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

Terminal Operations HITL 1B
Primary Results
Presented to: RTCA SC-228 WG-1

27 March, 2018
Objective

- **Purpose**: leverage the lessons learned from the Foundational Terminal Operations human-in-the-loop (HITL) simulation to test a DAA system better suited to the terminal environment

- **Objectives**:
  - Implement two candidates for a terminal area DAA well clear (DWC) definition
  - Further investigate the efficacy of the DAA Corrective alert in the terminal area
  - Compare pilot and system performance to previous studies
TOPS 1 Results Summary

- Phase 1 DWC definition resulted in an exceedingly high number of alerts in the terminal area
  - As a result pilots had a hard time judging when a maneuver was necessary to avoid high-severity LoDWC
    - **17 > 50% SLoWC & 6 > 70% SLoWC**
    - No SLoWC above 30% in PT6

- The DAA Corrective alert was shown to be less useful in the terminal area
  - Best performance seen in configuration with DAA Warning but no Corrective
  - Pilots rarely coordinated with tower before maneuvering against intruders
  - Intruders often spent < 15sec as Corrective before transitioning to Warning

- Encounters that occurred with ownship established on final were the most likely to lead to severe losses of DWC
Experimental Design

• 2 x 2 Mixed-Factorial Design
  – DWC Candidate (Within-Subjects):

<table>
<thead>
<tr>
<th></th>
<th>No Tau</th>
<th>Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Threshold*</td>
<td>1500ft</td>
<td>1500ft</td>
</tr>
<tr>
<td>Vertical Threshold</td>
<td>450ft</td>
<td>450ft</td>
</tr>
<tr>
<td>modTau</td>
<td>N/A</td>
<td>15sec</td>
</tr>
</tbody>
</table>

*HMD in Tau definition

– Alerting Configuration (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)
## Experimental Design

### No Corrective

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Time to Hazard Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warning Alert</td>
<td>30sec</td>
</tr>
<tr>
<td><img src="image1" alt="Symbol" /></td>
<td>Preventive Alert</td>
<td>45sec</td>
</tr>
<tr>
<td><img src="image2" alt="Symbol" /></td>
<td>Remaining Traffic</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Includes Only Warning Guidance and Regain DWC Guidance*

### With Corrective

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Time to Hazard Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Symbol" /></td>
<td>Warning Alert</td>
<td>30sec</td>
</tr>
<tr>
<td><img src="image4" alt="Symbol" /></td>
<td>Corrective Alert</td>
<td>45sec</td>
</tr>
<tr>
<td><img src="image5" alt="Symbol" /></td>
<td>Preventive Alert</td>
<td>45sec</td>
</tr>
<tr>
<td><img src="image6" alt="Symbol" /></td>
<td>Guidance Traffic</td>
<td>N/A</td>
</tr>
<tr>
<td><img src="image7" alt="Symbol" /></td>
<td>Remaining Traffic</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*All Remain & Regain DWC Guidance*
### Alerting Criteria for DWC Candidates

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>No Tau DWC Criteria</th>
<th>Tau DWC Criteria</th>
<th>Time to Loss of DWC</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Horz = 1500ft</td>
<td>DMOD = 1500ft</td>
<td>30 sec</td>
<td>“Traffic, Maneuver Now” x2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 450 ft</td>
<td>HMD = 1500ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 15 sec</td>
<td>ZTHR = 450 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Notify ATC as soon as practicable after taking action</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrective Alert</td>
<td>Horz = 1500ft</td>
<td>DMOD = 1500ft</td>
<td>45 sec</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 450 ft</td>
<td>HMD = 1500ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 15 sec</td>
<td>ZTHR = 450 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coordinate with ATC to determine an appropriate maneuver</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Preventive Alert</td>
<td>Horz = 1500ft</td>
<td>DMOD = 1500ft</td>
<td>45 sec</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 700 ft</td>
<td>HMD = 1500ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• On current course, corrective action should not be required</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Guidance Traffic</td>
<td>Associated w/ bands outside current course</td>
<td>Associated w/ bands outside current course</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic generating guidance bands outside of current course</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Remaining Traffic</td>
<td>Within surveillance field of regard</td>
<td>Within surveillance field of regard</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic within sensor range</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**
- Corrective alert only present in *With Corrective* alerting configuration
- No sensor uncertainty was modeled
- Alerting criteria was identical between DWC Candidates
• Generic MQ-9 Reaper
  – Speed:
    • Cruise: 110 knots
    • Landing: 90-110 knots
    • Min: 70 knots
  – Default Climb/Descent Rate:
    • 1000ft/min
  – Roll:
    • Max: +/- 20°
    • Rate: 5°/sec
  – Pitch:
    • Max: +/- 10°
    • Rate: 1°/sec
Ground Control Station (GCS)

