NASA UAS Integration Into the NAS Project Detect and Avoid Display Evaluations

Briefed to FAA Human Factors REDAC Subcommittee

Jay Shively (Robert.J.Shively@NASA.GOV)
NASA Ames Research Center

Lisa Fern (Lisa.Fern@NASA.GOV)
The Ohio State University

Me ?

- 25 years – Army (closely associated with NASA)
  - NASA-TLX
  - High Speed Research
  - MIDAS (Cognitive Modeling)
  - Rotorcraft (Brown-out symbology)
  - UAS – Control of Multiple UAS
  - Access 5

- NASA since 2012
  - UAS in the NAS
  - Human Systems Integration Lead
  - HAT Lab Lead (FDDRL)

Background

- Goal: Provide data on the effect of various Detect and Avoid (DAA) display features with respect to pilot performance of the self-separation function in order to determine the minimum information requirements for DAA displays

  1. What is the pilot contribution to the self-separation timeline in terms of expected response time to detect, determine and execute a maneuver in response to a potential loss of well clear?

  2. What configuration of display elements meets a minimum acceptable level of performance? What, if any, level of pilot maneuver guidance is required to support this performance?

Background

- Display Types:

  - 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.

Background

- Approach: Conduct a series of iterative human in the loop experiments, in a representative simulation environment, 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

  - Two "mini-HITLs"

    - TCAS interoperability
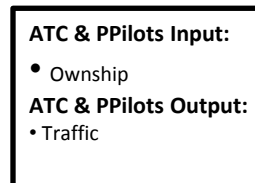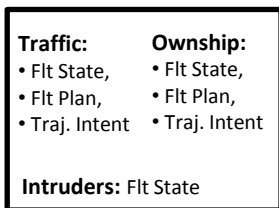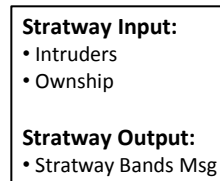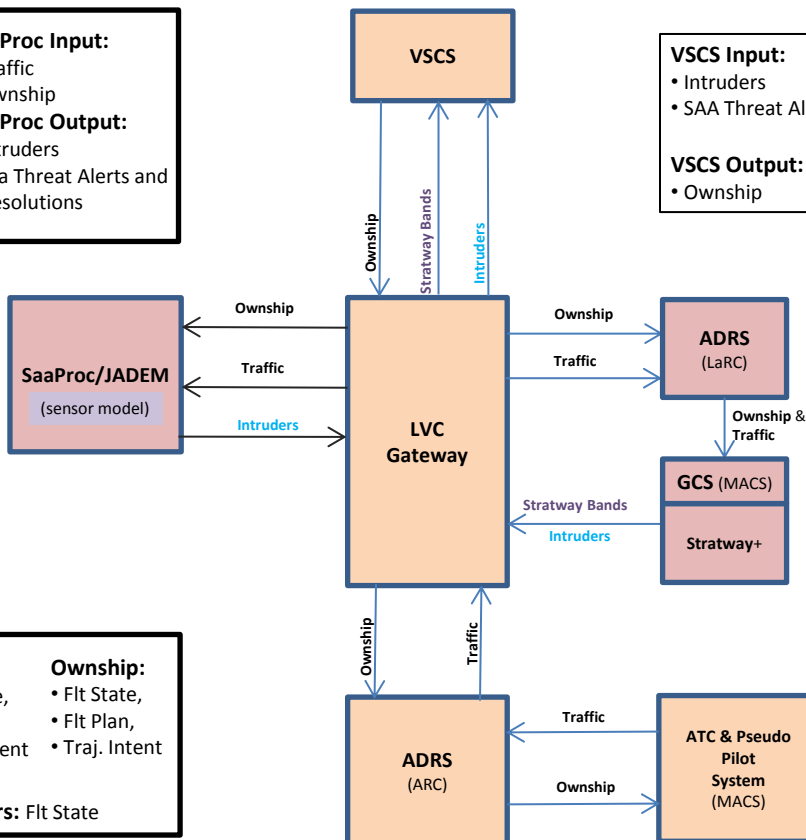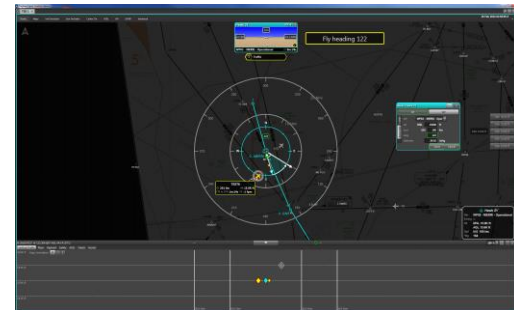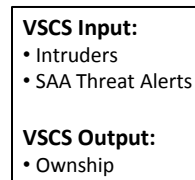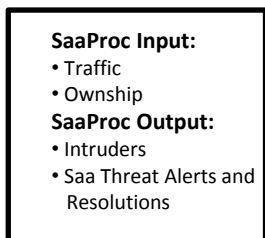
    - Missing Information

Simulation Environment:
Draft MOPS Alerting Structure

Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Alerting Time Threshold	Aural Alert Verbiage
	DAA Warning Alert	• **Immediate action required** • 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 approximate: 60 sec)	"Traffic, Maneuver Now"
	DAA Corrective Alert	• On current course, **corrective action required** • Coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
	DAA Preventive Alert	• On current course, corrective action **should not be required** • Monitor for intruder course changes • Talk with ATC if desired	DMOD = 1.0 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
	Remaining Traffic	• No action expected	Within surveillance field of regard	X	N/A

Simulation Environment: LVC Architecture

SaaProc Input:
- Traffic
- Ownship

SaaProc Output:
- Intruders
- Saa Threat Alerts and Resolutions

VSCS Input:
- Intruders
- SAA Threat Alerts

VSCS Output:
- Ownship

Stratway Input:
- Intruders
- Ownship

Stratway Output:
- Stratway Bands Msg

Traffic:
- Flt State,
- Flt Plan,
- Traj. Intent

Ownship:
- Flt State,
- Flt Plan,
- Traj. Intent

Intruders: Flt State

ATC & PPilots Input:
- Ownship

ATC & PPilots Output:
- Traffic

VSCS

SaaProc/JADEM
(sensor model)

LVC Gateway

ADRS (LaRC)

GCS (MACS)
Stratway+

ADRS (ARC)

ATC & Pseudo Pilot System (MACS)

Ownship

Stratway Bands

Intruders

Ownship

Traffic

Intruders

Ownship & Traffic

Stratway Bands

Intruders

Ownship

Traffic

Traffic

Ownship

Air Traffic Control Station

DAA/Traffic Avoidance Timeline

Time until CPA

| ? sec | ? sec | ? sec | ~35 sec | 0 sec |

Latency — ATC Interaction Time — Pilot Response Time — Aircraft Maneuver Time — Well Clear Threshold (~35 sec) — NMAC

TOTAL RESPONSE TIME:
Detect Intruders
Pilots Determine Resolution
Negotiate Clearance with ATC and uplink
maneuver to aircraft
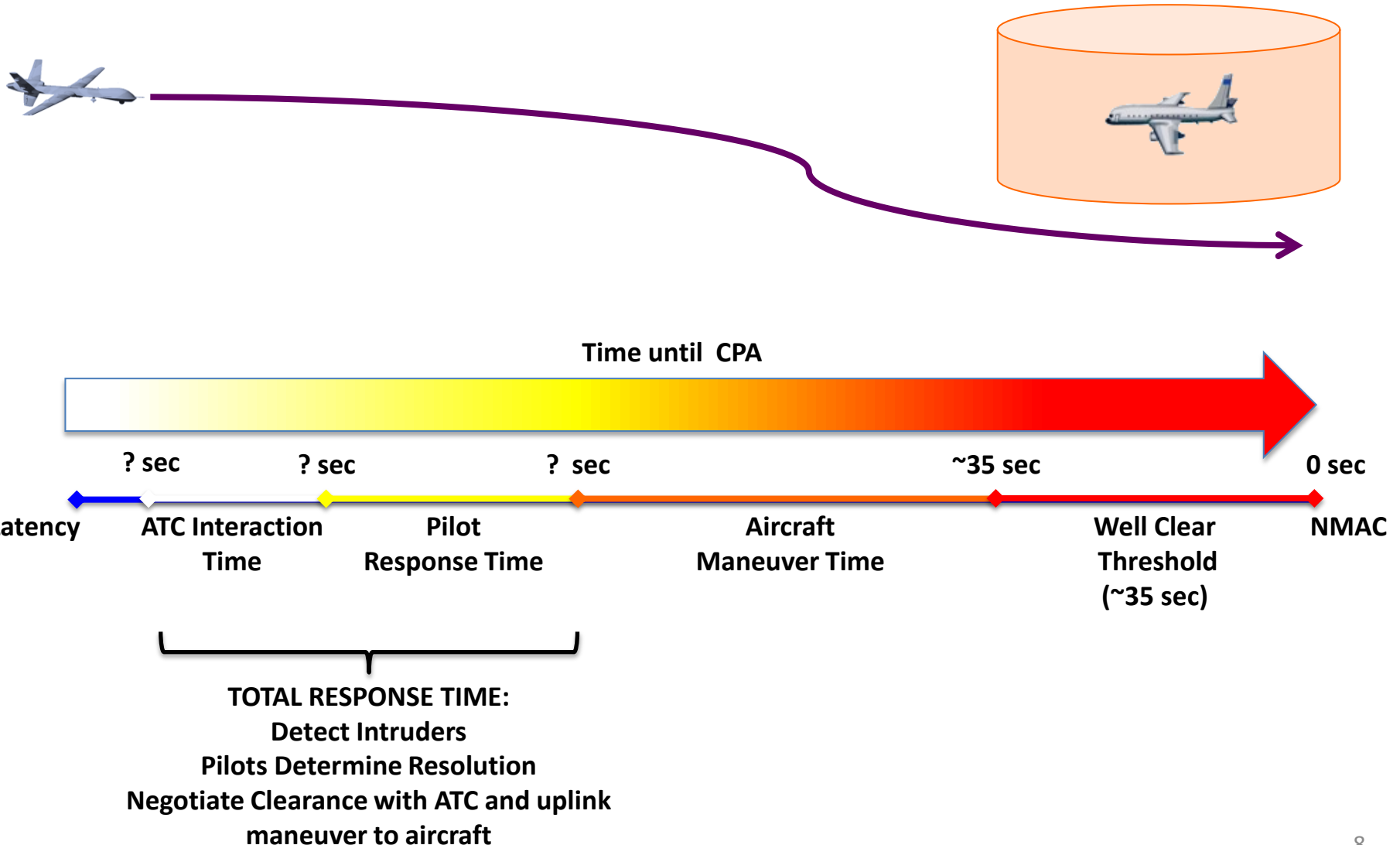
Pilot-DAA Timeline

Pilot-DAA Timeline

Compliance Time

Alert Duration Time

Total Response Time

Aircraft Response Time

Initial Response Time

Initial Edit Time (First Upload)

