



National Aeronautics and Space Administration

UAS Integration in the NAS Project DAA-TCAS Interoperability “mini” HITL Primary Results

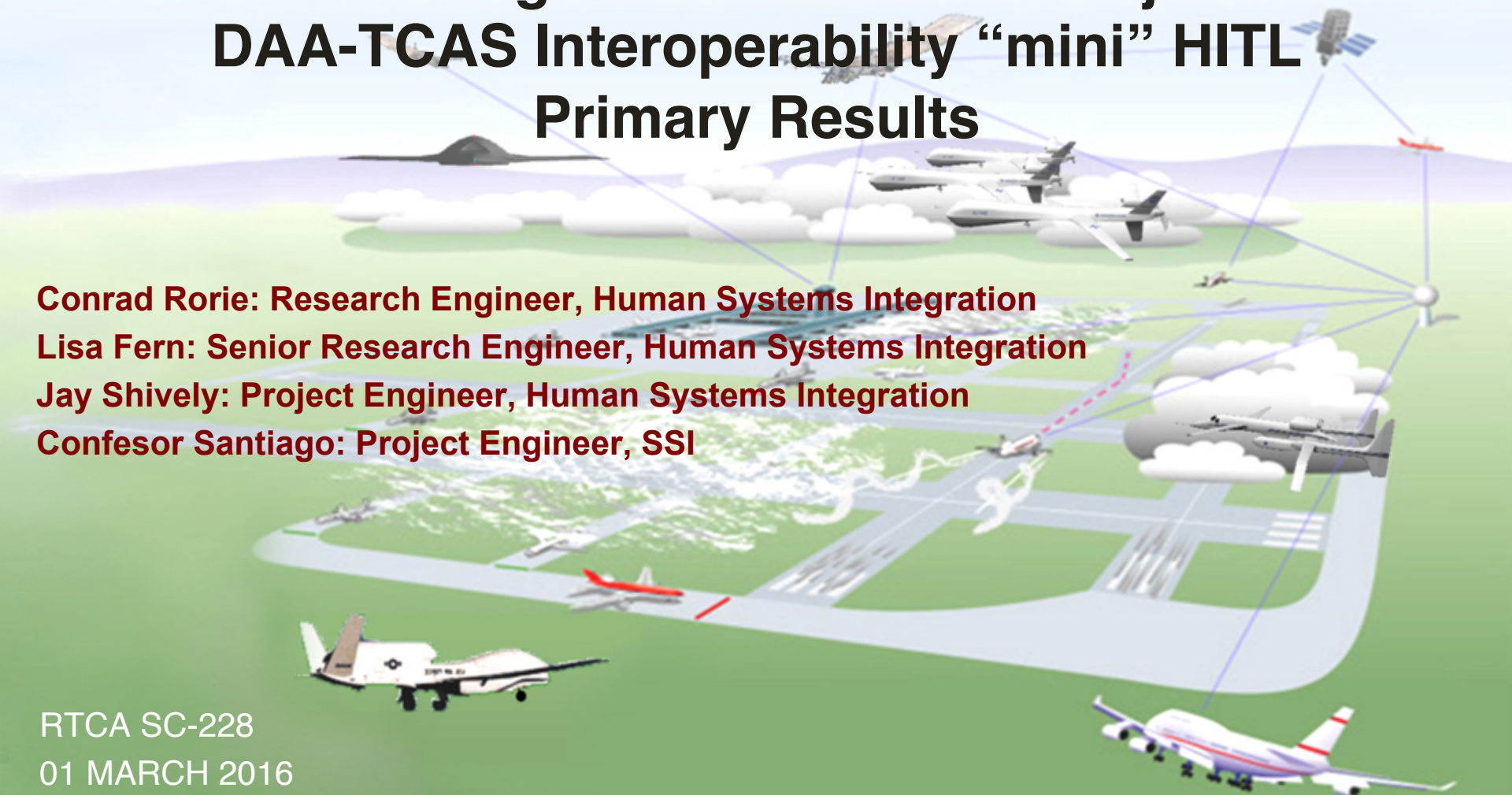
Conrad Rorie: Research Engineer, Human Systems Integration

Lisa Fern: Senior Research Engineer, Human Systems Integration

Jay Shively: Project Engineer, Human Systems Integration

Confesor Santiago: Project Engineer, SSI

RTCA SC-228
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- At the May 2015 SC-228 meeting, requirements for TCAS II interoperability became elevated in priority
- A TCAS interoperability workgroup was formed to identify and address key issues/questions
- The TCAS workgroup came up with an initial list of questions and a plan to address those questions
- As part of that plan, NASA proposed to run a “mini” HITL to address display, alerting and guidance issues
- A TCAS Interoperability Workshop was held to determine potential display/alerting/guidance issues that could be explored in future NASA “mini” HITLS
 - Consensus on main functionality of DAA guidance when TCAS II RA occurs
 - Prioritized list of independent variables for experimental design
 - Set of use cases to stress TCAS Interoperability



- Consensus on DAA functionality to be interoperable with TCAS II:
 1. Key interoperability issues occur during “well clear recovery”
 - When a loss of well clear can no longer be avoided
 2. Urgency of well clear penetration drives a directive or limited suggestive guidance solution
 3. Any target with an active corrective RA should be removed from all DAA guidance calculations
 - All horizontal guidance for for non-RA aircraft will be shown during an RA
 4. All DAA vertical guidance should be *suppressed* during a corrective RA
 5. DAA vertical guidance should be *consistent* with a preventive RA
 6. Well clear recovery is limited to horizontal only for cooperative intruders
 - Prevents degradation of TCAS II performance resulting from vertical maneuvers near the collision avoidance boundary
 7. HITL should explore how to minimize pilot response time when two maneuvers are required



- Prioritized list of independent variables:
 1. Are there performance differences with various methods of displaying well clear recovery guidance
 - Directive, directional, or limited suggestive
 2. Can preventive RAs be displayed as a DAA preventive alert icon
 - Make DAA vertical guidance consistent with preventive RA
 3. Should the current DAA warning alert be a caution instead of a warning while retaining the distinctive aural alert?
 4. Should there be a warning for cooperative targets that can progress to RA



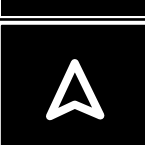
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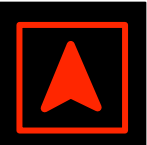
- Week 1: Mixed Factorial Design
 1. Well clear recovery/band saturation options (within subjects)
 - Limited suggestive wedge
 - General directional
 2. DAA Warning Alert for cooperative intruders (between subjects)
 - Cooperative intruders with DAA Warning Alert
 - Cooperative intruders without DAA Warning Alert
- Participants:
 - 4 active duty UAS pilots
 - Average Age: 49
 - Manned Flying Experience Total Hours: 5000
 - Unmanned Flying Experience Total Hours: 2100
 - 5 commercial pilots
 - Average Age: 44
 - Manned Flying Experience Total Hours: 15,500

Week 1 – No Warning Alert for Cooperative Aircraft Alerting Structure

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	TCAS RA	"Climb/Descend"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Week 1 – Warning Alert for Cooperative Aircraft Alerting Structure

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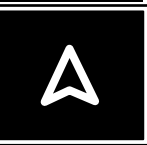


- Week 1 Observations:
 - Negative impact of removing DAA warning for cooperative targets
 - Observation of pilots attempting to negotiate with ATC while flying into an RA
 - Reintroduced DAA warning alert for cooperative targets



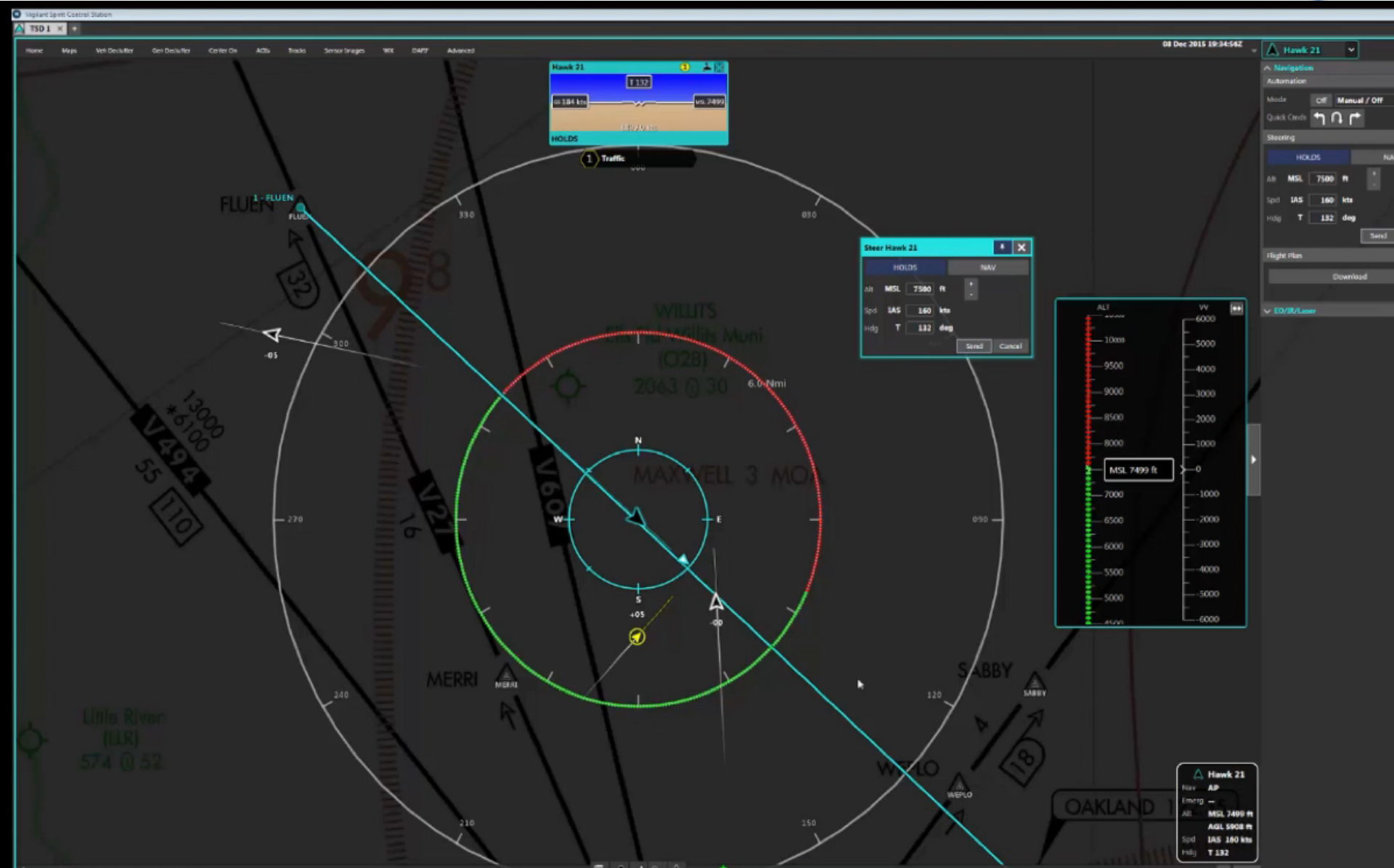
- Week 2: Mixed Factorial Design
 1. Well clear recovery/band saturation options (within subjects)
 - Limited suggestive/directive wedge
 - General directional
 2. Presence of green DAA banding (between subjects)
 - DAA guidance uses green banding to depict safe headings/altitudes
 - DAA guidance uses no banding to depict safe headings/altitudes
- Participants:
 - 6 active duty UAS pilots
 - Average Age: 36
 - Manned Flying Experience Total Hours: 1600
 - Unmanned Flying Experience Total Hours: 1400
 - 4 commercial pilots
 - Average Age: 30
 - Manned Flying Experience Total Hours: 9000

Week 2 Alerting Structure

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	TCAS RA	"Climb/Descend"
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Method: Experimental Design





- Changes from past NASA simulations:
 - Updates to the alerting structure to meet draft MOPS
 - Implemented dead reckoning/state projection for ownship
 - Removed proximate advisory
 - Used the *must alert* threshold times from the DAA MOPS for Preventive and Corrective DAA alerts
 - 75s reduced to 55s
 - Incorporated 4 second alert hysteresis
 - Made DMOD and HMD parameters equivalent
 - Changed corrective aural from “Traffic, Separate” to “Traffic, Avoid”
 - Green bands for predicted Preventive alerts
 - Previously used hashed yellow, but no longer making a distinction between the two caution alerts in the bands
 - Now, green = well clear, NOT absence of caution-level alerts/threats
 - Incorporated Preventive RA into DAA alert structure; incorporate guidance into vertical bands
 - Now all RAs presented to pilot require corrective action
 - Added quick vertical input capability to VSCS
 - Developed well clear recovery algorithm in JADEM
 - Was previously implemented for DAIDALUS but not JADEM



- Changes from past NASA simulations:
 - No secondary tasks for pilot
 - Only responsible for maintaining well clear from threats to well clear
 - To ensure encounters unfolded properly, participants were 'hands-off' the mouse until a Corrective DAA (or more severe) was triggered
 - No ATC in-the-loop
 - Simulated ATC comms by requesting clearance from researcher
 - Encounters injected using native VSCS tool
 - Did not allow for real-time adjustments
 - 20 encounters per display versus 8 in previous HITLs
- Expected impact on data compared to previous HITLs:
 - Shorter response times for all metrics
 - Higher rates of losses of well clear



- Simulation Hardware/Software:
 - Vigilant Spirit Control Station (VSCS) with tactical situation display (TSD) only
 - Integrated TCAS II RA alerts and guidance
 - Scripted encounters using VSCS's internal generation tool
 - TCAS II v 7.0 logic with 7.1 aural alerts
 - JADEM v5.4.1 DAA System
 - DAA alerting
 - DAA guidance (omni bands)
 - Well Clear Recovery guidance
 - Perfect surveillance data
 - Researcher served as surrogate ATC

Method: Simulation Environment

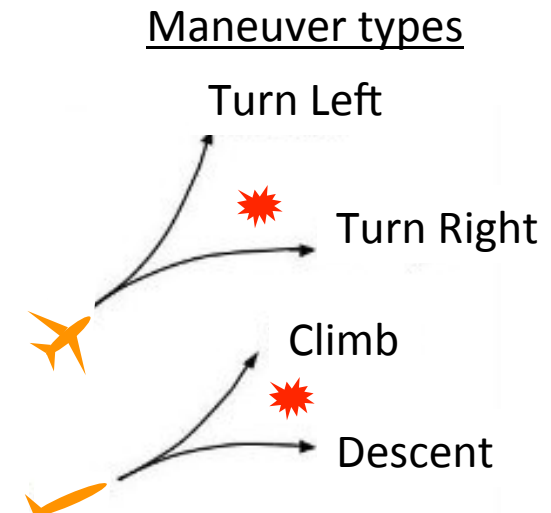


Separation Thresholds

Separation Volume	modTau	Horizontal	Vertical
Well Clear	35 sec	0.66 nm DMOD 0.66 HMD	450ft ZTHR
TCAS Corrective RA (5000 – 10,000 ft)	25 sec	0.55 nm DMOD	600 ft ZTHR 350 ALIM
NMAC	N/A	500 ft HMD	100 ft VMD

- Well-Clear Recovery (WCR) is based on an algorithm called Generic Resolution Advisor and Conflict Evaluator (GRACE)
- GRACE is a general purpose conflict detection and resolution algorithm that
 - Provides a faster-than-real-time alerting and guidance capability
 - Evaluates multiple intruders for conflicts (threats) based on user-defined separation standards
 - Drives other types of guidance supported in JADEM, i.e. generic collision avoidance algorithm and Vector Planner from PT4 and IHITL, underlying computations behind OmniBands, and, of course, WCR described here.