• Ground control station (GCS) contains:
  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

- Primary = Rwy14
- Runway 14/32
  - Length = 6000ft x 150ft
  - RNAV (GPS)
- Elevation = 129ft
- Traffic Pattern = 1150ft
- Downwind offsets:
  - Left = ~1.5nm
  - Right = ~0.5nm
- 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
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)
• Participants flew 2 types of approaches into Santa Rosa Rwy 14 under Instrument Flight Rules (IFR)
  – Instrument (RNAV GPS) Approach
  – “Visual” Approach

• Common across scenarios:
  – Start in Vigilant Spirit’s HOLDS mode & in Oakland center airspace
  – Coordinate transfer to KSTS Tower
  – Perform checklist actions as able (e.g., check ATIS, brief approach)
  – Fly final in Vigilant Spirit’s NAV mode (enables glide slope)
**Scenario Design**

**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 pattern alt (1150ft)
• Pilots flew 4 trials per day (2 Instrument & 2 Visual)
• 4 approaches flown per trial (= ~45min per trial)
• The following encounter types occurred every trial:
  • **Turn Into** = traffic blunders into UA on final and will result in NMAC without UAS pilot response [1 per trial]
  • **Turn In Front** = traffic turns in front of UAS with sufficient separation (~1.5-2nm) to land safely (the turn is coordinated w/ Tower) [1 per trial]
  • **Unscripted** = no encounter is scripted to occur but traffic expected to be on downwind as UAS is on final [2 per trial]

• Encounter type breakdown:

<table>
<thead>
<tr>
<th></th>
<th>Blunder?</th>
<th>Predicted HorzSep @ CPA</th>
<th>Corrective or Warning Alert Desired?</th>
<th>Maneuver Desired?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn Into</td>
<td>Yes</td>
<td>~0nm</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Turn In Front</td>
<td>No</td>
<td>~1.5-2nm</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Unscripted</td>
<td>No</td>
<td>N/A</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
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 controllers served as tower controller confederates
- 1 ATC SME served as center controller confederate
- 4 current general aviation pilots served as manned traffic confederates
RESULTS
DAA ALERTING AND MEASURED RESPONSE
• 32 total alerts desired per DWC candidate
  = 16 [pilots] * 2 [trials per pilot] * 1 [Turn Into encounter per trial]]
  • There was also 1 Turn In Front encounter per trial
• 215 different intruders registered (in truth) as a DAA alert
  – “Truth” alerts = all alerts captured by the DAA system, across all trials and conditions (ignores alert configuration variable)
• The Tau DWC candidate alerted more frequently overall, a consequence of disproportionately alerting to Unscripted traffic

DAA Alerting Statistics

<table>
<thead>
<tr>
<th># of DAA Alerts (Truth)</th>
<th># of Corrective or Warning DAA Alerts (Truth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWC Candidate</td>
<td>DWC Candidate</td>
</tr>
<tr>
<td>No Tau</td>
<td>Preventive</td>
</tr>
<tr>
<td>Tau</td>
<td>Corrective</td>
</tr>
<tr>
<td></td>
<td>Warning</td>
</tr>
<tr>
<td></td>
<td>Count</td>
</tr>
<tr>
<td></td>
<td># of DAA Alerts (Truth)</td>
</tr>
<tr>
<td></td>
<td># of Corrective or Warning DAA Alerts (Truth)</td>
</tr>
</tbody>
</table>

