

An Exploratory Evaluation of UAS Detect and Avoid Operations in the Terminal Environment

Conrad Rorie, Kevin Monk, Lisa Fern, Zahcary Roberts, Summer Brandt

New technical standards for Unmanned Aircraft Systems (UAS) detect and avoid (DAA) systems mark recent progress toward realizing the goal of full integration of UAS into the National Airspace System (NAS). The DAA system is intended to provide a means of compliance with operating regulations that required pilots on board manned aircraft to remain “well clear” of other aircraft which is accomplished through out-the-window visual acquisition of other aircraft and application of a subjective judgment of safe separation. The requirements for the DAA system, including the specification of a DAA well clear threshold as well as functional requirements for detecting, tracking, alerting and guidance processing, and displays, are specified in DO-365, Minimum Operational Performance Standards (MOPS) for DAA Systems developed within RTCA Special Committee 228 (SC-228). Intended as the first in a series of phased versions, these requirements are frequently referred to as the “Phase 1” DAA system. The Phase 1 DAA system is limited for use by aircraft transitioning to and from Class A or special use airspace, through Class D, E, and G airspace. In particular, the Phase 1 DAA MOPS are not intended for terminal airspace operations, a critical gap for enabling a full range of UAS operations. The application of the Phase 1 DAA system and DAA well clear threshold within the terminal area is predicted to result in a high number of unnecessary alerts when the UAS is safely separated from other traffic.

The goal of the present study was to examine pilot performance and operational issues related to the operation of the Phase 1 DAA system in a terminal area. This experiment was intended as an exploratory study that would be used to inform the development of a new terminal area-specific DAA well clear definition, and associated alerting and guidance requirements. The two main objectives of this study were to: 1) characterize pilot behavior in the terminal environment with the Phase 1 DAA system, and 2) investigate the effect of modifications to the Phase 1 DAA alerting and guidance structure. In particular, the authors were interested in determining whether the removal of specific alerting and guidance levels, without changing the DAA well clear definition or alerting thresholds, would impact pilot performance while conducting terminal operations. The results indicate that the Phase 1 well clear definition and alerting and guidance resulted in frequent alerting that degraded pilots’ ability to discriminate between encounters where another

aircraft was safely separated versus when a maneuver was necessary. The resulting impact on pilot performance was slower response times and higher frequency and severity of losses of DAA well clear compared to those observed for experiments examining pilot performance in the en route environment. There was no significant effect of alerting and guidance display configuration on pilot performance.



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

An Exploratory Evaluation of UAS Detect and Avoid Operations in
the Terminal Environment

Terminal Operations HITL 1



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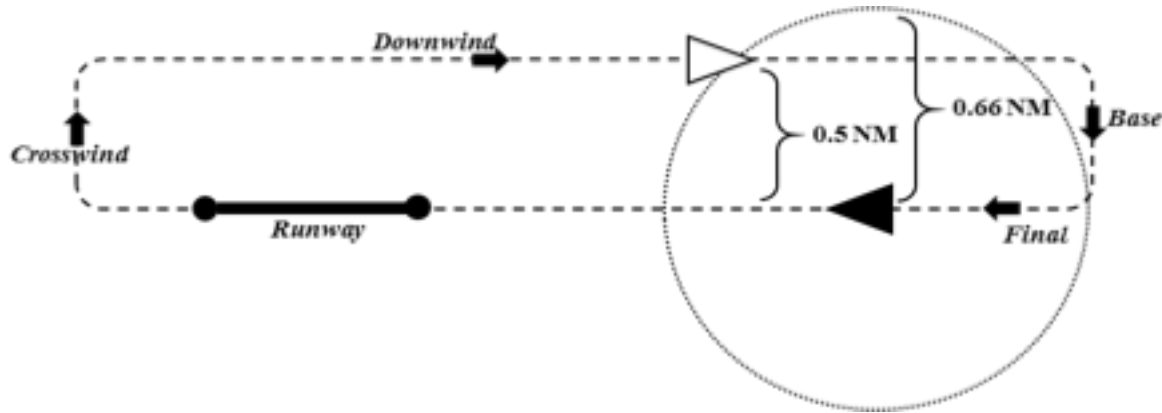
Background

- Detect and Avoid (DAA)
 - See and avoid (CFR 14 Part 91) requires pilots to visually acquire traffic out the window and maintain “well clear”
 - DAA system is necessary so that UAS can comply with Part 91
 - DAA uses electronic detection from surveillance equipment to track traffic and provide alerting and guidance to pilots on the ground
- Requirements for DAA systems are being developed by RTCA special committee 228 in phases
- DAA requirements include:
 - DAA Well Clear threshold
 - Detection requirements
 - Tracking requirements
 - Alerting and guidance processing
 - Displays
- Phase 1 DAA requirements are limited to operations transitioning through Class D, E, and G airspace to and from Class A or special use airspace
 - Phase 2 is introducing the DAA system to terminal operations



Background

- The phase 1 DAA Well Clear definition may not be well suited to the terminal environment
 - Some traffic pattern configurations could be inside the horizontal threshold for the Phase 1 DAA well clear definition (.66nm)



- As a result, using the Phase 1 DAA well clear threshold within the terminal environment is predicted to result in a higher frequency of nuisance alerts when the ownship is safely separated from other aircraft



Phase 2 Objective






- Purpose: Characterize Phase 1 DAA system and pilot performance while conducting terminal area operations
 - Alerting statistics
 - Pilot response times
 - Ability to maintain DAA Well Clear
 - Frequency, severity and cause of Loss of DAA Well Clear (LoDWC)
 - Airspace/ATC interaction



- One-Way Between Subjects Factorial
 - Independent Variable (Between-subjects):
 - DAA Alerting & Guidance – 3 levels
 - D1 = No corrective or warning DAA alert; no DAA guidance
 - D2 = No corrective DAA alert; DAA warning guidance only
 - D3 = Full Phase 1 MOPS DAA alerting and guidance (Class I)
 - Embedded Variables (Within-subjects):
 - Approach type
 - Instrument
 - Visual
 - Traffic Pattern
 - Encounter location
 - Before final
 - On final



Phase 1 DAA Alerting Structure

Symbol	Name	Pilot Action	DAA Well Clear Criteria	Time to Loss of DAA Well Clear	Aural Alert Verbiage
	Warning Alert	<ul style="list-style-type: none"> Notify ATC as soon as practicable after taking action 	DMOD = 0.66 nmi HMD = 0.66 nmi ZTHR = 450 ft modTau = 35 sec	25 sec	“Traffic, Maneuver Now” x2
	Corrective Alert	<ul style="list-style-type: none"> Coordinate with ATC to determine an appropriate maneuver 	DMOD = 0.66 nmi HMD = 0.66 nmi ZTHR = 450 ft modTau = 35 sec	55 sec	“Traffic, Avoid”
	Preventive Alert	<ul style="list-style-type: none"> On current course, corrective action should not be required 	DMOD = 0.66 nmi HMD = 0.66 nmi ZTHR = 700 ft modTau = 35 sec	55 sec	“Traffic, Monitor”
	Guidance Traffic	<ul style="list-style-type: none"> Traffic generating guidance bands outside of current course 	Associated w/ bands outside current course	X	N/A
	Remaining Traffic	<ul style="list-style-type: none"> Traffic within sensor range 	Within surveillance field of regard	X	N/A



