



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

Warning Alert HITL
Experiment Results





Experiment Objective

- Conduct a HITL simulation that further explores the distinct impact of the DAA Warning alert on pilots' performance with maintaining DAA Well Clear (DWC)
 - Evaluate whether the DAA Warning symbol and/or aural improves pilots' ability to remain well clear
 - Test manipulation that explicitly stresses DAA Warning alert utility with respect to the DAA task
 - Scripted conflicts with look ahead times closer to the warning threshold
 - Determine differential effects between integrated and standalone display configurations
- Performance is measured/quantified by response times and proportion of Loss of DWC (LoDWC)


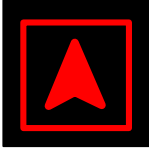






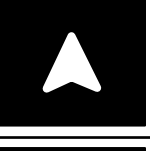


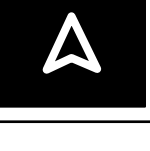




Experimental Design

- Independent Variables:
 - DAA Warning alert option (between-subjects)
 - D1: No DAA Warning alert (caution-only)
 - D2: DAA Warning aural only
 - Retain Corrective DAA symbol
 - D3: DAA Warning alert (aural + symbol)
 - Display Configuration (within-subjects)
 - Integrated x Standalone
- Embedded Variable
 - Use Cases: Time-to-LoDWC at first alert (within-scenarios)
 - A: 15s
 - B: 25s
 - **Warning alert onset (D2/D3)*
 - C: 35s
 - D: 45s
 - E: 55s
 - **Corrective alert onset*



Alerting Logic

| D1: Caution Only | | | D2: Warning Aural | | | D3: Warning Aural + Symbol | | |
|--|------------------------------|----------------------|---|------------------------------|----------------------------|---|------------------------------|----------------------------|
| Symbol | Name | Aural Alert Verbiage | Symbol | Name | Aural Alert Verbiage | Symbol | Name | Aural Alert Verbiage |
| N/A | N/A | N/A |  | DAA 'Maneuver' Alert | "Traffic, Maneuver Now" x2 |  | DAA Warning Alert | "Traffic, Maneuver Now" x2 |
|  | Corrective DAA Caution Alert | "Traffic, Avoid" |  | Corrective DAA Caution Alert | "Traffic, Avoid" |  | Corrective DAA Caution Alert | "Traffic, Avoid" |
|  | *Preventive DAA Alert | "Traffic, Monitor" |  | *Preventive DAA Alert | "Traffic, Monitor" |  | *Preventive DAA Alert | "Traffic, Monitor" |
|  | Guidance Traffic | N/A |  | Guidance Traffic | N/A |  | Guidance Traffic | N/A |
|  | None (Target) | N/A |  | None (Target) | N/A |  | None (Target) | N/A |

