



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

Low Size, Weight and Power (SWaP) HITL 2
SC-228 Outbrief
EO/IR & ATAR Breakout





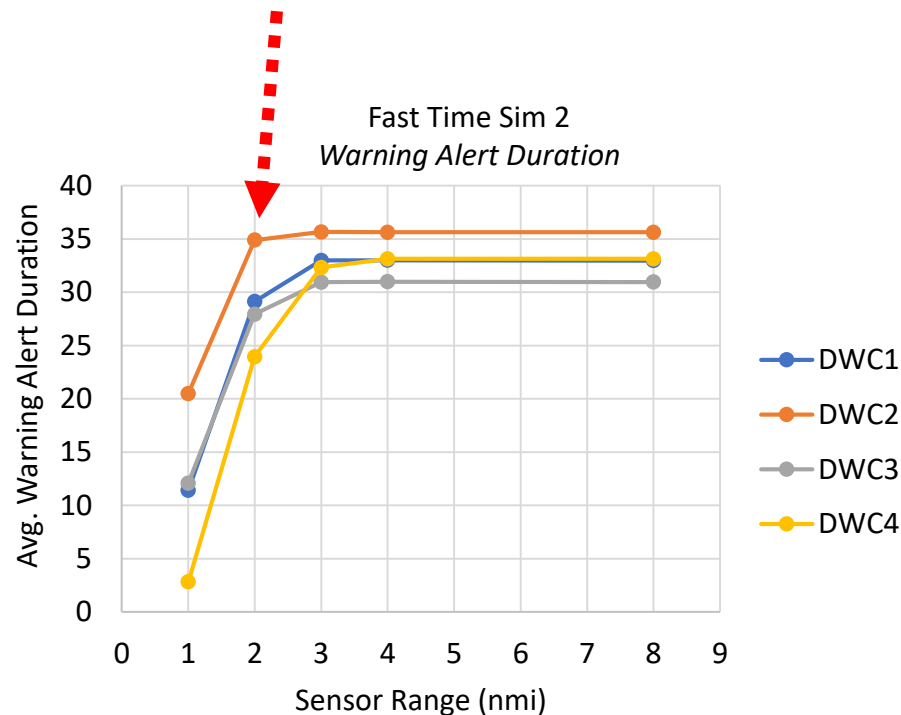
Background

- In support of Low SWaP MOPS, HSI conducted two human-in-the-loop (HITL) simulations that were designed to:
 - Identify DAA display, alerting and guidance requirements necessary for UAS equipped with low size, weight & power (SWaP) sensors
 - Serve as a validation of the fast-time simulation work performed by the Modeling and Sim (M&S) team
 - Establish a baseline for the Flight Test 6 Full Mission configuration flights
 - The scenario design & encounters used in these HITLs were replicated in FT6
- Low SWaP 1 (Nov 2018) examined pilot & DAA system performance with two candidate non-cooperative DAA well clear (DWC) definitions as informed by M&S fast-time sims
 - SC-228 selected **DWC2** as the new non-cooperative DWC definition
 - DWC2 = 2200ft horizontal & 450ft vertical (no modTau)
 - It was determined that a study was needed to look at smaller surveillance ranges with DWC2



Experiment Objective

- Low SWaP 2 assessed pilot & DAA system performance with four different RADAR declaration ranges (RDR)
 - Shorter than 3.5 NM modeled in Low SWaP HITL 1
 - Fast-time Sim 2 results demonstrated that DWC2 alerting time remains relatively constant *until the range drops below 2nm*



- Research Question: How does Low SWaP radar detection range impact pilot performance?
 - Will the 'knee in the curve' for response times & rates losses of DWC be at 2nm?



Experimental Design

- **Independent Variables**

- Low SWaP RADAR Declaration Range (within-subjects)
 - 3.0nm
 - 2.5nm
 - 2.0nm
 - 1.5nm
- Ownship speed (between-subjects)
 - Slow (60ktas)
 - Fast (100ktas)

- **Embedded Variable (within-trial)**

- Conflict type
 - Equipage
 - 1 cooperative & 4 non-cooperative encounters
 - Closure rate
 - Intruder speed (100 vs 170 kts)
 - Approach angle (head-on vs crossing)



Primary Metrics

- **Dependent Variables**

- Proportion & Severity of Losses of DWC (LoDWC)
- Response Times (RTs)
- Alerting Duration
- ATC Coordination
- Subjective Workload & Acceptability



Hypotheses

- **Expected Outcome**

- At detection ranges of 3.0 and 2.5nm, the LoDWC rates will be comparable to Low SWaP HITL 1
- The LoDWC rates will increase significantly at 2.0 and 1.5nm detection ranges

- **Reasoning**

- Ability to maintain DWC is largely a function of time to LoDWC at first alert
- At 2.0 and 1.5nm, the intruder will first appear as a Warning in **half or more** of the scripted encounters

Time to LoDWC (sec) by Detection Range and Encounter Geometry

Intruder Geometry	Slow Crossing		Slow Head-on		Fast Crossing		Fast Head-on	
Owship Speed	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
3.5nm (Low SwaP HITL 1)	60s	60s	60s	52s	58s	53s	45s	39s
3nm	60s	60s	48s	42s	49s	44s	36s	30s
2.5nm	54s	49s	40s	34s	41s	36s	31s	25s
2nm	43s	38s	31s	25s	33s	28s	26s	20s
1.5nm	32s	27s	24s	18s	25s	20s	21s	15s

Green = at least 15sec Corr Duration;