- GRACE maneuver selection logic
 1. Generates a conflict avoidance maneuver of each type as a candidate solution
 2. If a conflict-free solution can be found
 - selects a conflict-free solution with the lowest cost
 3. otherwise
 - selects a solution with the lowest cost



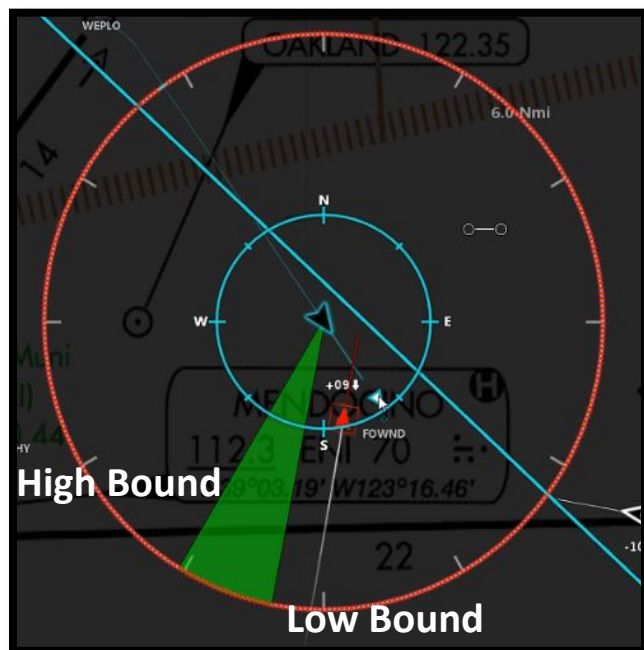
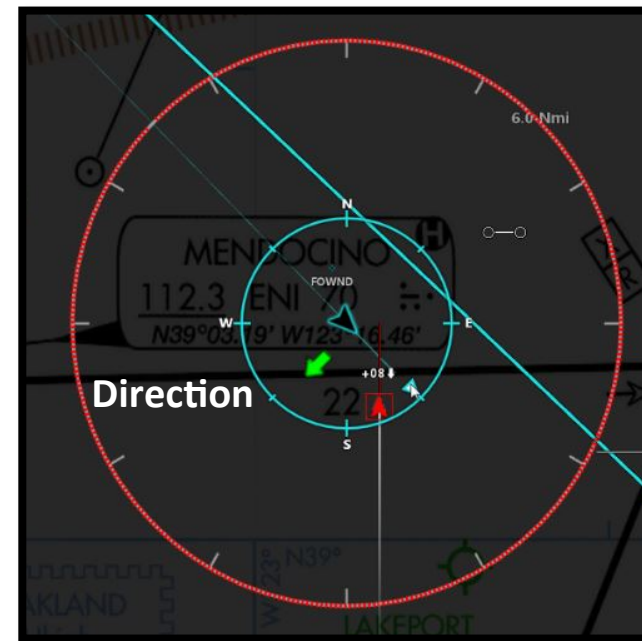


- Near mid-air collision (NMAC) cost
 - Penalizes all maneuvers too close to NMAC violation for any intruder, i.e. maximizes normalized separation at new, predicted closest point of approach
 - This cost naturally dominates when close to collision, which is the case in WCR
- Maneuver type (rank) cost
 - Favors right-of-way compliant maneuvers
- Specific maneuver type costs (preferences)
 - Can selectively enforce or suppress specific maneuver types
- Maneuver strength cost
 - Penalizes too aggressive maneuvers
- Maneuver duration cost
 - Penalizes long deviations from flight plan
- Maneuver change cost
 - Penalizes frequent changes of maneuver types
 - Can improve guidance stability in the presence of noise

Well-Clear Recovery Algorithm



- Directional Well-Clear Recovery
 - Displays only maneuver type selected by GRACE
- Limited suggestive Well-Clear Recovery
 - Displays the “wedge” between low and high bounds of control variable (relative heading or altitude)
 - Based on values selected by GRACE with certain corrections



- In general:
 - Low bound is the lowest value of control variable needed for a timely regain of well clear
 - High bound is maneuver limit typically the point at which CPA would be achieved, i.e. maneuver until diverging
- Both bounds are snapped to a specified grid
- In any case the difference between high and low bounds cannot be smaller than a configurable minimal wedge width

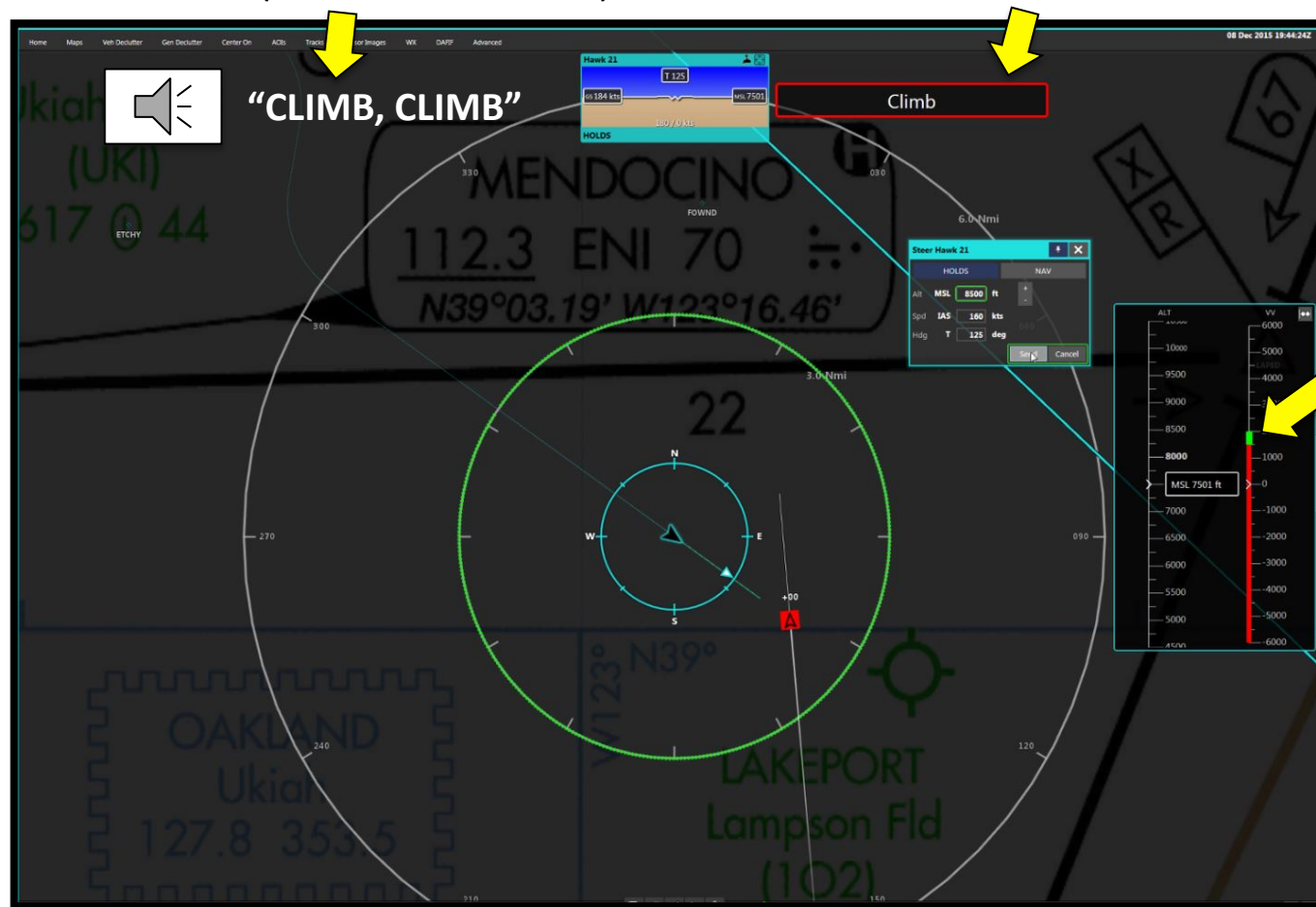
TCAS II Guidance

- Auditory Alert

- RA sense presented aurally (source: TCAS II v7.1)

- Text Based

- RA sense shown in text box next to Baseball Card



- Vertical Rate Guidance

- Presented within VVI
- Green = desired vertical speed
- Red = vertical speed to avoid



- TCAS II Research Questions:
 - Under nominal conditions, how many encounters progress to a corrective RA?
 - What is the average response time for pilots responding to a corrective RA?
 - How does it compare to response times to corrective and warning alerts?
 - What is the compliance rate to corrective RAs?
 - What is the rate of near mid air collisions (NMACs) for pilots responding to corrective RAs
- Well Clear Recovery Guidance Research Questions
 - Does well clear recovery display type have an effect on pilots' response times, well clear severity, or compliance rates?
 - What is pilots' preference between the two types of WCR displays?
- DAA Guidance Research Questions:
 - Does the presence or absence of green DAA affect pilot response times or loss of well clear rates?



- Interoperability Research Questions:
 - When a TCAS RA response results in a DAA warning alert with a non-cooperative intruder, will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - What is the compliance for this secondary maneuver?
 - Do pilots respond to secondary maneuver in a timely manner?
 - When a TCAS RA response results in a DAA corrective alert with a non-cooperative intruder, will pilots make the appropriate secondary horizontal maneuver provided by the DAA guidance to avoid a loss of well clear?
 - What is the compliance for this secondary maneuver?
 - Do pilots respond to secondary maneuver in a timely manner?
 - Are pilots confused by having two warning alerts?

Use Cases



Type	Multiple Intruder?	Intruder Type(s)	Purpose
Use Case A: <i>Well Clear Recovery Only</i>	No	RADAR-only	"Force" well clear recovery (WCR) guidance so that pilots spend time with the two different guidance options
Use Case B: <i>RA-to-DAA Warning</i>	Yes	TCAS-equipped & RADAR-only	Test how pilots respond when they respond to a TCAS RA that (when followed) generates a DAA Warning with a secondary RADAR-only target
Use Case C: <i>TCAS RA Only</i>	No	TCAS-equipped	Test how pilots respond to RA with single TCAS-equipped target
Use Case D: <i>RA-to-Corrective DAA</i>	Yes	TCAS-equipped & RADAR-only	Test how pilots respond when they respond to a TCAS RA that (when followed) generates a Corrective DAA alert with a secondary RADAR-only target
Use Case E: <i>Well Clear</i>	No	TCAS-equipped	See if pilots moved against intruders that were scripted to remain well clear



- 8 encounters generated per Use Case
 - Differed in encounter geometry (based on feedback from different members of 228 – MITRE, GA, NASA) and whether intruder was level or changing altitude
 - $\frac{1}{2}$ the encounters were scripted to 'blunder' to ensure desired use case was generated
 - $\frac{1}{2}$ the encounters were scripted to lead to the desired use case *absent pilot action*
 - Acted as test of how often pilots could **avoid** a given use case provided with sufficient time
- Encounters divided into 2 different scenarios
 - = 20 encounters per scenario, 4 of each use case, half of them 'blunders'
- Pilots saw each scenario twice (=total of 80 encounters per pilot)
 - = 800 encounters across all of Week 2 data collection



- Notes:
 - Intruders
 - Unable to generate encounters with very slow closure rates
 - Caused a (known) issue with the banding and lengthened scenarios considerably
 - Intruders came at ownship from between $\pm 130^\circ$ relative heading
 - In cases with a scripted blunder, the cooperative aircraft was on a 'well clear' trajectory *but accelerated in the direction of ownship* within range of a DAA Warning (Use Case A) or TCAS RA (Use Cases B, C & D)
 - **These cases greatly inflate the rate of losses of well clear**
 - All had 205 knots GS
 - Too many other variables for us to systematically vary speed
 - Ownship
 - Always level and 180 knots GS at initialization of encounter
 - Intruder injection tool used relative ownship position so ownship needed to remain constant once started



- Number of Encounters by First Alert Type
 - Corrective DAA = 378 encounters
 - DAA Warning = 376 encounters
 - TCAS RA = 96 encounters
 - “Climb” = 58 cases (all ‘well clear’)
 - “Descend” = 4 cases (all ‘well clear’)
 - “Monitor” = 34 cases (all ‘well clear’)
 - **“Well Clear RA” = RA that occurred when the intruder was well clear AND there was no DAA alerting**
 - Never Alerted = 271 encounters

