UAS Integration into the NAS: iHITL: DAA Display Evaluation Preliminary Results

Presented To: RTCA SC-228
18 NOV 2014

Lisa Fern (Lisa.Fern@NASA.GOV)
The Ohio State University

Conrad Rorie (Conrad.Rorie@NASA.GOV)
San Jose State University

Jay Shively (Robert.J.Shively@NASA.GOV)
NASA Ames Research Center
Overview

• Goals:
  1. Leverage the lessons learned from PT4 to continue the evaluation of candidate Sense and Avoid (SAA) with respect to pilot performance of the self-separation function
     • What are the individual contributions of the various PT4 advanced display features to pilots’ response times and ability to maintain well clear?
  2. Introduce non-cooperative intruders to examine effect of different sensor ranges on pilots’ ability to maintain well clear

• Rationale
  – PT4 compared a ‘Basic’ display configuration to a suite of ‘Advanced’ features
     • iHitL design will allow us to measure any differences between specific display features and determine the implications of their presence or absence in the GCS
  – Non-cooperative traffic are a major consideration in the development of SAA systems
     • The presence of non-cooperative aircraft provides a more realistic environment
     • Limited surveillance range and field of regard may have significant impact on pilot performance and behavior
Experimental Design

- One-Way Repeated Measures Factorial: Display Information Level (4 Level; Within Subjects)
  - D1: Advanced Display with Information Only
  - D2: Advanced Display with Information + Vector Planner
  - D3: Advanced Display with Information + Auto Resolutions
  - D4: Advanced Display with Information + Vector Planner + Auto Resolutions
    - Roughly same as ‘Advanced’ suite in PT4

- Embedded Variable
  - Track Type (manipulated within each scenario; not counterbalanced)
    1. Cooperative Traffic (ADS-B-equipped)
      - Range = 80nm & +/- 5000ft
    2. Non-Cooperative Traffic
      - Range = 6nm
      - Azimuth = +/- 110deg (from nose)
      - Elevation = +/- 20deg (from horizontal)
Alerting Criteria

**Vertical Separation**
- Well-clear: 400 feet
- Self Separation: 900 feet
- Preventive: 900 feet

- **“Well Clear” Threshold**: 400 feet
- **“Self Separation” Threshold**: 900 feet
- **“Preventive Alert” Threshold**: 900 feet

Time until CPA:
- 10 seconds: 07
- 25 seconds: 02
- 40 seconds: 00
- 110 seconds: 15

Vertical Separation:
- Well-clear: 400 feet
- Self Separation: 900 feet
- Preventive: 900 feet
Display Conditions

D1

D2

D3

D4
D1 Encounter
D2 Encounter
D3 Encounter
D4 Encounter
Participants

- Participants:
  - 4 MQ-1 Predator/MQ-9 Reaper Pilots (avg. 46 years old)
    - All received Undergraduate Pilot Training
  - 5 RQ-4 Global Hawk Pilots (avg. 33 years old)
    - 3 received Undergraduate Pilot Training
    - 1 received RQ-4 Basic Training (AF Specialty Code 18X)
    - 1 received cross training
  - All 9 pilots had military UAS experience
    - Military Combat & Non-Combat Experience = avg. 1182 hours
    - Civilian Airspace = avg. 153 hours
      - 5 pilots had less than 50 hours of experience flying in civilian airspace
  - 1 retired Air Traffic Controller with experience in Oakland Center airspace (confederate)
Procedure

• UAS Scenario (38min)
  – UAS: Predator B
  – Airspace: ZOA 40/41
    • Class A & E with mixed IFR/VFR traffic
    • Manned traffic modeled using real traffic data

• Primary Tasks:
  1. Fly HAWK21 along pre-filed path (Fire Line)
     • Only responsible for navigating the aircraft
     • Requires interaction with the GCS and coordination ATC
  2. Comply with ATC clearances and traffic display alerts to maintain safety of flight

• Secondary tasks:
  – ‘Chat’ directed
    • “Mission” Radio Frequency changes
    • Radial and Distance check
    • Nominal information requests (e.g., fuel level remaining)
  – System Alerts
    • Generator Failure (checklist)
    • Tanker Header Overpressure (checklist)
    • Annunciator checks
Initial Research Question

• What was the effect of the DAA guidance tools on pilots’ performance in response to self separation alerts?
  – Same measured response metrics as those captured in PT4

• Measured Response data were analyzed utilizing 5 separate One-Way Analyses of Variance (ANOVAs)

I. Independent Variable: Display
1) D1: Advanced Display with Information Only
2) D2: Advanced Display with Information + Vector Planner
3) D3: Advanced Display with Information + Auto Resolutions
4) D4: Advanced Display with Information + Vector Planner + Auto Resolutions

II. Analyses for: Alert Type and Intruder Type
1) All self separation (SS) alerts
2) Predictive SS alerts (yellow with red outline; collapsed across Intruder Type)
3) Non-Predictive SS alerts (yellow; collapsed across Intruder Type)
4) Cooperative SS alerts (collapsed across Alert Type)
5) Non-Cooperative SS alerts (collapsed across Alert Type)
Stages of Pilot DAA Task

<table>
<thead>
<tr>
<th>Stage</th>
<th>Time Mark</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Display Alert (SS or CA)</td>
<td>$T_0$</td>
<td>Pilot Notifies ATC</td>
</tr>
<tr>
<td>ATC Approval</td>
<td>$T_1$</td>
<td>Pilot Initiates Edit</td>
</tr>
<tr>
<td>Clearance Approval Time</td>
<td>$T_2$</td>
<td>Pilot Uploads First Edit</td>
</tr>
<tr>
<td>Notification Time</td>
<td>$T_3$</td>
<td>Pilot Uploads Final Edit</td>
</tr>
<tr>
<td>Total Response Time</td>
<td>$T_4a$</td>
<td>Traffic Alert Removed</td>
</tr>
<tr>
<td>Total Edit Time (Final Upload)</td>
<td>$T_4b$</td>
<td>UAS Completes Maneuver</td>
</tr>
<tr>
<td>Total Compliance Time</td>
<td>$T_5$</td>
<td></td>
</tr>
<tr>
<td>Upload Time</td>
<td>$T_6$</td>
<td></td>
</tr>
</tbody>
</table>

- $T_0$: Traffic Display Alert (SS or CA)
- $T_1$: Pilot Notifies ATC
- $T_2$: ATC Approval
- $T_3$: Pilot Initiates Edit
- $T_4a$: Pilot Uploads First Edit
- $T_4b$: Pilot Uploads Final Edit
- $T_5$: Traffic Alert Removed
- $T_6$: UAS Completes Maneuver

**Diagram:**
- Compliance Time
- Alert Duration Time
- Total Response Time
- Aircraft Response Time
- Initial Response Time
- Clearance Approval Time
- Initial Edit Time (First Upload)
- Total Edit Time (Final Upload)
Self-Separation Timeline

