UAS Pilot Evaluations of Suggestive Guidance on Detect-and-Avoid Displays

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Introduction

• UAS in the NAS Project Objectives
  – Address technical and safety barriers to the expansion and integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS)
    • Currently limited to public purposes (e.g., military training) in restricted airspace
  – Produce research findings that guide the development of RTCA Special Committee 228’s Minimum Operational Performance Standards (MOPS) for UAS
    • Identify minimum DAA display, alerting, & maneuver guidance that result in acceptable pilot performance and response times

• Detect and Avoid (DAA)
  – Existing regulations for manned flight operations require onboard pilots to “see and avoid” other aircraft in order to remain well clear (14CFR, Sec 91.113)
  – Unmanned operations will require a traffic display equipped with a “detect and avoid” system that provides the information necessary for self-separation
    • Effectively substituting for a manned pilots’ ability to see outside of their aircraft under normal operating conditions
Background

- Past studies have explored the minimum visual information requirements necessary to perform UAS pilot-in-the-loop DAA tasks
  - Predictive displays with integrated maneuver guidance tools for conflict avoidance have improved pilot performance compared to displays with less information
    - Less near midair collisions (NMACs) (Friedman-Berg et al., 2014)
    - Reduced severity of well clear violations (Bell et al., 2012; Santiago & Mueller, 2015)
    - Quicker response times (Rorie & Fern, 2015; Rorie et al., 2016)
    - Higher pilot preference ratings (Monk et al., 2015)
  - Advanced guidance tools were tightly coupled to the vehicle control interface
    - Auto-populated maneuver resolution directly into steering window
Purpose

• Examine pilot evaluations of four DAA displays with varied levels of suggestive guidance to further determine minimum information requirements for UAS ground control stations
  • Suggestive guidance tools decoupled from command-and-control interface
    – Presented range of solutions as opposed to a directive command

• *Are the pilots’ perceptions of the DAA system consistent with their objective performance?* (Rorie et al., 2016)
Method

• Participants
  – 16 active duty UAS pilots
    • $\mu_{age} = 37$ years old
    • Unmanned flight experience
      – Civil: 30 hours avg.
      – Military: 1100 hours avg.
    • Manned flight experience
      – Civil: 575 hours avg.
      – Military: 1760 hours avg.

• Simulation Environment
  – Vigilant Spirit Control Station (VSCS)
    • Developed by Air Force Research Laboratory (Feitshans et al., 2008)
    • Primary field of view was Tactical Situation Display (TSD):
      – Command-and-control interface
      – DAA guidance & traffic
      – Mission route
Experimental Design

- **DAA Display Configuration**
  - Minimum Information Only (Info Only)
  - No-Fly Bands
  - Omni Bands
  - Vector Planner

- **Minimum set of traffic information was constant across all displays**
  - Intruder Location & Direction
  - Relative Altitude
  - Vertical Trend Arrow
  - Call Sign (within data tag)
  - Ground Speed (within data tag)
  - Multi-Level Conflict Alerting Structure
# DAA System: Multi-Level Alerting Structure

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>Time to Loss of Well Clear</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
</table>
| ![DAA Warning Alert] | **DAA Warning Alert** | • **Immediate action required**  
• Notify ATC as soon as practicable after taking action | 25 sec  
(TCPA approximate: 60 sec) | “Traffic, Maneuver Now” |
| ![Corrective DAA Alert] | **Corrective DAA Alert** | • On current course, **corrective action required**  
• Coordinate with ATC to determine an appropriate maneuver | 75 sec  
(TCPA approximate: 110 sec) | “Traffic, Separate” |
| ![Preventive DAA Alert] | **Preventive DAA Alert** | • On current course, corrective action **should not be required**  
• Monitor for intruder course changes  
• Talk with ATC if desired | N/A | “Traffic, Monitor” |
| ![DAA Proximate Alert] | **DAA Proximate Alert** | • Monitor target for potential increase in threat level | N/A | N/A |
| ![None (Target)] | **None (Target)** | • No action expected | X | N/A |
Display Configurations

1. **Info Only**
   - Standard intruder information and multi-level alerting presented (no guidance)
     - Intruder Location & Direction
     - Relative Altitude
     - Vertical Trend Arrow
     - Call Sign (within data tag)
     - Ground Speed (within data tag)
     - Threat Level

![Display Configuration](image)
Display Configurations

2. No-Fly Bands
   - Indicated headings/vertical speeds that would lead to an eventual loss of well clear
     • Maneuver outside of banding to maintain well clear

[Images of Heading Bands and Vertical Speed Band]
3. Omni Bands
   - Constantly displayed predicted threat level at nearby headings/altitudes
     • Green = regions that would maintain well clear
     • Yellow = regions that would trigger at least one Corrective alert
     • Red = regions that would trigger at least one Warning alert
4. Vector Planner

– Allowed pilots to test a single heading/altitude option for predicted threat level
  • Green = option would maintain well clear
  • Solid Yellow = option would trigger at least one Corrective alert
  • Solid Red = option would trigger at least one DAA Warning

