National Aeronautics and Space Administration

UAS Integration in the NAS Project

An Evaluation of Detect and Avoid Displays for UAS: The Effect of Information Level and Display Location on Pilot Performance

Presented By:

Conrad Rorie, *San Jose State University*, conrad.rorie@nasa.gov

Co-Authors:

Lisa Fern, *San Jose State University*, lisa.fern.nasa.gov

Jessica Pack, *Infoscitex Corporation*, jessica.pack.ctr@us.af.mil

Jay Shively, *NASA Ames Research Center*, robert.j.shively@nasa.gov

Mark H. Draper, *Air Force Research Laboratory*, mark.draper.2@us.af.mil

25 JUNE 2015

Air Force Research Laboratory

Introduction

- UAS in the NAS Project
  - Developed to help address technical barriers to integration of unmanned aircraft systems (UAS) into the national airspace system (NAS)
    - Findings help guide development of RTCA Special Committee 228's Minimum Operational Performance Standards (MOPS) for UAS
  - An outstanding technical barrier is providing UAS pilots with a means to "detect and avoid" other aircraft
    - Means of compliance with 14CFR, Section 91.113 - pilots must remain *well clear* from other aircraft through "see and avoid"
- Detect and Avoid (DAA) System
  - A collection of technologies - consisting of both hardware & software – that can provide pilots with the necessary information to self-separate from other aircraft
  - A traffic display would serve as substitute for manned pilots' ability to see outside their aircraft
  - Critical question: what are the display requirements for such a system?

Introduction

- DAA Display Research
  - Several part-task studies have looked UAS traffic display
    - Friedman-Berg et al. (2014) & Draper et al. (2014) focused on identifying the minimum information requirements
      - Results were largely in agreement, most significant difference being the inclusion of maneuver recommendations (display guidance) in Draper et al.
    - Bell (2012) found that "advanced" displays – i.e., those that provided a level of display guidance – led to less severe separation violations than displays without guidance

Intruder Information	Friedman-Berg et al. (2014)	Draper et al. (2014)	Bell (2012)
Aircraft ID	✓	✓	
Intruder Position & Direction	✓	✓	✓
Range	✓	✓	✓
Bearing	✓	✓	✓
Altitude	✓	✓	✓
Alert Level/Threat Status	✓	✓	✓
Vertical & Horizontal Trend	✓		
Display Guidance		✓	✓

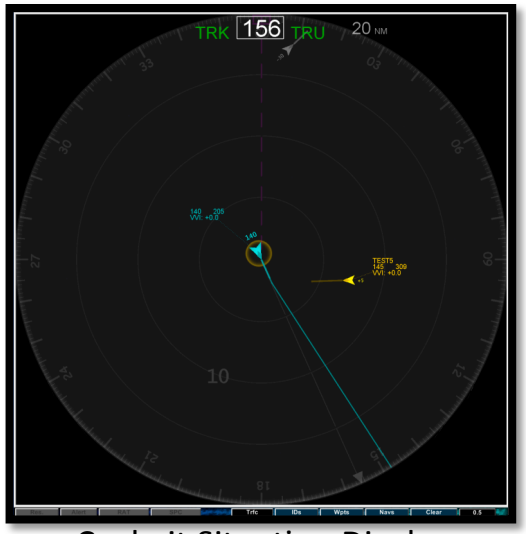
Introduction

- Current Study:
  - Continues examination of DAA display requirements within a "full mission" task environment
    - Tests different information levels (no guidance vs. guidance) and location of the traffic information
      - Standalone (i.e., bootstrap) displays may be easier to develop, but may hinder performance relative to displays integrated into command and control interface
    - Focus on the displays' impact on pilots' measured response (MR)
  - MR can be understood as the quantification of the end-to-end response time for a UAS pilot to complete a self separation maneuver in response to a DAA display alert
    - Measured response metrics can reveal the amount of time pilots spent interacting with different displays, allowing direct comparisons
    - Longer MR times may result in delayed maneuvering, which can in turn increase likelihood of a separation violation
    - MR times can also inform human response models that are used in fast-time simulation and the alerting threshold parameters used by the alerting logic

Method

- Participants
  - 12 active UAS pilots (M = 39 years of age)
    - All had military UAS experience (avg. 216 hrs)
    - 8/12 had civil UAS experience (avg. 60 hrs)
- Simulation Environment
  - Ground Control Station
    - Vigilant Spirit Control Station (VSCS; right)
      - Provided command and control interfaces, aircraft information, and a simulated out-the-window view, across 3 monitors
      - Displayed traffic information in select conditions
      - Mouse and keyboard inputs only
    - Cockpit Situation Display (CSD; right)
      - Standalone CDTI only active in select conditions
      - One monitor, directly to left of VSCS monitors

Vigilant Spirit Control Station



Cockpit Situation Display

Method

- 2 x 2 Repeated Measures Experimental Design
  - *Information Level*:
    - Basic Information
      - Standard intruder information (as set by Friedman-Berg et al., 2014)
        - » No display guidance
      - Multi-level alerting
    - Advanced Information
      - Standard intruder information
      - Multi-level alerting
        - » Included additional level
      - Suite of guidance tools
        - » Trial planning tools
        - » Recommended Maneuvers
  - *Display Location*:
    - Standalone Display
      - Information presented within CSD
      - Pilots still used VSCS to input changes to aircraft
    - Integrated Display
      - Information presented within VSCS command and control interface

Method

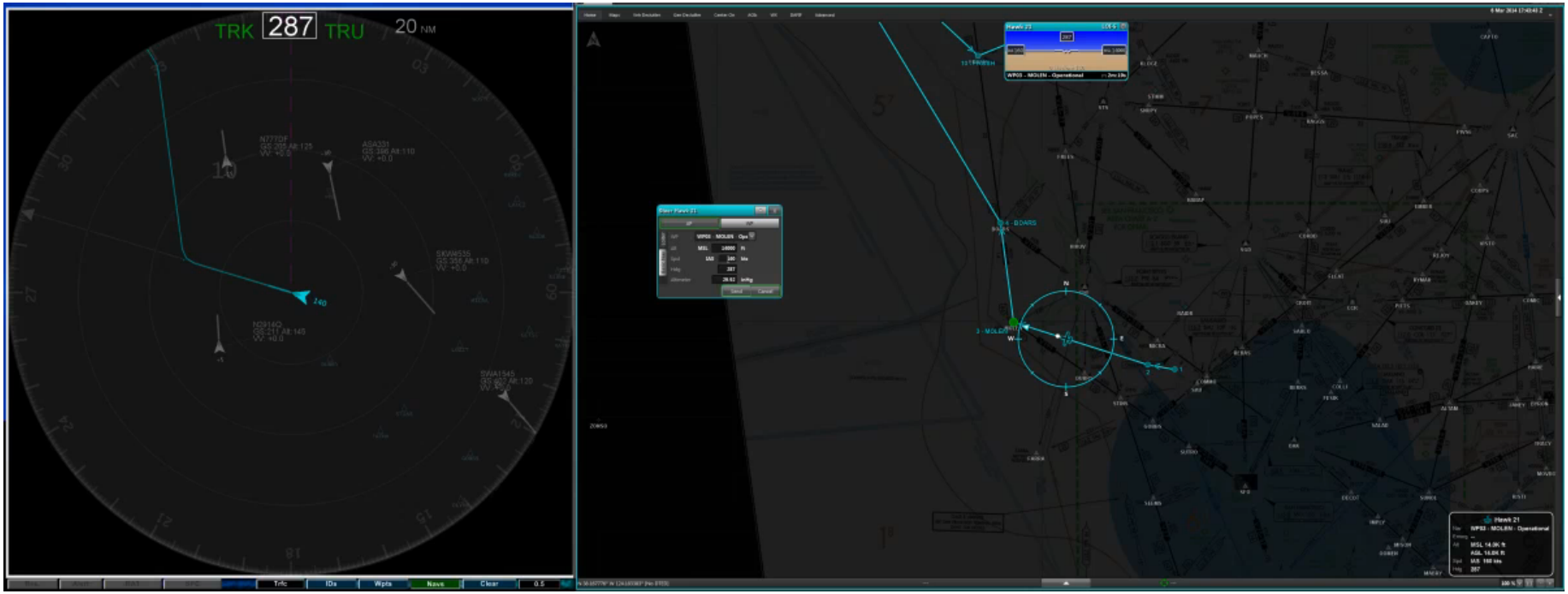
- Multi-Level Alerting
  - Visual and auditory alerts tied to predicted threat level of nearby traffic
  - Based on predicted closest point of approach (CPA) between ownship and intruder
    - Horizontal miss distance (HMD), vertical miss distance (ZTHR), and time to CPA criteria all had to be satisfied to be assigned given threat level
  - Pilots instructed to maneuver *prior* to collision avoidance alert being generated, which was their indication that separation had been lost

