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

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

• Purpose: Examine issues related to the operation of the Phase 1 DAA system within a Class D terminal area. The following operations were performed:
  – Instrument approach
  – Visual approach
  – Visual pattern

• Objectives:
  – Characterize pilot and Phase 1 DAA system performance while conducting terminal area operations
  – Investigate the effect of changes to the alerting and guidance structure intended to minimize frequency of alerts
  – Investigate the effect of the location of an encounter on pilot responses
Experimental Design

• One-Way Between Subjects Factorial
  – Independent Variable:
    • Level of DAA System Alerting & Guidance (Between-subjects)
      – D1 = No corrective or warning DAA alert; no DAA guidance
      – D2 = No corrective DAA alert; DAA warning guidance only
      – D3 = Full Phase 1 MOPS DAA alerting and guidance (Class I)
  – Embedded Variables:
    • Ownship approach type
      – Instrument
      – Visual
      – Traffic Pattern
    • Encounter location
      – Early (before final)
      – Late (on final)
### Experimental Design

<table>
<thead>
<tr>
<th>D1</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1" alt="Symbol" /></td>
<td>Preventive Alert</td>
</tr>
<tr>
<td></td>
<td><img src="image2" alt="Symbol" /></td>
<td>Remaining Traffic</td>
</tr>
</tbody>
</table>

**No Guidance**

<table>
<thead>
<tr>
<th>D2</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image3" alt="Symbol" /></td>
<td>Warning Alert</td>
</tr>
<tr>
<td></td>
<td><img src="image4" alt="Symbol" /></td>
<td>Preventive Alert</td>
</tr>
<tr>
<td></td>
<td><img src="image5" alt="Symbol" /></td>
<td>Remaining Traffic</td>
</tr>
</tbody>
</table>

**Warning Remain DWC Guidance Only**

<table>
<thead>
<tr>
<th>D3</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image6" alt="Symbol" /></td>
<td>Warning Alert</td>
</tr>
<tr>
<td></td>
<td><img src="image7" alt="Symbol" /></td>
<td>Corrective Alert</td>
</tr>
<tr>
<td></td>
<td><img src="image8" alt="Symbol" /></td>
<td>Preventive Alert</td>
</tr>
<tr>
<td></td>
<td><img src="image9" alt="Symbol" /></td>
<td>Guidance Traffic</td>
</tr>
<tr>
<td></td>
<td><img src="image10" alt="Symbol" /></td>
<td>Remaining Traffic</td>
</tr>
</tbody>
</table>

**All Remain & Regain DWC Guidance**

---

Note: used instantaneous turn assumption to generate guidance
# Phase 1 MOPS Alerting Criteria

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>DAA Well Clear Criteria</th>
<th>Time to Loss of DAA Well Clear</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warning Alert</td>
<td>• Notify ATC as soon as practicable after taking action</td>
<td>DMOD = 0.66 nmi</td>
<td>25 sec</td>
<td>“Traffic, Maneuver Now” x2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HMD = 0.66 nmi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 450 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 35 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corrective Alert</td>
<td>• Coordinate with ATC to determine an appropriate maneuver</td>
<td>DMOD = 0.66 nmi</td>
<td>55 sec</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HMD = 0.66 nmi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 450 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 35 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preventive Alert</td>
<td>• On current course, corrective action should not be required</td>
<td>DMOD = 0.66 nmi</td>
<td>55 sec</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HMD = 0.66 nmi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 700 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 35 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Guidance Traffic</td>
<td>• Traffic generating guidance bands outside of current course</td>
<td>Associated w/ bands outside current course</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Remaining Traffic</td>
<td>• Traffic within sensor range</td>
<td>Within surveillance field of regard</td>
<td>X</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note: used ‘unbuffered’ DWC criteria
Alerting & Guidance During *Preventive* Threat

