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

Warning Alert HITL

Experiment Results

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UAS INTEGRATION IN THE NAS

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Human Systems Integration

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

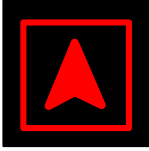- Performance is measured/quantified by response times and proportion of Loss of DWC (LoDWC)
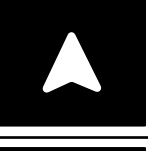
Experimental Design

- 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: 15*s*
    - B: 25*s*
      - **Warning alert onset (D2/D3)*
    - C: 35*s*
    - D: 45*s*
    - E: 55*s*
      - **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

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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 (≤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

Aircraft RT
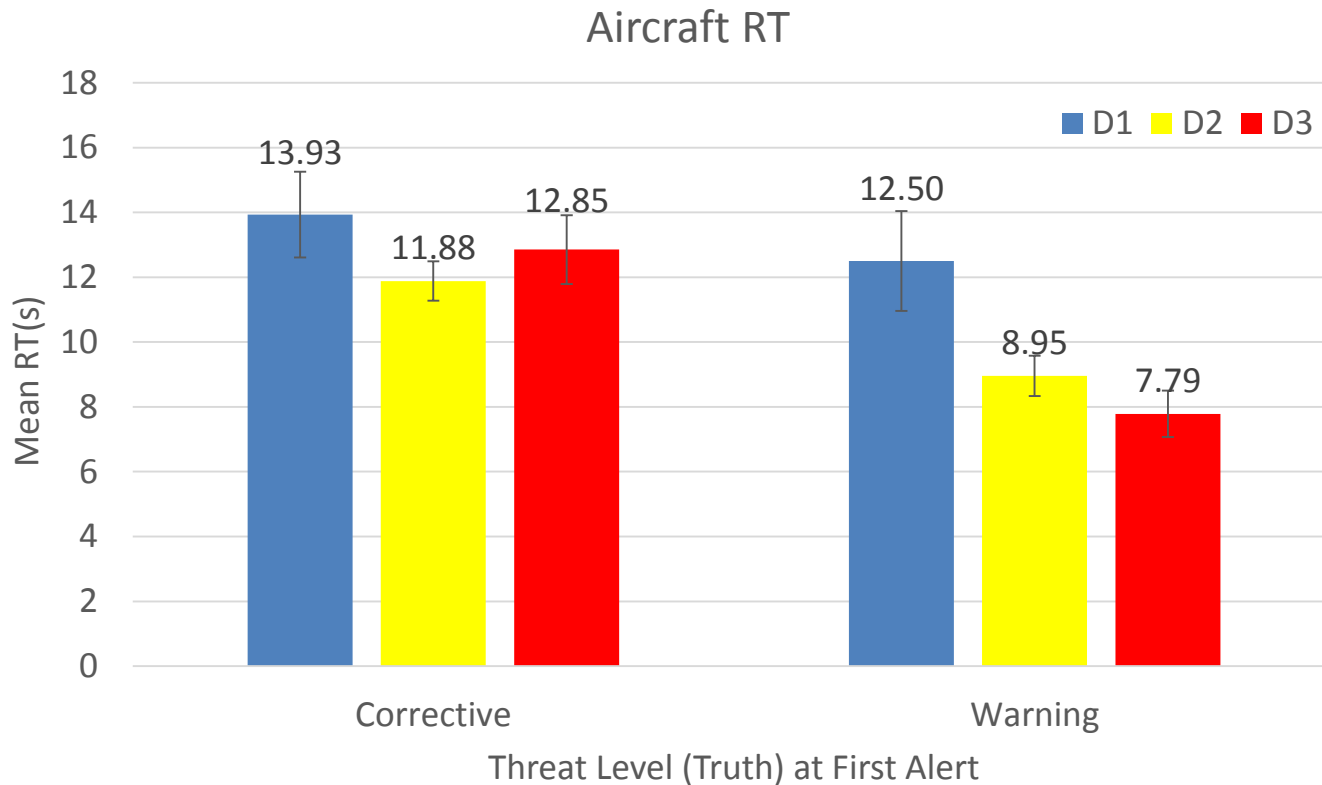
Initial Response Time

- 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

Initial RT

Mean RT (s) vs Threat Level (Truth) at First Alert

Corrective: D1 = 6.86, D2 = 5.51, D3 = 7.27
Warning: D1 = 5.86, D2 = 3.79, D3 = 2.89