Alert/Threat Level	HMD	ZTHR	Time to CPA	Symbol
Proximal	> 2 NM	> 900 FT	N/A	
Preventative	< 2 NM	< 900 FT	< 120 secs	
Self Separation	< 1.2 NM	< 900 FT	< 110 secs	
Predicted CA Alert*	< 0.8 NM	< 400 FT	< 110 secs	
Collision Avoidance	< 0.8 NM	< 400 FT	< 40 secs	

**Only present in the Advanced Information display conditions*

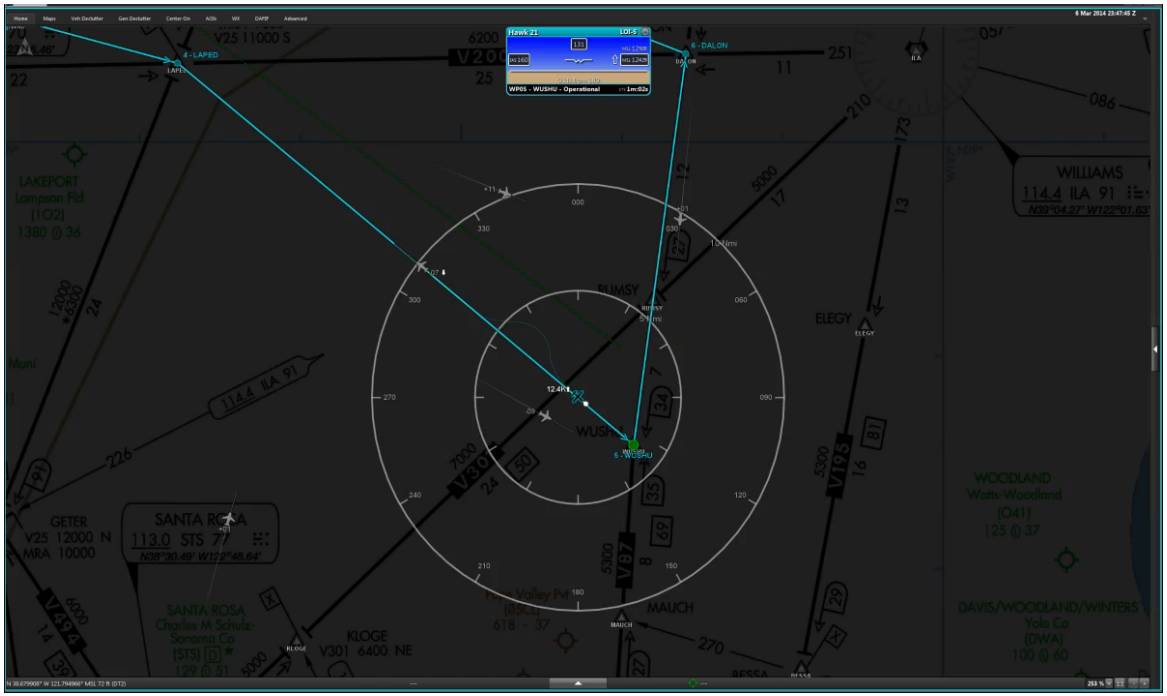
Method

1. Basic Standalone Display
   - Standard intruder information and multi-level alerting presented within CSD
     - No display guidance provided
     - VSCS served as command-and-control interface