*Applied to cooperative intruders only



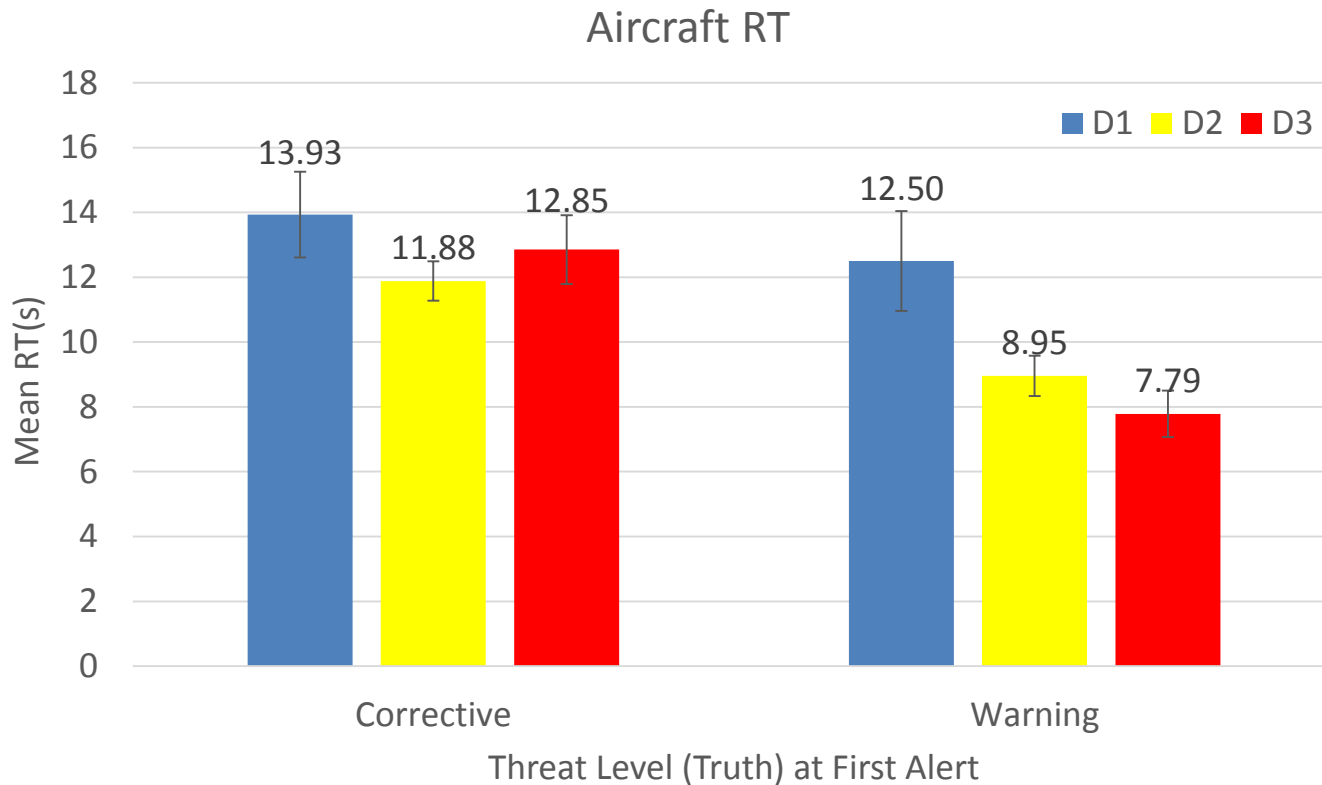
Hypotheses

- Research Question
 - What are the differential effects of the DAA Warning symbology and aural on pilot performance?
- Expected Outcome
 - ✓ Faster response times and better task performance in conditions with DAA Warning alert compared to no DAA Warning
 - ✓ Performance improvements with higher amount of warning information
 - ✓ $D3 > D2 > D1$
 - ✓ Benefit of warning-level information most pronounced for encounters alerting near well clear threshold ($\leq 25s$ to LoDWC)
 - ✓ Display configuration not expected to impact task performance
 - Based on Part Task 6 results



Aircraft Response Time

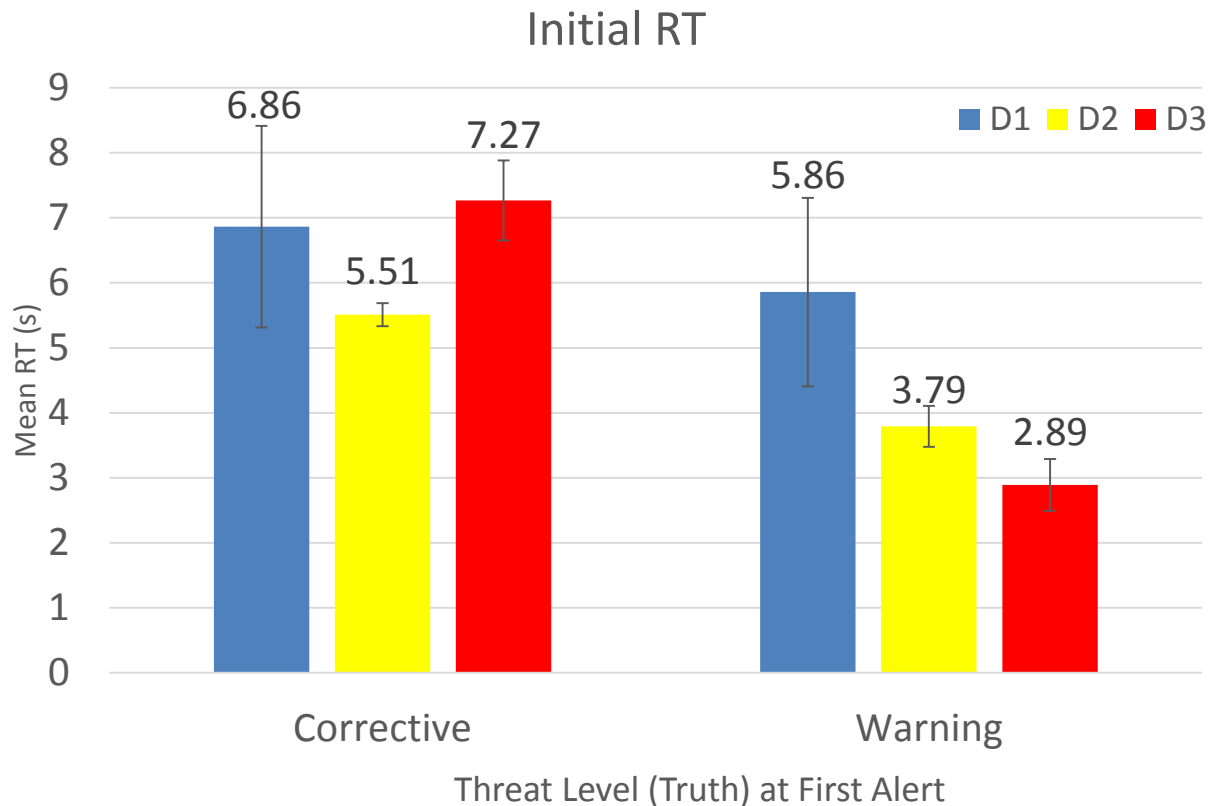
- Differences most prevalent in Use Cases A & B (Warning First)
 - Pilots with warning-level information available are quicker to upload resolutions against severe threats
 - Mainly due to initial response





Initial Response Time

- Differences most prevalent in Use Cases A & B (Warning First)
 - Pilots with warning-level information available are quicker to initiate edits against severe threats
 - Reduced variability

