UAS Integration in the NAS Project

An Evaluation of Detect and Avoid Displays for UAS: The Effect of Information Level and Display Location on Pilot Performance

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Introduction

• UAS in the NAS Project
  – Developed to help address technical barriers to integration of unmanned aircraft systems (UAS) into the national airspace system (NAS)
    • Findings help guide development of RTCA Special Committee 228’s Minimum Operational Performance Standards (MOPS) for UAS
  – An outstanding technical barrier is providing UAS pilots with a means to “detect and avoid” other aircraft
    • Means of compliance with 14CFR, Section 91.113 - pilots must remain well clear from other aircraft through “see and avoid”

• Detect and Avoid (DAA) System
  – A collection of technologies - consisting of both hardware & software – that can provide pilots with the necessary information to self-separate from other aircraft
  – A traffic display would serve as substitute for manned pilots’ ability to see outside their aircraft
  – Critical question: what are the display requirements for such a system?
DAA Display Research

Several part-task studies have looked UAS traffic display:

- Friedman-Berg et al. (2014) & Draper et al. (2014) focused on identifying the minimum information requirements.
  - Results were largely in agreement, most significant difference being the inclusion of maneuver recommendations (display guidance) in Draper et al.

- Bell (2012) found that “advanced” displays – i.e., those that provided a level of display guidance – led to less severe separation violations than displays without guidance.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Aircraft ID</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Intruder Position &amp; Direction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Range</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Bearing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Altitude</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Alert Level/Threat Status</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vertical &amp; Horizontal Trend</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>Display Guidance</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
• Current Study:
  – Continues examination of DAA display requirements within a “full mission” task environment
    • Tests different information levels (no guidance vs. guidance) and location of the traffic information
      – Standalone (i.e., bootstrap) displays may be easier to develop, but may hinder performance relative to displays integrated into command and control interface
    • Focus on the displays’ impact on pilots’ measured response (MR)
  – MR can be understood as the quantification of the end-to-end response time for a UAS pilot to complete a self separation maneuver in response to a DAA display alert
    • Measured response metrics can reveal the amount of time pilots spent interacting with different displays, allowing direct comparisons
    • Longer MR times may result in delayed maneuvering, which can in turn increase likelihood of a separation violation
    • MR times can also inform human response models that are used in fast-time simulation and the alerting threshold parameters used by the alerting logic
Method

• Participants
  – 12 active UAS pilots (M = 39 years of age)
    • All had military UAS experience (avg. 216 hrs)
    • 8/12 had civil UAS experience (avg. 60 hrs)

• Simulation Environment
  – Ground Control Station
    • Vigilant Spirit Control Station (VSCS; right)
      – Provided command and control interfaces, aircraft information, and a simulated out-the-window view, across 3 monitors
      – Displayed traffic information in select conditions
      – Mouse and keyboard inputs only
    • Cockpit Situation Display (CSD; right)
      – Standalone CDTI only active in select conditions
      – One monitor, directly to left of VSCS monitors
Method

• 2 x 2 Repeated Measures Experimental Design
  – Information Level:
    • Basic Information
      – Standard intruder information (as set by Friedman-Berg et al., 2014)
        » No display guidance
      – Multi-level alerting
    • Advanced Information
      – Standard intruder information
      – Multi-level alerting
        » Included additional level
      – Suite of guidance tools
        » Trial planning tools
        » Recommended Maneuvers
  – Display Location:
    • Standalone Display
      – Information presented within CSD
      – Pilots still used VSCS to input changes to aircraft
    • Integrated Display
      – Information presented within VSCS command and control interface
Method

- **Multi-Level Alerting**
  - Visual and auditory alerts tied to predicted threat level of nearby traffic
  - Based on predicted closest point of approach (CPA) between ownship and intruder
    - Horizontal miss distance (HMD), vertical miss distance (ZTHR), and time to CPA criteria all had to be satisfied to be assigned given threat level
  - Pilots instructed to maneuver *prior* to collision avoidance alert being generated, which was their indication that separation had been lost

<table>
<thead>
<tr>
<th>Alert/Threat Level</th>
<th>HMD</th>
<th>ZTHR</th>
<th>Time to CPA</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal</td>
<td>&gt; 2 NM</td>
<td>&gt; 900 FT</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Preventive</td>
<td>&lt; 2 NM</td>
<td>&lt; 900 FT</td>
<td>&lt; 120 secs</td>
<td></td>
</tr>
<tr>
<td>Self Separation</td>
<td>&lt; 1.2 NM</td>
<td>&lt; 900 FT</td>
<td>&lt; 110 secs</td>
<td></td>
</tr>
<tr>
<td>Predicted CA Alert*</td>
<td>&lt; 0.8 NM</td>
<td>&lt; 400 FT</td>
<td>&lt; 110 secs</td>
<td></td>
</tr>
<tr>
<td>Collision Avoidance</td>
<td>&lt; 0.8 NM</td>
<td>&lt; 400 FT</td>
<td>&lt; 40 secs</td>
<td></td>
</tr>
</tbody>
</table>

