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

Low Size, Weight and Power (SWaP) HITL 2
SC-228 Outbrief
EO/IR & ATAR Breakout
In support of Low SWaP MOPS, HSI conducted two human-in-the-loop (HITL) simulations that were designed to:

- Identify DAA display, alerting and guidance requirements necessary for UAS equipped with low size, weight & power (SWaP) sensors
- Serve as a validation of the fast-time simulation work performed by the Modeling and Sim (M&S) team
- Establish a baseline for the Flight Test 6 Full Mission configuration flights
  - The scenario design & encounters used in these HITLs were replicated in FT6

Low SWaP 1 (Nov 2018) examined pilot & DAA system performance with two candidate non-cooperative DAA well clear (DWC) definitions as informed by M&S fast-time sims

- SC-228 selected DWC2 as the new non-cooperative DWC definition
  - DWC2 = 2200ft horizontal & 450ft vertical (no modTau)
- It was determined that a study was needed to look at smaller surveillance ranges with DWC2
• Low SWaP 2 assessed pilot & DAA system performance with four different RADAR declaration ranges (RDR)
  – Shorter than 3.5 NM modeled in Low SWaP HITL 1
  – Fast-time Sim 2 results demonstrated that DWC2 alerting time remains relatively constant until the range drops below 2nm

**Research Question:** How does Low SWaP radar detection range impact pilot performance?
  – Will the ‘knee in the curve’ for response times & rates losses of DWC be at 2nm?
Independent Variables

- Low SWaP RADAR Declaration Range (within-subjects)
  - 3.0nm
  - 2.5nm
  - 2.0nm
  - 1.5nm

- Ownship speed (between-subjects)
  - Slow (60ktas)
  - Fast (100ktas)

Embedded Variable (within-trial)

- Conflict type
  - Equipage
    - 1 cooperative & 4 non-cooperative encounters
  - Closure rate
    - Intruder speed (100 vs 170 kts)
    - Approach angle (head-on vs crossing)
Primary Metrics

• Dependent Variables
  – Proportion & Severity of Losses of DWC (LoDWC)
  – Response Times (RTs)
  – Alerting Duration
  – ATC Coordination
  – Subjective Workload & Acceptability
• **Expected Outcome**
  - At detection ranges of 3.0 and 2.5nm, the LoDWC rates will be comparable to Low SWaP HITL 1
  - The LoDWC rates will increase significantly at 2.0 and 1.5nm detection ranges

• **Reasoning**
  - Ability to maintain DWC is largely a function of time to LoDWC at first alert
  - At 2.0 and 1.5nm, the intruder will first appear as a Warning in half or more of the scripted encounters

<table>
<thead>
<tr>
<th>Intruder Geometry</th>
<th>Slow Crossing</th>
<th>Slow Head-on</th>
<th>Fast Crossing</th>
<th>Fast Head-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ownship Speed</td>
<td>Slow Fast</td>
<td>Slow Fast</td>
<td>Slow Fast</td>
<td>Slow Fast</td>
</tr>
<tr>
<td>3.5nm (Low SwaP HITL 1)</td>
<td>60s 60s</td>
<td>60s 52s</td>
<td>58s 53s</td>
<td>45s 39s</td>
</tr>
<tr>
<td>3nm</td>
<td>60s 60s</td>
<td>48s 42s</td>
<td>49s 44s</td>
<td>36s 30s</td>
</tr>
<tr>
<td>2.5nm</td>
<td>54s 49s</td>
<td>40s 34s</td>
<td>41s 36s</td>
<td>31s 25s</td>
</tr>
<tr>
<td>2nm</td>
<td>43s 38s</td>
<td>31s 25s</td>
<td>33s 28s</td>
<td>26s 20s</td>
</tr>
<tr>
<td>1.5nm</td>
<td>32s 27s</td>
<td>24s 18s</td>
<td>25s 20s</td>
<td>21s 15s</td>
</tr>
</tbody>
</table>

**Green** = at least 15sec Corr Duration; **Black** = less than 15sec Corr Duration; **Red** = No Corrective (Warning at first alert)
• **Participants**
  – 9 active-duty UAS pilots

• **Ownship: Generic RQ-7 Shadow model**
  – Mission altitude: 8,000ft MSL
  – Maneuverability:
    • Cruise speed: 60 or 100 KTAS
    • Turn rate: 7°/sec
    • Climb/descent rate: 500 ft/min
  – Surveillance:
    • ADS-B In (cooperative)
      – Detection range: 15nm
    • Low SWaP RADAR (non-coop)
      – Variable detection range: 1.5 - 3nm
      – +/- 110° azimuth
      – +/- 15° elevation
Scenario Design

• Experimental Trials
  – 4 experimental trials per pilot (1 for each detection range)
    • 45-minute trial duration
  – Route: FT6 Full Mission “Racetrack”
    • Oakland Center (Class E)
    • Level at 8,000ft MSL
    • Active TFR