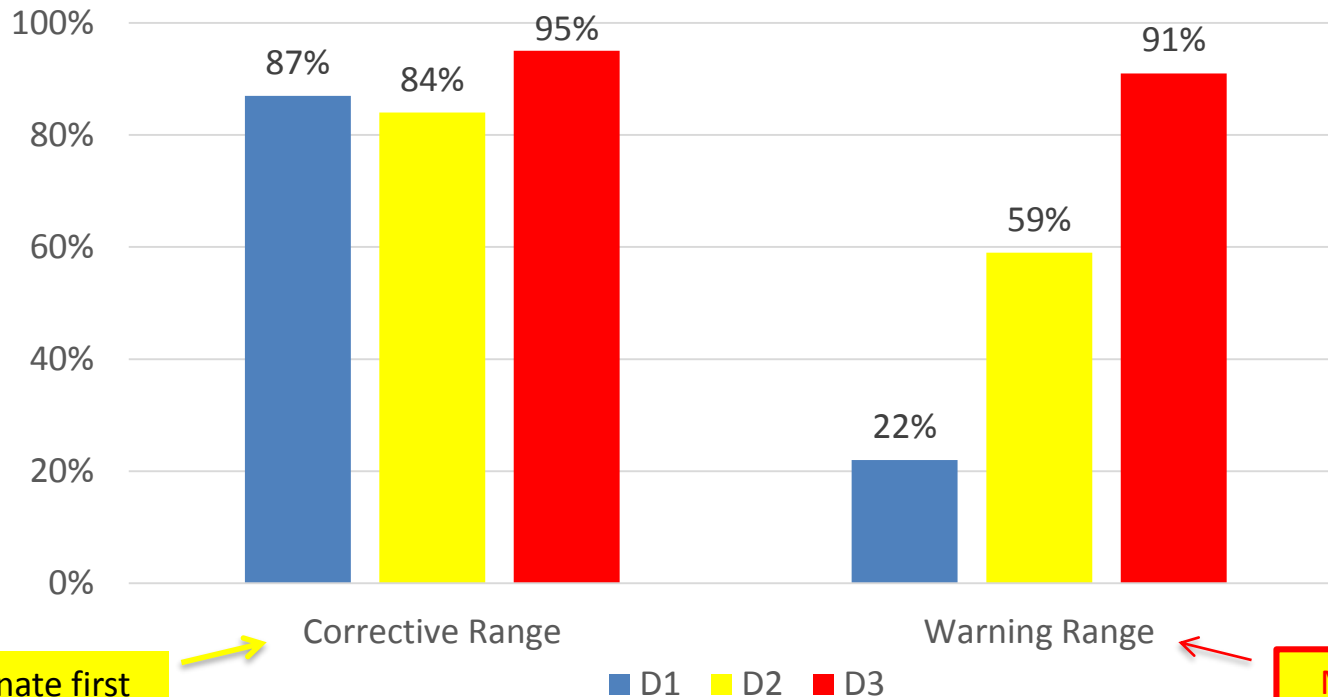




ATC Coordination

- Pilots presented with warning-level alerting were more likely to respond appropriately to severe threats within 25s-to-LoDWC
 - Warning alerts cue immediate maneuvers
 - Benefit most pronounced with the inclusion of DAA Warning symbology (D3)
 - 3 of 5 D1 pilots with Caution-Only alerting prioritized ATC coordination above maneuvers for *every* encounter regardless of intruder range

Appropriate Pilot Action



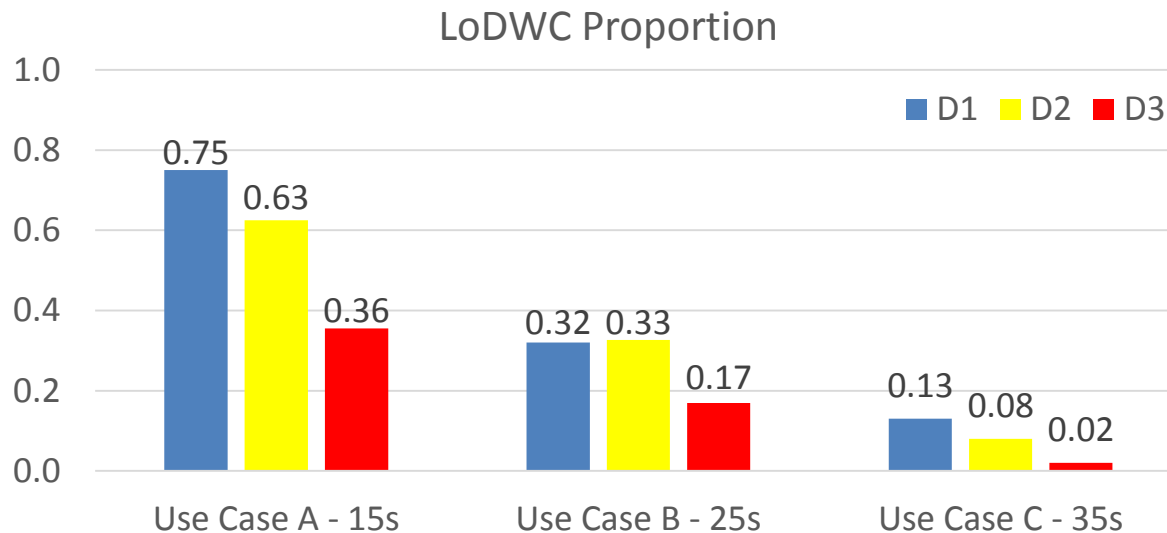
Coordinate first

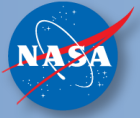
Maneuver first



Global LoDWC

- LoDWC Proportion
 - D1 – 22%
 - D2 – 19%
 - D3 – 10%
 - *91% of total LoDWC occurred in Use Cases A/B*
 - None outside of 35s in any condition
- Pilots were nearly twice as likely to remain DWC against the most severe threats with the DAA Warning Alert compared to Caution-only
 - Auditory Maneuver alert (D2) provided minimal benefit on its own





LoDWC Type

- Pilot Responsible (53% of total)
 - Inappropriate Coordination (43%)
 - Prioritized contacting ATC above immediate maneuver within 25s to Loss
 - Most common LoDWC cause
 - Rarely occurred in D3
 - Ineffective maneuver (8%)
 - Disregarded accurate conflict bands with sufficient time to achieve resolution
 - Most common with altitude changes
 - Slow Response (2%)
 - No true solution at time of upload
 - Only occurred in D1
- System Responsible (47% of total)
 - Late Acceleration (25%)
 - Slow Responses in Use Case A (15s)
 - Less than the time allotted for pilot & aircraft response in DAA timeline
 - Instantaneous turn assumption (22%)
 - Horizontal guidance bands influenced ineffective maneuver
 - Turn in opposite direction would have maintained DWC
 - Elevated threats at 25-35s ranges (B/C)
 - Increased Edit Times and LoDWC Duration
 - Did not anticipate LoDWC

| | Coordination | Late Acceleration | Turn Guidance | Bad maneuver | Slow Response | TOTAL |
|------------|--------------|-------------------|---------------|--------------|---------------|------------|
| D1 | 38 | 6 | 12 | 2 | 2 | 60 |
| D2 | 17 | 17 | 8 | 8* | 0 | 50 |
| D3 | 4 | 10 | 10 | 2 | 0 | 26 |
| ALL | 59 | 33 | 30 | 12 | 2 | 136 |

