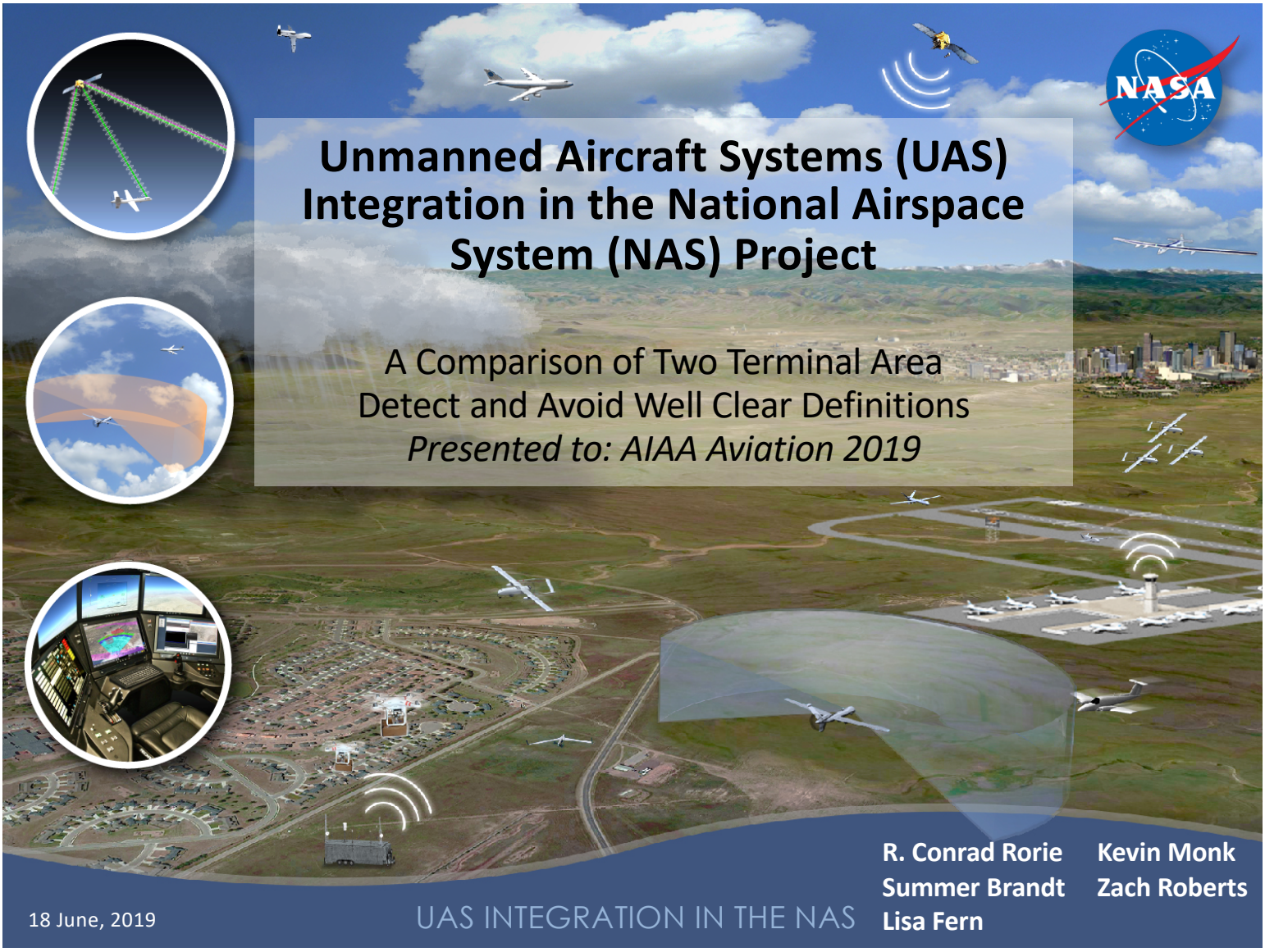

Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

A Comparison of Two Terminal Area Detect and Avoid Well Clear Definitions

Presented to: AIAA Aviation 2019

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Background

- Unmanned Aircraft Systems (UAS) Integration into the National Airspace System (NAS) Project
  - Researching how to overcome technical barriers associated with the operation of UAS in civil airspace [above 500ft AGL]
  - One emphasis has been on the development of **Detect and Avoid (DAA)** technologies and procedures