• Researchers played role of confederate ATC
  – Background traffic was generated using VS Sim intruder tool
Scenario Design

- **DAA Task**
  - Remain DAA well clear from other aircraft
    - 5 encounters scripted to lose DWC per trial

- **Scripted Encounters**
  - 4 non-cooperative intruders
    - Intruder speeds: 100 KTAS (‘slow’) or 170 KTAS (‘fast’)
    - Relative approach angles: Head-on or Crossing
    - *Note: all non-coops generated DAA alert at first appearance on display*
  - 1 cooperative intruder
    - Intruder speed: 200 KTAS
    - Relative approach angle: Crossing

- **Secondary Tasks**
  - Respond to scripted chat messages
  - Complete checklists to resolve scripted failures
    - Header Tank Overpressure or Generator Failure
## Alerting Logic

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Time to LoDWC</th>
<th>Pilot Action</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Symbol" /></td>
<td>DAA Warning Alert</td>
<td>30 sec</td>
<td>• <strong>Immediate action required to remain DAA well clear</strong>&lt;br&gt;• Prior ATC coordination not required</td>
<td>“Traffic, Maneuver Now, Traffic, Maneuver Now”</td>
</tr>
<tr>
<td><img src="image2.png" alt="Symbol" /></td>
<td>Corrective DAA Alert</td>
<td>60 sec</td>
<td>• On current course, <strong>corrective action required to remain DAA well clear</strong>&lt;br&gt;• Coordinate with ATC; maneuver following approval</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td><img src="image3.png" alt="Symbol" /></td>
<td>Preventive DAA Alert</td>
<td>N/A</td>
<td>• <strong>No action required to remain DAA well clear</strong>&lt;br&gt;• Not currently a threat; monitor for potential increase in threat level</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td><img src="image4.png" alt="Symbol" /></td>
<td>Guidance Traffic</td>
<td>N/A</td>
<td>• <strong>No action required to remain DAA well clear</strong>&lt;br&gt;• Traffic generating guidance bands outside of current course</td>
<td>N/A</td>
</tr>
<tr>
<td><img src="image5.png" alt="Symbol" /></td>
<td>Basic</td>
<td>N/A</td>
<td>• <strong>No action required to remain DAA well clear</strong>&lt;br&gt;• No coordination required</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Facilities & Resources

• Facilities
  – HAT Lab

• DAA System
  – JADEM/DAIDALUS v2
  – Honeywell Sensor Model & Tracker (v15)

• LVC Gateway

• Ground Control Station
  – Vigilant Spirit Control Station
    • Traffic display and control interface for pilot tasks
  – Vigilant Spirit Simulation
    • Event generation tool for researcher tasks
    • Located in sim manager area

• Voice Communication
  – PLEXSYS push-to-talk headsets
    • Researcher acted as ATC confederate
OBJECTIVE FINDINGS

*NON-COOPERATIVE ENCOUNTERS
Unmitigated Alerting

• 2.5 NM and 3 NM allow for full-duration Warning alerting on average
  – Worst case scenario at 2.5 NM range: Fast Head On w/ Fast Ownship (26s)
    • Pilots have typically needed 25sec alerting to maintain separation in past HITLs

• Prior ATC coordination generally not viable at any range
  – Short Corrective alert durations
    • Assumed 15sec needed for ATC coordination
  – No Corrective alerting at 1.5 NM

![Graph showing alerting times for different ranges and Ownship speeds.](image-url)
Corrective alerts were generated for 53% of non-coop conflicts.

Pilots were often unable to respond to Corrective alerts, especially below 3 NM:
- Over half progressed to Warning before first upload
  - Corrective alert duration range in these cases: 1-10 sec
  - Only 3NM enabled Corrective alerting across all encounter types

### Alerting Performance - Mitigated

**Threat Type at First Alert (non-coops)**

<table>
<thead>
<tr>
<th>RADAR Range</th>
<th>Corrective</th>
<th>Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 NM</td>
<td>36</td>
<td>0%</td>
</tr>
<tr>
<td>2 NM</td>
<td>13</td>
<td>86%</td>
</tr>
<tr>
<td>2.5 NM</td>
<td>28</td>
<td>72%</td>
</tr>
<tr>
<td>3 NM</td>
<td>36</td>
<td>64%</td>
</tr>
</tbody>
</table>

**Threat Type at First Upload (non-coops)**

<table>
<thead>
<tr>
<th>RADAR Range</th>
<th>Corrective</th>
<th>Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 NM</td>
<td>5</td>
<td>95%</td>
</tr>
<tr>
<td>2 NM</td>
<td>16</td>
<td>84%</td>
</tr>
<tr>
<td>2.5 NM</td>
<td>20</td>
<td>80%</td>
</tr>
<tr>
<td>3 NM</td>
<td>23</td>
<td>77%</td>
</tr>
</tbody>
</table>