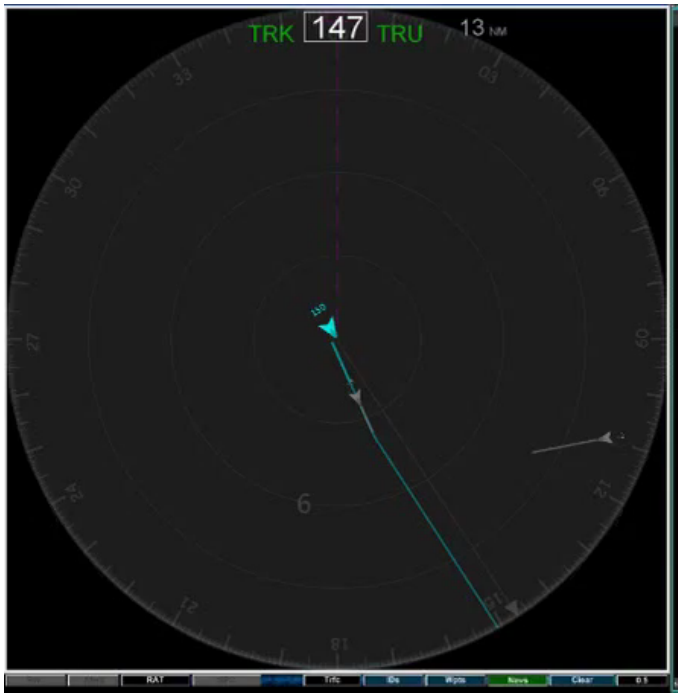
Method

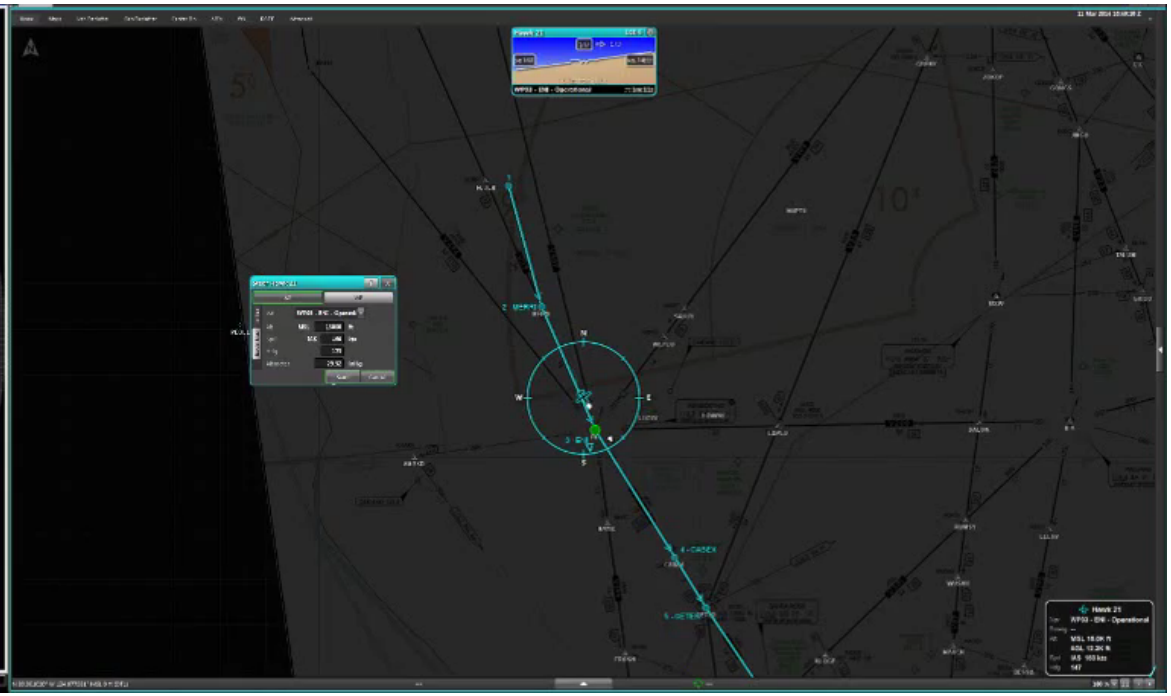
2. Basic Integrated Display
   - Standard intruder information and multi-level alerting presented within VSCS
     - No display guidance provided
     - Traffic info collocated with vehicle control interfaces



Method

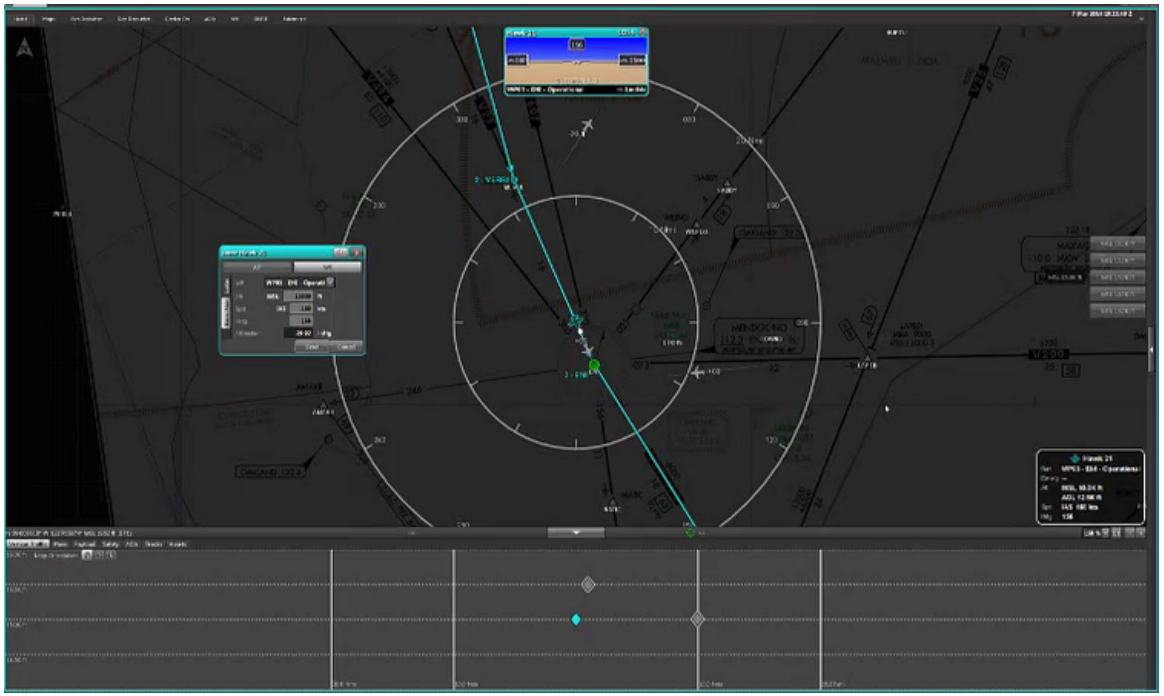
3. Advanced Standalone Display
   - Display guidance included, in addition to standard info and alerting:
     - Trial planning tools allowed pilots to test different heading/altitude maneuvers before uploading
     - Maneuver recommendations offered suggested solutions





Method

4. Advanced Integrated Display
   - Display guidance included, in addition to standard info and alerting
     - Trial planning tools allowed pilots to test different heading/altitude maneuvers before uploading
     - Maneuver recommendations offered suggested solutions



Method

- Pilot Task
  - Operate simulated MQ-9 Reaper within civil airspace, under Instrument Flight Rules
    - Routes contained entirely within Class E, Oakland Center airspace
      - Instructed to coordinate maneuvers with ATC (over push-to-talk headset)
    - Missions lasted 40 minutes
  - Maintain well clear from nearby aircraft
    - 8 scripted encounters with the ownship (i.e., would lose separation absent of pilot intervention)
    - Additional tracks were included to emulate busy day at Oakland Center
  - Attend to secondary tasks
    - Respond to requests for status information (e.g., current fuel level
    - Complete electronic checklists in response to system malfunctions

Method

- Confederate Participants
  - Retired ATC managed all aircraft within experimental airspace
  - "Pseudo" pilots controlled simulated manned aircraft within airspace
- A researcher coordinated in real-time to ensure conflicts were generated