Experimental Design – DAA Alerting Conditions

D1

Symbol	Name
	Preventive Alert
	Remaining Traffic

No DAA
Guidance

D2

Symbol	Name
	Warning Alert
	Preventive Alert
	Guidance Traffic
	Remaining Traffic

Warning & Remain
DWC Guidance Only

D3

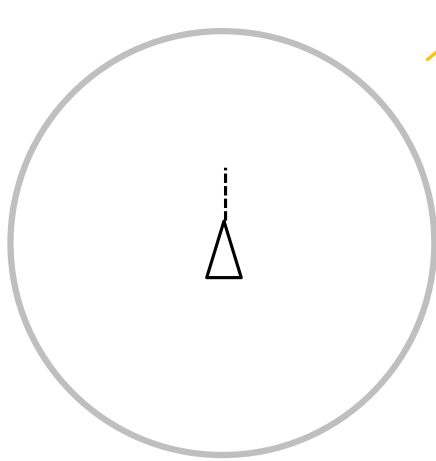
Symbol	Name
	Warning Alert
	Corrective Alert
	Preventive Alert
	Guidance Traffic
	Remaining Traffic

All Remain & Regain
DWC Guidance

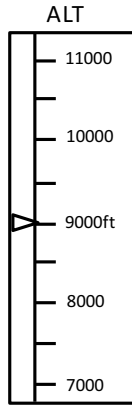


No Loss of DAA Well Clear (LoDWC) Predicted

D1

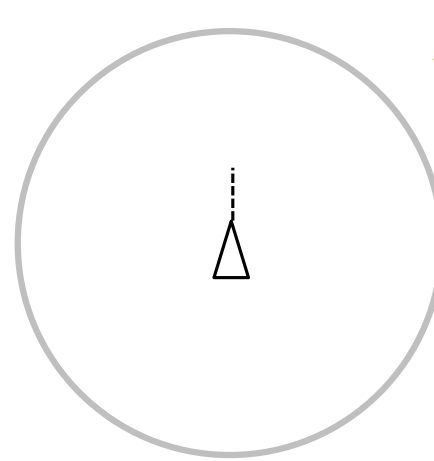


Inner Range Ring

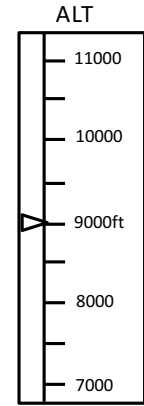


Altitude Tape

D2

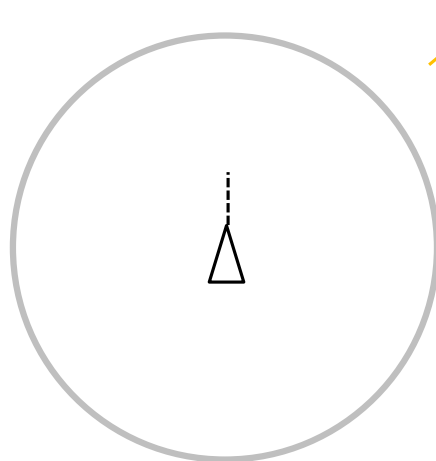


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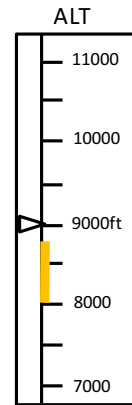


Altitude Tape

D3



Inner Range Ring



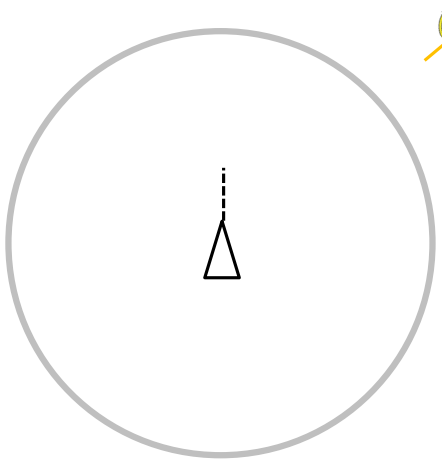
Altitude Tape

*notional encounter 8

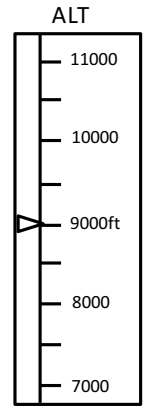


LoDWC Predicted < 55 sec

D1

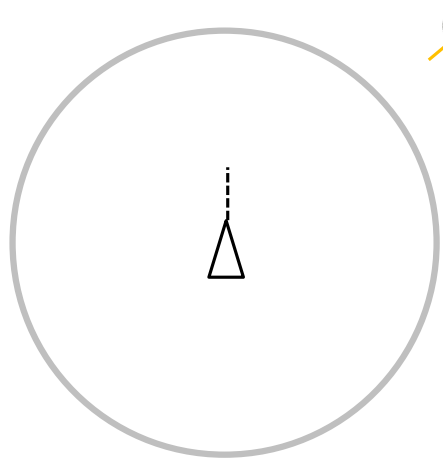


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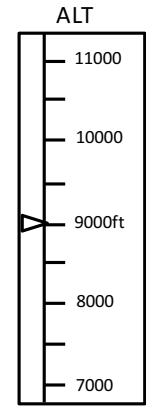


Altitude Tape

D2

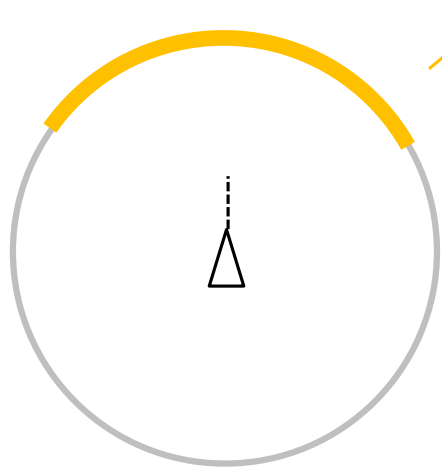


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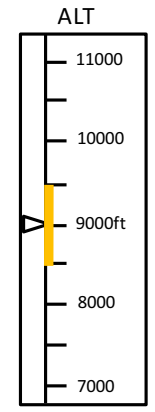