Legend: D1 (blue), D2 (yellow), D3 (red)
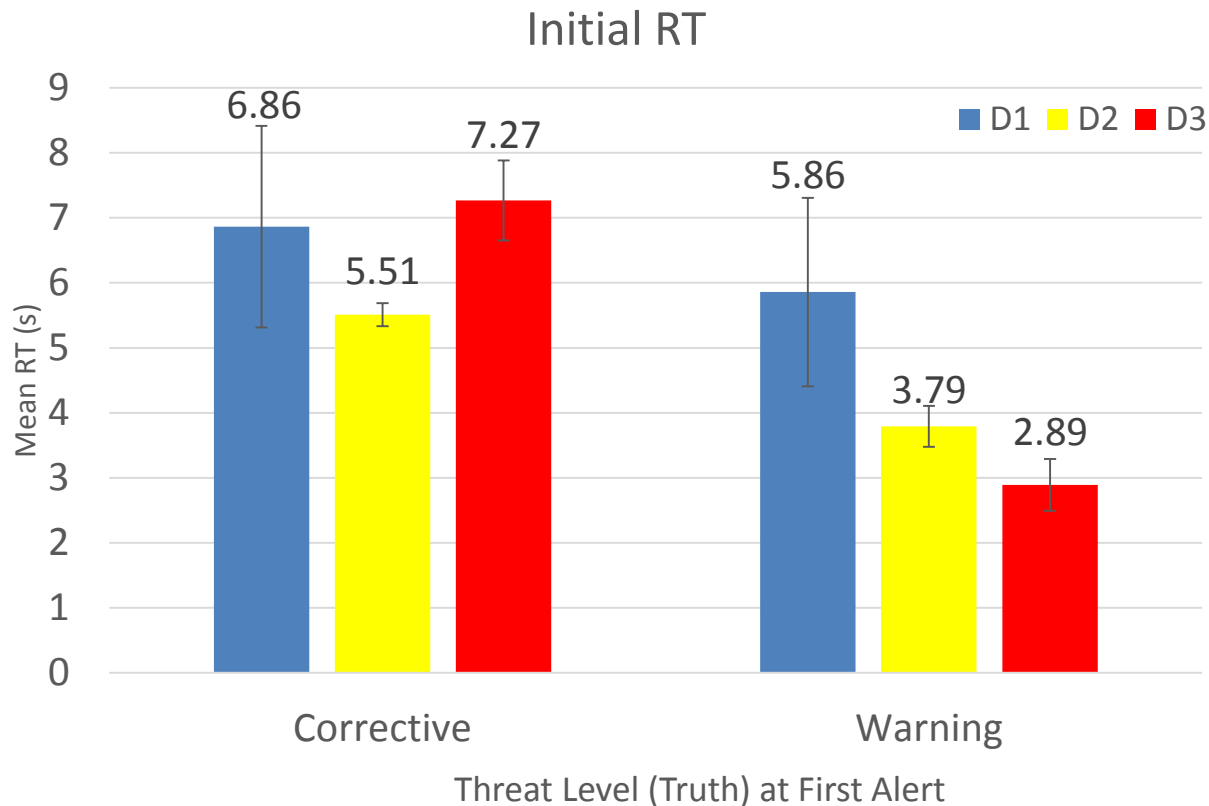
- Pilots presented with warning-level alerting were more likely to respond appropriately to severe threats within 25s-to-LoDWC
  - Warning alerts cue immediate maneuvers
    - Benefit most pronounced with the inclusion of DAA Warning symbology (D3)
  - 3 of 5 D1 pilots with Caution-Only alerting prioritized ATC coordination above maneuvers for *every* encounter regardless of intruder range