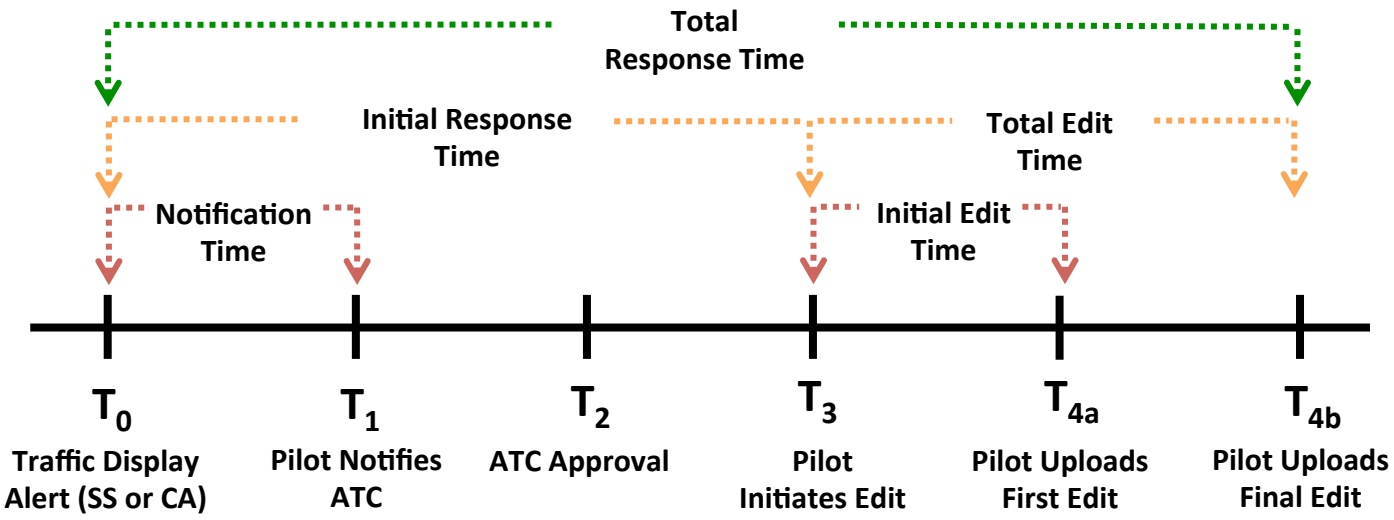
Method

- Measured Response Metrics
  - A pilot-DAA interaction timeline was constructed, with emphasis on the pilots' interaction with ATC and the GCS (below)
    - The timestamps for each stage of the timeline were collected from a variety of sources:
      - GCS output files, DAA algorithm output files, voice recordings and logs, and video recordings

Stage	Description
T_0	DAA (self separation or collision avoidance) alert appears on the display
T_1	Pilot notifies ATC and requests a maneuver clearance
T_2	ATC provides maneuver clearance
T_3	Pilot initiates an edit in GCS to maneuver
T_{4a}	Pilot uploads 1st maneuver to aircraft
T_{4b}	Pilot uploads final maneuver to aircraft

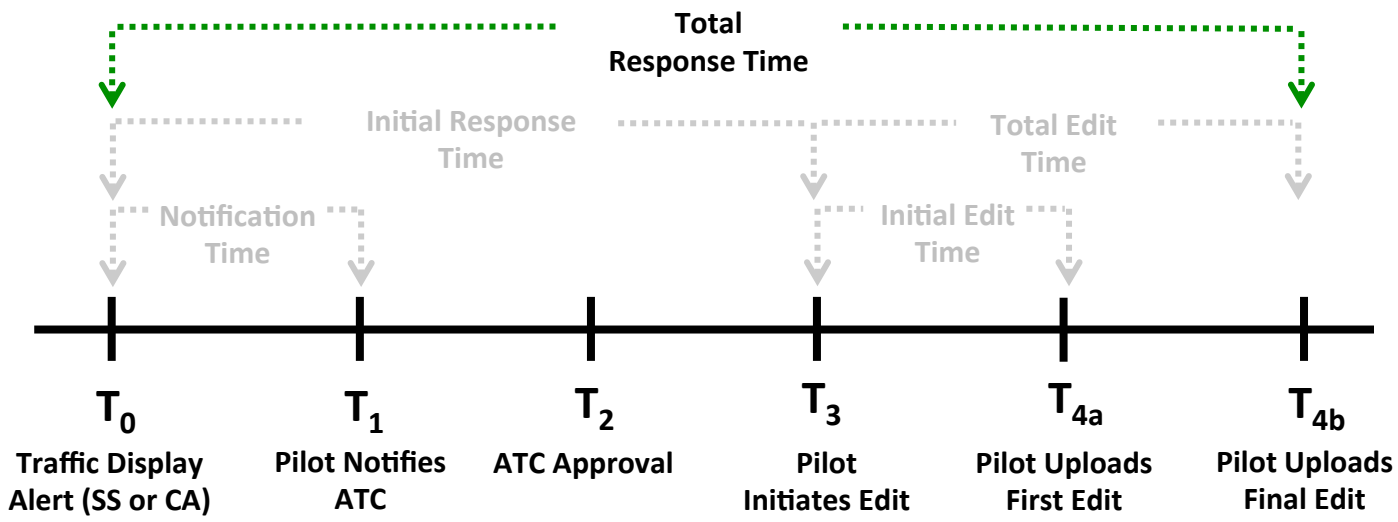
Method

- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - *Initial Response Time* (T_3-T_0) – how long it took the pilot to initiate an edit in the GCS
    - *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - *Notification Time* (T_1-T_0) – how long it took the pilot to notify ATC following an alert



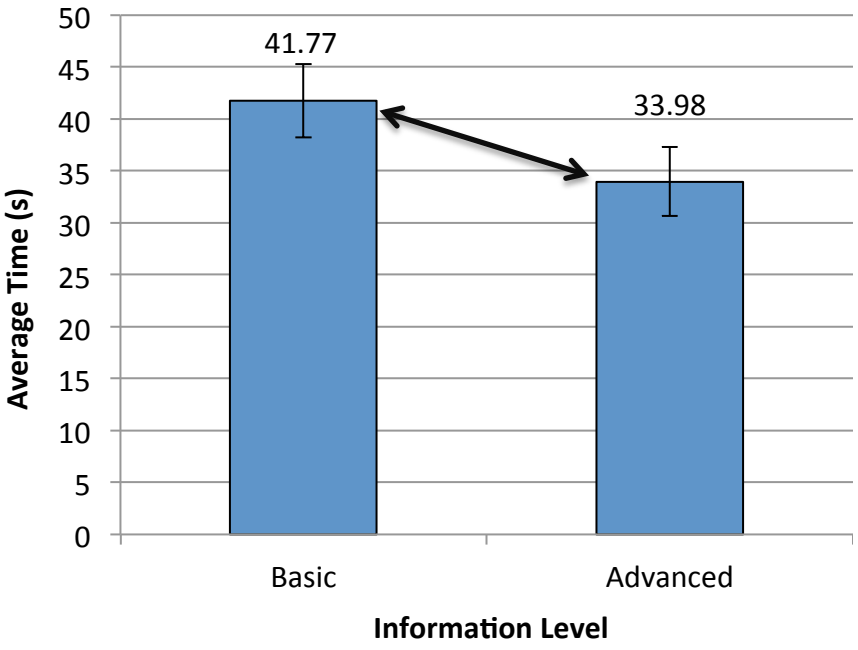
Results

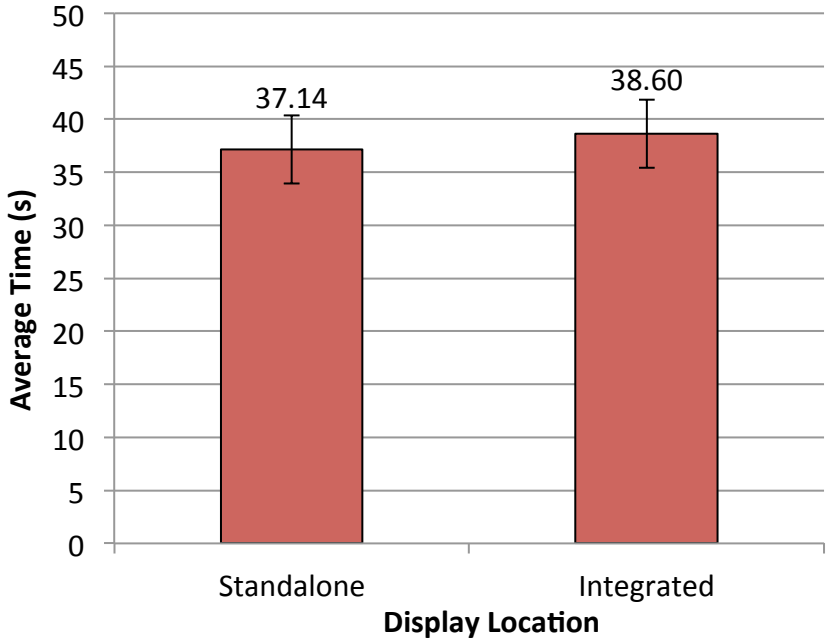
- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - *Initial Response Time* (T_3-T_0) – how long it took the pilot to initiate an edit in the GCS
    - *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - *Notification Time* (T_1-T_0) – how long it took the pilot to notify ATC following an alert



