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

A Comparison of Two Terminal Area Detect and Avoid Well Clear Definitions

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R. Conrad Rorie
Summer Brandt
Lisa Fern

Kevin Monk
Zach Roberts
• Unmanned Aircraft Systems (UAS) Integration into the National Airspace System (NAS) Project
  – Researching how to overcome technical barriers associated with the operation of UAS in civil airspace [above 500ft AGL]
  – One emphasis has been on the development of Detect and Avoid (DAA) technologies and procedures

• A DAA system would allow UAS to comply with the ‘see and avoid’ requirements [14 CFR Part 91] in manned aviation
  – The requirements authorize manned pilots to maneuver off their route to avoid potential/perceived collision hazards; i.e., maintain well clear

• To be applied to UAS operations, well clear had to be mathematically defined
  – “DAA well clear” (DWC) was initially defined for en-route operations
    • I.e., transitioning through Class E/D/G to Class A; explicitly excluded operations in and around airports
  – Defined through RTCA Special Committee 228 (SC-228) Phase 1 DAA Minimum Operational Performance Standards (MOPS)
  – DAA system includes alerting and guidance to help pilot determine when a maneuver is necessary
• Phase 2 of RTCA SC-228’s DAA MOPS expands the scope to include terminal area operations (Class C, D, E, and G airports)
  – Initial research attempted to apply the Phase 1 DAA well clear definition and alerting/guidance requirements to the terminal environment
  – The en-route DAA well clear hazard zone = 4000ft lateral, 450ft vertical, and 35sec modified Tau (approx. time to closest point of approach)
    • Incorporated ATC expectations and TCAS II interoperability

• A human-in-the-loop (HITL) simulation by these authors had pilots fly a Phase 1 UAS into a Class D airport (Sonoma County Airport [KSTS])
  – Pilots flew instrument and visual approaches
  – In some of the approaches a conflict was scripted to occur between airport traffic and the UAS
  – **Primary research question:**
    • How well can pilots maintain appropriate separation against traffic using the Phase 1 en-route DAA well clear definition?
• The results demonstrated the poor fit of the Phase 1, en-route DAA well clear definition in the terminal area

• The relatively large size of the Phase 1 definition led to an exceedingly high number of DAA alerts
  – As a result pilots had a hard time judging when a maneuver was truly necessary
  – Led to a much higher number of high-severity losses of DAA well clear than had been seen in earlier, Phase 1 research

• The DAA Corrective alert level was also shown to be less useful in the terminal area
  – The Corrective alert is designed to facilitate ATC coordination prior to maneuvering to maintain DAA well clear
  – ATC did not expect UAS pilots to coordinate with them prior to maneuvering
  – Corrective alerts often lasted less than 15sec
Purpose: investigate 2 new DAA well clear definitions tailored to the terminal environment

- The candidates were based on expected traffic pattern characteristics
- 2 aspects of the Phase 1 DAA well clear definition were identified as needing modification to better conform to standard terminal area operations:
  1. Reduce the horizontal threshold: 4000ft is too wide & will routinely alert against VFR traffic on the downwind leg of the traffic pattern
  2. Reduce the modified Tau (modTau) component: 35sec is too conservative & will alert too quickly against intruders that are maneuvering near the airport

Research Questions:
1. Are there meaningful differences between the 2 candidate definitions?
2. Is the Corrective alert useful with the new definitions?
Experimental Design

• Independent Variables:

1. DAA Well Clear Definition (2 levels; within-subjects):
   • No Tau = terminal area definition does not include modTau in its criteria
   • With Tau = terminal area does include modTau

<table>
<thead>
<tr>
<th>DAA Well Clear Parameters</th>
<th>No Tau</th>
<th>With Tau</th>
<th>Phase 1 (En-Route)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Threshold</td>
<td>1500ft</td>
<td>1500ft</td>
<td>4000ft</td>
</tr>
<tr>
<td>Vertical Threshold</td>
<td>450ft</td>
<td>450ft</td>
<td>450ft</td>
</tr>
<tr>
<td>modTau</td>
<td><strong>N/A</strong></td>
<td>15sec</td>
<td>35sec</td>
</tr>
</tbody>
</table>