Notification Time

Clearance Approval Time

Total Edit Time (Final Upload)

T_0 — Traffic Display Alert (SS or CA)

T_1 — Pilot Notifies ATC

T_2 — ATC Approval

T_3 — Pilot Initiates Edit

T_{4a} — Pilot Uploads First Edit

T_{4b} — Pilot Uploads Final Edit

T_5 — Traffic Alert Removed

T_6 — UAS Completes Maneuver

Notify vs Upload Time

Approval vs Upload Time

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)
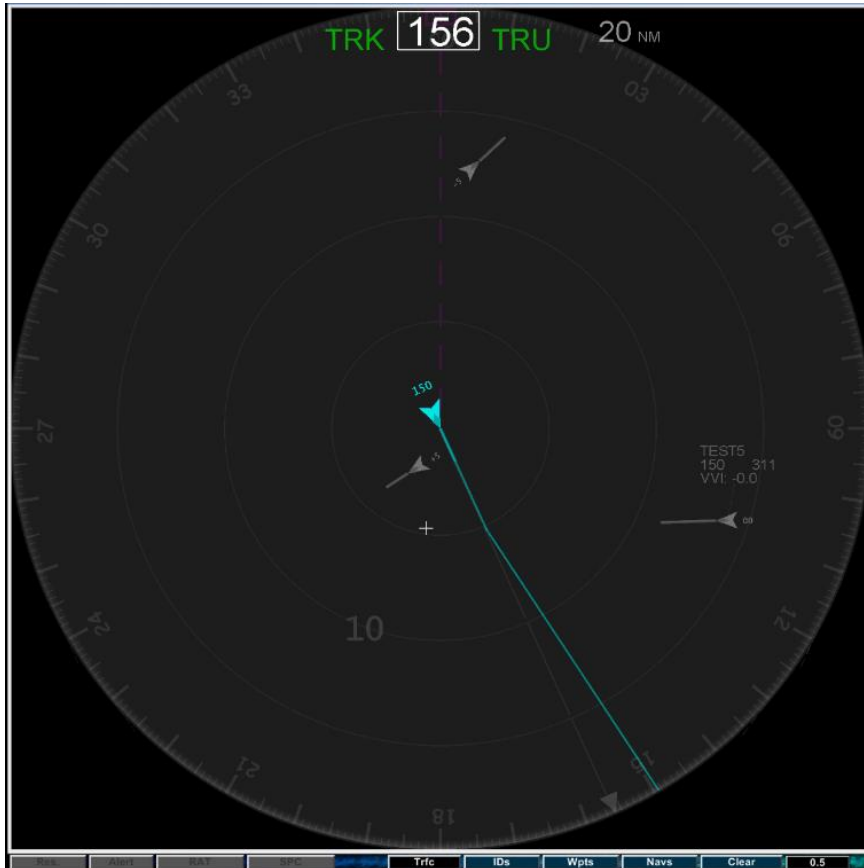
PT4 – Information Level

- 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)
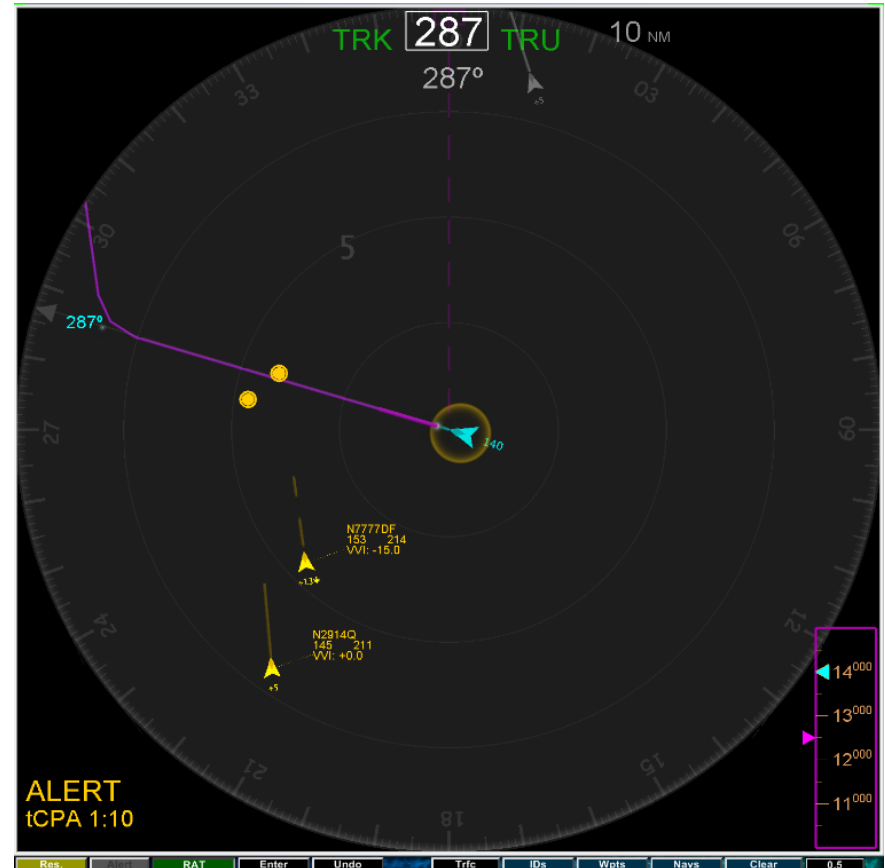   - Vertical situation display (Integrated only)
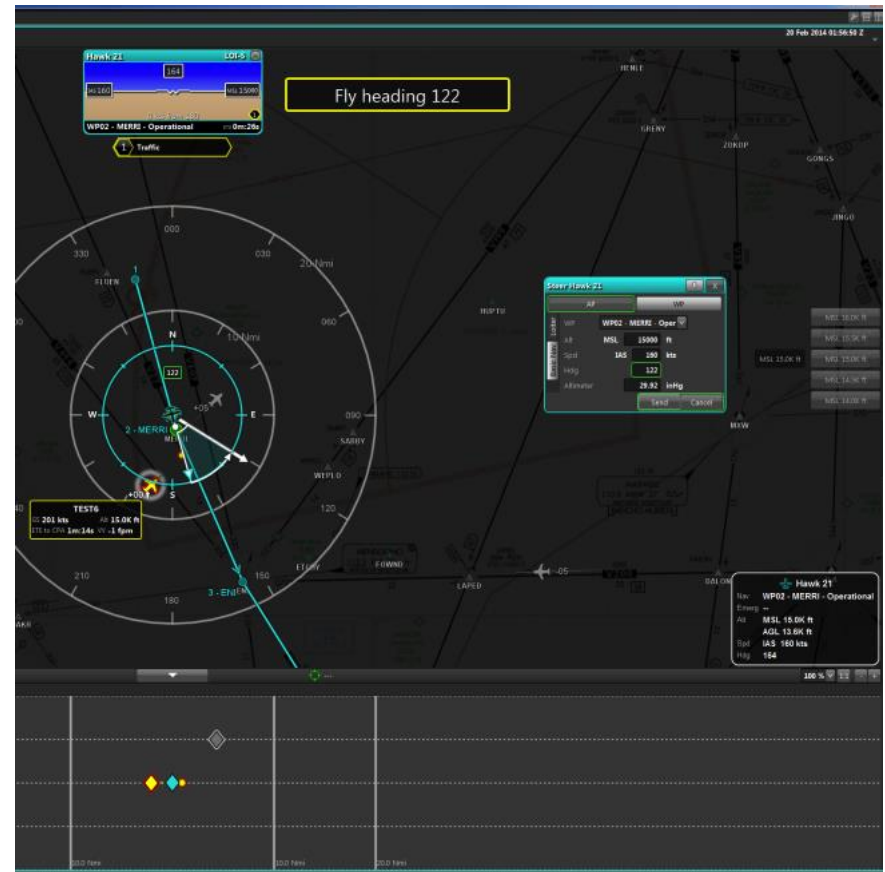
PT4 – Standalone Displays
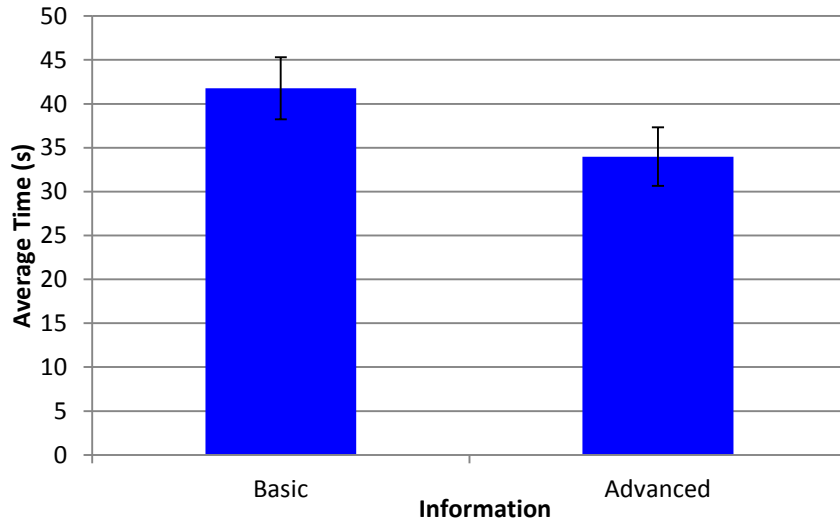
Basic