TOTAL RESPONSE TIME:
- Detect Intruders
- Pilots Determine Resolution
- Negotiate Clearance with ATC and uplink maneuver to aircraft

Time until CPA

110 sec

? sec

35 sec

Aircraft Maneuver Time

Well Clear Threshold
Encounter Statistics

• Total Number of Encounters:
  – Alert Type:
    • 134 Predictive SS Alerts
    • 115 Non-Predictive SS Alerts
  – Intruder Type:
    • 92 Cooperative
    • 157 Non-Cooperative

• Pilots responded to a total of 196 Self Separation Alerts
  – Alert Type:
    • 122 Predictive SS Alerts (91% of total)
    • 74 Non-Predictive SS Alerts (64% of total)
  – Intruder Type:
    • 61 Cooperative (66% of total)
    • 135 Non-Cooperative (86% of total)
  – Alert Type X Intruder Type:
    • 25 Cooperative/Predictive
    • 36 Cooperative/Non-Predictive
    • 97 Non-Cooperative/Predictive
    • 38 Non-Cooperative/Non-Predictive
Data Slides Organization

Slides organized by metric

- Analysis of Variance (ANOVA) results for All SS Alerts
  - Was there an effect of Display on the dependent variable?
- ANOVA by Alert Type
- ANOVA by Intruder Type
- Means of the Alert/Intruder Type by Display
- Means of Display by Alert/Intruder Type
- Comparison of display means for PT4 and iHITL
## iHITL Results

### Summary of Results

<table>
<thead>
<tr>
<th></th>
<th>PT4 Grand Mean</th>
<th>iHITL Grand Mean</th>
<th>All SS</th>
<th>Predictive</th>
<th>Non-Predictive</th>
<th>Cooperative</th>
<th>Non-Cooperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notification Time</td>
<td>29.07s</td>
<td>14.03s</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Clearance Approval Time</td>
<td>5.08s</td>
<td>5.54s</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ATC Notification vs Upload Time</td>
<td>3.51s</td>
<td>0.18s</td>
<td>$p = .075$</td>
<td>X</td>
<td>$p &lt; .05$</td>
<td>$p = -.55$</td>
<td>X</td>
</tr>
<tr>
<td>ATC Approval vs Upload Time</td>
<td>-1.52s</td>
<td>-6.46s</td>
<td>$p = .092$</td>
<td>X</td>
<td>$p &lt; .05$</td>
<td>$p = .070$</td>
<td>X</td>
</tr>
<tr>
<td>Initial Response Time</td>
<td>19.32s</td>
<td>8.52s</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Initial Edit Time</td>
<td>11.77s</td>
<td>6.29s</td>
<td>$p &lt; .01$</td>
<td>$p &lt; .05$</td>
<td>$p &lt; .05$</td>
<td>$p &lt; .01$</td>
<td>$p = .056$</td>
</tr>
<tr>
<td>Total Edit Time</td>
<td>17.65s</td>
<td>9.83s</td>
<td>X</td>
<td>$p &lt; .05$</td>
<td>X</td>
<td>X</td>
<td>$p = .064$</td>
</tr>
<tr>
<td>Aircraft Response Time</td>
<td>32.19s</td>
<td>14.54s</td>
<td>$p = .069$</td>
<td>$p = .059$</td>
<td>$p &lt; .05$</td>
<td>$p &lt; .01$</td>
<td>X</td>
</tr>
<tr>
<td>Total Response Time</td>
<td>37.87s</td>
<td>18.08s</td>
<td>X</td>
<td>$p = .056$</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Alert Duration Time</td>
<td>48.61s</td>
<td>33.58s</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Compliance Time</td>
<td>71.43s</td>
<td>37.53s</td>
<td>$p &lt; .05$</td>
<td>$p &lt; .05$</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Only 6 significant differences between display conditions
Some Results:
Total Edit Time
Total Response Time
Stages of Pilot DAA Task

- Traffic Display Alert (SS or CA)
- Pilot Notifies ATC
- ATC Approval
- Pilot Initiates Edit
- Pilot Uploads First Edit
- Pilot Uploads Final Edit
- Traffic Alert Removed
- UAS Completes Maneuver

Time Points:

- $T_0$: Traffic Display Alert
- $T_1$: Pilot Notifies ATC
- $T_2$: ATC Approval
- $T_3$: Pilot Initiates Edit
- $T_{4a}$: Pilot Uploads First Edit
- $T_{4b}$: Pilot Uploads Final Edit
- $T_5$: Traffic Alert Removed
- $T_6$: UAS Completes Maneuver
There was a not significant effect of Display on Total Edit Time for all SS alerts, p > .05

Pilots took an average of **9.83 seconds** to complete their final edit in response to SS alerts
• There was a significant effect of Display on Total Edit Time for Predictive alerts, $p < .05$
  
  — D3 was significantly faster than D2, but no different than the other two displays

• Pilots took an average of 8.83 seconds to complete their final edit in response to Predictive SS alerts

• There was no significant main effect of Display on Total Edit Time for Non-Predictive alerts, $p > .05$

• Pilots took an average of 12.862 seconds to complete their final edit in response to Non-Predictive SS alerts
There was no significant effect of Display on Total Edit Time for Cooperative SS alerts, $p > .05$

Pilots took an average of **12.08 seconds** to complete their final edit in response to Cooperative SS alerts

There was a near significant effect of Display on Total Edit Time for Non-Cooperative SS alerts, $p = .064$

Pilots took an average of **8.31 seconds** to complete their final edit in response to Non-Cooperative alerts
### Total Edit Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooperative/Predictive</strong></td>
<td>16.33</td>
<td>12.64</td>
<td>14.00</td>
<td>12.17</td>
</tr>
<tr>
<td><strong>Cooperative/Non-Predictive</strong></td>
<td>16.40</td>
<td>12.63</td>
<td>2.50</td>
<td>13.64</td>
</tr>
<tr>
<td><strong>Non-Cooperative/Predictive</strong></td>
<td>13.26</td>
<td>10.50</td>
<td>2.64</td>
<td>4.54</td>
</tr>
<tr>
<td><strong>Non-Cooperative/Non-Predictive</strong></td>
<td>8.21</td>
<td>10.86</td>
<td>13.17</td>
<td>9.40</td>
</tr>
</tbody>
</table>
Total Edit Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>16.33</td>
<td>16.40</td>
<td>13.26</td>
<td>8.21</td>
</tr>
<tr>
<td>D2</td>
<td>12.64</td>
<td>12.63</td>
<td>10.50</td>
<td>10.86</td>
</tr>
<tr>
<td>D3</td>
<td>14.00</td>
<td>2.50</td>
<td>2.64</td>
<td>13.17</td>
</tr>
<tr>
<td>D4</td>
<td>12.17</td>
<td>13.64</td>
<td>4.54</td>
<td>9.40</td>
</tr>
</tbody>
</table>
Stages of Pilot DAA Task

- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit
- **T₅**: Traffic Alert Removed
- **T₆**: UAS Completes Maneuver

**Key Times**:
- **Initial Response Time**
- **Initial Edit Time (First Upload)**
- **Total Edit Time (Final Upload)**
- **Aircraft Response Time**
- **Notification Time**
- **Clearance Approval Time**
- **Compliance Time**
- **Alert Duration Time**
- **Total Response Time**
- **Time (First Upload)**
- **Time (Final Upload)**

**Notations**:
- **Initial Notify vs Upload Time**
- **Approval vs Upload Time**
• There was not a significant effect of Information on Total Response Time for all SS alerts, $p > .05$

• Pilots took an average of 18.08 seconds to complete their final edit in response to SS alerts (from first alert appearance)
There was a near significant effect of Display on Total Response Time for Predictive SS alerts, $p = .056$

- Pilots took an average of **16.22 seconds** to complete their final edit in response to Predictive SS alerts (from first alert appearance)

There was no significant effect of Display on Total Response Time, $p > .05$

- Pilots took an average of **22.86 seconds** to complete their final edit in response to Non-Predictive SS alerts (from first alert appearance)
There was no significant effect of Information on Aircraft Response Time for Cooperative SS alerts, p > .05

Pilots took an average of 23.92 seconds to complete their final edit in response to Cooperative SS alerts (from first alert appearance)

There was no significant effect of Display on Aircraft Response Time for Non-Cooperative SS alerts, p > .05

Pilots took an average of 15.15 seconds to complete their final edit in response to Non-Cooperative SS alerts (from first alert appearance)
## Total Response Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>26.33</td>
<td>30.36</td>
<td>31.17</td>
<td>19.00</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>26.90</td>
<td>23.46</td>
<td>15.70</td>
<td>24.71</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>18.28</td>
<td>15.48</td>
<td>10.52</td>
<td>11.23</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>21.64</td>
<td>16.67</td>
<td>22.90</td>
<td>16.10</td>
</tr>
</tbody>
</table>
Total Response Time

Cooperative/Predictive  | Cooperative/Non-Predictive  | Non-Cooperative/Predictive  | Non-Cooperative/Non-Predictive
---|---|---|---
D1  | 26.33 | 26.90 | 18.28 | 21.64
D2  | 30.36 | 23.46 | 15.48 | 16.67
D3  | 31.17 | 15.70 | 10.52 | 22.90
D4  | 19.00 | 24.71 | 11.23 | 16.10

0.00  | 5.00  | 10.00 | 15.00 | 20.00 | 25.00 | 30.00 | 35.00 | 40.00

Bars represent the total response time for different scenarios with error bars indicating variability.
iHITL Results Summary

• Few Meaningful Significant Results
  – Except for one, all for edit times where D3, and sometimes D4, are significantly faster
  – Does not translate to significant difference in total response time
    • No more than 8.5s difference between fastest and slowest times from Non-Cooperative/Predictive

• Some overall Trends:
  – Predictive alerts tended to have faster response times than Non-Predictive alerts
  – Non-Cooperative alerts tended to have faster response times than Cooperative alerts
  – Except for Edit Times, appears to be less variability across Intruder/Alert (especially Non-Cooperative/Predictive) type than Display type
iHITL Results Summary

- **Initial Response Time:**
  - Non-Cooperative on average 5 seconds faster than Cooperative
  - Intruder/alert type appears more predictive of response time with low variability between D1 – D4
  - Non-Cooperative/Predictive fastest overall

- **Initial Edit Time:**
  - D3 consistently significantly fastest
  - D1 consistently significantly slowest
  - Lower variability for D3 and D2, higher variability for D1 and D4 across Intruder type

- **Total Edit Time:**
  - D3 significantly faster than D2 for Predictive SS alerts only (about 8 seconds faster)
  - Non-Cooperative on average 4 seconds faster than Cooperative
  - Least variability in D2 across Intruder/Alert Type

- **Aircraft Response Time**
  - D4 significantly faster than D1 and D2 (10-20 seconds)
  - Lowest and least variability in response times for Non-Cooperative/Predictive
  - Least variability in D4

- **Total Response Time**
  - No significant results
  - Predictive on average 5.5 seconds faster than Non-Predictive
  - Non-Cooperative on average 9 seconds faster than cooperative
iHITL and PT4 Results

- iHITL Response Times faster than PT4 Response Times
- Closest comparisons:
  - PT4 Basic_Integrated (Basic) vs. iHITL D1
    - D1 added information: predictive alert level, well clear ring, intruder CPA location
  - PT4 Advanced_Integrated (Advanced) vs. iHITL D4
    - D4 removed information: vertical situation display, ownship CPA, time to CPA
- Initial Response Time, about 11 seconds faster overall (19.32s vs. 8.52s)
- Total Edit Time, about 8 seconds faster overall (17.65s vs. 9.82s)
- Total Response Time, about 8 seconds faster overall (37.87s vs. 18.08s)

<table>
<thead>
<tr>
<th>Measure</th>
<th>PT4 Basic</th>
<th>iHITL D1</th>
<th>PT4 Advanced</th>
<th>iHITL D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Response Time</td>
<td>22</td>
<td>8</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>Total Edit Time</td>
<td>23</td>
<td>13</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Total Response Time</td>
<td>45</td>
<td>21</td>
<td>32</td>
<td>16</td>
</tr>
</tbody>
</table>
Initial Response Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Response Time</td>
<td>7.89</td>
<td>8.28</td>
<td>9.60</td>
<td>7.24</td>
<td>21.62</td>
<td>22.09</td>
<td>15.26</td>
<td>18.30</td>
</tr>
</tbody>
</table>

*Note: The values represent response times in seconds.*
Total Edit Time

IHITL and PT4 Display Comparison

- D1: 12.65
- D2: 11.43
- D3: 6.74
- D4: 8.51
- Int_Basic: 22.65
- Int_Advanced: 10.08
- SA_Basic: 21.60
- SA_Advanced: 16.28
Total Response Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>20.54</td>
<td>19.71</td>
<td>16.34</td>
<td>15.74</td>
<td>44.86</td>
<td>32.35</td>
<td>38.68</td>
<td>35.60</td>
</tr>
</tbody>
</table>
Self-Separation Timeline

TOTAL RESPONSE TIME:
Detect Intruders
Pilots Determine Resolution
Negotiate Clearance with ATC and uplink maneuver to aircraft

Time until CPA
110 sec  ? sec  35 sec

Aircraft Maneuver Time
Well Clear Threshold
Self-Separation Timeline

Latest SS alerting time that allows pilot to upload final maneuver by display

- Basic Integrated (45s) at 55 sec
- Basic Standalone (39s) at 94 sec
- Advanced Standalone (36s) at 91 sec
- Advanced Integrated (32s) at 87 sec