– Tool was off by default
  • Engaged by dragging vector arrow or clicking option on altitude tape
  • 5 second time-out
Method: Procedure

- DAA Pilot Task
  - Operate simulated MQ-9 through Class E airspace under Instrument Flight Rules
    - Maintain well clear with other aircraft
    - Four 37-minute scenarios
      - Two pre-filed flight plans
      - 9 scripted encounters with ownship
        » 6 encounters would lead to loss of well clear without pilot action
    - Background traffic emulated busy day at Oakland Center (DOA 40/41)
      - Controlled by ‘pseudopilots’ via Multi-Aircraft Control Station (MACS; Prevot, 2002)
      - Sector managed by confederate ATC
  - Attend to secondary tasks
    - Chat messages requesting health/status information (e.g. fuel remaining)
    - Electronic checklists for system failure events
Measures

• Pilots completed post-trial and post-simulation questionnaires with subjective ratings pertaining to the preceding display configuration
  – Responses were analyzed using a one-way repeated measures Analysis of Variance (ANOVA)

• Post Trial Questionnaire
  – Workload (NASA TLX)
  – Conflict Assessment and Avoidance
  – Ease of Use

• Post-Simulation Questionnaire
  – Information Sufficiency
  – Display Preference

\( \alpha = 0.05 \)
Results: Post-Trial

- **Conflict Assessment**
  - ‘This display provided the information necessary to predict a potential loss of well clear’
  - Omni Bands received higher assessment ratings compared to the Info Only and Vector Planner displays, $p < .001$
  - No-Fly Bands received higher assessment ratings compared to the Info Only display, $p < .05$
Results: Post-Trial

- Conflict Avoidance
  - ‘This display provided the information necessary to perform avoidance maneuvers for well clear maintenance’
  - Conflict avoidance ratings were greater for the No-Fly and Omni Bands displays compared to the Info Only and Vector Planner displays, $p < .001$
Results: Post-Trial

• Ease of Use
  – ‘This display was easy to use’
  • Pilots rated the Omni Bands display as easier to use than the Info Only, No-Fly Bands, and Vector Planner displays, $p = .001$
    – Info Only display was rated easier to use than Vector Planner, $p < .05$
• Omni Bands resulted in significantly lower workload ratings than the Vector Planner for 5 of the 6 scales:
  – Mental, Temporal, Effort, Frustration, & Performance Degradation
  • Only Physical Demands failed to result in a significant difference
Results: Post-Sim

• Display Preference
  – ‘Rank the displays in order of their effects on your ability to maintain well clear’
    • Banding displays were most favored overall
      – 88% of pilots voted **Omni Bands** as the most beneficial
      – No-Fly Bands ranked second by 63% of pilots
    • Vector Planner received the lowest average ranking (ranked last by 50% of pilots)
    • Only one pilot rated Info Only display as top-2 preferred

  – ‘How did the three suggestive guidance displays affect your ability to maintain well clear compared to Info Only?’

![Bar chart showing the impact of different display configurations. No-Fly Bands have the highest average rating at 3.81, followed by Omni Bands at 4.81, and Vector Planner at 2.56.]

<table>
<thead>
<tr>
<th>Display Configuration</th>
<th>Significantly Better</th>
<th>About the Same</th>
<th>Significantly Worse</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-Fly Bands</td>
<td>3.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omni Bands</td>
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<tr>
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Discussion

- Subjective ratings revealed that suggestive maneuver guidance in the form of banding is highly favored by UAS pilots
  - Information on all displays were rated as sufficient to DAA task performance overall
  - Banding displays rated most conducive to conflict detection and resolution
    - Provided guidance that was constantly visible to pilots
    - Omni Bands ranked most preferred and easiest to use
      - Indicated severity of potential threat(s)
      - Provided specific altitude values to achieve
    - Reduced cognitive workload compared to Vector Planner and Info Only
      - Vector Planner required manual activation that lasted just five seconds
        » “Added an undesirable lag in decision-making”
        » Only display rated difficult to use
  - Consistent with objective performance (Rorie et al., 2016)
    - Quicker response times and less well clear violations with the banding displays
Conclusion

- Suggestive maneuver guidance in the form of banding is advantageous to pilot acceptability, response time, and performance

- DAA display considerations
  - Suggestive guidance that is not readily available may fare worse for task performance compared to no guidance at all if not implemented well
    - Trial planning tools previously rated more favorably when coupled with navigation interface in past research (Monk et al., 2015)
  - Further research needed to determine minimum information requirements
    - All displays rated as sufficient despite differences in subjective/objective performance
    - Interoperability with existing collision avoidance systems
    - Variations in aircraft performance, airspace environment, navigation interface, etc.
The End

Questions?
Display Conditions (VIDEO BACKUP)
Results: Post-Trial (Backup?)

- **Task Performance**
  - ‘*Rate your ability to handle all pilot responsibilities*’
  - Pilots indicated greater ability to handle DAA tasks in the No-Fly and Omni Bands displays compared to Info Only and Vector Planner, \( p = .001 \)