Desired alerts
• More Corrective (truth) alerts issued when Tau DWC definition used
  – No Tau = 42 total
  – Tau = 75 total

• Majority of these Corrective alerts lasted less than 6sec
  – NOTE: 4sec is min. alert duration
  – Most did not progress to a Warning alert
    • No Tau = 17/22 (77%)
    • Tau = 44/53 (83%)

• Avg. Corrective alert duration
  – No Tau = 6.9sec
    • Median = 5sec
  – Tau = 7.5sec
    • Median = 5sec
  – Typically allot 10-15sec for ATC coordination
• Corrective (truth) alerts least common during the Turn Into encounter types
  – Only **13 Corrective** alerts issued against Turn Into encounters

• Correctives more common with Turn In Front & Unscripted encounters
  – Turn In Front = 30
  – Unscripted = 74

• Avg. Corrective duration
  – Turn Into = 10.8sec
    • Median = 9sec
  – Turn In Front = 9.6sec
    • Median = 5sec
  – Unscripted = 5.5sec
    • Median = 5sec
• More Warning (truth) alerts issued when Tau DWC definition used
  – No Tau = 40
  – Tau = 67
• Warnings typically lasted less than 10sec
  – However, Tau candidate led to more alerts w/ **20sec duration**
• Avg. Warning alert duration
  – No Tau = 10.9sec
    • Median = 8sec
  – Tau = 12.4sec
    • Median = 8sec
• Warning (truth) alerts most common during the Turn Into encounter types
  – 58 Warning alerts issued against Turn Into encounters
• Warnings less common with Turn In Front & Unscripted encounters
  – Turn In Front = 16
  – Unscripted = 33
• Avg. Warning duration
  – Turn Into = 15.2sec
    • Median = 15sec
  – Turn In Front = 7.3sec
    • Median = 6sec
  – Unscripted = 7.5sec
    • Median = 6sec
Aircraft Response Time

- **Aircraft Response Time** = time to upload a maneuver to the aircraft following the onset of a Corrective or Warning alert (whichever appeared first)
- Difficult to capture response times to Corrective alerts – not visible in all conditions and (as shown earlier) they were typically of short duration
- Pilots respond slightly faster to Warning alerts in the No Tau DWC condition
  - Later alerting w/ No Tau means that the threat is often more apparent by the time an alert is issued

[Bar chart showing Aircraft RT by DWC Candidate & Alert Type]

- No Tau
  - Corrective (Truth): 16.29
  - Warning: 8.70
- Tau
  - Corrective (Truth): 17.47
  - Warning: 12.10
- TOPS 1 (Phase 1)
  - Corrective (Truth): 29.89
  - Warning: 18.04
- PT6
  - Corrective (Truth): 18.29
  - Warning: 10.03
SEPARATION DATA
Losses of DAA Well Clear (Counts)

- Loss of DAA Well Clear (LoDWC) Criteria:
  - **No Tau**: Horz=1500ft, Vert=450ft, no tau
  - **Tau**: Horz=1500ft, Vert=450ft, 15sec modTau, 1500ft DMOD
- For reference: 82 LoDWC in TOPS 1 against similar encounters
- Tau had 10 more LoDWC than No Tau (also had larger hazard zone)
  - Tau candidate had more than twice as many LoDWC in the With Corrective alerting configuration
Proportion of losses of DAA Well Clear (LoDWC)
- # of LoDWC / # aircraft that generated a DAA Corrective or Warning

For **All Encounters**, identical proportion of LoDWC between No Tau and Tau DWC candidates

LoDWC was most common against **Turn Into** encounters
- 32 total were scripted (per condition), but one encounter failed to generate in each
- Twice as many LoDWC with Tau candidate

0 LoDWC in Turn In Front encounter type

3 total LoDWC against Unscripted encounters (all in Tau condition)
Losses of DAA Well Clear (Severity)

- Phase 1 SLoWC = % of the **Phase 1** DAA well clear volume (which includes tau) penetrated by intruder
  - Higher % = greater penetration
- No substantial effect of DWC candidate or alerting configuration
  - No Tau & Tau DWC candidates led to