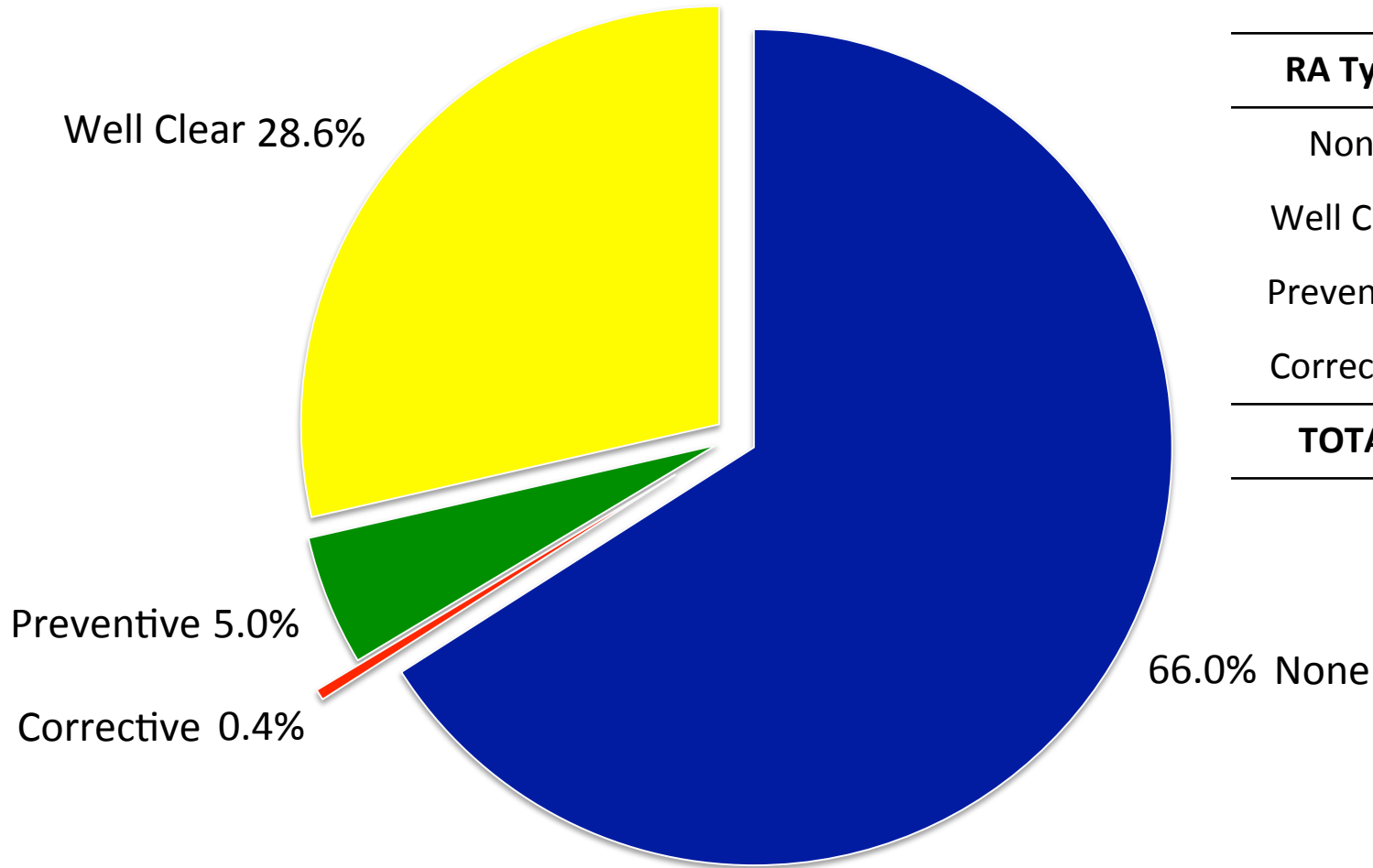


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TCAS II Overall Results



Occurrence of RAs (by type) when intruder did not blunder

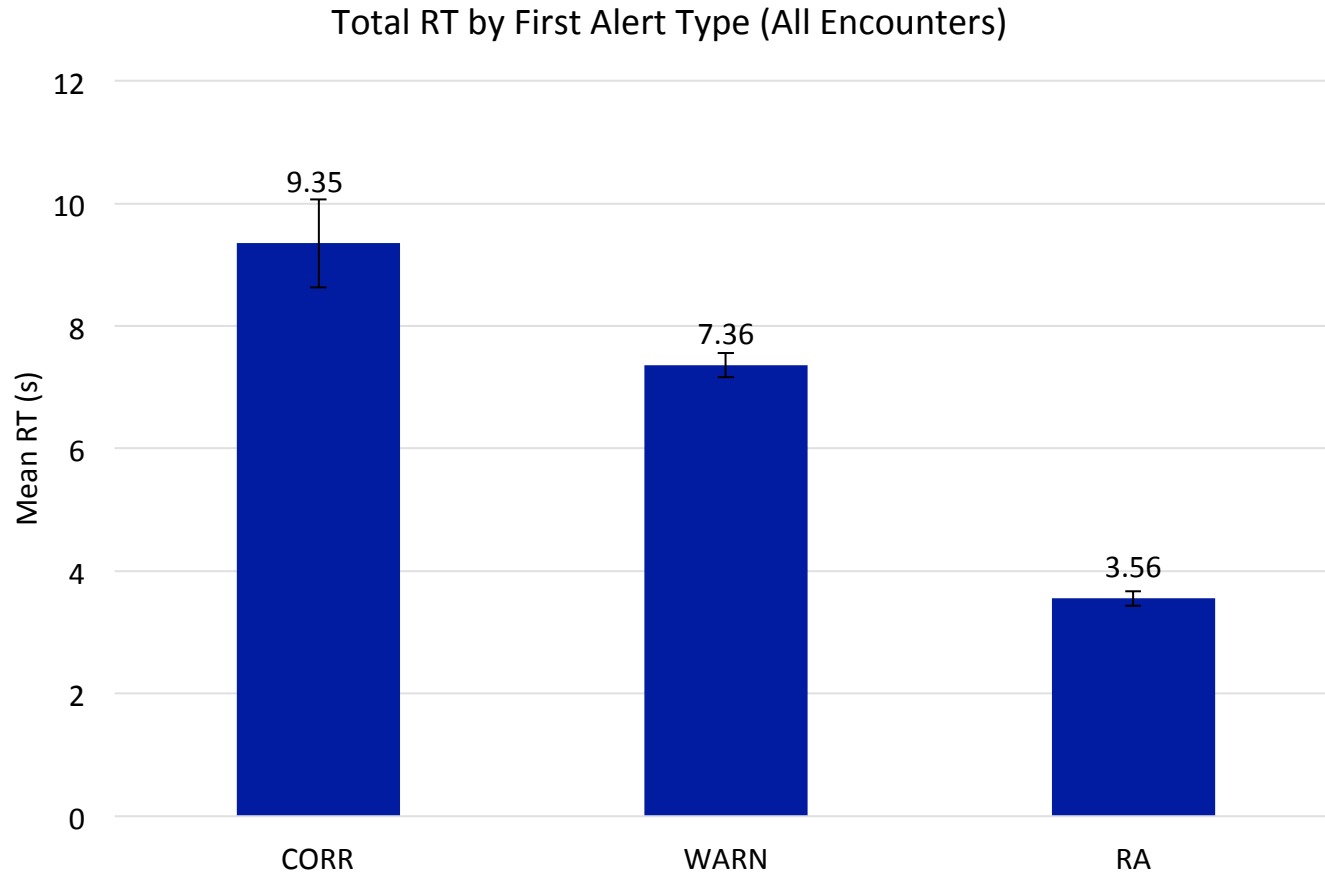


RA Type	Number
None	157
Well Clear	68
Preventive	12
Corrective	1
TOTAL	238



- TCAS II Research Questions:
 - Under nominal conditions, how many encounters progress to a corrective RA?
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Pilot Total Response Time by Threat Type at First Alert

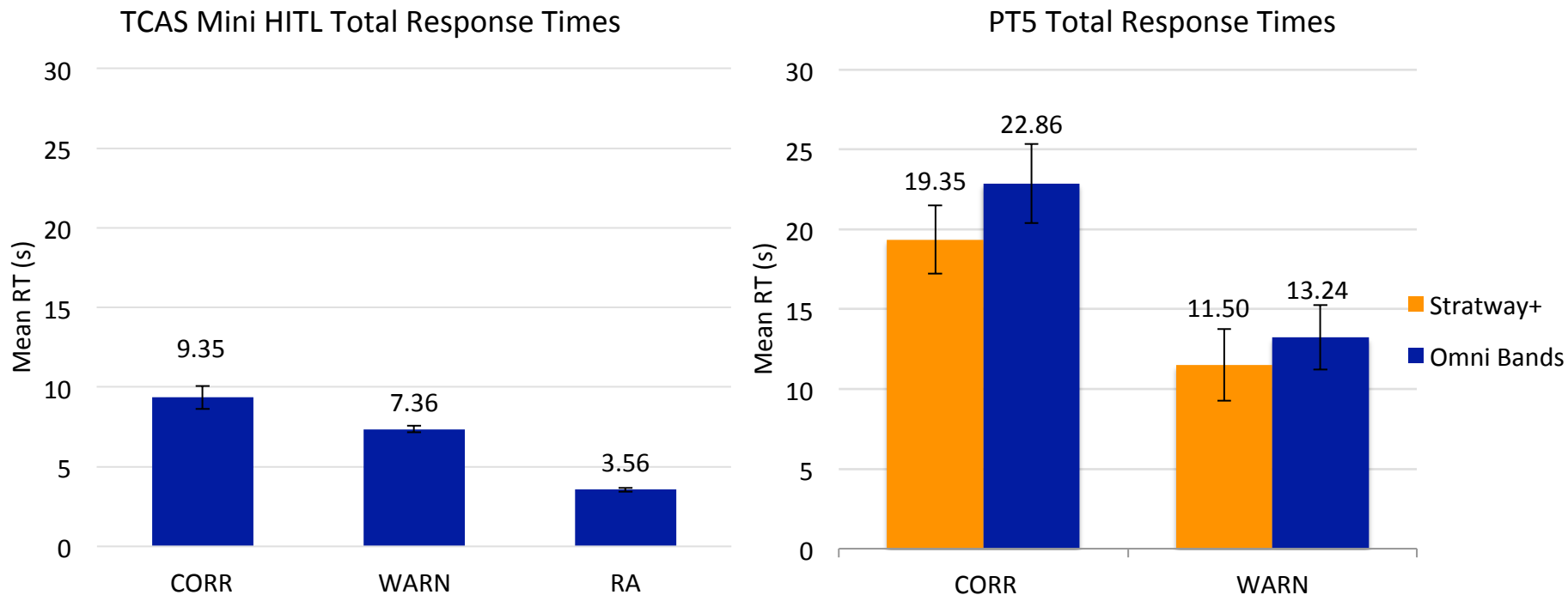


NOTE: ALL of the RAs at First Alert were 'well clear' RAs

TCAS II Overall Results



Pilot Response Time by Threat Type at First Alert Comparison to PT5 Data



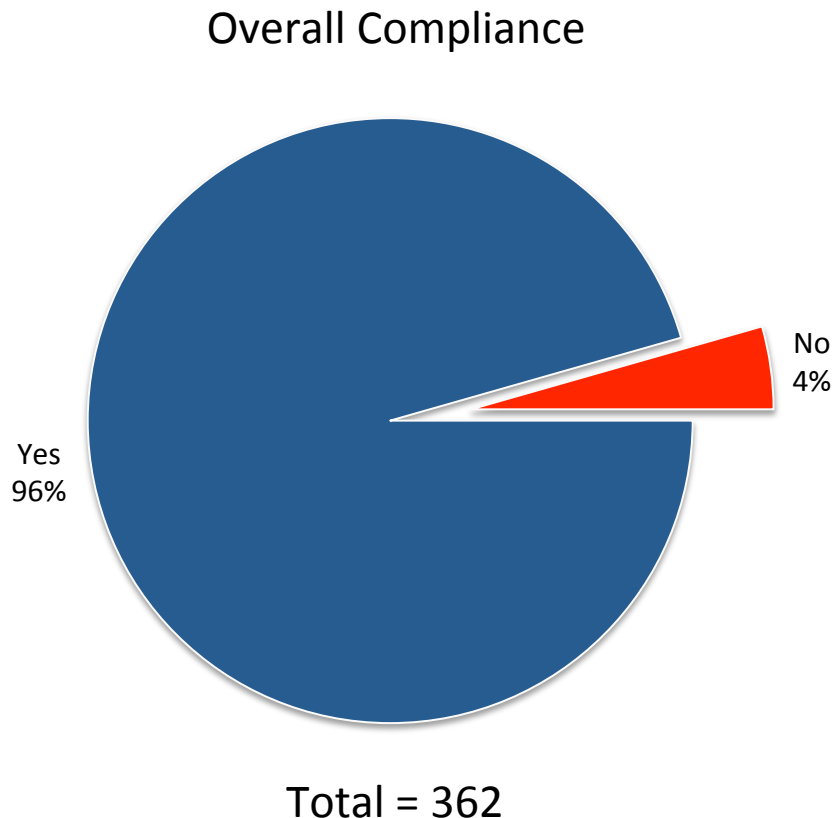


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TCAS II Overall Results



RA Compliance (all Corrective and “well clear” RAs)



Reason for Non-Compliance	Number
Disregarded because conflict was well clear	6 (38%)
Pilot maneuvered in opposite vertical sense due to awareness of secondary threat (all Use Case B)	6 (38%)
Pilot made horizontal maneuver but disregarded RA due to awareness of secondary threat (all Use Case B)	3 (19%)
Pilot felt horizontal maneuver was sufficient (Use Case C)	1 (6%)
TOTAL	16



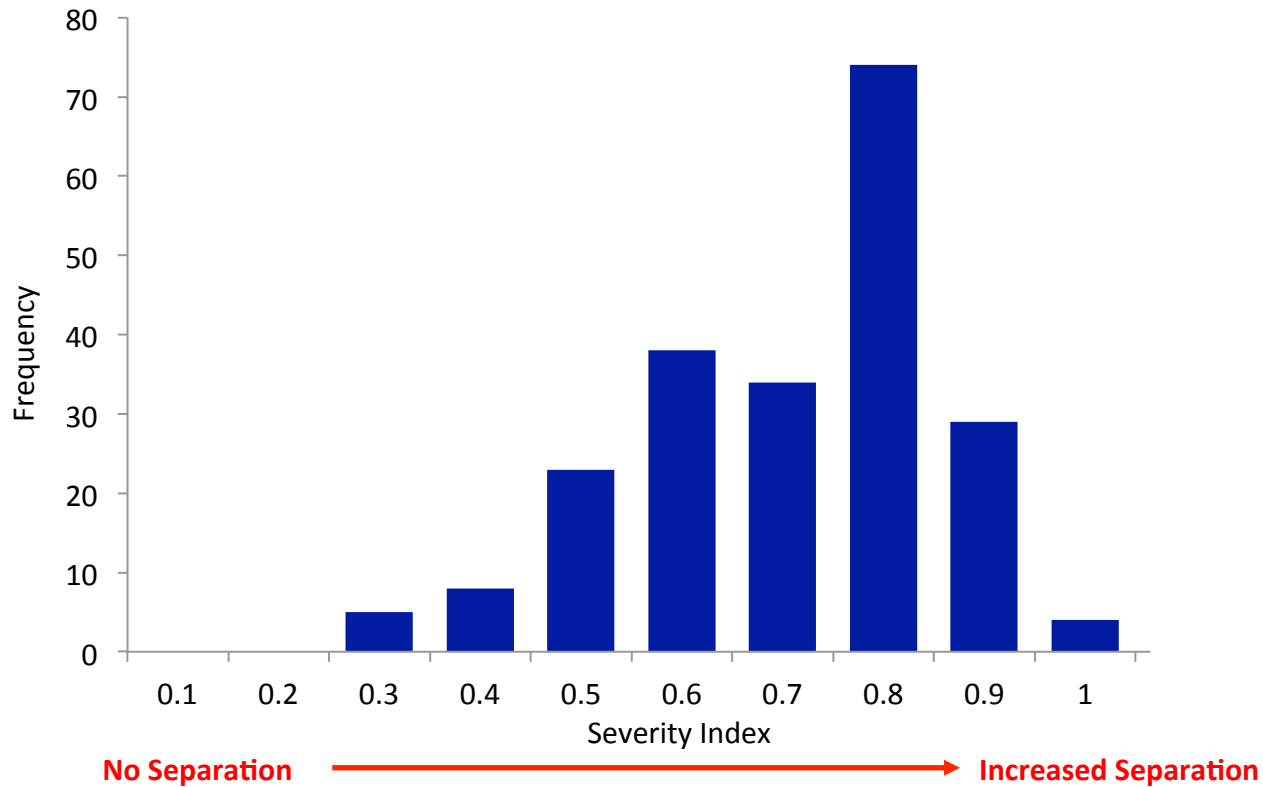
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TCAS II Overall Results



