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

UAS Pilot Performance Comparisons with Different Low Size, Weight and Power Sensor Ranges

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39th Digital Avionics Systems Conference

UAS in the NAS Project

- Project Objective
  - Address technical & safety issues related to integration of UAS in the NAS
  - Produce research findings that guide development of Minimum Operational Performance Standards (MOPS)
    - Support compliance with existing “see and avoid” regulations
      - Remain “well clear” of surrounding aircraft

- Human Systems Integration
  - Identify display requirements for detect-and-avoid (DAA) systems
    - Minimum information elements necessary for acceptable pilot performance:
      - Aircraft position, velocity, & directionality
      - Conflict detection & resolution aids

DAA System

- Predictive information to remain “DAA well clear” (DWC)
  - Supports DAA task: Detect → Determine → Execute
  - Color-coded alerting for conflict detection
  - Suggestive guidance bands for conflict avoidance

Symbol	Alert	Look-ahead Time	Priority
	Corrective	≤60 sec	ATC Coordination
	Warning	≤30 sec	Maneuver

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Background

- Phase 1 DAA MOPS
  - Intended for large UAS in transit
    - Minimum 6.7nmi radar surveillance
    - TCAS interoperability

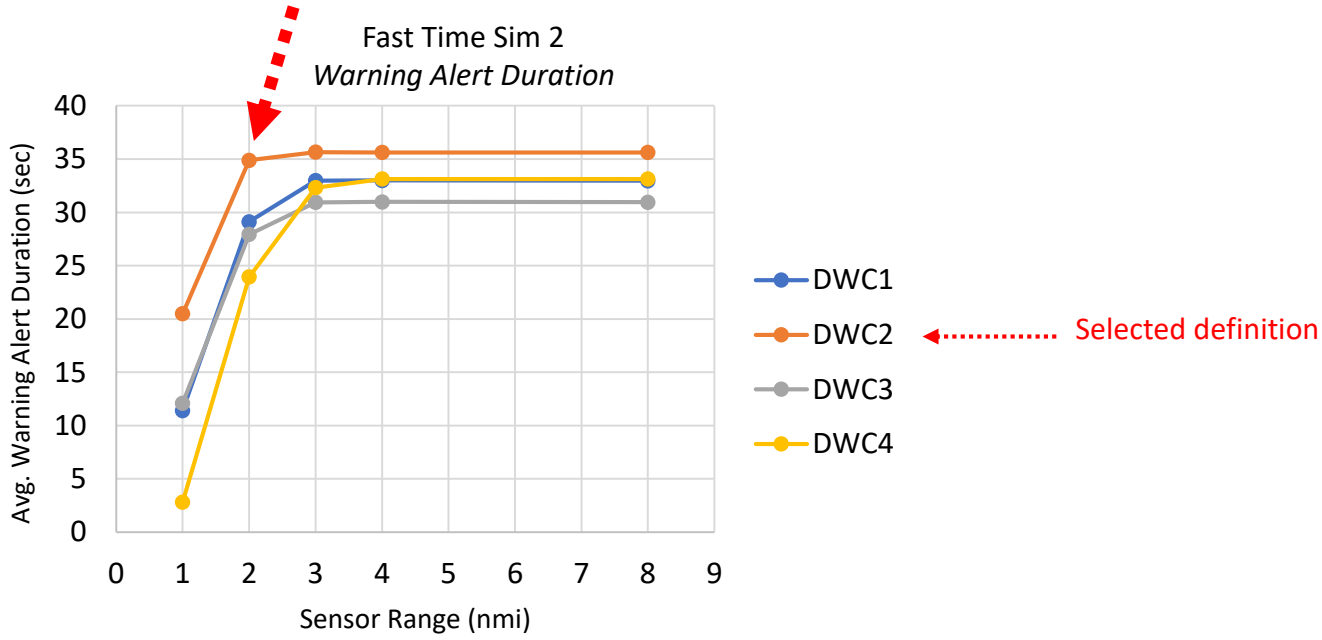
Phase 1 Hazard Zone	
Horizontal Threshold	4,000 ft
Vertical Threshold	450 ft
Modified Tau (modTau)	35 sec

- Phase 2 DAA MOPS
  - Extend requirements to small-to-medium UAS
    - Low size, weight & power (SWaP) sensors
    - Limited aircraft performance
  - Reduced hazard zone for non-cooperative intruders:
    - Maintained existing levels of safety observed in Phase 1
    - Preserved DAA alerting timeline at 3.5nmi range
      - Must support further reductions to surveillance volume requirement