- A DAA system would allow UAS to comply with the 'see and avoid' requirements [14 CFR Part 91] in manned aviation
  - The requirements authorize manned pilots to maneuver off their route to avoid potential/perceived collision hazards; i.e., **maintain well clear**

- To be applied to UAS operations, well clear had to be mathematically defined
  - "DAA well clear" (DWC) was initially defined for **en-route operations**
    - I.e., transitioning through Class E/D/G to Class A; explicitly excluded operations in and around airports
  - Defined through RTCA Special Committee 228 (SC-228) Phase 1 DAA Minimum Operational Performance Standards (MOPS)
  - DAA system includes alerting and guidance to help pilot determine when a maneuver is necessary

Background

- Phase 2 of RTCA SC-228's DAA MOPS expands the scope to include terminal area operations (Class C, D, E, and G airports)
  - Initial research attempted to apply the Phase 1 DAA well clear definition and alerting/guidance requirements to the terminal environment
  - The en-route DAA well clear hazard zone = 4000ft lateral, 450ft vertical, and 35sec modified Tau (approx. time to closest point of approach)
    - Incorporated ATC expectations and TCAS II interoperability

- A human-in-the-loop (HITL) simulation by these authors had pilots fly a Phase 1 UAS into a Class D airport (Sonoma County Airport [KSTS])
  - Pilots flew instrument and visual approaches
  - In some of the approaches a conflict was scripted to occur between airport traffic and the UAS
  - **Primary research question**:
    - How well can pilots maintain appropriate separation against traffic using the Phase 1 en-route DAA well clear definition?

Previous Research

- The results demonstrated the poor fit of the Phase 1, en-route DAA well clear definition in the terminal area

- The relatively large size of the Phase 1 definition led to an exceedingly high number of DAA alerts
  - As a result pilots had a hard time judging when a maneuver was truly necessary
  - Led to a much higher number of high-severity losses of DAA well clear than had been seen in earlier, Phase 1 research

- The DAA Corrective alert level was also shown to be less useful in the terminal area
  - The Corrective alert is designed to facilitate ATC coordination *prior* to maneuvering to maintain DAA well clear
  - ATC did not expect UAS pilots to coordinate with them prior to maneuvering
  - Corrective alerts often lasted less than 15sec

Current Objective

❖ Purpose: investigate 2 new DAA well clear definitions tailored to the terminal environment

- The candidates were based on expected traffic pattern characteristics
- 2 aspects of the Phase 1 DAA well clear definition were identified as needing modification to better conform to standard terminal area operations:
  1. Reduce the horizontal threshold: 4000ft is too wide & will routinely alert against VFR traffic on the downwind leg of the traffic pattern
  2. Reduce the modified Tau (modTau) component: 35sec is too conservative & will alert too quickly against intruders that are maneuvering near the airport

❖ Research Questions:

1. Are there meaningful differences between the 2 candidate definitions?
2. Is the Corrective alert useful with the new definitions?

Experimental Design

- Independent Variables:
  1. DAA Well Clear Definition (2 levels; within-subjects):
     - No Tau = terminal area definition does **not** include modTau in its criteria
     - With Tau = terminal area **does** include modTau

DAA Well Clear Parameters	No Tau	With Tau	Phase 1 (En-Route)
Horizontal Threshold	1500ft	1500ft	**4000ft**
Vertical Threshold	450ft	450ft	450ft
modTau	**N/A**	**15sec**	**35sec**

  2. Alerting Configuration (2 levels; 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)

Alerting Criteria

Symbol	Name	Pilot Action	Time to Loss of DWC	Aural Alert Verbiage
	Warning Alert	• **Maneuver now to avoid a loss of DAA well clear** • Notify ATC as soon as practicable *after* taking action	30 sec	"Traffic, Maneuver Now" x2
	Corrective Alert*	• **Coordinate with ATC *then* maneuver to avoid a loss of DAA well clear**	45 sec	"Traffic, Avoid"
	Preventive Alert	• Intruder nearby in altitude • Corrective action *should not* be required	45 sec	"Traffic, Monitor"
	Guidance Traffic	• Traffic is generating guidance bands *outside* of current course	X	N/A
	Remaining Traffic	• Traffic within sensor range	X	N/A