Altitude Tape

D3



Inner Range Ring



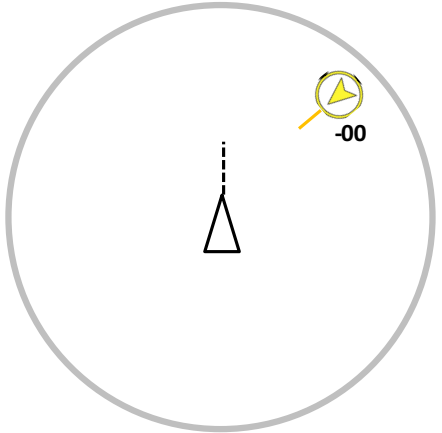
Altitude Tape

*notional encounter 9

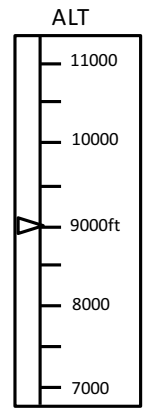


LoDWC Predicted < 25 sec

D1

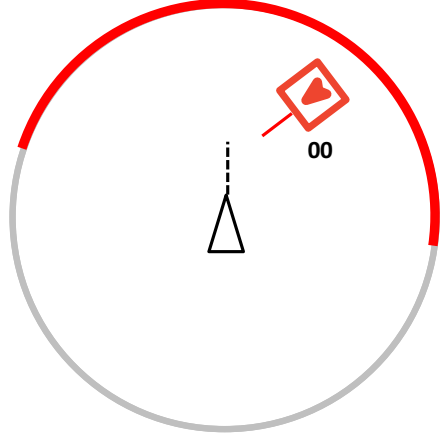


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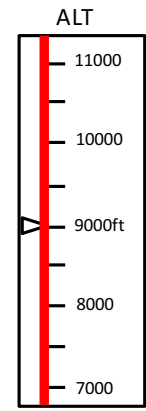


Altitude Tape

D2

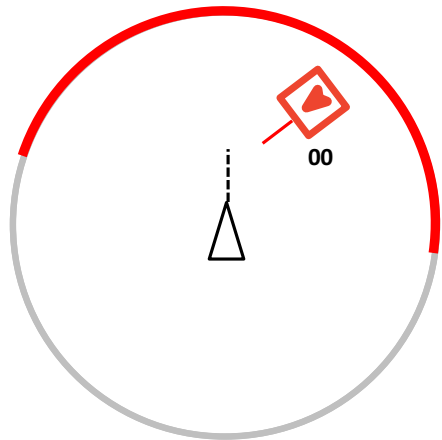


Inner Range Ring

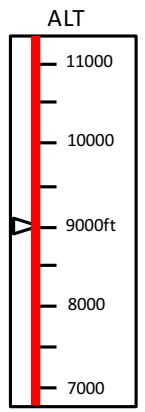


Altitude Tape

D3



Inner Range Ring



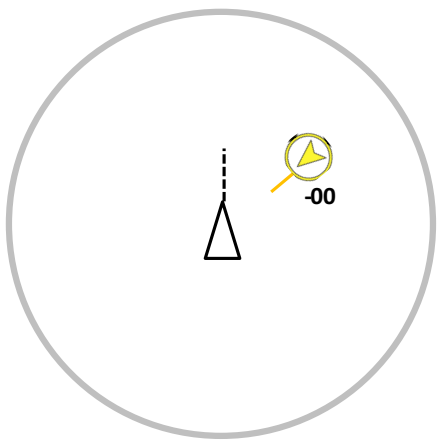
Altitude Tape

*notional encounter

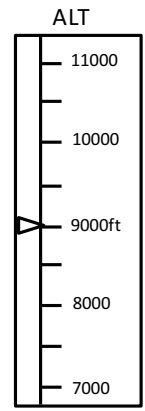


LoDWC Unavoidable – Regain Well Clear

D1

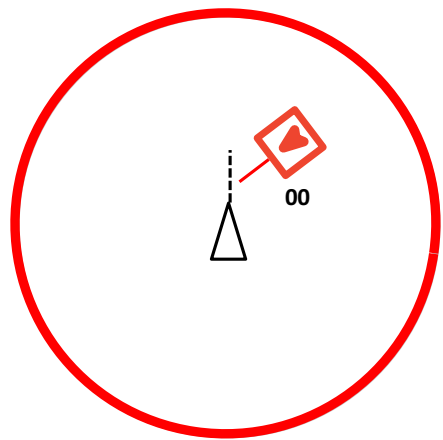


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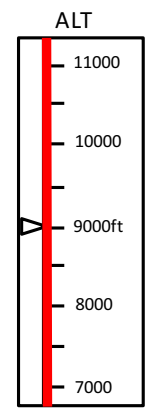