Results

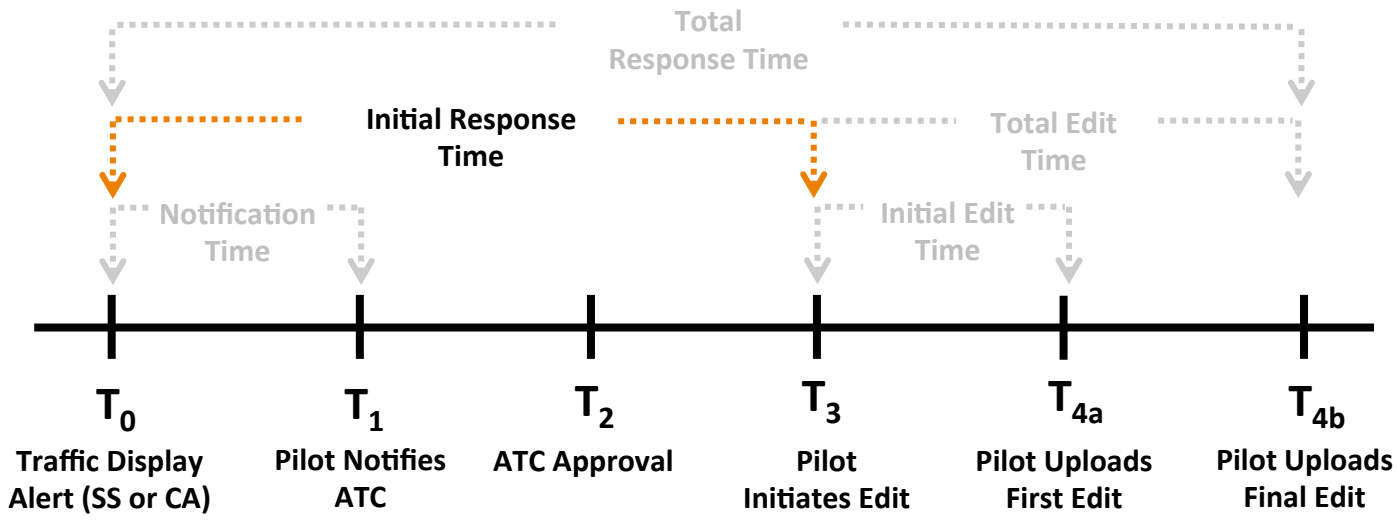
- Total Response Time
  - Significant main effect of Information Level on Total Response Times ($p < .05$)
    - Pilots took an average of **37.87s** to complete their final edit in response to SS/CA alerts (from first alert appearance)
      - Pilots **8s** faster (19%) on average in Advanced than Basic conditions
  - No other significant main effects or interaction





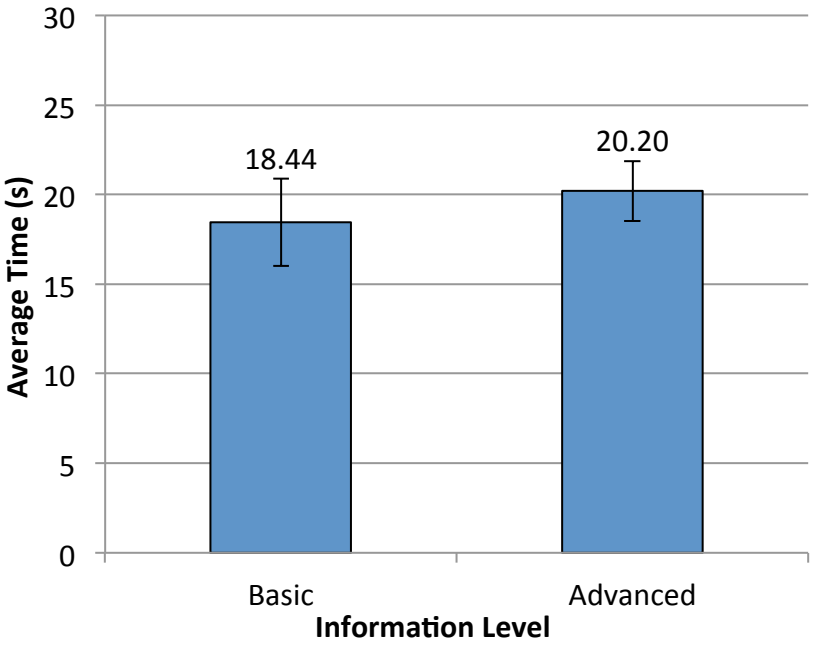
Results

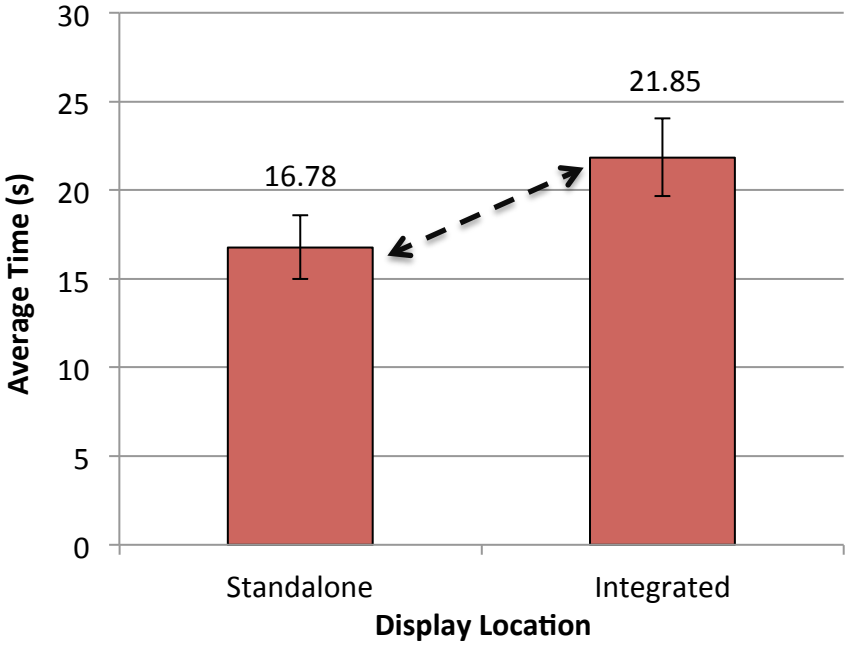
- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - *Initial Response Time* (T_3-T_0) – how long it took the pilot to initiate an edit in the GCS
    - *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - *Notification Time* (T_1-T_0) – how long it took the pilot to notify ATC following an alert