LoWC Severity when RAs Occurred

0 NMACs across ALL conditions



$Severity\ Index = Actual\ Spatial\ Separation / Spatial\ Separation\ Threshold$
(excluding Tau)

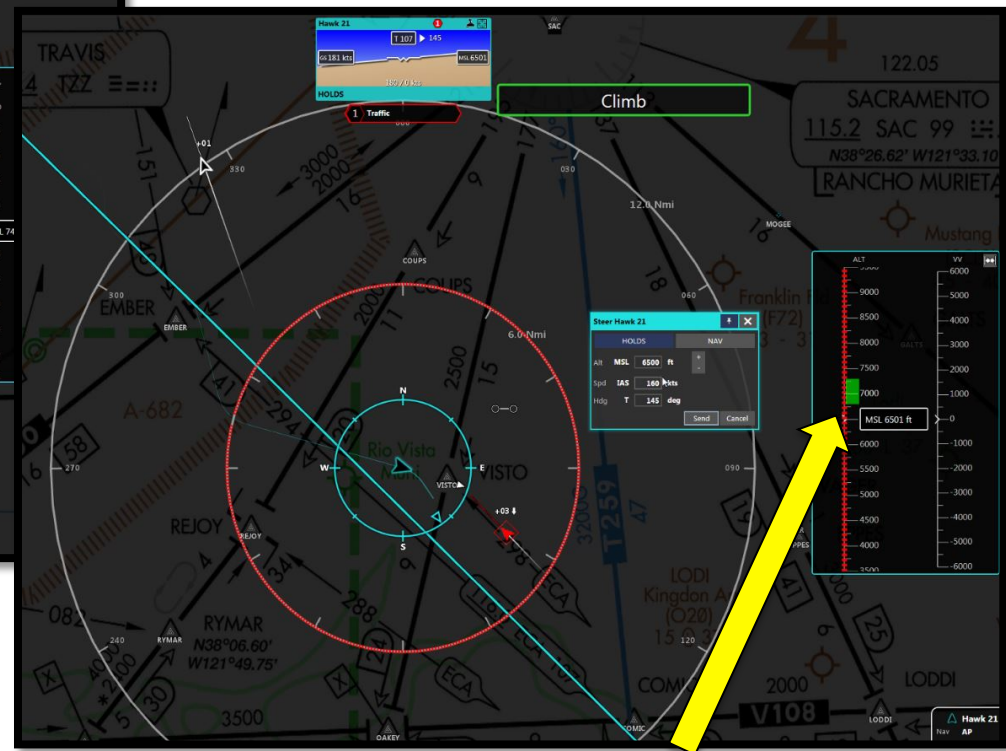
Well Clear Recovery Overall Results



Limited Suggestive



Horizontal Guidance



Vertical Guidance

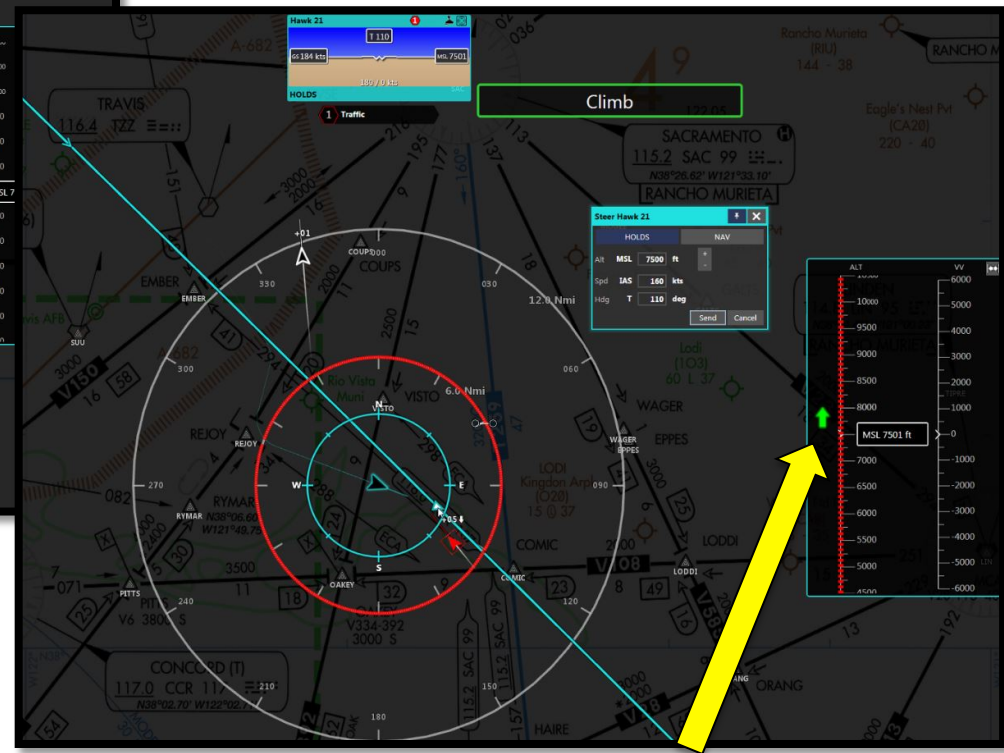
Well Clear Recovery Overall Results



Directinal



Horizontal Guidance



Vertical Guidance

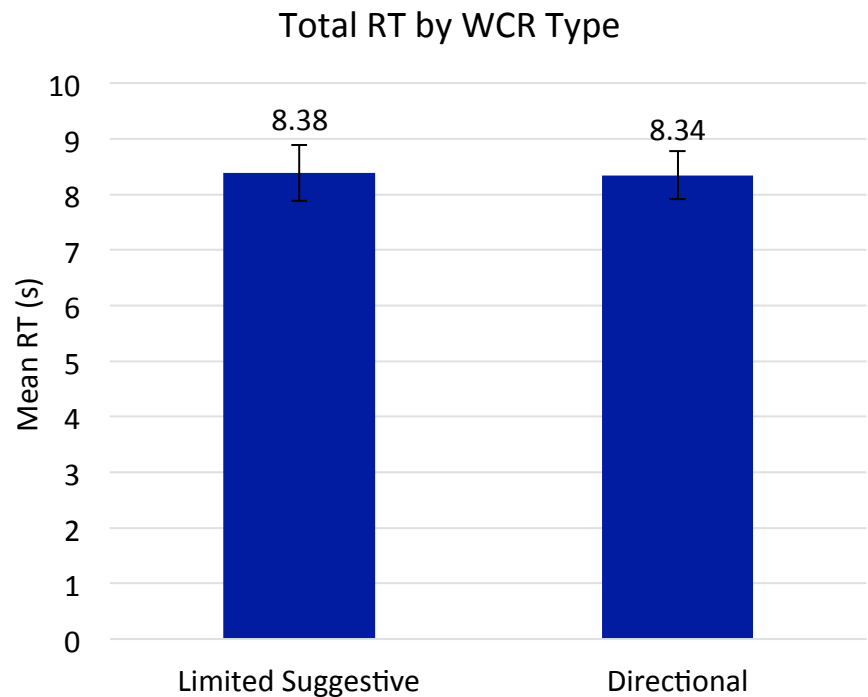
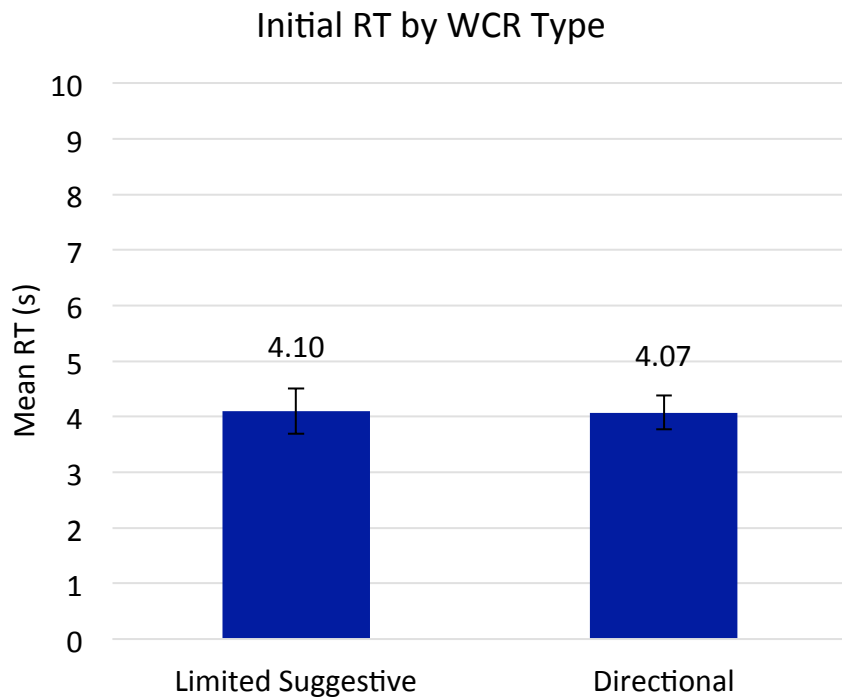


- Well Clear Recovery Guidance Research Questions
 - Does well clear recovery display type have an effect on pilots' response times?
 - Does well clear recovery display type effect well clear severity?
 - What are pilots' compliance rates with well clear recovery guidance?
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Well Clear Recovery Overall Results



Effect of Well Clear Recovery Displays on Pilot Performance



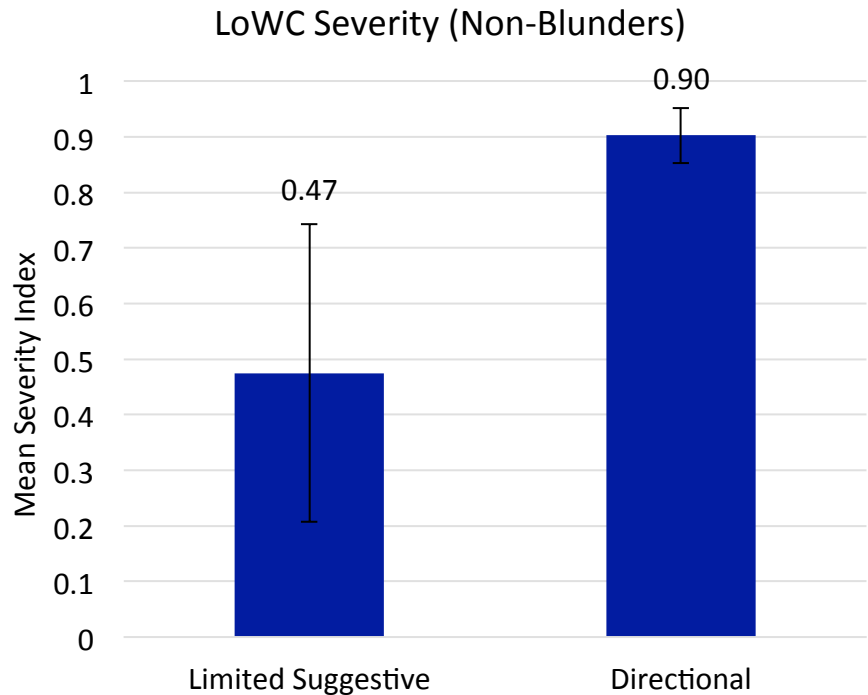
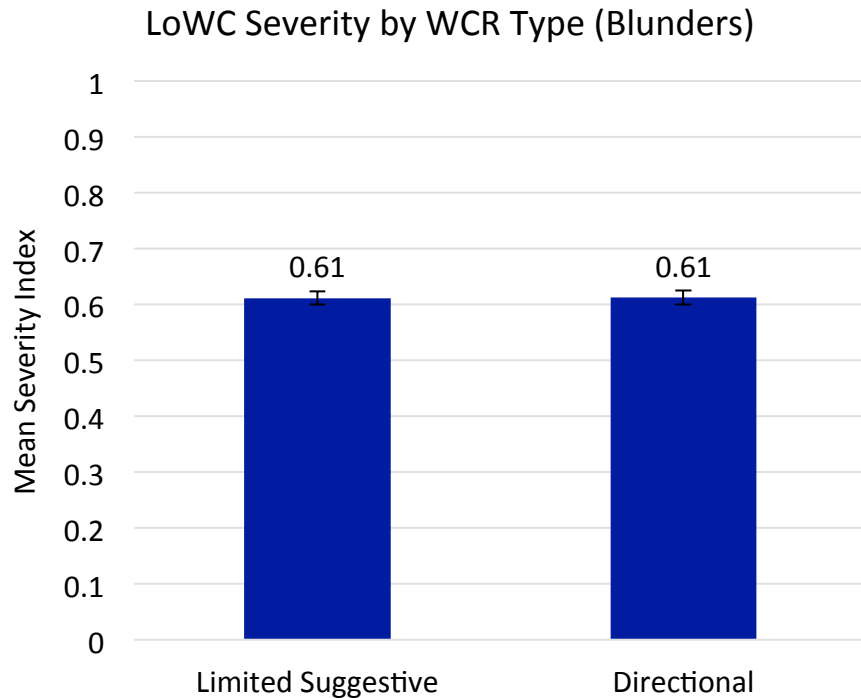


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Well Clear Recovery Overall Results



Effect of Well Clear Recovery Displays on Pilot Performance



*Small number of secondary conflicts with dedicated maneuvers accounts for high variability