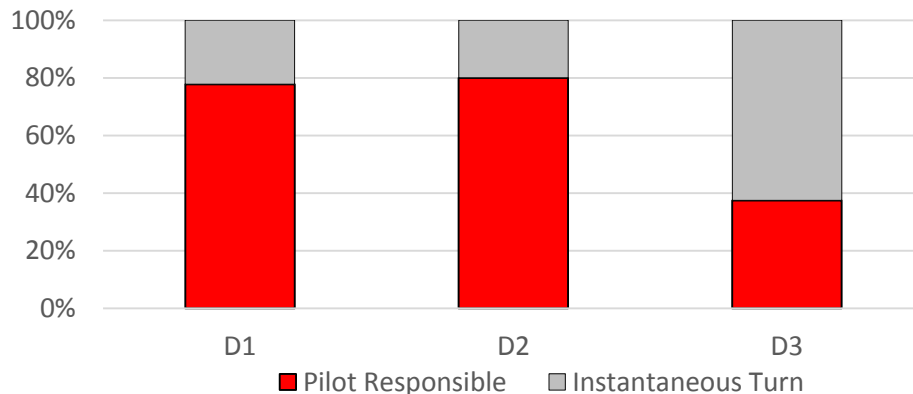
*Outliers



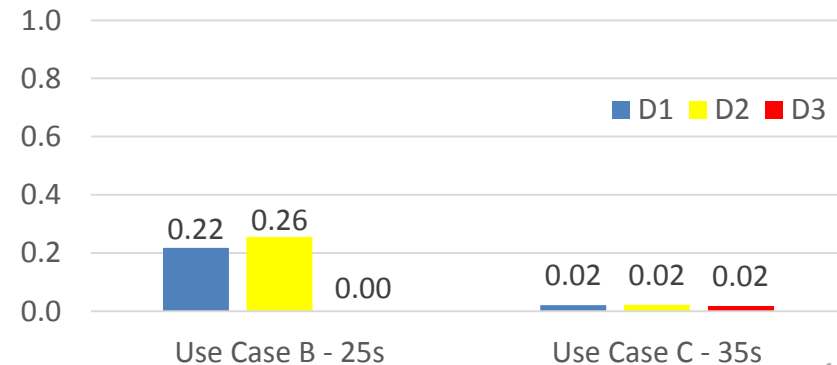
Instantaneous Turn Guidance Implications

- Necessary to preserve data points in Use Case A
 - Delayed onset of WCR allowed for full alert progression
- Influenced heading changes that made situation worse
 - Triggered DWC violations 5 seconds earlier than initially predicted
 - Accounted for 51% of LoDWC in Use Case B (22 of 43)
 - Accounted for 73% of LoDWC in Use Case C (8 of 11)
 - Increased LoDWC duration & number of uploads compared to other LoDWC categories
 - Potential misunderstanding of recovery guidance concept
 - Inconsistent display behavior
 - High subjective confidence did not match objective performance
 - Rare WCR Compliance
 - » *“I was safe... I already flew into the green bands”*

LoDWC Type (Use Cases B/C)



LoDWC Proportion (Excluding Guidance Fault)





Display Location

- No impact on objective performance
 - Response times and LoDWC durations nearly identical
 - LoDWC Proportion:
 - Integrated - 22%
 - Standalone – 18%
- Integrated Display preferred by 13 of 15 pilots (87%)
- Majority of pilots matched their map orientations in Standalone configuration



Warning Alerting Implications

- Warning-level information improves pilot performance against *severe* threats within 25 seconds to LoDWC
 - Faster response times
 - Prioritized actions appropriately with indication of increased severity
 - ATC notification attempts = most common cause of LoDWC
 - Performance remains stable at farther ranges
 - Only 1 pilot-responsible LoDWC per display (all in Use Case C)
- Warning alerting is most conducive to DWC maintenance when auditory cue is coupled with a change in symbology
 - Least pilot-responsible LoDWCs with Phase 1 MOPS DAA Warning alert
 - ‘Maneuver Now’ aural alone did not improve separation performance compared to Caution-Only
 - Potential to miss the aural change while already coordinating with ATC
 - Most likely when intruder alerts at ~35s to LoDWC
 - *“Aurals start with the same word; not as attention-grabbing without distinct changes in symbology”*
 - *“Harder to distinguish between Preventive and Corrective without no Warning symbol; trained that Red means severe”*



THE END

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BACKUP



Background

- Phase 1 DAA alerting structure provides crucial information about when a resolution maneuver is required to avoid loss of DAA well clear
 - Corrective Alert
 - Caution-level: immediate awareness is required; coordinate response, followed by subsequent maneuver
 - Warning Alert
 - Warning-level: immediate maneuver is required and prioritized above contacting ATC
 - Advisory Circular 25.1322-1
- A series of human-in-the-loop (HITL) simulations have revealed performance benefits associated with the DAA Warning alert
 - Faster response times
 - Fewer losses of well clear
 - Fewer ATC coordination attempts near well clear threshold, and better coordination overall