Results

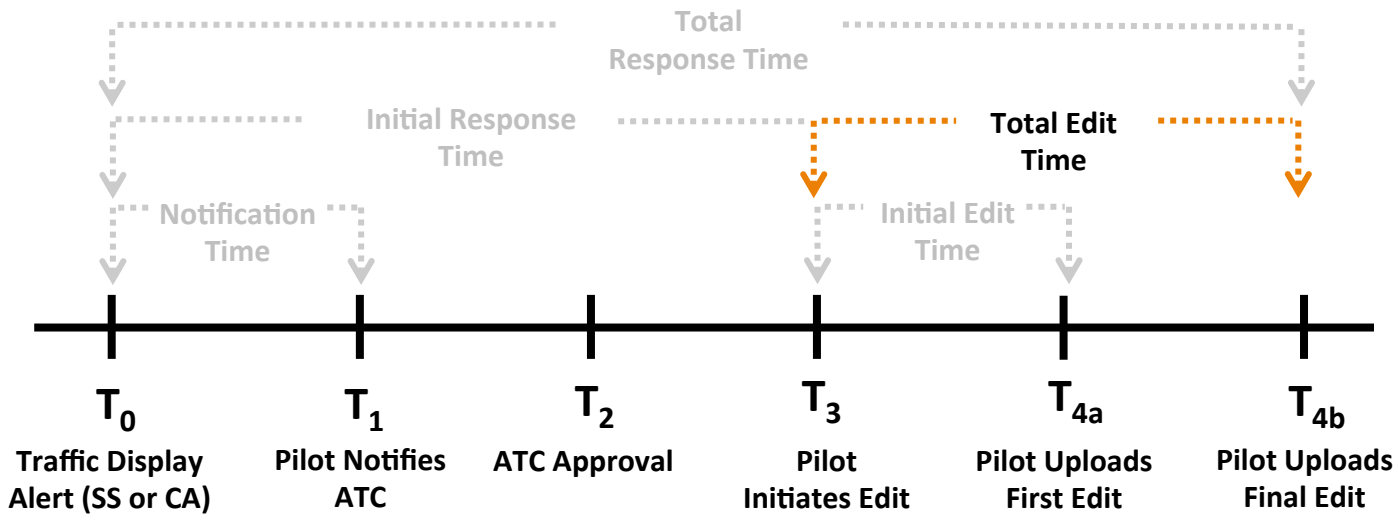
- Initial Response Time
  - Near significant effect of Display Location on Initial Response Times (p = .054)
    - Pilots took an average of **19.32s** to initiate an edit in response to a SS/CA alert
      - Pilots **5s** faster (23%) in Standalone display conditions
  - No other significant main effects or interaction





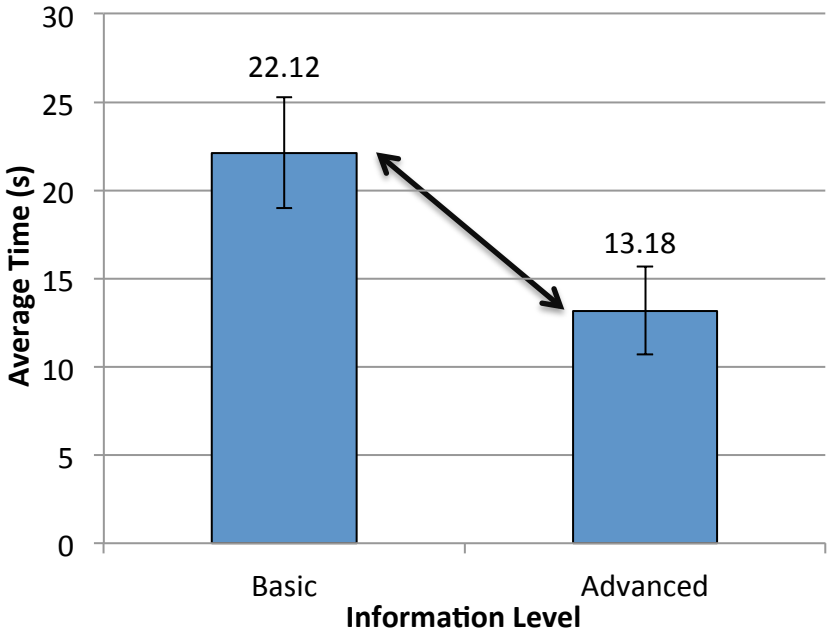
Results

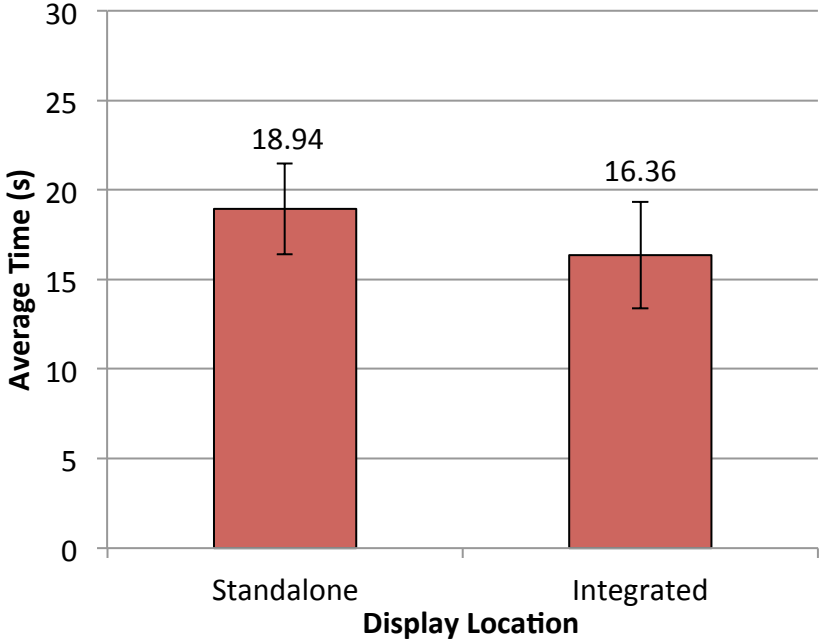
- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - *Initial Response Time* (T_3-T_0) – how long it took the pilot to initiate an edit in the GCS
    - *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - *Notification Time* (T_1-T_0) – how long it took the pilot to notify ATC following an alert