Well Clear Threshold at 40 sec

Time until CPA
Self-Separation Timeline

- Time until CPA:
  - 110 sec
  - ? sec
  - 35 sec

- Aircraft Maneuver Time:
  - Basic Integrated (45s): 30 sec
  - Basic Standalone (39s): 36 sec
  - Advanced Standalone (36s): 39 sec
  - Advanced Integrated (32s): 43 sec

- Well Clear Threshold
Self-Separation Timeline

- **Time until CPA**
  - 110 sec
  - ? sec
  - 35 sec

- **Aircraft Maneuver Time**
  - D1 (21s): 54 sec
  - D2 (20s): 55 sec
  - D3 (16s): 59 sec
  - D4 (16s): 59 sec

- **Well Clear Threshold**
DAA Task

• What does the DAA Task add to pilot response times?
  – A number of subtasks:
    • Detect
    • Determine
    • Execute

• Can compare to pilot response times when responding to ATC clearances in same navigation mode (AutoPilot; full mission simulation)
  – Assumption that ATC response is near immediate
  – Auto resolution conditions (D3 and D4) actually reduce edit times

<table>
<thead>
<tr>
<th>Measure</th>
<th>FM AP Mean</th>
<th>iHITL Grand Mean</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial RT</td>
<td>1.23s</td>
<td>8.25s</td>
<td>+7.02s</td>
</tr>
<tr>
<td>Initial Edit Time</td>
<td>9.11s</td>
<td>6.29s</td>
<td>-2.82s</td>
</tr>
<tr>
<td>Total Edit Time</td>
<td>9.25s</td>
<td>9.83s</td>
<td>+0.58s</td>
</tr>
<tr>
<td>Aircraft RT</td>
<td>10.43s</td>
<td>14.54s</td>
<td>+4.11s</td>
</tr>
</tbody>
</table>
HSI Follow on Research

- Part Task Simulation 5
  - Goal: Continue examining DAA display concepts
  - Revisit a minimum information display condition – PT4 Basic with predictive alert level
  - Evaluate suggestive and informative displays
  - Evaluate effect of nominal uncertainty on displays and pilot performance
  - Data Collection March 2014
All Results Slides
Stages of Pilot DAA Task

- **T0**: Traffic Display Alert (SS or CA)
- **T1**: Pilot Notifies ATC
- **T2**: ATC Approval
- **T3**: Pilot Initiates Edit
- **T4a**: Pilot Uploads First Edit
- **T4b**: Pilot Uploads Final Edit
- **T5**: Traffic Alert Removed
- **T6**: UAS Completes Maneuver

**Parameters**:
- Compliance Time
- Alert Duration Time
- Total Response Time
- Aircraft Response Time
- Initial Response Time
- Initial Edit Time (First Upload)
- Total Edit Time (Final Upload)

**Times**:
- **T0**
- **T1**
- **T2**
- **T3**
- **T4a**
- **T4b**
- **T5**
- **T6**

**Key Times**:
- **Notification Time**
- **Clearance Approval Time**
- **Initial Response Time**
- **Total Response Time**
- **Total Edit Time** (First/_Final Upload)
- **Approval vs Upload Time**
- **Notify vs Upload Time**

**Additional Notes**:
- **Approval** vs **Upload Time**
- **Clearance** Approval Time

**Legend**:
- **NASA** logo
- **UAS Integration in the NAS** logo
• There was a not a significant main effect of Display on ATC Notification Time for all SS alerts, \( p > .05 \)

• Pilots took an average of **14.03 seconds** to notify ATC of a maneuver in response to a SS alert
• There was no significant effect of Display on ATC Notification Time for Predictive SS alerts, p > .05
• Pilots took an average of **14.05 seconds** to notify ATC of a maneuver in response to a Predictive SS alert

• There was no significant effect of Display on ATC Notification Time for Non-Predictive SS alerts, p > .05
• Pilots took an average of **14.52** to notify ATC of a maneuver in response to a Non-Predictive SS alert
ATC Notification Time

- There was no significant effect of Display on ATC Notification Time for Cooperative SS alerts, $p > .05$
- Pilots took an average of **16.40 seconds** to notify ATC of a maneuver in response to a Cooperative SS alert

- There was no significant effect of Display on ATC Notification Time for Non-Cooperative SS alerts, $p > .05$
- Pilots took an average of **13.15 seconds** to notify ATC of a maneuver in response to a Non-Cooperative SS alert
ATC Notification Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>15.67</td>
<td>23.21</td>
<td>15.67</td>
<td>7.33</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>18.88</td>
<td>15.14</td>
<td>12.40</td>
<td>20.72</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>11.49</td>
<td>14.50</td>
<td>13.28</td>
<td>15.94</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>14.83</td>
<td>14.08</td>
<td>8.43</td>
<td>22.75</td>
</tr>
</tbody>
</table>
ATC Notification Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>15.67</td>
<td>18.88</td>
<td>11.49</td>
<td>14.83</td>
</tr>
<tr>
<td>D2</td>
<td>23.21</td>
<td>15.14</td>
<td>14.50</td>
<td>14.08</td>
</tr>
<tr>
<td>D3</td>
<td>15.67</td>
<td>12.40</td>
<td>13.28</td>
<td>8.43</td>
</tr>
<tr>
<td>D4</td>
<td>7.33</td>
<td>20.72</td>
<td>15.94</td>
<td>22.75</td>
</tr>
</tbody>
</table>
ATC Notification Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>13.05</td>
<td>14.52</td>
<td>12.08</td>
<td>16.49</td>
<td>32.40</td>
<td>26.76</td>
<td>31.91</td>
<td>25.22</td>
</tr>
</tbody>
</table>
Stages of Pilot DAA Task

- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit
- **T₅**: Traffic Alert Removed
- **T₆**: UAS Completes Maneuver
• There was no significant main effect of Information on Clearance Approval Time, \( p > 0.05 \)

• It took an average of **5.54 seconds** for pilots to receive and an ATC approval for a maneuver in response to a SS alert
• There was no significant main effect of Information on Clearance Approval Time, p > .05
• It took an average of **5.50 seconds** for pilots to receive and an ATC approval for a maneuver in response to a Predictive SS alert

• There was no significant main effect of Display on Clearance Approval Time, p > .05
• It took an average of **5.96 seconds** for pilots to receive and an ATC approval for a maneuver in response to a Non-Predictive SS alert
Clearance Approval Time

Cooperative SS Alerts

- There was not a significant effect of Display on Clearance Approval Time for Cooperative SS alerts, $p > .05$
- It took an average of $5.72$ seconds for pilots to receive and an ATC a Cooperative SS alert