Appropriate Pilot Action

	Corrective Range			Warning Range		
D1	87%			22%		
D2		84%			59%	
D3			95%			91%

Coordinate first → Corrective Range   Warning Range ← Maneuver first

■ D1　■ D2　■ D3
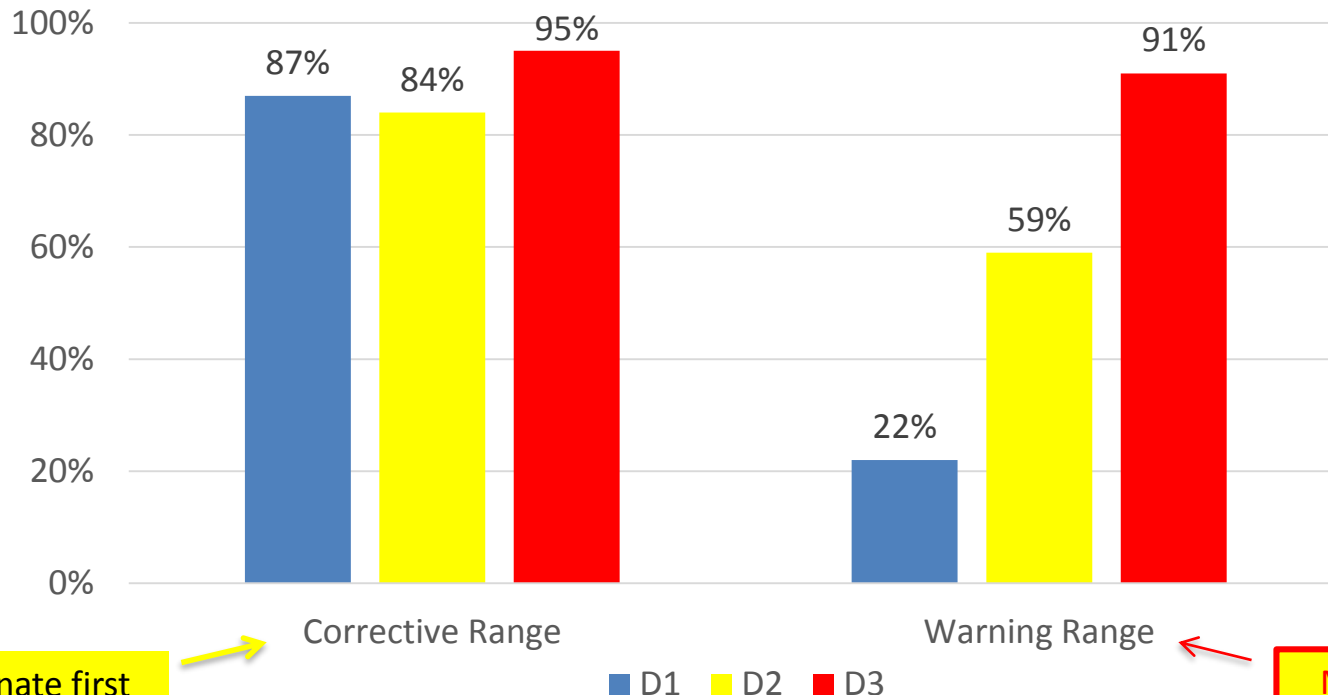
Global LoDWC

- LoDWC Proportion
  - D1 – 22%
  - D2 – 19%
  - D3 – 10%
  - *91% of total LoDWC occurred in Use Cases A/B*
    - None outside of 35*s* 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 Proportion

Legend: D1 (blue), D2 (yellow), D3 (red)

	Use Case A - 15s	Use Case B - 25s	Use Case C - 35s
D1	0.75	0.32	0.13
D2	0.63	0.33	0.08
D3	0.36	0.17	0.02
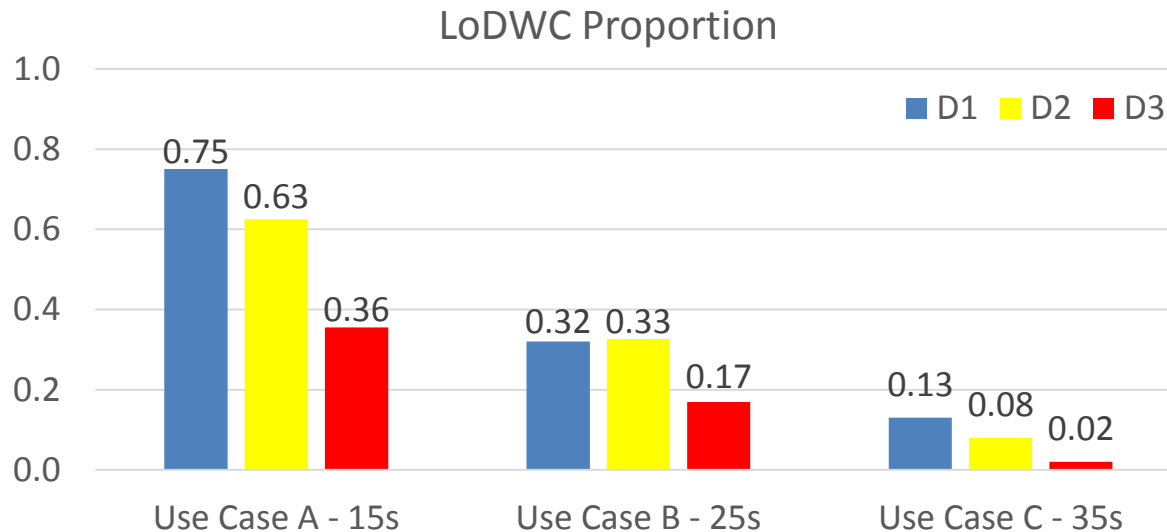
LoDWC Type