Results

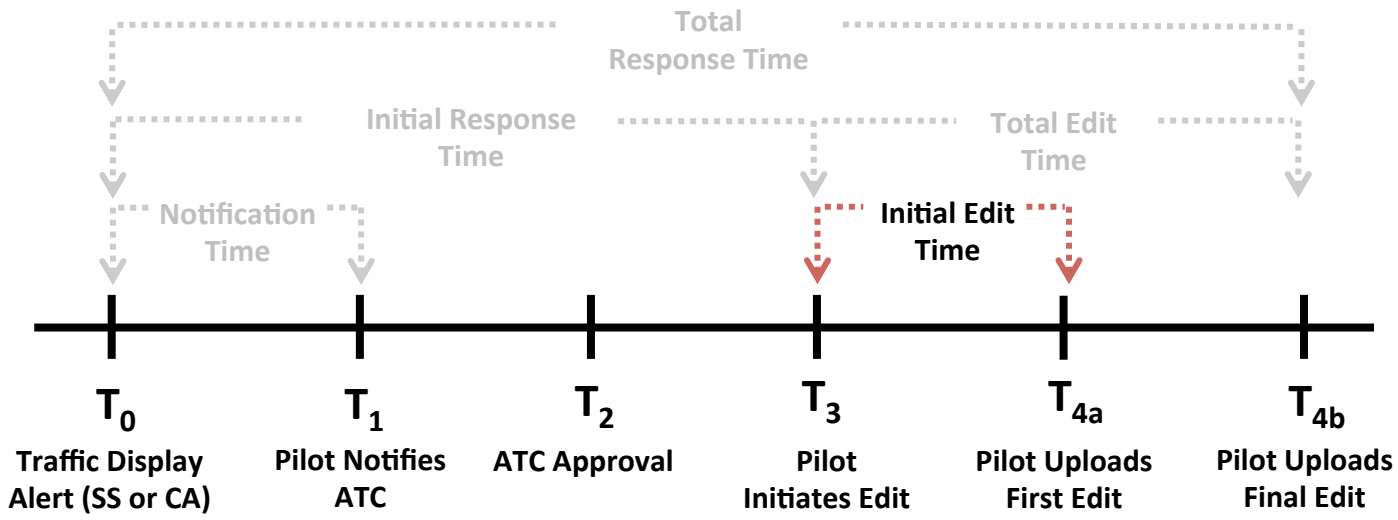
- Total Edit Time
  - Significant main effect of Information Level on Total Edit Times ($p < .01$)
    - Pilots took an average of **17.65s** to complete their final edit in response to SS/CA alerts
      - Pilots **9s** faster (40%) in Advanced display conditions
  - No other significant main effects or interaction





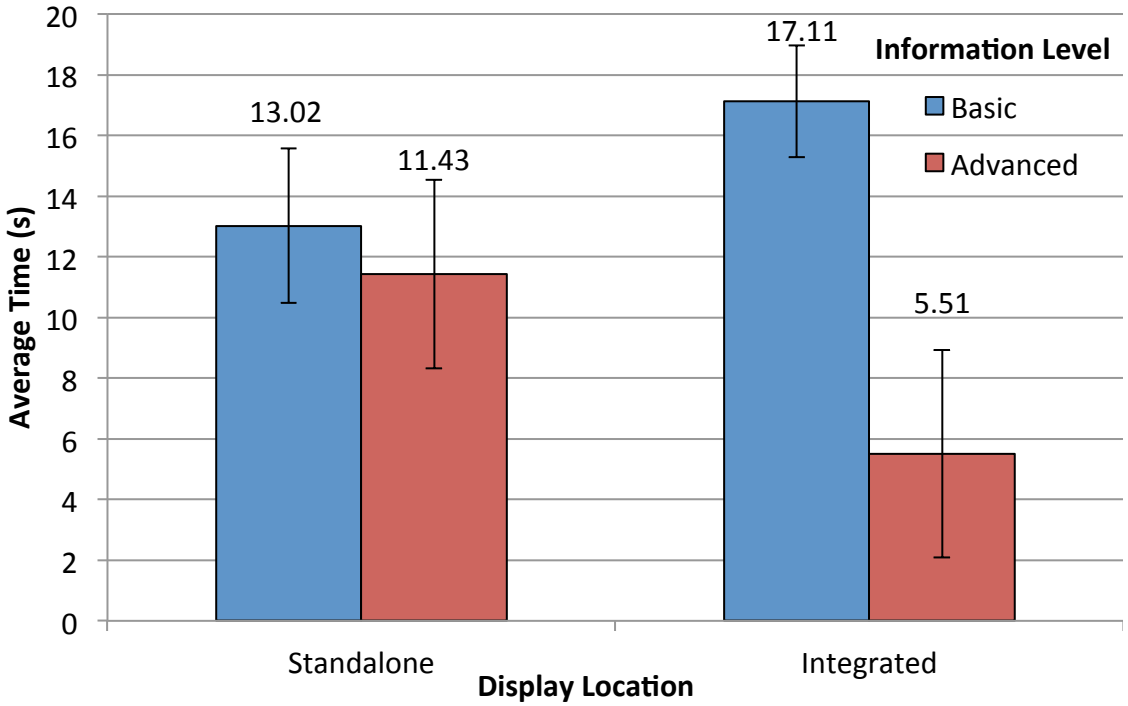
Results

- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - *Initial Response Time* (T_3-T_0) – how long it took the pilot to initiate an edit in the GCS
    - *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - *Notification Time* (T_1-T_0) – how long it took the pilot to notify ATC following an alert



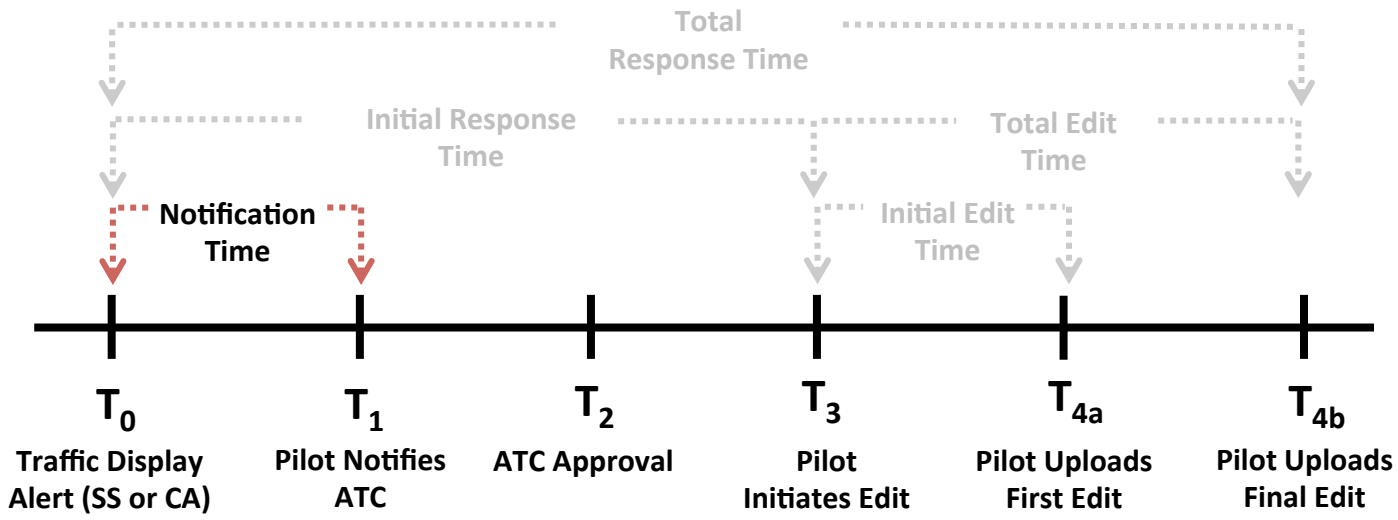
Results

- Initial Edit Time
  - Significant interaction between Information Level and Display Location on Initial Edit Times ($p < .01$)
    - Pilots took an average of **11.77s** to complete their first edit in response to SS/CA alerts
      - Difference between Basic and Advanced displays in Integrated conditions was **12s** (68%), while only **2.5s** (12%) in Standalone conditions
  - Information Level had a significant main effect ($p < .05$), **6.5s** faster in Advanced