Advanced

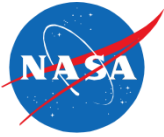# PT4 – Integrated Displays

Basic

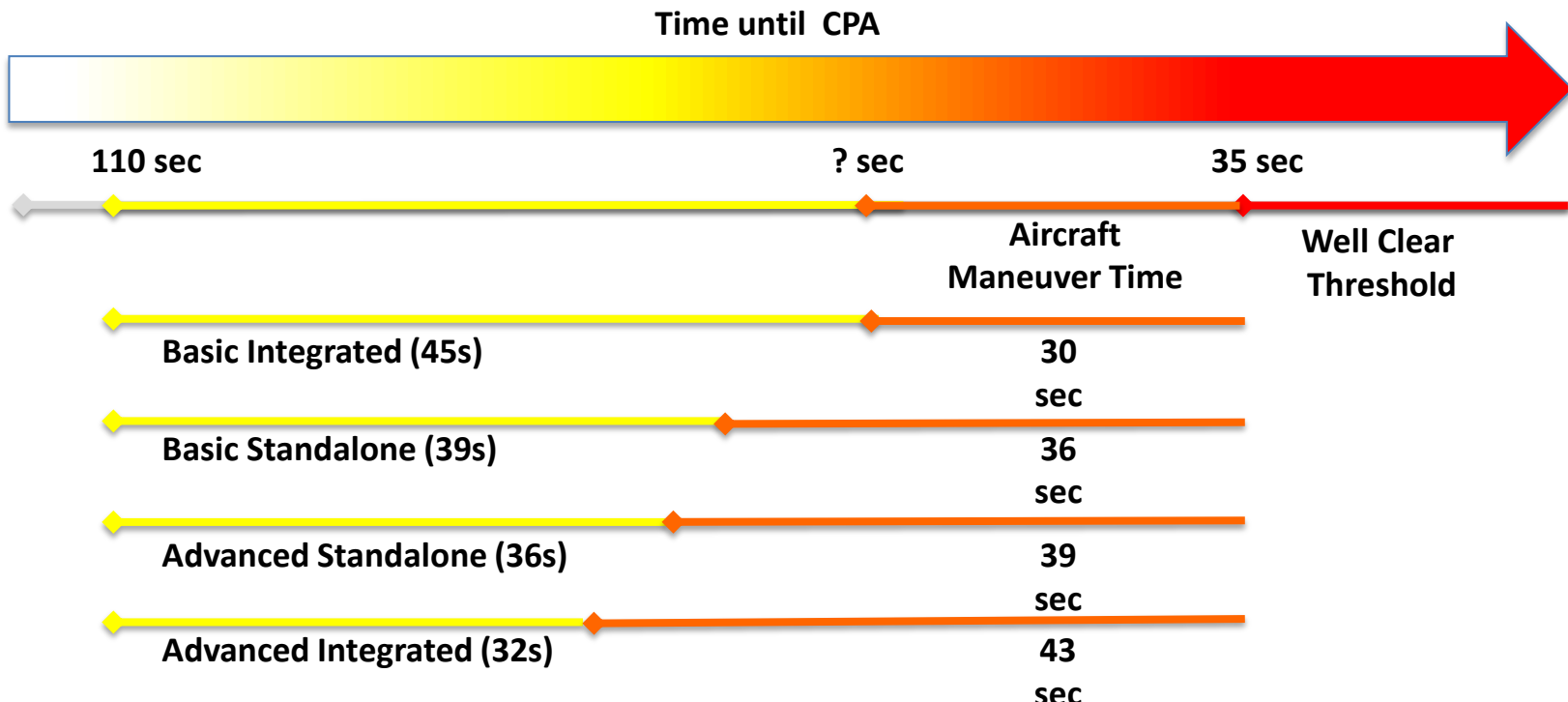Advanced

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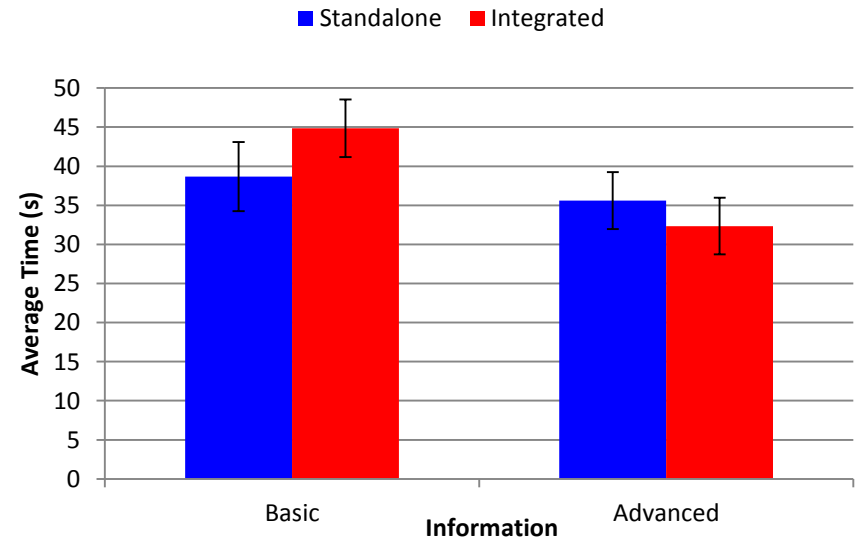
- There was not a significant interaction of Information by Display for Total Response Time, $p > .05$
- Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
  - Basic Standalone = 38.68 sec
  - Basic Integrated = 44.86 sec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

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PT4 – Response Time Results

Time until CPA

110 sec	? sec	35 sec

Aircraft Maneuver Time

Well Clear Threshold

Basic Integrated (45s) 30 sec

Basic Standalone (39s) 36 sec

Advanced Standalone (36s) 39 sec
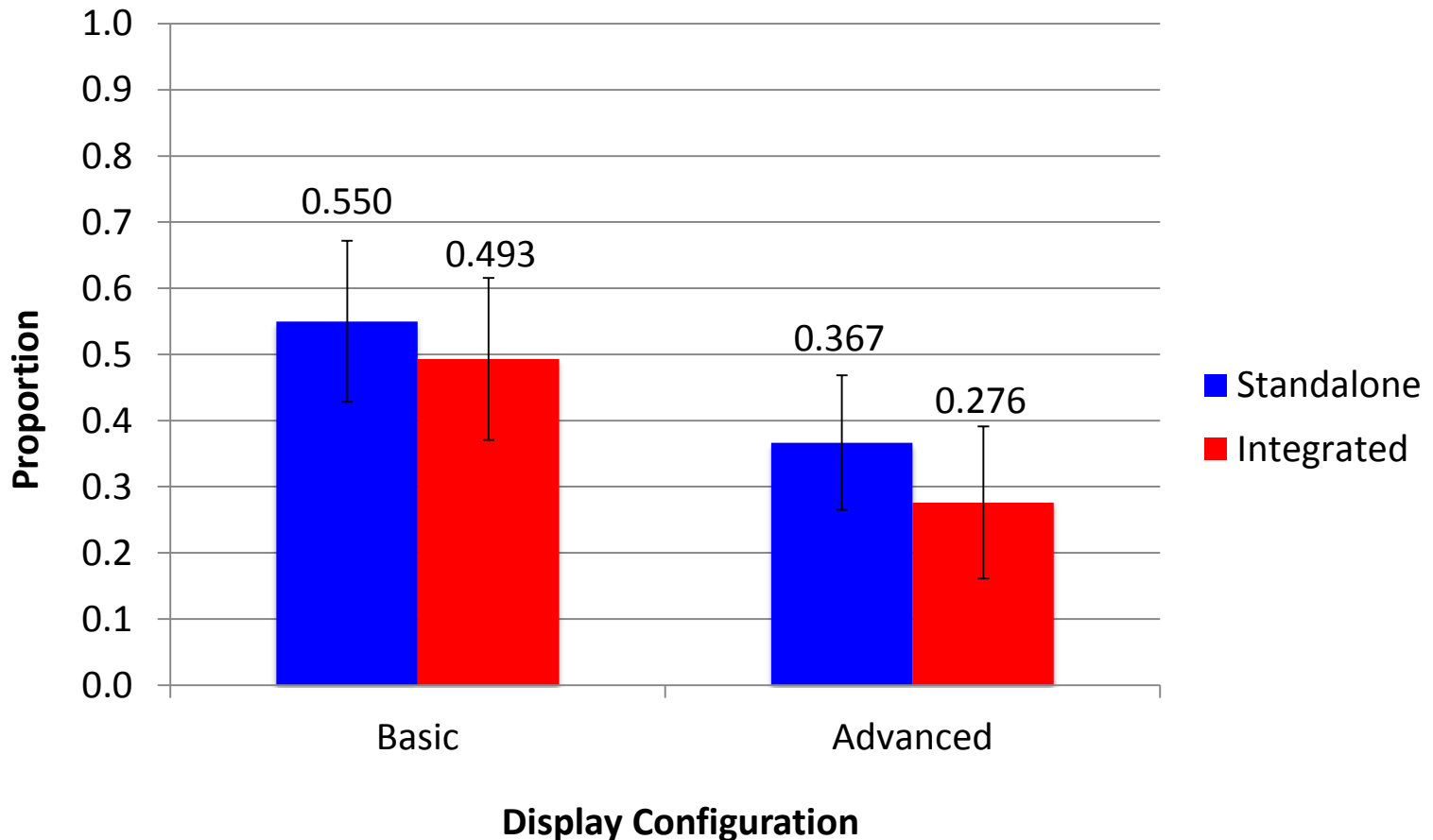
Advanced Integrated (32s) 43 sec

16

PT4 – Losses of Well Clear

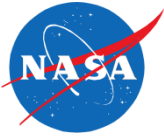
Proportion of Losses of Well Clear

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 proportion or severity of losses of well clear, however:
  - Advanced trended toward 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