Low SWaP Hazard Zone	
Horizontal Threshold	2,200 ft
Vertical Threshold	450 ft

Experiment Objective

- Inform Phase 2 DAA MOPS development
  - Explore differential effects of limited surveillance on DAA system
    - Characterize pilot performance with each reduction to sensor range
    - Validate fast-time simulation findings with a human in-the-loop:

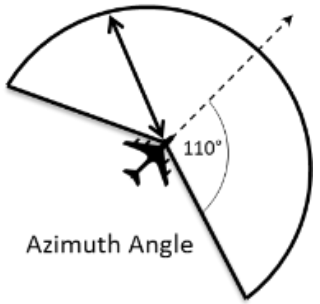


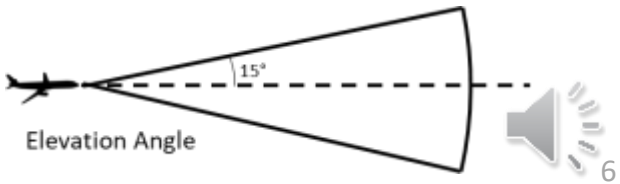
  - Identify necessary revisions to DAA display, alerting and guidance requirements for UAS equipped with low SWaP sensors

Test Setup

- Participants
  - 9 active-duty UAS pilots

- Ownship: Generic **RQ-7 Shadow** model
  - Mission altitude: 8,000ft MSL
    - Oakland Center airspace (Class E)
  - Maneuverability:
    - Cruise speed: 60 or 100 KTAS
    - Turn rate: 7°/sec
    - Climb/descent rate: 500 ft./min
  - Air-to-Air Radar Surveillance (non-cooperatives)
    - Sensor Range: 1.5nmi, 2.0nmi, 2.5nmi, or 3.0nmi
    - Field of Regard coverage:
      - +/- 110° azimuth
      - +/- 15° elevation





Scenario Design

- Four experimental trials
  - 45 minutes with each sensor range:
    - 1.5nmi, 2.0nmi, 2.5nmi, 3.0nmi

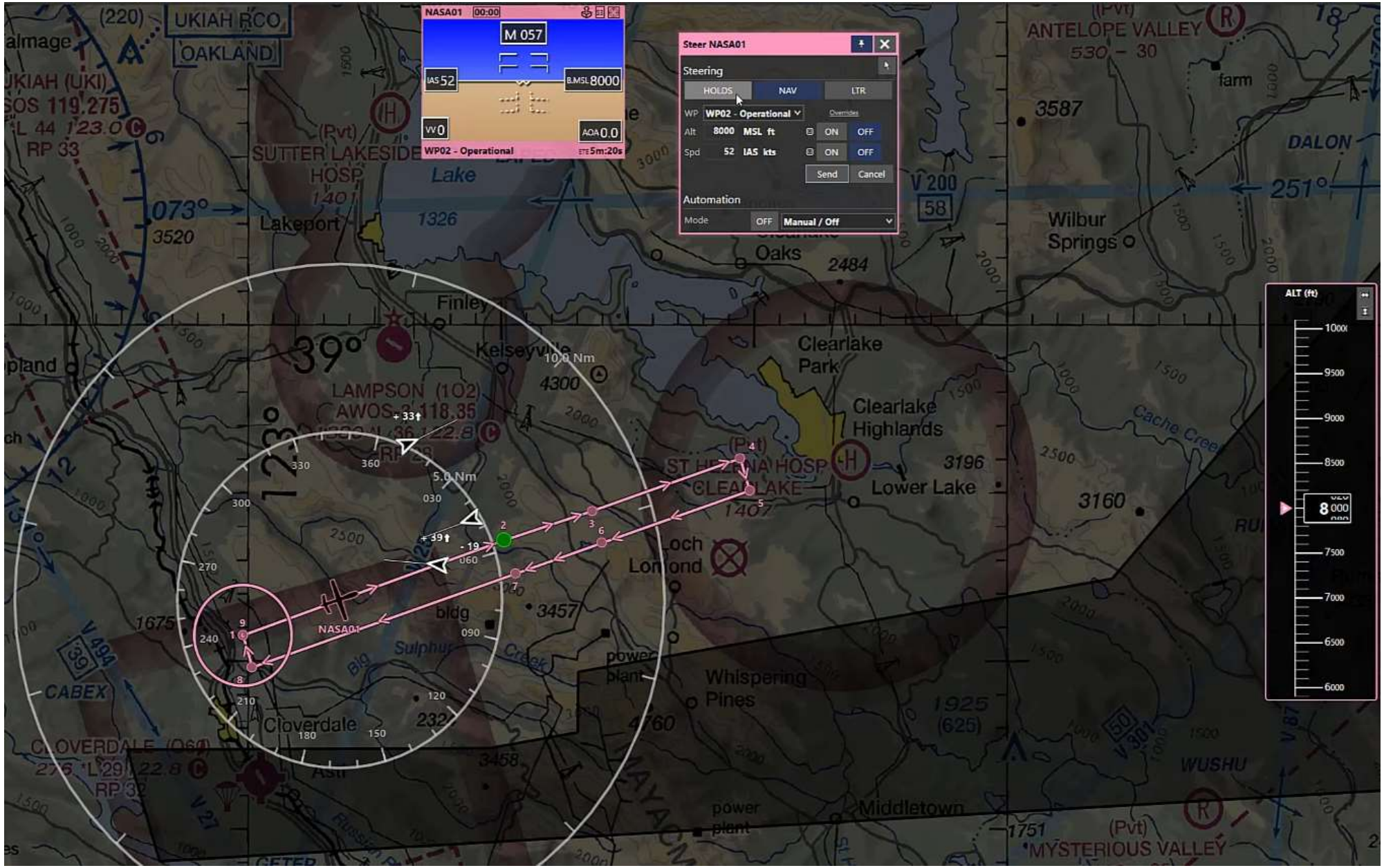
- Pilot Task
  - Remain DAA well clear (Traffic Display)
    - Four non-cooperative DAA conflicts per trial:

Encounter	Intruder Speed	Approach Angle
Fast Head On	170 KTAS	0˚
Slow Head On	100 KTAS	0˚
Fast Crossing	170 KTAS	+/- 90˚
Slow Crossing	100 KTAS	+/- 90˚

  - Secondary Tasks (Status Panel)
    - Respond to mission status queries in chat window
    - Electronic checklists for system health alerts

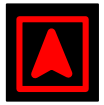
Vigilant Spirit Control Station

Example: Fast Crossing Encounter (2.5nmi)



Performance Metrics

- Alerting Performance
  - Alert Look-ahead Time
  - Alert Progression

Symbol	Alert	Look-ahead Time	Priority
	Corrective	≤60 sec	ATC Coordination
	Warning	≤30 sec	Maneuver

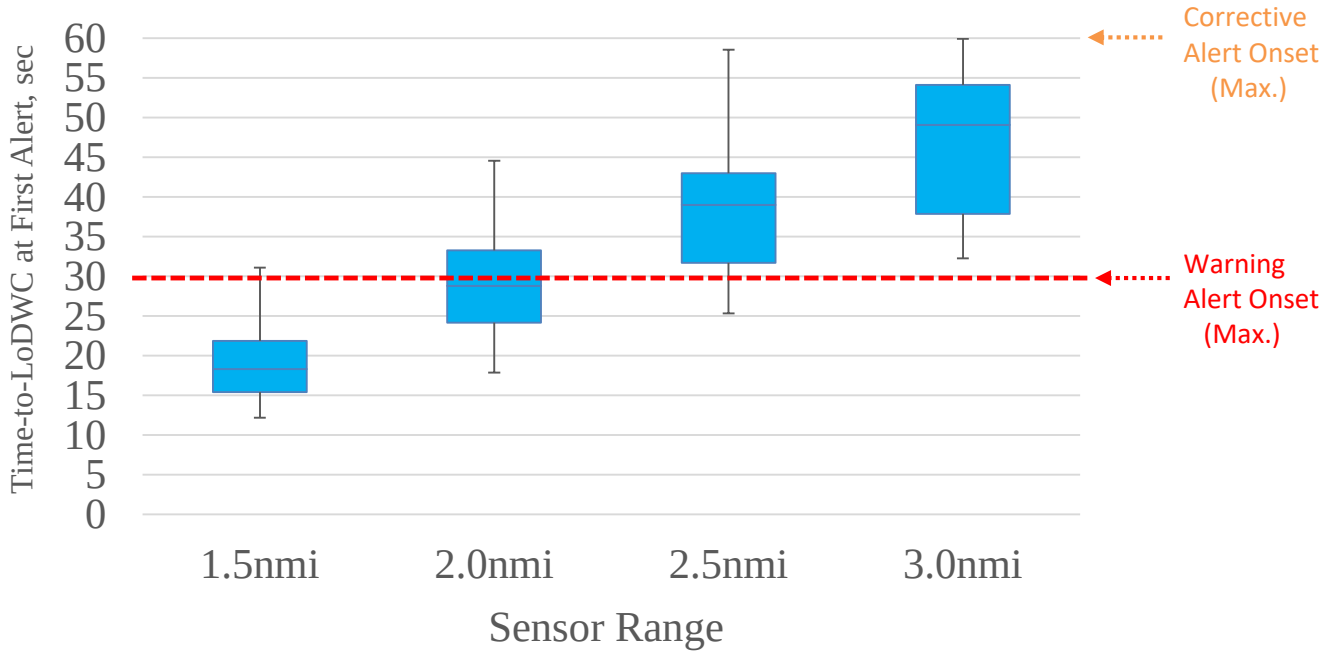
- Pilot Performance
  - Response Times
  - ATC Coordination
  - Separation Maintenance
    - Losses of DAA Well Clear (LoDWC)
    - Near Mid-air Collisions (NMAC)