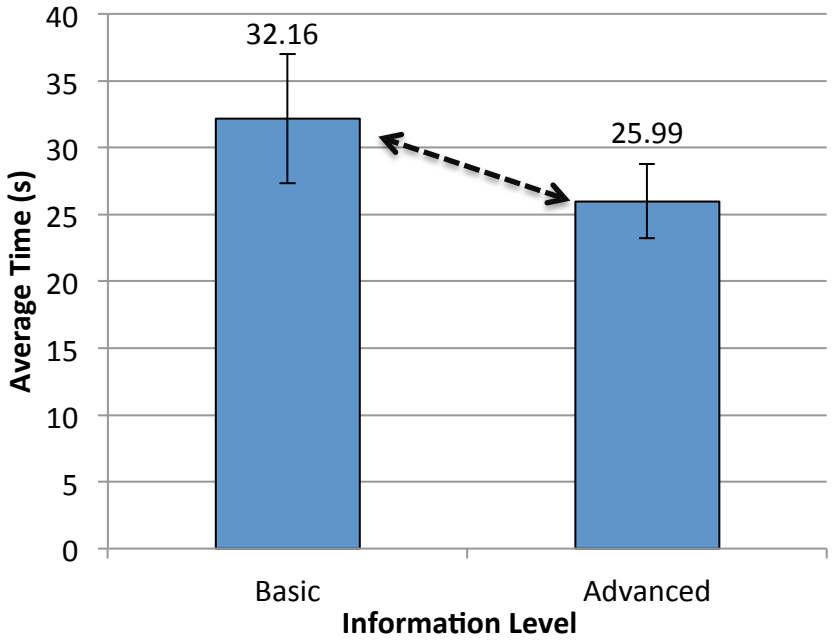
Results

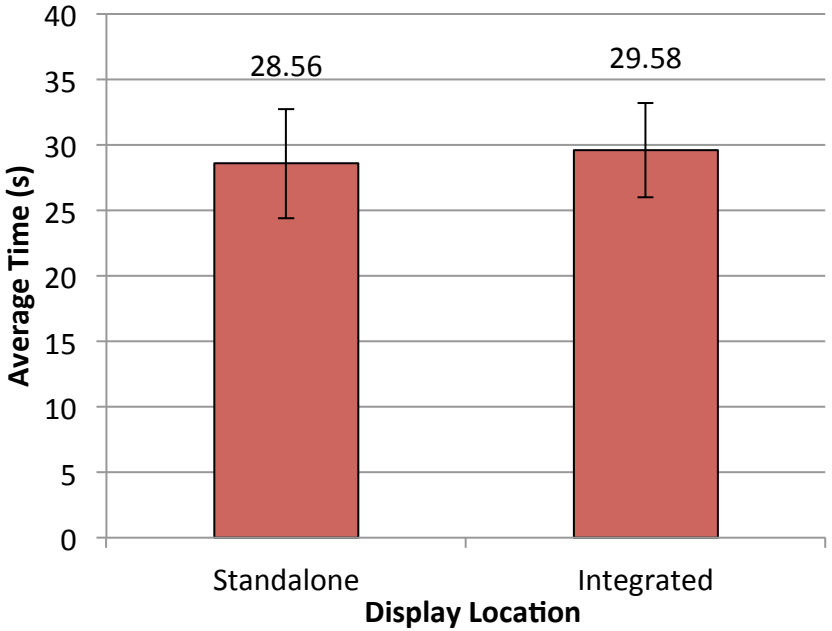
- Measured Response Metrics
  - From these timestamps, five metrics were extrapolated:
    - *Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
    - *Initial Response Time* (T_3-T_0) – how long it took the pilot to initiate an edit in the GCS
    - *Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
      - *Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
    - *Notification Time* (T_1-T_0) – how long it took the pilot to notify ATC following an alert



Results

- Notification Time
  - Near main effect of Information Level on Notification Times (p = .059)
    - Pilots took an average of **29.07s** to notify ATC of a maneuver in response to a SS/CA alert
      - Pilots **6s** faster (19%) in the Advanced information conditions
  - No other significant main effects or interaction





Results

- Summary
  - Advanced Information displays showed advantage in four of five reported metrics
    - Total Response Times 19% shorter in Advanced conditions
    - Total Edit Times 40% shorter in Advanced conditions
    - Initial Edit Times 70% shorter in Advanced Integrated condition than in the Basic Integrated condition
    - Notification Times 20% shorter in Advanced conditions
  - Overall benefit seen for lower Total Response Times was due to a reduction in *how long pilots spent interacting with the display*
    - Not how quickly they got 'in-the-loop' (Information Level did not impact Initial Response Times)
  - Display Location only approached significance in one of the metrics
    - Initial Response Times 23% shorter for Standalone display

Discussion

- Advanced Information
  - The presence of display guidance (in a variety of forms) reduced the amount of work required of the UAS pilot
    - The Advanced displays unambiguously alerted pilots of which self separation threats were predicted to lose well clear
    - The tools provided the pilot with a pre-determined maneuver, limiting the amount of time they had to spend calculating their own
  - Led to pilots contacting ATC more quickly
    - However it was clear that pilots often initiated edits prior to contacting ATC
      - Roughly 50% of maneuvers occurred without prior ATC approval
- Display Location
  - Did not have a significant impact on pilot performance
  - The lack of *immediate* pilot responses may have mitigated the lack of an effect of display location (Initial Response Times were on the order of **20s**)

Conclusion

- The first in a collection of studies, this sim demonstrated that Information Level, namely the absence or presence of display guidance, can substantially impact pilots' response times
  - Future studies have been conducted that look at different sorts of display guidance to see if certain implementations result in superior performance
- This data is supplemental to other objective metrics – mainly rates of separation violations and pilot feedback – but supports inclusion of display guidance
  - Santiago and Mueller (2015) – found 45% fewer losses of well clear when pilots were provided with display guidance
    - Faster pilot responses is one reason for the finding, among less ambiguous alerting and eliminating the need for the pilot to self-determine a maneuver
    - Quick pilot inputs were especially important in cases of 'pop-up' encounters, where there was a small amount of time before a loss of well clear would appear
  - Monk et al. (2015) – found pilots preferred the Advanced displays
    - Supported more immediate responses
    - While all displays were rated as sufficient, Advanced Integrated was rated as most preferable

Conclusion

- Limitations
  - Cannot necessarily generalize to other GCS
    - Different GCS have different vehicle control inputs
    - There was a high level of integration between the Advanced features and the GCS in the Advanced Integrated condition
      - It is possible to present display guidance with less integration, which may impact pilot performance
  - There were multiple feature changes between the Basic and Advanced conditions
    - Several tools were included, as were several advanced pieces of information, including a new alerting level
- 2 follow-on studies have been submitted to different conferences
  - Both look at different ways to provide display guidance in an integrated fashion
  - HITL data to be validated in flight test environment