*Corrective alert only present in the With Corrective alerting configuration

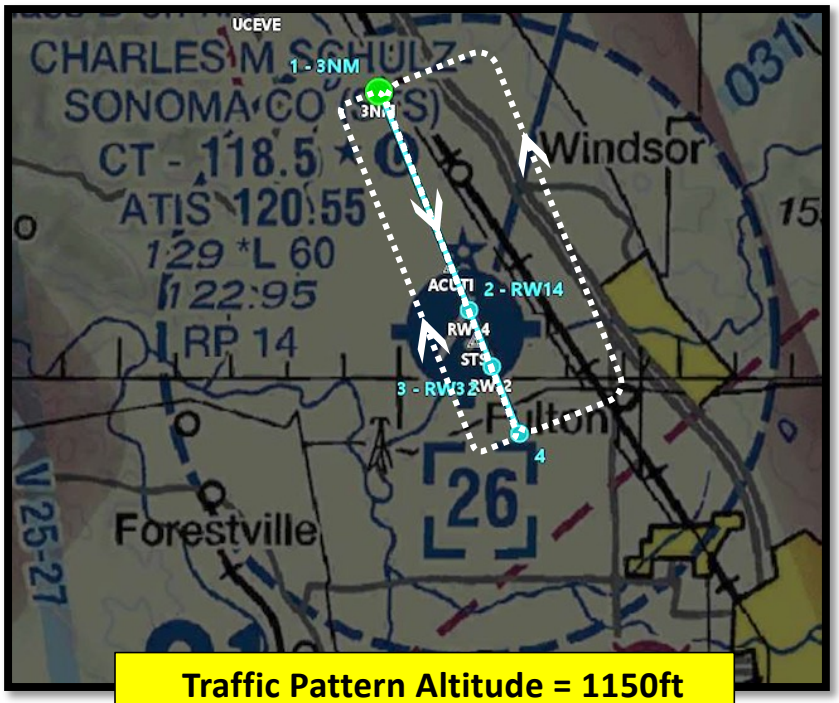
Test Setup

- Ground control station (GCS) contained:
  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.

Vigilant Spirit Control Station (AFRL)

Sonoma County Airport (KSTS)

- Class D
- Runway 14/32
  - Length = 6000ft x 150ft
  - RNAV (GPS)
- Elevation = 129ft
- Traffic Pattern = 1150ft
- Downwind lateral offsets:
  - Left = 1.5nm (~9000ft)
  - Right = 0.5nm (~3000ft)
- Runway 20/02
  - *Not used*



Traffic Pattern Altitude = 1150ft
3NM (WP1) to RW14 (WP2) = 3nm
RW14 (WP2) to RW32 (WP3) = 1nm

Simulation Components

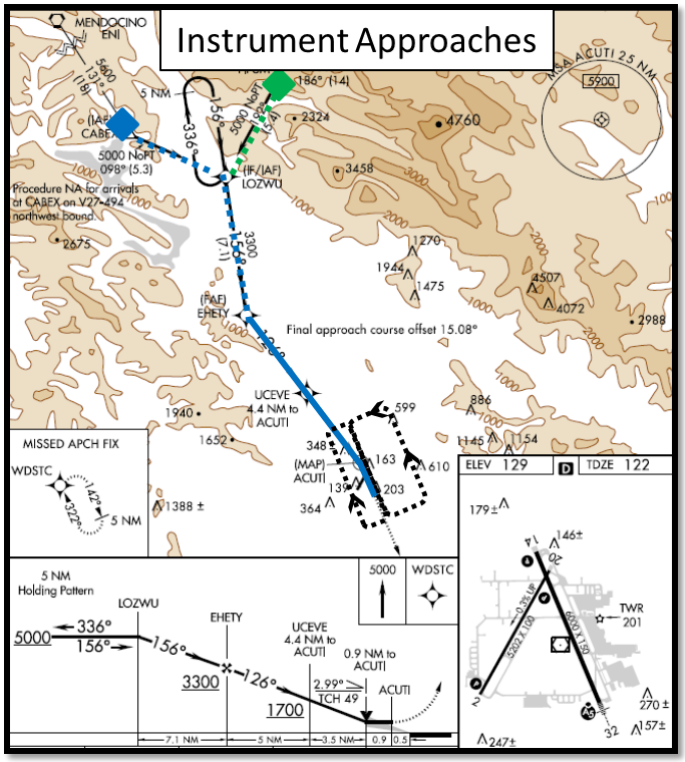
- Pseudo-pilots monitored and managed all manned traffic (IFR & VFR)
  - Multi-Aircraft Control System (MACS) software suite
- Air Traffic Control managed UAS and manned traffic
  - Tower controller managing Santa Rosa (KSTS)
  - Center controller managing Oakland Center (ZOA 40/41)
  - Sector traffic 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