*Only present in the Advanced Information display conditions*
Method

1. Basic Standalone Display
   - Standard intruder information and multi-level alerting presented within CSD
     - No display guidance provided
     - VSCS served as command-and-control interface
Method

2. Basic Integrated Display
   - Standard intruder information and multi-level alerting presented within VSCS
     - No display guidance provided
     - Traffic info collocated with vehicle control interfaces
Method

3. Advanced Standalone Display
   - Display guidance included, in addition to standard info and alerting:
     - Trial planning tools allowed pilots to test different heading/altitude maneuvers before uploading
     - Maneuver recommendations offered suggested solutions
4. **Advanced Integrated Display**

- Display guidance included, in addition to standard info and alerting
  - Trial planning tools allowed pilots to test different heading/altitude maneuvers before uploading
  - Maneuver recommendations offered suggested solutions
Method

• Pilot Task
  – Operate simulated MQ-9 Reaper within civil airspace, under Instrument Flight Rules
    • Routes contained entirely within Class E, Oakland Center airspace
      – Instructed to coordinate maneuvers with ATC (over push-to-talk headset)
    • Missions lasted 40 minutes
  – Maintain well clear from nearby aircraft
    • 8 scripted encounters with the ownship (i.e., would lose separation absent of pilot intervention)
    • Additional tracks were included to emulate busy day at Oakland Center
  – Attend to secondary tasks
    • Respond to requests for status information (e.g., current fuel level)
    • Complete electronic checklists in response to system malfunctions
Method

- Confederate Participants
  - Retired ATC managed all aircraft within experimental airspace
  - “Pseudo” pilots controlled simulated manned aircraft within airspace
- A researcher coordinated in real-time to ensure conflicts were generated
Method

• Measured Response Metrics
  – A pilot-DAA interaction timeline was constructed, with emphasis on the pilots’ interaction with ATC and the GCS (below)
    • The timestamps for each stage of the timeline were collected from a variety of sources:
      – GCS output files, DAA algorithm output files, voice recordings and logs, and video recordings

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_0$</td>
<td>DAA (self separation or collision avoidance) alert appears on the display</td>
</tr>
<tr>
<td>$T_1$</td>
<td>Pilot notifies ATC and requests a maneuver clearance</td>
</tr>
<tr>
<td>$T_2$</td>
<td>ATC provides maneuver clearance</td>
</tr>
<tr>
<td>$T_3$</td>
<td>Pilot initiates an edit in GCS to maneuver</td>
</tr>
<tr>
<td>$T_{4a}$</td>
<td>Pilot uploads 1st maneuver to aircraft</td>
</tr>
<tr>
<td>$T_{4b}$</td>
<td>Pilot uploads final maneuver to aircraft</td>
</tr>
</tbody>
</table>
Method

• Measured Response Metrics
  – From these timestamps, five metrics were extrapolated:
    • *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    • *Initial Response Time* ($T_3 - T_0$) – how long it took the pilot to initiate an edit in the GCS
    • *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      – *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    • *Notification Time* ($T_1 - T_0$) – how long it took the pilot to notify ATC following an alert
Results

• Measured Response Metrics
  – From these timestamps, five metrics were extrapolated:
    • Total Response Time ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    • Initial Response Time ($T_{3} - T_0$) – how long it took the pilot to initiate an edit in the GCS
    • Total Edit Time ($T_{4b} - T_{3}$) – how long it took the pilot to implement appropriate maneuver
      – Initial Edit Time ($T_{4a} - T_{3}$) – how long it took the pilot to implement an initial maneuver
    • Notification Time ($T_{1} - T_0$) – how long it took the pilot to notify ATC following an alert
Results

• Total Response Time
  – Significant main effect of Information Level on Total Response Times ($p < .05$)
    • Pilots took an average of 37.87s to complete their final edit in response to SS/CA alerts (from first alert appearance)
      – Pilots 8s faster (19%) on average in Advanced than Basic conditions
    – No other significant main effects or interaction
Results

• Measured Response Metrics
  – From these timestamps, five metrics were extrapolated:
    • *Total Response Time* \((T_{4b} - T_0)\) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    • *Initial Response Time* \((T_3 - T_0)\) – how long it took the pilot to initiate an edit in the GCS
    • *Total Edit Time* \((T_{4b} - T_3)\) – how long it took the pilot to implement appropriate maneuver
      – *Initial Edit Time* \((T_{4a} - T_3)\) – how long it took the pilot to implement an initial maneuver
    • *Notification Time* \((T_1 - T_0)\) – how long it took the pilot to notify ATC following an alert
Results

- **Initial Response Time**
  - Near significant effect of Display Location on Initial Response Times ($p = .054$)
    - Pilots took an average of **19.32s** to initiate an edit in response to a SS/CA alert
      - Pilots 5s faster (23%) in Standalone display conditions
    - No other significant main effects or interaction
Results

- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - Total Response Time ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - Initial Response Time ($T_3 - T_0$) – how long it took the pilot to initiate an edit in the GCS
    - Total Edit Time ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - Initial Edit Time ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - Notification Time ($T_1 - T_0$) – how long it took the pilot to notify ATC following an alert
Results