Non-Cooperative SS Alerts

- There was no significant effect of Display on Clearance Approval Time for Non-Cooperative SS alerts, $p > .05$
- It took an average of $5.47$ seconds for pilots to receive and an ATC approval for a maneuver in response to a Non-Cooperative SS alert
Clearance Approval Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>4.50</td>
<td>5.93</td>
<td>6.00</td>
<td>4.58</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>5.62</td>
<td>6.38</td>
<td>5.60</td>
<td>6.86</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>5.36</td>
<td>5.43</td>
<td>5.57</td>
<td>5.21</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>5.25</td>
<td>5.47</td>
<td>6.14</td>
<td>6.25</td>
</tr>
</tbody>
</table>
Clearance Approval Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>4.50</td>
<td>5.93</td>
<td>6.00</td>
<td>4.58</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>5.62</td>
<td>6.38</td>
<td>5.60</td>
<td>6.86</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>5.36</td>
<td>5.43</td>
<td>5.57</td>
<td>5.21</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>5.25</td>
<td>5.47</td>
<td>6.14</td>
<td>6.25</td>
</tr>
</tbody>
</table>
Clearance Approval Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.50</td>
<td>5.62</td>
<td>5.66</td>
<td>5.39</td>
<td>4.85</td>
<td>5.20</td>
<td>5.40</td>
<td>4.89</td>
</tr>
</tbody>
</table>
Stages of Pilot DAA Task

- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit
- **T₅**: Traffic Alert Removed
- **T₆**: UAS Completes Maneuver

Key Times:
- Initial Response Time
- Initial Edit Time (First Upload)
- Total Edit Time (Final Upload)
- Alert Duration Time
- Compliance Time
- Total Response Time
- Aircraft Response Time
- Notification Time
- Clearance Approval Time
- Initial Edit Time
- Total Response Time
- Approval Time

Comparison Times:
- Notify vs Upload Time
- Approval vs Upload Time
Across all maneuvers, pilots requested a clearance **93.4%** of the time

On average, pilots who *requested* an ATC clearance did so prior to maneuvering in response to SS alerts **57.2%** of the time (65.1% overall)

- D1 = 71.3%
- D2 = 56.0%
- D3 = 49.8%
- D4 = 51.8%
• There was a near significant effect of Display on ATC Notification vs Upload Time for all SS alerts, $p = .075$

• On average, pilots *requested* an ATC clearance *0.18 seconds prior to* uploading a maneuver in response to a Predictive SS alert
• There was no significant effect of Display on ATC Notification vs Upload Time for Predictive SS alerts, $p > .05$

• On average, pilots requested an ATC clearance 1.01 sec after uploading a maneuver in response to a Predictive SS alert

• There was a significant effect of Display on ATC Notification vs Upload Time for Non-Predictive SS alerts, $p < .05$
  – No differences between displays were significant

• On average, pilots requested an ATC clearance 2.24 seconds prior to uploading a maneuver in response to a Non-Predictive SS alert
• There was a near significant effect of Information on ATC Notification vs Upload Time for Cooperative SS alerts, \( p = .055 \)

• On average, pilots requested an ATC clearance **2.40 seconds prior** to uploading a maneuver in response to a Cooperative SS alert

• There was no significant effect of Display on ATC Notification vs Upload Time for Non-Cooperative SS alerts, \( p > .05 \)

• On average, pilots requested an ATC clearance **0.76 seconds after** uploading a maneuver in response to a Non-Cooperative alert
ATC Notification vs Upload Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>2.50</td>
<td>8.13</td>
<td>0.69</td>
<td>6.92</td>
</tr>
<tr>
<td>D2</td>
<td>4.86</td>
<td>4.67</td>
<td>-1.66</td>
<td>2.58</td>
</tr>
<tr>
<td>D3</td>
<td>6.00</td>
<td>2.10</td>
<td>-3.43</td>
<td>-0.21</td>
</tr>
<tr>
<td>D4</td>
<td>4.08</td>
<td>-7.29</td>
<td>-4.79</td>
<td>-4.38</td>
</tr>
</tbody>
</table>
ATC Notification vs Upload Time

IHITL and PT4 Display Comparison

Values:
- D1: 2.83
- D2: 2.41
- D3: -0.48
- Int_Basic: -4.04
- Int_Advanced: 6.57
- SA_Basic: 4.85
- SA_Advanced: 2.40
Stages of Pilot DAA Task

- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit
- **T₅**: Traffic Alert Removed
- **T₆**: UAS Completes Maneuver

**Timelines**:
- **Total Edit Time**: (Final Upload)
- **Initial Edit Time**: (First Upload)
- **Initial Response Time**
- **Notification Time**
- **Clearance Approval Time**
- **Aircraft Response Time**
- **Alert Duration Time**
- **Compliance Time**

**Comparison**:
- **Approval vs Upload Time**
- **Notify vs Upload Time**
Across all maneuvers, pilots received a clearance **92.9%** of the time

On average, pilots who *received* an ATC clearance, did so prior to maneuvering in response to SS alerts **56.2%** of the time (62.8% overall)

- D1 = 49.8%
- D2 = 48.3%
- D3 = 43.5%
- D4 = 33.6%
• There was a near significant effect of Display on ATC Approval vs Upload Time for all SS alerts, $p = .092$

• On average, pilots received an ATC clearance 6.46 seconds after uploading a maneuver in response to a Predictive SS alert
• There was no significant effect of Display on ATC Approval vs Upload Time for Predictive SS alerts, $p > .05$

• On average, pilots received an ATC clearance **6.46 seconds after** uploading a maneuver in response to a Predictive SS alert

• There was a significant effect of Display on ATC Approval vs Upload Time for Non-Predictive SS alerts, $p < .05$
  
  — No differences between displays were significant

• On average, pilots received an ATC clearance **3.71 seconds after** uploading a maneuver in response to a Non-Predictive SS alert
There was a near significant effect of Display on ATC Approval vs Upload Time for Cooperative SS alerts, p = .070.

On average, pilots received an ATC clearance 3.33 seconds after uploading a maneuver in response to a Cooperative SS alert.

There was no significant effect of Display on ATC Approval vs Upload Time for Non-Cooperative SS alerts, p > .05.

On average, pilots received an ATC clearance 6.20 seconds after uploading a maneuver in response to a Non-Cooperative SS alert.
### ATC Approval vs Upload Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>-2.00</td>
<td>-1.07</td>
<td>0.00</td>
<td>-0.50</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>2.50</td>
<td>-1.71</td>
<td>-3.50</td>
<td>-14.14</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>-4.47</td>
<td>-7.08</td>
<td>-9.00</td>
<td>-10.00</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>1.67</td>
<td>-2.89</td>
<td>-6.36</td>
<td>-10.63</td>
</tr>
</tbody>
</table>
### ATC Approval vs Upload Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>-2.00</td>
<td>2.50</td>
<td>-4.47</td>
<td>1.67</td>
</tr>
<tr>
<td>D2</td>
<td>-1.07</td>
<td>-1.71</td>
<td>-7.08</td>
<td>-2.89</td>
</tr>
<tr>
<td>D3</td>
<td>0.00</td>
<td>-3.50</td>
<td>-9.00</td>
<td>-6.36</td>
</tr>
<tr>
<td>D4</td>
<td>-0.50</td>
<td>-14.14</td>
<td>-10.00</td>
<td>-10.63</td>
</tr>
</tbody>
</table>
ATC Approval vs Upload Time

