



National Aeronautics and Space Administration



UAS Integration into the NAS: HSI Display Evaluation Overview

**Presented To: RTCA SC-228 DAA Working Group
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Overview



- Goal: Provide data on the effect of various Detect and Avoid (DAA) display and guidance features with respect to pilot performance of the self-separation function in order to determine the minimum information requirements for DAA displays
 - What configuration of display elements meets a minimum acceptable level of performance? What level of pilot maneuver guidance is required?
 - Definitions:
 - Informative: Provides essential information of a hazard that the remote pilot may use to develop and execute an avoidance maneuver. **No maneuver guidance or decision aiding is provided to the pilot.**
 - Suggestive: **Provides a range of potential resolution maneuvers to avoid a hazard with manual execution.** An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers.
 - Directive: **Provides specific recommended resolution guidance to avoid a hazard with manual or automated execution.** An algorithm provides the pilot with specific maneuver guidance on when and how to perform the maneuver.



Overview



- Approach: Conduct a series of iterative human in the loop experiments with different display configuration to objectively measure pilot performance on maintaining well clear
 - Key metrics: pilot response time, losses of well clear, severity of losses of well clear
 - Three simulations have been conducted: PT4, iHITL, PT5
 - Displays are modified/improved/changed based on data/observations
 - Displays are carried through to new HITLs to create anchors or linkages to previous data for comparison
 - New displays are developed for test
 - Test/simulation environment/protocols also updated and improved between HITLs



PT4 – Experimental Design



- Goal: Evaluate candidate Detect and Avoid (DAA) displays and algorithms with respect to self-separation and collision avoidance.
 - What are the appropriate alerting thresholds for self separation?
 - What are the minimum information requirements for DAA displays?
 - Is there a performance difference between integrated and standalone displays?
 - What advanced display features improve pilot performance on maintaining well clear from other traffic?
- What advanced display features improve pilot performance on maintaining well clear from other traffic?
 - Experimental Design: Mixed Factorial Design
 - 2 (Display: Standalone, Integrated)
 - X 2 (Information: Basic, Advanced)
 - X 2 (Self-Separation Alerting Threshold)



PT4 – Overview



Part Task 4

Integrated Basic
(Minimum
Information)

Integrated
Advanced

Standalone Basic
(Minimum
Information)

Standalone
Advanced

Display Types:

Informative

Suggestive

Directive



PT4 – Information Level



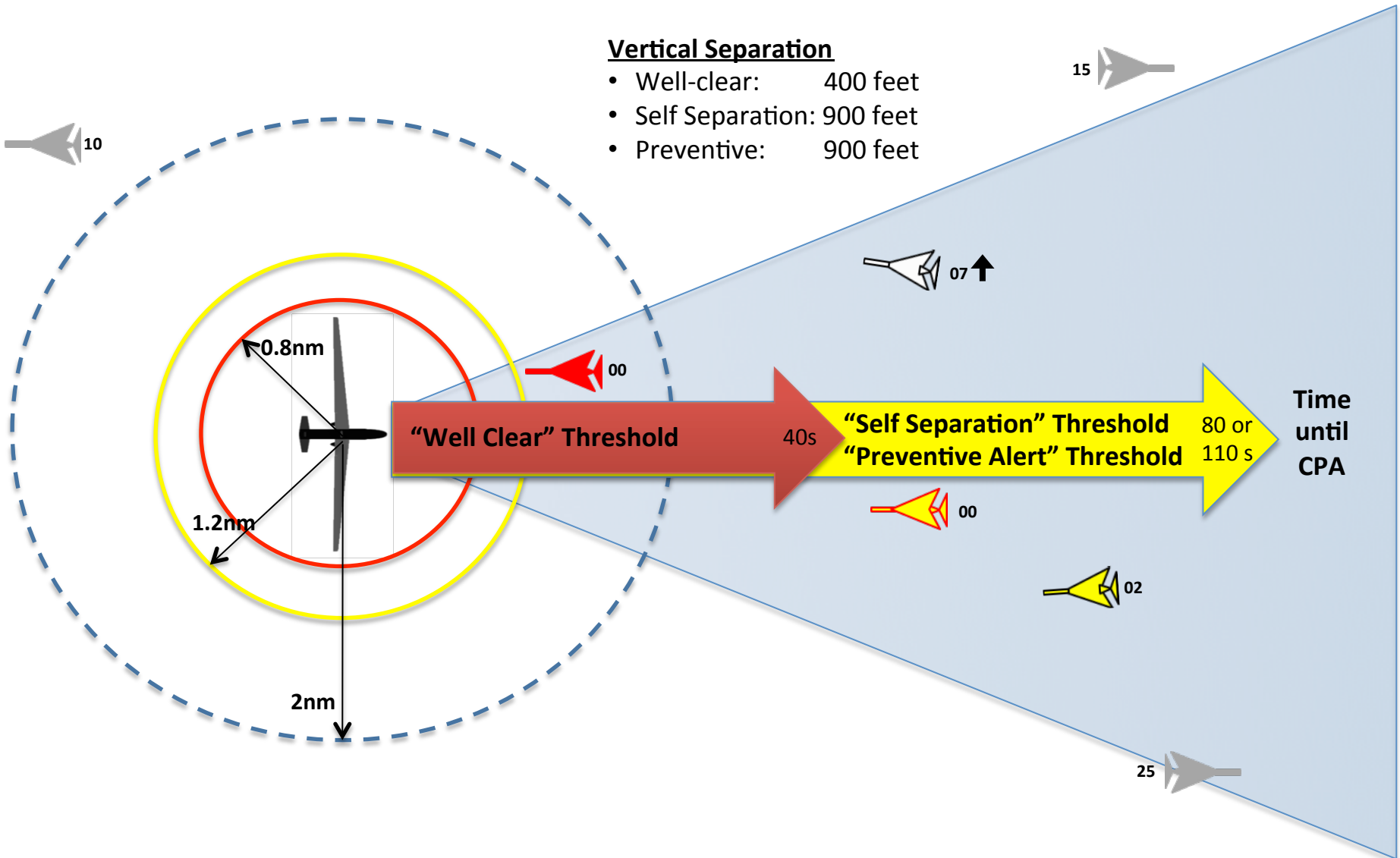
- Display Information Level: Basic versus Advanced
 1. Basic presents minimum information requirements only
 - Implementation identical as possible between Standalone and Integrated displays
 - Based on separate literature/requirements reviews by NASA and AFRL HMI teams
 - Vetted with FAA tech center (based on study they were running)
 - Similar to DO-317B (was a source document)
 - Alerting considered part of the min set
 2. Advanced information elements:
 - Implementation different between Standalone and Integrated displays
 - Additional alerting information (predictive CA)
 - Time to and location of predicted CPA (intruder and ownship)
 - Pilot guidance
 - Trial/vector planner (suggestive)
 - Maneuver recommendations (directive)
 - Vertical situation display (Integrated only)