Altitude Tape

D2

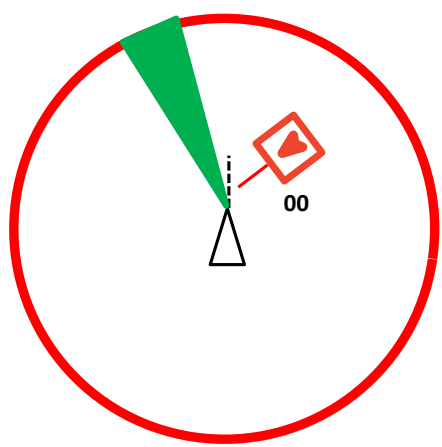


Inner Range Ring

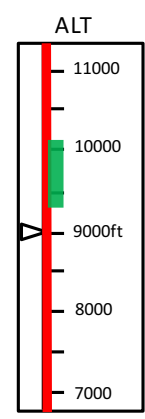


Altitude Tape

D3



Inner Range Ring



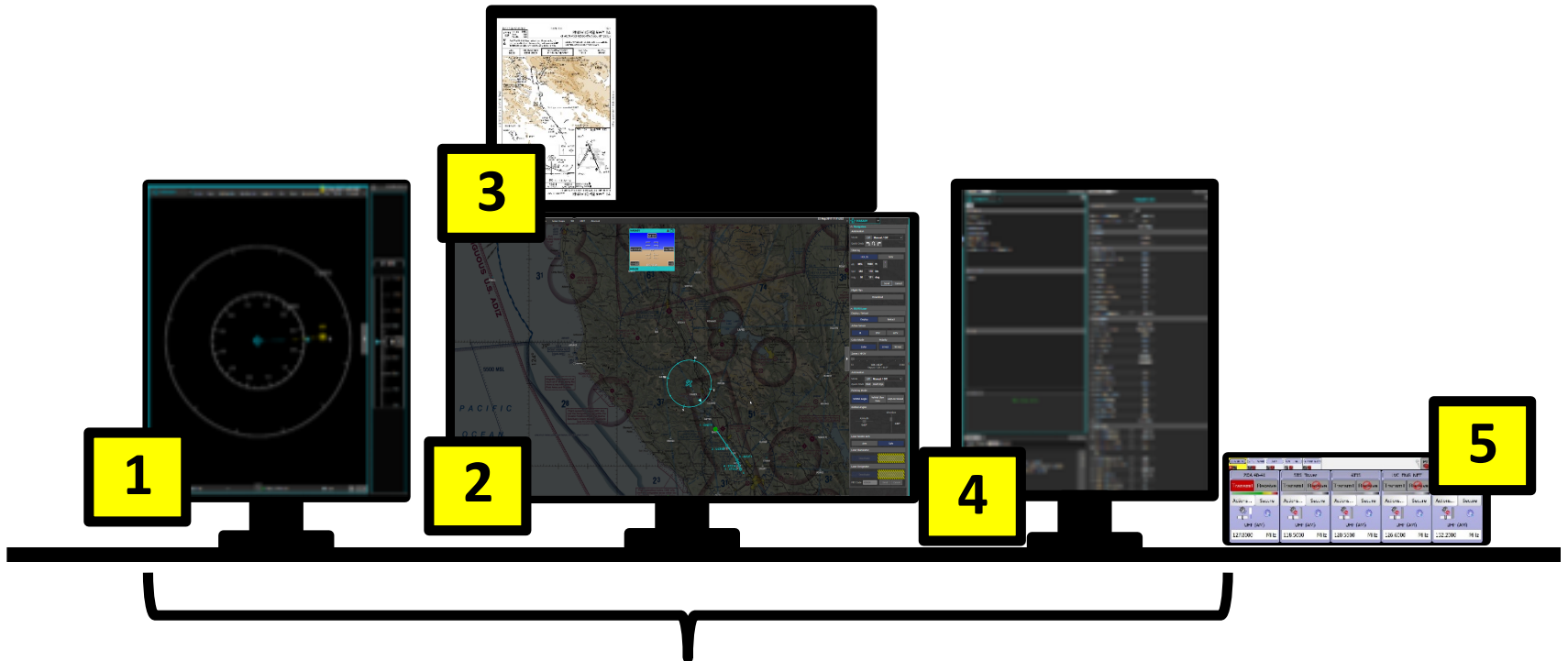
Altitude Tape

*notional encounter 11



Ground Control Station (GCS)

- Ground control station (GCS) contains:
 1. DAA Display – traffic & DAA alerting
 2. Tactical Situation Display (TSD) – vehicle control interfaces & maps
 3. Viewer Tool – approach plate & airport facility directory (AFD)
 4. Right Panel – landing checklist and additional aircraft info
 5. Voice communication panel – touchscreen, transmit/receive on select freqs.



Vigilant Spirit Control Station (AFRL)



Scenario Design



Instrument Approach:

- 15° offset final approach course
- Missed approach procedures = climb to 5000ft, fly runway heading (140°)

“Visual” Approach:

- Report airport “in sight” 10-12nm from runway
- Line up for 3-5nm final stabilized approach
- Traffic pattern @ 1150ft

Pattern Approach:

- Traffic pattern @ 1150ft
- Controllers will give pattern entry instructions
 - 45° entry, mid-field entry or direct base
 - May extend downwind and call your base
- Offset from Rwy14 should be ~1.5nm



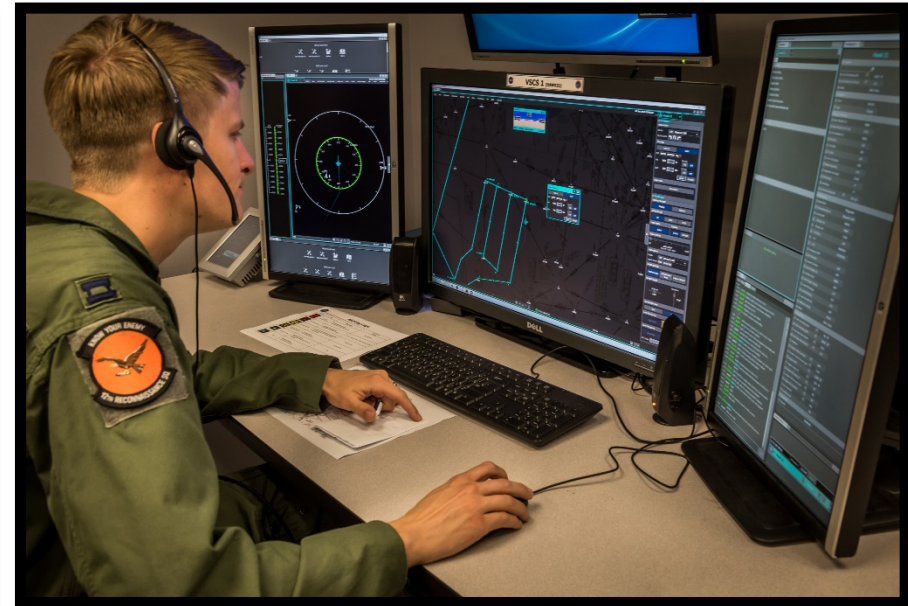
Scenarios

- Each scenario had 6 approaches:
 - 4 included a scripted loss of DAA well clear (LoDWC) somewhere along approach:
 - 2 scripted to occur **before final**; 5-10nm from airport
 - 2 scripted to occur **on final**; within 3nm of airport
 - 2 included no scripted conflict but interactions with traffic around airport were expected
 - Alerts and LoDWC possible due to size of DWC definition and 0.5nm offset of right downwind from runway



Participants

- Participants
 - 18 participants ($M = 38.5$ years of age)
 - All had manned flying experience ($M = 2200$ hours) and were IFR rated
 - Manned: $M = 3000$ hrs in civilian airspace
 - Unmanned: $M = 1000$ hrs in civilian airspace
 - $\frac{1}{2}$ had experience with unmanned aircraft ($M = 1100$ hours)
 - 3 Air Traffic Control confederates
 - 1 retired tower controllers (from Stockton)
 - 2 retired center controllers (from Oakland Center)
 - 4 Pseudo pilot confederates (General aviation)





Results

- Alerting statistics
- Pilot response times
- Ability to maintain DAA Well Clear
 - Frequency, severity and cause of Loss of DAA Well Clear (LoDWC)
- Airspace/ATC interaction



Alerting Statistics

- 216 total scripted conflicts (all single-threat encounters)
 - = 18 (pilots) * 3 (scenarios per pilot) * 4 (scripted conflicts per scenario)
- 536 intruders registered (*in truth*) as DAA preventive, corrective or warning
 - 40% were against scripted conflicts
 - 60% were against unscripted conflicts
- Breakdown of (truth) alert types generated by intruders:



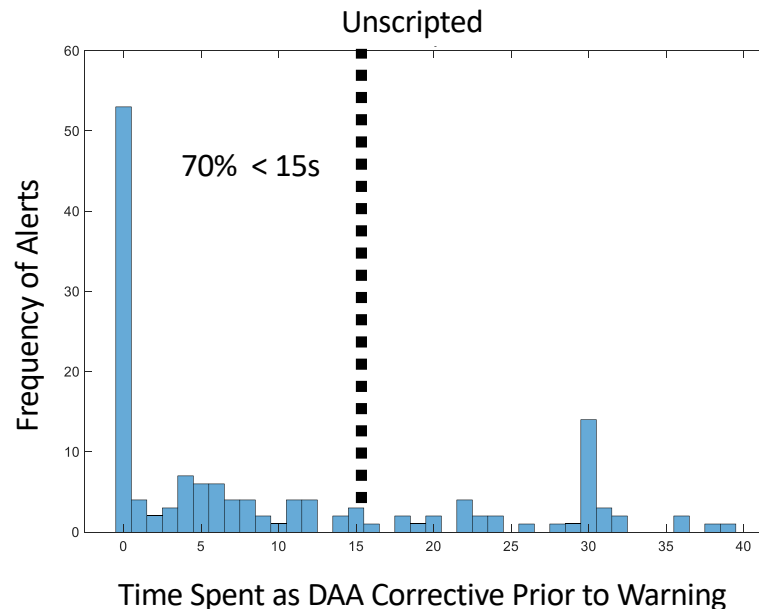
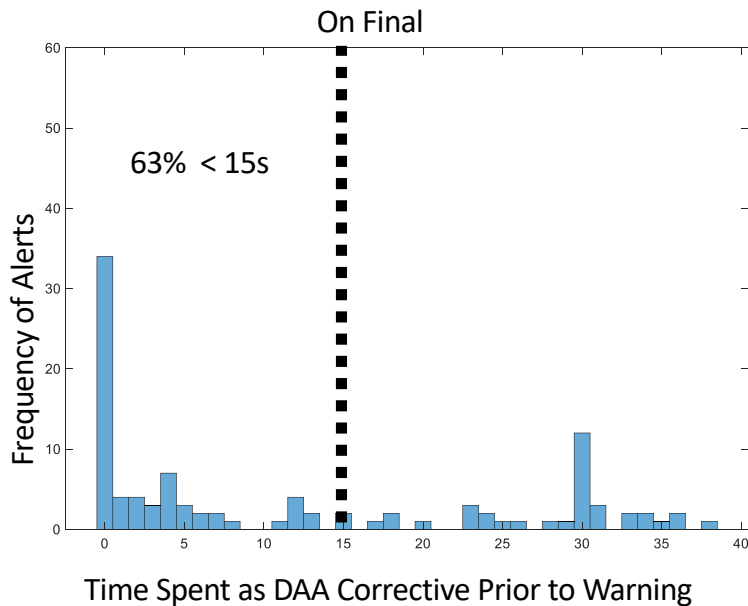
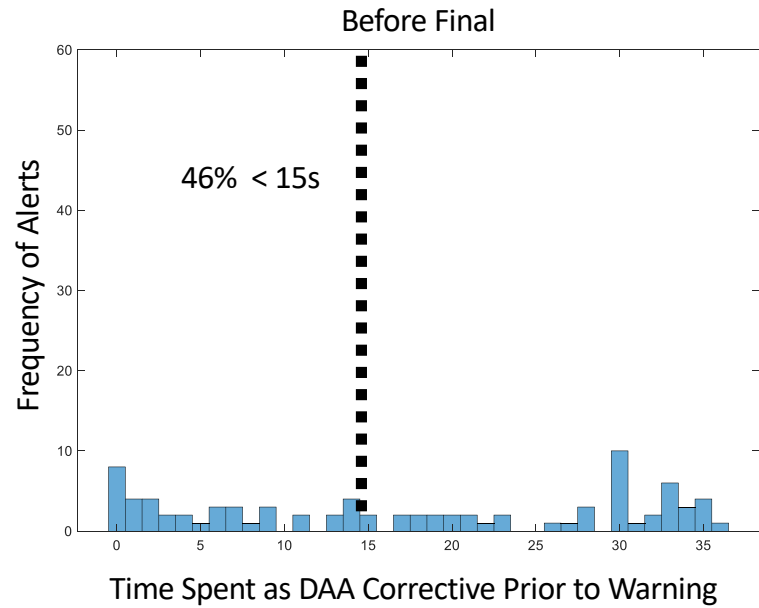
	# of Unique Intruders	DAA Preventive	DAA Corrective	DAA Warning
Scripted	210	147 (70%)	162 (77%)	191 (90%)
Unscripted	326	160 (49%)	215 (66%)	149 (46%)

NOTE:
 “Truth” alerts = actual alert level recorded by
 DAA system, regardless of display condition



Time Spent as DAA Corrective Prior to Warning

- 340 intruders registered as DAA Warning
 - 29% spent 0 time as DAA Corrective
 - 63% spent < 15 seconds as DAA Corrective
- Encounters on final and Unscripted encounters were most likely to spend < 15 seconds as DAA Corrective before registering as DAA Warning

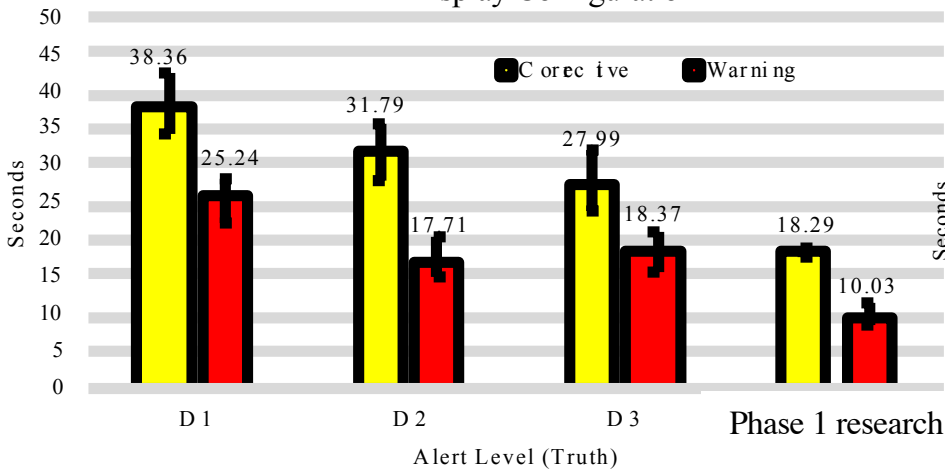




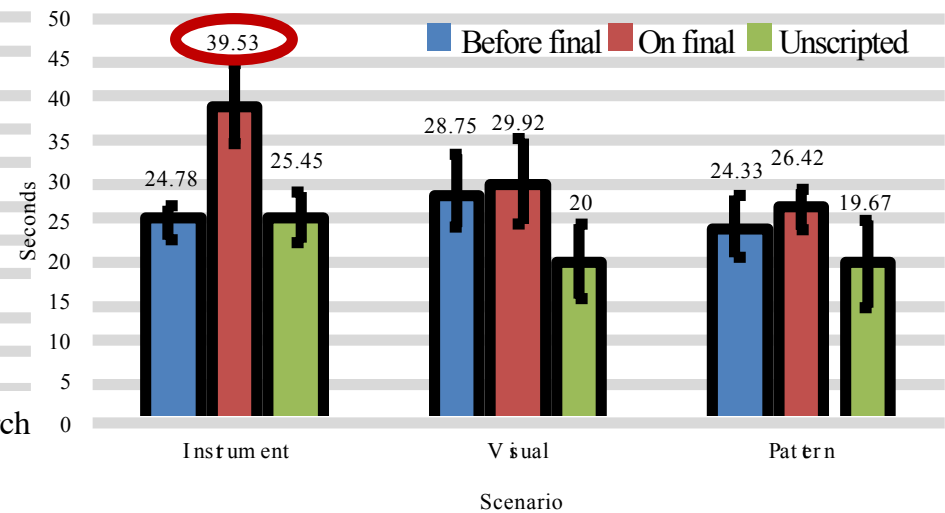
Aircraft Response Time (AC RT)