- Embedded Variable
  - *Intruder Equipage* (manipulated within each scenario)
    - Transponder-equipped (detected via UAS's ADS-B)
    - No Transponder (detected via UAS's on-board RADAR)
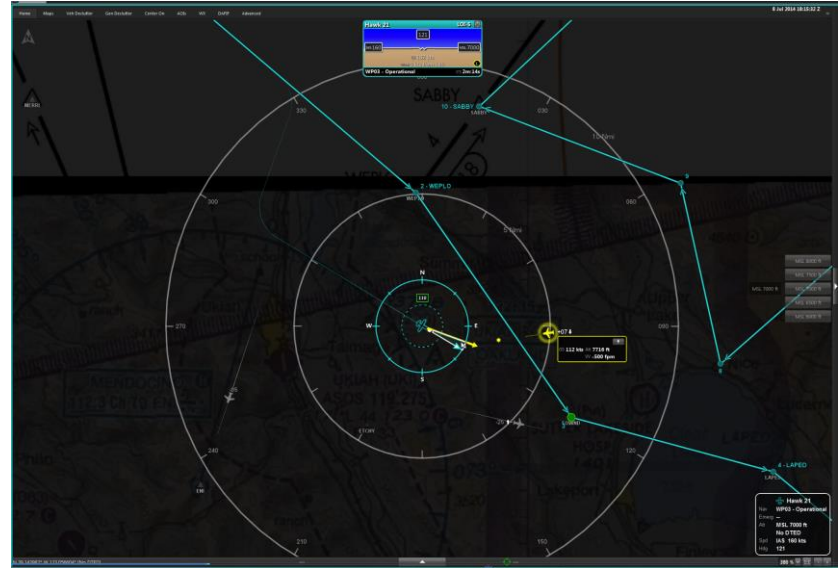
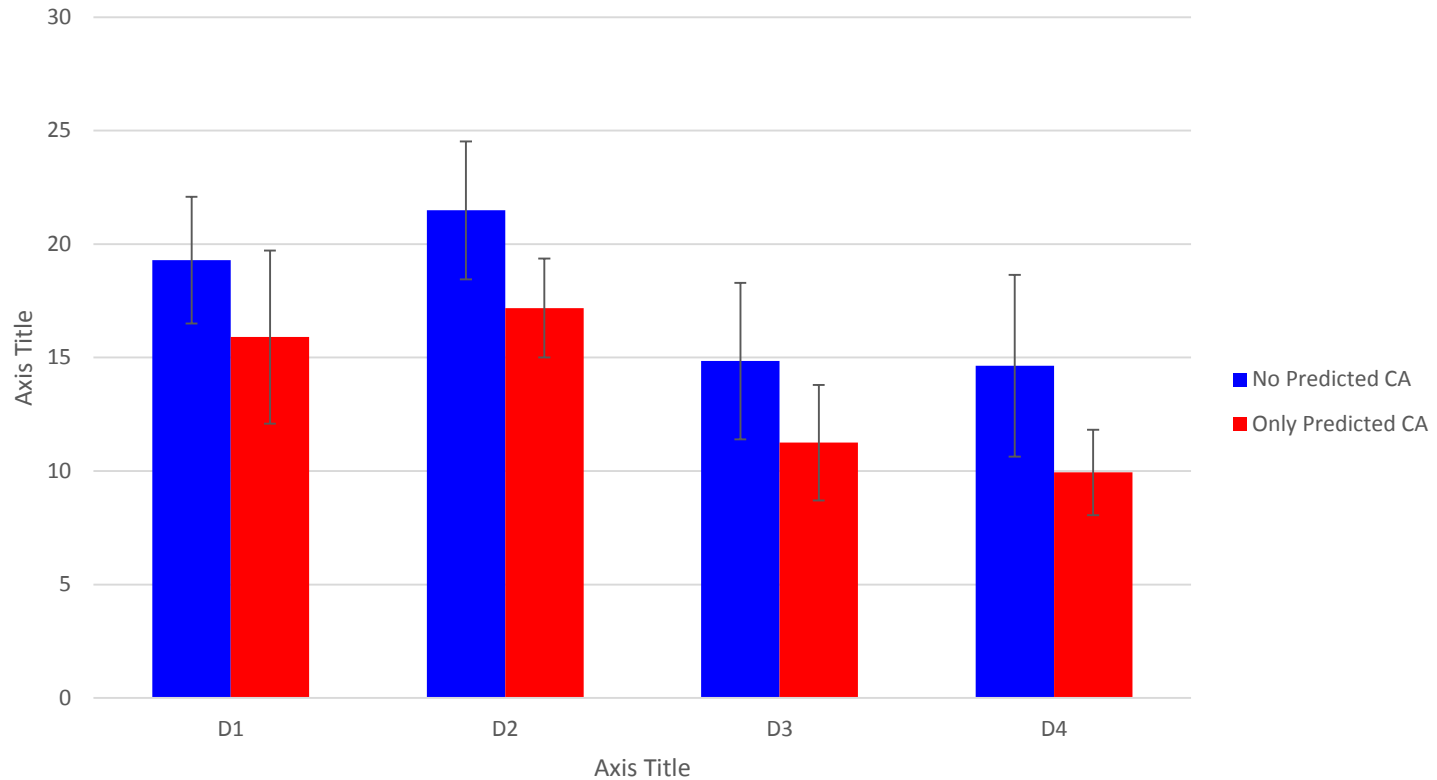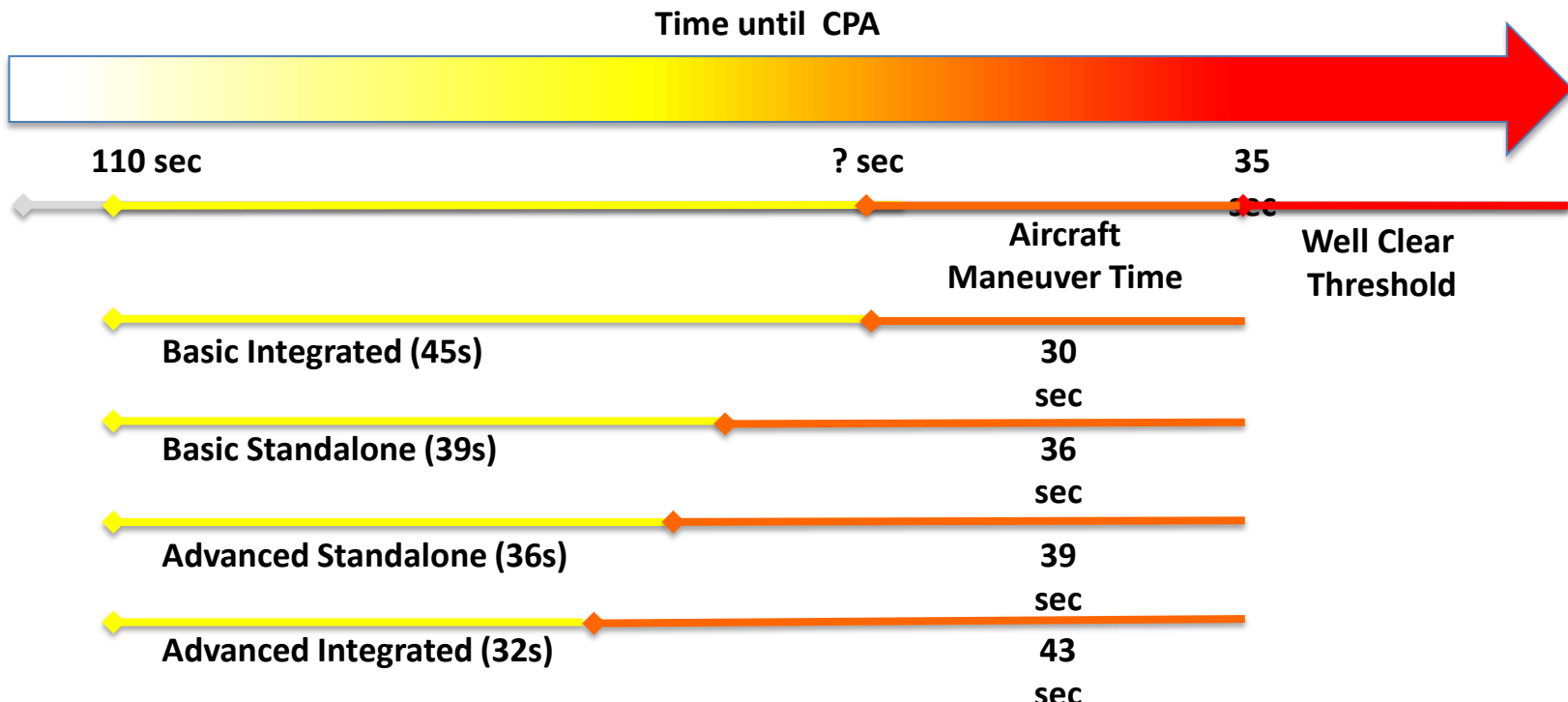# iHITL – Display Conditions

D1

D2

D3

D4

iHITL – Total Response Time Results

- 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)
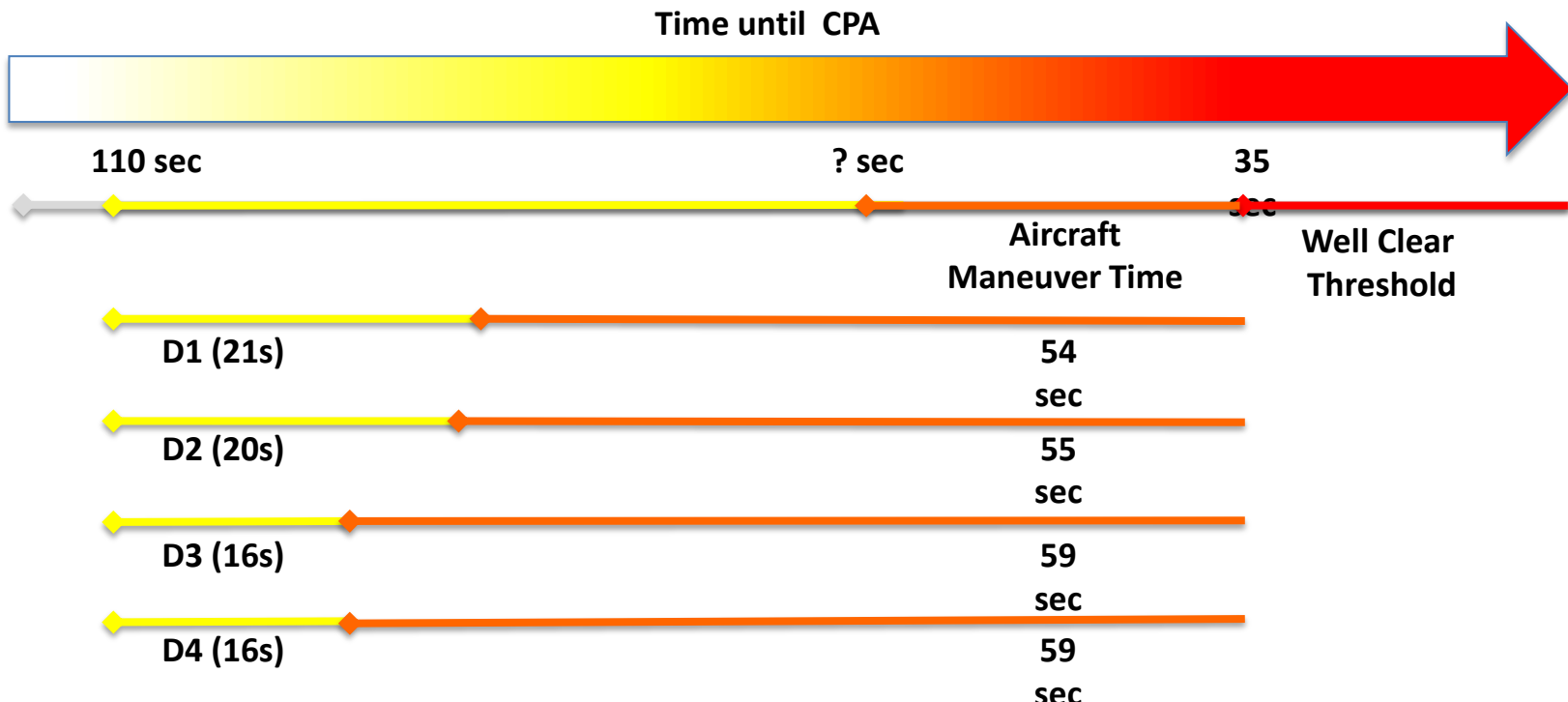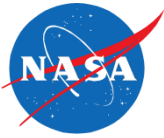
PT4 – Response Time Results

Time until CPA

110 sec

? sec

35 sec

Aircraft Maneuver Time

Well Clear Threshold

Basic Integrated (45s)

30 sec

Basic Standalone (39s)

36 sec

Advanced Standalone (36s)

39 sec

Advanced Integrated (32s)

43 sec

iHITL – Response Time Results

Time until CPA

110 sec   **? sec**   **35 sec**

Aircraft Maneuver Time   **Well Clear Threshold**

D1 (21s)   **54 sec**

D2 (20s)   **55 sec**

D3 (16s)   **59 sec**

D4 (16s)   **59 sec**

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

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 (AFRL): 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 – Experimental Design

- Mixed Factorial Design
  - *Display Configuration* (Within-Subjects Independent Variable):
    - Configuration 1: Minimum Information Set (No Guidance)
    - Configuration 2: Stratway+ No Fly Bands
    - Configuration 3: JADEM Omni Bands
    - Configuration 4: JADEM Vector Planning Tools
  - *Sensor Performance* (Between-Subjects Independent Variable)
    - Level 1: Perfect Surveillance Data
    - Level 2: Imperfect Surveillance Data