Alerting Criteria

Vertical Separation

- Well-clear: 400 feet
- Self Separation: 900 feet
- Preventive: 900 feet

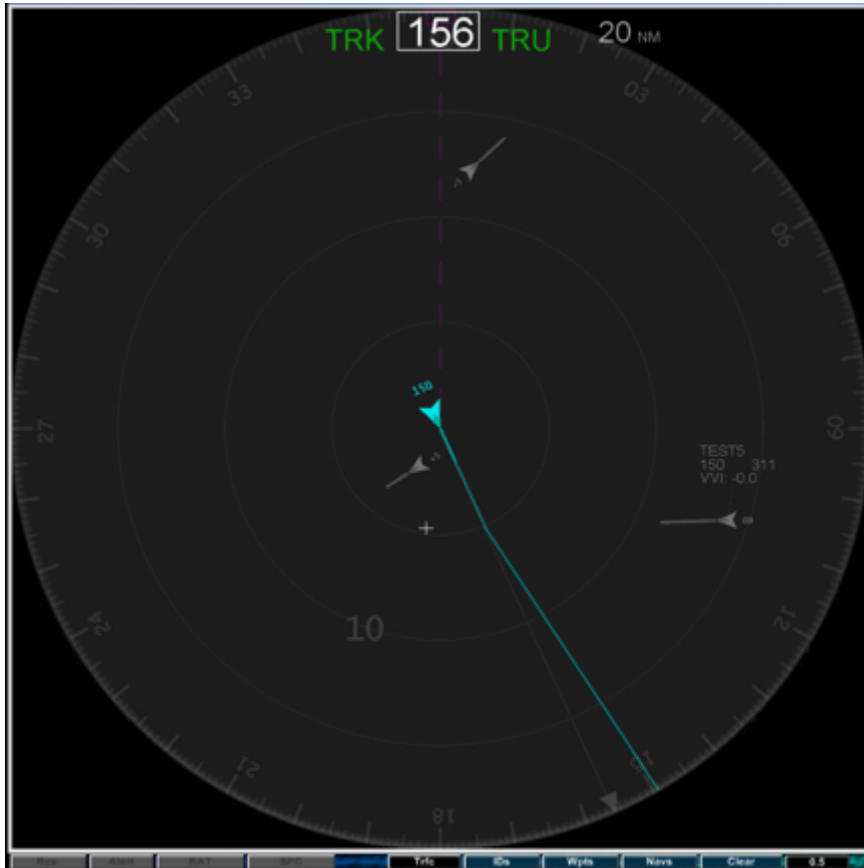




PT4 – Standalone Displays



Basic



Advanced





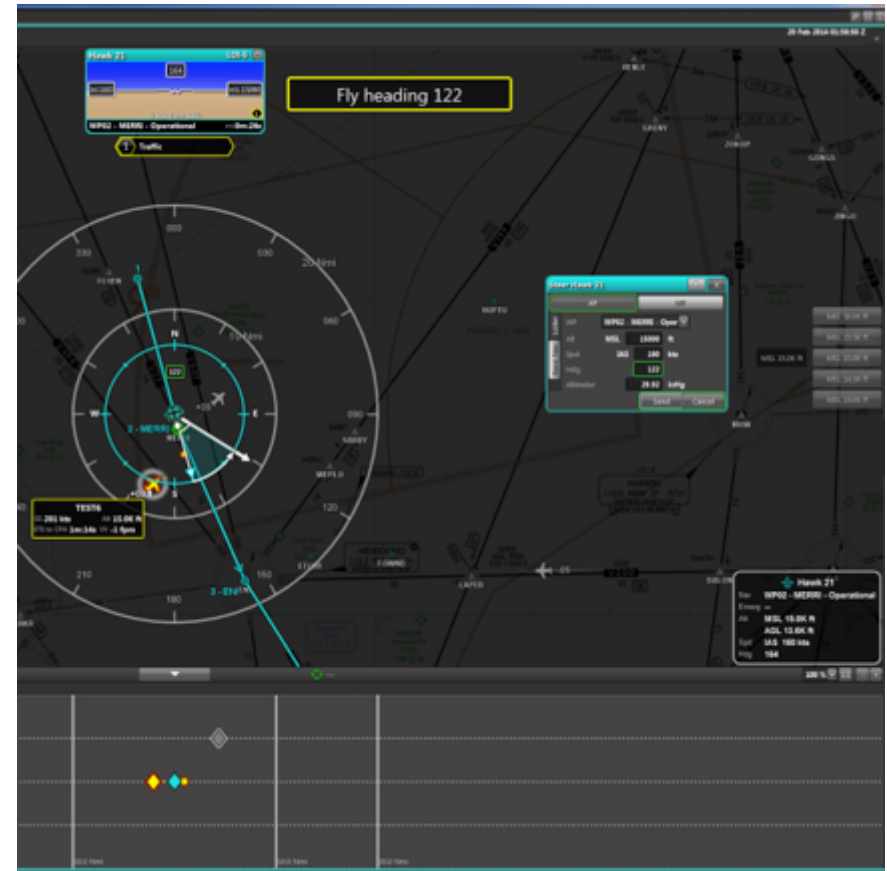
PT4 – Integrated Displays



Basic

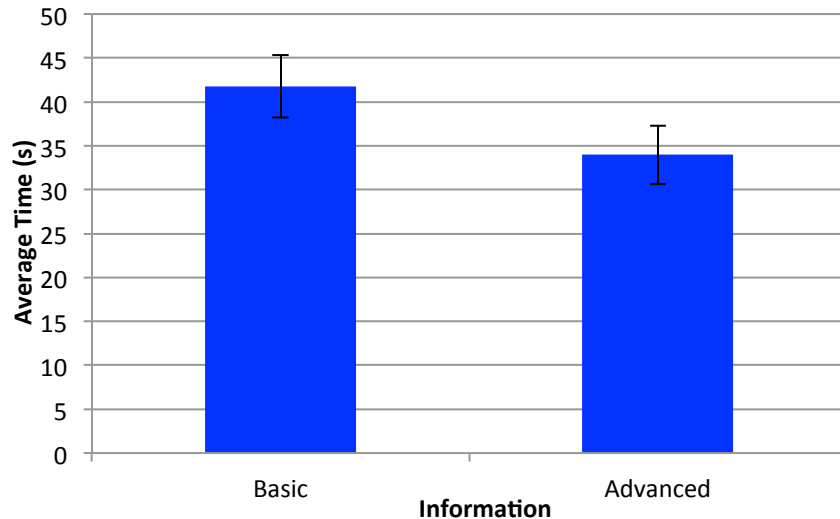


Advanced

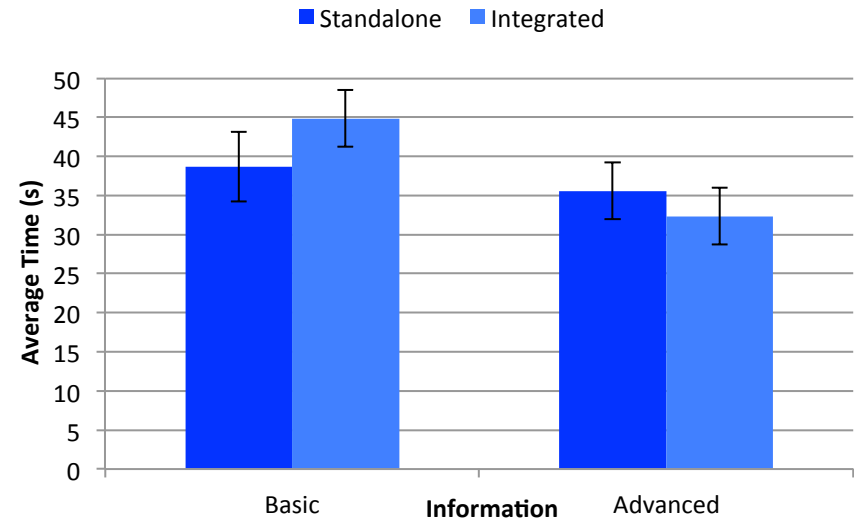




PT4 – Total Response Time Results



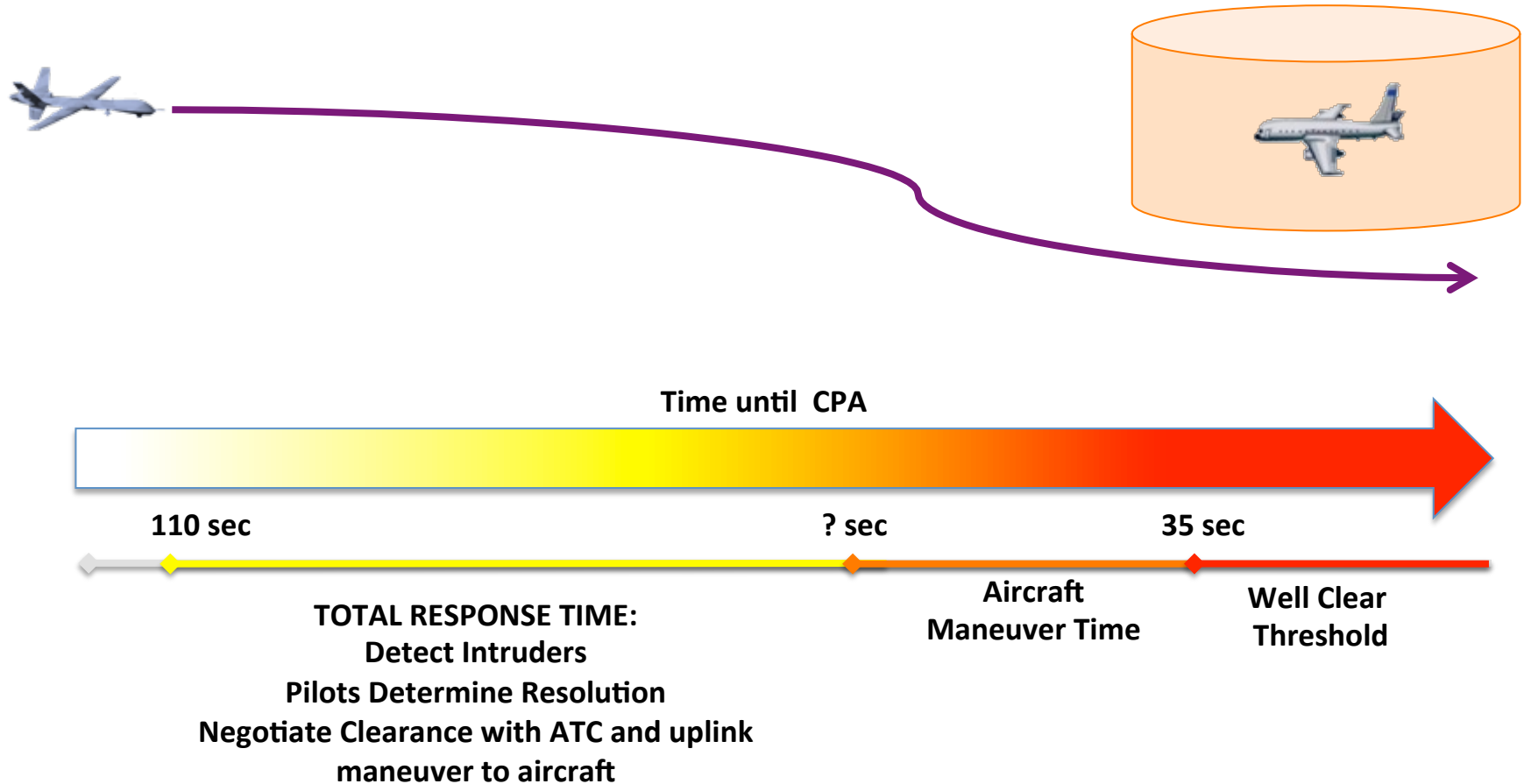
- There was a significant main effect of Information on Total Response Time, $p < .05$
 - Advanced was significantly faster (by 13.79 seconds on average) compared to Basic
- Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
 - Basic = 47.77 sec
 - Advanced = 33.98 sec



- There was not a significant interaction of Information by Display for Total Response Time, $p > .05$
- Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
 - Basic Standalone = 38.68 sec
 - Basic Integrated = 44.86 sec
 - Advanced Standalone = 35.60 sec
 - Advanced Integrated = 32.35 sec

