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

Conrad Rorie
Zach Roberts
Summer Brandt

Kevin Monk

UAS INTEGRATION IN THE NAS
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>![Symbol]</td>
<td>Warning Alert</td>
<td>30sec</td>
</tr>
<tr>
<td>![Symbol]</td>
<td>Preventive Alert</td>
<td>45sec</td>
</tr>
<tr>
<td>![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>![Symbol]</td>
<td>Warning Alert</td>
<td>30sec</td>
</tr>
<tr>
<td>![Symbol]</td>
<td>Corrective Alert</td>
<td>45sec</td>
</tr>
<tr>
<td>![Symbol]</td>
<td>Preventive Alert</td>
<td>45sec</td>
</tr>
<tr>
<td>![Symbol]</td>
<td>Guidance Traffic</td>
<td>N/A</td>
</tr>
<tr>
<td>![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>Warning Alert</td>
<td>• Notify ATC as soon as practicable after taking action</td>
<td>Horz = 1500ft, ZTHR = 450 ft</td>
<td>DMOD = 1500ft, HMD = 1500ft, ZTHR = 450 ft</td>
<td>30 sec</td>
<td>“Traffic, Maneuver Now” x2</td>
</tr>
<tr>
<td>![ ]</td>
<td>Corrective Alert</td>
<td>• Coordinate with ATC to determine an appropriate maneuver</td>
<td>Horz = 1500ft, ZTHR = 450 ft</td>
<td>DMOD = 1500ft, HMD = 1500ft, ZTHR = 450 ft</td>
<td>45 sec</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td>![ ]</td>
<td>Preventive Alert</td>
<td>• On current course, corrective action should not be required</td>
<td>Horz = 1500ft, ZTHR = 700 ft</td>
<td>DMOD = 1500ft, HMD = 1500ft, ZTHR = 700 ft</td>
<td>45 sec</td>
<td>“Traffic, Monitor”</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>Associated w/ bands outside current course</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>![ ]</td>
<td>Remaining Traffic</td>
<td>• Traffic within sensor range</td>
<td>Within surveillance field of regard</td>
<td>Within surveillance field of regard</td>
<td></td>
<td>X</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) 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.
• 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)
Scenario Design

• 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>DWC Candidate</th>
<th>Preventive</th>
<th>Corrective</th>
<th>Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>35</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>Tau</td>
<td>52</td>
<td>75</td>
<td>67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DWC Candidate</th>
<th>Turn Into</th>
<th>Turn In Front</th>
<th>Unscripted</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>31</td>
<td>19</td>
<td>46</td>
</tr>
<tr>
<td>Tau</td>
<td>31</td>
<td>21</td>
<td>113</td>
</tr>
</tbody>
</table>
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 = 15.2 sec
    • Median = 15 sec
  – Turn In Front = 7.3 sec
    • Median = 6 sec
  – Unscripted = 7.5 sec
    • Median = 6 sec
• **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

**Aircraft RT by DWC Candidate & Alert Type**

![Bar chart showing Aircraft Response Time by DWC Candidate and Alert Type]
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

### Total # LoDWC

<table>
<thead>
<tr>
<th>LoDWC Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>8</td>
</tr>
<tr>
<td>Tau</td>
<td>18</td>
</tr>
<tr>
<td>TOPS 1</td>
<td>82</td>
</tr>
</tbody>
</table>

### # LoDWC by DWC Candidate & Alerting Configuration

<table>
<thead>
<tr>
<th>DWC Candidate</th>
<th>Alerting Configuration</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>No Corrective</strong></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>With Corrective</strong></td>
<td>5</td>
</tr>
<tr>
<td>Tau</td>
<td><strong>No Corrective</strong></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>With Corrective</strong></td>
<td>13</td>
</tr>
</tbody>
</table>
• 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](image)

<table>
<thead>
<tr>
<th>DWC Candidate</th>
<th>No Corrective</th>
<th>With Corrective</th>
<th>Avg. Phase 1 SLoWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>46.32</td>
<td>45.06</td>
<td>45.61</td>
</tr>
<tr>
<td>Tau</td>
<td>42.16</td>
<td>45.82</td>
<td>44.44</td>
</tr>
<tr>
<td>TOPS 1</td>
<td>26.46</td>
<td>30.36</td>
<td>28.40</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 *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 at Closest Point in LoDWC**

<table>
<thead>
<tr>
<th>Horizontal Separation</th>
<th>Vertical Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tau</td>
<td>944.85 ft</td>
</tr>
<tr>
<td>Tau</td>
<td>1,970.10 ft</td>
</tr>
<tr>
<td>No Tau</td>
<td>394.14 ft</td>
</tr>
<tr>
<td>Tau</td>
<td>406.94 ft</td>
</tr>
</tbody>
</table>