Black = less than 15sec Corr Duration

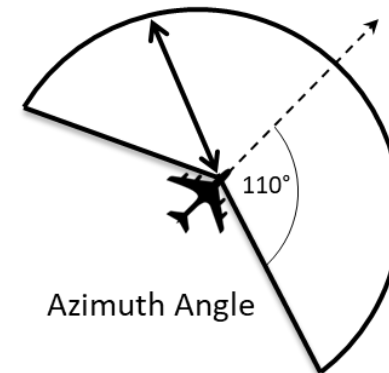
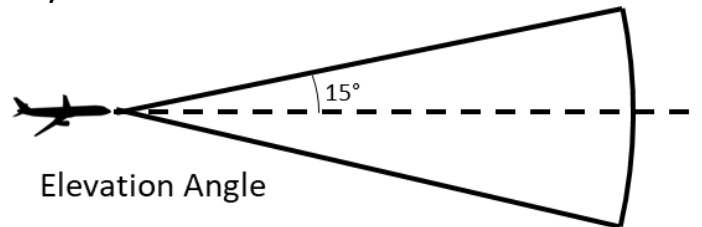
Red = No Corrective (Warning at first alert)

- **Participants**

- 9 active-duty UAS pilots

- **Ownship: Generic RQ-7 Shadow model**

- Mission altitude: 8,000ft MSL
- Maneuverability:
 - Cruise speed: 60 or 100 KTAS
 - Turn rate: $7^\circ/\text{sec}$
 - Climb/descent rate: 500 ft/min
- Surveillance:
 - ADS-B In (cooperative)
 - Detection range: 15nm
 - Low SWaP RADAR (non-coop)
 - Variable detection range: 1.5 - 3nm
 - $\pm 110^\circ$ azimuth
 - $\pm 15^\circ$ elevation



- **Experimental Trials**

- 4 experimental trials per pilot (1 for each detection range)
 - 45-minute trial duration
- Route: FT6 Full Mission “Racetrack”
 - Oakland Center (Class E)
 - Level at 8,000ft MSL
 - Active TFR



- Researchers played role of confederate ATC
 - Background traffic was generated using VS Sim intruder tool



Scenario Design

- **DAA Task**

- Remain DAA well clear from other aircraft
 - 5 encounters scripted to lose DWC per trial

- **Scripted Encounters**

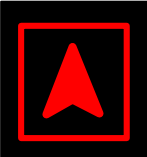
- 4 non-cooperative intruders
 - Intruder speeds: 100 KTAS ('slow') or 170 KTAS ('fast')
 - Relative approach angles: Head-on or Crossing
 - *Note:* all non-coops generated DAA alert at first appearance on display
- 1 cooperative intruder
 - Intruder speed: 200 KTAS
 - Relative approach angle: Crossing

- **Secondary Tasks**

- Respond to scripted chat messages
- Complete checklists to resolve scripted failures
 - Header Tank Overpressure or Generator Failure



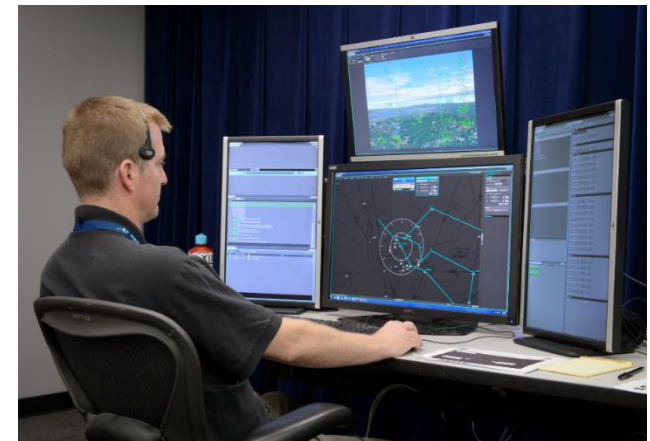
Alerting Logic

Symbol	Name	Time to LoDWC	Pilot Action	Aural Alert Verbiage
	DAA Warning Alert	30 sec	• Immediate action required to remain DAA well clear • Prior ATC coordination not required	"Traffic, Maneuver Now, Traffic, Maneuver Now"
	Corrective DAA Alert	60 sec	• On current course, corrective action required to remain DAA well clear • Coordinate with ATC; maneuver following approval	"Traffic, Avoid"
	Preventive DAA Alert	N/A	• No action required to remain DAA well clear • Not currently a threat; monitor for potential increase in threat level	"Traffic, Monitor"
	Guidance Traffic	N/A	• No action required to remain DAA well clear • Traffic generating guidance bands outside of current course	N/A
	Basic	N/A	• No action required to remain DAA well clear • No coordination required	N/A



Facilities & Resources

- Facilities
 - HAT Lab
- DAA System
 - JADEM/DAIDALUS v2
 - Honeywell Sensor Model & Tracker (v15)
- LVC Gateway
- Ground Control Station
 - Vigilant Spirit Control Station
 - Traffic display and control interface for pilot tasks
 - Vigilant Spirit Simulation
 - Event generation tool for researcher tasks
 - Located in sim manager area
- Voice Communication
 - PLEXSYS push-to-talk headsets
 - Researcher acted as ATC confederate