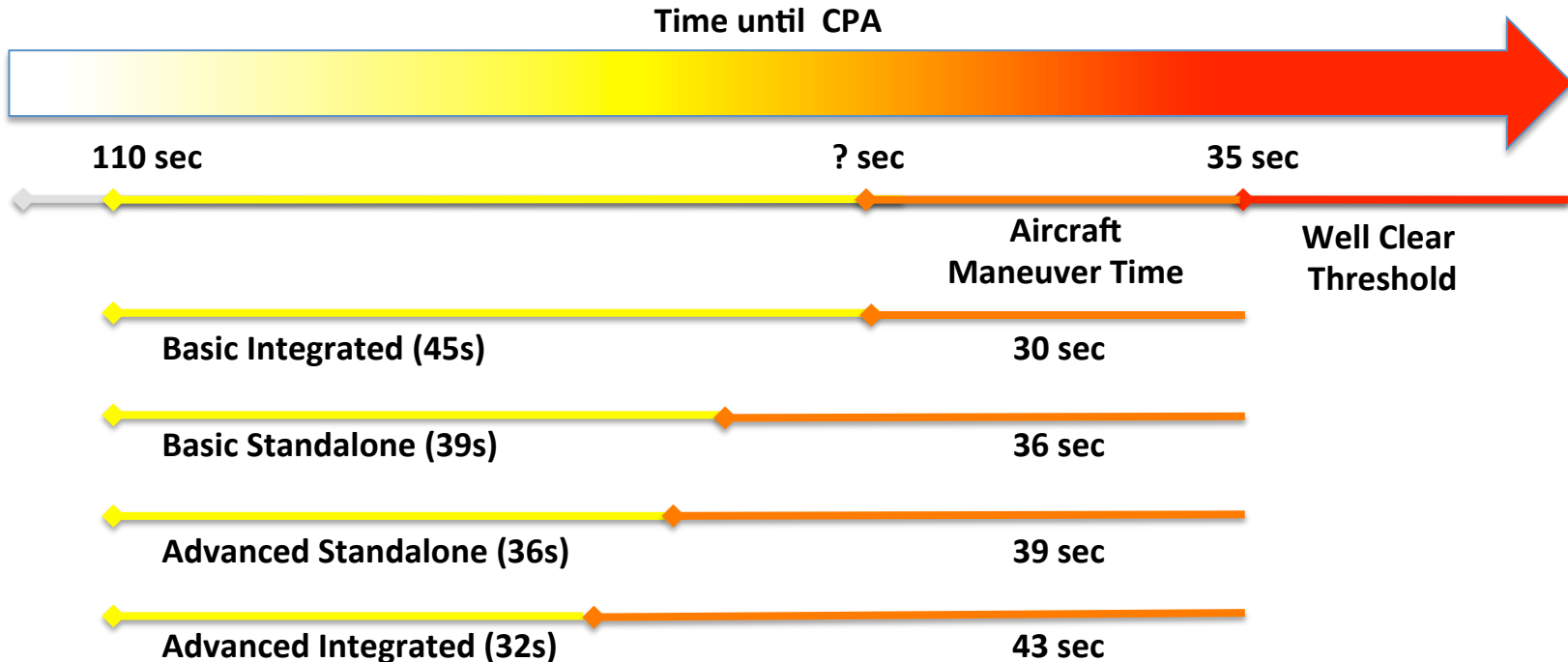


Self-Separation Timeline





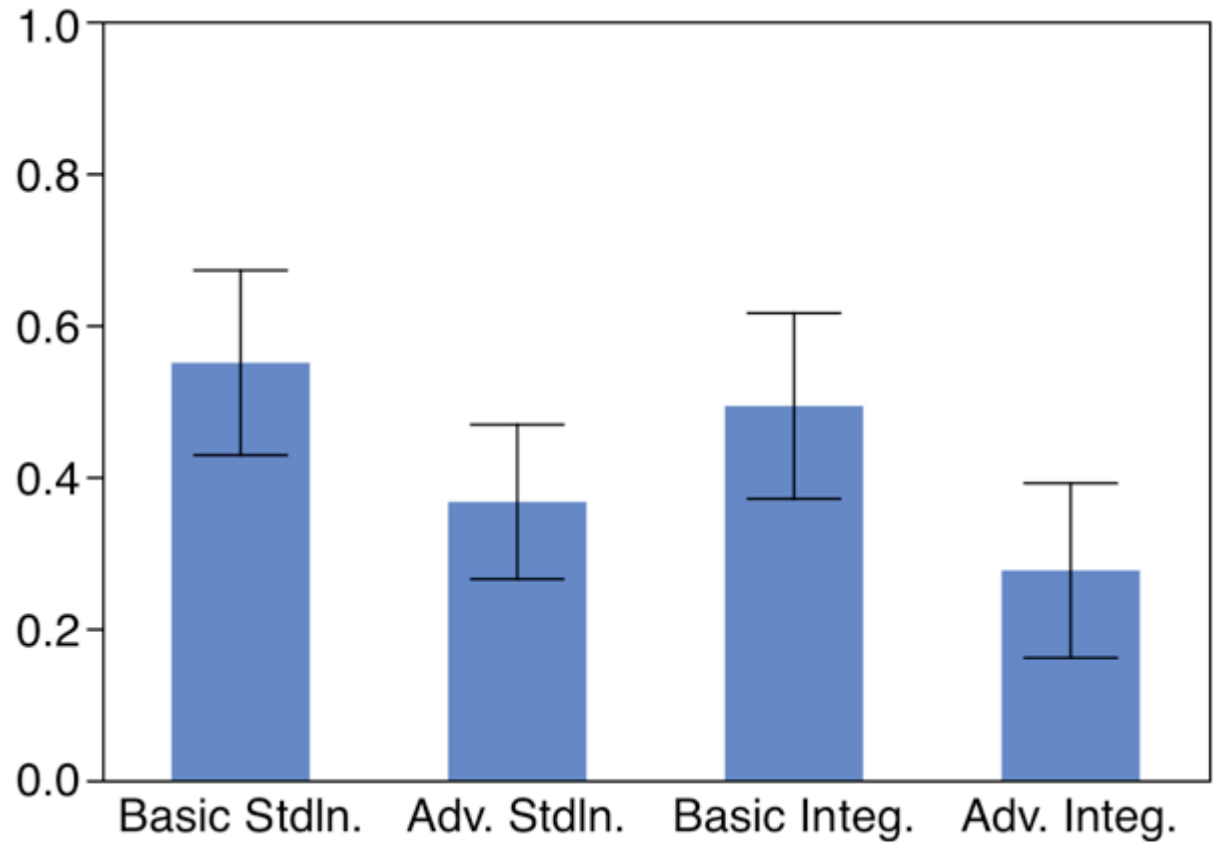
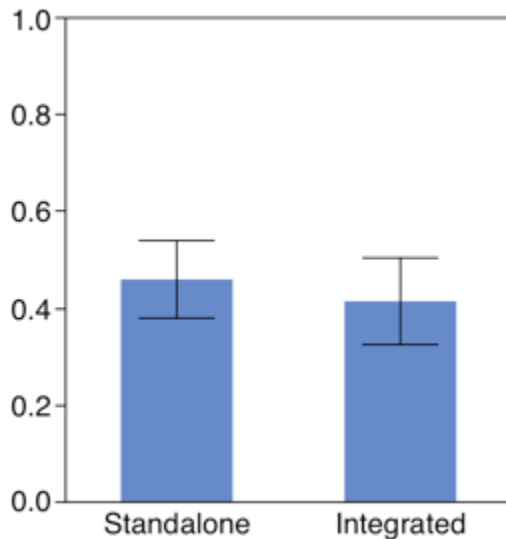
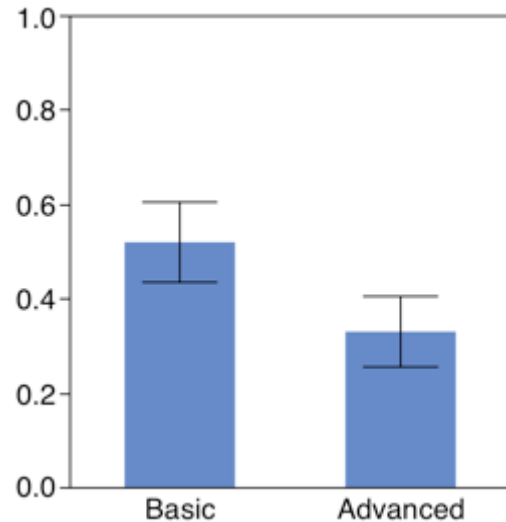
PT4 – Response Time Results





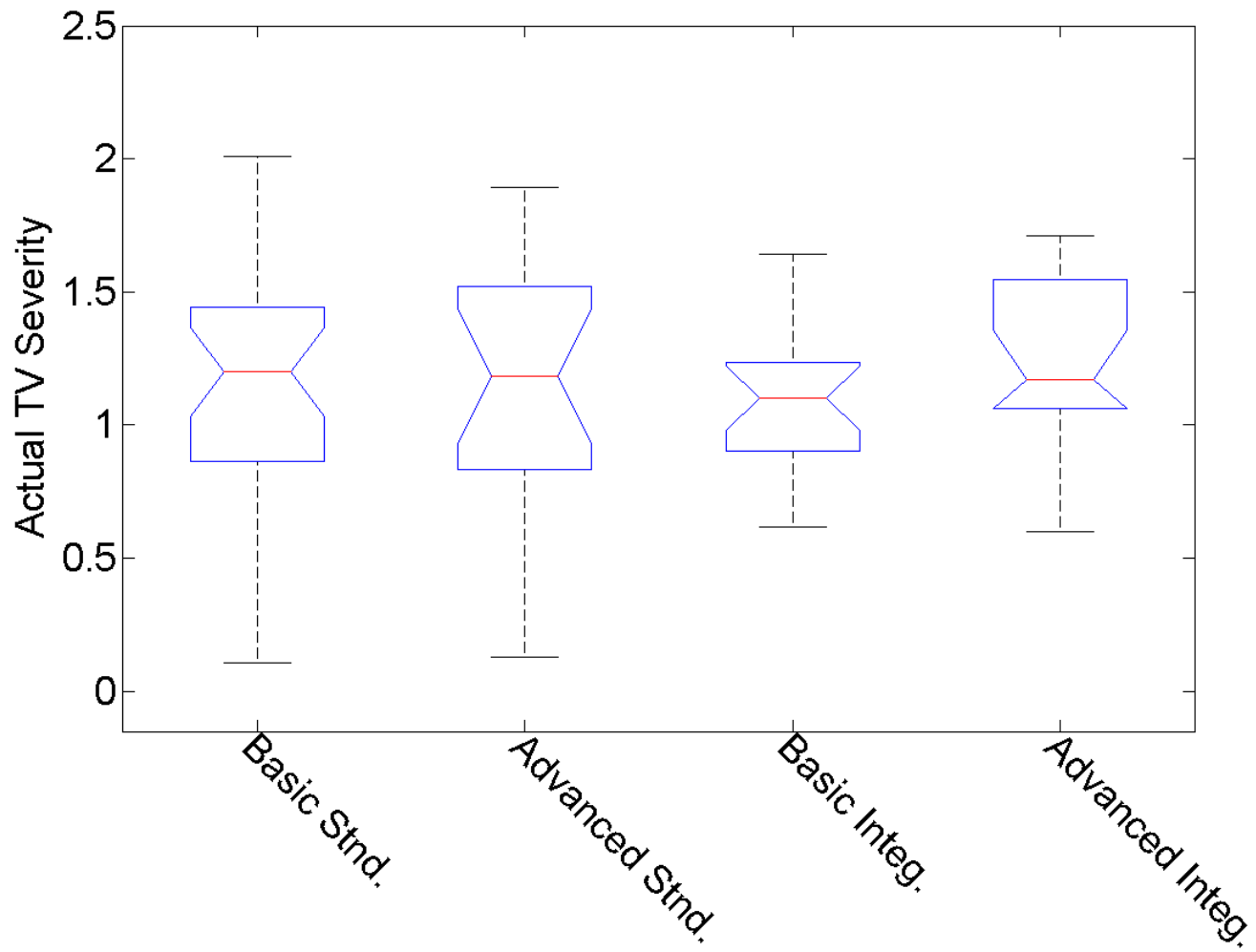
PT4 - WCVs

Proportion of Losses of Well Clear





PT4 – WCV Severity





PT4 – Results Summary



- Consistent advantage seen for Advanced over Basic displays in pilot response times
 - Overall, the Advanced displays had a faster Total Response Time (from initial alert appearance to the final maneuver upload) compared to Basic (14s faster, on average)
- There were no significant differences between the Standalone and Integrated condition
- No significant differences in number of, or severity of, losses of well clear, however:
 - Advanced had lower rates of LoWC than basic
 - No difference between Standalone and Integrated in rates of LoWC
 - Severity of well clear about the same across all displays