-- No LoDWC Predicted --

**D1**
- Inner Range Ring
- Altitude Tape

**D2**
- Inner Range Ring
- Altitude Tape

**D3**
- Inner Range Ring
- Altitude Tape

*notional encounter*
Alerting & Guidance During **Corrective** Threat

-- LoDWC Predicted < 55 sec --

**D1**

- Inner Range Ring
- Altitude Tape

**D2**

- Inner Range Ring
- Altitude Tape

**D3**

- Inner Range Ring
- Altitude Tape

*notional encounter*
Alerting & Guidance During **Warning** Threat  
-- LoDWC Predicted < 25 sec --

**D1**  
- Inner Range Ring
- Altitude Tape

**D2**  
- Inner Range Ring
- Altitude Tape

**D3**  
- Inner Range Ring
- Altitude Tape

*notional encounter
Alerting & Guidance During **Well Clear Recovery**

-- LoDWC Unavoidable --

**D1**

- Inner Range Ring
- Altitude Tape

**D2**

- Inner Range Ring
- Altitude Tape

**D3**

- *notional encounter*
Aircraft Flight Model

• Generic MQ-9 Reaper
  – Speed:
    • Cruise: 110 knots
    • Landing: 90-110 knots
    • Max: 200 knots
    • Min: 70 knots
  – Default Climb Rate:
    • 1000ft/min
  – Default 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. **DAA Display** – traffic & alerting
  2. **Tactical Situation Display (TSD)** – vehicle control interfaces & maps
  3. **Viewer Tool** – contains approach plate & airport facility directory (AFD)
  4. **Right Panel** – landing checklist and additional info
  5. **Voice communication panel** – touchscreen, transmit/receive on select freqs.

Vigilant Spirit Control Station (AFRL)
- 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
  - Center controller managing Oakland Center (ZOA 40/41)
  - Tower controller managing Santa Rosa (KSTS)
  - Sector traffic modeled using real sector activity and data
- All participants communicated via push-to-talk headsets
  - Oakland Center frequency: 127.80
  - KSTS Tower frequency: 118.50
  - KSTS ATIS: 120.55
• 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
• Pilots were trained last on how to fly the approach
• Informed that:
  – Phase 1 DAA system was designed to assist pilots in maintaining DAA well clear during transit/en route operations in Class D, E, and G airspace
  – A Phase 2 DAA system is being developed to support terminal operations and therefore:
    • Phase 1 DAA well clear definition and associated alerting/guidance *may or may not be suitable* in terminal environments

❖ Told to use the DAA system *at their discretion* to conduct safe operations in the terminal environment
• Participants flew 3 different types of approaches into Santa Rosa Rwy 14 under Instrument Flight Rules (IFR)
  – Instrument (RNAV GPS) Approach
  – “Visual” Approach
  – Traffic Pattern

• 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 Approaches**

- Final approach coarse offset 15°
- Missed approach procedures = climb to 5000ft, fly runway heading (140°)

**Visual Approaches**

- “Visual” Approach Notes:
  - Airport “in sight” 10-12nm from runway
  - Line up for 3nm final stabilized approach
  - Traffic pattern @ 1150ft

**Pattern Approaches**

- Pattern Approach Notes:
  - Traffic pattern @ 1150ft
  - Controllers will give pattern entry instructions
    - 45° entry, mid-field entry or direct base
    - May extend downwind and call your base
  - Offset from Rwy14 should be ~1.5nm
Each scenario had 6 runs:

- 4 included a **scripted loss of DAA well clear** somewhere along approach:
  - 2 scripted to occur **Early** - before final; 5-10nm from airport
  - 2 scripted to occur **Late** - on final; within 3nm of airport
- 2 included **no scripted conflict** but interactions with traffic around airport were expected
  - Alerts and LoDWC possible due to size of DWC definition and 0.5nm offset of right downwind from runway
Participants

- 18 participants ($M = 38.5$ years of age)
  - All had manned flying experience ($M = 2200$ hours) and were IFR rated
    - Manned: $M = 3000$ hrs in civilian airspace; Unmanned: $M = 1000$ hrs in civilian airspace
  - $\frac{1}{2}$ had experience with unmanned aircraft ($M = 1100$ hours)
- 3 Air Traffic Control confederates
  - 1 retired tower controllers (Stockton)
  - 2 retired center controllers (Oakland Center)
- 4 Pseudo pilot confederates (current general aviation)
RESULTS
Global Statistics