IHITL and PT4 Display Comparison

-2.57
-3.21
-6.14
-9.43
1.70
-4.97
-2.79

Int_Basic
Int_Advanced
SA_Basic
SA_Advanced
• There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05

• Pilots took an average of **8.25 seconds** to initiate an edit in response to a Predictive SS alert
There was no significant effect of Display on Initial Response Time for Predictive SS alerts, $p > .05$

- Pilots took an average of 7.40 seconds to initiate an edit in response to a Predictive SS alert

There was no significant effect of Display on Initial Response Time for Non-Predictive SS alerts, $p > .05$

- Pilots took an average of 10.00 seconds to initiate an edit in response to a Non-Predictive SS alert
• There was no significant effect of Display on Initial Response Time for Cooperative SS alerts, $p > .05$
• Pilots took an average of **11.84 seconds** to initiate an edit in response to a Cooperative SS alert

• There was no significant effect of Display on Initial Response Time for Non-Cooperative SS alerts, $p > .05$
• Pilots took an average of **6.84 seconds** to initiate an edit in response to a Non-Cooperative SS alert
Initial Response Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>10.00</td>
<td>17.71</td>
<td>17.17</td>
<td>6.83</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>10.50</td>
<td>10.83</td>
<td>13.20</td>
<td>11.07</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>5.02</td>
<td>4.98</td>
<td>7.88</td>
<td>6.69</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>13.43</td>
<td>5.81</td>
<td>9.73</td>
<td>6.70</td>
</tr>
</tbody>
</table>
Initial Response Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>7.89</td>
<td>8.28</td>
<td>9.60</td>
<td>7.24</td>
<td>21.62</td>
<td>22.09</td>
<td>15.26</td>
<td>18.30</td>
</tr>
</tbody>
</table>
Stages of Pilot DAA Task

- **Traffic Display Alert (SS or CA)**
- **Pilot Notifies ATC**
- **ATC Approval**
- **Pilot Initiates Edit**
- **Pilot Uploads First Edit**
- **Pilot Uploads Final Edit**
- **Traffic Alert Removed**
- **UAS Completes Maneuver**
• There was a significant effect of Display on Initial Edit Time for all SS alerts, p < .01
  – D3 was significantly faster than D1 and D2
• Pilots took an average of 6.29 seconds to complete their first edit in response to SS alerts
**Initial Edit Time**

- There was a significant effect of Display on Initial Edit Time for Predictive SS alerts, $p < .05$
  - D3 was significantly faster than D1
- Pilots took an average of **5.67 seconds** to complete their first edit in response to Predictive SS alerts

- There was a significant effect of Display on Initial Edit Time for Non-Predictive SS alerts, $p < .05$
  - D3 was significantly faster than D1 and D2
- Pilots took an average of **6.86 seconds** to complete their first edit in response to Non-Predictive SS alert
There was a significant effect of Display on Initial Edit Time for Cooperative SS alerts, $p < .01$
  - D3 and D4 were both significantly faster than D1 and D2
  - No difference between D1 and D2
  - No difference between D3 and D4

Pilots took an average of **7.04 seconds** to complete their first edit in response to Cooperative SS alerts

There was a near significant effect of Display on Initial Edit Time for Non-Cooperative Alerts, $p = .056$

Pilots took an average of **5.84 seconds** to complete their first edit in response to Non-Cooperative alerts
### Initial Edit Time

<table>
<thead>
<tr>
<th>Type</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>8.17</td>
<td>10.36</td>
<td>4.50</td>
<td>4.58</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>14.80</td>
<td>9.75</td>
<td>1.30</td>
<td>2.43</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>7.18</td>
<td>7.86</td>
<td>1.97</td>
<td>4.54</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>6.07</td>
<td>10.86</td>
<td>3.04</td>
<td>9.40</td>
</tr>
</tbody>
</table>

![Bar chart showing initial edit time for different types of cooperation and prediction.](chart.png)
Initial Edit Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>8.17</td>
<td>14.80</td>
<td>7.18</td>
<td>6.07</td>
</tr>
<tr>
<td>D2</td>
<td>10.36</td>
<td>9.75</td>
<td>7.86</td>
<td>10.86</td>
</tr>
<tr>
<td>D3</td>
<td>4.50</td>
<td>1.30</td>
<td>1.97</td>
<td>3.04</td>
</tr>
<tr>
<td>D4</td>
<td>4.58</td>
<td>2.43</td>
<td>4.54</td>
<td>9.40</td>
</tr>
</tbody>
</table>
Initial Edit Time

IHITL and PT4 Display Comparison

D1: 8.33
D2: 8.93
D3: 2.66
D4: 5.24
Basic_Int: 17.11
Advanced_Int: 5.51
Basic_SA: 13.02
Advanced_SA: 11.43
Stages of Pilot DAA Task

- **T₀** Traffic Display Alert (SS or CA)
- **T₁** Pilot Notifies ATC
- **T₂** ATC Approval
- **T₃** Pilot Initiates Edit
- **T₄a** Pilot Uploads First Edit
- **T₄b** Pilot Uploads Final Edit
- **T₅** Traffic Alert Removed
- **T₆** UAS Completes Maneuver

**Timeline:**
- **Compliance Time**
- **Alert Duration Time**
- **Total Response Time**
- **Aircraft Response Time**
- **Initial Response Time**
- **Clearance Approval Time**
- **Initial Edit Time** (First Upload)
- **Total Edit Time** (Final Upload)

**Measures:**
- **Notification Time**
- **Upload Time**
- **Approval Time**
• There was a not significant effect of Display on Total Edit Time for all SS alerts, p > .05
• Pilots took an average of **9.83 seconds** to complete their final edit in response to SS alerts
• There was a significant effect of Display on Total Edit Time for Predictive alerts, p < .05
  – D3 was significantly faster than D2, but no different than the other two displays
• Pilots took an average of 8.83 seconds to complete their final edit in response to Predictive SS alerts

• There was no significant main effect of Display on Total Edit Time for Non-Predictive alerts, p > .05
• Pilots took an average of 12.862 seconds to complete their final edit in response to Non-Predictive SS alerts
• There was no significant effect of Display on Total Edit Time for Cooperative SS alerts, p > .05
• Pilots took an average of **12.08 seconds** to complete their final edit in response to Cooperative SS alerts