iHITL – Experimental Design

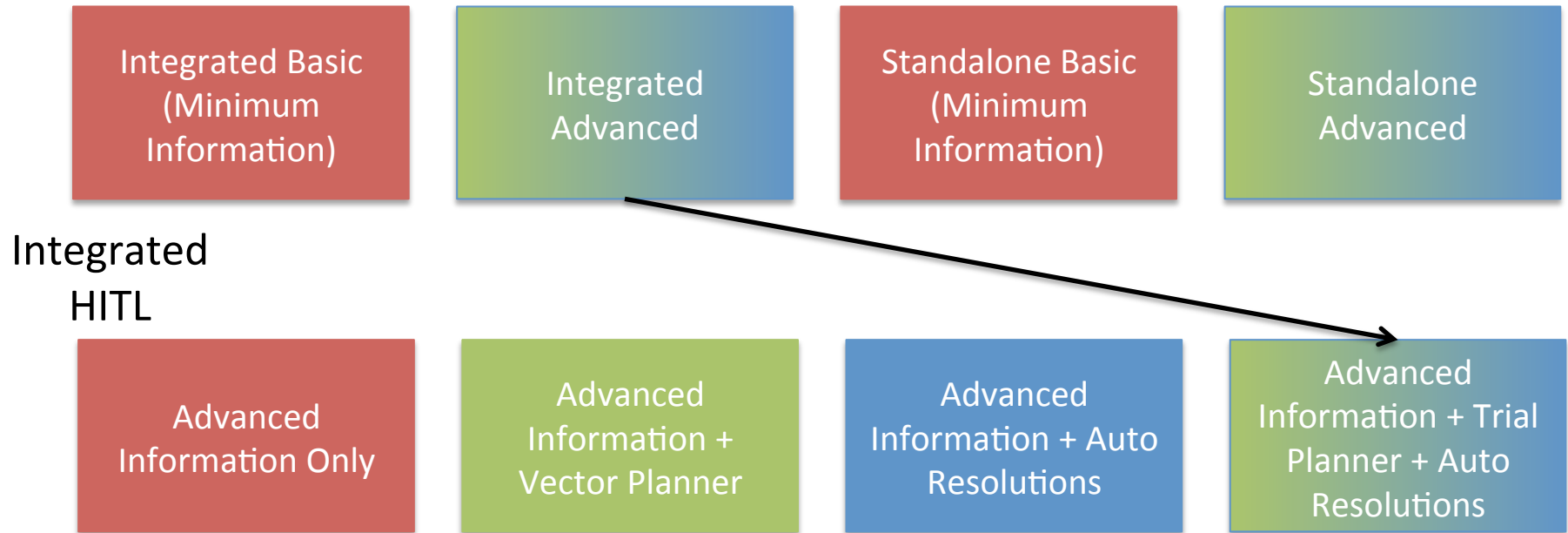


- Goals:
 - 1) Determine the individual contributions of the various PT4 advanced display features to pilots' response times and ability to maintain well clear
 - 2) Introduce non-cooperative intruders to examine effect of different sensor ranges on pilots ability to maintain well clear
- One-Way Repeated Measures Factorial: Display Information Level (4 Level; Within Subjects)
 - D1: Advanced Display with Information Only (**Informative**)
 - D2: Advanced Display with Information + Vector Planner (**Suggestive**)
 - D3: Advanced Display with Information + Auto Resolutions (**Directive**)
 - D4: Advanced Display with Information + Vector Planner + Auto Resolutions (**Suggestive + Directive**)
 - Roughly same as 'Advanced' suite in PT4



iHITL – Overview

Part Task 4



Display Types:

Informative

Suggestive

Directive

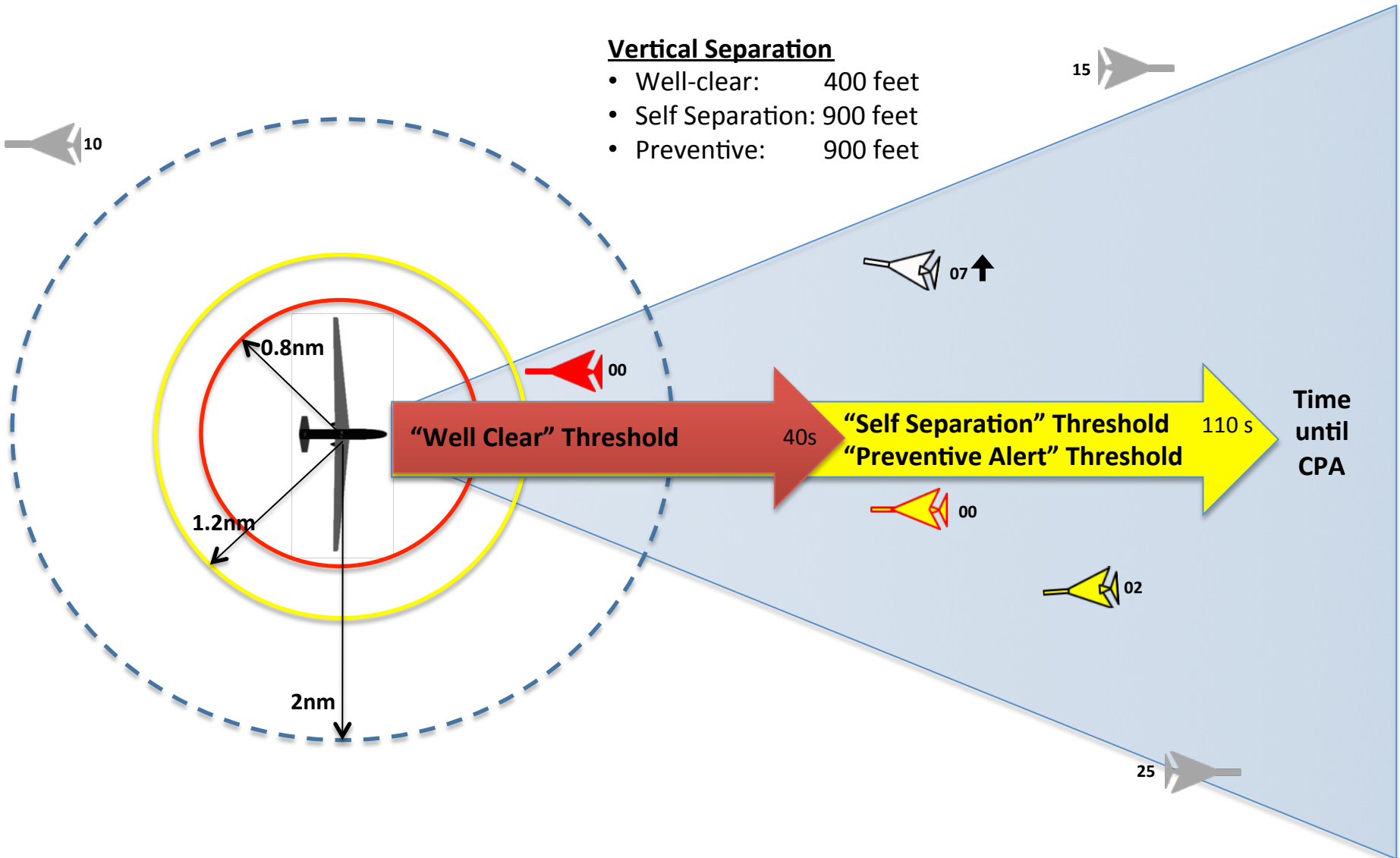


iHITL – Alerting Criteria



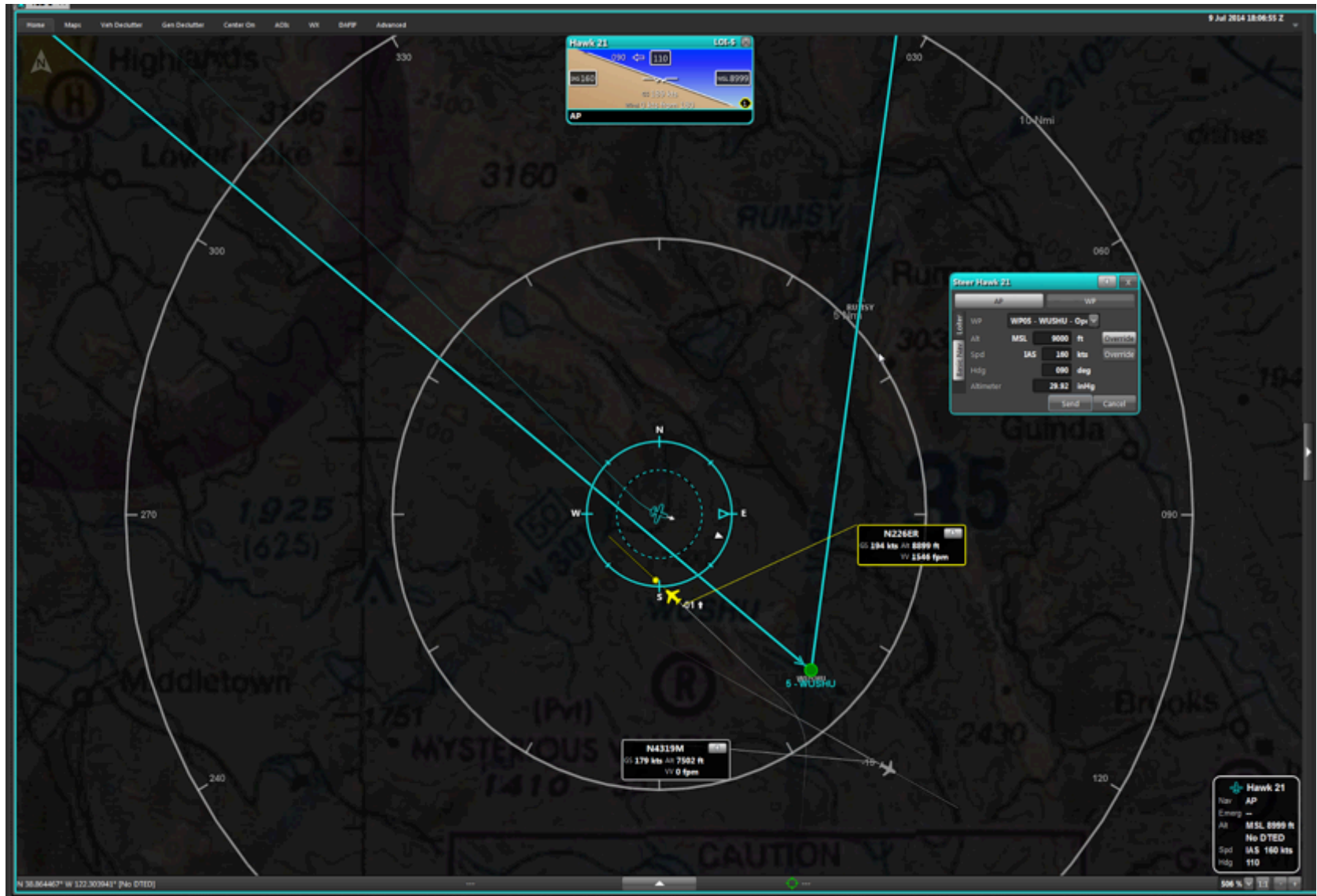
Vertical Separation

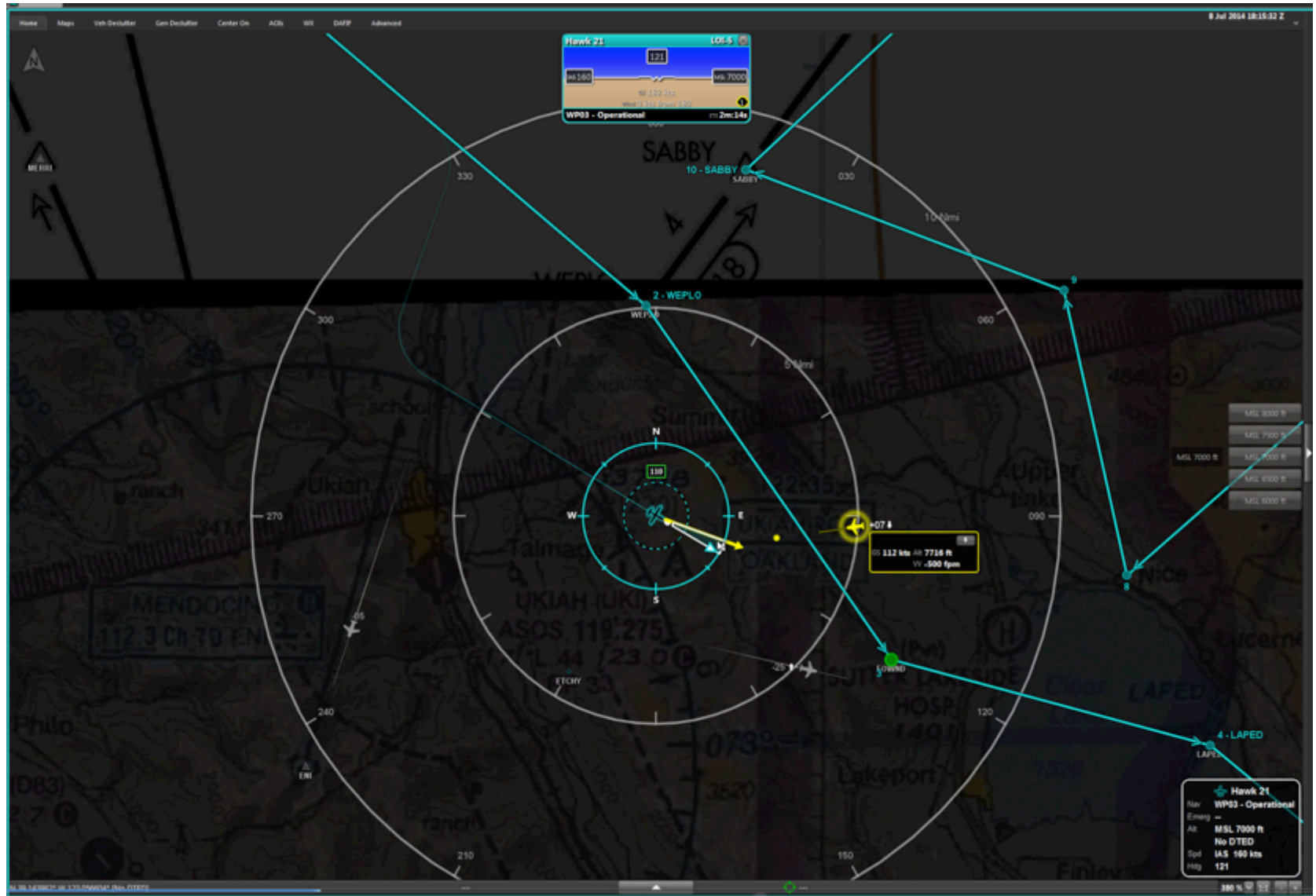
- Well-clear: 400 feet
- Self Separation: 900 feet
- Preventive: 900 feet





