Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Warning Alert HITL Experiment Results

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Human Systems Integration

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Experiment Objective

• Conduct a HITL simulation that further explores the distinct impact of the DAA Warning alert on pilots’ performance with maintaining DAA Well Clear (DWC)
  – Evaluate whether the DAA Warning symbol and/or aural improves pilots’ ability to remain well clear
    • Test manipulation that explicitly stresses DAA Warning alert utility with respect to the DAA task
      – Scripted conflicts with look ahead times closer to the warning threshold
    • Determine differential effects between integrated and standalone display configurations

• Performance is measured/quantified by response times and proportion of Loss of DWC (LoDWC)
Experimental Design

• Independent Variables:
  – DAA Warning alert option (between-subjects)
    • D1: No DAA Warning alert (caution-only)
    • D2: DAA Warning aural only
      – Retain Corrective DAA symbol
    • D3: DAA Warning alert (aural + symbol)
  – Display Configuration (within-subjects)
    • Integrated x Standalone

• Embedded Variable
  – Use Cases: Time-to-LoDWC at first alert (within-scenarios)
    • A: 15s
    • B: 25s
      – *Warning alert onset (D2/D3)
    • C: 35s
    • D: 45s
    • E: 55s
      – *Corrective alert onset
### Alerting Logic

<table>
<thead>
<tr>
<th><strong>D1: Caution Only</strong></th>
<th><strong>D2: Warning Aural</strong></th>
<th><strong>D3: Warning Aural + Symbol</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>Name</td>
<td>Aural Alert Verbiage</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Corrective DAA Caution Alert</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>*Preventive DAA Alert</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Guidance Traffic</td>
<td>N/A</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>None (Target)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Applied to cooperative intruders only*
Hypotheses

• Research Question
  – What are the differential effects of the DAA Warning symbology and aural on pilot performance?

• Expected Outcome
  ✓ Faster response times and better task performance in conditions with DAA Warning alert compared to no DAA Warning
    ✓ Performance improvements with higher amount of warning information
      ✓ D3 > D2 > D1
    ✓ Benefit of warning-level information most pronounced for encounters alerting near well clear threshold (≤25s to LoDWC)
  ✓ Display configuration not expected to impact task performance
    – Based on Part Task 6 results
• Differences most prevalent in Use Cases A & B (Warning First)
  – Pilots with warning-level information available are quicker to upload resolutions against severe threats
    • Mainly due to initial response

Aircraft Response Time

<table>
<thead>
<tr>
<th>Threat Level (Truth) at First Alert</th>
<th>Mean RT (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrective</td>
<td>D1: 13.93</td>
</tr>
<tr>
<td></td>
<td>D2: 11.88</td>
</tr>
<tr>
<td></td>
<td>D3: 12.85</td>
</tr>
<tr>
<td>Warning</td>
<td>D1: 12.50</td>
</tr>
<tr>
<td></td>
<td>D2: 8.95</td>
</tr>
<tr>
<td></td>
<td>D3: 7.79</td>
</tr>
</tbody>
</table>
Initial Response Time

- Differences most prevalent in Use Cases A & B (Warning First)
  - Pilots with warning-level information available are quicker to initiate edits against severe threats
- Reduced variability

![Initial RT Chart]

<table>
<thead>
<tr>
<th>Threat Level (Truth) at First Alert</th>
<th>Corrective</th>
<th>Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>6.86</td>
<td>5.86</td>
</tr>
<tr>
<td>D2</td>
<td>5.51</td>
<td>3.79</td>
</tr>
<tr>
<td>D3</td>
<td>7.27</td>
<td>2.89</td>
</tr>
</tbody>
</table>
Pilots presented with warning-level alerting were more likely to respond appropriately to severe threats within 25s-to-LoDWC
- Warning alerts cue immediate maneuvers
  - Benefit most pronounced with the inclusion of DAA Warning symbology (D3)
- 3 of 5 D1 pilots with Caution-Only alerting prioritized ATC coordination above maneuvers for every encounter regardless of intruder range

![Appropriate Pilot Action Diagram]

- Coordinate first
- Maneuver first
Global LoDWC

- LoDWC Proportion
  - D1 – 22%
  - D2 – 19%
  - D3 – 10%
  - 91% of total LoDWC occurred in Use Cases A/B
    - None outside of 35s in any condition

- Pilots were nearly twice as likely to remain DWC against the most severe threats with the DAA Warning Alert compared to Caution-only
  - Auditory Maneuver alert (D2) provided minimal benefit on its own
LoDWC Type