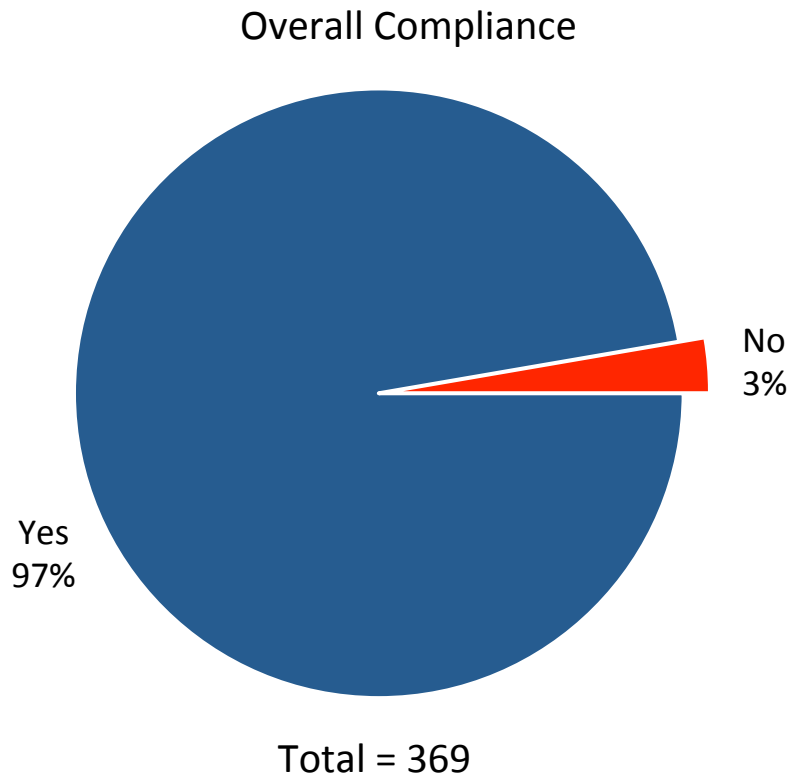


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Well Clear Recovery Overall Results



Well Clear Recovery Compliance



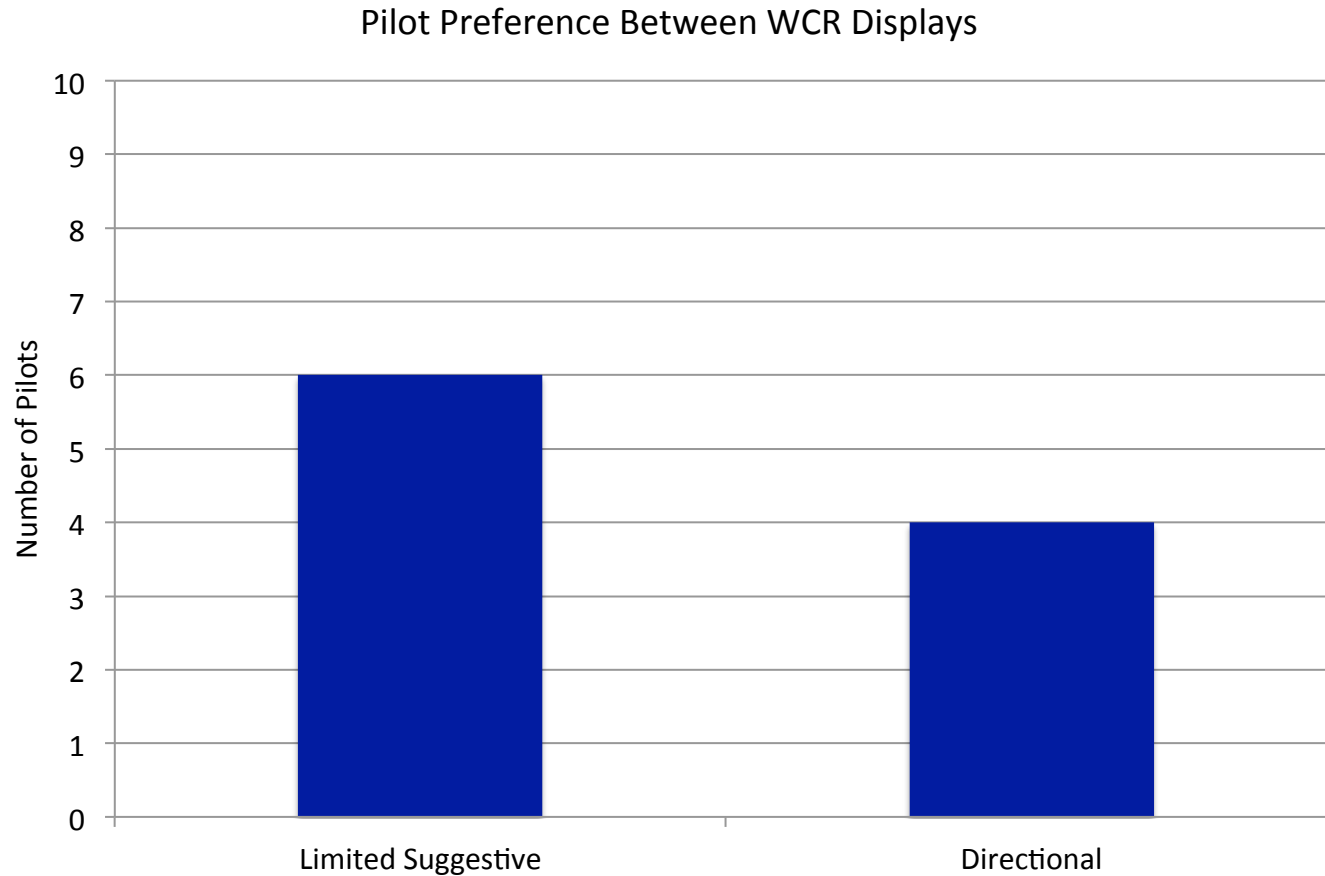
Reason for Non-Compliance	Number
WCR Recommended Turn but Pilot Preferred Vertical Maneuver	5 (50%)
No time for DAA maneuver prior to TCAS RA	2 (20%)
Pilot made DAA maneuver in different sense prior to WCR	2 (20%)
Pilot Preferred Turn in Opposite Direction	1 (10%)
TOTAL	10

*WCR Type had no effect on whether or not pilots complied – 5 non-compliance in each WCR type

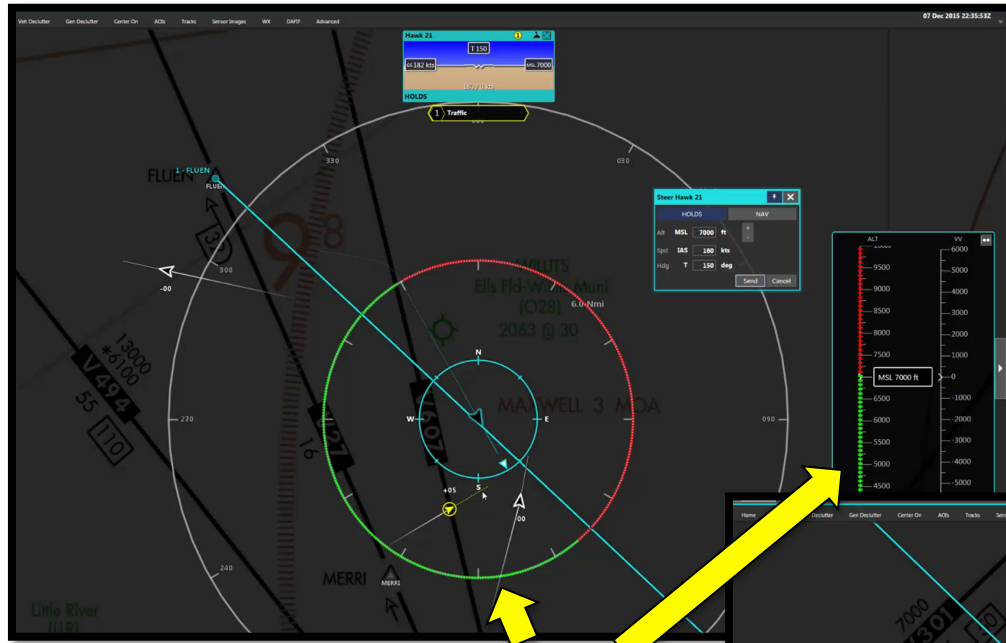


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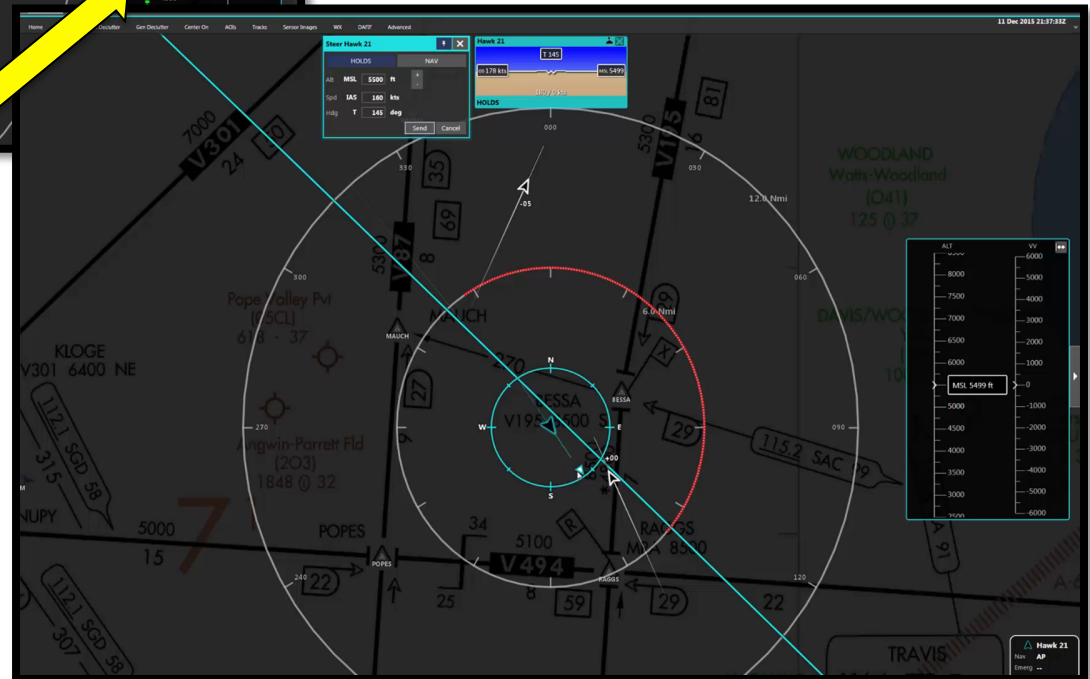
Well Clear Recovery Preference Ratings



DAA Guidance (green bands) Overall Results



Green Bands



No Green Bands

Key Research Questions

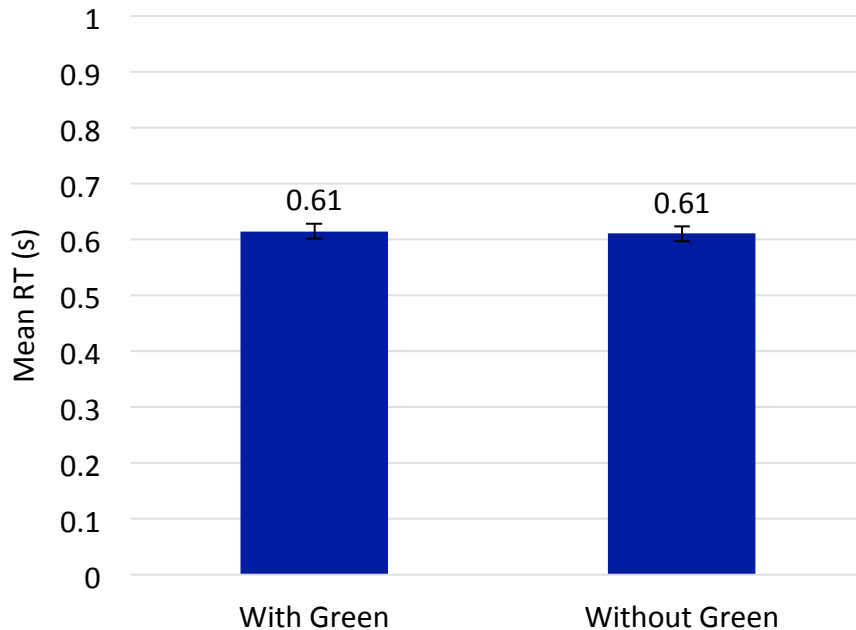


- DAA Guidance Research Questions:
 - Does the presence or absence of green DAA affect pilot response times?
 - Do their presence impact the rate of loss of well clear?