2. Alerting Configuration (2 levels; between-subjects):
   • No Corrective = No DAA Corrective alert or guidance, all other alerting/guidance remains
   • With Corrective = Full Phase 1 MOPS DAA alerting and guidance structure (Class I)
## Alerting Criteria

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>Time to Loss of DWC</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Warning Alert" /></td>
<td>Warning Alert</td>
<td>• Maneuver now to avoid a loss of DAA well clear</td>
<td>30 sec</td>
<td>“Traffic, Maneuver Now” x2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Notify ATC as soon as practicable after taking action</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Corrective Alert*" /></td>
<td>Corrective Alert*</td>
<td>• Coordinate with ATC then maneuver to avoid a loss of DAA well clear</td>
<td>45 sec</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td><img src="image" alt="Preventive Alert" /></td>
<td>Preventive Alert</td>
<td>• Intruder nearby in altitude</td>
<td>45 sec</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td><img src="image" alt="Guidance Traffic" /></td>
<td>Guidance Traffic</td>
<td>• Traffic is generating guidance bands <em>outside</em> of current course</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td><img src="image" alt="Remaining Traffic" /></td>
<td>Remaining Traffic</td>
<td>• Traffic within sensor range</td>
<td>X</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Corrective alert only present in the With Corrective alerting configuration*
• Ground control station (GCS) contained:
  1. **Viewer Tool** – contains approach plate & airport facility directory (AFD)
  2. **Tactical Situation Display (TSD)** – DAA information and vehicle control interfaces
  3. **Right Panel** – landing checklist and additional info
  4. **Voice communication panel** – touchscreen, transmit/receive on select freqs.
Sonoma County Airport (KSTS)

- Class D
- Runway 14/32
  - Length = 6000ft x 150ft
  - RNAV (GPS)
- Elevation = 129ft
- Traffic Pattern = 1150ft
- Downwind lateral offsets:
  - Left = 1.5nm (~9000ft)
  - Right = 0.5nm (~3000ft)
- Runway 20/02
  - Not used

Traffic Pattern Altitude = 1150ft
3NM (WP1) to RW14 (WP2) = 3nm
RW14 (WP2) to RW32 (WP3) = 1nm
Simulation Components

- Pseudo-pilots monitored and managed all manned traffic (IFR & VFR)
  - Multi-Aircraft Control System (MACS) software suite
- Air Traffic Control managed UAS and manned traffic
  - Tower controller managing Santa Rosa (KSTS)
  - Center controller managing Oakland Center (ZOA 40/41)
  - Sector traffic modeled using real sector activity and data
- All participants communicated via push-to-talk headsets
  - KSTS Tower frequency: 118.50
  - Oakland Center frequency: 127.80
  - KSTS ATIS: 120.55
• Participants flew 2 types of approaches under Instrument Flight Rules (IFR)
  – Instrument (RNAV GPS) Approach
  – “Visual” Approach

• Operated a simulated MQ-9 (Reaper; Group 5)
  – 65ft wingspan
  – 110kts cruise speed
  – 1000 FPM climb/descent rate
  – 3°/sec turn rate
Scenarios

Instrument Approach Notes:
- Final approach coarse offset 15°
- **Missed approach procedures** = climb to 5000ft, fly runway heading (143°)

“Visual” Approach Notes:
- Airport “in sight” 10-12nm from runway
- Line up for 3nm final stabilized approach
- Traffic pattern @ 1150ft
- **Go-around** = climb to 1150/2000ft
Scenarios

• Encounter Type
  – Turn Into = traffic blunders into us on final and is intended to lead to NMAC without UAS pilot response
  – Turn In Front = traffic turns in front of UAS with sufficient separation (~1.5-2nm) to land safely (turn is coordinated w/ Tower)
  – Unscripted = no encounter is scripted to occur but traffic expected to be on downwind as UAS is on final

• Pilots flew 4 approaches per trial
  – 1 Turn Into & 1 Turn In Front per trial
  – All other traffic considered Unscripted
Participants

- 16 UAS pilot participants (avg. age = 33 years)
  - All IFR rated with manned & unmanned flying experience
    - Manned experience = avg. 1000 civilian flight hours, 1600 military flight hours
    - Unmanned experience = avg. 500 civilian flight hours, 700 military flight hours
  - 2 retired tower controls served as tower controller confederates
RESULTS