- AC RT = time from when the alert is first displayed until the maneuver is uploaded to the aircraft
 - D1 condition resulted in slower responses to both corrective and warning alerts (~ 7-10sec)
 - All conditions slower had slower response times than observed in Phase 1 research
 - Slowest AC RT when responding to encounters on final in Instrument Approach scenario

Avg. AC Response Time by Alert Level (Truth) & Display Configuration



Avg. AC RT by Scenario and Encounter Location

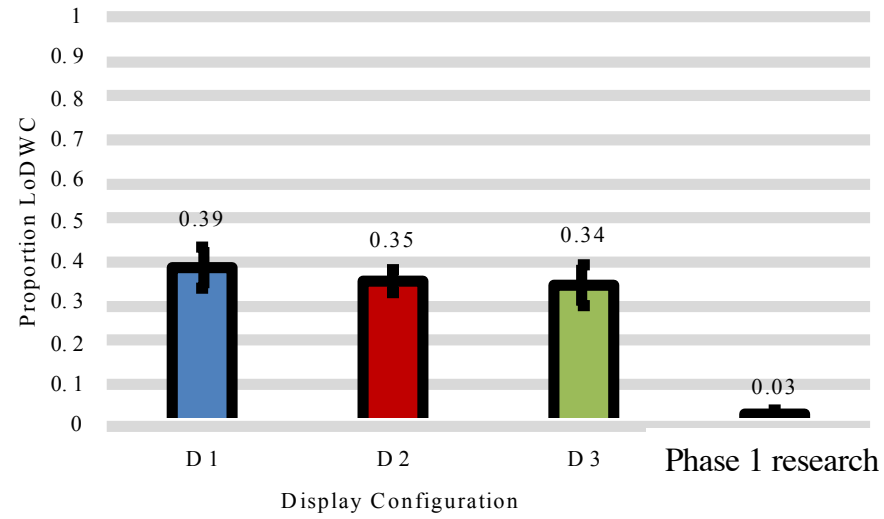




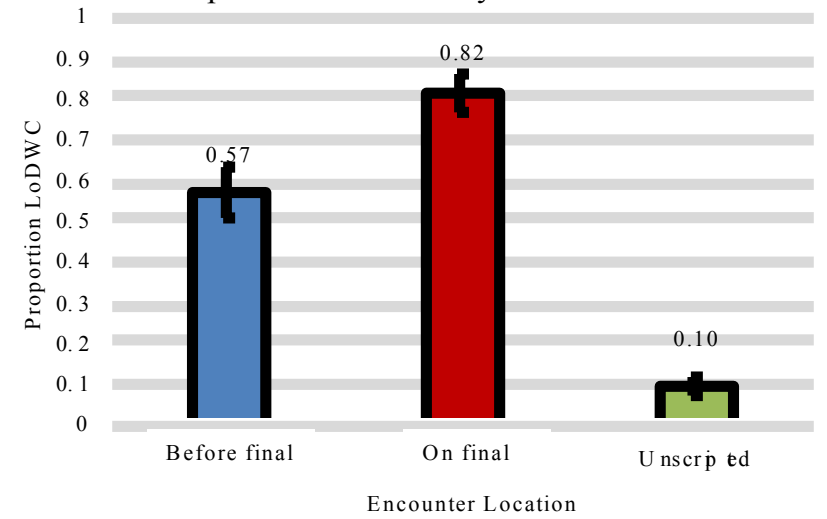
Proportion of Losses of DAA Well Clear

- Proportion of losses of DAA Well Clear (LoDWC)
 - # of LoDWC / # aircraft that generated a DAA Corrective or Warning
- **176 total LoDWC / 472 total DAA Corrective and/or Warning alerts = 37% overall**
 - Consistent across conditions (34-39%)
- Alerted traffic most likely to lead to LoDWC when occurring **on final**
 - Much smaller number of unscripted alerts actually led to LoDWC (26/249)

Proportion of LoDWC by Display Configuration



Proportion of LoDWC by Encounter Location

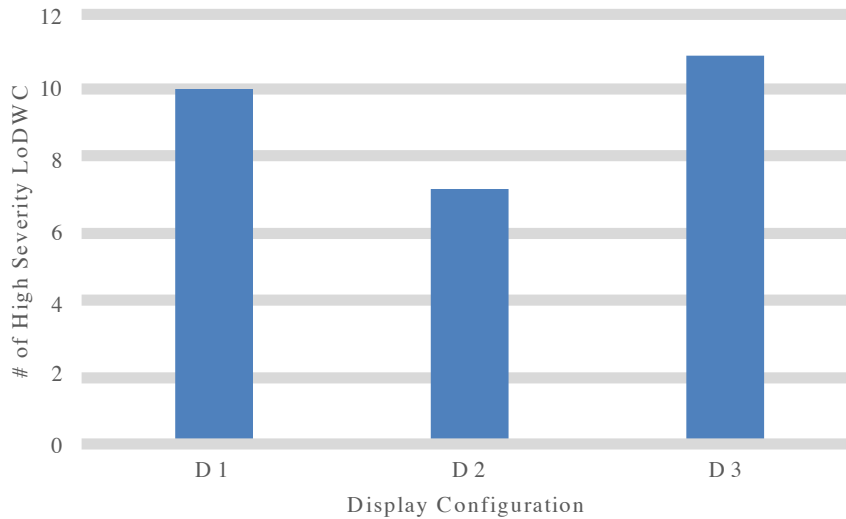




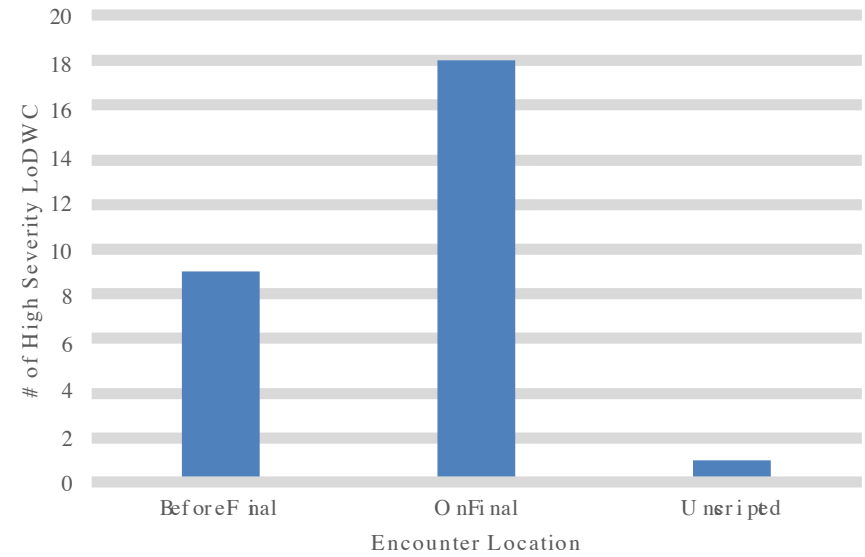
Loss of DAA Well Clear Severity (SLoWC) > 50%