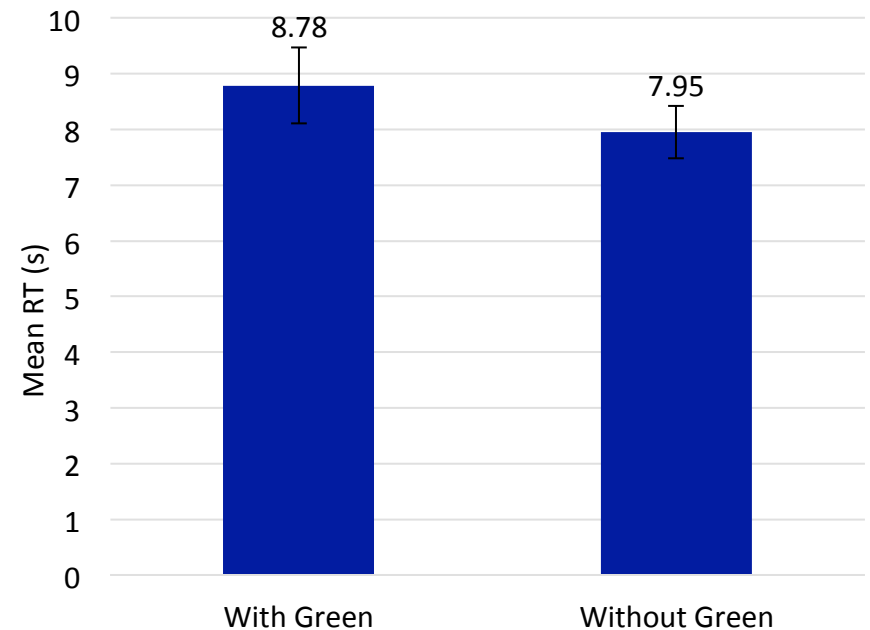


Effect of Green DAA Bands on Pilot Performance

Initial RT by DAA Bands Display



Total RT by DAA Bands Display



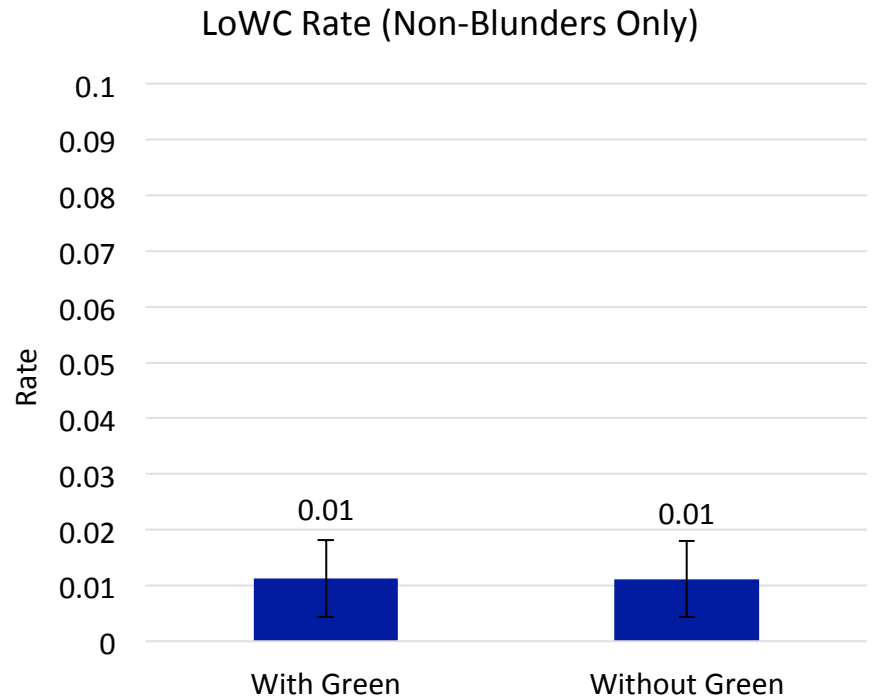
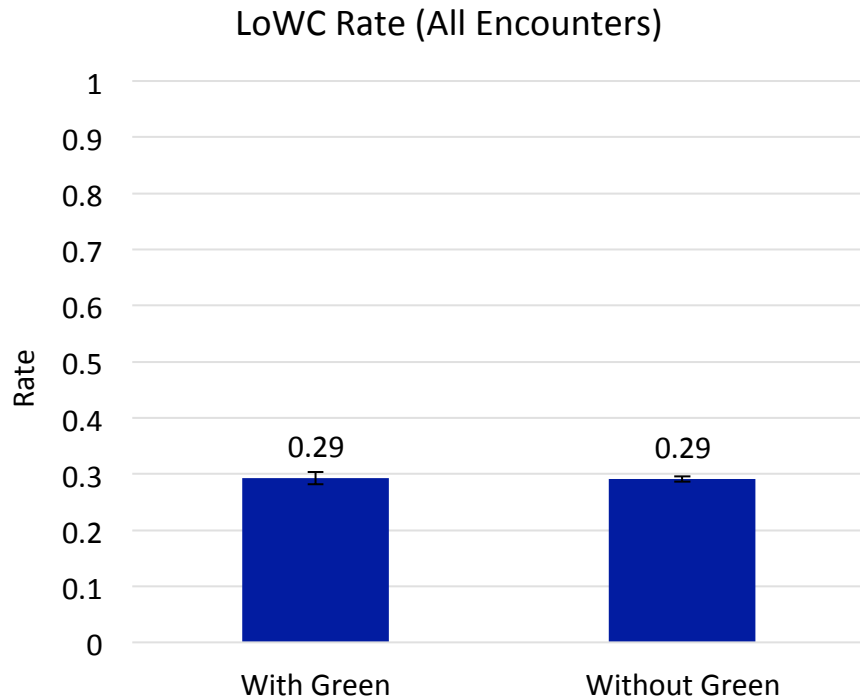
Key Research Questions



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 - Does the presence or absence of green DAA affect pilot response times?
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Effect of Green DAA Bands on Pilot Performance





- TCAS II Results Summary:
 - Under nominal conditions, 0.4% of encounters progress to true corrective RAs
 - 28.6% progress to corrective RAs despite being well clear and outside of the DAA alerting thresholds
 - 5% progress to preventive RAs
 - On average, pilots responded to TCAS RAs within **3.5s**, compared to **7.4s** for Warnings and **9.4s** for Corrective DAA alerts
 - Pilots responded to Corrective alerts in current study more quickly than they responded to Warnings in PT5
 - Pilots complied with corrective RAs 96% of the time
 - Non-compliance appears to be due to pilots maneuvering prior to the RA being issued or due being well clear despite RA
 - There were 0 NMACs across all encounters

Summary Results



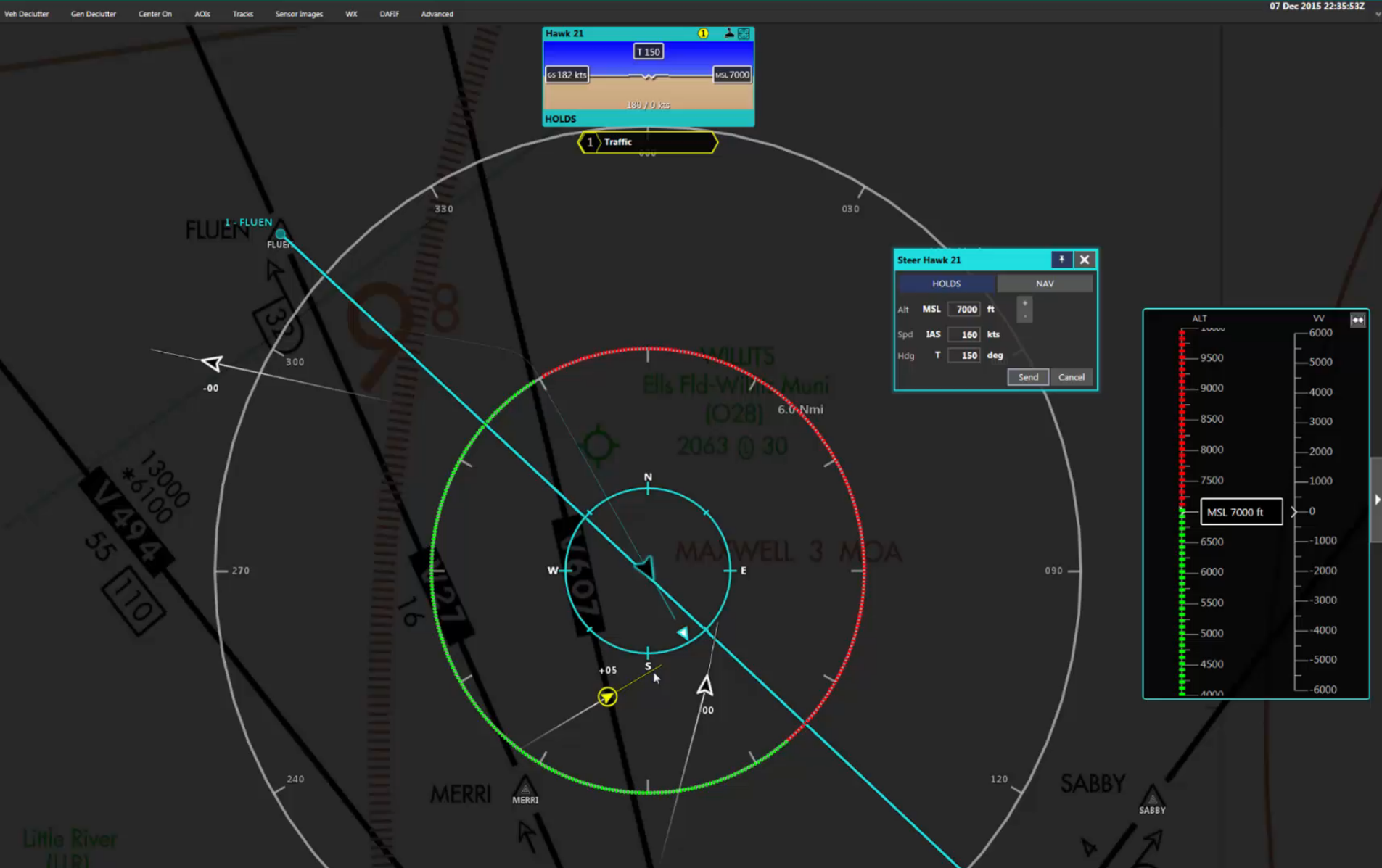
- Well Clear Recovery Results Summary:
 - Pilot performance was nearly identical between the two different well clear recovery displays
- DAA Guidance Results Summary:
 - Pilot performance was nearly identical between the two different DAA band displays
 - Total response time was slight longer for the With Green display, however the difference is not statistically significant
 - The rate of losses of well clear across all displays was 0.29 for all encounters
 - The rate of losses of well clear across all displays was 0.01 for non-blunder encounters
 - The mean separation index for losses of well clear across all displays was 0.61
 - When losses of well clear happened, they penetrated approximately 40% of the well clear spatial threshold

Key Research Questions



- Interoperability Research Questions:
 - When a TCAS RA response results in a DAA warning alert with a non-cooperative intruder (Use Case B):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
 - Will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - Do pilots respond to secondary maneuver in a timely manner?
 - When a TCAS RA response results in a DAA corrective alert with a non-cooperative intruder (Use Case D):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
 - Will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - Do pilots respond to secondary maneuver in a timely manner?
 - How do the LoWC rates for secondary threats compare between Use Cases B & D?
 - Are pilots confused by having two warning alerts?

Use Case B Interoperability Results



Use Case B Interoperability Results



Pilot Response to Primary Threats

Complied With RA	88%
Pilot made a horizontal maneuver (consistent with WCR) prior to RA and then complied with RA	62 (82%)
Pilot made simultaneous, 2-dimensional maneuver in response to primary threat (consistent with WCR and RA)	2 (3%)
Pilot made RA maneuver (consistent with RA) but no DAA maneuver	1 (1%)
Pilot made vertical maneuver prior to RA that wound up being consistent with RA	1 (1%)
Pilot made horizontal maneuver (inconsistent with WCR) prior to RA and then complied with RA	1 (1%)
Did Not Comply with RA*	11%
Pilot made a horizontal maneuver (consistent with WCR) prior to RA and then flew in opposite sense of RA (due to secondary traffic)	4 (5%)
Pilot made a horizontal maneuver (consistent with WCR) prior to RA and made no vertical maneuver in response to RA	3 (4%)
Pilot made a vertical maneuver prior to RA that was inconsistent with RA	2 (2%)

***This use case had highest rate of non-compliance due to pilot awareness of secondary traffic in direction of RA sense**

Use Case B Interoperability Results



Pilot Response to Secondary Threats

Complied with WCR	99%
Pilot did not make a dedicated secondary maneuver but <i>was already turning in appropriate direction</i>	40 (53%)
Pilot made a dedicated secondary maneuver and <i>complied with WCR</i>	16 (21%)
N/A – secondary threat never alerted due to maneuver against primary threat	19 (25%)
Did Not Comply with WCR*	1%
Pilot made dedicated secondary maneuver but <i>did not comply with WCR</i>	1 (1%)

Key Research Questions

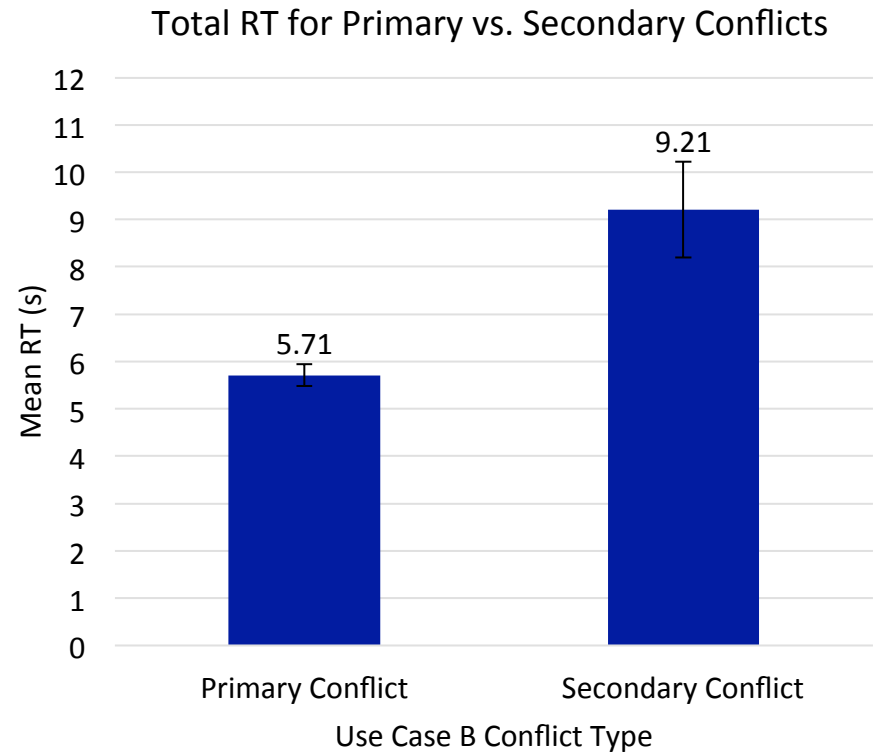
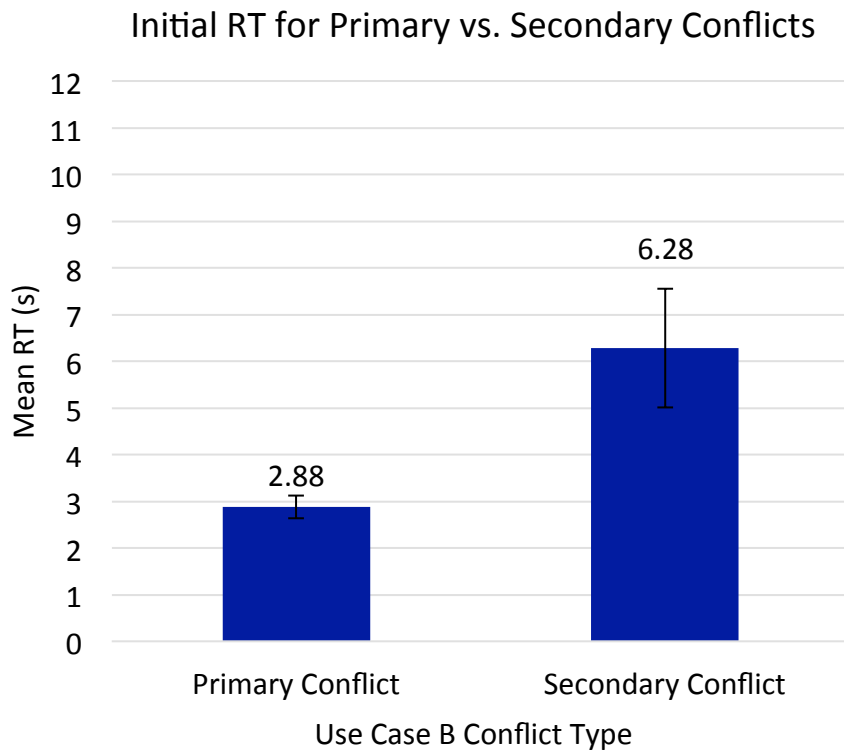


- Interoperability Research Questions:
 - When a TCAS RA response results in a DAA warning alert with a non-cooperative intruder (Use Case B):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
 - Will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - Do pilots respond to secondary maneuver in a timely manner?
 - When a TCAS RA response results in a DAA corrective alert with a non-cooperative intruder (Use Case D):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
 - Will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - Do pilots respond to secondary maneuver in a timely manner?
 - How do the LoWC rates for secondary threats compare between Use Cases B & D?
 - Are pilots confused by having two warning alerts?