**Avg. Phase 1 SLoWC by DWC Candidate & Alerting Configuration**

<table>
<thead>
<tr>
<th>DWC Candidate</th>
<th>Alerting Configuration</th>
<th>Avg. Phase 1 SLoWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>No Corrective</td>
<td>46.32</td>
</tr>
<tr>
<td></td>
<td>With Corrective</td>
<td>45.06</td>
</tr>
<tr>
<td>Tau</td>
<td>No Corrective</td>
<td>42.16</td>
</tr>
<tr>
<td></td>
<td>With Corrective</td>
<td>45.82</td>
</tr>
<tr>
<td>TOPS 1</td>
<td>No Corrective</td>
<td>26.46</td>
</tr>
<tr>
<td></td>
<td>With Corrective</td>
<td>30.36</td>
</tr>
</tbody>
</table>
Losses of DAA Well Clear (Severity)

- Phase 1 SLoWC ranged overall from 20-72%
  - Highest SLoWC seen in With Corrective alerting configuration
- Fewer high-severity SLoWC with current DWC candidates than seen in TOPS 1
• Closest point defined as minimum slant range \textit{with vertical separation} < 450ft
• 22\% (4/18) of LoDWC in the Tau DWC candidate came within 1500ft horizontal separation (i.e., violated the No Tau candidate criteria)
  – 4 intruders came within 1215ft horizontal separation (the lower-bound recommendation)
- Closest point defined as minimum slant range *with vertical separation* < 450ft
- Tau candidate adds approximately 1000ft additional minimum horizontal separation
- Minimum vertical constant across the four conditions
- No clear effect of alerting configuration

### Avg. Minimum Separation by DWC Candidate, Separation Type & Alerting Configuration

<table>
<thead>
<tr>
<th>DWC Candidate x Separation Type</th>
<th>No Tau</th>
<th>Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Separation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Corrective</td>
<td>1,195.08</td>
<td>1,970.10</td>
</tr>
<tr>
<td>With Corrective</td>
<td>944.85</td>
<td>1,933.58</td>
</tr>
<tr>
<td>Vertical Separation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Corrective</td>
<td>394.14</td>
<td>362.97</td>
</tr>
<tr>
<td>With Corrective</td>
<td>375.74</td>
<td>406.94</td>
</tr>
</tbody>
</table>
Losses of DAA Well Clear (Causes)

- Pilot responsible for LoDWC:
  - 38% (3/8) of time with No Tau candidate
  - 33% (6/18) of time with Tau candidate
    - Only one entered No Tau boundary
- Late acceleration was a disproportionate contributor to LoDWC
  - 38% (3/8) of time with No Tau
  - 56% (10/18) of time with Tau
- Proportion of LoDWC drops significantly when only including pilot-responsible

<table>
<thead>
<tr>
<th>LoDWC Causes</th>
<th>No Tau</th>
<th>Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot Responsible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot Hesitation</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Insufficient Vertical Maneuver</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ineffective Maneuver</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pilot Not Responsible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Acceleration</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Intruder Mis-Flown</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>No Safe Maneuver</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>18</td>
</tr>
</tbody>
</table>

All Encounters

- Turn Into
  - 0.11 (No Tau) ± 0.04 (Tau)
- Turn In Front
  - 0.25 (No Tau) ± 0.09 (Tau)
- Unscripted
  - 0.02 (No Tau) ± 0.19 (Tau)

Pilot-Responsible LoDWC Only

- Turn Into
  - 0.47 (No Tau) ± 0.04 (No Tau)
  - 0.02 (No Tau) ± 0.19 (Tau)
- Turn In Front
  - 0.04 (No Tau) ± 0.04 (No Tau)
  - 0.09 (No Tau) ± 0.19 (Tau)
- Unscripted
  - 0.01 (No Tau) ± 0.02 (No Tau)
  - 0.02 (No Tau) ± 0.19 (No Tau)
• SLoWC drops substantially when only including pilot-responsible LoDWC
  – Approx. reduction of 12-16% SLoWC
  – No noticeable difference between DWC candidates
• The No Tau candidate had 0 SLoWC above 50% with pilot responsible
• The Tau candidate had 2 SLoWC above 50% & 0 SLoWC above 70% (both due to ‘pilot hesitation’)
  – For reference: TOPS 1 had 17 SLoWC above 50% & 6 SLoWC above 70% with pilot responsible