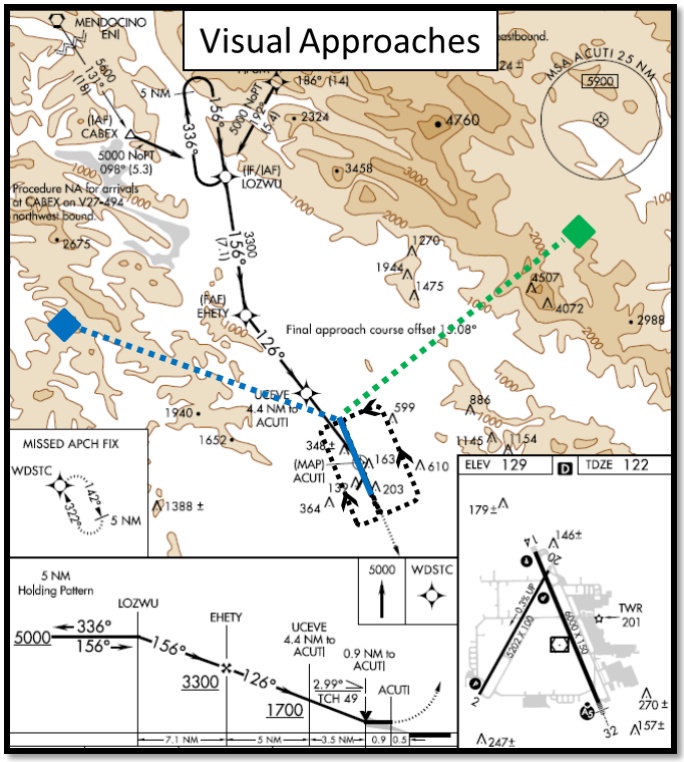
Scenarios

- Participants flew 2 types of approaches under Instrument Flight Rules (IFR)
  - Instrument (RNAV GPS) Approach
  - "Visual" Approach

- Operated a simulated MQ-9 (Reaper; Group 5)
  - 65ft wingspan
  - 110kts cruise speed
  - 1000 FPM climb/descent rate
  - 3°/sec turn rate

Scenarios





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 1150/2000ft

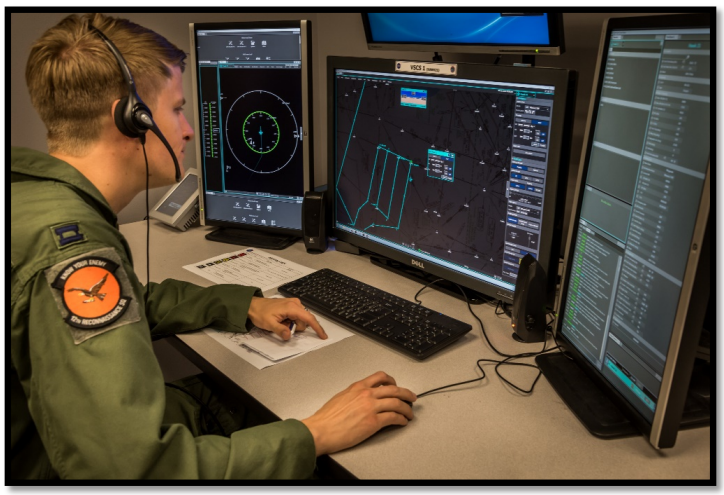
Scenarios

- Encounter Type
  - **Turn Into** = traffic blunders into us on final and is intended to lead to NMAC without UAS pilot response
  - **Turn In Front** = traffic turns in front of UAS with sufficient separation (~1.5-2nm) to land safely (turn is coordinated w/ Tower)
  - **Unscripted** = no encounter is scripted to occur but traffic expected to be on downwind as UAS is on final

- Pilots flew 4 approaches per trial
  - 1 Turn Into & 1 Turn In Front per trial
  - All other traffic considered Unscripted

Participants

- 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 controls served as tower controller confederates