Use Case B Interoperability Results



Pilots Response Time for Responding to TCAS RA Scripted to Trigger a DAA Warning alert with Secondary Aircraft



*Much smaller number of secondary conflicts with dedicated maneuvers accounts for high variability

Key Research Questions



- Interoperability Research Questions:
 - When a TCAS RA response results in a DAA warning alert with a non-cooperative intruder (Use Case B):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
 - Will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - Do pilots respond to secondary maneuver in a timely manner?
 - When a TCAS RA response results in a DAA corrective alert with a non-cooperative intruder (Use Case D):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
 - Will pilots make the appropriate secondary horizontal maneuver provided by the well clear recovery guidance?
 - Do pilots respond to secondary maneuver in a timely manner?
 - How do the LoWC rates for secondary threats compare between Use Cases B & D?
 - Are pilots confused by having two warning alerts?

Use Case D Interoperability Results



Use Case D Interoperability Results



Pilot Responses to *Primary Threat*

Complied With RA	100%
Pilot made a horizontal maneuver (consistent with WCR) prior to RA and then complied with RA	75 (94%)
Pilot made vertical maneuver <i>prior to RA that wound up being consistent</i>	4 (5%)
Pilot made RA maneuver (consistent with RA) <i>but no DAA maneuver</i>	1 (1%)

Pilot Responses to *Secondary Threat*

Complied With WCR	99%
Secondary threat <i>never alerted</i> (due to horizontal maneuver for primary threat)	48 (60%)
Secondary threat <i>progressed no further than Corrective alert</i> , 'solved' due to maneuver against primary threat	26 (33%)
Secondary threat <i>progressed to WCR</i> , pilot made dedicated secondary maneuver consistent with WCR	4 (5%)
Secondary threat progressed no further than Corrective alert, pilot <i>made dedicated secondary maneuver</i>	1 (1%)
Did Not Comply with WCR	1%
Secondary threat progressed to WCR but pilot <i>did not make dedicated maneuver</i>	1 (1%)

Key Research Questions

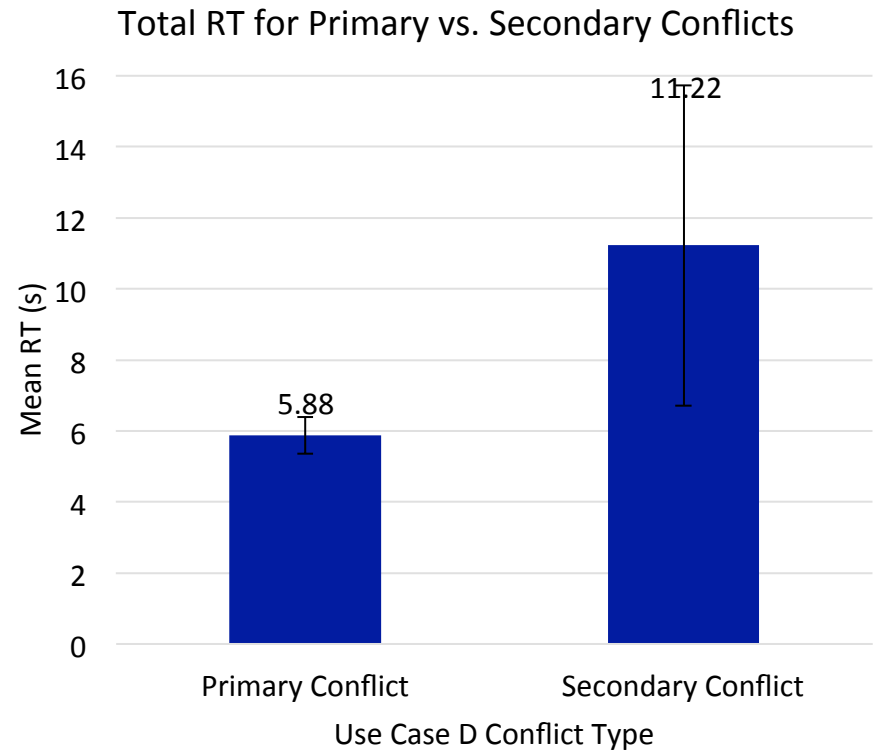
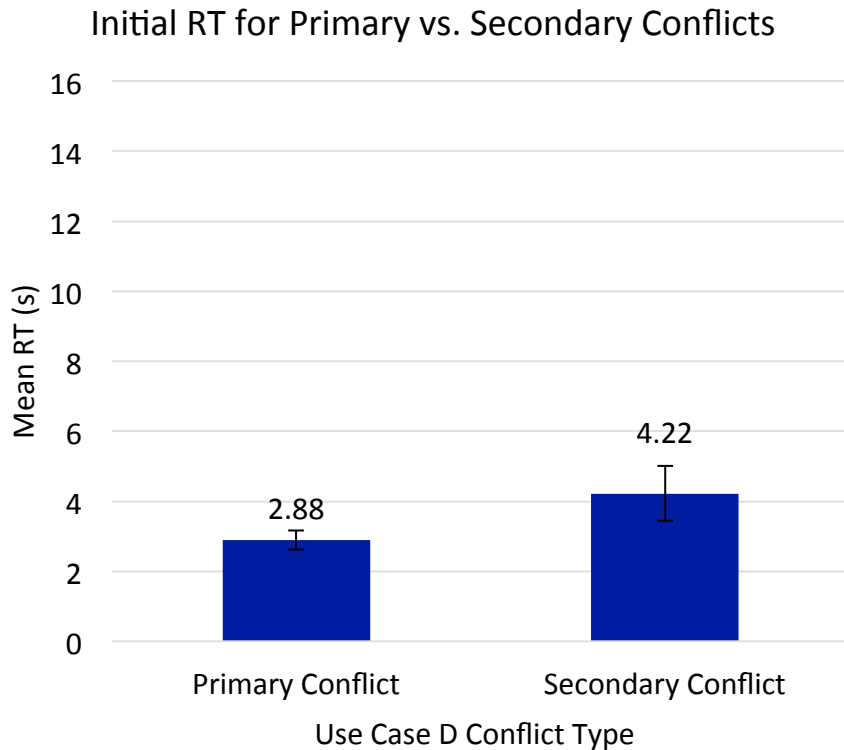


- Interoperability Research Questions:
 - When a TCAS RA response results in a DAA warning alert with a non-cooperative intruder (Use Case B):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
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Use Case D Interoperability Results



Pilots Response Time for Responding to TCAS RA Scripted to Trigger a Corrective DAA alert with Secondary Aircraft



*Small number of secondary conflicts with dedicated maneuvers accounts for high variability

Key Research Questions

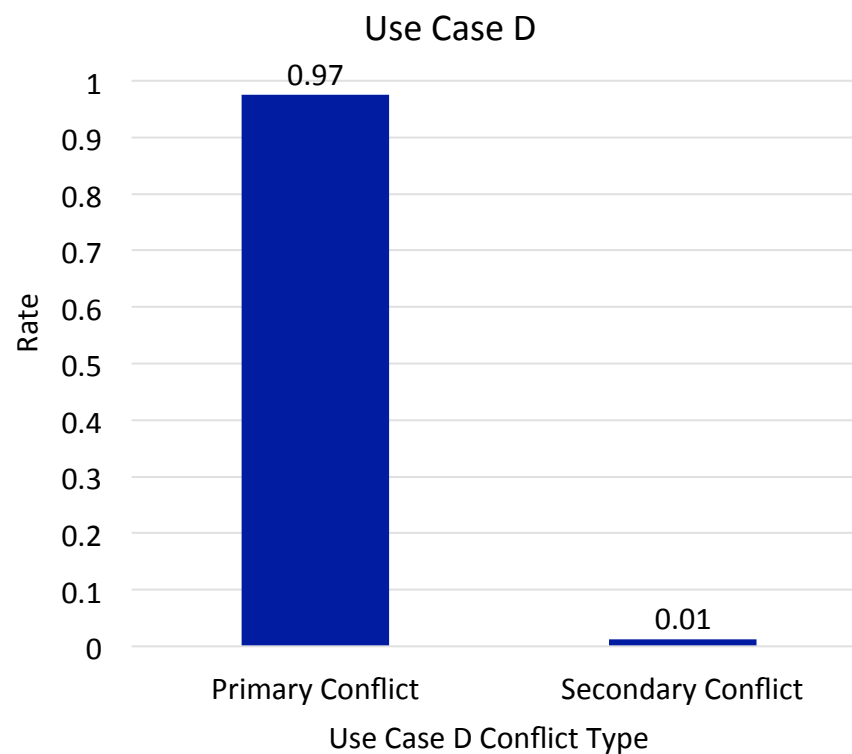
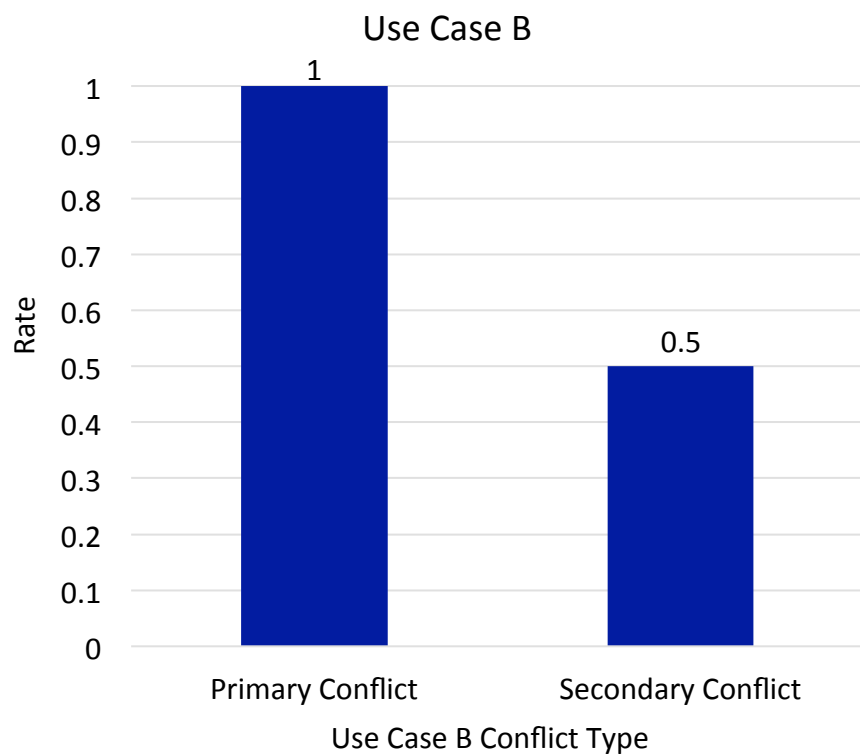


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 - How do the LoWC rates for secondary threats compare between Use Cases B & D?
 - Are pilots confused by having two warning alerts?