- SLoWC = % of the DAA well clear volume penetrated by intruder
 - Higher % = greater penetration
 - SLoWC greater than 50% = High-severity LoDWC

High Severity LoDWC by Display Configuration



High Severity LoDWC by Encounter Location

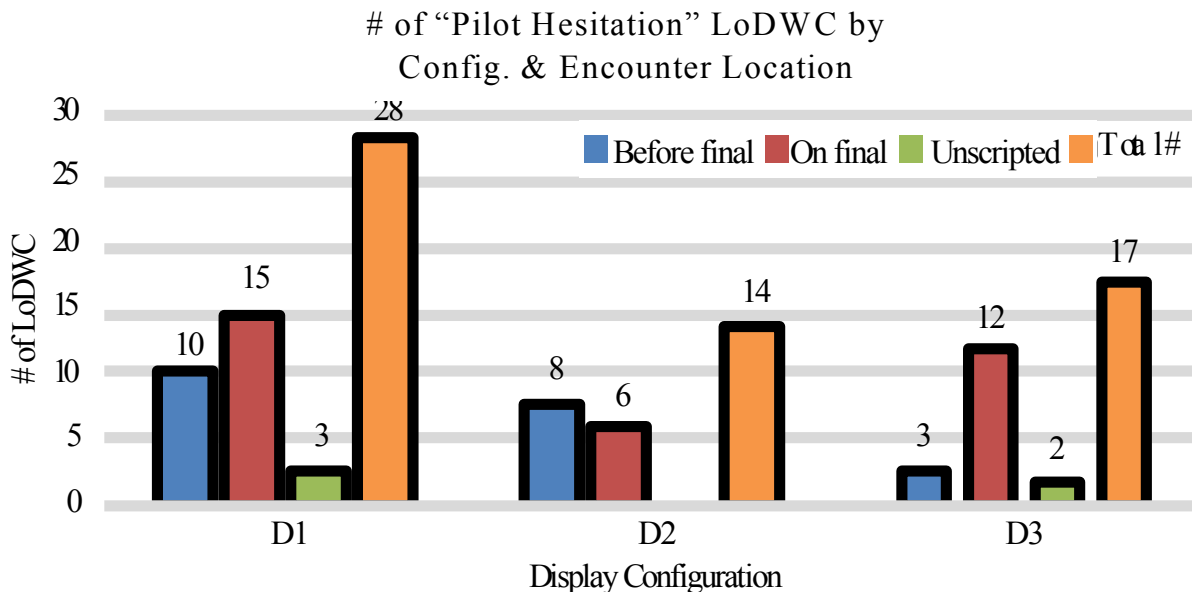




Causes of LoDWC

- Pilot responsible accounted for 63% of LoDWC
 - Most common cause of LoDWC was pilot hesitating
- Late acceleration (< 15sec to LoDWC at first alert) 2nd most common cause of LoDWC
- D1 resulted in greatest number of pilot hesitation
 - D2 resulted in less pilot hesitation against encounters **on final** than D1 and D3

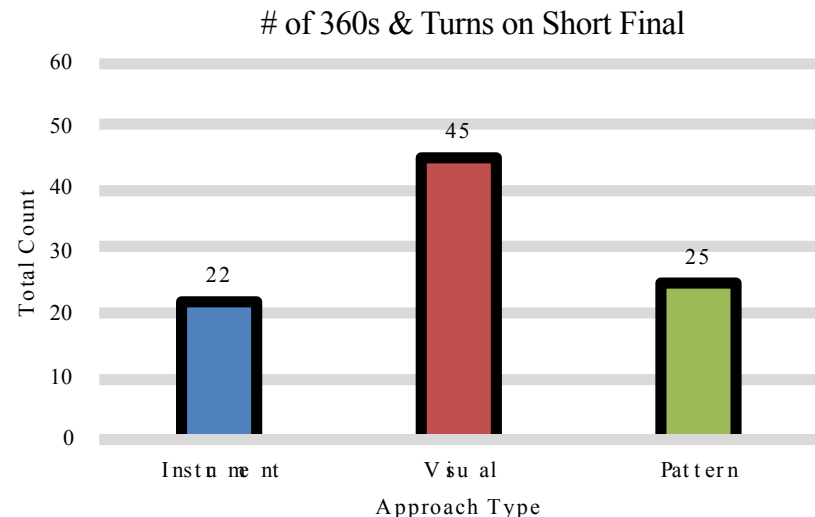
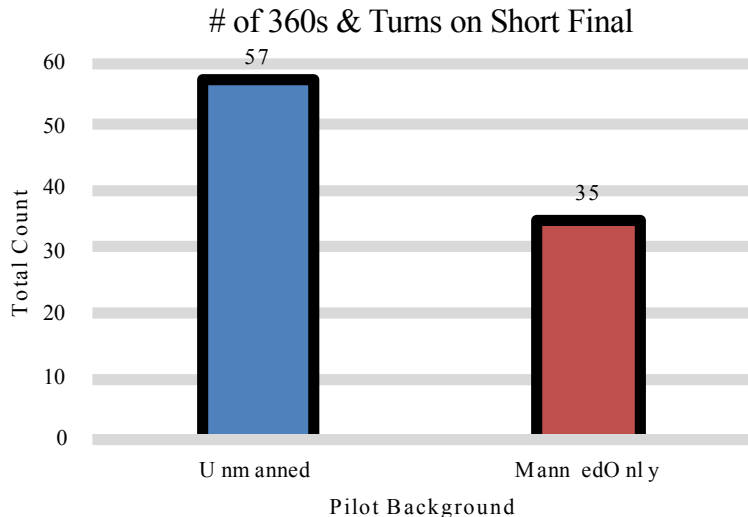
	LoDWC Category	Total
Pilot Responsible	Pilot Hesitation	34%
	Ineffective Maneuver	11%
	Return Too Soon	9%
	Turned Base/Final Too Soon	5%
	No Maneuver	2%
	Secondary Cause by Pilot	2%
Pilot Not Responsible	Late Acceleration (<15 sec)	33%
	Pattern Activity	5%