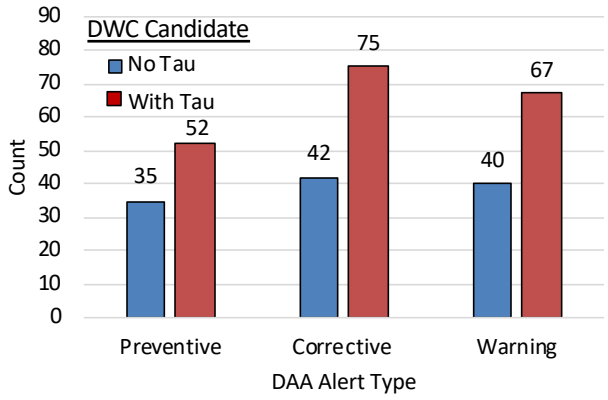
RESULTS

ALERTING PERFORMANCE…
LOSSES OF DAA WELL CLEAR…
MANEUVER PREFERENCES…

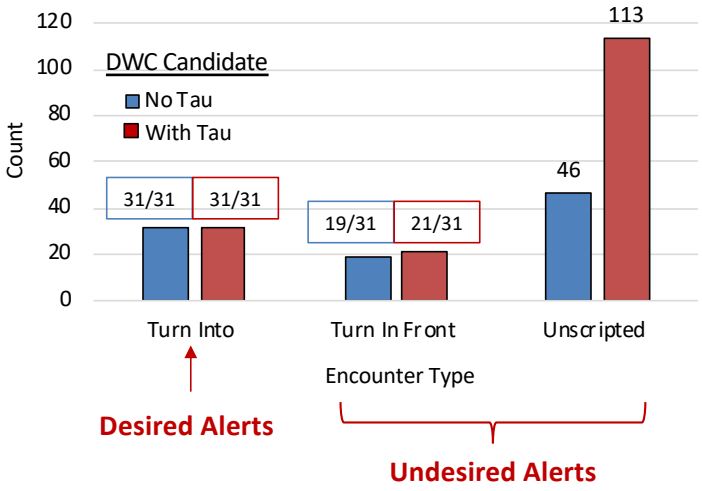
DAA Alerting Performance

- The *With Tau* candidate alerted more frequently to all alert types
  - Biggest difference was against Corrective alerts
- Driven by how often **Unscripted** traffic triggered an alert
  - The 2 definitions alerted (nearly) identically against the scripted encounter types (Turn Into & Turn In Front)

# of DAA Alerts

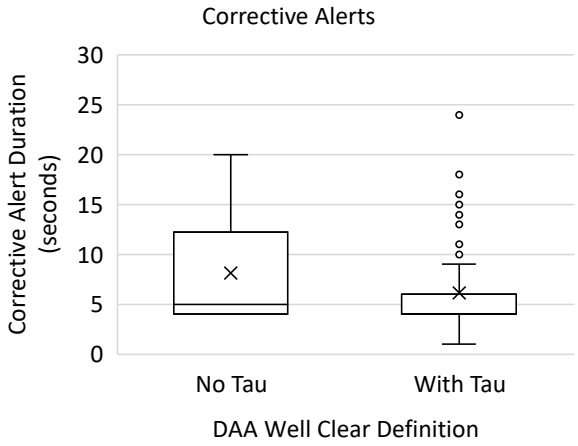


# of Corrective or Warning DAA Alerts

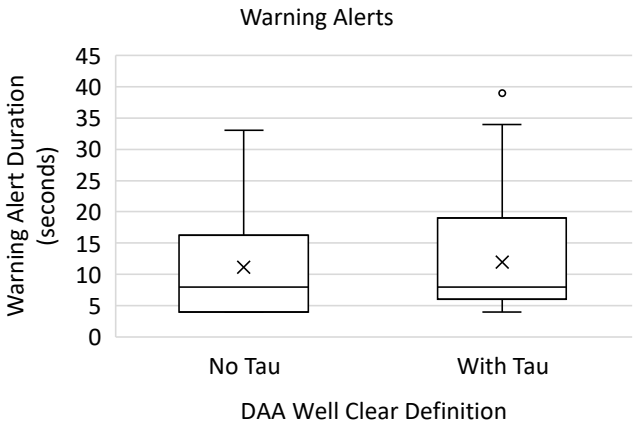


Alerting Performance

- Corrective alerts were particularly short in the *With Tau* DAA well clear definition
  - Frequently only lasted the *minimum* duration (4 seconds)
  - Not enough time to coordinate with ATC