Use Case D Interoperability Results



LoWC Rate for Use Case B vs. Use Case D



*1 LoWC with a secondary conflict. Was caused by returning to route too soon

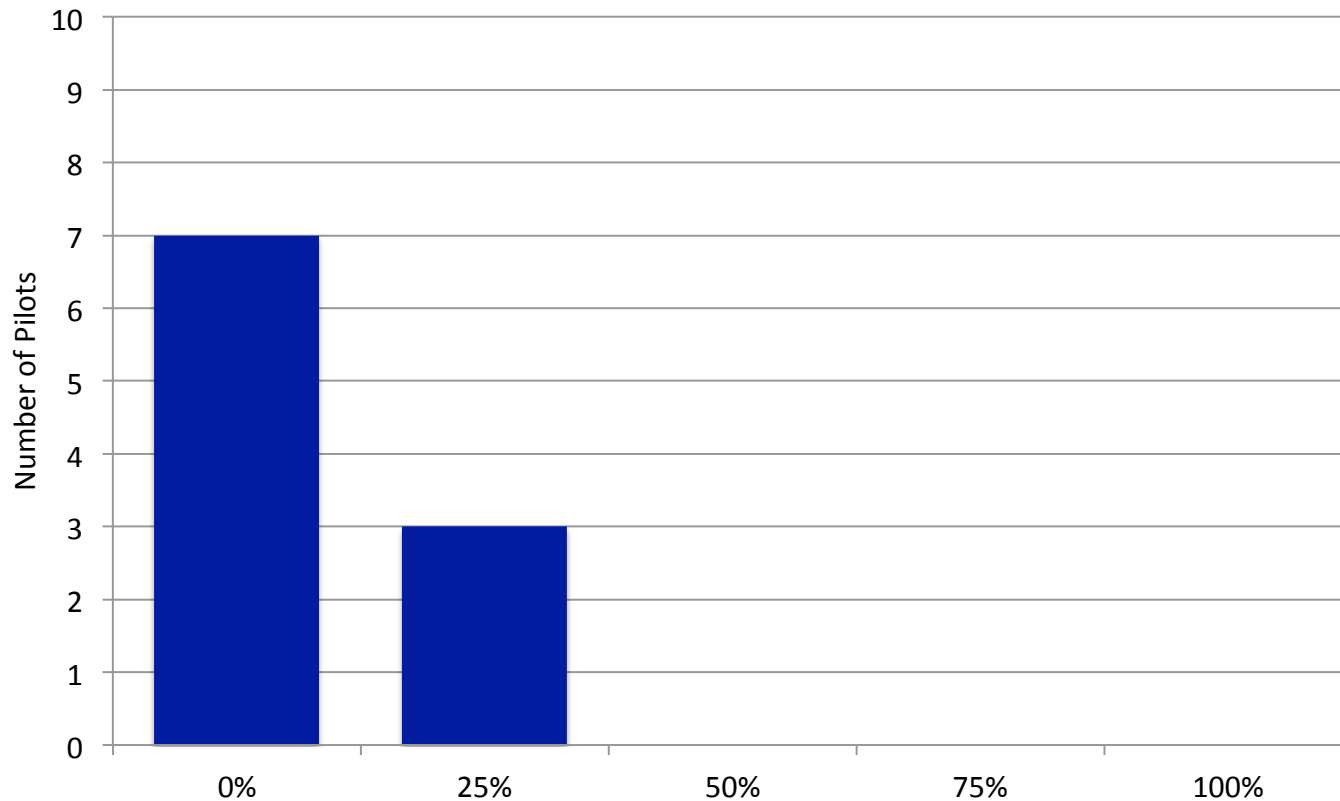
Key Research Questions



- **Interoperability Research Questions:**
 - When a TCAS RA response results in a DAA warning alert with a non-cooperative intruder (Use Case B):
 - Will pilots comply with RA despite presence of non-cooperative traffic in direction of RA sense?
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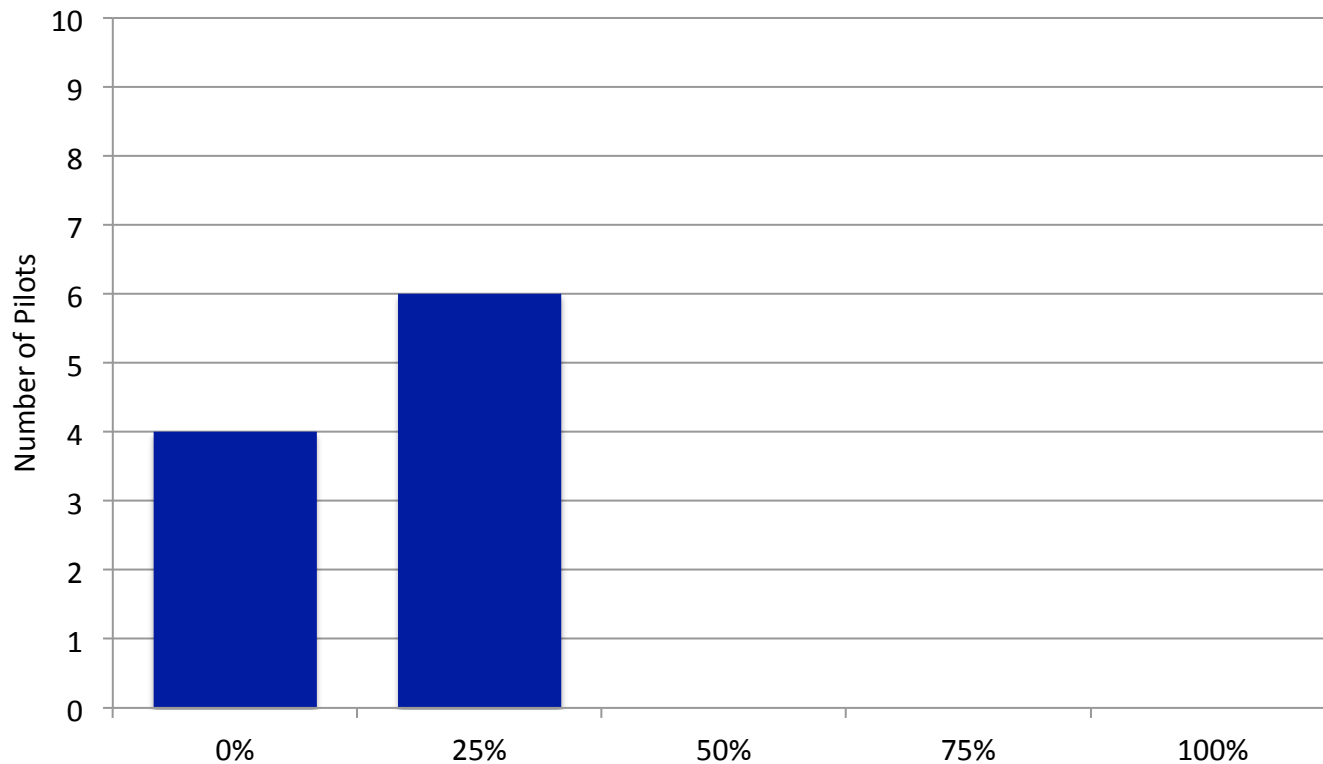
Pilot Confusion of TCAS RAs and DAA Warning Alerts

Pilots ratings of how often they misidentified a TCAS RA alert
as a DAA Warning alert

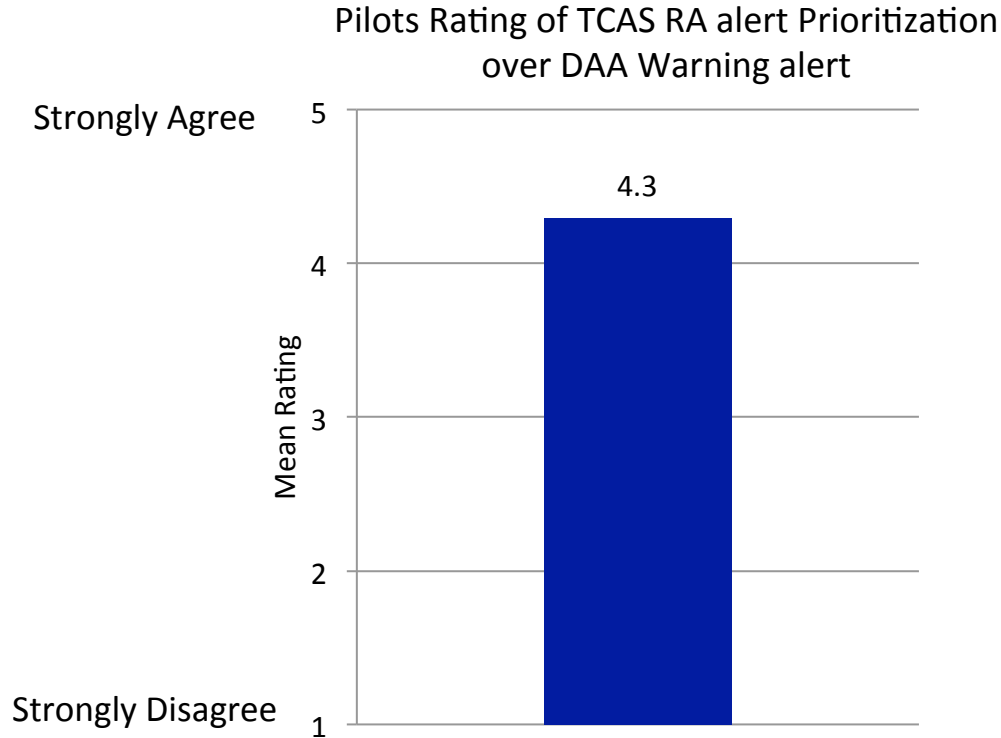


Pilot Confusion of TCAS RAs and DAA Warning Alerts

Pilots ratings of how often they misidentified a DAA Warning alert
as a TCAS RA alert



Pilot Confusion of TCAS RAs and DAA Warning Alerts



"I always prioritized responding to TCAS RA over a Warning when they occurred at the same time"



OLD/UNFINISHED

Mini HITL Week 2 Stats



- Ability to Avoid TCAS RA in Non-Blunder Scenarios
 - 1 instance of Corrective RA issued
 - Pilot made series of poor maneuvers, complied with TCAS when it was issued (P13,Tr2,20:19:00)
- Ability of Pilot to Make Secondary Maneuver Against Secondary Traffic in Use Cases B & D
 - 154 instances where pilot made a DAA maneuver against the primary conflict in a multi-threat encounter (Use Cases B/D) **BEFORE** a Corrective RA was issued
 - 153 instances of pilot maneuvering laterally before onset of RA
 - 1 case had already maneuvered vertically before onset of RA
 - 3 instances of pilot having no time for DAA maneuver prior to RA
 - 3 instances of missing data (TSD froze/no recording/negative response times)
 - 91 cases (Use Case=B/D, Encounters=1-4, Traffic=NonCoop, Any Alert=Yes)
 - 26 times pilots made dedicated maneuver against this guy
 - 65 times pilots did not make a dedicated maneuver, overwhelmingly because they had made multi-dimensional maneuver for initial conflict

Results by Use Case



- Use Case A – non-cooperative encounter causes well clear recovery guidance
 - 160 single-intruder encounters
 - 80 Blunder cases ('forced' WCR)
 - 65 LoWC
 - » Avg. initial RT = 3.15
 - » 59 cases with A1/2/4NCP – higher closure rates
 - » 62 cases pilot complied with WCR
 - 15 no LoWC
 - » Avg. initial RT = 3.20
 - » 14 of the cases were with A3NCP – the intruder with the slowest closure rate and stayed longest as warning before transitioning to WCR
 - » 3 cases pilots complied with WCR, 1 went against WCR, and 11 no WCR issued (all with A3NCP)
 - Non-blunder cases
 - 0 LoWC
 - » 23 cases of DAA Warning being issued
 - » Avg. initial RT = 6.25

- Use Case B – RA with primary threat leads to DAA Warning with secondary threat
 - 160 multi-threat encounters
 - Blunder cases
 - 80 primary threats ('forced' RA every time)
 - » 77 LoWC (3 instances of missing data)
 - » 74 instances of pilot making horizontal maneuver (typically following WCR) prior to TCAS RA issuance
 - 80 secondary threats
 - » 38 LoWC
 - » Only 19 instances of pilot making dedicated secondary maneuver
 - Non-blunder cases
 - 80 primary threats
 - » 0 LoWC
 - » 2 progressed to a DAA Warning (but no further)
 - » 11 RAs issued (all 'well clear')
 - 80 secondary threats
 - » 2 LoWC
 - 1 case primary threat had last second 'well clear' RA, which caused LoWC when followed
 - 1 case pilot made descent (which DAA guidance said was OK) and cleared threats until he leveled off, which re-engaged them
 - » 4 progressed to DAA Warning (no further, not equipped with TCAS anyway)

Results by Use Case



- Use Case C – testing RA only
 - 160 total single threat encounters
 - Blunder cases
 - 65 LoWC
 - » Avg. initial RT = 3.38
 - 15 non LoWC
 - » All with N2517Q (gave pilots slightly more time to maneuver before RA)
 - » Avg. initial RT = 2.87
 - Non-blunder cases
 - 1 LoWC
 - » Returned to course too soon
 - Avg. initial RT = 4.90
 - 0 TCAS corrective RAs issues

Results by Use Case



- Use Case D – testing RA that leads to Corrective DAA
 - 320 total, ½ blunder, ½ non-blunder

Results by Use Case



- Use Case E – remains well clear
 - 160 total, ½ blunder, ½ non-blunder



- TCAS RA Stats
 - “Climb” = 161 instances (86 were “well clear”)
 - 156 pilot compliance (96.9%)
 - 5 cases where pilot had already uploaded a maneuver in correct sense prior to RA
 - 83 cases of pilot receiving DAA guidance that they were ‘well clear’ but still responded to RA
 - 5 no pilot compliance (3%)
 - 2 cases of pilot flying in opposite sense, both were due to pilot’s awareness of secondary threat
 - 3 cases of ‘well clear RA’ and pilot did not respond to RA
 - “Descend” = 203 instances (43 were “well clear”)
 - 192 pilot compliance
 - 2 cases where pilot had already uploaded a maneuver in correct sense prior to RA
 - 40 cases of pilot receiving DAA guidance that they were ‘well clear’ but still responded to RA
 - 11 no pilot compliance
 - 4 pilot flew in opposite sense
 - 4 cases of pilot failing to respond to RA because they had started turn prior to its issuance and did not find it necessary
 - 3 cases of ‘well clear RA’ and pilot did not respond to RA
 - “Monitor” = 49 instances (all were “well clear”)
 - Never maneuvered against

Mini HITL Week 2 Stats



- Well Clear Recovery Compliance

Mini HITL Week 2 Stats



- Well Clear RAs



BACK UP

Potential Video Examples



- Good example of how pilots were able to avoid multi-threat encounters by following WCR just before onset of an RA:
 - P15, Tr3, 21:57:40
- Good example of pilots following RA then responding to WCR for secondary
 - P17, Tr4, 22:39:40

Weird Cases/Fixes



- 6 cases I had to manually change which alert was first because the distance between any two successive alerts was always less than 3
 - 11,2,DKW8932
 - **12,2,UAL730(only had to change this one when not include WCR as First Alert)**
 - 13,1,N613B
 - 16,3,N12845
 - 17,1,N613B
 - 19,4,N613B
- TSD froze, discarded all times for both intruders in the encounter
 - 12,3,N12845 & B3NCP
- Incorrectly entered late well clear encounter
 - 12,2,UAL730 – removed the Tw and Tr and changed it to CORR first

Week 1

Alerting Structure for Cooperative with DAA Warning

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	TCAS RA	"Climb/Descend"
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Week 1

Alerting Structure for Cooperative without DAA Warning

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	TCAS RA	"Climb/Descend"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A



➤ At First Alert (*w/ 3sec requirement*)

- Corrective DAA = 382 encounters
 - 349 instances of pilots maneuvering against the intruder
 - 33 instances of pilots not maneuvering since the same maneuver that caused the alert got them out of it
 - E.g., pilot turned right against DAA Warning, and then quickly climbed as soon as it went to an RA, which triggered a secondary threat that was subsequently solved by the pilot's initial right turn
- DAA Warning = 64 encounters
 - 50 instances of pilots maneuvering against the intruder
 - 14 instances of pilots not maneuvering since they had made a previous maneuver that would solve it
 - 1 of these cases had the threat progress to TCAS RA before pilot made DAA upload
- DAA Warning w/ Well Clear Recovery (WCR) = 299 encounters
 - 273 instances of pilots maneuvering against the intruder
 - 26 instances of pilots not maneuvering since they had made a previous maneuver that would solve it
- TCAS RA = 111 encounters
 - "Climb" = 57 cases (all 'well clear')
 - "Descend" = 20 cases (4 were 'well clear')
 - 12 non-'well clear' caused by N613BT & 4 by N12845 (only these had geometries that allowed aircraft to register as an RA within 3 seconds)
 - "Monitor" = 34 cases (all 'well clear')
- Never Alerted = 265 encounters
 - Use Case B/C/D Non-Blunders = 150 instances
 - Use Cases B/C/D Blunders = 71 instances
 - Use Case E = 44 instances (were supposed to remain well clear entire way)