Alerting Configuration:
- No Corrective
- With Corrective
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>

Pilot-Responsible LoDWC Only
• 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
MANEUVERING & ATC INTEROPERABILITY
• 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
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)
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**
  - Inner Range Ring
  - Altitude Tape

- **Corrective (Truth) Alert**
  - Inner Range Ring
  - Altitude Tape

**With Corrective**

- **Preventive (Truth) Alert**
  - Inner Range Ring
  - Altitude Tape

- **Corrective (Truth) Alert**
  - Inner Range Ring
  - Altitude Tape
**DAA Alerting & Guidance**

**No Corrective**
- Warning (Truth) Alert

**With Corrective**
- Warning (Truth) Alert

**Regain DWC Guidance**

[Diagram showing the alerting and guidance features for both no corrective and with corrective options.]
After each encounter, tower controller answered the following questions:

- 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
DAA Alerts Without a Maneuver

- 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

![Chart showing # Alerts Without a Maneuver]

No Corrective | With Corrective
---|---
No Tau | 6 | 0 | 0 | 6
Tau | 23 | 11

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 Made Without a DAA Alert

- Speed Decrease
- Climb
- Heading Change

<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></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

### Maneuver Type x Maneuver Order

<table>
<thead>
<tr>
<th>Maneuver Type</th>
<th>1st Maneuver</th>
<th>2nd Maneuver</th>
<th>3rd Maneuver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading Change</td>
<td>15 18</td>
<td>7 5</td>
<td>3 6</td>
</tr>
<tr>
<td>Missed Approach</td>
<td>16 9</td>
<td>7 2</td>
<td>3 6</td>
</tr>
<tr>
<td>Speed Decrease</td>
<td>38 54</td>
<td>3 6</td>
<td>5 4</td>
</tr>
<tr>
<td>Temporary Climb</td>
<td>1 0</td>
<td>2 6</td>
<td>4 0</td>
</tr>
</tbody>
</table>

### Count of Maneuvers

- **Heading Change**: 15 Instrument, 16 Visual
- **Missed Approach**: 18 Instrument, 15 Visual
- **Speed Decrease**: 54 Instrument, 38 Visual
- **Temporary Climb**: 10 Instrument, 11 Visual
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

Highest SLoWC Encounter

```
<table>
<thead>
<tr>
<th>Longitude (deg)</th>
<th>Ownship</th>
<th>Warning Alert active</th>
</tr>
</thead>
<tbody>
<tr>
<td>-122.92</td>
<td>-122.94</td>
<td>-122.92</td>
</tr>
<tr>
<td>-122.88</td>
<td>-122.86</td>
<td>-122.86</td>
</tr>
<tr>
<td>-122.84</td>
<td>-122.82</td>
<td>-122.82</td>
</tr>
<tr>
<td>-122.82</td>
<td>-122.80</td>
<td>-122.80</td>
</tr>
<tr>
<td>-122.78</td>
<td>-122.80</td>
<td>-122.80</td>
</tr>
<tr>
<td>-122.88</td>
<td>-122.92</td>
<td>-122.92</td>
</tr>
<tr>
<td>-122.84</td>
<td>-122.86</td>
<td>-122.86</td>
</tr>
<tr>
<td>-122.82</td>
<td>-122.82</td>
<td>-122.82</td>
</tr>
<tr>
<td>-122.78</td>
<td>-122.80</td>
<td>-122.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Latitude (deg)</th>
<th>Ownship</th>
<th>Warning Alert active</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.46</td>
<td>-122.92</td>
<td>-122.94</td>
</tr>
<tr>
<td>38.48</td>
<td>-122.86</td>
<td>-122.86</td>
</tr>
<tr>
<td>38.50</td>
<td>-122.82</td>
<td>-122.82</td>
</tr>
<tr>
<td>38.52</td>
<td>-122.80</td>
<td>-122.80</td>
</tr>
<tr>
<td>38.54</td>
<td>-122.80</td>
<td>-122.80</td>
</tr>
<tr>
<td>38.56</td>
<td>-122.82</td>
<td>-122.82</td>
</tr>
<tr>
<td>38.58</td>
<td>-122.84</td>
<td>-122.84</td>
</tr>
<tr>
<td>38.60</td>
<td>-122.86</td>
<td>-122.86</td>
</tr>
<tr>
<td>38.62</td>
<td>-122.88</td>
<td>-122.88</td>
</tr>
<tr>
<td>38.64</td>
<td>-122.90</td>
<td>-122.90</td>
</tr>
</tbody>
</table>
```

UA made left 360
• 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.