• 216 total scripted conflicts (all single-threat encounters)
  = 18 (pilots) * 3 (scenarios per pilot) * 4 (scripted conflicts per scenario)

• 536 intruders registered (*in truth*) as DAA preventive, corrective or warning
  – 40% were against *scripted* conflicts
  – 60% were against *unscripted* conflicts

• Breakdown of (truth) alert types generated by intruders:

<table>
<thead>
<tr>
<th></th>
<th># of Unique Intruders</th>
<th>DAA Preventive</th>
<th>DAA Corrective</th>
<th>DAA Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scripted</td>
<td>210</td>
<td>147 (70%)</td>
<td>162 (77%)</td>
<td>191 (90%)</td>
</tr>
<tr>
<td>Unscripted</td>
<td>326</td>
<td>160 (49%)</td>
<td>215 (66%)</td>
<td>149 (46%)</td>
</tr>
</tbody>
</table>

**NOTE:**
“Truth” alerts = actual alert level registered by DAA system, regardless of experimental condition
• Results centered on the effect of display configuration and location of encounter
  – Display configuration was primary IV
  – Encounter location resulted in most pronounced results
    • Early = before final
    • Late = on final
    • Unscripted = almost exclusively pattern traffic (similar in location to ‘late’ encounters)
• Effects of pilot background, approach type and trial were examined but not focus of this presentation
  – Metrics where they had noteworthy effect are pointed out
RESPONSE AND ALERT TIMES
Visible Alerts

Visible Alerts (& Truth Alert) by Display Configuration

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visible</td>
<td>Truth</td>
<td>Visible</td>
</tr>
<tr>
<td>Preventive</td>
<td>178</td>
<td>97</td>
<td>165</td>
</tr>
<tr>
<td>Corrective</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>128</td>
<td></td>
<td>125</td>
</tr>
<tr>
<td>(visible as</td>
<td>(visible as</td>
<td>(visible as</td>
<td></td>
</tr>
<tr>
<td>preventive)</td>
<td>preventive)</td>
<td>preventive)</td>
<td></td>
</tr>
<tr>
<td>Warning</td>
<td></td>
<td></td>
<td>117</td>
</tr>
<tr>
<td>(visible as</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>preventive)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Alert levels were suppressed in D1 and D2
  - As a result pilots received greater number of DAA Preventive alerts and had to interpret if they were a legitimate threat
- Slightly fewer (~10%) DAA Warning (truth) alerts triggered in D3
• AC RT = time to upload maneuver following alert onset
• D1 condition resulted in slower responses to both corrective and warning alerts (~ 7-10 sec)
  – All conditions slower than was observed in Part Task 6
• Slowest AC RT when responding to encounters on final in Instrument Approach scenario
• Slower in first trial of day

**Aircraft Response Time (AC RT)**

**Avg. AC Response Time by Alert Level (Truth) & Display Configuration**

<table>
<thead>
<tr>
<th>Alert Level (Truth)</th>
<th>Corrective</th>
<th>Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>25.24</td>
<td>27.99</td>
</tr>
<tr>
<td>D2</td>
<td>17.71</td>
<td>18.37</td>
</tr>
<tr>
<td>D3</td>
<td>18.29</td>
<td>10.03</td>
</tr>
<tr>
<td>PT6 Avg</td>
<td>24.78</td>
<td>25.45</td>
</tr>
</tbody>
</table>

**Avg. AC RT by Scenario and Encounter Location**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Early</th>
<th>Late</th>
<th>Unscripted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>24.78</td>
<td>25.45</td>
<td>24.33</td>
</tr>
<tr>
<td>Visual</td>
<td>28.75</td>
<td>29.92</td>
<td>26.42</td>
</tr>
<tr>
<td>Pattern</td>
<td>19.67</td>
<td>20.00</td>
<td>19.67</td>
</tr>
</tbody>
</table>