• There was a near significant effect of Display on Total Edit Time for Non-Cooperative SS alerts, p = .064
• Pilots took an average of **8.31 seconds** to complete their final edit in response to Non-Cooperative alerts
Total Edit Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>16.33</td>
<td>12.64</td>
<td>14.00</td>
<td>12.17</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>16.40</td>
<td>12.63</td>
<td>2.50</td>
<td>13.64</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>13.26</td>
<td>10.50</td>
<td>2.64</td>
<td>4.54</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>8.21</td>
<td>10.86</td>
<td>13.17</td>
<td>9.40</td>
</tr>
</tbody>
</table>
Total Edit Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>16.33</td>
<td>16.40</td>
<td>13.26</td>
<td>8.21</td>
</tr>
<tr>
<td>D2</td>
<td>12.64</td>
<td>12.63</td>
<td>10.50</td>
<td>10.86</td>
</tr>
<tr>
<td>D3</td>
<td>14.00</td>
<td>2.50</td>
<td>2.64</td>
<td>13.17</td>
</tr>
<tr>
<td>D4</td>
<td>12.17</td>
<td>13.64</td>
<td>4.54</td>
<td>9.40</td>
</tr>
</tbody>
</table>
Total Edit Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>12.65</td>
<td>11.43</td>
<td>6.74</td>
<td>8.51</td>
<td>22.65</td>
<td>10.08</td>
<td>21.60</td>
<td>16.28</td>
</tr>
</tbody>
</table>

- IHITL: IHITL and PT4 Display Comparison
- Total Edit Time

[Bar chart showing the comparison between different conditions and categories.]
Stages of Pilot DAA Task

- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit
- **T₅**: Traffic Alert Removed
- **T₆**: UAS Completes Maneuver

**Times**:
- Initial Response Time
- Initial Edit Time (First Upload)
- Total Edit Time (Final Upload)
- Compliance Time
- Alert Duration Time
- Total Response Time
- Aircraft Response Time

**Activities**:
- Notification Time
- Clearance Approval Time
- Initial Response Time
- Total Edit Time (Final Upload)
- Initial Edit Time (First Upload)
- Compliance Time
- Alert Duration Time
- Total Response Time

**Comparisons**:
- Notify vs Upload Time
- Approval vs Upload Time
Aircraft Response Time

- There was a near significant effect of Display on Aircraft Response Time for all SS alerts, $p = .069$
- Pilots took an average of **14.54 seconds** to upload their first maneuver in response to SS alerts (from first alert appearance)
• There was a near significant effect of Display on Aircraft Response Time for Predictive SS alerts, \( p = 0.059 \)

• Pilots took an average of **13.06 seconds** to upload their first maneuver in response to Predictive SS alerts (from first alert appearance)

• There was a significant effect of Display on Aircraft Response Time for Non-Predictive SS alerts, \( p < 0.05 \)
  
  – No differences between displays were significant

• Pilots took an average of **16.86 seconds** to upload their first maneuver in response to Non-Predictive SS alerts (from first alert appearance)
There was a significant effect of Display on Aircraft Response Time for Cooperative SS alerts, $p < .01$
- D4 was significantly faster than D1 and D2
- Pilots took an average of **18.87 seconds** to upload their first maneuver in response to Cooperative SS alerts (from first alert appearance)

There was no significant effect of Display on Aircraft Response Time for Non-Cooperative SS alerts, $p > .05$
- Pilots took an average of **12.68 seconds** to upload their first maneuver in response to Non-Cooperative SS alerts (from first alert appearance)
### Aircraft Response Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>18.17</td>
<td>28.07</td>
<td>31.67</td>
<td>11.42</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>25.30</td>
<td>20.58</td>
<td>14.50</td>
<td>13.50</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>12.20</td>
<td>12.84</td>
<td>9.85</td>
<td>11.23</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>19.50</td>
<td>16.67</td>
<td>12.77</td>
<td>16.10</td>
</tr>
</tbody>
</table>
## Aircraft Response Time

![Bar chart showing aircraft response times for different scenarios](chart.png)

### Table of Aircraft Response Times

<table>
<thead>
<tr>
<th>Scenario</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>18.17</td>
<td>28.07</td>
<td>31.67</td>
<td>11.42</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>25.30</td>
<td>20.58</td>
<td>14.50</td>
<td>13.50</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>12.20</td>
<td>12.84</td>
<td>9.85</td>
<td>11.23</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>19.50</td>
<td>16.67</td>
<td>12.77</td>
<td>16.10</td>
</tr>
</tbody>
</table>
Aircraft Response Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time (s)</td>
<td>16.22</td>
<td>17.20</td>
<td>12.26</td>
<td>12.47</td>
<td>38.66</td>
<td>27.50</td>
<td>32.96</td>
<td>29.64</td>
</tr>
</tbody>
</table>
Stages of Pilot DAA Task

- **Traffic Display Alert (SS or CA)**
- **Pilot Notifies ATC**
- **ATC Approval**
- **Pilot Initiates Edit**
- **Pilot Uploads First Edit**
- **Pilot Uploads Final Edit**
- **Traffic Alert Removed**
- **UAS Completes Maneuver**

**Key Times:**

- **$T_0$** (Traffic Display Alert)
- **$T_1$** (Pilot Notifies ATC)
- **$T_2$** (ATC Approval)
- **$T_3$** (Pilot Initiates Edit)
- **$T_{4a}$** (Pilot Uploads First Edit)
- **$T_{4b}$** (Pilot Uploads Final Edit)
- **$T_5$** (Traffic Alert Removed)
- **$T_6$** (UAS Completes Maneuver)
• There was not a significant effect of Information on Total Response Time for all SS alerts, $p > .05$

• Pilots took an average of **18.08 seconds** to complete their final edit in response to SS alerts (from first alert appearance)
There was a near significant effect of Display on Total Response Time for Predictive SS alerts, \( p = 0.056 \)

Pilots took an average of 16.22 seconds to complete their final edit in response to Predictive SS alerts (from first alert appearance)

There was no significant effect of Display on Total Response Time, \( p > 0.05 \)

Pilots took an average of 22.86 seconds to complete their final edit in response to Non-Predictive SS alerts (from first alert appearance)
Total Response Time

Cooperative SS Alerts

- There was no significant effect of Information on Aircraft Response Time for Cooperative SS alerts, $p > .05$
- Pilots took an average of **23.92 seconds** to complete their final edit in response to Cooperative SS alerts (from first alert appearance)

Non-Cooperative SS Alerts

- There was no significant effect of Display on Aircraft Response Time for Non-Cooperative SS alerts, $p > .05$
- Pilots took an average of **15.15 seconds** to complete their final edit in response to Non-Cooperative SS alerts (from first alert appearance)
## Total Response Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>26.33</td>
<td>30.36</td>
<td>31.17</td>
<td>19.00</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>26.90</td>
<td>23.46</td>
<td>15.70</td>
<td>24.71</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>18.28</td>
<td>15.48</td>
<td>10.52</td>
<td>11.23</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>21.64</td>
<td>16.67</td>
<td>22.90</td>
<td>16.10</td>
</tr>
</tbody>
</table>

The bar chart above visualizes the total response time across different conditions.
Total Response Time

