Overview of Sense and Avoid/Separation Assurance Interoperability (SSI)

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Separation Assurance/Sense and Avoid Interoperability

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Overview

• Motivation and Scope

• Detect and Avoid - Capabilities and Models

• Example Results
Motivation

Interoperability?

Requirements?

Air Traffic Control

Airspace Procedures

“See and Avoid”

Instrument Flight Rules (IFR)

Visual Flight Rules (VFR)

“Detect and Avoid”

Unmanned Aircraft Systems (UAS)

Safety

All aircraft are required to “see and avoid” and remain well clear of other traffic.

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Scope

• Stakeholder: RTCA Special Committee (SC) 228
  – RTCA: Public-Private committee for developing consensus on critical aviation modernization issues
  – SC-228: Initial phase is to develop standards for civil UAS equipped to operate under Instrument Flight Rules.
  – Operational Environment: UAS transitioning to and from Class A airspace (18k feet and above) or special use airspace traversing Class D, E, and G airspace in the process.

• Detect and Avoid - Minimum Operational Performance Standards
  – Equipment requirements for UAS’s detect and avoid system in order to operate in the National Airspace System safely
  – Surveillance, alerting, guidance, human-machine interface requirements
• Well clear is vague, subjective, but vitally important, because it’s the basis of developing a detect and avoid system

• A well clear separation standard is recommended to be,

  - Large enough to:
    - Avoid inducing collision avoidance maneuvers
    - Avoid excessive concern for pilots of proximate piloted aircraft
    - Minimize traffic alert issuances by air traffic control

  But, small enough to:

  - Prevent the need for large deviations that potentially disrupt traffic flow and ATC separation management plans

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Well Clear Definition


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Capabilities
Airspace Concept Evaluation System (ACES)

- **NAS-wide Simulation**
  - Gate-to-gate simulation of ATM operations
  - Full flight schedule with flight plans
  - Sector and center models with some airspace procedures

- **Simulation Agents**
  - Air traffic controller decision making
  - Traffic flow management models
  - Individual aircraft characteristics
  - UAS Detect-and-Avoid (DAA) System [JADEM]

- **4-DOF Trajectory Model**
  - Aerodynamic models of aircraft
  - Models replicate pilot behavior
  - User-definable uncertainty characteristics

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Airspace Concept Evaluation System (ACES)

**NAS-wide Simulation**
- Full flight schedule with flight plans
- Sector and center models with some airspace procedures

**Regional Traffic Management**

**Simulation Agents**
- Traffic flow management models
- Individual aircraft characteristics
- UAS Detect-and-Avoid (DAA) System [JADEM]

**4-DOF Trajectory Model**
Aerodynamic models of aircraft
Models replicate pilot behavior

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## UAS Mission Characteristics

<table>
<thead>
<tr>
<th>UAS Group</th>
<th>Duration (per flight)</th>
<th>Cruise Speed (knots)</th>
<th>Cruise Alt. (ft)</th>
<th>Flight Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air Quality Monitoring</strong></td>
<td>Shadow-B</td>
<td>1-4 hrs.</td>
<td>74-89</td>
<td>4k, 5k, and 6k ft AGL</td>
</tr>
<tr>
<td><strong>Cargo Transport</strong></td>
<td>Cessna 208</td>
<td>varies</td>
<td>137-172</td>
<td>2k-16k</td>
</tr>
<tr>
<td><strong>Atmospheric Sampling</strong></td>
<td>Global Hawk</td>
<td>1.5-13 hrs.</td>
<td>151-321</td>
<td>5k-35k ft AGL</td>
</tr>
<tr>
<td><strong>On-demand Remote Air Taxi - Cirrus</strong></td>
<td>Cirrus SR22T</td>
<td>varies</td>
<td>153-166</td>
<td>6k-11k</td>
</tr>
<tr>
<td><strong>On-demand Remote Air Taxi - Mustang</strong></td>
<td>Cessna Mustang</td>
<td>varies</td>
<td>156-340</td>
<td>9k-20k</td>
</tr>
<tr>
<td><strong>Strategic Fire Monitoring</strong></td>
<td>Predator-B</td>
<td>20 hrs.</td>
<td>~209</td>
<td>31k ft MSL</td>
</tr>
<tr>
<td><strong>Tactical Fire Monitoring</strong></td>
<td>Shadow-B</td>
<td>1-1.5 hrs.</td>
<td>72-75</td>
<td>3k-7k AGL</td>
</tr>
<tr>
<td><strong>Flood Inundation Mapping</strong></td>
<td>Aerosonde</td>
<td>1-4 hrs.</td>
<td>46-51</td>
<td>4k ft AGL</td>
</tr>
<tr>
<td><strong>Flow Stream Monitoring</strong></td>
<td>Aerosonde</td>
<td>1-4 hrs.</td>
<td>46-51</td>
<td>4k AGL</td>
</tr>
<tr>
<td><strong>Border Patrol</strong></td>
<td>Predator-B</td>
<td>2-7 hrs.</td>
<td>129-173</td>
<td>4k – 15k AGL</td>
</tr>
</tbody>
</table>

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Large Database of Historical Flight Tracks

- 3-months database of historical radar data courtesy of RADES (84\textsuperscript{th} Radar Evaluation Squadron)
  - Data contain the radar hits collected from hundreds of radar sites in U.S
  - Developed methodology for associating distinct tracks and classify tracks as IFR or VFR (cooperative and non-cooperative)