Violation	Horizontal Sep.	Vertical Sep.
LoDWC	2200 feet	450 feet
NMAC	500 feet	100 feet

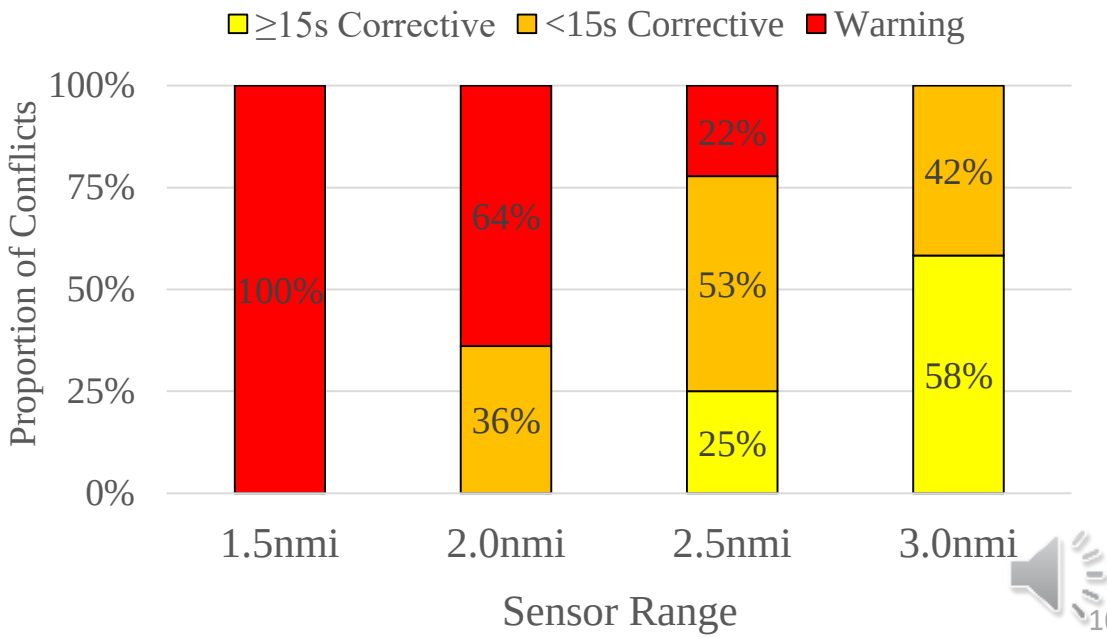
Alert Look-ahead Time

- 2.5nmi was the minimum range necessary to:
  - Preserve the Warning alert timeline in the worst-case scenario
    - Desired minimum alert duration = 25 seconds
  - Generate Corrective alerts for majority of conflicts
    - Mostly short-duration (<15 seconds)