<table>
<thead>
<tr>
<th></th>
<th>Cooperative/Predictive</th>
<th>Cooperative/Non-Predictive</th>
<th>Non-Cooperative/Predictive</th>
<th>Non-Cooperative/Non-Predictive</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>26.33</td>
<td>26.90</td>
<td>18.28</td>
<td>21.64</td>
</tr>
<tr>
<td>D2</td>
<td>30.36</td>
<td>23.46</td>
<td>15.48</td>
<td>16.67</td>
</tr>
<tr>
<td>D3</td>
<td>31.17</td>
<td>15.70</td>
<td>10.52</td>
<td>22.90</td>
</tr>
<tr>
<td>D4</td>
<td>19.00</td>
<td>24.71</td>
<td>11.23</td>
<td>16.10</td>
</tr>
</tbody>
</table>
Total Response Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>20.54</td>
<td>19.71</td>
<td>16.34</td>
<td>15.74</td>
<td>44.86</td>
<td>32.35</td>
<td>38.68</td>
<td>35.60</td>
</tr>
</tbody>
</table>
Stages of Pilot DAA Task

Compliance Time

Alert Duration Time

Total Response Time

Aircraft Response Time

Initial Response Time

Clearance Approval Time

Initial Edit Time (First Upload)

Total Edit Time (Final Upload)

Time

Traffic Display Alert (SS or CA)

Pilot Notifies ATC

ATC Approval

Pilot Initiates Edit

Pilot Uploads First Edit

Pilot Uploads Final Edit

Traffic Alert Removed

UAS Completes Maneuver

T_0

T_1

T_2

T_3

T_4a

T_4b

T_5

T_6

Notify vs Upload Time

Approval vs Upload Time

T_0

T_1

T_2

T_3

T_4a

T_4b

T_5

T_6

Traffic Display Alert (SS or CA)

Pilot Notifies ATC

ATC Approval

Pilot Initiates Edit

Pilot Uploads First Edit

Pilot Uploads Final Edit

Traffic Alert Removed

UAS Completes Maneuver

Notify vs Upload Time

Approval vs Upload Time
There was no significant effect of Display on Alert Duration Time for all SS alerts, $p > .05$

- Pilots had an average duration of **33.58 seconds** for all Predictive SS alerts
Alert Duration Time

**Predictive SS Alerts**

- There was no significant effect of Display on Alert Duration Time for Predictive SS alerts, $p > .05$
- Pilots had an average duration of **32.52 seconds** for all Predictive SS alerts

**Non-Predictive SS Alerts**

- There was no significant effect of Display on Alert Duration Time for Non-Predictive SS alerts, $p > .05$
- Pilots had an average duration of **30.56 seconds** for all Non-Predictive SS alerts
• There was no significant effect of Display on Alert Duration Time for Cooperative SS alerts, \( p > .05 \)
• Pilots had an average duration of **36.21 seconds** for all Cooperative SS alerts

• There was no significant effect of Display on Alert Duration Time for Non-Cooperative SS alerts, \( p > .05 \)
• Pilots had an average duration of **30.25 seconds** for all Non-Cooperative SS alerts
Alert Duration Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>36.67</td>
<td>57.36</td>
<td>55.33</td>
<td>54.08</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>25.00</td>
<td>31.96</td>
<td>19.30</td>
<td>25.07</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>33.87</td>
<td>32.51</td>
<td>21.94</td>
<td>27.79</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>31.29</td>
<td>22.75</td>
<td>29.52</td>
<td>24.30</td>
</tr>
</tbody>
</table>
Alert Duration Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>36.67</td>
<td>57.36</td>
<td>55.33</td>
<td>54.08</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>25.00</td>
<td>31.96</td>
<td>19.30</td>
<td>25.07</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>33.87</td>
<td>32.51</td>
<td>21.94</td>
<td>27.79</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>31.29</td>
<td>22.75</td>
<td>29.52</td>
<td>24.30</td>
</tr>
</tbody>
</table>
Alert Duration Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>33.00</td>
<td>37.08</td>
<td>29.62</td>
<td>34.59</td>
<td>57.21</td>
<td>44.91</td>
<td>45.69</td>
<td>46.65</td>
</tr>
</tbody>
</table>
There was a significant effect of Display on Compliance Time for all SS alerts, $p < .05$

- No differences between displays were significant

Pilots took an average of 37.53 seconds to fully complete a maneuver in response to SS alerts (alert to end of aircraft maneuver)
There was a significant effect of Display on Compliance Time for all SS alerts, p < .05
  – No differences between displays were significant

Pilots took an average of 37.60 seconds to fully complete a maneuver in response to Predictive SS alerts (alert to end of aircraft maneuver)

There was no significant effect of Display on Compliance Time for Non-Predictive SS alerts, p > .05

Pilots took an average of 41.03 seconds to fully complete a maneuver in response to Non-Predictive SS alerts (alert to end of aircraft maneuver)
There was no significant effect of Display on Compliance Time for Cooperative SS alerts, $p > .05$

Pilots took an average of 39.27 seconds to fully complete a maneuver in response to Cooperative SS alerts (alert to end of aircraft maneuver)

There was no significant effect of Display on Compliance Times for Non-Cooperative SS alerts, $p > .05$

Pilots took an average of 36.56 seconds to fully complete a maneuver in response to Non-Cooperative SS alerts (alert to end of aircraft maneuver)
Compliance Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative/Predictive</td>
<td>48.50</td>
<td>59.50</td>
<td>37.67</td>
<td>38.25</td>
</tr>
<tr>
<td>Cooperative/Non-Predictive</td>
<td>35.50</td>
<td>40.13</td>
<td>33.40</td>
<td>37.64</td>
</tr>
<tr>
<td>Non-Cooperative/Predictive</td>
<td>39.91</td>
<td>42.38</td>
<td>31.88</td>
<td>29.80</td>
</tr>
<tr>
<td>Non-Cooperative/Non-Predictive</td>
<td>48.08</td>
<td>44.70</td>
<td>35.48</td>
<td>39.00</td>
</tr>
</tbody>
</table>
## Compliance Time

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooperative/Predictive</strong></td>
<td>48.50</td>
<td>59.50</td>
<td>37.67</td>
<td>38.25</td>
</tr>
<tr>
<td><strong>Cooperative/Non-Predictive</strong></td>
<td>35.50</td>
<td>40.13</td>
<td>33.40</td>
<td>37.64</td>
</tr>
<tr>
<td><strong>Non-Cooperative/Predictive</strong></td>
<td>39.91</td>
<td>42.38</td>
<td>31.88</td>
<td>29.80</td>
</tr>
<tr>
<td><strong>Non-Cooperative/Non-Predictive</strong></td>
<td>48.08</td>
<td>44.70</td>
<td>35.48</td>
<td>39.00</td>
</tr>
</tbody>
</table>
Compliance Time

IHITL and PT4 Display Comparison

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>Int_Basic</th>
<th>Int_Advanced</th>
<th>SA_Basic</th>
<th>SA_Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39.63</td>
<td>43.57</td>
<td>33.24</td>
<td>33.67</td>
<td>84.79</td>
<td>59.18</td>
<td>73.50</td>
<td>68.25</td>
</tr>
</tbody>
</table>