Background

- There is still a degree of uncertainty with regard to the effectiveness of DAA Warning
 - No studies have directly assessed the utility of the warning-level alert as part of the DAA alerting structure
- Even as recently as Phase 1 DAA FRAC, there has been question as to whether a warning-level alert is needed in addition to the caution-level alerts
 - There's a preference to reserve warning-level alerts for Collision Avoidance



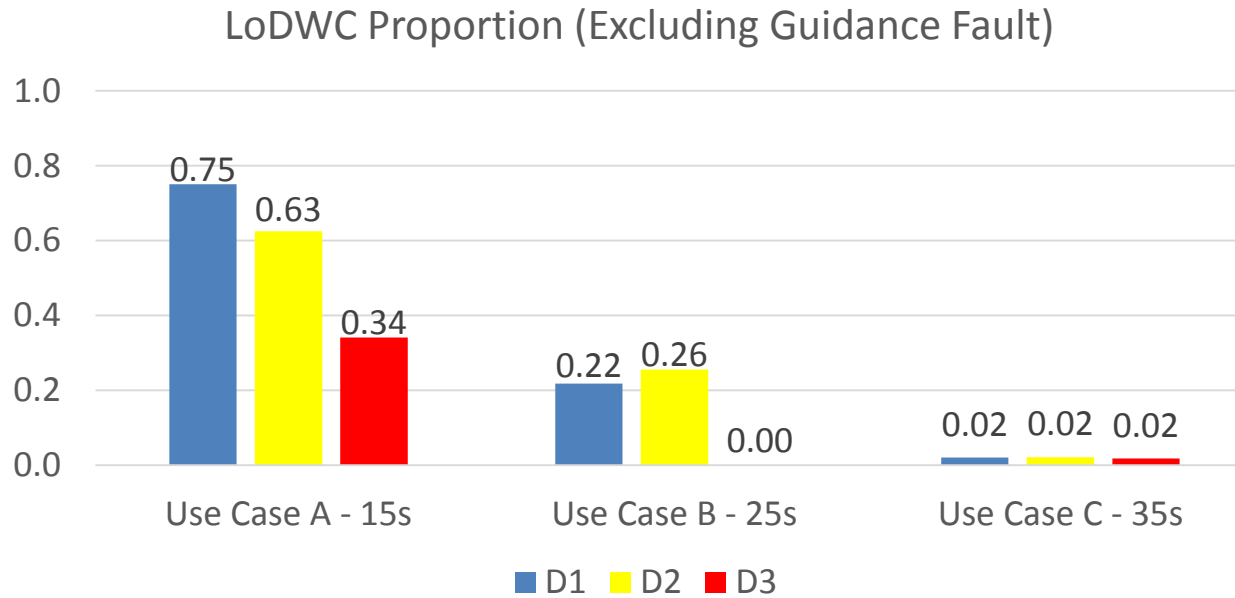
Test Setup

- 15 participants
 - 5 per Alerting condition
 - Manned aviation pilots
- DAA Pilot Task
 - Fly simulated MQ-9 reaper along mission route (ZOA 40/41)
 - Remain Well Clear from intruder aircraft
 - Minimal deviation from mission route/altitude
 - Coordinate with ATC (when necessary)
 - Prioritize maneuver over contacting ATC after the onset of a DAA Warning alert
 - Researcher acting as surrogate ATC from sim manager room
 - Attend to secondary tasks
 - Chat messages requesting status information



Pilot-Responsible LoDWC

- LoDWC Proportion
 - D1 – 22% → 15%
 - D2 – 19% → 9%
 - D3 – 10% → 2%





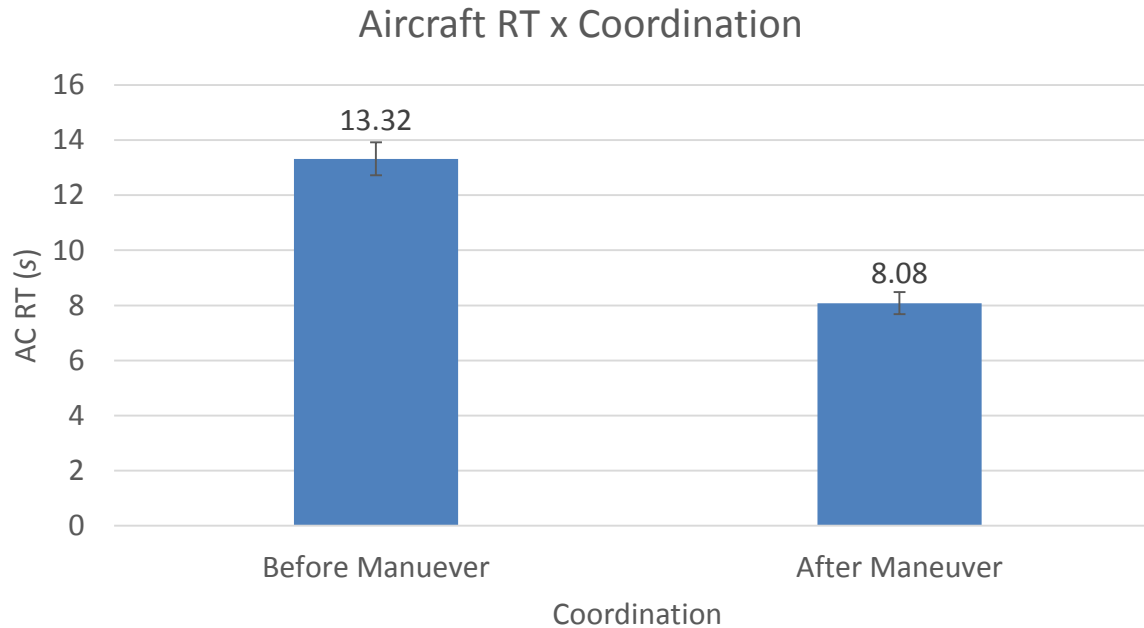
Misc Notes from Debrief

- “Did you refer to the altitude bands often?”
 - Most replied “Yes”, including the D2 pilots that frequently climbed into yellow bands
 - Referenced them, but did not find them all that useful
 - Outside of traffic scan pattern
 - Impossible to avoid LoDWC with vertical resolutions in Use Case A/B due to aircraft performance
 - Only possible in Use Case C if uploaded within 7 seconds, but that time is spent contacting ATC