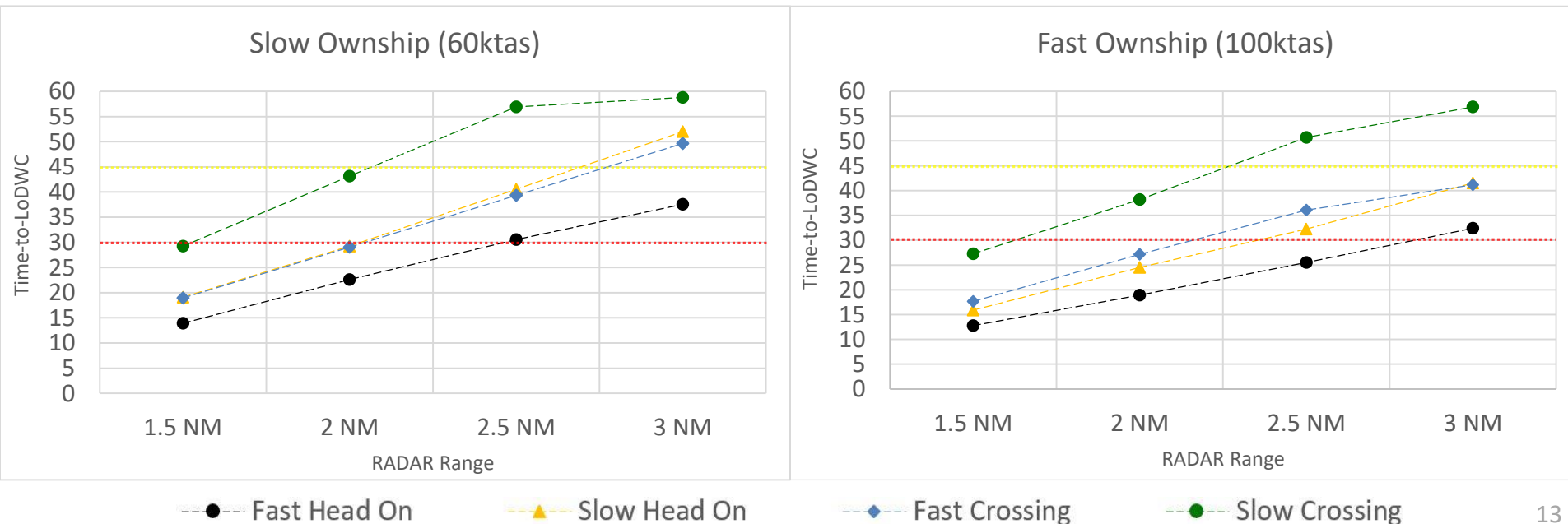
OBJECTIVE FINDINGS

***NON-COOPERATIVE ENCOUNTERS**



Unmitigated Alerting

- 2.5 NM and 3 NM allow for full-duration Warning alerting on average
 - Worst case scenario at 2.5 NM range: Fast Head On w/ Fast Ownship (26s)
 - Pilots have typically needed 25sec alerting to maintain separation in past HITLs
- Prior ATC coordination generally not viable at any range
 - Short Corrective alert durations
 - Assumed 15sec needed for ATC coordination
 - No Corrective alerting at 1.5 NM

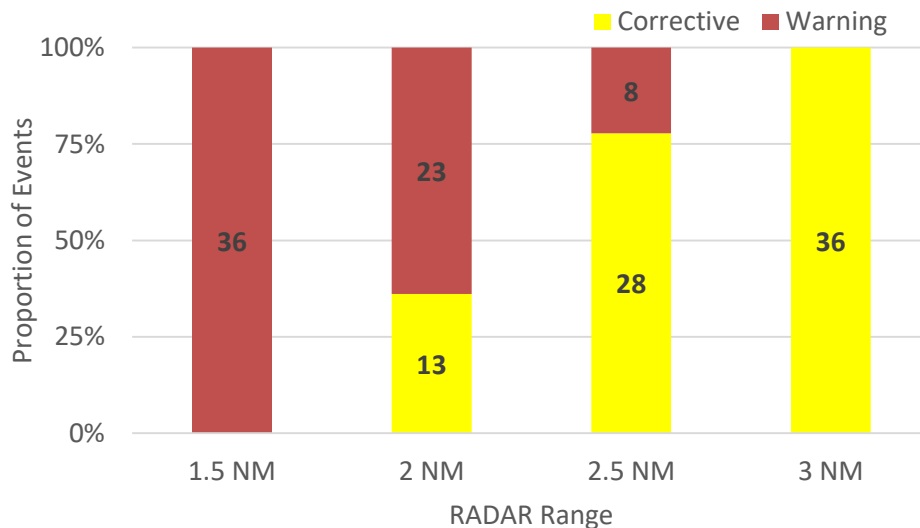




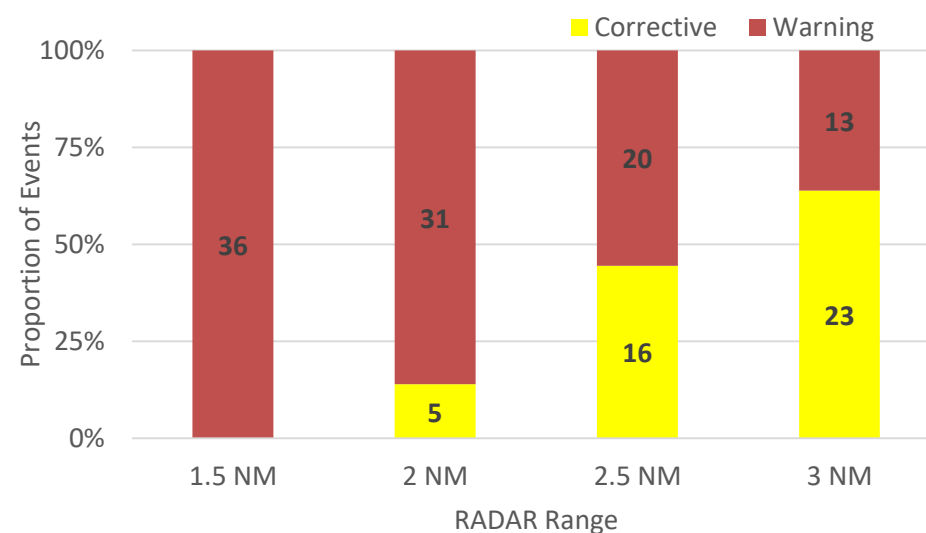
Alerting Performance - Mitigated

- Corrective alerts were generated for 53% of non-coop conflicts
- Pilots were often unable to respond to Corrective alerts, especially below 3 NM
 - Over half progressed to Warning before first upload
 - Corrective alert duration range in these cases: **1-10sec**
 - Only 3NM enabled Corrective alerting across all encounter types

Threat Type at First Alert (non-coops)



Threat Type at First Upload (non-coops)