- **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)

Pilot Responsible — Instantaneous Turn

LoDWC Proportion (Excluding Guidance Fault)

D1 — D2 — D3

Use Case B - 25s: 0.22, 0.26, 0.00
Use Case C - 35s: 0.02, 0.02, 0.02
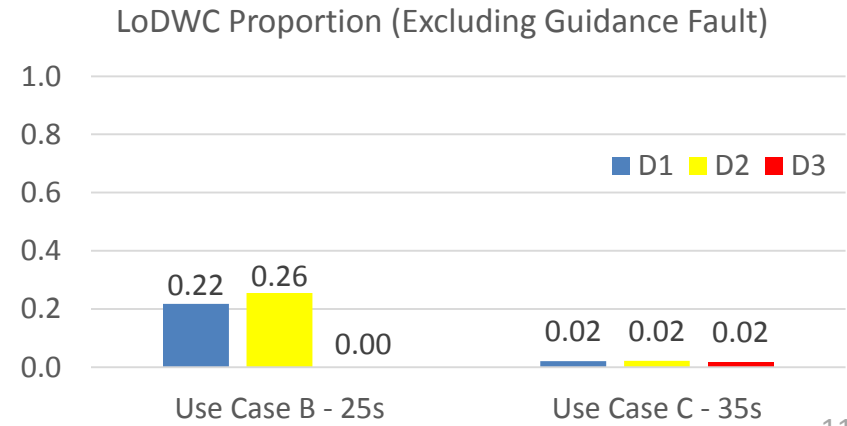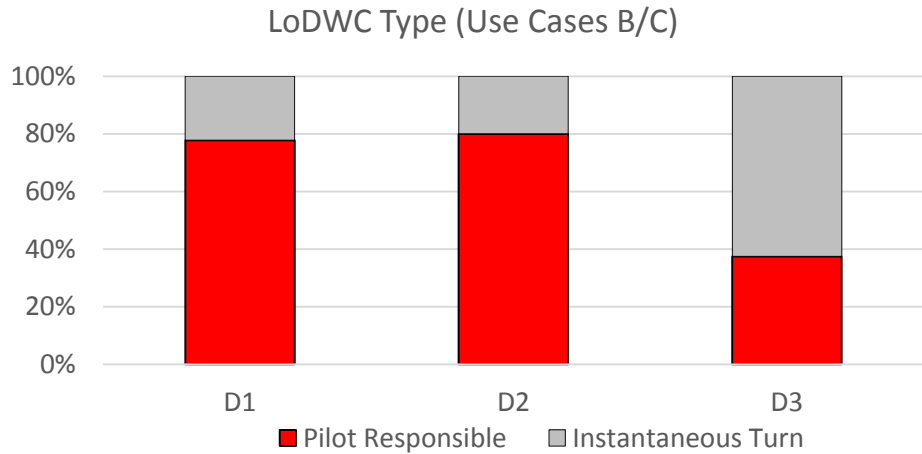
Display Location

- 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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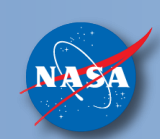
BACKUP