*N = 144 non-coops (36 per Range condition)*
MEASURED RESPONSE TIME
&
ATC COORDINATION
Pilot Responses

- RADAR range did not impact pilot response times
  - Majority of encounters required immediate response

- ATC Coordination rates were low across all ranges
  - Mostly due to short Corrective alert duration
    - Rarely able to coordinate in time despite being only pilot on frequency
  - Against non-coops, pilots received prior ATC approval for:
    - 26% of all uploads
    - 42% of all uploads when conflict was Corrective at First Alert

![Aircraft Response Time Graph](image)

![Proportion of Maneuvers with ATC Approval Graph](image)

*N = 144 non-coops (36 per Range condition)*
DAA PERFORMANCE
• **Time-to-LoDWC at first alert**
  – Primary factor in pilots’ ability to maintain DWC
  – 94% of all LoDWC occurred with less than 25 seconds to avoid
    • Only possible below 2.5 NM
    • 2 remaining LoDWC due to Early Returns to Course after azimuth drop
      – Azimuth drops before Clear-of-Conflict were common (discussed later)
  – Pilots *always* violated DWC with less than 15s to maneuver (*n* = 9)
    • Avg. Aircraft RT in these cases = **7.4 sec**
    • Only possible below 2.0 NM

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**Separation Performance**

- **Separation by Range (non-coops)**
  - 72% **LoDWC Rate**
  - 3% **NMAC Rate**

- **Separation by Time-to-LoDWC (non-coops)**
  - 9/9 **LoDWC Rate**
  - 17/22 **NMAC Rate**

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*N = 144 non-coops (36 per Range condition)*
• Both NMACs occurred in the 1.5 or 2.0 NM conditions
  – Closer horizontal separation at 1.5 NM:

<table>
<thead>
<tr>
<th>Range</th>
<th>Avg. sLoWC%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 NM</td>
<td>21.97</td>
</tr>
<tr>
<td>2 NM</td>
<td>2.48</td>
</tr>
</tbody>
</table>

*Excluding Early RTC
SUBJECTIVE FEEDBACK
• NASA Task Load Index (TLX)
  – 1.5 nm & 2 nm had higher composite TLX scores compared to 2.5 & 3 nm
  • Biggest differences observed with Temporal demand
  – No significant differences between 2.5 and 3 nm overall

![NASA TLX – Overall Workload](chart1)

![Temporal Demand](chart2)
• NAS Safety
  – 2.5 and 3 nm were both rated as more comfortable than 1.5 and 2 nm
  – 1.5 and 2 nm had similar ratings, as did 2.5 and 3 nm

I would feel comfortable flying with a DAA system with this RADAR detection range in the National Air Space:
1 = Strongly Disagree, 5 = Strongly Agree

Average Response

<table>
<thead>
<tr>
<th>Detection Range</th>
<th>Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 nm</td>
<td>2.67</td>
</tr>
<tr>
<td>2 nm</td>
<td>3.22</td>
</tr>
<tr>
<td>2.5 nm</td>
<td>4.33</td>
</tr>
<tr>
<td>3 nm</td>
<td>4.22</td>
</tr>
</tbody>
</table>
• 5 pilots considered **2.5 NM** as minimally acceptable, while 4 pilots chose **2 NM**
  – All Fast Ownship pilots chose 2.5 NM
  – 4 of 5 Slow Ownship pilots chose 2 NM (did not experience worst case scenario)

• Most pilots found little use for Corrective alerts in the **current** test setup
  – Correctives either too infrequent or too short:
    – “If you quickly transition to a warning anyway, it would be pointless.”
    – “That would depend on aircraft capability and how close the warning threshold is.”
    – “Correctives only helpful with enough time to call ATC. In reality, I would probably not make the call until after.”

**How valuable is Caution-level alerting for LSNC?**

<table>
<thead>
<tr>
<th>Necessary</th>
<th>Preferred, Time Permitting</th>
<th>Unnecessary</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

**Based on today’s experience, which RADAR range do you consider minimally acceptable?**

<table>
<thead>
<tr>
<th>Detection Range</th>
<th>Response Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 nm</td>
<td>0</td>
</tr>
<tr>
<td>2 nm</td>
<td>4</td>
</tr>
<tr>
<td>2.5 nm</td>
<td>5</td>
</tr>
<tr>
<td>3 nm</td>
<td>0</td>
</tr>
</tbody>
</table>

*N = 9 pilots*
Field of Regard Considerations

• It was common for intruders to fall out of FOR during avoidance
  – Shorter detection ranges necessitate larger heading changes that stress the 110° azimuth limit, especially at fast closure rates
  – Absence of DAA information elevates risk of premature Return-to-Course
    • LoDWC events caused by Early RTC are often high-severity
      – Caused NMAC in current study
    • ‘Coasting’ logic may promote safer return paths if trajectories remain constant