Alert Look-ahead Time



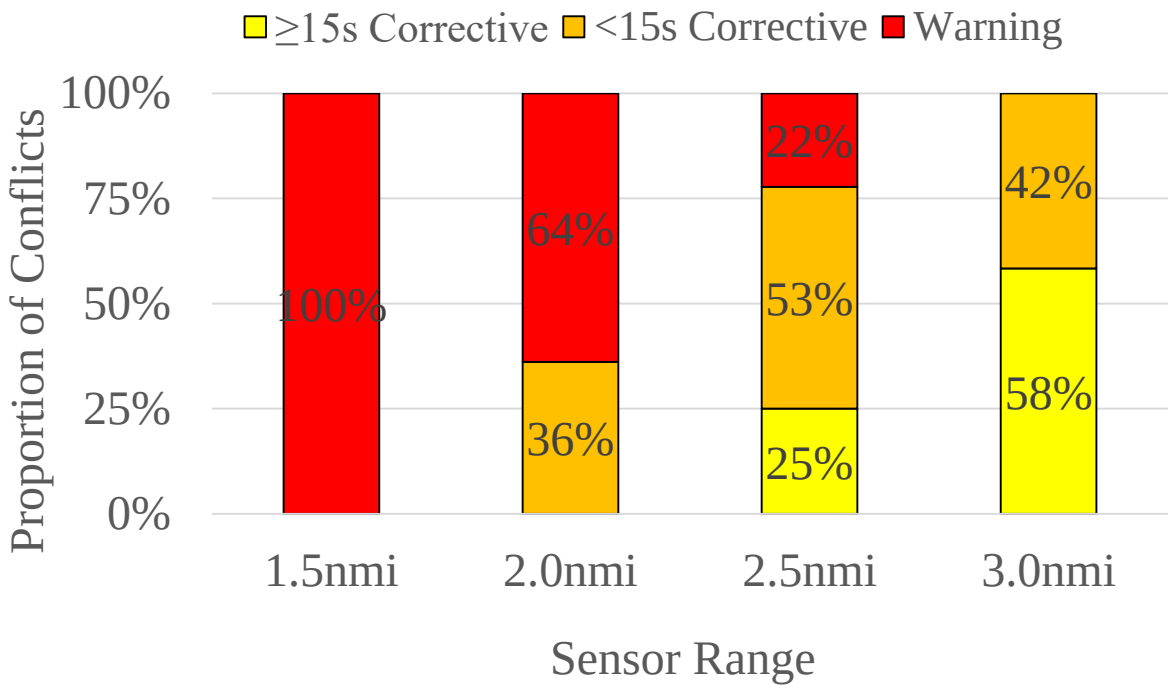
First Alert Level



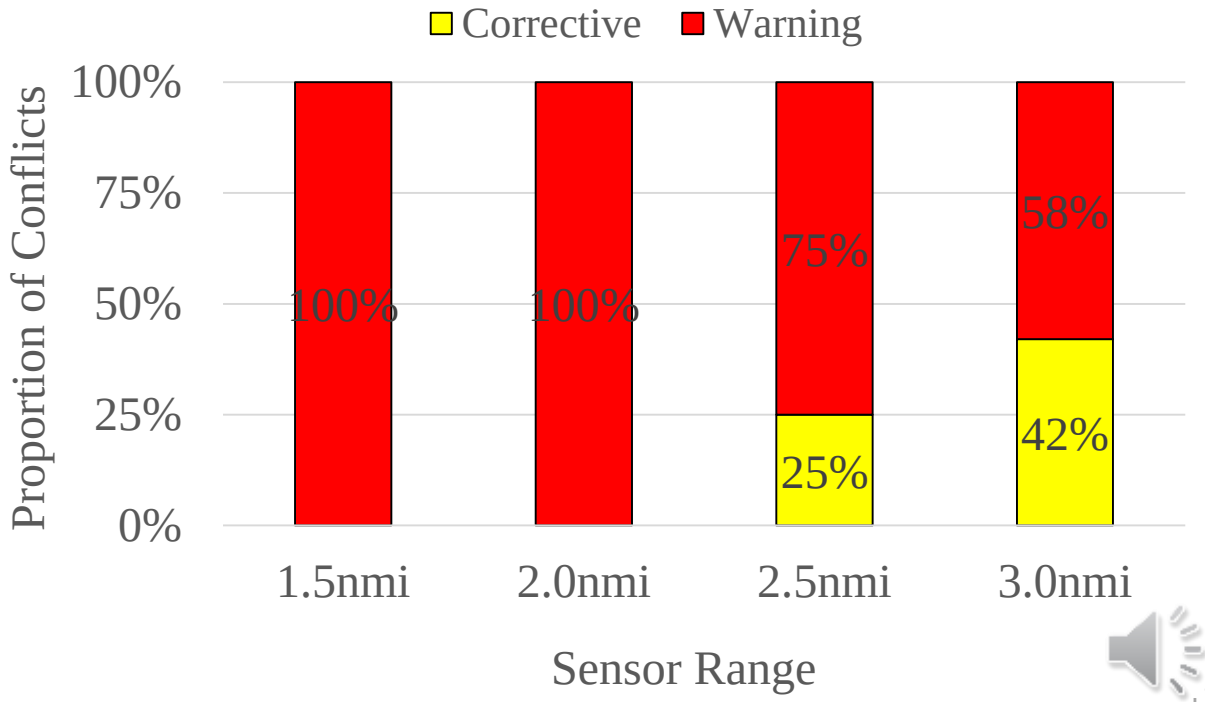
Alert Progression

- Most conflicts reached warning-level severity before resolution
  - Warning alerts generated for 83% of conflicts overall
    - Always progressed to Warning in 1.5nmi and 2.0nmi range conditions