Cooperative VFR Traffic – July 25, 2013
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Detect and Avoid Models
Surveillance

- Automated Dependent Surveillance – Broadcast (ADS-B)
- Mode S/C Transponder
- Airborne Radar

Uncertainties

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# Alerting

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Alert Time</th>
<th>Separation</th>
<th>Pilot Action</th>
</tr>
</thead>
</table>
| ![DAA Alert](image) | DAA Warning Alert     | 25 seconds  | Horz: 0.75 nmi Vert: 450 feet Tau: 35 sec          | • **Immediate action required**  
• Notify ATC as soon as practicable after taking action |
| ![DAA Alert](image) | Corrective DAA Alert  | 55 seconds  | Horz: 0.75 nmi Vert: 450 feet Tau: 35 sec          | • On current course, **corrective action required**  
• Coordinate with ATC to determine an appropriate maneuver |
| ![DAA Alert](image) | Preventive DAA Alert  | 55 seconds  | Horz: 1.0 nmi Vert: 700 feet Tau: 35 sec           | • On current course, corrective action **should not be required**  
• Monitor for intruder course changes  
• Talk with ATC if desired |

1. Alert time is approximately the timeliness prior to predicted loss of well clear an alert is displayed to pilot
2. Separation values are similar well clear separation definition, however small buffers do (can) exist

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Detect and Avoid Maneuver Guidance
Vector Planner

Pilot searches different altitude options that would resolve the problem

Pilot searches different heading directions that would resolve the problem

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Autoresolver

• Pilot is given maneuver recommendation

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OmniBands

- Pilot receives ranges of heading and altitude maneuvers in which would maintain well clear against alerted traffic (green bands), and which would not (yellow bands)
- OmniBands display is our current baseline for guidance/display requirements

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How All Research Capabilities Tie Together

New UAS-related modeling and simulation capabilities

UAS-NAS integration concepts

Human-in-the-Loop and Flight Test Evaluation

NAS-wide Simulation

Traffic displays, DAA algorithms, ATC, Ground Control Station

ACES: Flight plan and NAS-agent modeling system

17 UAS types

19 UAS mission profiles

UAS models, comm. link models

DAA algorithms

DAA sensor models

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Results
Surveillance Requirements
(ACES Simulation)

• Research Objective:
  – Analyze the performance of updated sensor (ADS-B, TCAS, and radar) range and fields of regard requirements and sensitivities against Draft MOPS Alerting requirements
  – Assess airborne radar intruder detection frequency against realistic NAS traffic (IFR, cooperative VFR, and non-cooperative VFR) to inform radar tracker requirements

• Results, Conclusions, and Recommendations
  – 5-nm range appears to cover 99% of potential warning alerts DAA system would encounter with non-cooperative VFR providing verification that 5-nm declaration range for airborne radar is suitable
  – When UAS had at least one non-cooperative VFR intruder in its field of regard, there were 3 or fewer non-cooperative aircraft 98% of the time
Integrated Human-in-the-loop Experiment (Test 1)

• Research Objective:
  – Evaluate air traffic controller acceptability of UAS maneuvers in response to detect and avoid advisories and pilot performance for remaining Well Clear

• Results, Conclusions, and Recommendations:
  – Controllers reported maneuvers requested between 60 and 90 seconds until closest point of approach were acceptable, and at 120 seconds were unacceptable.
  – Size of requested maneuvers was frequently judge to be too large, indicating a difference between the separation standard used by UAS pilots to remain Well Clear and manned aircraft.
• Research Objective:
  – Evaluate the pilot’s ability to remain well clear as a function of detect-and-avoid display features and whether the display was stand-alone or integrated within the main traffic display

• Results, Conclusions, and Recommendations:
  – Of all advanced maneuver guidance tested, maneuver recommendations (Autoresolver) were the most effective in aiding the pilots to remain well clear
  – Although non-cooperative aircraft can only be detected at a limited range, most losses of Well Clear can be prevented given alert time of at least 60 seconds to closet point of approach
• Research Objective:
  – Gather data to support development of alerting logic, methods, and performance requirements using cooperative and non-cooperative VFR traffic and the SC-228 definition of Well Clear considering target level of safety and NAS-interoperability

• Interim Results, Conclusions, and Recommendations:
  – DAA Warning Alerts that actually result in a loss of well clear have at least 15 seconds of lead time to LOWC in 83% of cases
  – 72% of DAA Warning alerts resulted in a loss of well clear suggest alerting criteria is within suitable performance bounds
  – Even though a large proportion of false alerts were observed, most of the encounter fall near the well clear boundary, thus trading these false alerts for minimizing missed alerts seemed acceptable
  – Also, given the low frequency of DAA alerts (about 1 every 10 flight hours), these large false alert proportions are minimal

Self-Separation Alerting Requirements for DAA MOPS
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Upcoming: Flight Test 4

Objectives:

1. Validate DAA requirements in stressing cases that drive MOPS requirements
   – High-speed intruder ( > 500 knots )
   – Low-speed intruder ( ~ 100 knots )
2. Validate collision avoidance/DAA alerting and guidance interoperability concept in the presence of realistic sensor, tracking and navigational errors
3. Validate well clear recovery guidance when well clear is lost in the presence of realistic sensor, tracking and navigation errors
4. Validate DAA alerting and guidance requirements under normal circumstances in the presence of realistic sensor, tracking and navigational errors

Key verification and validation activity for RTCA SC-228

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Questions?

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