• 44 cases of azimuth drops during active Corrective/Warning:

<table>
<thead>
<tr>
<th>Range</th>
<th>Azimuth Drops before CoC</th>
<th>Avg. Turn Size (Fast Intruders)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 NM</td>
<td>20/36 (56%)</td>
<td>113deg</td>
</tr>
<tr>
<td>2 NM</td>
<td>9/36 (25%)</td>
<td>101deg</td>
</tr>
<tr>
<td>2.5 NM</td>
<td>9/36 (25%)</td>
<td>90 deg</td>
</tr>
<tr>
<td>3 NM</td>
<td>6/36 (17%)</td>
<td>90 deg</td>
</tr>
</tbody>
</table>
Analysis Summary

• Pilot performance primarily influenced by Warning alert duration
  – 94% of total LoDWC events had less than 25sec-to-LoDWC at first alert
    • Comparable to performance trends observed in past HITLs
    • Needed at least **2.5 NM** to ensure 25sec alerting in current test
  – Corrective alert duration allowed little time for ATC coordination
    • 57% of caution threats progressed to Warning before initial maneuver
    • Only 42% of initial maneuvers against caution threats were pre-approved
      – Note: 85% approval rate for cooperative encounters (matches past findings)

• Subjective ratings generally favor 2.5 NM as the minimum RDR
  – Voted most acceptable by pilots that experienced fastest closure rates
  – Significant increases in overall workload observed under 2.5 NM
    • Temporal demand, Frustration, Safety
  – 1.5 NM received the least favorable ratings for all metrics

<table>
<thead>
<tr>
<th>Sensor Range</th>
<th>&gt;25sec Alert?</th>
<th>Min. Alerting</th>
<th>Max. Alerting</th>
<th>Total LoDWC</th>
<th>Total NMACs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 NM</td>
<td>25%</td>
<td>13s</td>
<td>29s</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>2.0 NM</td>
<td>63%</td>
<td>19s</td>
<td>43s</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2.5 NM</td>
<td>100%</td>
<td>26s</td>
<td>57s</td>
<td>1 (RTC)</td>
<td>0</td>
</tr>
<tr>
<td>3.0 NM</td>
<td>100%</td>
<td>32s</td>
<td>60s</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusion

- **Minimum** RADAR declaration range -> **2.5 NM**
  - Sufficient alerting time (≥25s) across all tested encounter types
    - Allowed for at least 10sec of Remain DWC guidance in worst cases
      - 99% of Warning RTs were within 10sec
    - Automation support likely necessary if smaller ranges are considered
      - Currently out of scope for DAA
      - Swift transition to Regain DWC/CA guidance below 2.5 NM
  - Favorable safety, workload, and acceptability ratings

- Corrective alerting provided minimal benefit at tested ranges
  - Delayed aircraft response without enabling consistent ATC coordination
    - Need more than 3 NM to ensure prior ATC coordination if desired
  - Caution alerts were not rated as absolutely necessary for non-coops
  - Potential mitigation: extended Warning alert threshold in lieu of Corrective
    - Removal of coordination component reduces the 25sec pilot response time assumption, thus adding flexibility to the minimum RDR requirement
Low SWaP Radar Declaration Range (RDR)

NASA proposes to define RDR by MIR + 15 seconds

**Green**: test points in the HITL  
**Red**: stressing case that drives RDR requirements

RDR computed with 15 sec response time is ~ 2.5 nmi

<table>
<thead>
<tr>
<th>Own. Speed (KTAS)</th>
<th>Int. Speed (KTAS)</th>
<th>Bearing (°)</th>
<th>RDR (nmi) with 25 sec response</th>
<th>RDR (nmi) with 15 sec response</th>
<th>MIR (nmi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0°</td>
<td>3.44</td>
<td>2.86</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0°</td>
<td>3.24</td>
<td>2.63</td>
<td>1.71</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0°</td>
<td>3.13</td>
<td>2.49</td>
<td>1.53</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0°</td>
<td>3.22</td>
<td>2.47</td>
<td>1.35</td>
<td></td>
</tr>
</tbody>
</table>

Note: MIR results were computed by AAG
Related considerations

• Is additional data needed for making this decision?
• If we adopt MIR + 15 seconds for low SWaP sensors’ declaration range, what about the RDR for high UA speed and medium UA speed ATAR?
• We think the same declaration range can be applied to both the low SWaP radar and EO/IR
  – EO/IR achieves reasonable range/range rate estimates < 3 nmi
BACKUP
Low SWaP 2: Response Times to **CORR** Non-Cooperative Intruders

Low SWaP 2: Response Times to **WARN** Non-Cooperative Intruders