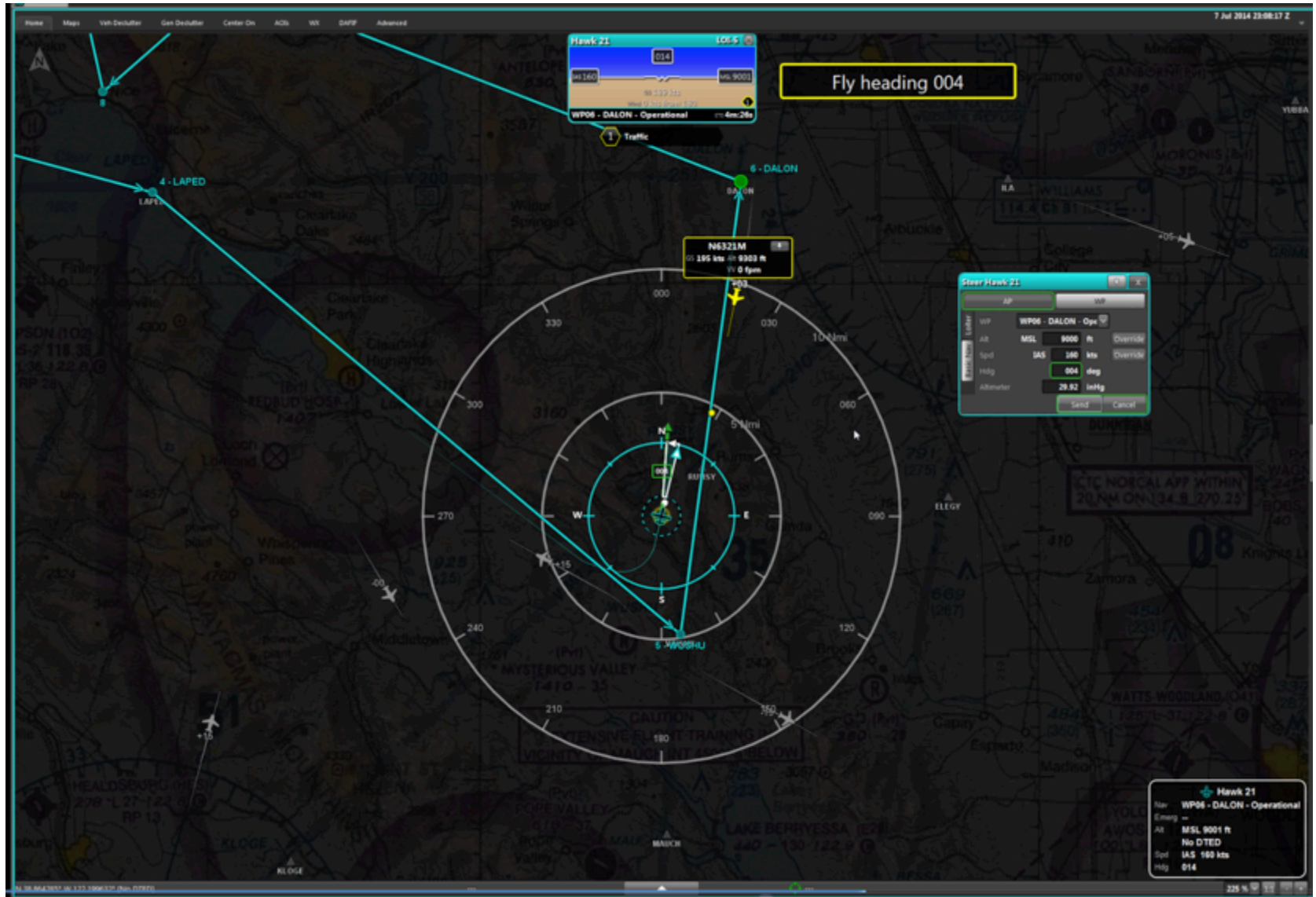
iHITL – D1







iHITL – D3





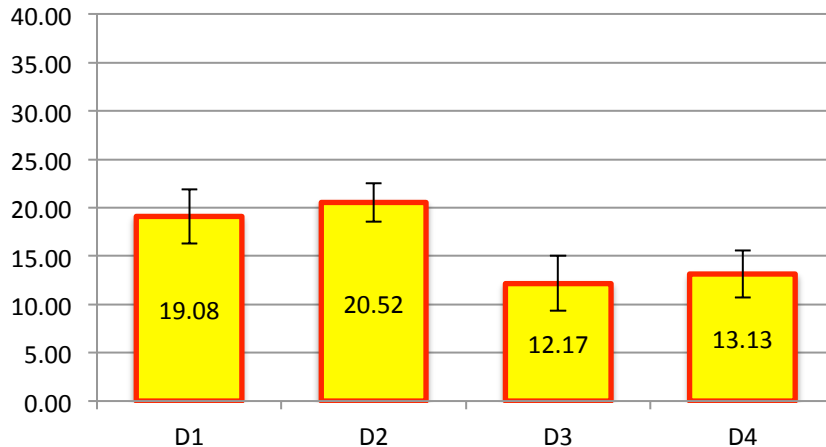
iHITL – D4





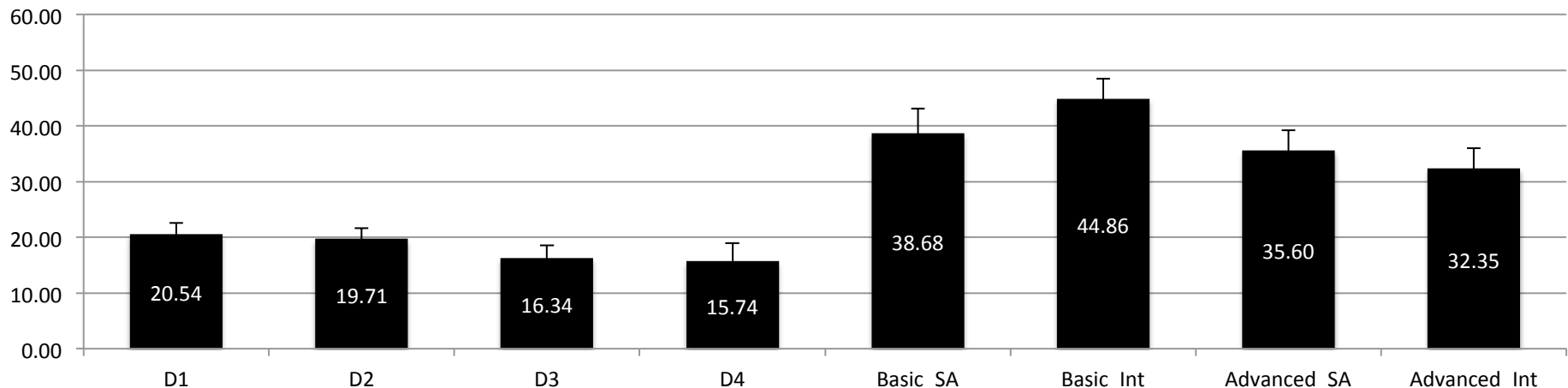
iHITL – Response Time Results

Predictive SS Alerts



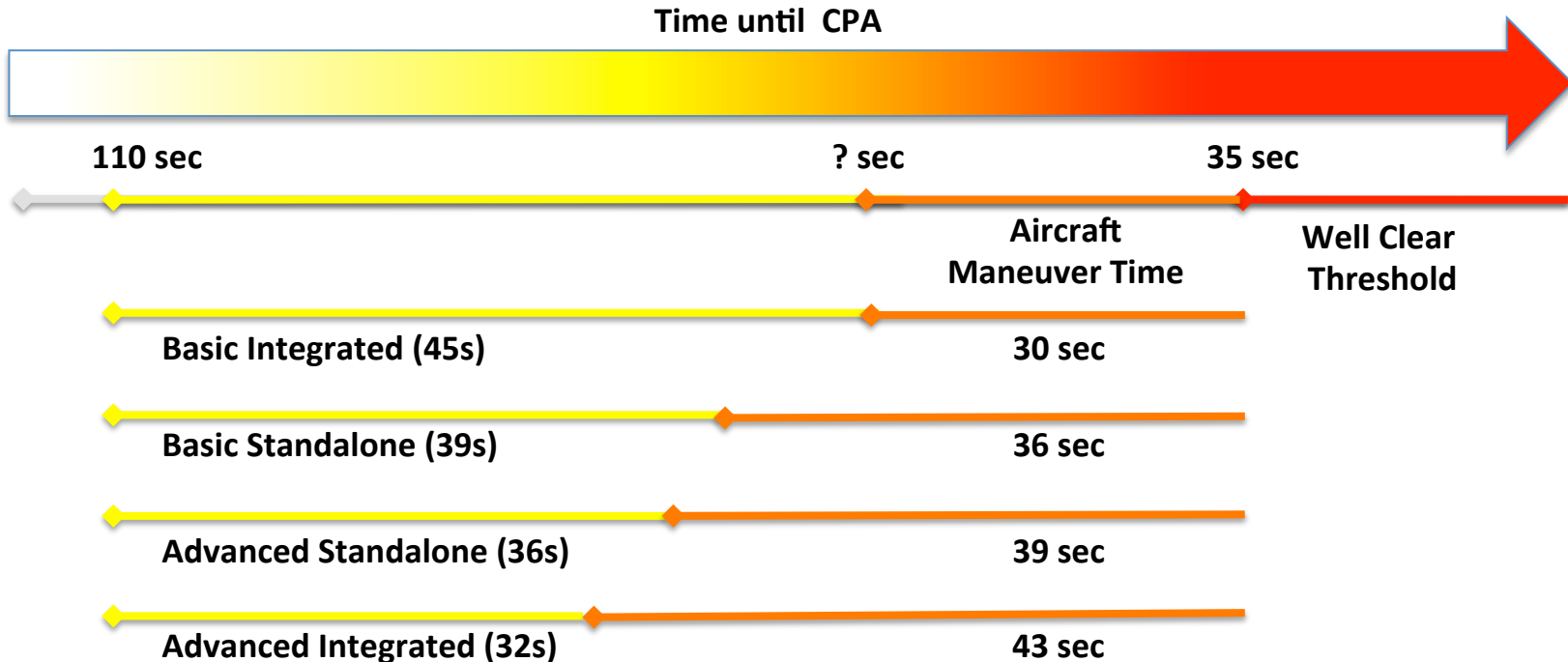
- Predictive SS = encounters that are predicted to lose well clear at any point during the encounter
- There was a near significant effect of Display on Total Response Time for Predictive SS alerts, $p = .056$
- Pilots took an average of **16.22 seconds** to complete their final edit in response to Predictive SS alerts (from first alert appearance)

iHITL and PT4 Display Comparison (All Encounters)



