MIT Lincoln Laboratory to Support to Unmanned Aircraft Systems Integration into the US National Airspace

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Outline

• Background

• UAS Program Elements
  – Standards
  – Maneuver Algorithms
  – Modeling and Simulation
  – Testbeds

• Summary
Growing Demand for UAS Operations in the National Airspace

Crew Training

CONUS Basing for International Missions

Oceanic and Littoral Surveillance

Coastal Surveillance

Border Surveillance

Environmental Monitoring (Law Enforcement, Disaster Relief)

Diverse operational requirements for UAS in the national airspace
Growth in UAS Domestic Operations

“2009 is the first year the AF will train more ground-based UAV operators than 'fighter jockeys' and bomber pilots.”
- Gen. Stephen Lorenz, head of Air Education and Training Command

2010: 146 Units, 66 Locations
2015: 197 Units, 105 Locations

Growing demand for UAS access to the national airspace
# Barriers to UAS Airspace Integration*

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Time</th>
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<td>Current (Today)</td>
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<tr>
<td>Pilot Qualifications</td>
<td>Basic UAS Qualification Levels</td>
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<td>Airworthiness</td>
<td>Airworthiness Standards Update</td>
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<td>Ops Stds &amp; Procedures</td>
<td>Night Ops Multiple UAS</td>
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<td>Equipage</td>
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<td>Sense-and-Avoid (SAA)</td>
<td>Performance Standards</td>
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</table>

## Lincoln focus

Sense and avoid is the principal technical hurdle to airspace integration

* JUAS COE “Airspace Integration Capabilities Based Assessment”, 2009.
"SAA is the capability of an unmanned aircraft to remain well clear from and avoid collisions with other airborne traffic"*

- **Primary sense and avoid system functions:**
  - **Self-separation** – strategic maneuvering to maintain “Well Clear”
  - **Collision avoidance** – tactical, last-minute maneuver to avoid a collision

- **Principal sub-functions are:**
  - Airspace surveillance
  - Threat detection
  - Threat avoidance maneuver

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Sense and Avoid Concepts

Ground-Based

- Rapid deployment enabled by leveraging existing ground-based surveillance and tools
- The same surveillance and support hardware supports a diverse range of platforms
- Operational volume limited by surveillance coverage

Airborne

- Unconstrained operations enabled by surveillance volume fixed to platform
- Longer timelines associated with developing and certifying airborne components
- Smaller platforms may not have the size, weight, or power to support airborne hardware

Path forward: GBSAA ➔ ABSAA ➔ Hybrid
Sense and Avoid Elements

- COTS ground based 3D radar, FAA
- Airborne sensor development

Sensors

- Data fusion and Tracking
- Threat detection and Maneuver

Algorithms

- Decision Support Aids

System Elements

Sense and Avoid System

Lincoln Enabling Activities

- Modeling & Simulation
- Standards
- Airspace Characterization
- Safety Case
- Open Architectures
- Testbeds

Fault Tree & Event Trees to Assess Risk

- Loss of separation (Encounter)
- Miss
- Midair Collision
- Well Clear

ATC saves

Manned See-

Avoid saves

Self Separation saves

Collision Avoidance saves

ATC fails

See-

Avoid fails

SS fails

CA fails

Consequences

Hazard

Event Tree

Hazard Mitigations

Fault Tree

Hazard Causes

- ATC services not available
- ATC services available but fail
- OR
- Pilot deviates from clearance
- Pilot loses flight control
- OR
- Aircraft are proximate
- Aircraft on collision course

Causes

- Aircraft receiving ATC services AND OR
- UAS receiving ATC services AND OR
- UAS pilot deviates from clearance
- UAS control system fails
- UAS loses communications link
- OR
- ATC systems fail
- Manned aircraft systems fail
- UAS systems fail
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Standards Development Activities

• FAA-sponsored Sense & Avoid Workshops
  – Co-leadership of well clear and target level of safety work areas
  – Proposal of an analytical basis for definition of well clear

• OSD Target Level of Safety (TLS) Workshop
  – Leadership in determining DoD-recommended Target Level of Safety

• RTCA Special Committee 203
  – Continued support of sense & avoid working group
  – Leads for engaging industry feedback in two areas of FAA-sponsored Sense & Avoid Workshop

MIT/LL is Strongly Engaged in UAS Community and Regulatory Standards Development
Standards Development: Well Clear

Well Clear Definition

- FAA-sponsored workshop requirement for SAA system to perform self separation
  - Ability to stay “well clear” of air traffic
  - Well clear concept from regulatory language, but is not defined

- MIT LL is establishing a risk-based separation standard based on our safety assessment framework
  - Provides quantitative, analytical definition as the basis for system evaluation
  - Definition based on risk of collision after crossing the separation boundary

Analytical Well Clear Boundary

Well clear threshold
Derived based on unmitigated probability of NMAC from random encounters

Near Midair Collision (NMAC) Volume

Laboratory is playing key role in developing and defining standards to support UAS airspace integration
Standards Development: Target Level of Safety

Required target level(s) of safety is currently being determined by the FAA/DoD/NATO

* Aircraft not under ATC control
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Threat Detection and Maneuver Logic (MITCAS)

- Optimal Alert Logic generated automatically using Dynamic Programming
- Increases Safety with Reduced Alert Rate
- More Robust to Pilot Variations
- Easily Tailored for Changes in Aircraft, Airspace or Surveillance

**Decision Theoretic Probabilistic Approach to Collision Avoidance**

- Developed to replace TCAS on manned aircraft
- FAA planning preproduction prototype
- Extended to UAS separation assurance and collision avoidance