• Total Edit Time
  – Significant main effect of Information Level on Total Edit Times ($p < .01$)
    • Pilots took an average of 17.65s to complete their final edit in response to SS/CA alerts
      – Pilots 9s faster (40%) in Advanced display conditions
    – No other significant main effects or interaction
Results

• Measured Response Metrics
  – From these timestamps, five metrics were extrapolated:
    • Total Response Time \((T_{4b} - T_0)\) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    • Initial Response Time \((T_3 - T_0)\) – how long it took the pilot to initiate an edit in the GCS
    • Total Edit Time \((T_{4b} - T_3)\) – how long it took the pilot to implement appropriate maneuver
      – Initial Edit Time \((T_{4a} - T_3)\) – how long it took the pilot to implement an initial maneuver
    • Notification Time \((T_1 - T_0)\) – how long it took the pilot to notify ATC following an alert
Results

• Initial Edit Time
  – Significant interaction between Information Level and Display Location on Initial Edit Times ($p < .01$)
    • Pilots took an average of 11.77s to complete their first edit in response to SS/CA alerts
      – Difference between Basic and Advanced displays in Integrated conditions was 12s (68%), while only 2.5s (12%) in Standalone conditions
    – Information Level had a significant main effect ($p < .05$), 6.5s faster in Advanced
Results

• Measured Response Metrics
  – From these timestamps, five metrics were extrapolated:
    • *Total Response Time* \((T_{4b} - T_0)\) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    • *Initial Response Time* \((T_3 - T_0)\) – how long it took the pilot to initiate an edit in the GCS
    • *Total Edit Time* \((T_{4b} - T_3)\) – how long it took the pilot to implement appropriate maneuver
      – *Initial Edit Time* \((T_{4a} - T_3)\) – how long it took the pilot to implement an initial maneuver
    • *Notification Time* \((T_1 - T_0)\) – how long it took the pilot to notify ATC following an alert
Results

• Notification Time
  – Near main effect of Information Level on Notification Times ($p = .059$)
    • Pilots took an average of 29.07 s to notify ATC of a maneuver in response to a SS/CA alert
      – Pilots 6 s faster (19%) in the Advanced information conditions
  – No other significant main effects or interaction
Results

• Summary
  – Advanced Information displays showed advantage in four of five reported metrics
    • Total Response Times 19% shorter in Advanced conditions
    • Total Edit Times 40% shorter in Advanced conditions
    • Initial Edit Times 70% shorter in Advanced Integrated condition than in the Basic Integrated condition
    • Notification Times 20% shorter in Advanced conditions
  – Overall benefit seen for lower Total Response Times was due to a reduction in *how long pilots spent interacting with the display*
    • Not how quickly they got ‘in-the-loop’ (Information Level did not impact Initial Response Times)
  – Display Location only approached significance in one of the metrics
    • Initial Response Times 23% shorter for Standalone display
Discussion

• Advanced Information
  – The presence of display guidance (in a variety of forms) reduced the amount of work required of the UAS pilot
    • The Advanced displays unambiguously alerted pilots of which self separation threats were predicted to lose well clear
    • The tools provided the pilot with a pre-determined maneuver, limiting the amount of time they had to spend calculating their own
  – Led to pilots contacting ATC more quickly
    • However it was clear that pilots often initiated edits prior to contacting ATC
      – Roughly 50% of maneuvers occurred without prior ATC approval

• Display Location
  – Did not have a significant impact on pilot performance
  – The lack of immediate pilot responses may have mitigated the lack of an effect of display location (Initial Response Times were on the order of 20s)
Conclusion

• The first in a collection of studies, this sim demonstrated that Information Level, namely the absence or presence of display guidance, can substantially impact pilots’ response times
  – Future studies have been conducted that look at different sorts of display guidance to see if certain implementations result in superior performance

• This data is supplemental to other objective metrics – mainly rates of separation violations and pilot feedback – but supports inclusion of display guidance
  – Santiago and Mueller (2015) – found 45% fewer losses of well clear when pilots were provided with display guidance
    • Faster pilot responses is one reason for the finding, among less ambiguous alerting and eliminating the need for the pilot to self-determine a maneuver
    • Quick pilot inputs were especially important in cases of ‘pop-up’ encounters, where there was a small amount of time before a loss of well clear would appear
  – Monk et al. (2015) – found pilots preferred the Advanced displays
    • Supported more immediate responses
    • While all displays were rated as sufficient, Advanced Integrated was rated as most preferable
Conclusion

• Limitations
  – Cannot necessarily generalize to other GCS
    • Different GCS have different vehicle control inputs
    • There was a high level of integration between the Advanced features and the GCS in the Advanced Integrated condition
      – It is possible to present display guidance with less integration, which may impact pilot performance
  – There were multiple feature changes between the Basic and Advanced conditions
    • Several tools were included, as were several advanced pieces of information, including a new alerting level
• 2 follow-on studies have been submitted to different conferences
  – Both look at different ways to provide display guidance in an integrated fashion
  – HITL data to be validated in flight test environment