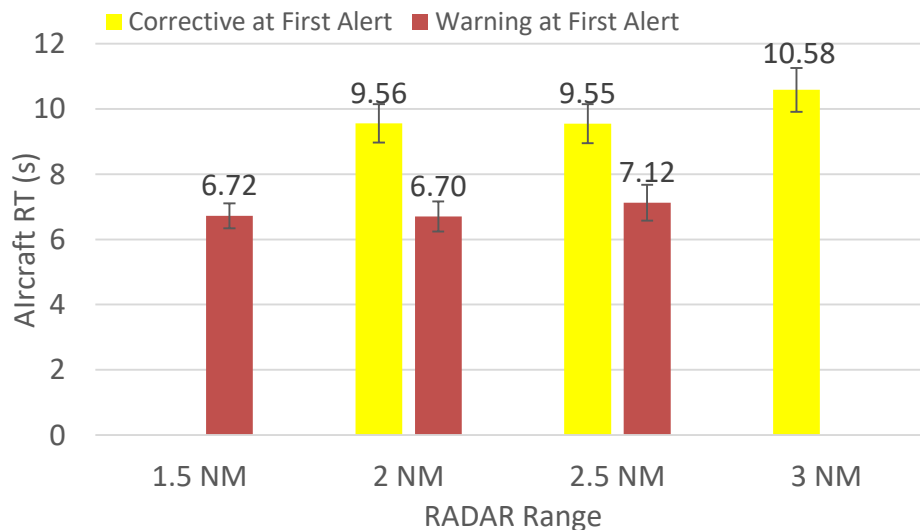
MEASURED RESPONSE TIME & ATC COORDINATION



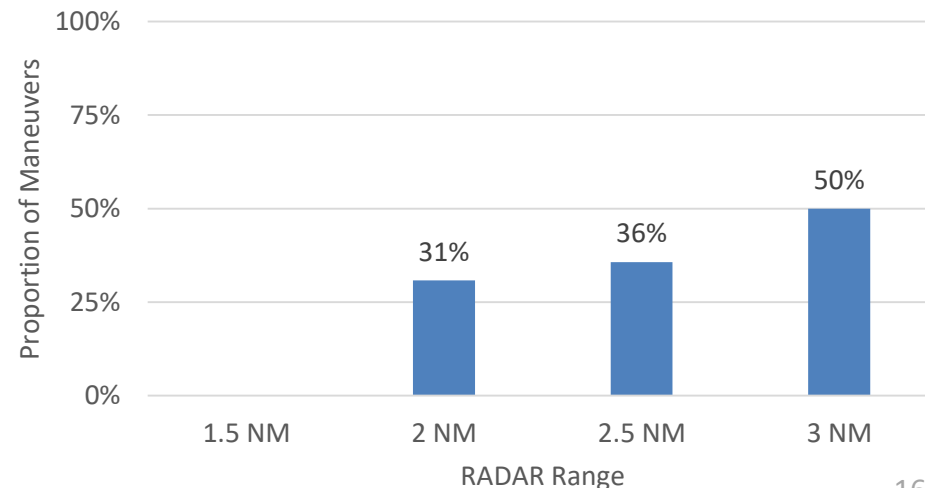
Pilot Responses

- RADAR range did not impact pilot response times
 - Majority of encounters required immediate response
- ATC Coordination rates were low across all ranges
 - Mostly due to short Corrective alert duration
 - Rarely able to coordinate in time despite being only pilot on frequency
 - Against non-coops, pilots received prior ATC approval for:
 - 26% of all uploads
 - 42% of all uploads when conflict was Corrective at First Alert

Aircraft Response Time



Proportion of Maneuvers w/ ATC Approval
(Corrective at First Alert)