ATC Coordination

- Volpe (1991)
 - Pilots took an average of **5.28s** to complete responses to ATC clearances
- Warning Alert HITL
 - ATC Coordination added **5.24s** to Aircraft RTs, on average:



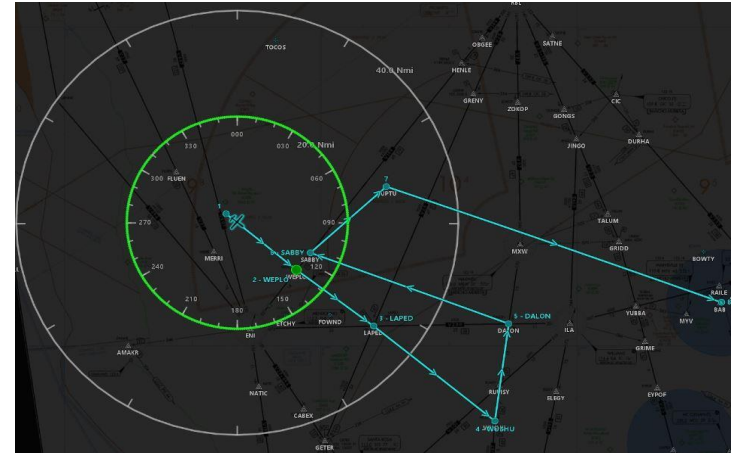


Scenario Design

- Two traffic scenarios
 - 45 minutes each
 - 15 encounters scripted to lose DAA well clear
 - 3 per use case
 - Vary by Time-to-LoDWC

- Ownship configuration
 - Call sign: HAWK21
 - Surveillance: ADS-B In, RADAR
 - Flight Model: MQ-9 Reaper
 - Mission altitude: 12,000 MSL
 - Cruise speed: 160 kts
 - Climb/descent rate: 1000 ft/min

Mission Route





Display Location: Post-Block

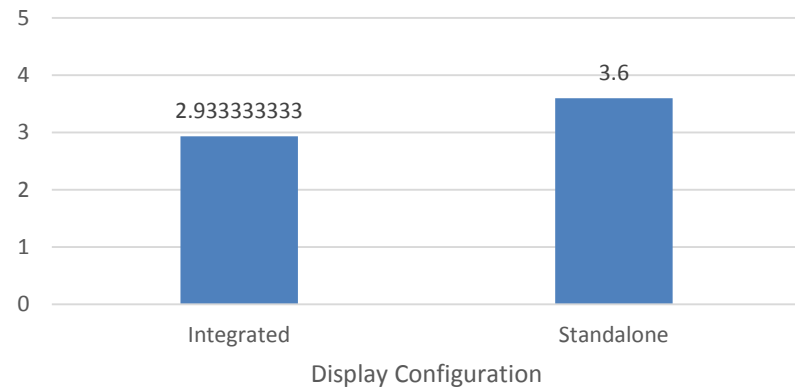
- Q1 This display was easy to use:
 - (p = 0.01) Integrated = 4.67, Standalone = 3.73
- Q2 This display was easy to understand:
 - (p = 0.072) Integrated = 4.73, Standalone = 4.20
- Q3 The location of the DAA & Traffic information within the GCS supported my ability to maintain separation:
 - (p = 0.065) Integrated = 4.73, Standalone = 4.07
- Q6 The display provided the necessary information to perform a maneuver to a loss of Well Clear:
 - (p = 0.065) Integrated = 4.73 Standalone = 4.07
- Q7 The display supported my ability to respond immediately to DAA alerts:
 - (p = 0.017) Integrated = 4.67 Standalone = 3.87
- Q8 I trusted the accuracy of the information provided by the display
 - (p = 0.041) Integrated = 4.8 Standalone = 4.27



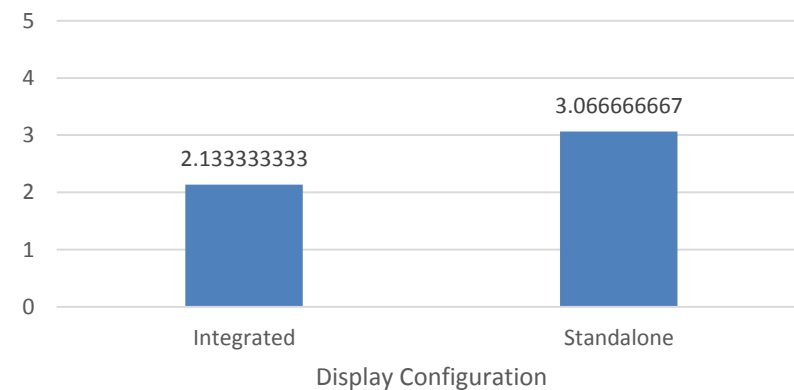
Workload by Display Location

- NASA TLX 1-7 likert-like scale
- Mental, $p = .027$
 - Mean score for Mental for integrated = 2.93, Standalone = 3.9
- Effort, $p = .008$
 - Mean score for Effort for Integrated = 2.13, Standalone = 3.07

