assembled from Distribution A material previously cleared for public release:

Overview

• Agenda
  – System Overview and Program Status
  – Prototyping and Modeling and Simulation
  – Operator User Interface and Processing
  – Conjunction Assessment Study

• Key Messages
  – Space Fence Will Provide Unprecedented Capability for Space Situational Awareness
  – Extensive Modeling, Simulation and Prototyping Completed
  – User Evaluation Periods have optimized operator controls and interfaces
  – System design is focused on automating operator functions and reducing operator workload
  – Program On-Track to 2018 Initial Operational Capability

The authors would like to acknowledge and thank the USAF Space Fence Program Office at AFLCMC and their partners for their support.
Space Fence Solution Movie
Space Fence Mission

- Ground-based system of S-Band radars that greatly enhance the USAF Space Surveillance Network
- Consists of two minimally manned radar sites and the Space Fence Operations Center
- Detects, tracks, catalogs objects in Low Earth Orbit (LEO)
- Also provides significant capability in Medium Earth Orbit (MEO) and Geosynchronous Orbit (GEO)

Space Fence System Architecture

As the earth rotates, the two sensor sites complement each other to provide assured coverage

Space Fence Uses Advanced S-Band Digital Beamforming (DBF) Radars to Provide Unprecedented Space Situational Awareness

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Sensor Site 1 Construction Progress

Space Fence Program On-Track to 2018 Initial Operational Capability

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Integration Test Bed (ITB)

- Scaled down end-to-end system with end-item cabinets, electronics and antenna support structure
- Used for:
  - Form/Fit check
  - Hardware, software, firmware integration and test
  - System test
  - Requirements verification
  - Training
  - Extended operational test
  - Maintainability demonstrations
  - Remote resolution support of sensor site integration issues
Detailed Modeling & Simulation (M&S)

High Fidelity M&S Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Name</th>
<th>Description</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>External World</td>
<td>Perf. Assessment Simulator (PAS)</td>
<td>Government provided satellite / C2 simulators and data validation</td>
<td>USAF / MIT LL</td>
</tr>
<tr>
<td>SF Operations Center (SOC)</td>
<td>SOC Mission Processing</td>
<td>Tactical software and functionality for multi-site control and data processing</td>
<td>Lockheed Martin</td>
</tr>
<tr>
<td>Space Fence (SF) Sensor Site (SS)</td>
<td>SS Mission Processing</td>
<td>Tactical software and functionality for SS control and processing (e.g., tasking, tracking, association)</td>
<td>Lockheed Martin</td>
</tr>
<tr>
<td></td>
<td>Radar Control Processing</td>
<td>Tactical software and functionality for the radar (e.g., tracker, beam scheduler)</td>
<td>Lockheed Martin</td>
</tr>
<tr>
<td></td>
<td>Radar Antennas and Signal</td>
<td>Effects-based model of the radar performance (e.g., sensitivity, accuracy)</td>
<td>Lockheed Martin</td>
</tr>
</tbody>
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Key Functional Threads Operational in End-to-End System Modeling and Simulation Environment (Independently Assessed by USAF and MIT/Lincoln Laboratory)

Surveillance
Probability of Observation > 99% (plot contains a single dot for each crossing object)

Search
Captures orbital uncertainty

Track
SS Tracks (Side View)

Catalog Buildup
LM scenario (using 2030 NASA debris catalog) demonstrated multi-day run, continued database buildup and > 90% correlation success on initial passes of UCTs

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Net-Centric Operations and Services

Service-Oriented, Standards-Based Architecture Achieves Net-Centric Operations and Ensures Warfighters Receive Information in an Efficient Manner

Net-Centric Architecture
- SOAP/WSDL standards-based web services
- High availability network
- Publish/Subscribe architecture
- Community of Interest (COI) defined XML data definitions
- SKIWeb, GeoRSS feeds