Avg. Phase 1 SLoWC by DWC Candidate & LoDWC Responsibility

Min. Separation at Closest Point in LoDWC – Pilot Responsible Only

Legend:
- No Tau
- With Tau
MANEUVERING & ATC INTEROPERABILITY
Initial Maneuver Types

• Heading changes and missed approaches (or go-arounds in visual scenario) were most likely in the Turn Into encounter type
  – Even split between heading changes and missed approaches

• Pilots relied on speed reductions almost exclusively to resolve perceived conflicts in the Turn In Front and Unscripted encounter types
  – Larger number of maneuvers seen for Tau DWC candidate, largely a result of more speed decreases against Unscripted encounters

**Initial Maneuver Type by DWC Candidate, Maneuver Type & Encounter Type**

<table>
<thead>
<tr>
<th>Maneuver Type x Encounter Type</th>
<th>No Tau</th>
<th>Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading Change, Turn Into</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Missed Approach, Turn Into</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Speed Decrease, Turn Into</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Temporary Climb, Turn Into</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| Heading Change, Turn In Front | 0     | 2   |
| Missed Approach, Turn In Front| 0     | 0   |
| Speed Decrease, Turn In Front | 18    | 17  |
| Temporary Climb, Turn In Front| 2     | 0   |

| Heading Change, Unscripted    | 6     | 1   |
| Missed Approach, Unscripted   | 1     | 1   |
| Speed Decrease, Unscripted    | 16    | 3   |
| Temporary Climb, Unscripted   | 3     | 3   |
Pilots were most consistent when coordinating a missed approach/go-around
  – Pilots fairly consistent in coordinating heading changes, slightly more so in Tau condition

Speed decreases were rarely coordinated

ATC coordination was ~20% in TOPS 1

When pilots did coordinate, it was typically after they had made their maneuver
  – 67% of coordination occurred after the maneuver had been made (identical rate for missed & non-missed approach maneuvers)
Conclusions

• Both DWC candidates appropriately tailored to the operational environment
  – Substantially fewer high-severity LoDWC than TOPS 1
    • The 2 candidates had identical avg. Phase 1 SLoWC when including only pilot-responsible
  – Response times returned to expected averages (consistent with PT6)
  – Pilots did not report noticing a difference between the candidates during debrief
• Tau candidate generated more alerts and more LoDWC, however:
  – Tau candidate led to more LoDWC overall but they typically stayed outside of the 1500ft x 450ft boundary
  – Additional alerts not found to correspond with more disruptive maneuvers – pilots relied heavily on speed reductions
• Corrective alerts continue to show lack of utility in the terminal area
  – Corrective duration grand mean = 7sec (median = 5sec)
  – 81% (61/75) of time short duration Correctives failed to progress to a Warning
  – Pilot performance in the No Corrective alerting configuration either did not differ from or was better than performance in With Corrective condition
BACKUP
DAA Alerting & Guidance

No Corrective

Preventive (Truth) Alert

Corrective (Truth) Alert

With Corrective

Preventive (Truth) Alert

Corrective (Truth) Alert
DAA Alerting & Guidance

**No Corrective**

**Warning (Truth) Alert**

- Inner Range Ring
- Altitude Tape

**Regain DWC Guidance**

- Inner Range Ring
- Altitude Tape

**With Corrective**

**Warning (Truth) Alert**

- Inner Range Ring
- Altitude Tape

**Regain DWC Guidance**

- Inner Range Ring
- Altitude Tape
After each encounter, tower controller answered the following questions:

1. In this encounter did the UAS pilot maintain adequate separation?  
   - Yes: 255  
   - No: 0

2. Did the UAS pilot maneuver unnecessarily for the encounter?  
   - Yes: 14  
   - No: 242

3. Were there issues with the UAS pilot communications?  
   - Yes: 4  
   - No: 252

Tower rated UAS behaviors as overwhelmingly appropriate:
- UA pilots were able to detect appropriate traffic
- Disruptive turn-outs on instrument approach where pilots should have executed missed approach
- 1.5 nm separation on approach worked for simulation