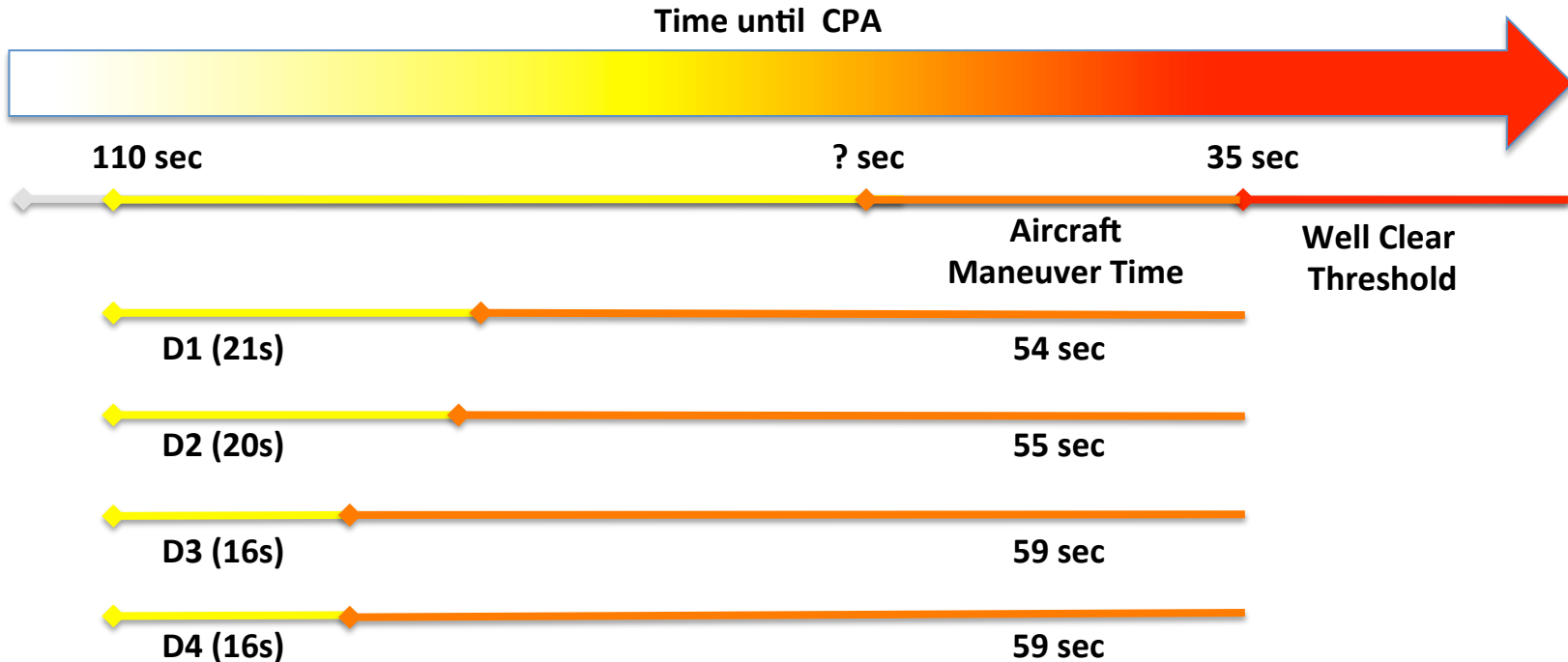


PT4 – Response Time Results





iHITL – Response Time Results

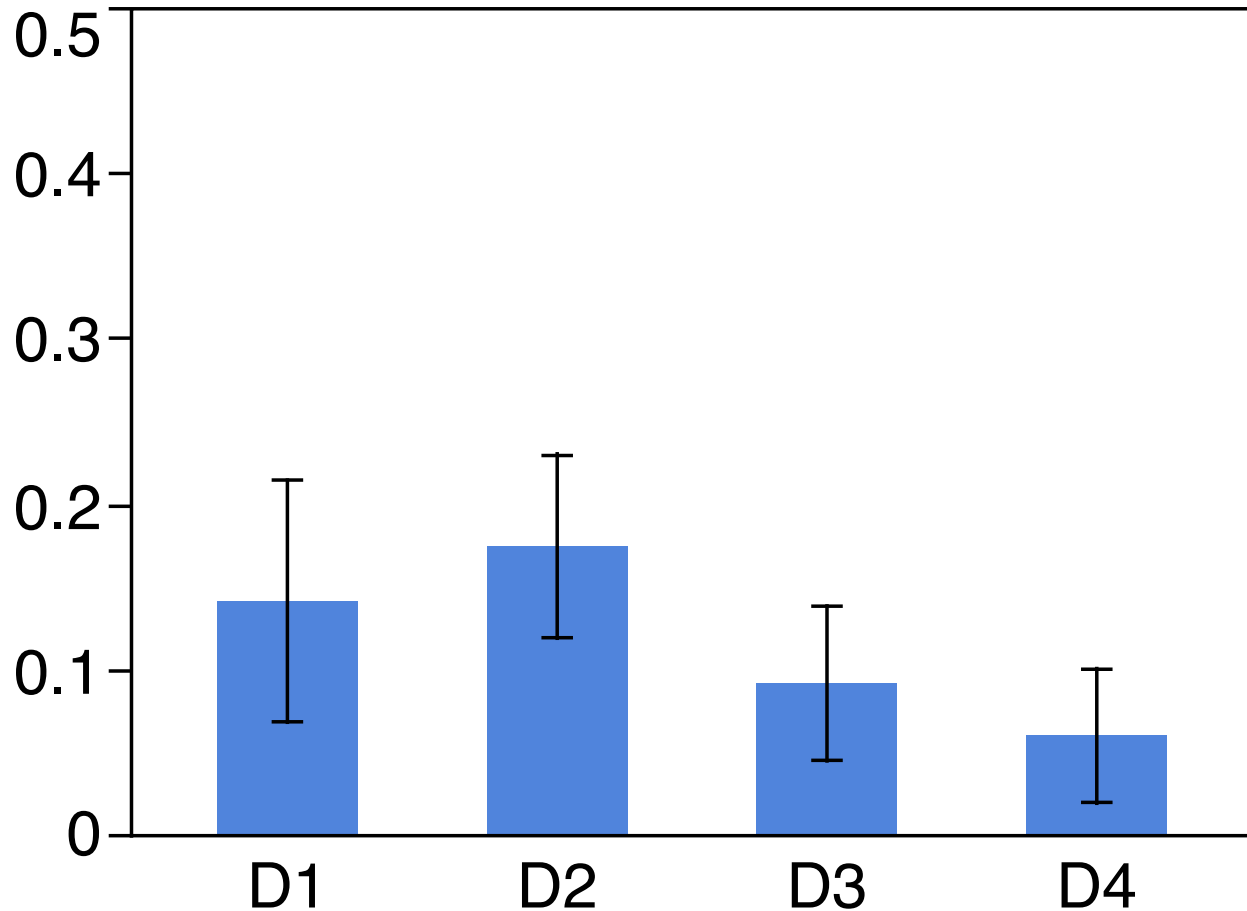




iHITL - LoWC

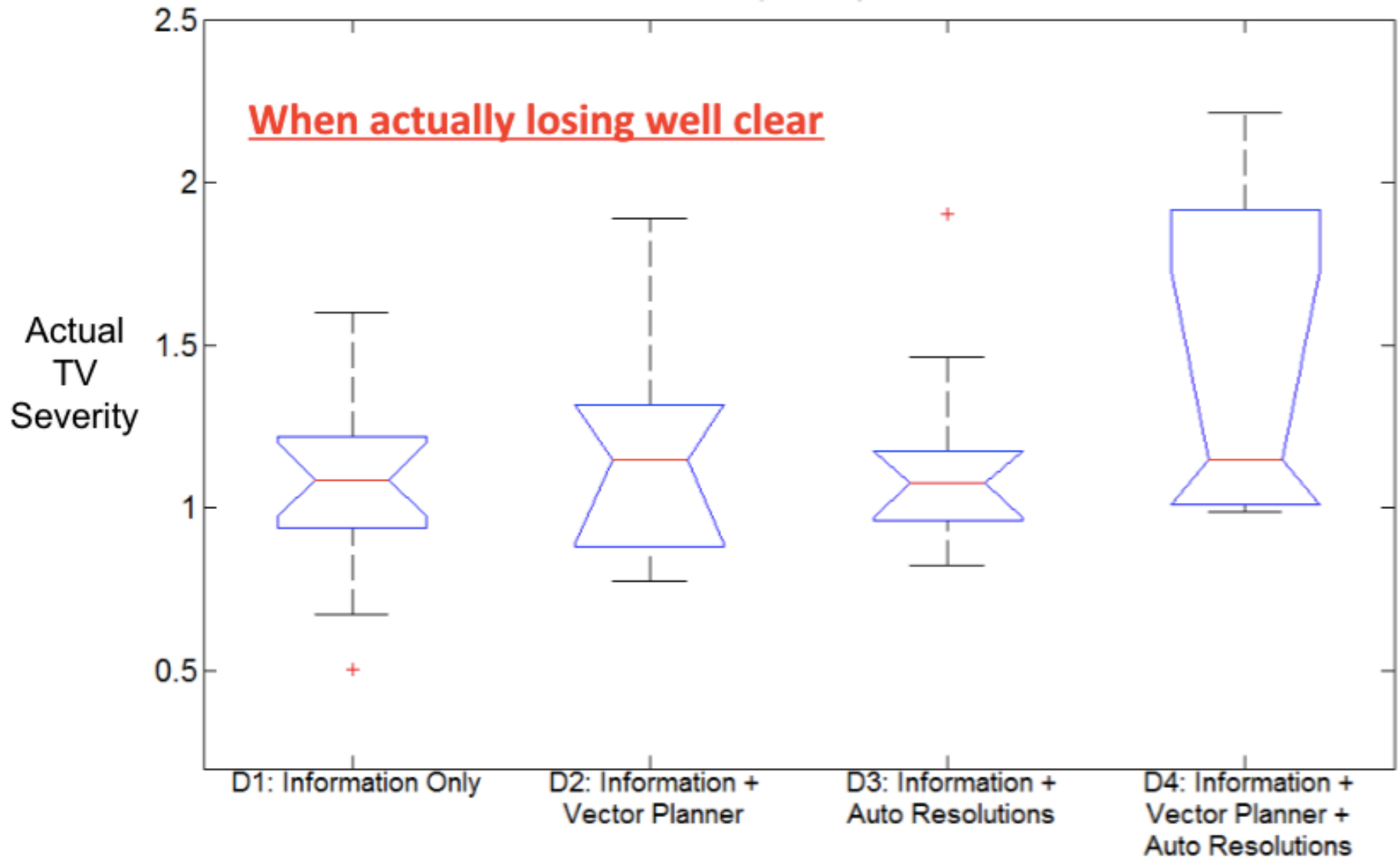


Proportion of Losses of Well Clear





iHITL – LoWC Severity





iHITL – Results Summary



- Total Response Time:
 - No significant differences between displays
 - Trend shows **Directive Only** and **Suggestive + Directive** as faster than Information Only and Suggestive Only
- Well Clear Metrics:
 - No significant differences between displays
 - **Information** and **Suggestive Only** (D1 and D2) display conditions had 2.5X as many LoWCs than the **Suggestive + Directive** combined (D4)
 - Severity data shows evidence of trends toward performance benefits with **Suggestive + Directive** compared to other three displays
- **What does this mean for minimum information requirements??**



PT5 - Overview

- Goal: Continue evaluation of candidate Detect and Avoid (DAA) displays and algorithms with respect to self-separation and collision avoidance to inform SC-228 DAA Minimum Operational Performance Standards
- Method:
 - Build upon results of previous hitl simulations results and lessons learned to identify minimum DAA display and guidance requirements for draft SC228 MOPS
 - PT4: Advanced better than Basic (but issues; well clear & display training, pop-ups)
 - iHITL: No significant differences between Advanced information features from PT4, but trends favoring combined **Suggestive + Directive (D4)** guidance
 - Maneuver Study: Banding display showed faster response time compared to informative and directive displays; banding and advanced informative had least losses of well clear (neither results statistically significant)



PT5 – Proposed Experimental Design

- Can test up to four displays in a HITL
- Assume Directive Only not min requirement for MOPS
- Candidate displays for PT5
 - Informative:
 - Minimum Information (rerun from PT4 with updated alerting scheme)
 - Advanced Information (iHITL D1)
 - Relative Vector Display (based on Garmin)
 - Translated Well Clear Ring
 - Suggestive:
 - Vector Planner (iHITL D2)
 - Stratway+ Banding
 - JADEM Banding (same underlying algorithm as Vector Planner)
 - Suggestive + Directive:
 - Vector planner + Resolutions (iHITL D4)
 - Banding + Resolutions

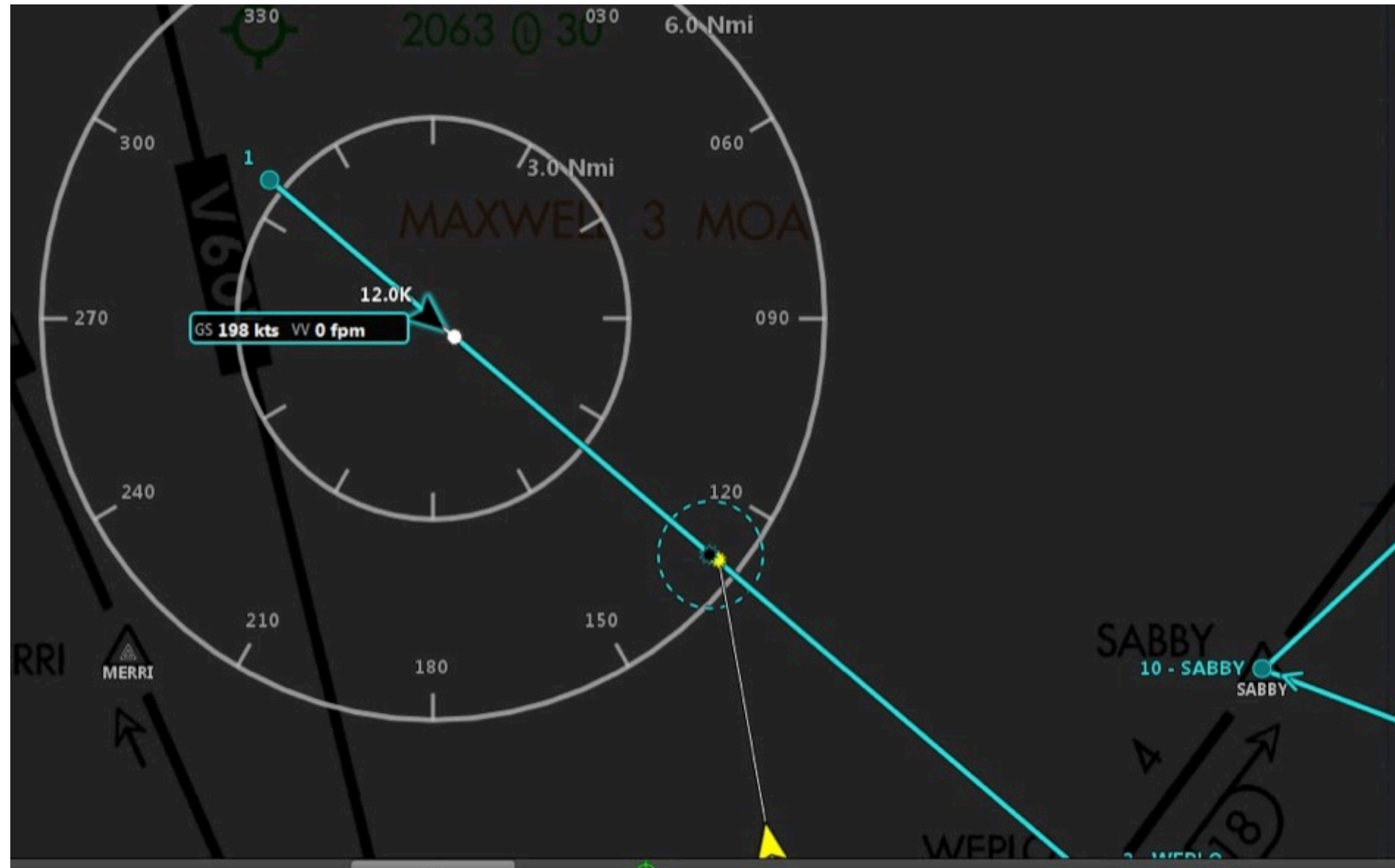


PT5 – Relative Vector Display





PT5 – Translated Well Clear





PT5 – Proposed Experimental Design

- Decisions:
 - Eliminated Suggestive + Directive options to focus on Informative and Suggestive Only displays
 - Prototyped and eliminated Relative Vector and Translated Well Clear Ring
 - Concerns for multiple intruder encounters in terms of potential clutter, prioritization of intruders and ambiguity of potential safe maneuvers
 - Informative display concepts inherently difficult to design to support mathematically complex well clear definition – use of automation to do the math makes most sense
 - Chose minimum information display as baseline (and verification of results from PT4)
 - Chose Vector Planner to baseline to iHITL
 - To be modified to be less integrated with the auto pilot and more equal to bands displays
 - Chose Stratway+ and JADEM bands displays
 - Bands showed performance benefits in Maneuver study
 - Different presentation of suggestive display guidance
 - Stratway+ and JADEM bands have different approaches (No Fly versus Fly/No Fly)
 - JADEM uses same algorithm as Vector Planner (so results are directly comparable to previous HITLs)



PT5 – Final Experimental Design

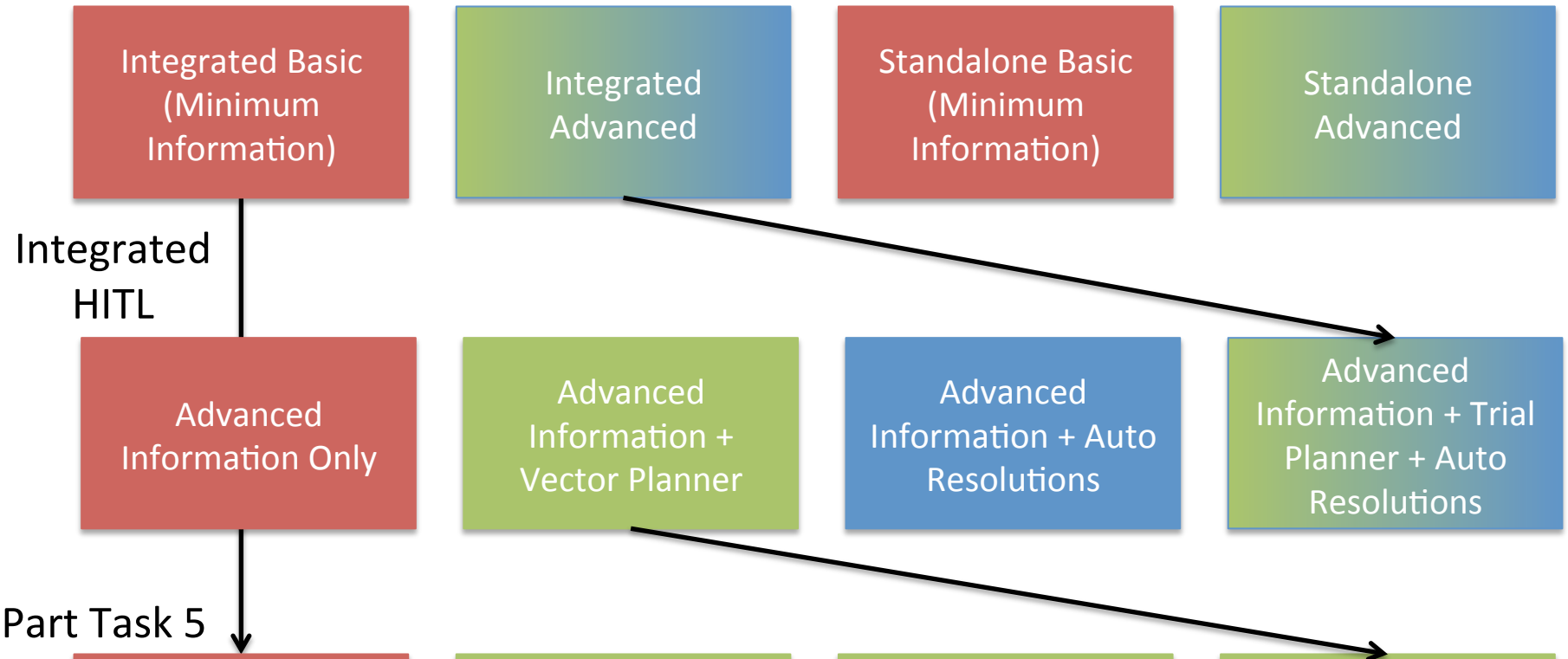


- Mixed Factorial Design – 2 variables of interest:
 - Display Configuration (Within Subjects Independent Variable):
 - Display 1: Minimum Set
 - Display 2: Stratway+ No Fly Bands
 - Display 3: JADEM Fly/No Fly Bands
 - Display 4: JADEM Vector Planning Tools
 - Surveillance Performance (Between-Subjects Independent Variable)
 - Level 1: Perfect Surveillance Data
 - Level 2: Imperfect Surveillance Data