- 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

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

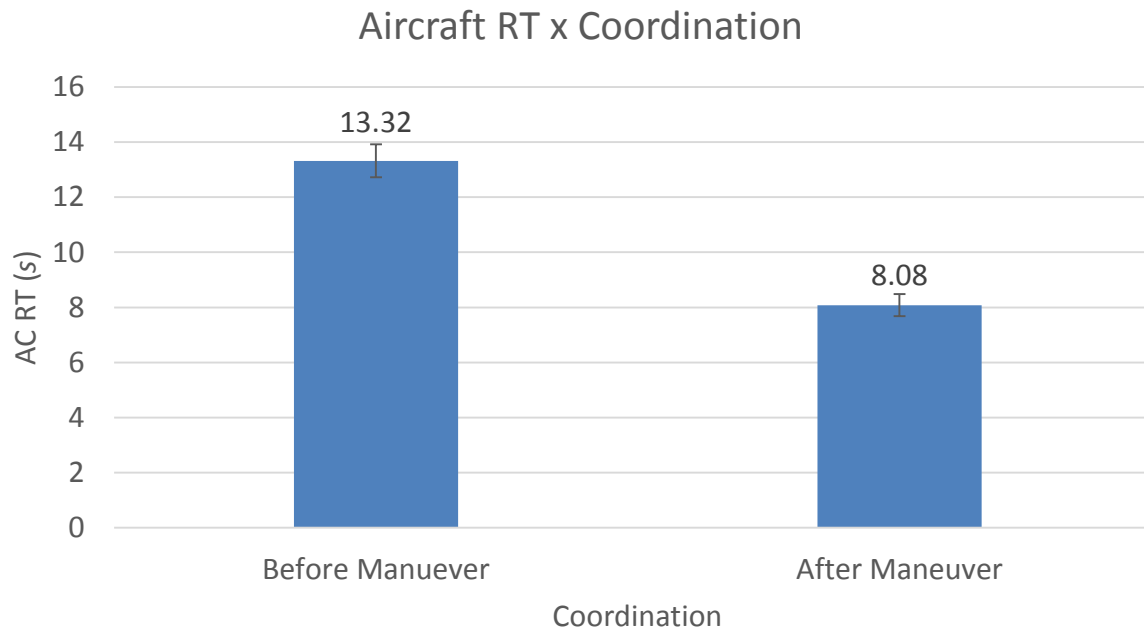LoDWC Proportion (Excluding Guidance Fault)
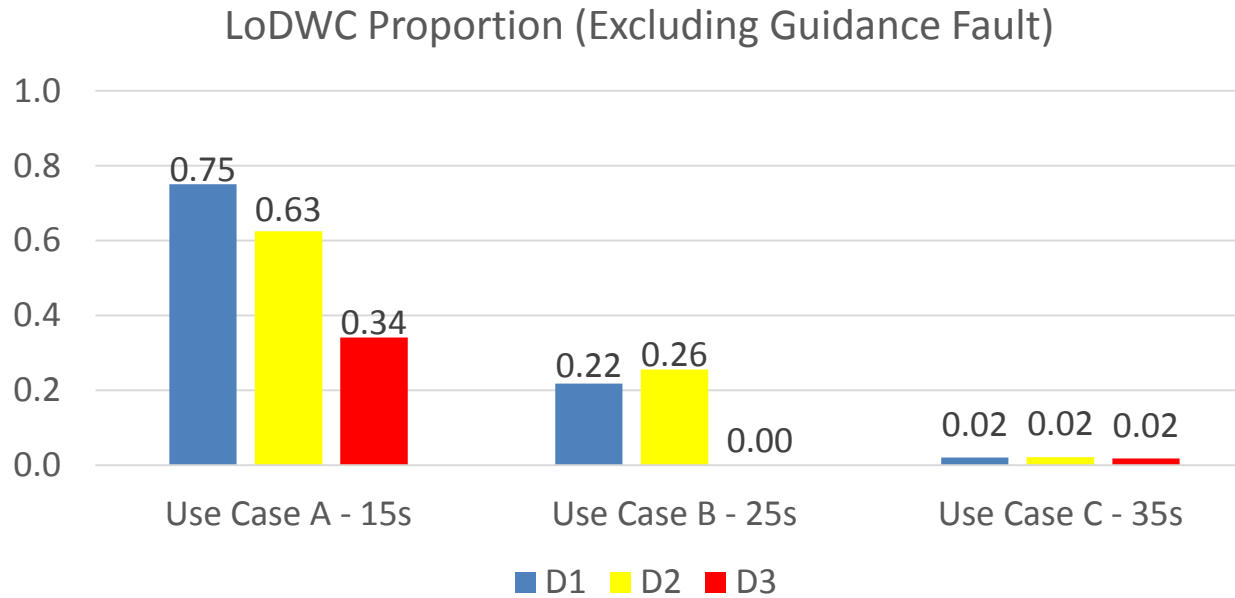
Misc Notes from Debrief

- "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

- 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:

Aircraft RT x Coordination

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

Mission Route

- 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

- Q1 This display was <u>easy to use</u>:
  - (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 <u>respond immediately</u> to DAA alerts:
  - (p = 0.017) Integrated = 4.67 Standalone = 3.87
- Q8 I trusted the accuracy of the information provided by the display
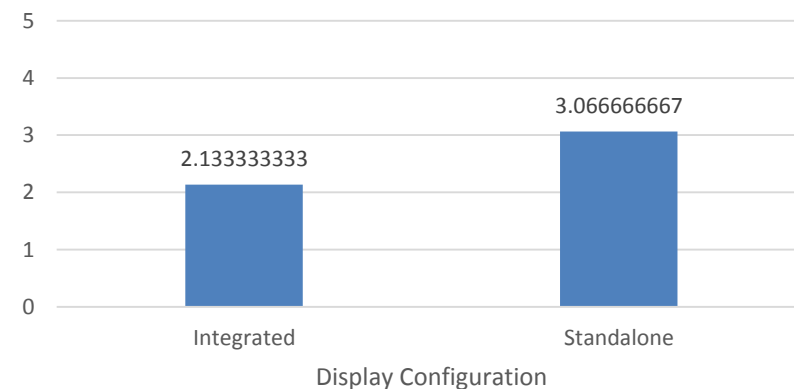 - (p = 0.041) Integrated = 4.8 Standalone = 4.27

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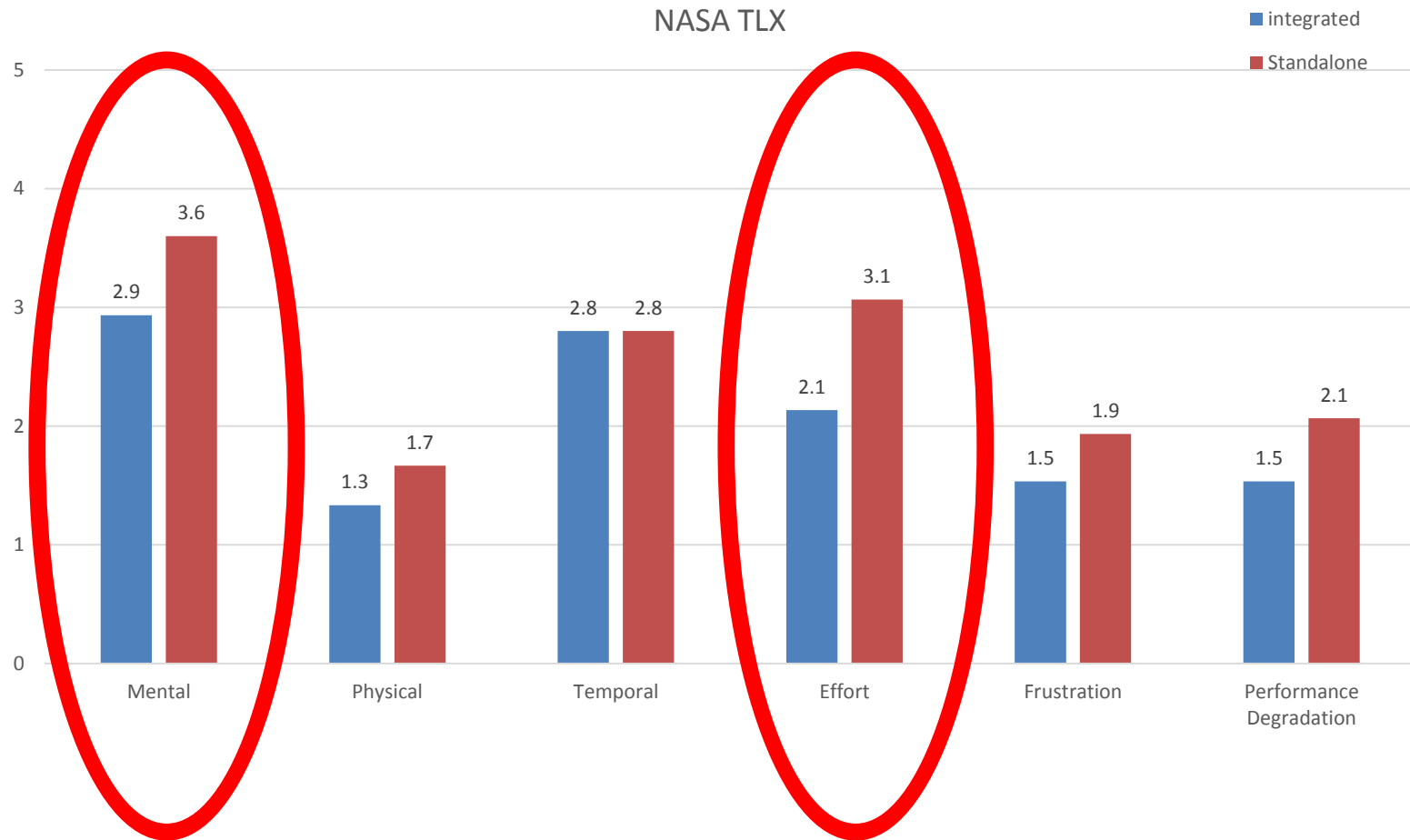 - Mean score for Effort for Integrated = 2.13, Standalone = 3.07