Pilot responses to traffic on final was left to their discretion – although training emphasized the expectation to go missed/go-around:
- During debrief pilots explained that they (often) reflexively looked to make a heading change as a way to immediately increase separation
- Altitude bands typically indicated that a climb would not resolve the conflict
• Tau DWC candidate had far more instances of a DAA alert that did not lead to a UAS maneuver
  – No Tau = 7 alerts w/o maneuver
  – Tau = 40 alerts w/o maneuver
• 62% (29/47) of these cases were against a Corrective alert
  – None of these alerts resulted in a loss of DWC
    – Avg. alert duration = 6sec

DAA Alerts Without a Maneuver

No Corrective with Tau

No Corrective with No Tau

With Corrective with Tau

With Corrective with No Tau

# Alerts Without a Maneuver

Alerting Configuration

Corrective

Warning

DWC Candidate x Alerting Configuration
40 total maneuvers were made against traffic that did not register a DAA alert
   – Evenly distributed between the 2 DWC candidates
Maneuvers were typically speed decreases to provide enough space for aircraft in front
   – No Tau had minority of climbs and heading changes against non-alerted traffic

Maneuvers Without a DAA Alert

<table>
<thead>
<tr>
<th>DWC Candidate</th>
<th>Speed Decrease</th>
<th>Climb</th>
<th>Heading Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>16</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Tau</td>
<td>20</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
• Tau candidate was far more likely to alert to unscripted traffic, particularly jet traffic and traffic turning to base
  – Jet traffic approached KSTS from the NE before getting established on a 5nm straight-in; during the Instrument approach scenario, it briefly pointed at UA

• Discrepancy between conditions is smaller when comparing # of maneuvers
  – No Tau candidate actually led to more maneuvers than alerts; Tau candidate had ~1/2 as many maneuvers than alerts

• Count of Corrective/Warning alerts and maneuvers against unscripted traffic types by DWC candidate:

<table>
<thead>
<tr>
<th>Unscripted Traffic Location</th>
<th>No Tau at First Corr/Warn</th>
<th>Tau at First Corr/Warn</th>
<th>No Tau at Maneuver</th>
<th>Tau at Maneuver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn to Base</td>
<td>12</td>
<td>32</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Jet Traffic</td>
<td>0</td>
<td>24</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Right Downwind</td>
<td>5</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Left Downwind</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Base</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Final</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18</strong></td>
<td><strong>70</strong></td>
<td><strong>26</strong></td>
<td><strong>38</strong></td>
</tr>
</tbody>
</table>
Maneuvers Made by Scenario Type

- Speed changes were the most common type of maneuver made (94 total)
- Missed Approaches & Heading Changes were equally common (43 vs. 42)
  - Missed approach more prevalent in Instrument
  - Heading changes more common in Visual
- Pilots occasionally saved their missed approach for a later upload
Highest SLoWC Encounter

• Worst case was with the Tau DWC candidate, With Corrective alert config.
  – Instrument scenario
  – ‘Late Acceleration’ – *lost DWC at the same time it became a warning*
  – Pilot exacerbated it by turning with the traffic and delaying a climb
• No Tau candidate had fewer alerts
  – None occurred far away from the 2 downwind legs
• Tau candidate had more alerts overall with several occurring far away from runway
  – Tau candidate was more consistent in where the intruder was at first alert
How did pilots continue the approach when they maneuvered for traffic but did not go missed?

- **Re-Engage**: turn back to final and/or continue descent
- **Runway Heading**: turn back toward runway without engaging descent
- **Re-Fly**: made a 360 or enter the right/left downwind to re-do the approach entirely

In Instrument scenario, pilots most often tried to re-engage the approach.

In Visual scenario, pilots most often re-flew the approach.
LoDWC_LaRC typically started with ownship established on final with intruder still near right/left downwind (likely at the start of the turn base)
• CPA typically occurred once the intruder neared or crossed our final approach path