First Alert Level

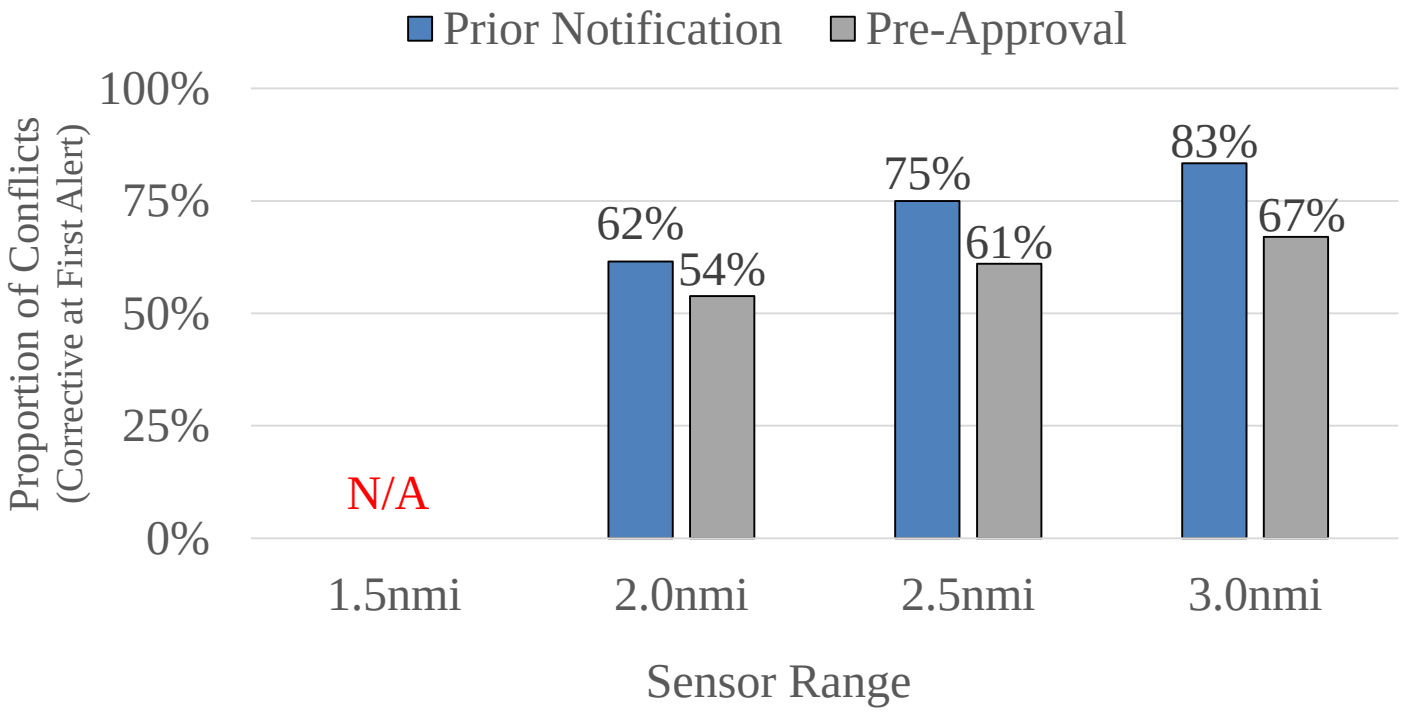


Final Alert Level



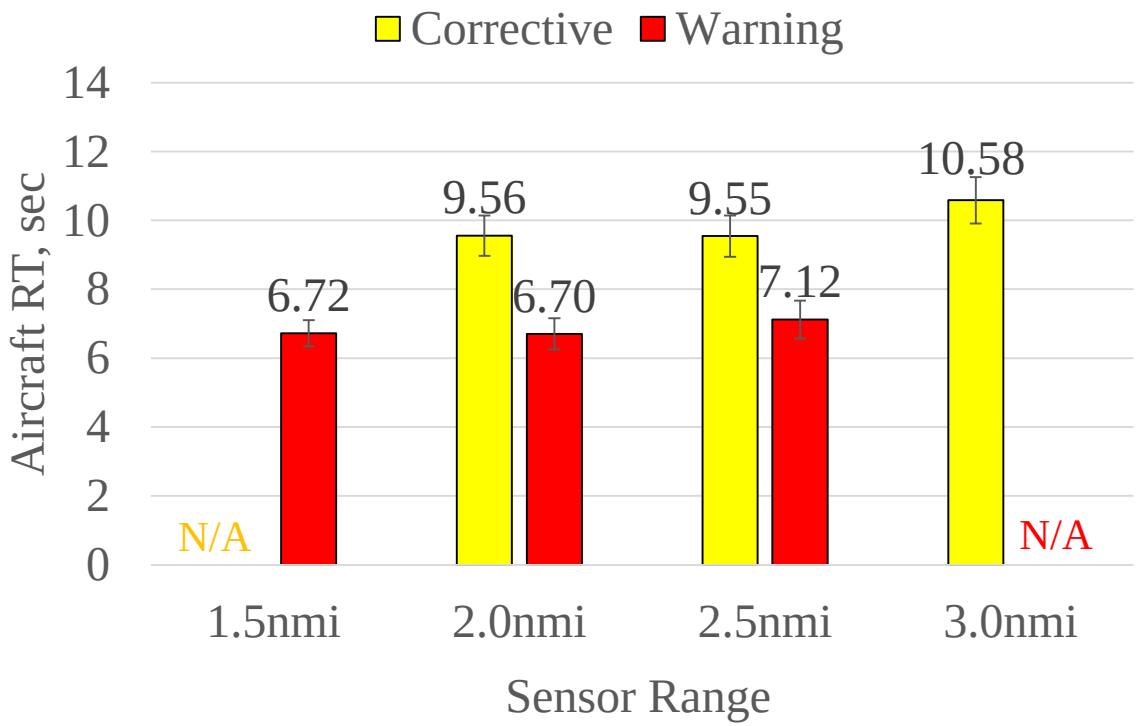
ATC Coordination

- ATC coordination rates decreased with each reduction to sensor range
  - Prior ATC coordination only required at caution level
  - Corrective alerts were either shortened or eliminated altogether (e.g., 1.5nmi)
    - Often unable to wait for ATC approval after initial transmission
  - Pilots did eventually notify ATC after uncoordinated maneuvers



Pilot Response Times

- Minimal impact of Sensor Range on response times
  - Majority of encounters required immediate response
  - Hard cap on responses to Corrective alerts (short-duration)