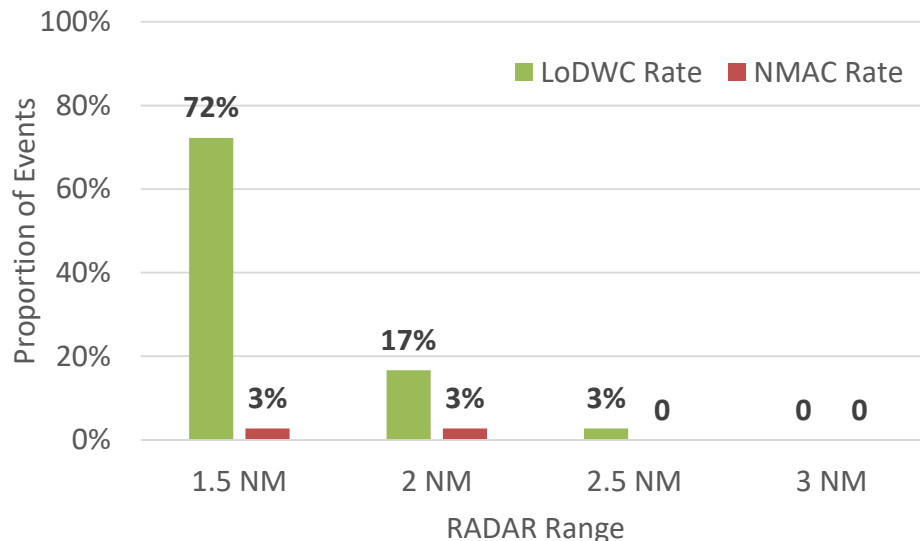
DAA PERFORMANCE



Separation Performance

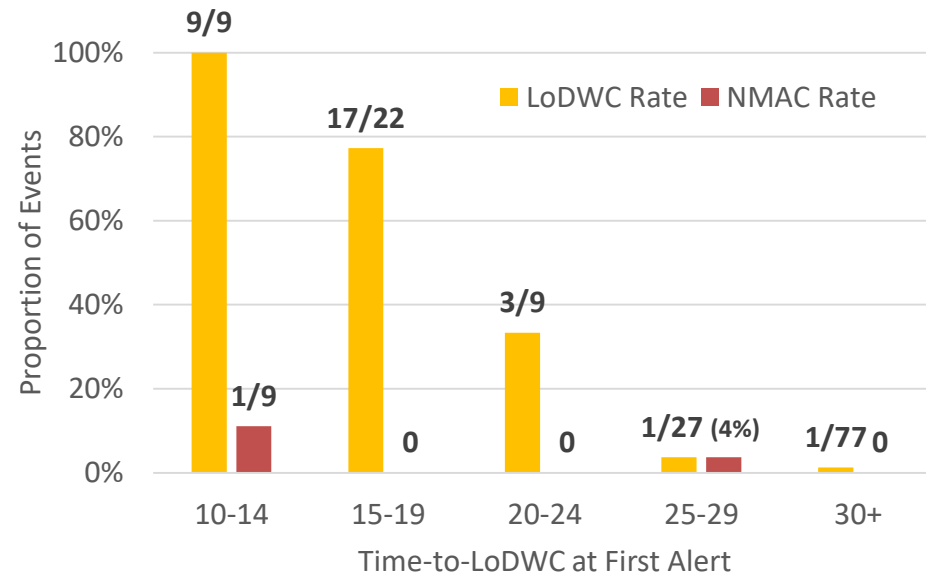
- Time-to-LoDWC at first alert
 - Primary factor in pilots' ability to maintain DWC
 - 94% of all LoDWC occurred with less than 25 seconds to avoid
 - Only possible below 2.5 NM
 - 2 remaining LoDWC due to Early Returns to Course after azimuth drop
 - Azimuth drops before Clear-of-Conflict were common (discussed later)
 - Pilots *always* violated DWC with less than 15s to maneuver ($n = 9$)
 - Avg. Aircraft RT in these cases = **7.4sec**
 - Only possible below 2.0 NM

Separation by Range (non-coops)



$N = 144$ non-coops (36 per Range condition)

Separation by Time-to-LoDWC (non-coops)



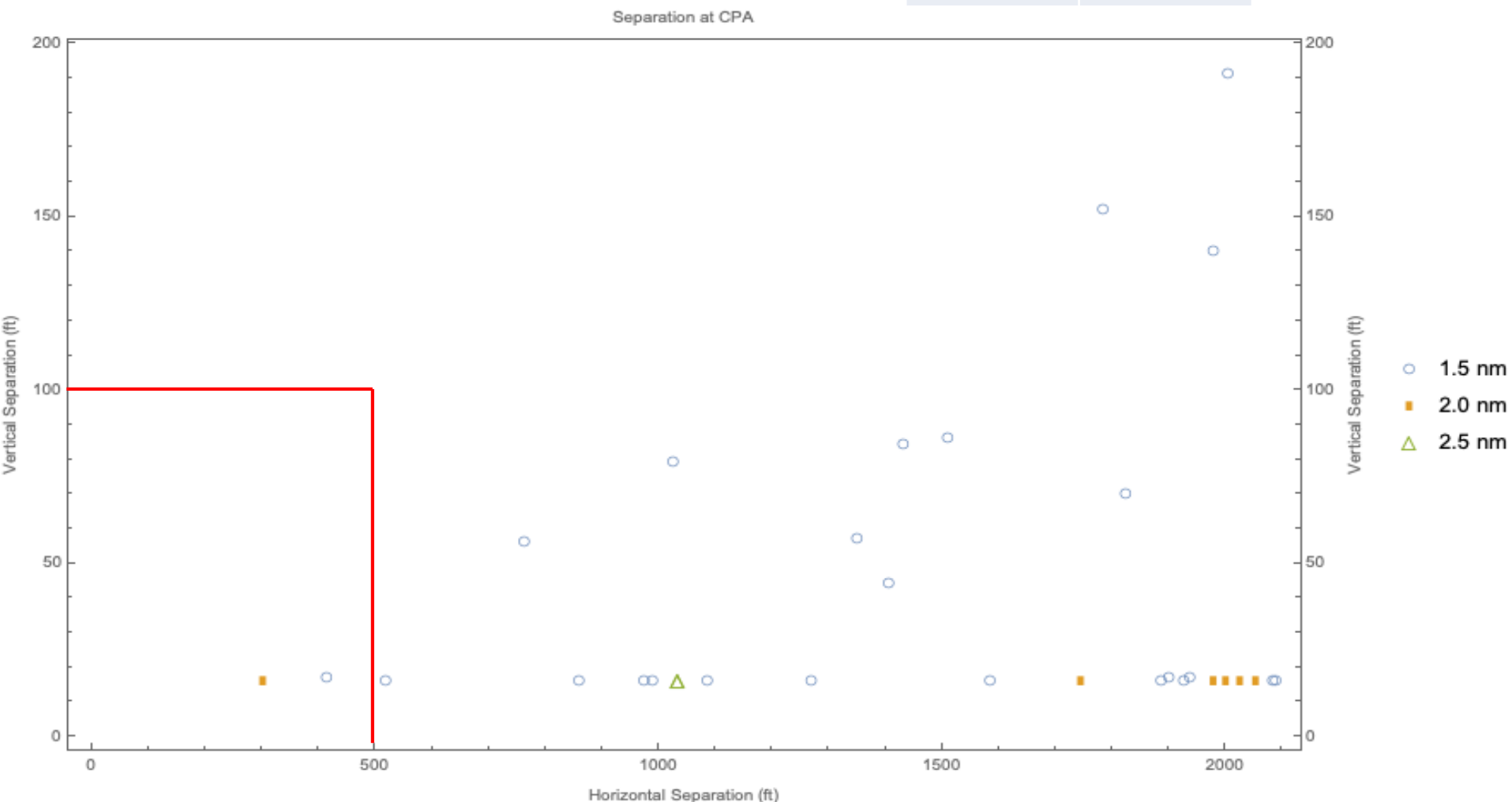


Separation Performance

- Both NMACs occurred in the 1.5 or 2.0 NM conditions
 - Closer horizontal separation at 1.5 NM:

Range	Avg. sLoWC%*
1.5 NM	21.97
2 NM	2.48

*Excluding Early RTC





SUBJECTIVE FEEDBACK

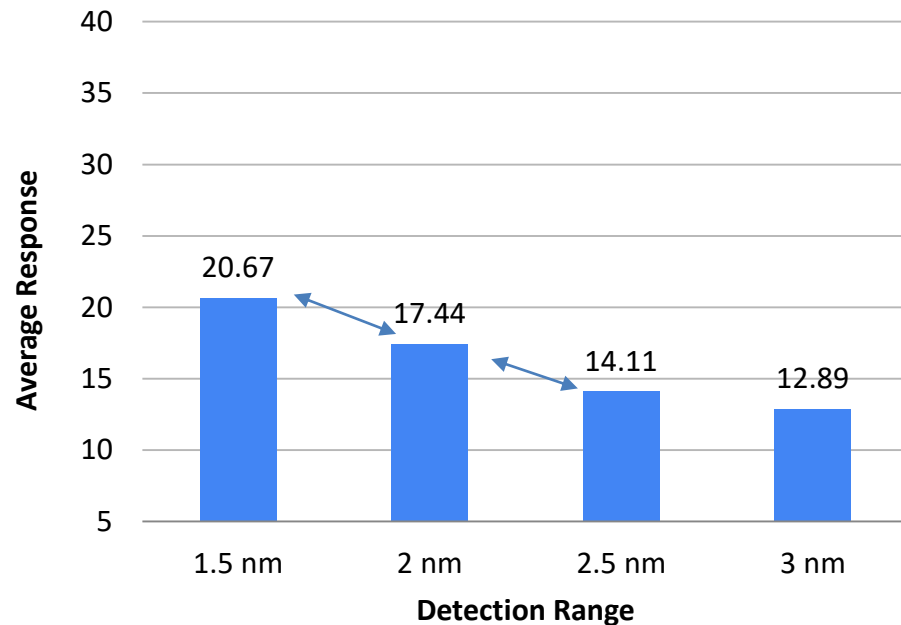


Post-Trial

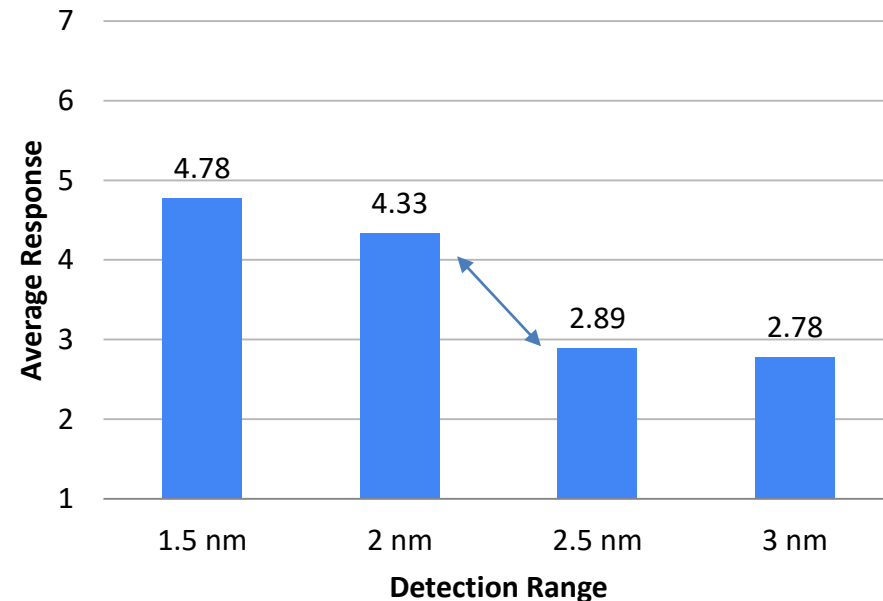
- **NASA Task Load Index (TLX)**

- 1.5 nm & 2 nm had higher composite TLX scores compared to 2.5 & 3 nm
 - Biggest differences observed with Temporal demand
- No significant differences between 2.5 and 3 nm overall