- Embedded Variable
  - *Intruder Equipage* (manipulated within each scenario)
    - Transponder-equipped (detected via UAS's ADS-B)
    - No Transponder (detected via UAS's on-board RADAR)
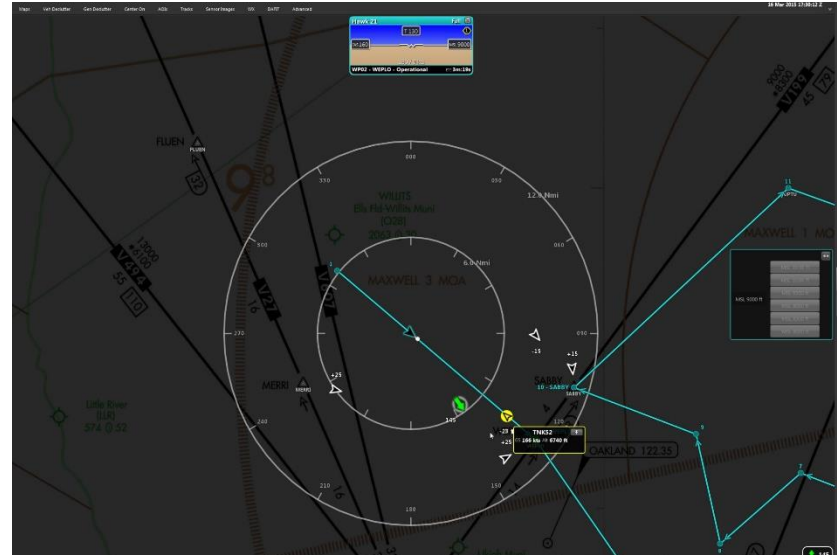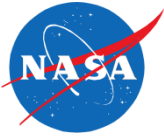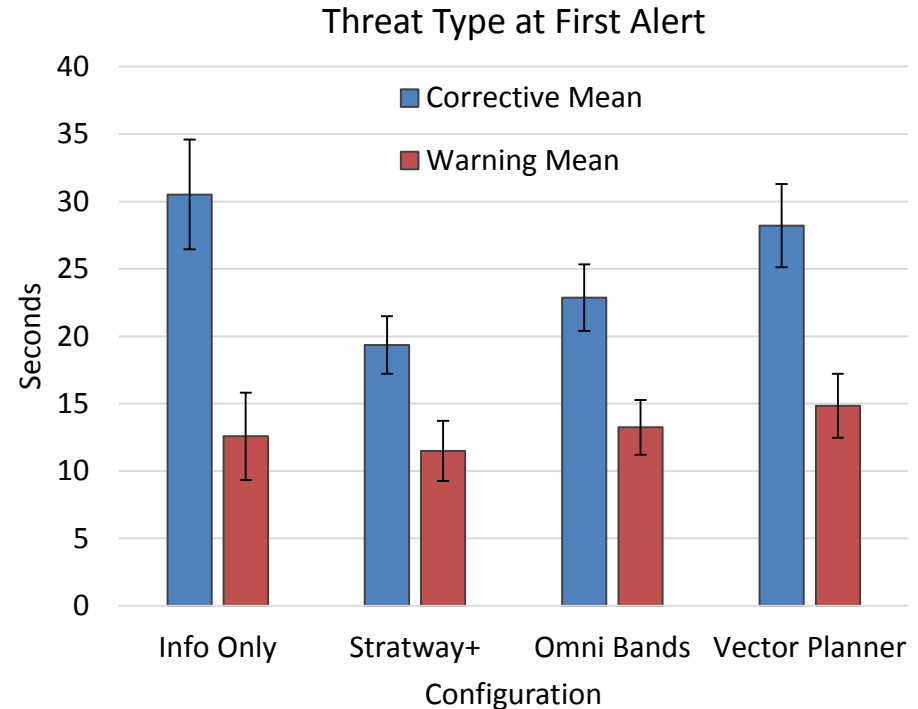
PT5 – Display Conditions