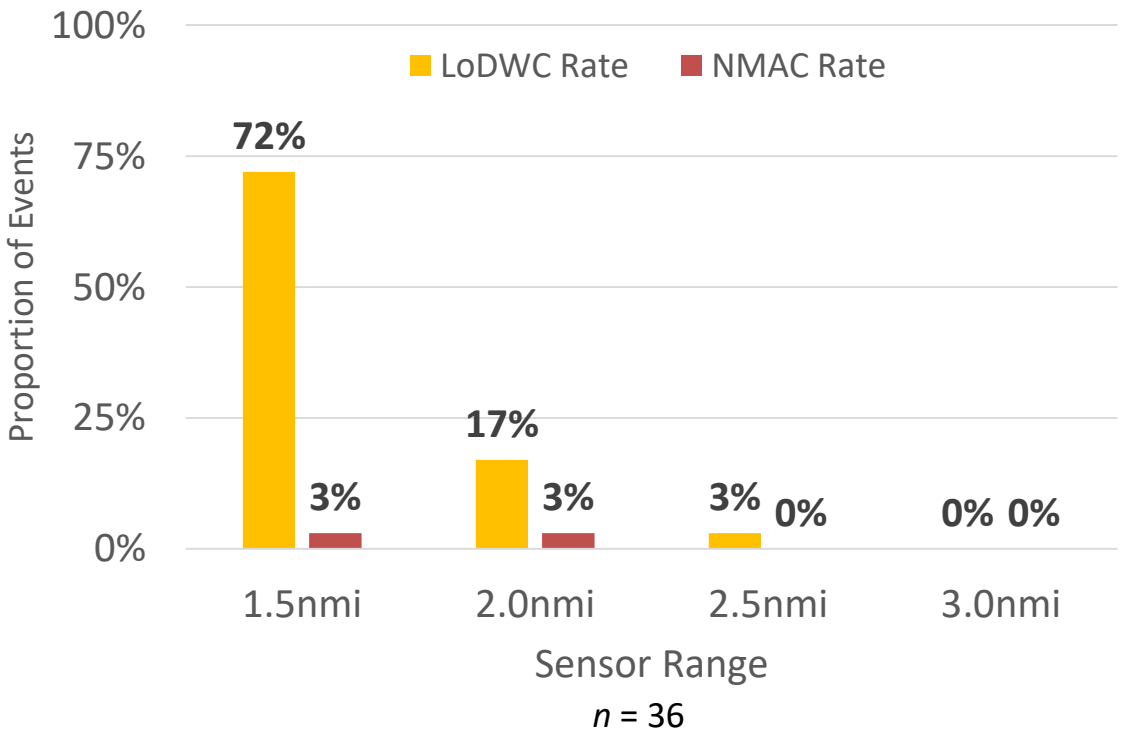


Response time **– elapsed time from alert to first maneuver upload**

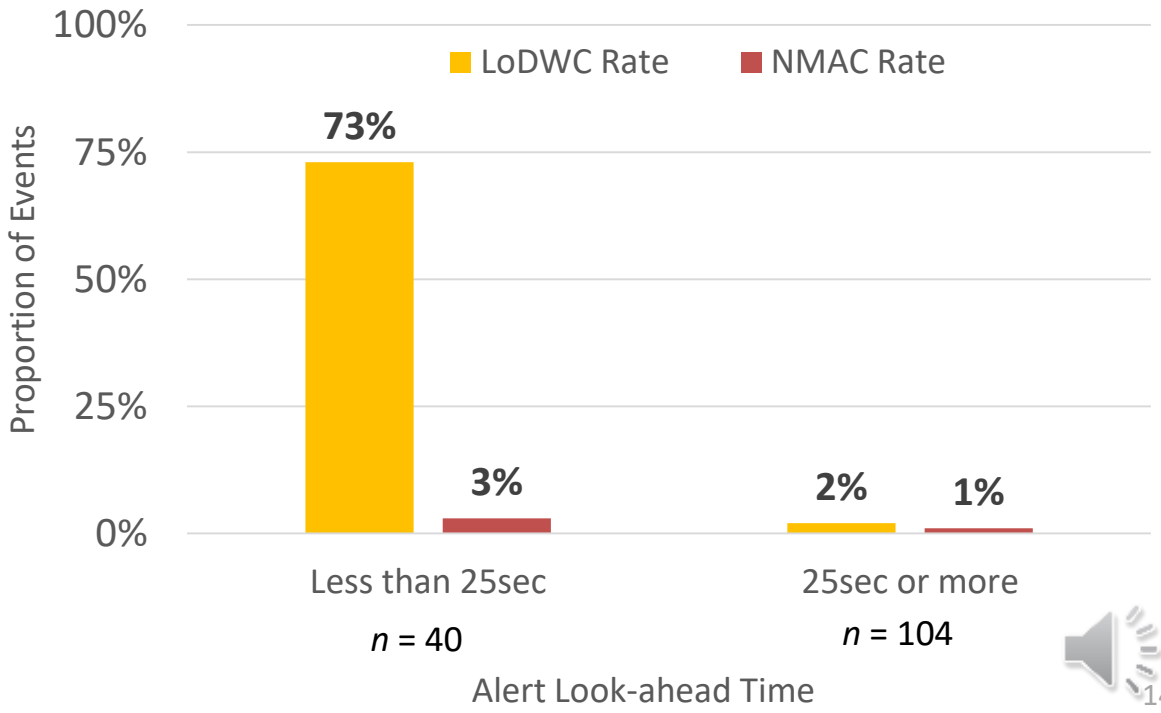
Separation Performance

- Steep decline in performance at ranges below 2.5nmi
  - Increased DWC violations & NMACs
  - Primary factor: alert look-ahead time
    - Truncated warning alerts under 2.5nmi

Performance by Sensor Range

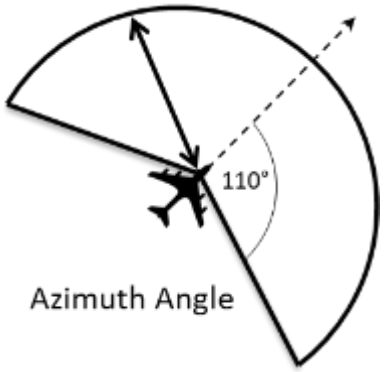


Performance by Alert Look-ahead Time



Field of Regard Considerations

- Increased turn magnitude required for low SWaP conflict resolution
  - Especially at fast closure rates
    - Avg. turn was 99° off course
      - Stresses 110° field of regard:



  - No DAA information while off scope
    - Elevated risk of unsafe return path
    - Increased time spent off course
    - Most prevalent in 1.5nmi condition

Conclusion

- Limited utility of Corrective alerts overall
  - Delayed aircraft response without enabling consistent ATC coordination
    - Quick alert progression capped response times
  - Most pilots did not rate Caution alerts as absolute necessity for low SWaP (Keeler et al., 2020)

- DAA system remained resilient until **2nmi** range
  - Truncated warning alerts degraded pilot performance

- NASA recommended a *minimum* sensor range requirement of **2.5nmi**
  - Sufficient alert time for conflict avoidance with a human in-the-loop
    - Automation support likely necessary at smaller ranges
  - Additional considerations:
    - Field of regard
    - Sensor noise
    - Latency
    - Declaration time

END

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Questions?

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