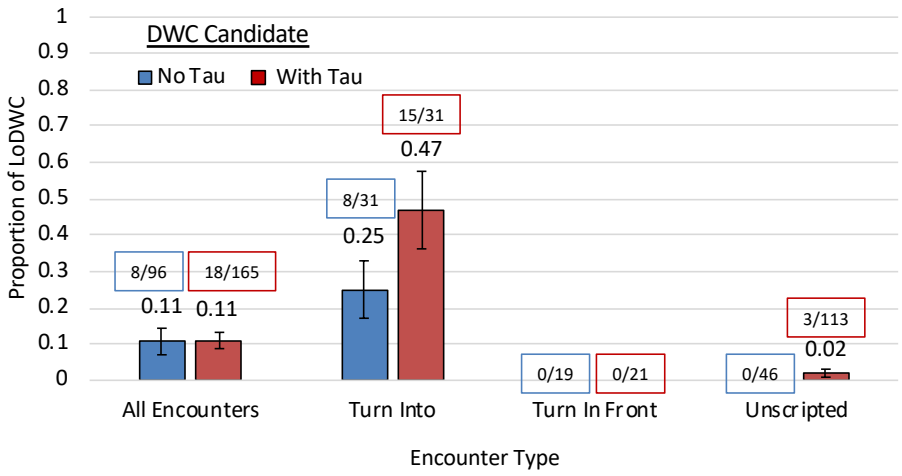
- Warning alerts tended to last longer in both DAA well clear definitions



Losses of DAA Well Clear

- Proportion of losses of DAA Well Clear (LoDWC) =
  - # of LoDWC / # aircraft that generated a DAA Corrective or Warning

- Pilots were twice as likely to lose DAA well clear against the **Turn Into** encounter in the *With Tau* condition
  - Larger hazard zone made it harder for pilots to avoid separation violation



Losses of DAA Well Clear

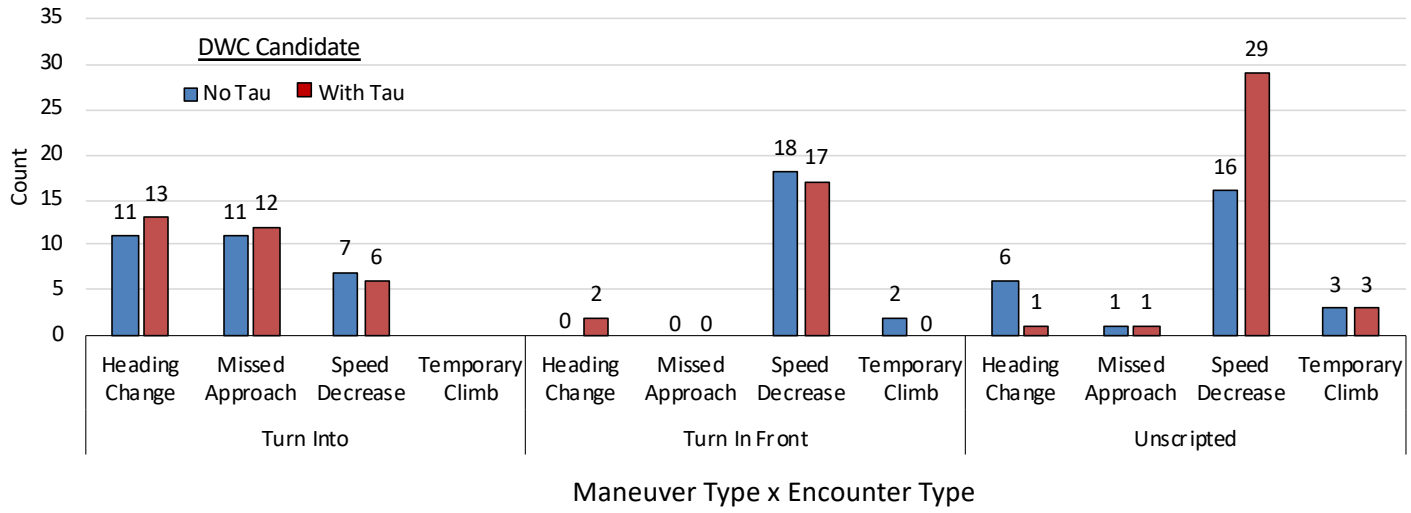
- With Tau condition resulted in more losses of DAA well clear that were effectively unavoidable:

Time to Loss of DAA Well Clear	No Tau	With Tau
Less than 15 sec	1/8 (13%)	8/15 (53%)
Less than 5 sec	0	5/15 (33%)