**Avg. AC RT by Trial**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tr1</td>
<td>32.03</td>
</tr>
<tr>
<td>Tr2</td>
<td>26.68</td>
</tr>
<tr>
<td>Tr3</td>
<td>27.54</td>
</tr>
</tbody>
</table>
340 intruders registered as DAA Warning
- 29% spent 0 time as DAA Corrective
- 63% spent < 15 seconds as DAA Corrective

Late and Unscripted encounters most likely to spend < 15 seconds as DAA Corrective before registering as DAA Warning
SEPARATION DATA
Proportion of Losses of DAA Well Clear

- Proportion of losses of DAA Well Clear (LoDWC)
  - # of LoDWC / # aircraft that generated a DAA Corrective or Warning
- **176** total LoDWC / **472** total DAA Corrective and/or Warning alerts = **37% overall**
  - Consistent across conditions (34-39%)
- Alerted traffic most likely to lead to LoDWC when occurring late
  - Much smaller number of unscripted alerts actually led to LoDWC (26/249)
Loss of DAA Well Clear Severity (SLoWC)

- SLoWC = % of the DAA well clear volume (including tau) penetrated by intruder
  - Higher % = greater penetration
- On average, D2 resulted in less severe LoDWC (reduction ~6-8%)
- Late encounters consistently resulted in more severe LoDWC
  - Especially pronounced in D1 condition

![Graph showing Avg. SLoWC by Display Configuration and Encounter Location](image-url)
• Median SLoWC generally low (< 20%) across display configurations
• Median rises to 30% for late encounters
  – Median < 15% for early and unscripted encounters

• All display configurations and both early and late encounters experienced multiple high-severity losses of DAA well clear (> 50%)
Loss of DAA Well Clear Severity (SLoWC) > 50%

- D2 showed fewer high-severity LoDWC than D1 & D3
- Late encounters resulted in disproportionate # of high-severity LoDWC

<table>
<thead>
<tr>
<th></th>
<th>Early</th>
<th>Late</th>
<th>Unscripted</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLoWC Above 50</td>
<td>9 (16%)</td>
<td>18 (20%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>SLoWC Above 70</td>
<td>2 (3%)</td>
<td>6 (7%)</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: 60% were pilot error; 40% ”too slow”

Note: 75% ”too slow” or “no maneuver”
• 60% of all LoDWC breached the horizontal & vertical Phase 1 DWC thresholds (discarding tau component)
  – 13% breached CalAnalytics terminal area DWC

Actual Separation at CPA

|％ of Early/Late/Unscripted LoDWC |
|---|---|---|---|
|“Spatial” LoDWC | Early | Late | Unscripted |
|“Cal” LoDWC    | 10%  | 18%  | 0        |
|Total LoDWC    | 56%  | 89%  | 31%      |

Legend:
- Early
- Late
- Unscripted
Separation Results Summary

• Display configuration smaller effect on proportion and severity of LoDWC than encounter location
  – Late encounters disproportionately bad
  – Unscripted encounters low in number and severity

• All display configurations had instances of high severity SLoWC (> 50%)
  – Slight trend of less-severe LoDWC in D2
  – Most were due to pilot error (slow responses in particular)

• 105 cases of ‘spatial’ LoDWC and 22 cases using CalAnalytics criteria
  – Unscripted encounters never reached CalAnalytics volume
LoDWC BREAKDOWN
• Generally clustered around final with handful of losses during transition from Oakland center airspace to terminal area
• Majority of intruders are on or near right downwind
Legend:
- Intruder Position
- Ownship Position

Intruder & Own Lat/Long
• Encounters designed to turn directly into us while ownship was on final were most likely to result in LoDWC (97%)
• Encounters with a head-on KSTS departure while ownship was on final were most likely to result in “spatial” LoDWC (83%)