NASA TLX – Overall Workload



Temporal Demand

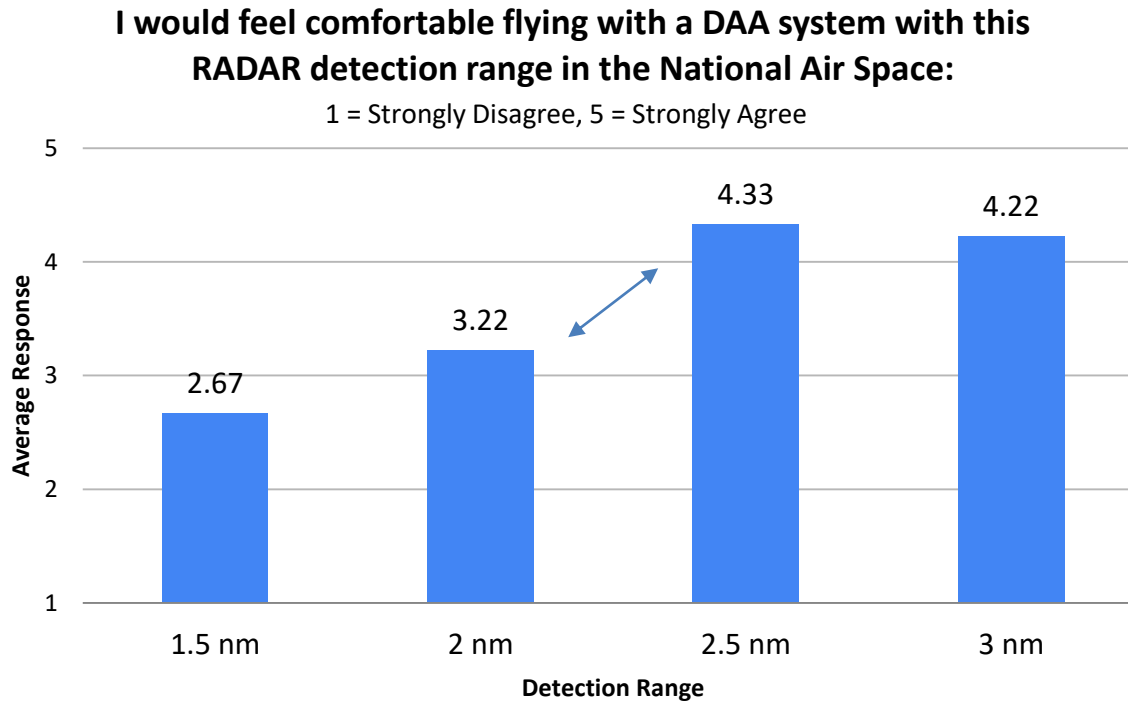




Post-Trial

- **NAS Safety**

- 2.5 and 3 nm were both rated as more comfortable than 1.5 and 2 nm
- 1.5 and 2 nm had similar ratings, as did 2.5 and 3 nm

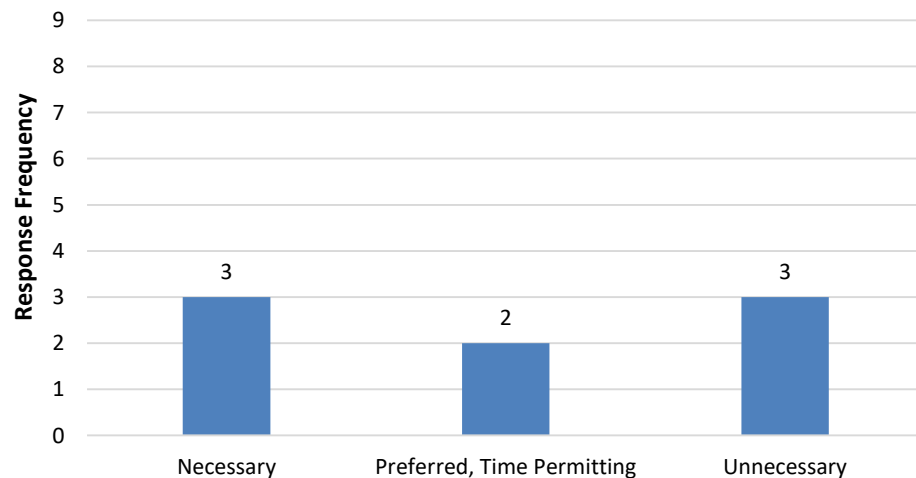




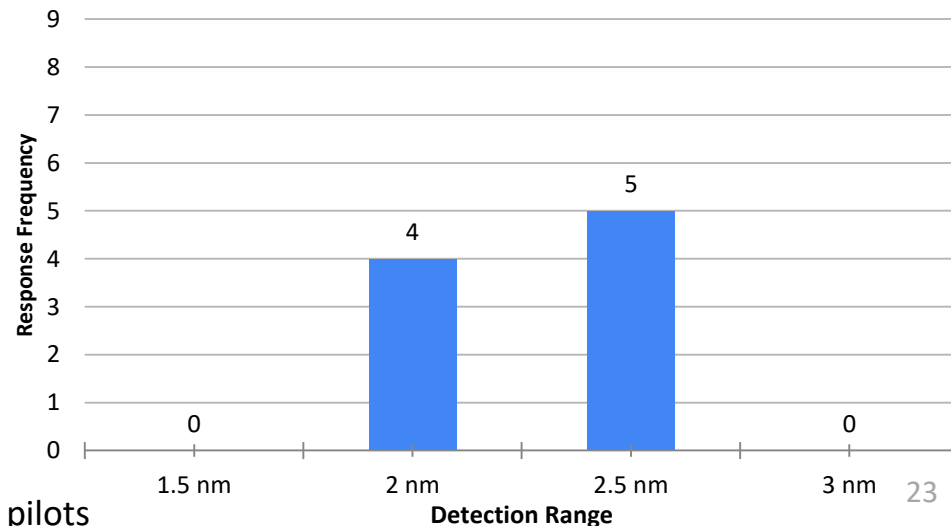
Post-Sim

- 5 pilots considered **2.5 NM** as minimally acceptable, while 4 pilots chose **2 NM**
 - All Fast Ownship pilots chose 2.5 NM
 - 4 of 5 Slow Ownship pilots chose 2 NM (did not experience worst case scenario)
- Most pilots found little use for Corrective alerts in the current test setup
 - Correctives either too infrequent or too short:
 - *“If you quickly transition to a warning anyway, it would be pointless.”*
 - *“That would depend on aircraft capability and how close the warning threshold is.”*
 - *“Correctives only helpful with enough time to call ATC. In reality, I would probably not make the call until after.”*

How valuable is Caution-level alerting for LSNC?



Based on today's experience, which RADAR range do you consider minimally acceptable?



N = 9 pilots



Field of Regard Considerations

- It was common for intruders to fall out of FOR during avoidance
 - Shorter detection ranges necessitate larger heading changes that stress the 110° azimuth limit, especially at fast closure rates
 - Absence of DAA information elevates risk of premature Return-to-Course
 - LoDWC events caused by Early RTC are often high-severity
 - Caused NMAC in current study
 - ‘Coasting’ logic may promote safer return paths if trajectories remain constant
- 44 cases of azimuth drops during active Corrective/Warning:

Range	Azimuth Drops before CoC	Avg. Turn Size (Fast Intruders)
1.5 NM	20/36 (56%)	113deg
2 NM	9/36 (25%)	101deg
2.5 NM	9/36 (25%)	90 deg
3 NM	6/36 (17%)	90 deg