Mental

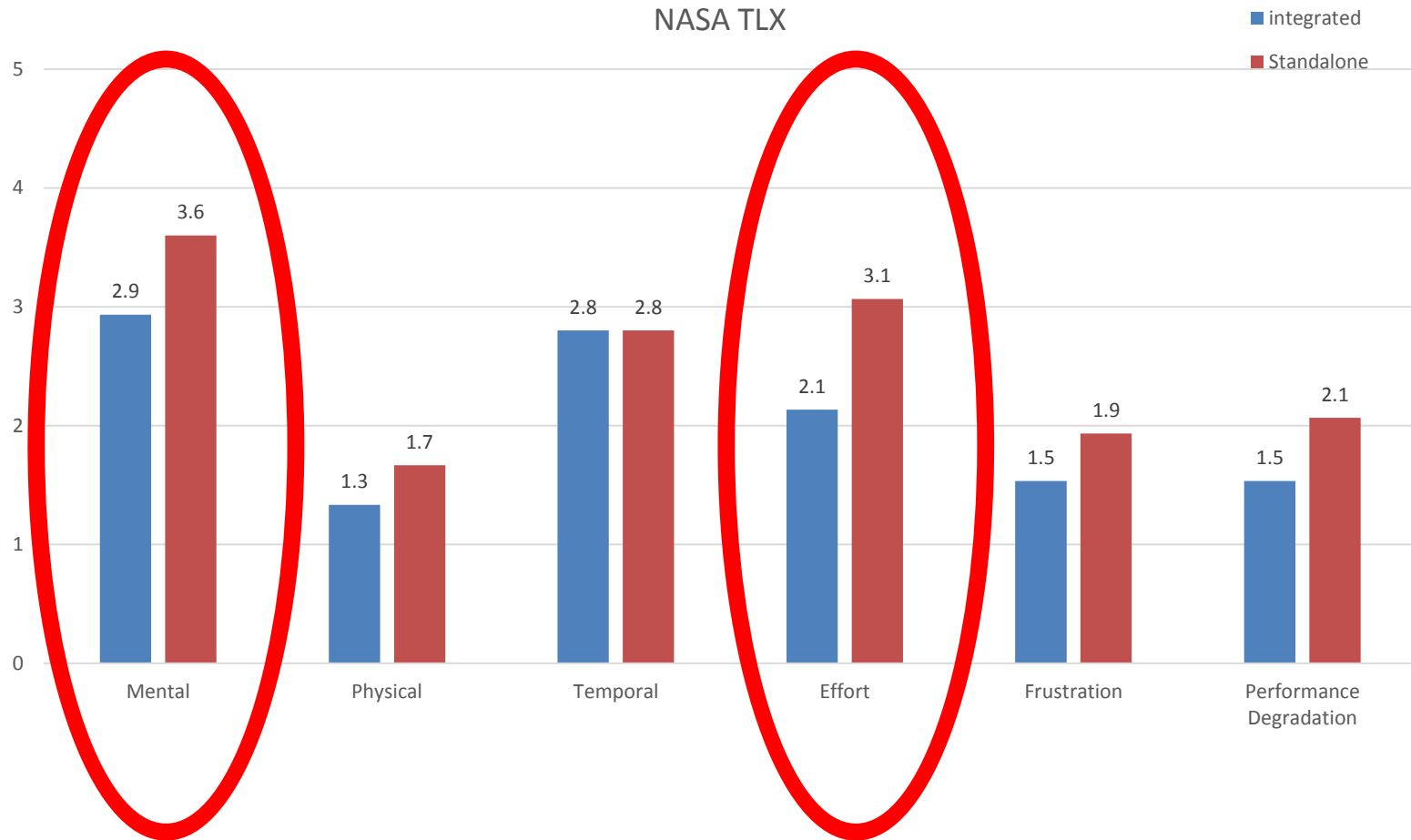


Effort





Workload by Display Location





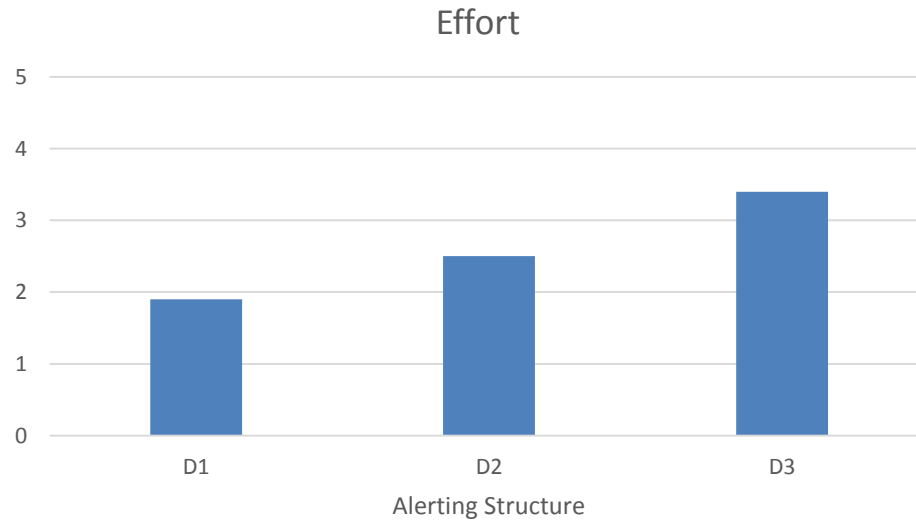
Post Sim (within)

- Very similar answers across the board (no sig differences)
- Pilot preference:
 - Of the 2 configurations (Integrated and Standalone) which did you prefer?
 - 13 – Integrated, 2 – Standalone
 - The difference between preventive DAA Alerts and Corrective DAA alerts was always clear
 - All pilots rated this somewhat to strongly agree
 - 9 - strongly agree, 6 - somewhat agree