Mental

	Integrated	Standalone
	2.933333333	3.6

Display Configuration

Effort
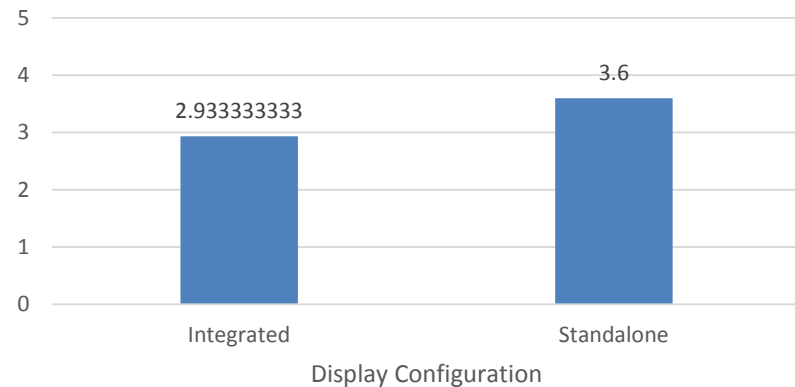
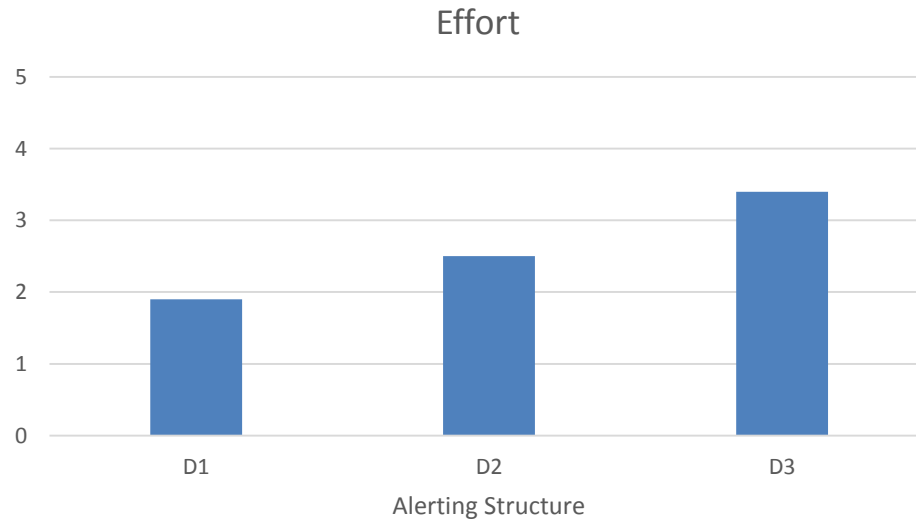|	Integrated	Standalone
	2.133333333	3.066666667