<table>
<thead>
<tr>
<th>Encounter Type</th>
<th>Encounter Location</th>
<th>% LoDWC</th>
<th>% &quot;Spatial&quot; LoDWC</th>
<th>Total Scripted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn Into Ownship</td>
<td>Late</td>
<td>97%</td>
<td>63%</td>
<td>36</td>
</tr>
<tr>
<td>Departure</td>
<td>Late</td>
<td>88%</td>
<td>83%</td>
<td>18</td>
</tr>
<tr>
<td>Overflight</td>
<td>Late</td>
<td>72%</td>
<td>44%</td>
<td>18</td>
</tr>
<tr>
<td>Turn in Front</td>
<td>Late</td>
<td>69%</td>
<td>47%</td>
<td>36</td>
</tr>
<tr>
<td>Overflight</td>
<td>Early</td>
<td>61%</td>
<td>29%</td>
<td>54</td>
</tr>
<tr>
<td>Cut-Off (Base)</td>
<td>Early</td>
<td>55%</td>
<td>38%</td>
<td>18</td>
</tr>
<tr>
<td>Parallel Track</td>
<td>Early</td>
<td>50%</td>
<td>22%</td>
<td>18</td>
</tr>
<tr>
<td>Departure</td>
<td>Early</td>
<td>22%</td>
<td>11%</td>
<td>18</td>
</tr>
</tbody>
</table>
Late Encounter Examples

<table>
<thead>
<tr>
<th>Turn Into Ownship</th>
<th>Turn In Front</th>
</tr>
</thead>
<tbody>
<tr>
<td># of LoDWC</td>
<td># of &quot;Spatial&quot; LoDWC</td>
</tr>
<tr>
<td>35 (97%)</td>
<td>23 (63%)</td>
</tr>
<tr>
<td>25 (69%)</td>
<td>17 (47%)</td>
</tr>
</tbody>
</table>
Late Encounter Examples

<table>
<thead>
<tr>
<th></th>
<th># of LoDWC</th>
<th># of &quot;Spatial&quot; LoDWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSTS Departure</td>
<td>16 (88%)</td>
<td>15 (83%)</td>
</tr>
<tr>
<td>Overflight (Late)</td>
<td>13 (72%)</td>
<td>8 (44%)</td>
</tr>
</tbody>
</table>
Early Encounter Examples

<table>
<thead>
<tr>
<th># of LoDWC</th>
<th># of &quot;Spatial&quot; LoDWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 (61%)</td>
<td>16 (29%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># of LoDWC</th>
<th># of &quot;Spatial&quot; LoDWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 (61%)</td>
<td>16 (29%)</td>
</tr>
</tbody>
</table>
Unscripted LoDWC

- Instances of LoDWC with unscripted encounters most often happened as intruder was on right downwind
  - Intruders turning base or final was second most common cause
- Ownship was typically established on final when these LoDWC occurred
  - Minority occurred when ownship was turning base/final or approaching the 3nm fix

<table>
<thead>
<tr>
<th>Intruder Location</th>
<th># LoDWC</th>
<th>&quot;Spatial&quot; LoDWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downwind</td>
<td>13</td>
<td>6 (46%)</td>
</tr>
<tr>
<td>Turning (Base or Final)</td>
<td>10</td>
<td>3 (30%)</td>
</tr>
<tr>
<td>On Final</td>
<td>4</td>
<td>3 (75%)</td>
</tr>
<tr>
<td>On Base</td>
<td>2</td>
<td>1 (50%)</td>
</tr>
<tr>
<td>Approaching Final</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Jet Traffic</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>31</strong></td>
<td><strong>11</strong></td>
</tr>
</tbody>
</table>
Pilot error accounted for 63% of LoDWC

- Most common cause of LoDWC was the pilot responding too slowly

Late acceleration (< 15sec to LoDWC at first alert)
2nd most common cause

D1 resulted in greatest number of slow responses
- D2 resulted in fewer slow responses against late encounters than D1 and D3

<table>
<thead>
<tr>
<th>LoDWC Category</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too Slow</td>
<td>34%</td>
</tr>
<tr>
<td>Ineffective Maneuver</td>
<td>11%</td>
</tr>
<tr>
<td>Return Too Soon</td>
<td>9%</td>
</tr>
<tr>
<td>Turned Base/Final Too Soon</td>
<td>5%</td>
</tr>
<tr>
<td>No Maneuver</td>
<td>2%</td>
</tr>
<tr>
<td>Secondary Cause by Pilot</td>
<td>2%</td>
</tr>
<tr>
<td>Pilot Not Responsible</td>
<td></td>
</tr>
<tr>
<td>Late Acceleration</td>
<td>33%</td>
</tr>
<tr>
<td>Pattern Activity</td>
<td>5%</td>
</tr>
</tbody>
</table>