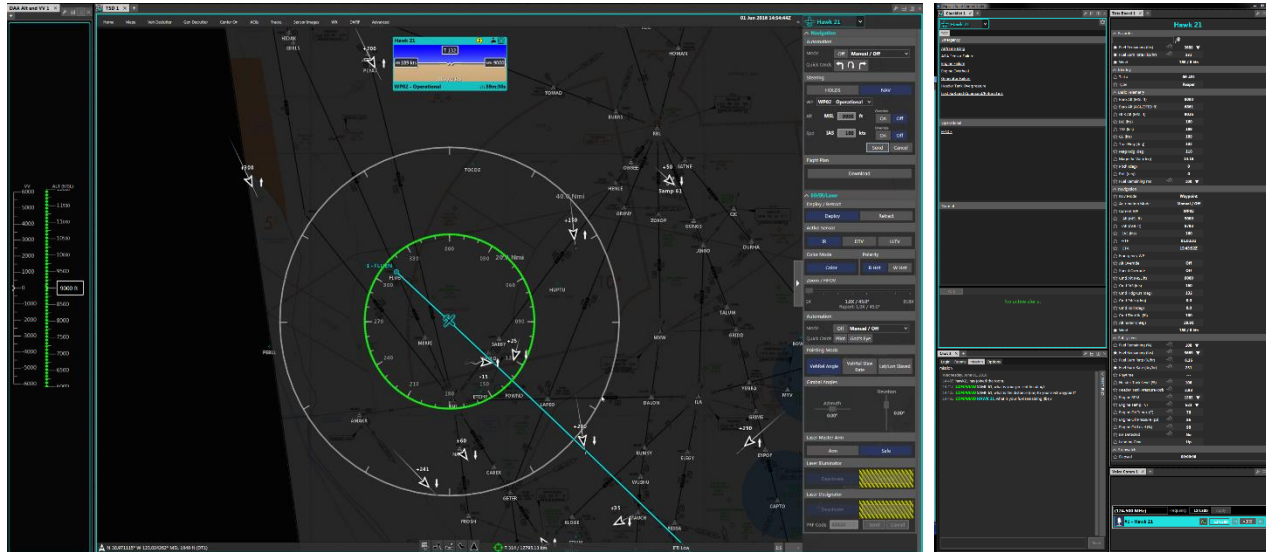
TLX by Alerting (between)

- Effort, ($p = .03$)
 - Mean score D1 = 1.9, D2 = 2.5, D3 = 3.4





Integrated Display Configuration



TSD w/ DAA Display

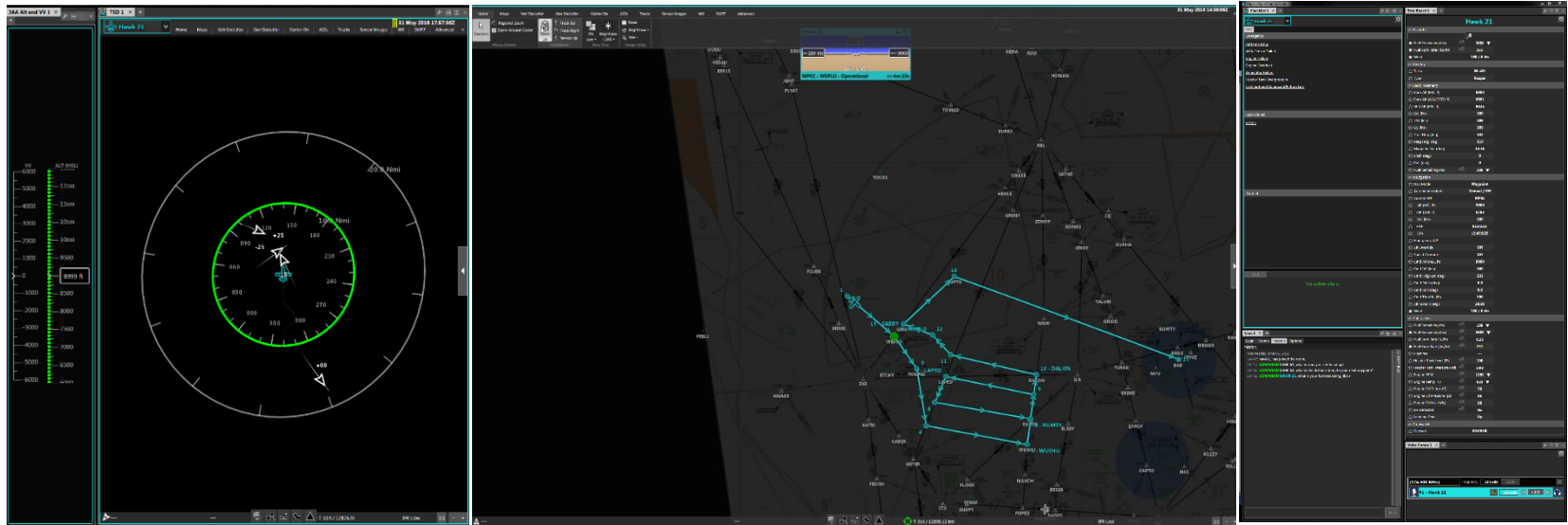
- Traffic Alerting & Guidance
- Range Rings
- Mission Route
- Navigation

Side Panel

- Electronic Checklist
- Status panel
- Chat client



Standalone Display Configuration



DAA Display

- Traffic Alerting & Guidance
- Range rings

TSD

- Mission Route
- Navigation

Side Panel

- Electronic Checklist
- Status panel
- Chat client



Resident Staff

- Lead Researcher / Sim Manager
 - Kevin J. Monk
- Supporting Researchers
 - Zach Roberts
 - Conrad Rorie
- Software Engineer
 - Dominic Wong
- Interns
 - Ricky Russell
 - Kyle Wilson
 - Armando Alvarez
 - Allen Chen
 - Anar Salayev
- Responsible Tech Lead
 - Lisa Fern