ALERTING PERFORMANCE...
LOSSES OF DAA WELL CLEAR...
MANEUVER PREFERENCES...
• The *With Tau* candidate alerted more frequently to all alert types
  – Biggest difference was against Corrective alerts
• Driven by how often **Unscripted** traffic triggered an alert
  – The 2 definitions alerted (nearly) identically against the scripted encounter types (Turn Into & Turn In Front)
• Corrective alerts were particularly short in the *With Tau* DAA well clear definition
  – Frequently only lasted the *minimum* duration (4 seconds)
  – Not enough time to coordinate with ATC

• Warning alerts tended to last longer in both DAA well clear definitions
• Proportion of losses of DAA Well Clear (LoDWC) =
  – # of LoDWC / # aircraft that generated a DAA Corrective or Warning

• Pilots were twice as likely to lose DAA well clear against the Turn Into encounter in the With Tau condition
  – Larger hazard zone made it harder for pilots to avoid separation violation

![Graph showing the proportion of LoDWC for different encounter types and conditions.]

DWC Candidate

<table>
<thead>
<tr>
<th>Encounter Type</th>
<th>No Tau</th>
<th>With Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Encounters</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Turn Into</td>
<td>0.25</td>
<td>0.47</td>
</tr>
<tr>
<td>Turn In Front</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Unscripted</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Losses of DAA Well Clear
• With Tau condition resulted in more losses of DAA well clear that were effectively unavoidable:

<table>
<thead>
<tr>
<th>Time to Loss of DAA Well Clear</th>
<th>No Tau</th>
<th>With Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 15 sec</td>
<td>1/8 (13%)</td>
<td>8/15 (53%)</td>
</tr>
<tr>
<td>Less than 5 sec</td>
<td>0</td>
<td>5/15 (33%)</td>
</tr>
</tbody>
</table>

• Product of the larger size of its hazard zone
The two DAA well clear definitions resulted in very similar types of maneuvers

- Exception being a larger number of speed decreases against Unscripted encounters in the *With Tau* condition
- Speed changes *not* considered disruptive
Pilots made the greatest number of maneuvers when the *With Corrective* alerting condition was paired with the *With Tau* DAA well clear definition.

- Increased ~30% relative to the other 3 conditions
Conclusions

• With Tau candidate led to more:
  – DAA alerts against Unscripted encounters
  – Short-duration Corrective alerts
  – Unavoidable losses of DAA well clear against the Turn Into encounter
  – Maneuvers against Unscripted traffic (although it was typically non-disruptive)

• No Tau candidate determined to be a better fit, however:
  – Losing DAA well clear against the No Tau definition should be considered a more severe/hazardous loss of separation

• Corrective alert level continued to show limited utility
  – Short duration Corrective alerts with both candidates, particularly With Tau

• Future work needed to investigate **when to switch** from the Phase 1/ena-route definition to the terminal area definition
QUESTIONS?
CONRAD.RORIE@NASA.GOV
DAA Alerting & Guidance

No Corrective
Warning (Truth) Alert

[Diagram: Two circles, one with a red triangle indicating 'ALT 9000ft' and another with a green triangle indicating 'Regain DWC Guidance'.]

With Corrective
Warning (Truth) Alert

[Diagram: Two circles, one with a red triangle indicating 'ALT 9000ft' and another with a green triangle indicating 'Regain DWC Guidance'.]
Aircraft Flight Model

• Generic MQ-9 Reaper
  – Speed:
    • Cruise: 110 knots
    • Landing: 90-110 knots
    • Max: 200 knots
    • Min: 70 knots
  – Climb/Descent Rate:
    • 1000ft/min (default)
    • Captures 3° glide slope on final
  – Turn Performance:
    • Max Roll: +/- 20°
    • Turn Rate: 5°/sec
Training on DAA System

• Pilots trained first on the ground control station followed by training on the DAA system
  – Trained on the meaning of each alert/guidance type in their given configuration
  – Practice en-route scenario flown with conflicts & ATC in-the-loop
• Pilots trained last on how to fly the given approach
  – 2 practice approaches flown, one with a scripted conflict
• Informed that a DAA system has been specifically developed to support terminal operations
  – Told the hazard zone was 1500ft x 450ft (did not explain tau component)

▶ Told to use the DAA system to maintain DAA well clear from traffic in the terminal environment (i.e., expected to utilize the alerts/guidance)