Maneuver Characteristics

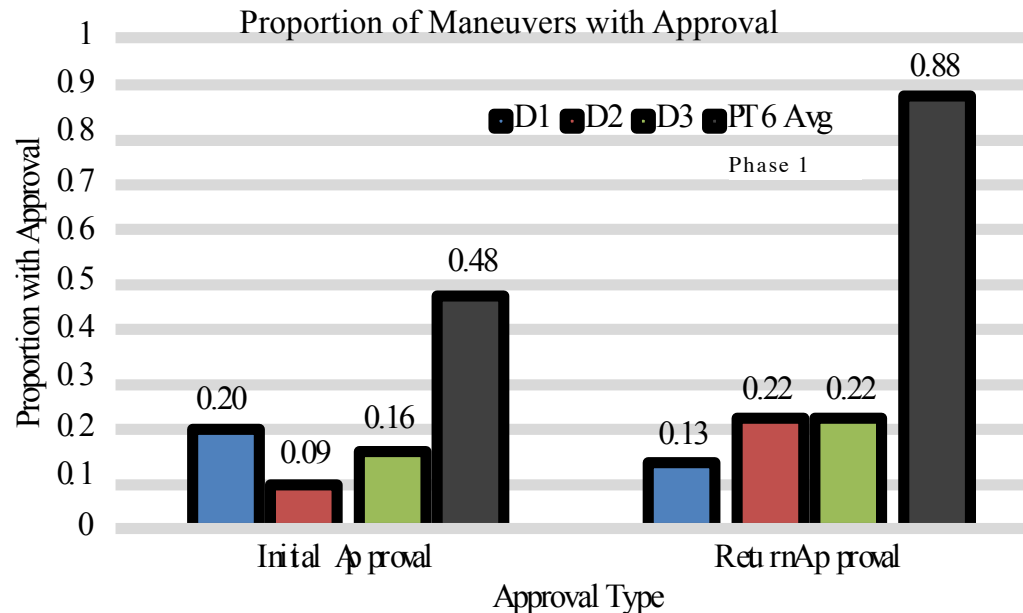
- 2 flights into terrain occurred during data collection runs (pilots not provided with integrated terrain awareness)
 - Both occurred during “visual” approach scenario where pilots descended to pattern altitude at their discretion
- Tower raised concern with number of 360s & turns made near runway
 - Much more common among pilots with unmanned experience and flying visual approach





ATC Coordination

- Receiving ATC approval was rare, regardless of condition
 - Slightly more frequent when returning to course
 - Far less common than Phase 1 research

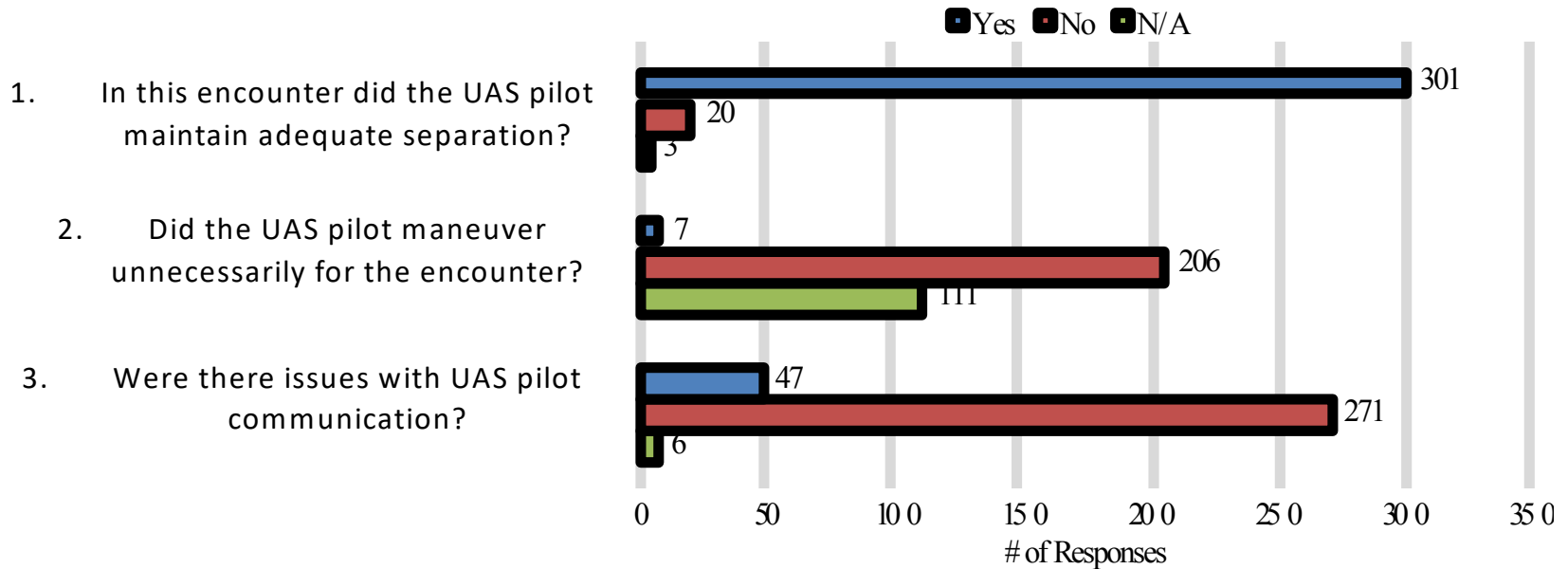


- Initial Approval = # of initial maneuvers with approval from ATC / # of total maneuvers made
- Return Approval = # of returns to course with approval from ATC / # of total returns to course



Tower Controller Feedback

- After each encounter, tower controller answered the following questions:



- Tower rated UAS behavior as overwhelmingly appropriate
 - Rated ‘inadequate’ separation typically when SLoWC > 50%
 - Unnecessary maneuvers were noted typically identified when pilot disrupted pattern sequencing
 - Communications was the most common issue (primarily not receiving advisory from pilot on traffic or maneuver)



Results Summary

- Alerting statistics
 - High number of unscripted alerts
 - Corrective alerts the most prevalent
 - Utility of corrective alert diminished near the airport
 - Most Warning alerts either had < 15 sec Corrective ($M = 8$ sec) or no prior Corrective
- Pilot response times
 - D1 overall slowest response times
 - Slowest response times observed on final in the instrument approach
 - Response times overall slower than phase 1 research
- Ability to maintain DAA Well Clear
 - Proportion
 - Encounter location had larger effect than display condition on maintaining DAA Well Clear
 - Most common on final
 - Severity
 - High Severity LoDWC most frequent in D3 and least frequent in D2
 - High Severity LoDWC most frequent on final than before final or unscripted encounters
 - Cause
 - Pilot hesitation and late acceleration
- Airspace/ATC interaction
 - Major concerns with large turns near runway and lack of coordination
 - Overall Tower controllers rated UAS pilot performance very highly



Conclusion

- Phase 1 DAA Well Clear Definition is inappropriate for the terminal area
 - Pilots had difficulty judging when a maneuver was necessary to avoid high-severity LoDWC
 - None above 30% in Phase 1 research
 - 17 > 50% SLoWC; 6 > 70% due to pilot responsibility (pilot hesitation was most common)
 - Phase 1 Well clear definition too large to differentiate between threats and safely separated aircraft
- Follow on work:
 - Study looking at new DAA well clear definitions tailored to the terminal area
 - Study looking at when to transition from the Phase 1 well clear definition to the terminal well clear definition



Questions?