- Product of the larger size of its hazard zone

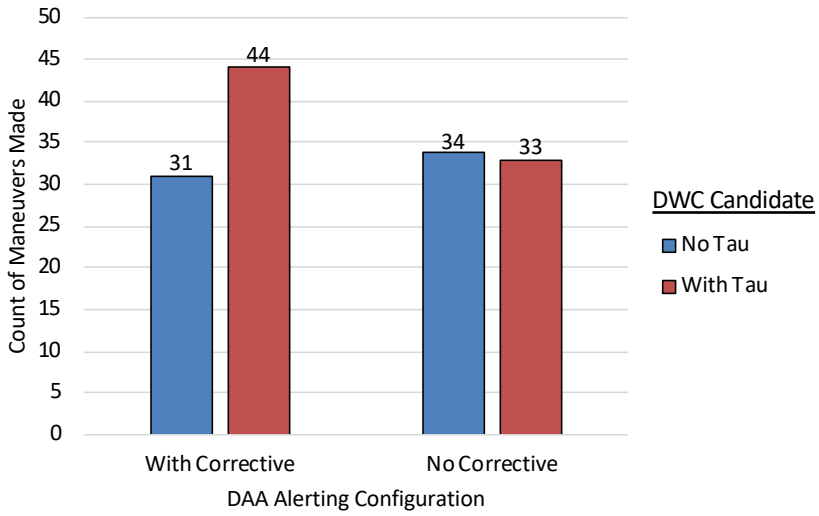
Initial Maneuver Types

- The two DAA well clear definitions resulted in very similar types of maneuvers
  - Exception being a larger number of speed decreases against Unscripted encounters in the *With Tau* condition
  - Speed changes *not* considered disruptive



Number of Maneuvers Made

- Pilots made the greatest number of maneuvers when the *With Corrective* alerting condition was paired with the *With Tau* DAA well clear definition
  - Increased ~30% relative to the other 3 conditions



Conclusions

- With Tau candidate led to more:
  - DAA alerts against Unscripted encounters
  - Short-duration Corrective alerts
  - Unavoidable losses of DAA well clear against the Turn Into encounter
  - Maneuvers against Unscripted traffic (although it was typically non-disruptive)

- No Tau candidate determined to be a better fit, however:
  - Losing DAA well clear against the No Tau definition should be considered a more severe/hazardous loss of separation

- Corrective alert level continued to show limited utility
  - Short duration Corrective alerts with both candidates, particularly With Tau

- Future work needed to investigate **when to switch** from the Phase 1/en-route definition to the terminal area definition

QUESTIONS?

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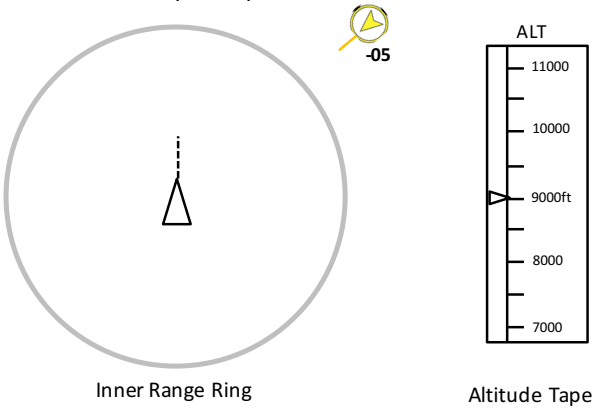
BACKUP