D1

D2

D3

D4

Threat Type at First Alert

Threat Type at First Alert
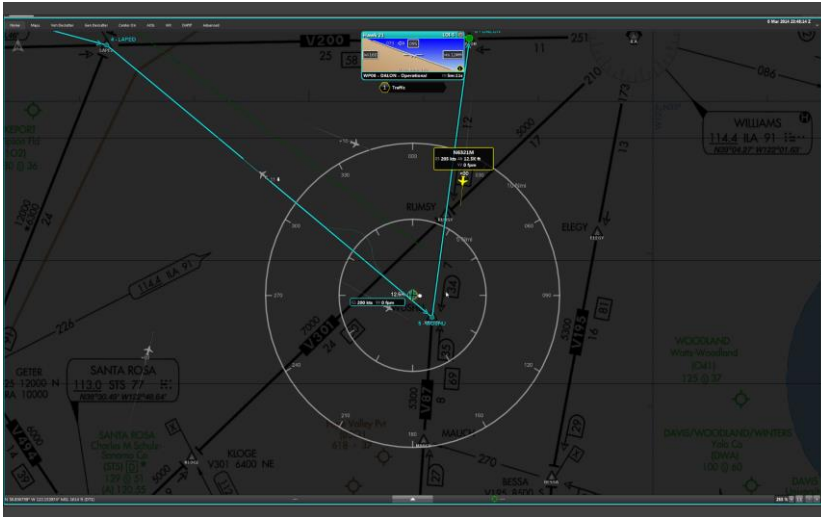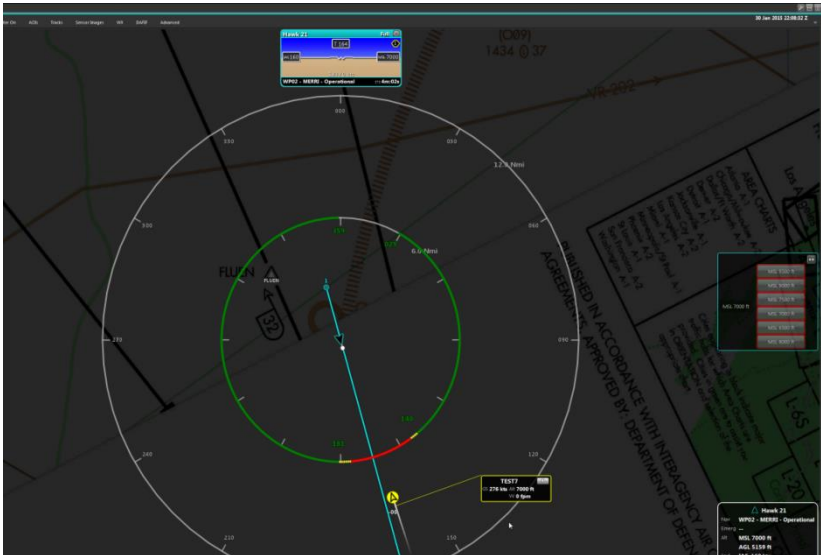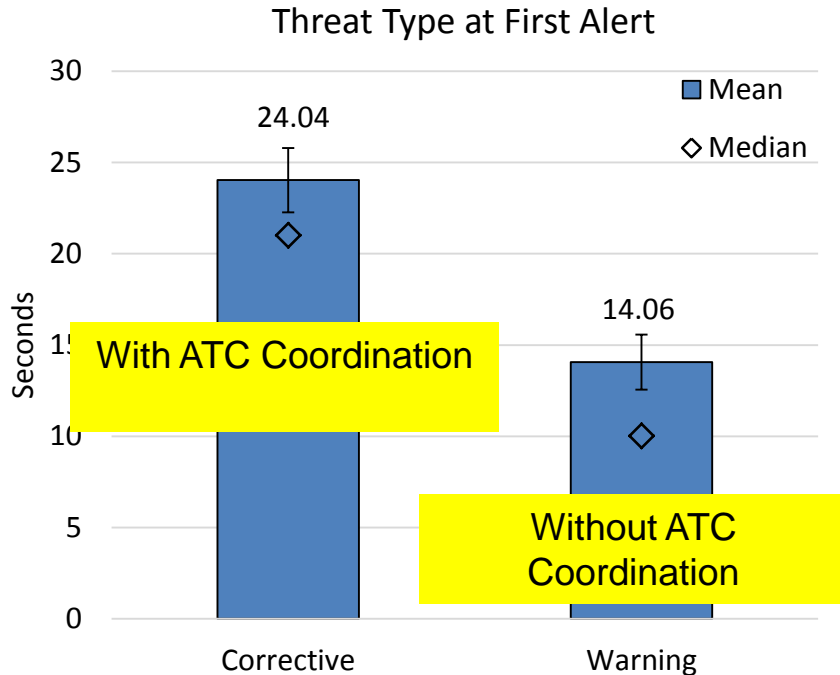
- Pilots responded, on average, **10s** faster to SS Warning Alerts than they did to Corrective SS Alerts
  - Pilots exhibited less variability between displays when responding to SS Warning Alerts than to Corrective SS Alerts
    - Range for SS Warning Alerts: 11s - 15s
    - Range for Corrective SS Alerts: 19s – 30s
  - Variability due to coordination with ATC – adds ~ 10 secs to total response time
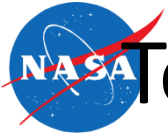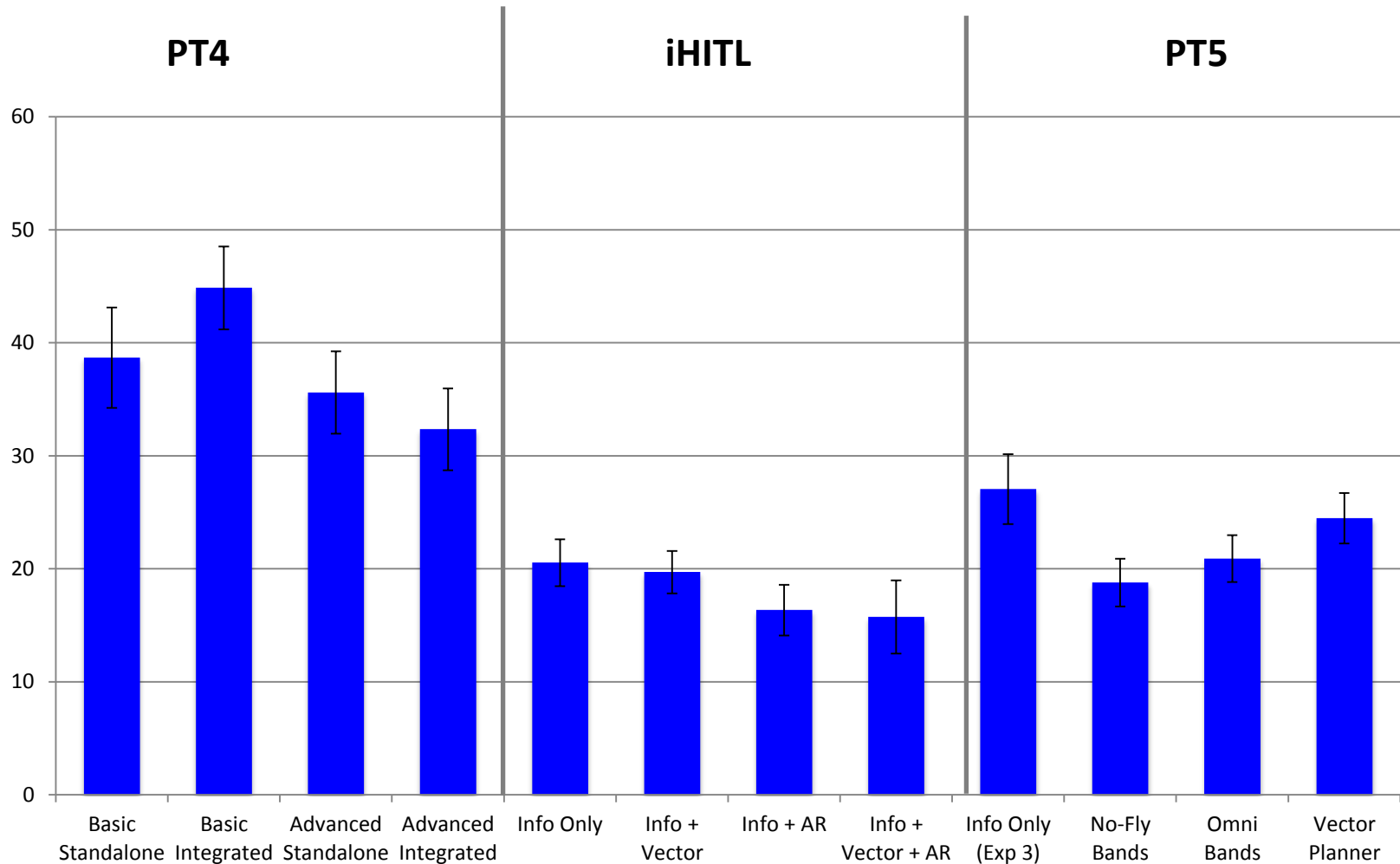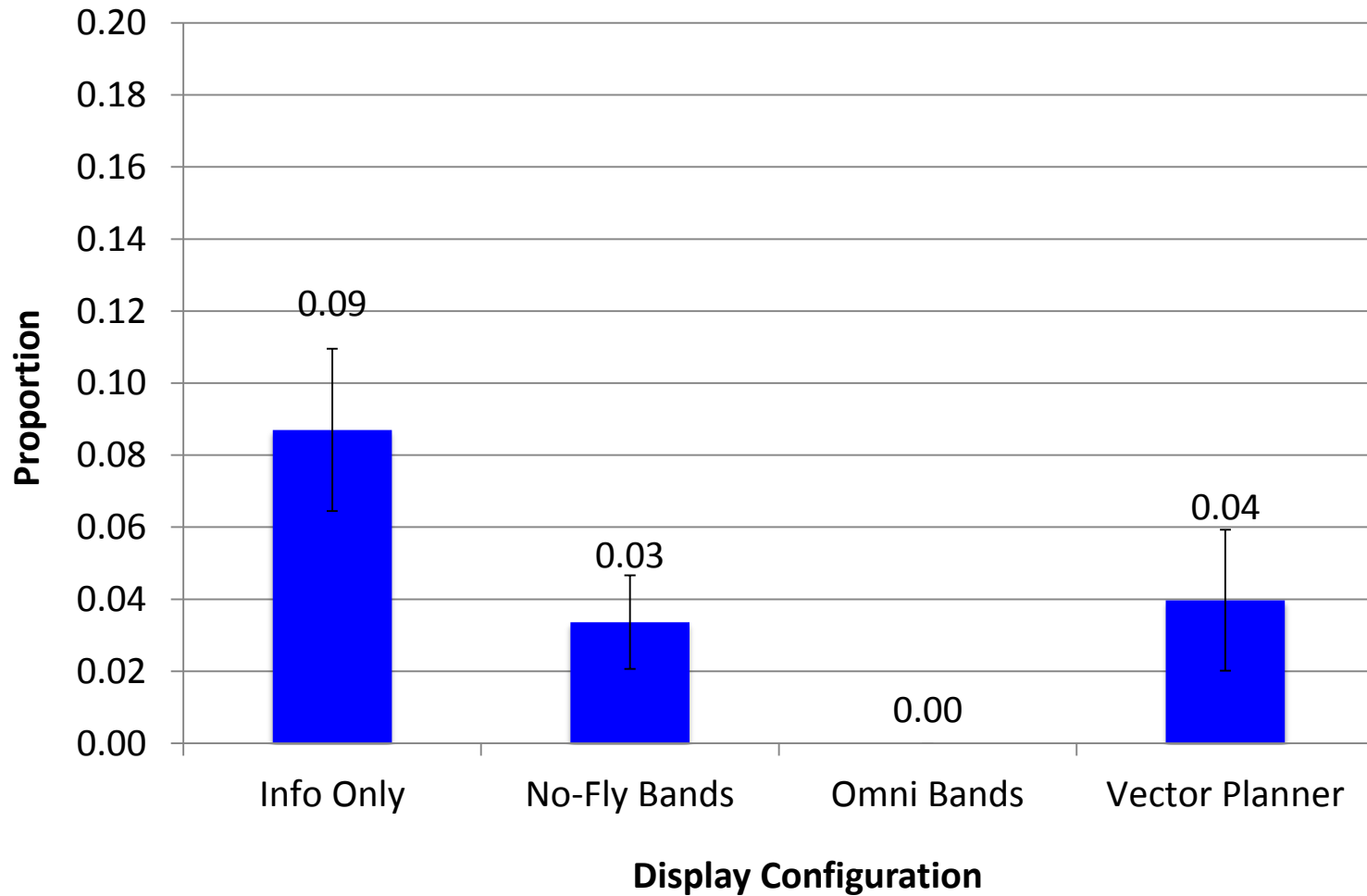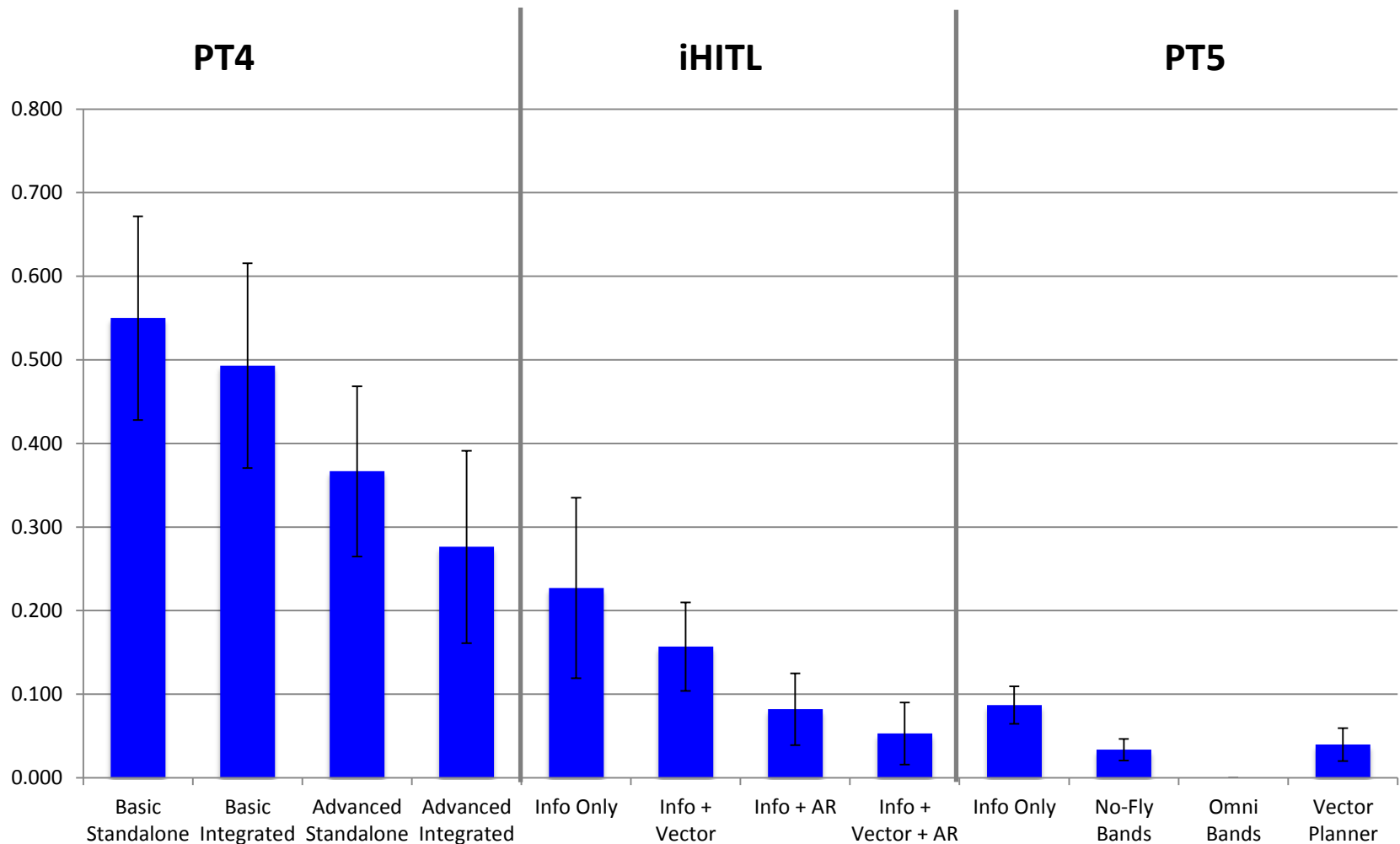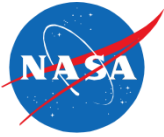
PT5 –Losses of Well Clear

Losses of Well Clear Proportions Across Simulations

Self-Separation Timeline

Time until CPA

~90 sec   ~80 sec   ~65 sec   ~35 sec   0 sec

Latency   **ATC Interaction Time (~10 sec)**   **Pilot Response Time (~15 sec)**   **Aircraft Maneuver Time (~30 sec)**   **Well Clear Threshold (~35 sec)**   NMAC

TOTAL RESPONSE TIME:

Approximate detection range = 8 nm

Detect Intruders

Approximate detection range = 6 nm

Pilots Determine Resolution

**Negotiate Clearance with ATC and uplink maneuver to aircraft**
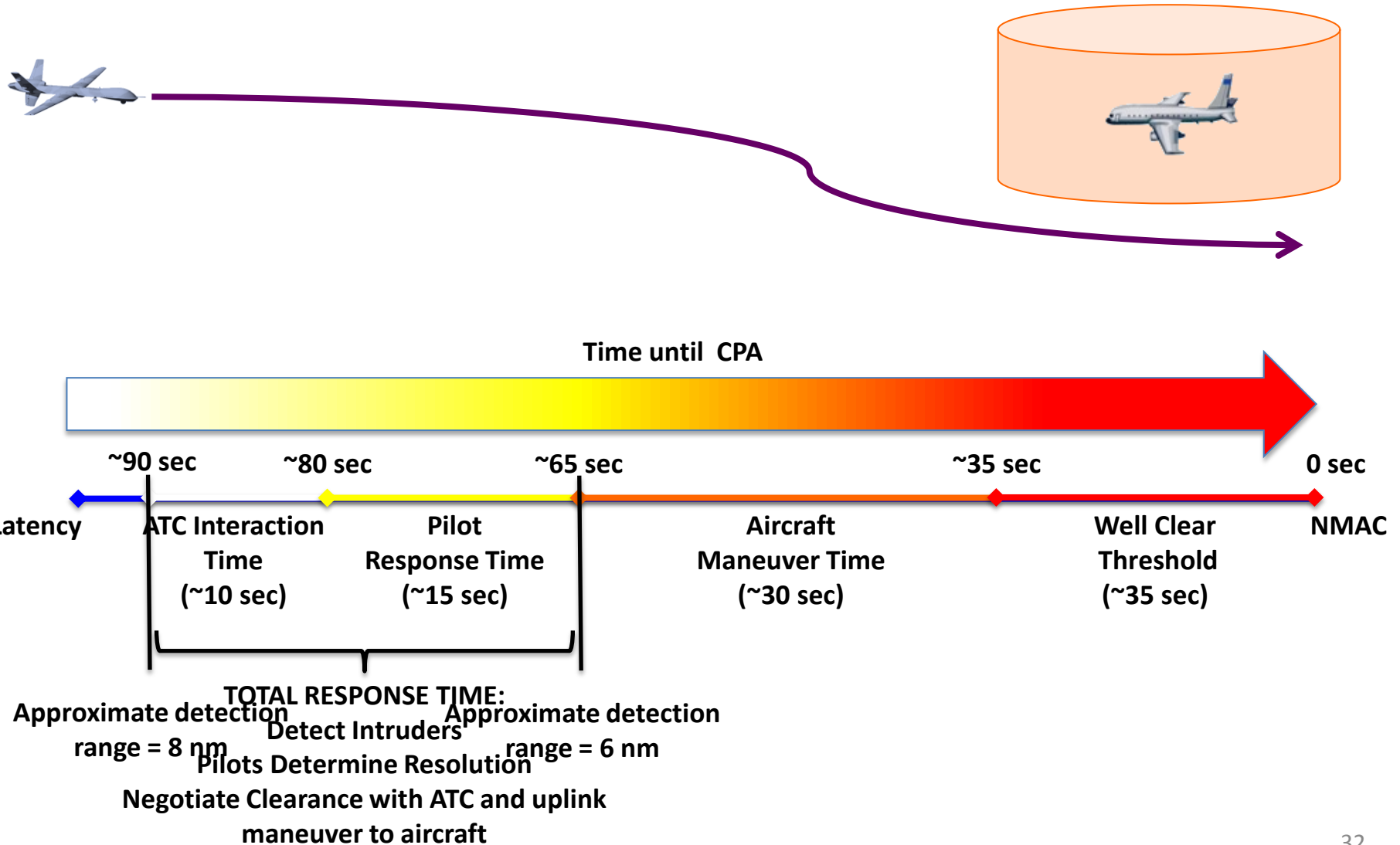
PT5 – Results Summary

- Suggestive guidance in the form of banding resulted in *safer* and *more timely* maneuvers away from conflicts
  - Lower overall proportion of LoWC for both banding displays (none for omni bands)
  - Least severe LoWC for both banding displays; most severe with info only
  - Shorter Total RTs for both banding displays
  - Pilots self-report as preferring the banding displays
- Results support decision for suggestive guidance as a minimum information requirement for DAA displays
  - Although Vector Planner display had similar performance, design approach not according to good HF principles and very poor performance compared to Omni Bands (despite same underlying algorithm)
- Results indicate that pilots can respond to a DAA Warning alert (no ATC coordination required) in ~ 15 seconds
- Results indicate that pilots can respond to a DAA Corrective alert (ATC coordination **is** required) in ~ 25 seconds
- ATC coordination adds approximately 10 seconds to DAA timeline
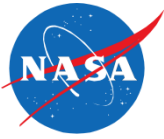
DAA-TCAS Interoperability HITL Overview

- Goal: Examine two remaining issues for SC-228 HMI MOPS

  - How to display "well clear recovery" guidance

  - How to interoperate with TCAS II

- Method:

  - Employ a part-task HITL design to examine pilot comprehension and performance responding to DAA and TCAS alerting and guidance near well clear and collision avoidance boundaries

Method: Experimental Design

- 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

Method: Experimental Design
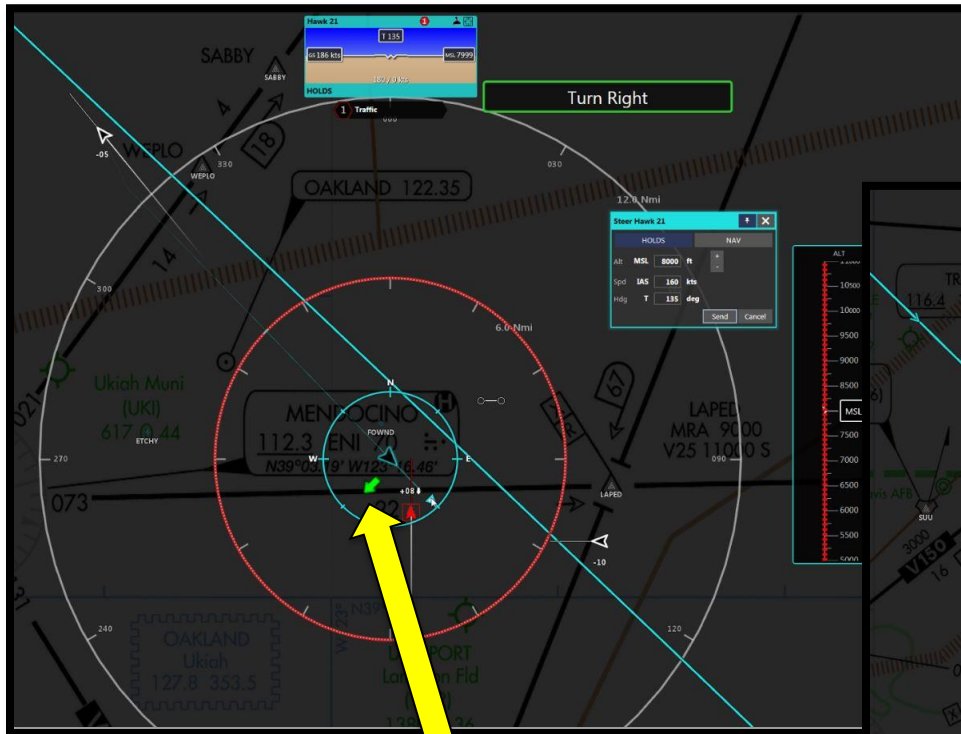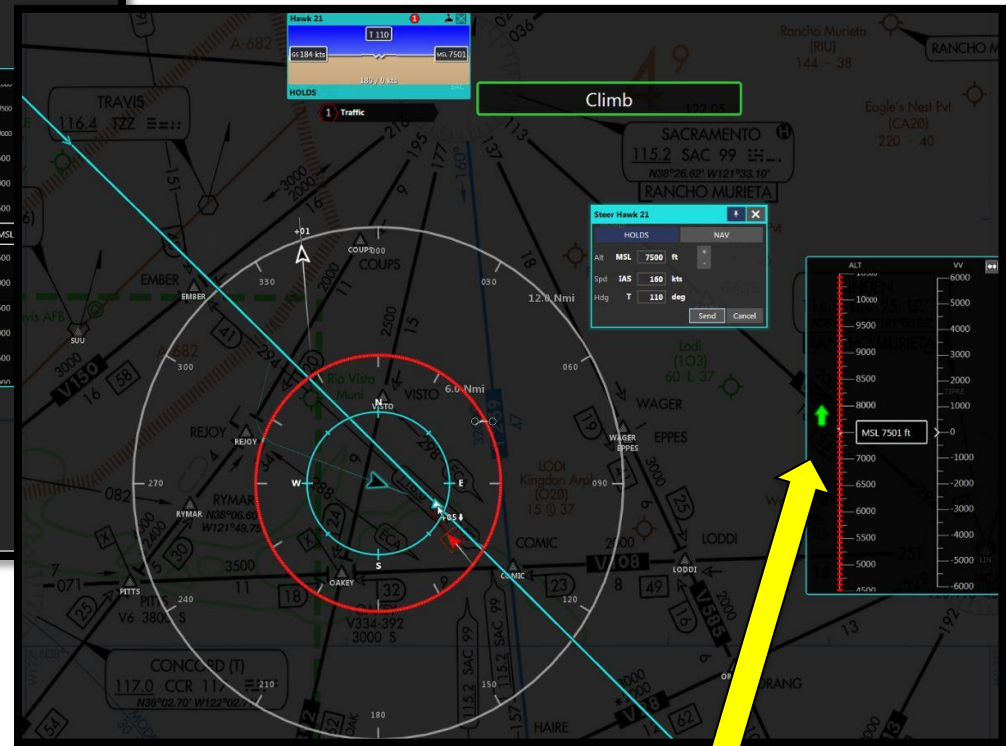