<table>
<thead>
<tr>
<th>System Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert Service</td>
<td>Allows subscribers to view SF alert settings</td>
</tr>
<tr>
<td>Calibration Service</td>
<td>Provides insight into atmospheric impacts to obs.</td>
</tr>
<tr>
<td>Catalog Service</td>
<td>Receives incremental updates of JSpOC catalog</td>
</tr>
<tr>
<td>Data Store Service</td>
<td>Provides fence configuration parameters</td>
</tr>
<tr>
<td>Mission Configuration Service</td>
<td>Access to SF internal Mission and performance data</td>
</tr>
<tr>
<td>Notification Service</td>
<td>Common end-point for externally received information (e.g. JMS)</td>
</tr>
<tr>
<td>Raw Data Service</td>
<td>Visibility of detailed data collection settings</td>
</tr>
<tr>
<td>Subscription Service</td>
<td>Pub/Sub mechanism for data dissemination (e.g. observations)</td>
</tr>
<tr>
<td>Tasking Service</td>
<td>Flexible coverage control and task management</td>
</tr>
</tbody>
</table>

Net-Centric Operations Allows Authorized Users to Access Space Fence System in Real Time

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Automated and Efficient Space Surveillance

Sensor Automation

• Sensor resource management feedback
• Observations generated from radar measurement data
• Automated UCT and IOD processing using Astro Standards algorithms
• Automatic orbit state improvements
• Remotely commanded, local sensor operator, and automatic search tasking
• Internal space object catalog automatically maintained and synchronized with JSpOC catalog

Operator Friendly

• Experienced USAF user groups provided periodic feedback during design phase
• Intuitive controls and visual/audible cues
• System alerts prioritize operator activities
• Rapid tasking directly from system alerts
• Visual depiction of fence crossings
• Web browser-based operator display thin client
• Built-in training capability

User Evaluation Periods Throughout Program to Test Usability and Incorporate Operator Feedback
Space Fence Data Management

- Sensor data accessed in multiple ways
  - Operator displays
  - Net-centric services
  - Removable media
- 2D/3D visualization of space object ephemeris
- Customizable user interface layout
- Sortable/searchable observation lists
- Automatic space event data recording
- External Services Protected Environment (ESPE) allows analyst to run external algorithms within the SF environment

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Conjunction Assessment Study (slide 1 of 2)

- Scenario for Analyzing Catalog Build-Up
  - NASA 2030 catalog: > 150,000 objects
  - 5 day scenario run with SS1 un-cued LEO surveillance fence
  - Assumed known RSO catalog of ~ 14k objects
  - Debris objects ranged in size down to 1 cm with orbits in all regimes: LEO, MEO, HEO, and GEO

- Space Fence Performance
  - Steady-state catalog includes new well-maintained orbits on over 50k new objects
  - Excellent LEO coverage using un-cued surveillance
    - Mostly semi-circular orbits were detected
    - Many objects found across a range of inclinations
    - Very low inclination orbits would need to be tasked
  - Tasking and fences in other regimes would increase the catalog further

Catalog Expansion

Space Fence Successfully Processes Expected Catalog Growth Based on NASA 2030 Debris Catalog
Conjunction Assessment Study (slide 2 of 2)

Overview

- **Population**
  - > 150,000 objects (known and unknown)
  - 32 satellites of interest for CA
    - Representative to NASA's interest
    - Inclinations: 20 to 99 degrees
    - Altitudes: 370 to 1350 km

- **Surveillance and Tasking Setup**
  - **Space Fence Config (for 32 CA Objects)**
    - **Track Initiation**
      - Fence
    - **Track Duration**
      - 3 obs
    - **Total # of Passes**
      - 260
    - **Total Track Time (min)**
      - 167

  - **Un-Cued Surveillance**
    - Fence
  - **Un-Cued Surv, Extended Track**
    - 20 obs
  - **Tasked Object**
    - Cue
  - **Total Track Time (min)**
    - 1116

Orbit Determination Error

- **Error Sources Studied**
  - **Periodic Error**
    - Inaccuracies in inclination, eccentricity, or argument of perigee
    - Cyclic error frequency related to period
  - **Drift Error**
    - Inaccuracies in period or drag
    - Growing linear error over short period
    - Long-term periodic (objects lap each other)

- **Results**
  - Significant error reduction for both drift and periodic errors from the additional observations when comparing un-cued surveillance routine vs. extended track

Orbit-Based Improvement Options

- **Polar Orbits**
  - Use un-cued surveillance with extended tracks
  - Option to task for extra passes within the FoR (in addition to routine un-cued surveillance crossings)

- **Low Inclination Orbits**
  - Option to task for the abundance of passes near parallel to the un-cued surveillance fence
  - For objects with inclination below site latitude, tasking enables track where un-cued fence does not cover

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Summary

• Space Fence Will Provide Unprecedented Capability for Space Situational Awareness

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