DAA Alerting & Guidance

No Corrective

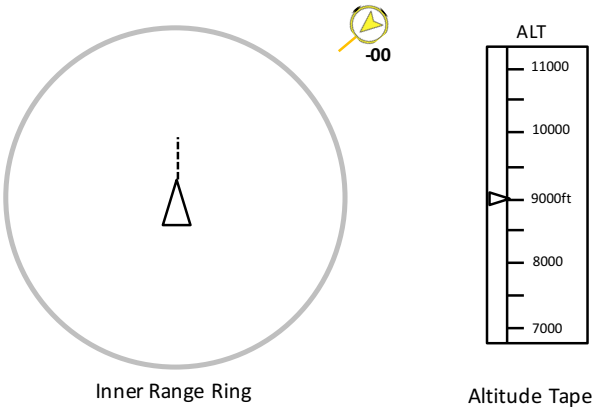
Preventive (Truth) Alert



Inner Range Ring

Altitude Tape

Corrective (Truth) Alert

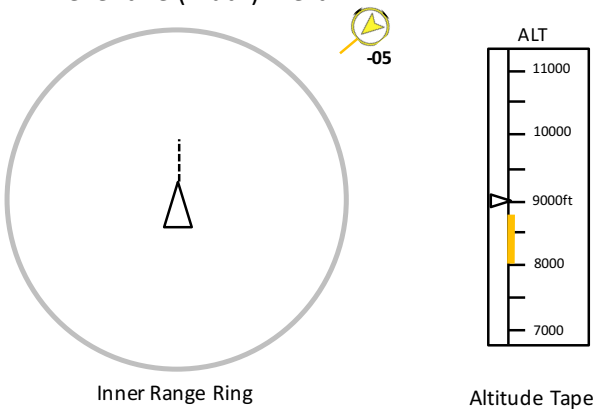


Inner Range Ring

Altitude Tape

With Corrective

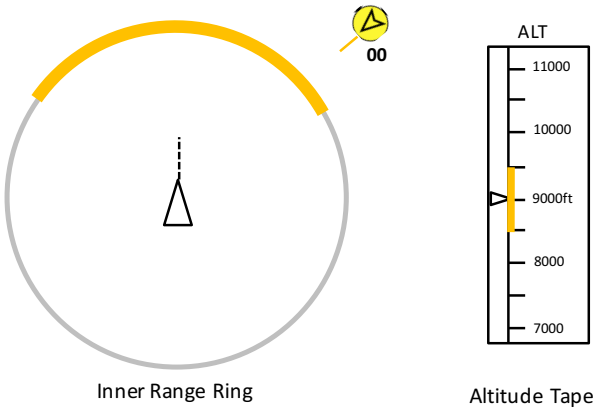
Preventive (Truth) Alert



Inner Range Ring

Altitude Tape

Corrective (Truth) Alert



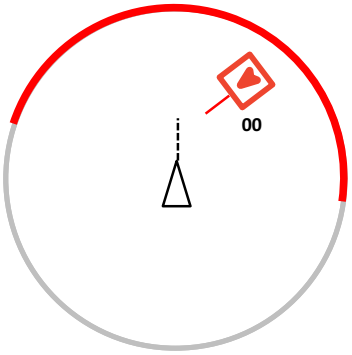
Inner Range Ring

Altitude Tape

DAA Alerting & Guidance

No Corrective

Warning (Truth) Alert



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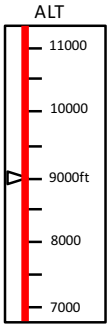
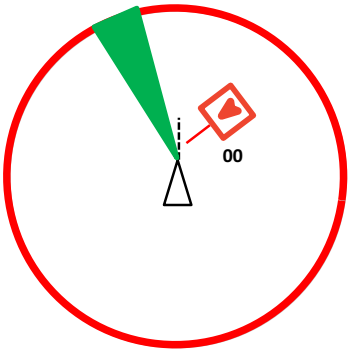


Altitude Tape

Regain DWC Guidance



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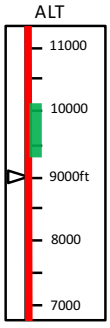
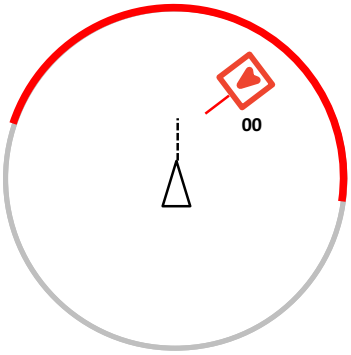


Altitude Tape

With Corrective

Warning (Truth) Alert



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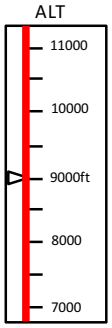

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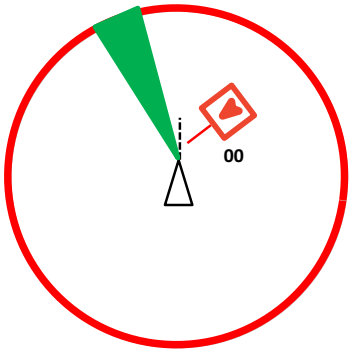

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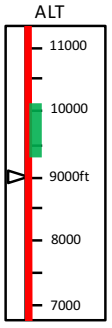

Altitude Tape

Aircraft Flight Model

- Generic MQ-9 Reaper
  - Speed:
    - Cruise: 110 knots
    - Landing: 90-110 knots
    - Max: 200 knots
    - Min: 70 knots
  - Climb/Descent Rate:
    - 1000ft/min (default)
    - Captures 3° glide slope on final
  - Turn Performance:
    - Max Roll: +/- 20°
    - Turn Rate: 5°/sec

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)