**Offline Logic Optimization**
- Performed on high-performance computers

**Real-time Logic Usage**
- Executed onboard aircraft (once per second)

- Encounter Model
- Performance Metric
- Model Discretization
- Discrete Model
- Dynamic Programming
- Cost Table
- Tracker
- State
- Action Selection
- Action

1 million close encounters
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Safety Modeling and Simulation Framework

Realistic Fast-Time Simulation: millions of encounters

- Raw radar data
- Tracking and fusion
- Feature extraction
- Encounter models
- Aircraft flight profiles and dynamics
- Collision avoidance system models (algorithms)
- Fast-time simulation
- Collisions per encounter
- Relative risk analysis
- Collisions per flight-hour
- Target Level of Safety risk analysis
- Encounters per flight-hour
- Density processing
- Density models
- Encounter rate estimation
- Cooperative: Observed encounters per flight-hour
- Noncoop: Proportional to traffic density and airspeeds

Encounter Rate Model
M&S Applied to Notional GBSAAS

Simulation of close encounters

10 million encounters

Track Intruder

Self Separation

Collision Avoidance

Generic 3D radar

Horizontal maneuver

Vertical maneuver

10 million outcomes

Couple simulation results with airspace density

Estimated unmitigated collision rates

Safety framework supports the analysis of sensors and algorithms to ascertain if SAA architecture achieves required target level of safety

<table>
<thead>
<tr>
<th>Unmitigated collision rate (per flight hr)</th>
<th>With mitigation collision rate (per flight hr)</th>
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<tbody>
<tr>
<td>25%-tile: $5 \times 10^{-8}$</td>
<td>$4 \times 10^{-10}$</td>
</tr>
<tr>
<td>50%-tile: $3 \times 10^{-7}$</td>
<td>$2 \times 10^{-9}$</td>
</tr>
<tr>
<td>75%-tile: $2 \times 10^{-6}$</td>
<td>$2 \times 10^{-8}$</td>
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Testbed Efforts

Army (GBSAA)
- Elimination of ground observers
- Enable night training operations
- Reference architecture to support RFP
- First deployment to Dugway Proving Grounds spring/summer 2011
  - Restricted airspace allows for unfettered testing
- Open architecture
- Effort includes data fusion/tracking and maneuver algorithm development

Air Force (GBSAA)
- Focus on consolidating ground observer task
- Closed, Proprietary
- Cannon and Palmdale

Lincoln roles:
- Airspace characterization
- Modeling and simulation to estimate level of safety
- Safety case process development

DHS (ABSAA)
- Demonstrate flexible, scalable airborne radar based system customizable to a broad set of UAS
- Prototype a flexible low SWAP phased array radar for SAA surveillance
- Flight tests on surrogate manned aircraft
- Test with both JOCA and MITCAS maneuver logic

FAA
- Army testbed effort briefed to FAA Research and Technology Development (RTD) office
- FAA RTD has expressed interest in the concept and potential application to support UAS research initiatives and NexGen technology implementation activities
- MIT and FAA RTD office to hold further discussions
Army
Ground-Based Sense and Avoid Program

Initial deployment to Dugway Proving Grounds summer 2011

**Lincoln Roles**

- Define Open Reference Architecture for sense and avoid
- Self separation and collision avoidance requirements and algorithms
- Sensor fusion and tracking requirements and algorithms
- Assessments of system components: sensors, avoidance logic, display concepts

**Candidate Sensors**

- 3-D
- Wide Area
- Weather
- Other Sensors*

Ground Based Radars
FAA/DoD Radars And Data Bases
CIWS
EO/IR
Airborne

* Possible future extension

**Sensor and Decision Support Services**

- Sensor Fusion
- Conflict Detection
- Sensor Cuing
- Resolution Advisory Logic

**Common Network Services**

- Messaging
- Alert Notification
- Directory Services
- Data Recording
- Databases

**UAS Sense and Avoid DDS Bus**

- UAS Telemetry
- UAS Operator Displays

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**Initial deployment to Dugway Proving Grounds summer 2011**
GBSAA Architecture Validation

Millions of Encounters

- Encounter models
- Sense and Avoid logic
- Sensor models
- Tracker models

Component requirements:
- Real airspace
- Sense and Avoid logic
- Real Sensors

Model validation

Testbed/Operational Prototype

General Safety Metrics

Modeling & Simulation

Testbed Architecture

Site Specific Metrics
Customs and Border Protection
Southern Border Patrol Operations

- Requires Certificate of Authorization
- Advanced coordination with ATC
- Observers/chase aircraft < 18K ft
- Generally daylight, visual conditions
- Mission ops at 19,000 ft only

• Desire ability to drop to 5,000 ft AGL for close-up observations
• Requires airborne sense and avoid

Under ATC Control

18,000 ft.

3000 ft.

Chase Aircraft

Ground Observer

Ground Observer
Radar is preferred sensor if UAS size, weight, and power constraints can be satisfied

Program will demonstrate scalable SWAP, low cost radar technology

Initial phase will include single antenna with offline avoidance logic

Surrogate aircraft with realistic UA flight constraints used to accelerate development

Objective: reduce system development risk by demonstrating enabling technologies
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- MIT Lincoln Laboratory has a broad capability portfolio in UAS sense & avoid safety

- The Laboratory has leading roles:
  - Developing standards for UAS integration
  - Modeling and simulation to demonstrate safety
  - Sensor and algorithm development
  - Real-time architectures
  - Engaged with multiple stakeholders: U.S. DoD, DHS, FAA
  - Programs spanning airborne and ground-based sense & avoid