- **Pilot Responsible (53% of total)**
  - Inappropriate Coordination (43%)
    - Prioritized contacting ATC above immediate maneuver within 25s to Loss
    - Most common LoDWC cause
      - Rarely occurred in D3
  - Ineffective maneuver (8%)
    - Disregarded accurate conflict bands with sufficient time to achieve resolution
      - Most common with altitude changes
  - Slow Response (2%)
    - No true solution at time of upload
    - Only occurred in D1

- **System Responsible (47% of total)**
  - Late Acceleration (25%)
    - Slow Responses in Use Case A (15s)
      - Less than the time allotted for pilot & aircraft response in DAA timeline
    - Instantaneous turn assumption (22%)
      - Horizontal guidance bands influenced ineffective maneuver
        - Turn in opposite direction would have maintained DWC
        - Elevated threats at 25-35s ranges (B/C)
    - Increased Edit Times and LoDWC Duration
      - Did not anticipate LoDWC

<table>
<thead>
<tr>
<th></th>
<th>Coordination</th>
<th>Late Acceleration</th>
<th>Turn Guidance</th>
<th>Bad maneuver</th>
<th>Slow Response</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D1</strong></td>
<td>38</td>
<td>6</td>
<td>12</td>
<td>2</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td><strong>D2</strong></td>
<td>17</td>
<td>17</td>
<td>8</td>
<td>8*</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td><strong>D3</strong></td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td><strong>ALL</strong></td>
<td><strong>59</strong></td>
<td><strong>33</strong></td>
<td><strong>30</strong></td>
<td><strong>12</strong></td>
<td><strong>2</strong></td>
<td><strong>136</strong></td>
</tr>
</tbody>
</table>

*Outliers
Instantaneous Turn Guidance Implications

- Necessary to preserve data points in Use Case A
  - Delayed onset of WCR allowed for full alert progression

- Influenced heading changes that made situation worse
  - Triggered DWC violations 5 seconds earlier than initially predicted
  - Accounted for 51% of LoDWC in Use Case B (22 of 43)
  - Accounted for 73% of LoDWC in Use Case C (8 of 11)
  - Increased LoDWC duration & number of uploads compared to other LoDWC categories

- Potential misunderstanding of recovery guidance concept
  - Inconsistent display behavior
  - High subjective confidence did not match objective performance
  - Rare WCR Compliance
    - “I was safe... I already flew into the green bands”

**Diagram:**

- LoDWC Type (Use Cases B/C)
- LoDWC Proportion (Excluding Guidance Fault)
Display Location

• No impact on objective performance
  – Response times and LoDWC durations nearly identical
  – LoDWC Proportion:
    • Integrated - 22%
    • Standalone – 18%

• Integrated Display preferred by 13 of 15 pilots (87%)

• Majority of pilots matched their map orientations in Standalone configuration
Warning Alerting Implications

• Warning-level information improves pilot performance against severe threats within 25 seconds to LoDWC
  – Faster response times
    • Prioritized actions appropriately with indication of increased severity
      – ATC notification attempts = most common cause of LoDWC
  – Performance remains stable at farther ranges
    • Only 1 pilot-responsible LoDWC per display (all in Use Case C)

• Warning alerting is most conducive to DWC maintenance when auditory cue is coupled with a change in symbology
  – Least pilot-responsible LoDWCs with Phase 1 MOPS DAA Warning alert
  – ‘Maneuver Now’ aural alone did not improve separation performance compared to Caution-Only
    • Potential to miss the aural change while already coordinating with ATC
      – Most likely when intruder alerts at ~35s to LoDWC
    • “Aurals start with the same word; not as attention-grabbing without distinct changes in symbology”
    • “Harder to distinguish between Preventive and Corrective without no Warning symbol; trained that Red means severe”
THE END

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BACKUP
Phase 1 DAA alerting structure provides crucial information about when a resolution maneuver is required to avoid loss of DAA well clear

- Corrective Alert
  - Caution-level: immediate awareness is required; coordinate response, followed by subsequent maneuver
- Warning Alert
  - Warning-level: immediate maneuver is required and prioritized above contacting ATC
- Advisory Circular 25.1322-1

A series of human-in-the-loop (HITL) simulations have revealed performance benefits associated with the DAA Warning alert

- Faster response times
- Fewer losses of well clear
- Fewer ATC coordination attempts near well clear threshold, and better coordination overall
There is still a degree of uncertainty with regard to the effectiveness of DAA Warning

- No studies have directly assessed the utility of the warning-level alert as part of the DAA alerting structure

Even as recently as Phase 1 DAA FRAC, there has been question as to whether a warning-level alert is needed in addition to the caution-level alerts

- There’s a preference to reserve warning-level alerts for Collision Avoidance
15 participants
  – 5 per Alerting condition
  – Manned aviation pilots