# of "Too Slow" LoDWC by Config. & Encounter Location

- Display Configuration
- # of LoDWC
- Early
- Late
- Unscripted
- Total #
LoDWC Results Summary

• LoDWC occurred near final, and specifically alongside right downwind
  – Turns directly into ownership on final and a departure were most likely encounter
types to progress to LoDWC
  – Right downwind traffic was the biggest cause of LoDWC against unscripted
intruders
• 2/3 of LoDWC a result of slow pilot response or late acceleration (both
more common with late encounters)
MANEUVERING & ATC INTEROPERABILITY
Pilots resolved most maneuvers with heading changes

- Late encounters resulted in more altitude and speed changes than early encounters

**Maneuver Preferences**

**Early**

- Instrument
- Visual
- Pattern

**Late**

- Instrument
- Visual
- Pattern

**Unscripted**

- Instrument
- Visual
- Pattern
• 2 flights into terrain occurred during data collection runs
  – Both occurred during “visual” approach scenario where pilots descended to pattern altitude early

• Tower raised concern with number of 360s & turns made near runway
  – Much more common among pilots with unmanned experience and flying visual approach
Receiving ATC approval was rare, regardless of condition
- Slightly more frequent when returning to course
- Far less common than PT6

Initial Approval = # of initial maneuvers with approval from ATC / # of total maneuvers made
Return Approval = # of returns to course with approval from ATC / # of total returns to course
After each encounter, tower controller answered the following questions:

1. In this encounter did the UAS pilot maintain adequate separation?
   - Yes: 301
   - No: 20
   - N/A: 3

2. Did the UAS pilot maneuver unnecessarily for the encounter?
   - Yes: 271
   - No: 111
   - N/A: 7

3. Were there issues with UAS pilot communication?
   - Yes: 47
   - No: 206
   - N/A: 20

Tower rated UAS behavior as overwhelmingly appropriate
- Rated ‘inadequate’ separation typically when SLoWC > 50%
- Unnecessary maneuvers were noted typically identified when pilot disrupted pattern sequencing
- Communications was the most common issue (primarily not receiving advisory from pilot on traffic or maneuver)
• Heading maneuvers most common, more altitude/speed changes against late and unscripted encounters
• Major maneuver issues were flights into terrain and 360s/turns near runway
• UAS actions largely rated appropriate by tower
  – Tower often called out cases with SLoWC > 50% & unnecessary turns near pattern
  – Lack of coordination biggest issue raised by Tower
Phase 1 DAA Well Clear Definition

- Pilots had a hard time judging when a maneuver was necessary to avoid high-severity LoDWC
  - None above 30% in PT6
  - 17 > 50% SLoWC; 6 > 70% due to pilot error (slow responses most common)

Display Configuration

- Modest benefits for D2
  - D1 resulted in slower average pilot response times and twice as many LoDWC caused by slow responses compared to D2
  - D3 had greatest proportion of high-severity LoDWC
- Utility of corrective alert diminished near airport
  - Most Warning alerts either had no prior Corrective or Corrective < 15s

Encounter Location

- Late encounters responsible for most LoDWC
- LoDWC with unscripted encounters were low in frequency and severity

Additional

- LoDWC typically resulted from pilot hesitation and late acceleration
- Pilot rated well by ATC across the board with a few exceptions
  - E.g., rate of coordination, excessive maneuvering around final, flights into terrain
• Purpose: measure performance of DAA system using terminal-specific DAA well clear definitions

• Lessons learned to be leveraged in follow-on experiment
  – Removing pattern approach & early encounters from experimental design
  – Fewer scripted encounters

• Proposed IV’s:
  – Terminal DAA Well Clear candidate definitions:
    • AFRL: Horizontal = 0.2nm (~1215ft), Vertical = ±450ft, no Tau
    • Langley: TBD
  – Alert structure: with vs. without DAA Corrective

• Data collection begins 26 JANUARY