Horizontal Guidance
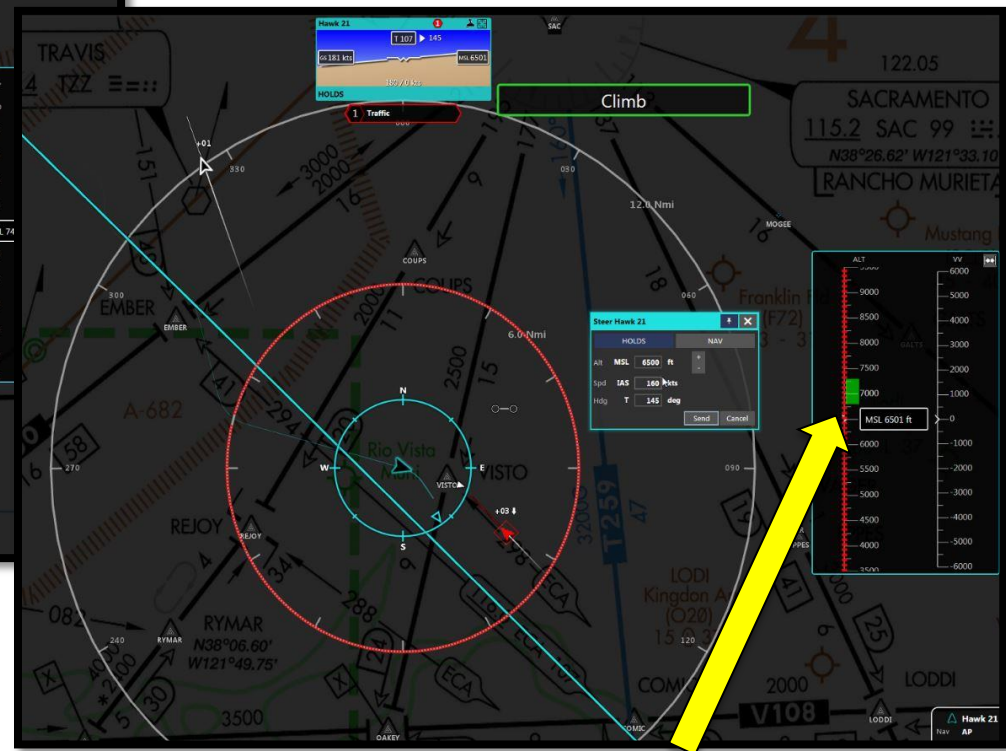
Vertical Guidance

Limited Suggestive
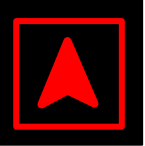
Method: Experimental Design
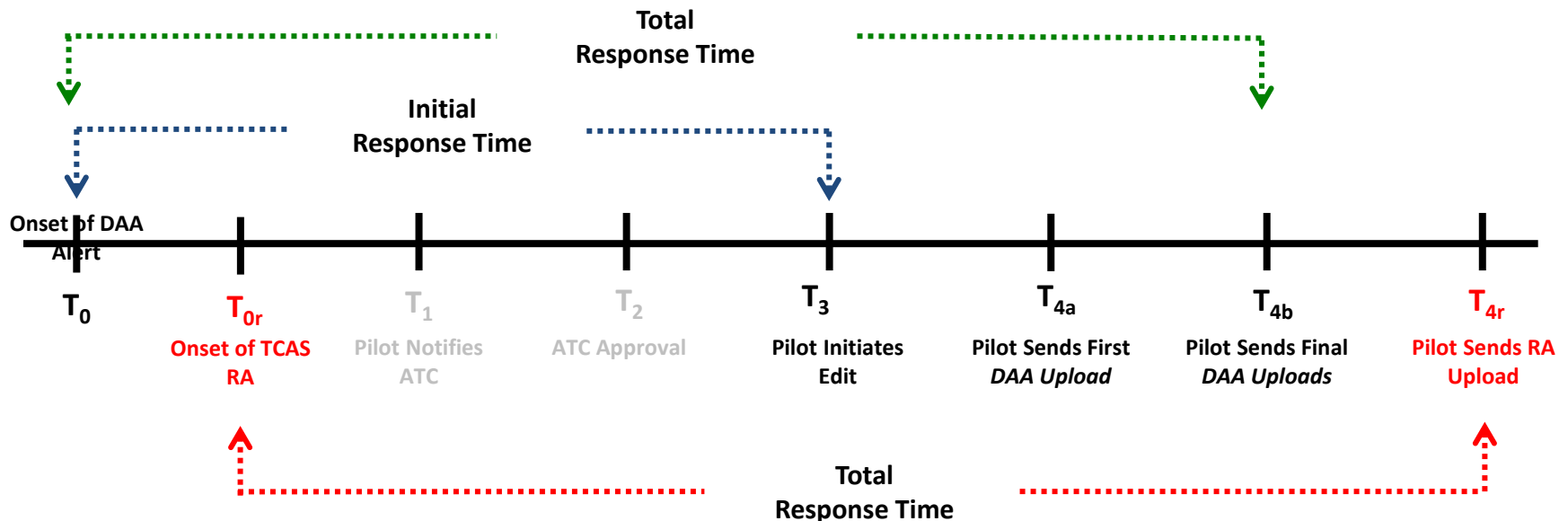

Horizontal Guidance

Vertical Guidance

Directional

DAA-TCAS Alerting Structure

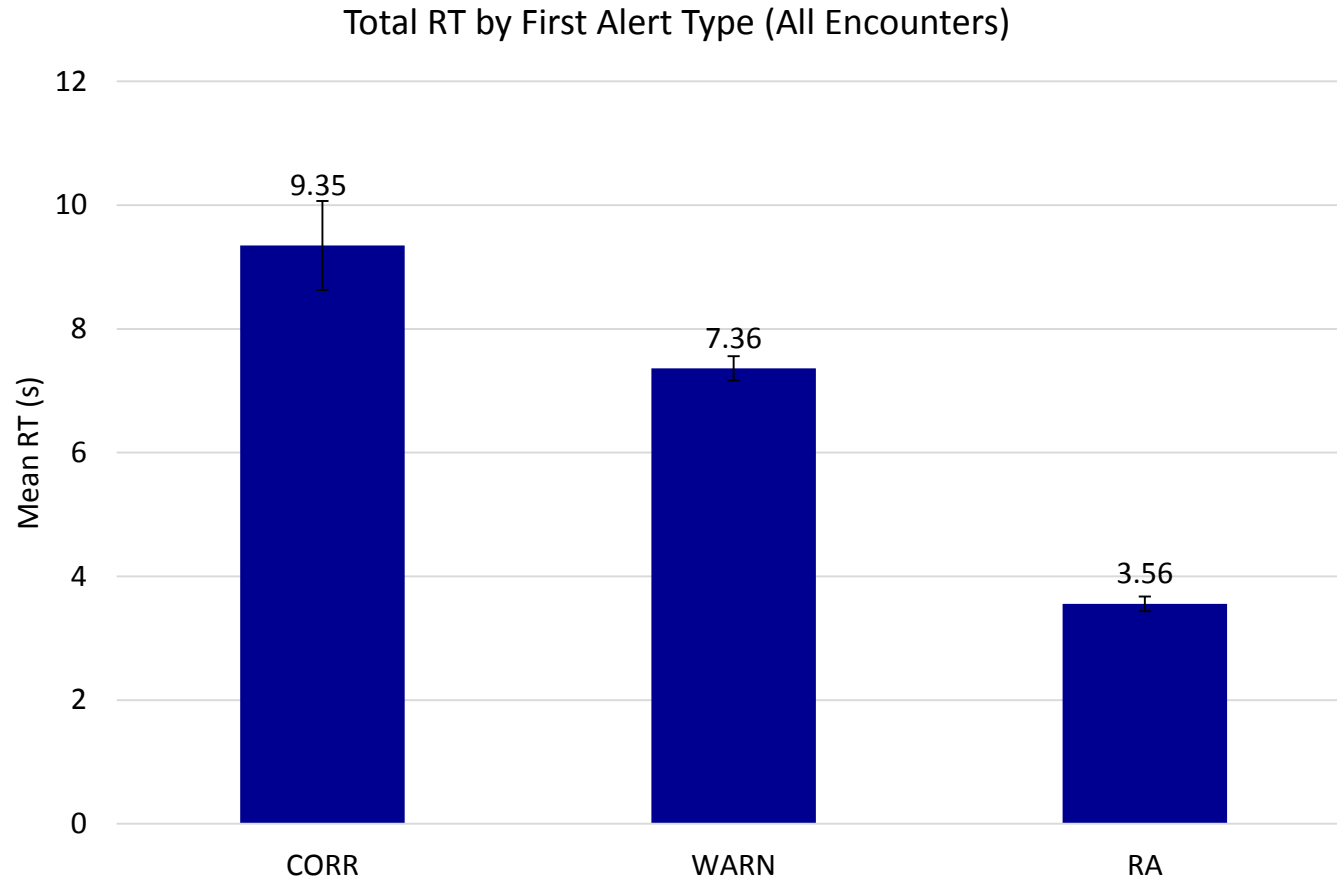| Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Alerting Time Threshold	Aural Alert Verbiage
(red square with arrow)	TCAS RA	• **Immediate action required** • Comply with RA sense and vertical rate • Notify ATC as soon as practicable after taking action	(Driven by TCAS-II)	x	"Climb/Descend"
(red square with red arrow)	DAA Warning Alert	• ***Immediate action required*** • 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 approximate: 60 sec)	"Traffic, Maneuver Now"
(yellow circle with arrow)	DAA Corrective Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
(yellow circle outline with arrow)	DAA Preventive Alert	• On current course, corrective action ***should not be required*** • Monitor for intruder course changes • Talk with ATC if desired	DMOD = 1.0 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
(white arrow outline)	Remaining Traffic	• No action expected	Within surveillance field of regard	X	N/A

Metrics

- Measured Response timeline modified slightly to account for "mini HITL" configuration
  - Pilot-ATC communications not recorded
  - Uploads in response to TCAS RAs given a dedicated timestamp
    - Allowed us to have measure of pilot responses to DAA and TCAS in the event they made multiple uploads

Total Response Time

Initial Response Time

Total Response Time

Onset of DAA Alert

T_0	T_{0r}	T_1	T_2	T_3	T_{4a}	T_{4b}	T_{4r}
	Onset of TCAS RA	Pilot Notifies ATC	ATC Approval	**Pilot Initiates Edit**	**Pilot Sends First** *DAA Upload*	**Pilot Sends Final** *DAA Uploads*	**Pilot Sends RA Upload**

TCAS II Overall Results

Pilot Total Response Time by Threat Type at First Alert

Total RT by First Alert Type (All Encounters)

TCAS Interop Discussion

- Overall, data provides support for the DAA-TCAS Interoperability concept developed at the TCAS Interoperability Workshop:
  - Pilots exhibit comprehension of, and appropriate prioritization within, the DAA alert structure with DAA warning alert and TCAS RA
  - Pilots show good compliance to well clear recovery and TCAS RA guidance
  - In many instances, pilots were able to prevent secondary conflicts with non-cooperative aircraft by inputting horizontal well clear recovery maneuvers prior to an RA being issued
- Instances of non-compliance reinforces key issue for DAA-TCAS Interoperability:
  - TCAS is unaware of non-cooperative aircraft and following RA guidance may result in secondary conflicts
    - This may cause pilots to non-comply or maneuver in opposite direction as TCAS RA guidance
  - Strong case for the need for ACAS Xu
- No substantive difference between different well clear recovery and DAA guidance displays
  - Allows flexibility for implementation by manufacturers

Summary
RTCA SC 228 Phase 1 MOPS

- Suggestive Displays
  - Guidance Bands
- Integrated or stand alone*
- Alerting Logic
- Minimum Information tags
- TCAS/DAA interop logic
- Well Clear Recovery logic/display
- Pilot response timeline
  - Derived RADAR Requirements

Next Steps

- Eng Anal – Missing/incorrect data (just completed)
- V & V Simulation (June, 2016)
- Support SC 228 Phase 2 MOPS
  - Terminal Areas
  - ACAS-Xu
  - Alternative Sensors
  - GBSAA
  - Mid-size A/C
- Support ICAO – RPAS - Human In The System (HITS) working group
- "Common" GCS
- GCS Guidelines

Questions?