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](image) | 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](image) | 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](image) | 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](image) | DAA Proximate Alert | • Monitor target for potential increase in threat level | N/A | N/A |
| ![None (Target)](image) | 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
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
Display Configurations

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, $p < .05$
Post-Trial: Workload

• 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

![Mental Workload Ratings](image)
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?**’

The bar chart shows the comparison of display configurations:

- **No-Fly Bands**
  - Significantly Better: 3.81
  - About the same: 4.81
  - Significantly Worse: 2.56
- **Omni Bands**
  - Significantly Better: 4.81
  - About the same: 4.81
  - Significantly Worse: 2.56
- **Vector Planner**
  - Significantly Better: 3.81
  - About the same: 4.81
  - Significantly Worse: 2.56
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.
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, $p = .001$