DAA Pilot Task
  – Fly simulated MQ-9 reaper along mission route (ZOA 40/41)
    • Remain Well Clear from intruder aircraft
      – Minimal deviation from mission route/altitude
    • Coordinate with ATC (when necessary)
      – Prioritize maneuver over contacting ATC after the onset of a DAA Warning alert
      – Researcher acting as surrogate ATC from sim manager room
  – Attend to secondary tasks
    • Chat messages requesting status information
Pilot-Responsible LoDWC

- LoDWC Proportion
  - D1 – 22% → 15%
  - D2 – 19% → 9%
  - D3 – 10% → 2%
“Did you refer to the altitude bands often?”

- Most replied “Yes”, including the D2 pilots that frequently climbed into yellow bands
- Referenced them, but did not find them all that useful
  - Outside of traffic scan pattern
  - Impossible to avoid LoDWC with vertical resolutions in Use Case A/B due to aircraft performance
    - Only possible in Use Case C if uploaded within 7 seconds, but that time is spent contacting ATC
• Volpe (1991)
  – Pilots took an average of 5.28s to complete responses to ATC clearances
• Warning Alert HITL
  – ATC Coordination added 5.24s to Aircraft RTs, on average:

![Graph showing Aircraft RT x Coordination](image)
• Two traffic scenarios
  – 45 minutes each
  – 15 encounters scripted to lose DAA well clear
    • 3 per use case
      – Vary by Time-to-LoDWC

• Ownship configuration
  – Call sign: HAWK21
  – Surveillance: ADS-B In, RADAR
  – Flight Model: MQ-9 Reaper
    • Mission altitude: 12,000 MSL
    • Cruise speed: 160 kts
    • Climb/descent rate: 1000 ft/min
• Q1 This display was easy to use:
  – ($p = 0.01$) Integrated = 4.67, Standalone = 3.73
• Q2 This display was easy to understand:
  – ($p = 0.072$) Integrated = 4.73, Standalone = 4.20
• Q3 The location of the DAA & Traffic information within the
  GCS supported my ability to maintain separation:
  – ($p = 0.065$) Integrated = 4.73, Standalone = 4.07
• Q6 The display provided the necessary information to perform
  a maneuver to a loss of Well Clear:
  – ($p = 0.065$) Integrated = 4.73 Standalone = 4.07
• Q7 The display supported my ability to respond immediately to
  DAA alerts:
  – ($p = 0.017$) Integrated = 4.67 Standalone = 3.87
• Q8 I trusted the accuracy of the information provided by the
  display
  – ($p = 0.041$) Integrated = 4.8 Standalone = 4.27
• NASA TLX 1-7 likert-like scale
• Mental, $p = .027$
  – Mean score for Mental for integrated = 2.93, Standalone = 3.9
• Effort, $p = .008$
  – Mean score for Effort for Integrated = 2.13, Standalone = 3.07
Workload by Display Location

NASA TLX

<table>
<thead>
<tr>
<th>Category</th>
<th>Integrated</th>
<th>Standalone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental</td>
<td>2.9</td>
<td>3.6</td>
</tr>
<tr>
<td>Physical</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Temporal</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Effort</td>
<td>2.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Frustration</td>
<td>1.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Performance Degradation</td>
<td>1.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>
• Very similar answers across the board (no sig differences)

• Pilot preference:
  – Of the 2 configurations (Integrated and Standalone) which did you prefer?
    • 13 – Integrated, 2 – Standalone
  – The difference between preventive DAA Alerts and Corrective DAA alerts was always clear
    • All pilots rated this somewhat to strongly agree
    • 9 - strongly agree, 6 - somewhat agree
• Effort, (p = .03)
  – Mean score D1 = 1.9, D2 = 2.5, D3 = 3.4
Integrated Display Configuration

TSD w/ DAA Display
- Traffic Alerting & Guidance
- Range Rings
- Mission Route
- Navigation

Side Panel
- Electronic Checklist
- Status panel
- Chat client
Standalone Display Configuration

DAA Display
- Traffic Alerting & Guidance
- Range rings

TSD
- Mission Route
- Navigation

Side Panel
- Electronic Checklist
- Status panel
- Chat client
Resident Staff

- Lead Researcher / Sim Manager
  - Kevin J. Monk

- Supporting Researchers
  - Zach Roberts
  - Conrad Rorie

- Software Engineer
  - Dominic Wong

- Interns
  - Ricky Russell
  - Kyle Wilson
  - Armando Alvarez
  - Allen Chen
  - Anar Salayev

- Responsible Tech Lead
  - Lisa Fern