Analysis Summary

- Pilot performance primarily influenced by Warning alert duration
 - 94% of total LoDWC events had less than 25sec-to-LoDWC at first alert
 - Comparable to performance trends observed in past HITLs
 - Needed at least **2.5 NM** to ensure 25sec alerting in current test
 - Corrective alert duration allowed little time for ATC coordination
 - 57% of caution threats progressed to Warning before initial maneuver
 - Only 42% of initial maneuvers against caution threats were pre-approved
 - Note: 85% approval rate for cooperative encounters (matches past findings)
- Subjective ratings generally favor 2.5 NM as the minimum RDR
 - Voted most acceptable by pilots that experienced fastest closure rates
 - Significant increases in overall workload observed under 2.5 NM
 - Temporal demand, Frustration, Safety
 - 1.5 NM received the least favorable ratings for all metrics

Sensor Range	>25sec Alert?	Min. Alerting	Max. Alerting	Total LoDWC	Total NMACs
1.5 NM	25%	13s	29s	24	1
2.0 NM	63%	19s	43s	6	1
2.5 NM	100%	26s	57s	1 (RTC)	0
3.0 NM	100%	32s	60s	0	0



Conclusion

- *Minimum* RADAR declaration range -> **2.5 NM**
 - Sufficient alerting time ($\geq 25s$) across all tested encounter types
 - Allowed for at least 10sec of Remain DWC guidance in worst cases
 - 99% of Warning RTs were within 10sec
 - Automation support likely necessary **if smaller ranges are considered**
 - Currently out of scope for DAA
 - Swift transition to Regain DWC/CA guidance below 2.5 NM
 - Favorable safety, workload, and acceptability ratings
- Corrective alerting provided minimal benefit at tested ranges
 - Delayed aircraft response without enabling consistent ATC coordination
 - Need more than 3 NM to ensure prior ATC coordination if desired
 - Caution alerts were not rated as absolutely necessary for non-coops
 - Potential mitigation: extended Warning alert threshold in lieu of Corrective
 - Removal of coordination component reduces the 25sec pilot response time assumption, thus adding flexibility to the minimum RDR requirement



Low SWaP Radar Declaration Range (RDR)

NASA proposes to define RDR by MIR + 15 seconds

Green: test points in the HITL

Red: stressing case that drives RDR requirements

RDR computed with 15 sec response time is ~ 2.5 nmi

Own. Speed (KTAS)	Int. Speed (KTAS)	Bearing (°)	RDR (nmi) with 25 sec response	RDR (nmi) with 15 sec response	MIR (nmi)
40	170	0°	3.44	2.86	1.98
50		0°	3.24	2.63	1.71
60		0°	3.13	2.49	1.53
100		0°	3.22	2.47	1.35

Note: MIR results were computed by AAG



Low SWaP Radar Declaration Range (Cont'd)

Related considerations

- Is additional data needed for making this decision?
- If we adopt MIR + 15 seconds for low SWaP sensors' declaration range, what about the RDR for high UA speed and medium UA speed ATAR?
- We think the same declaration range can be applied to both the low SWaP radar and EO/IR
 - EO/IR achieves reasonable range/range rate estimates < 3 nmi

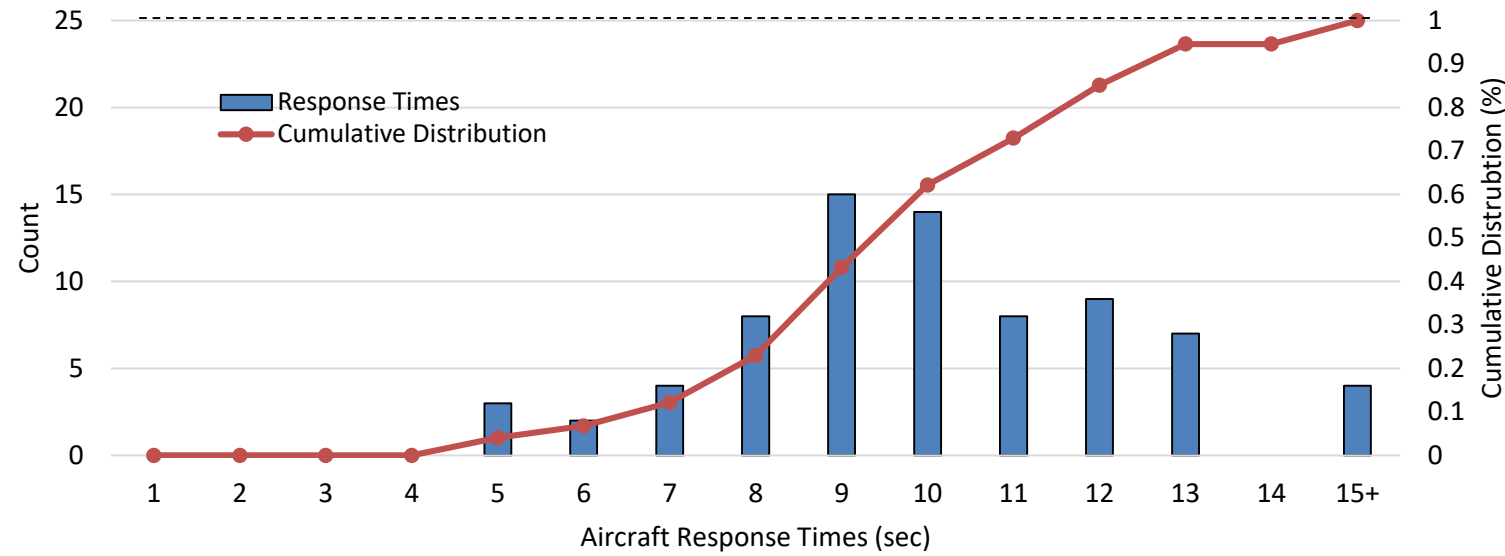


BACKUP



RT Distribution

Low SWaP 2: Response Times to **CORR** Non-Cooperative Intruders



Low SWaP 2: Response Times to **WARN** Non-Cooperative Intruders