iHITL – Overview

Part Task 4

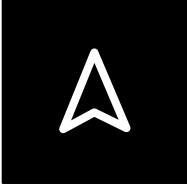


Display Types:

Informative

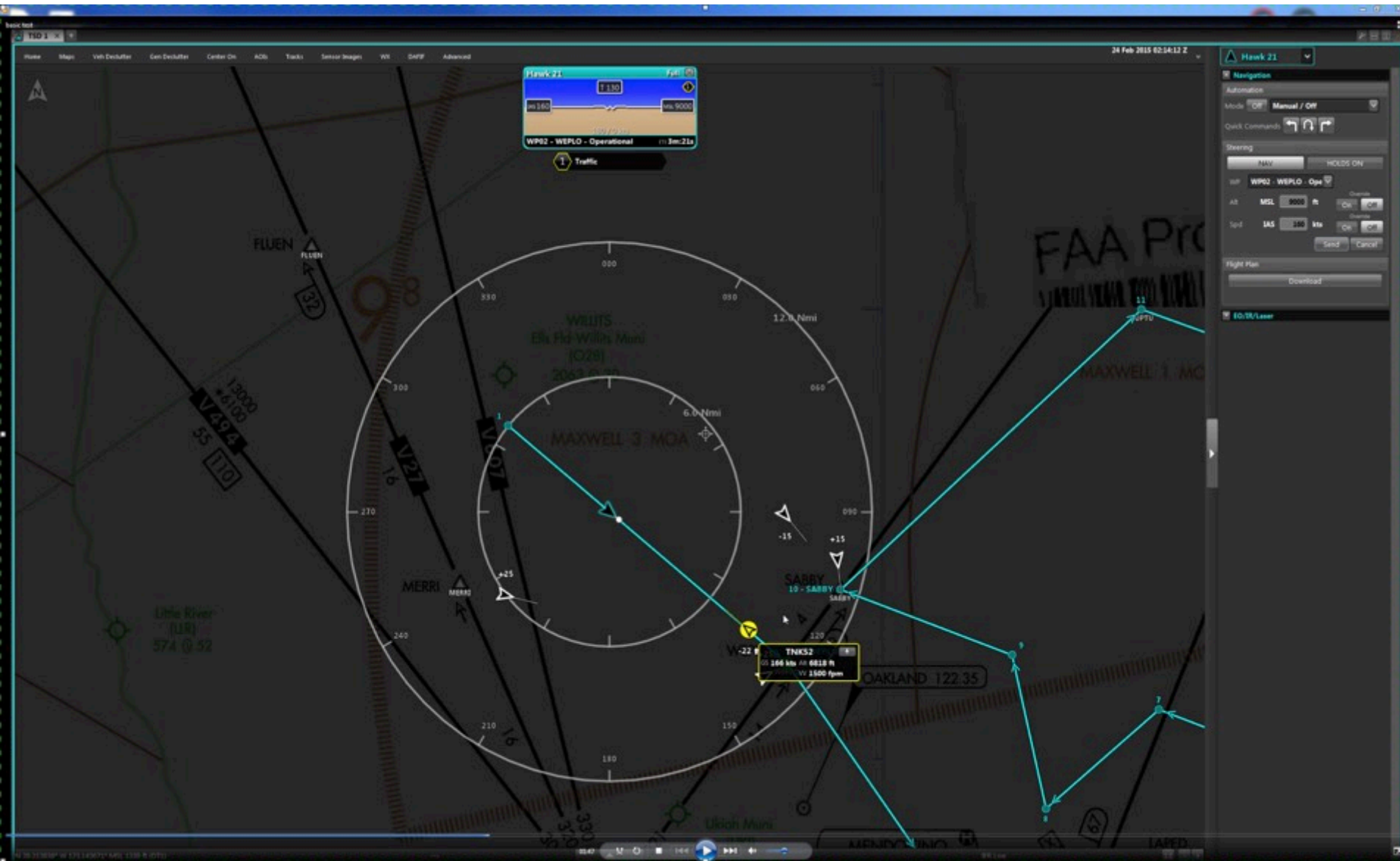
Suggestive

Directive

Alert Level	Name	Pilot Action	DAA Separation Criteria	SST (Time Until Penetrating Separation Criteria)	Symbology	Aural Alert Verbiage
4	Self Separation Warning Alert	Immediate action required to avoid a well clear violation, notify ATC as soon as practicable after taking action	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA equivalency: 60 sec)		"Traffic, Maneuver Now"
3	Corrective Self Separation Alert	Action to remain well clear will be necessary if the encounter does not change, coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	75 sec (TCPA equivalency: 110 sec)		"Traffic, Separate"
2	Preventive Self Separation Alert	Action to remain well clear will be necessary only if one or both aircraft make both a horizontal and vertical maneuver, do not climb/descend or turn into the intruder and be prepared to respond if the intruder begins climbing/descending or turning towards you. You may want to coordinate with ATC about the intentions of the intruder.	DMOD = 0.75 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	75 sec (TCPA equivalency: 110 sec)		"Traffic, Monitor"
1	Self Separation Proximate Alert	No action necessary to avoid this aircraft, but its presence should be considered when determining a resolution maneuver to avoid other aircraft.	DMOD = 0.75 nmi HMD = 1.5 nmi ZTHR = 1200 ft modTau = 35s	85 sec (TCPA equivalency: 120 sec)		N/A
0	None (Target)	No action necessary, There is an aircraft within your sensor range, but it is not expected to present a threat.	Within surveillance field of regard	X		N/A



Display 1: Min Info





Display 2: Stratway+ No Fly Bands





Display 3: JADEM Fly/No Fly Bands





Display 4: Vector Planner





Flight Test 3

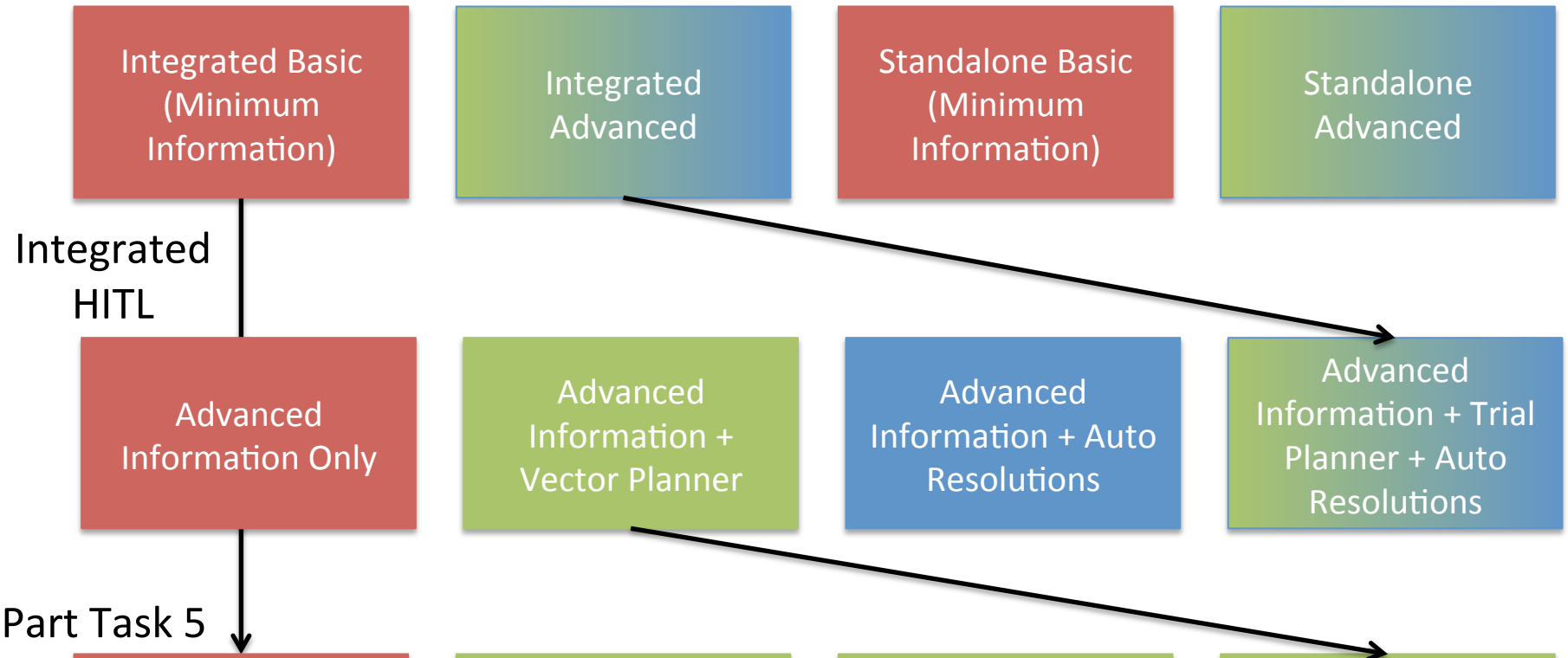


- Full Mission Configuration (Aug/Sept) will allow for verification of pilot performance results from HITLs in live flight environment with live intruders
 - Maintain as many of the test conditions constant
 - GCS (with surrogate)
 - Mission profile & pilot tasks
 - Airspace & ATC
 - Real world uncertainty
 - Real sensors (ADS-B)
 - Real control delay
- Can test up to three displays
 - Will be any three that have already been developed and tested in HITLs, with minor modifications
 - Decision to be made after PT5 results are analyzed



Overview

Part Task 4



Display Types:

Informative

Suggestive

Directive