Display Configuration

- 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
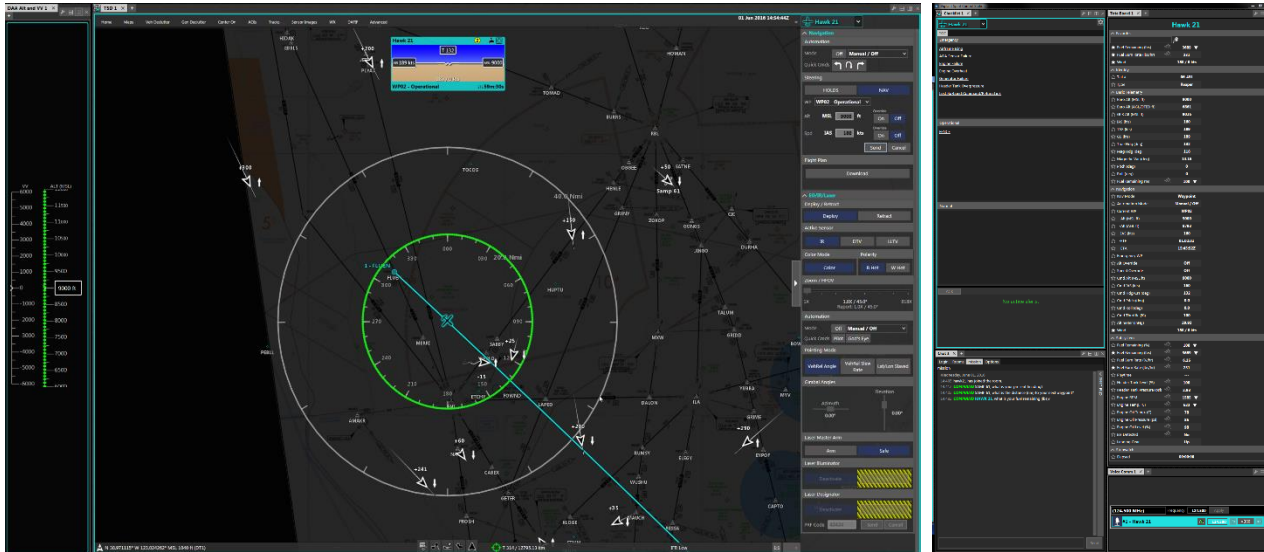   - 9 - strongly agree, 6 - somewhat agree

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

Effort

Alerting Structure

Integrated Display Configuration
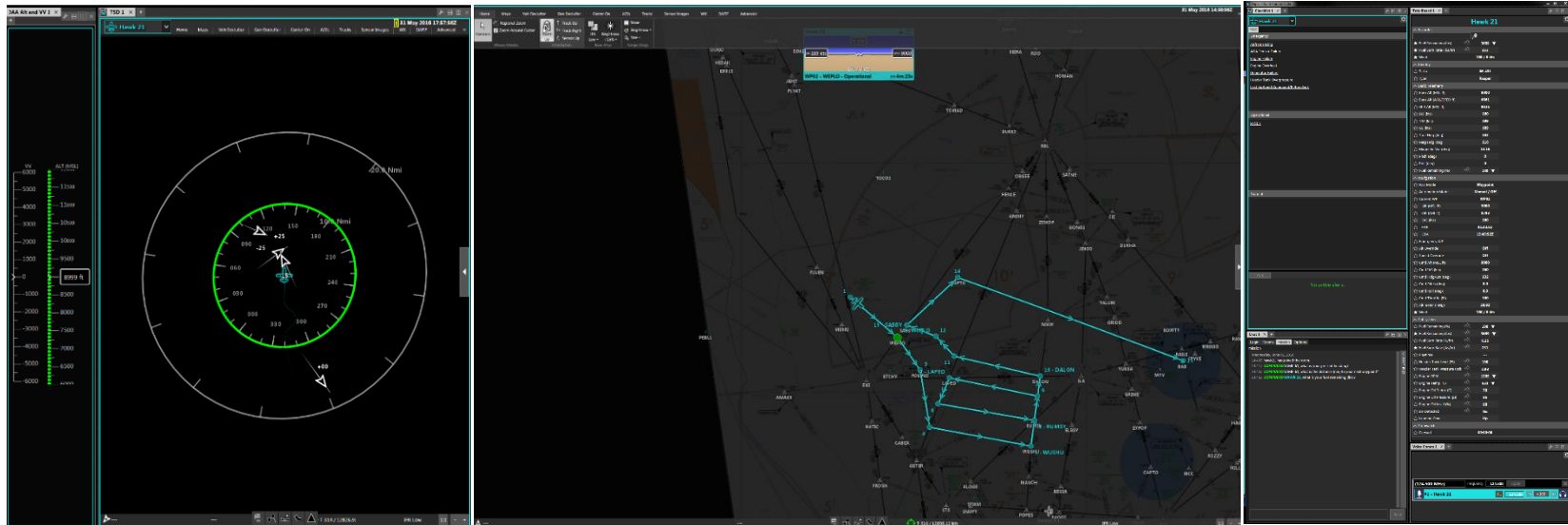

TSD w/ DAA Display
- Traffic Alerting & Guidance
- Range Rings
- Mission Route
- Navigation

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

- 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