



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

ACAS Xu Engineering Analysis Results
RTCA SC-228/SC-147 Joint Meeting



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UAS INTEGRATION IN THE NAS

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Background

- Two-part study looking at various aspects of ACAS Xu
 - Created ‘canned’ Xu messages to mimic different types of RAs
 - Limited number of participants (5 per part)
 - No background traffic or secondary tasks
- Part 1 Objectives:
 - Investigate the effects of different display configurations on pilot responses to ACAS Xu Resolution Advisories (RAs)
 - Gather pilot feedback on the presentation of different RA types
 - Characterize pilot responses to RAs (e.g., response times, compliance rates)
 - Use findings to inform design of ACAS Xu full mission HITL (June 2019)
- Part 2 Objectives:
 - Gather pilot feedback on our implementation of *automated* Collision Avoidance (CA) and Return-to-Course (RTC) functions
 - Conform to draft automation requirements to extent possible
 - Focus primarily on subjective feedback



PART 1 OVERVIEW



Part 1 Experimental Design

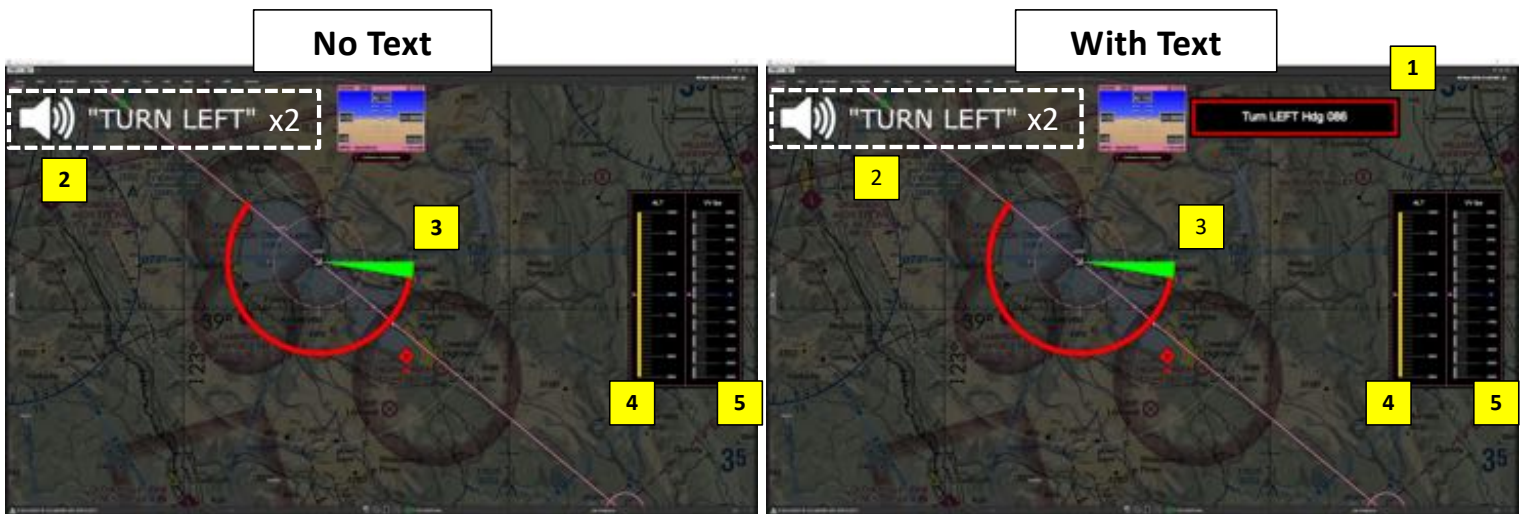
- Independent Variables (2-by-2, within-subjects):
 1. RA Text Box (2 levels)
 - **Text**: text box appears at onset of RA containing information re: RA type
 - **No Text**: no text box included
 2. Blended-Offset RA Aural Alerts (2 levels)
 - **Basic**: present aural alerts with no modification
 - **Advanced**: aural alerts manipulated to account for new, additional RA type
- Embedded Variable (within-trial):
 - RA Type
 1. **Vertical-only**: target vertical rate provided
 2. **Horizontal-only**: target heading provided
 3. **Blended-simultaneous**: target heading & vertical rate provided at same time
 4. **Blended-offset**: second RA dimension added 8 seconds after the initial RA
 - ½ started as horizontal RA, ½ started as vertical RA

Note: we did not include RA reversals, strengthenings, or multi-threat encounters



RA Text Box Variable

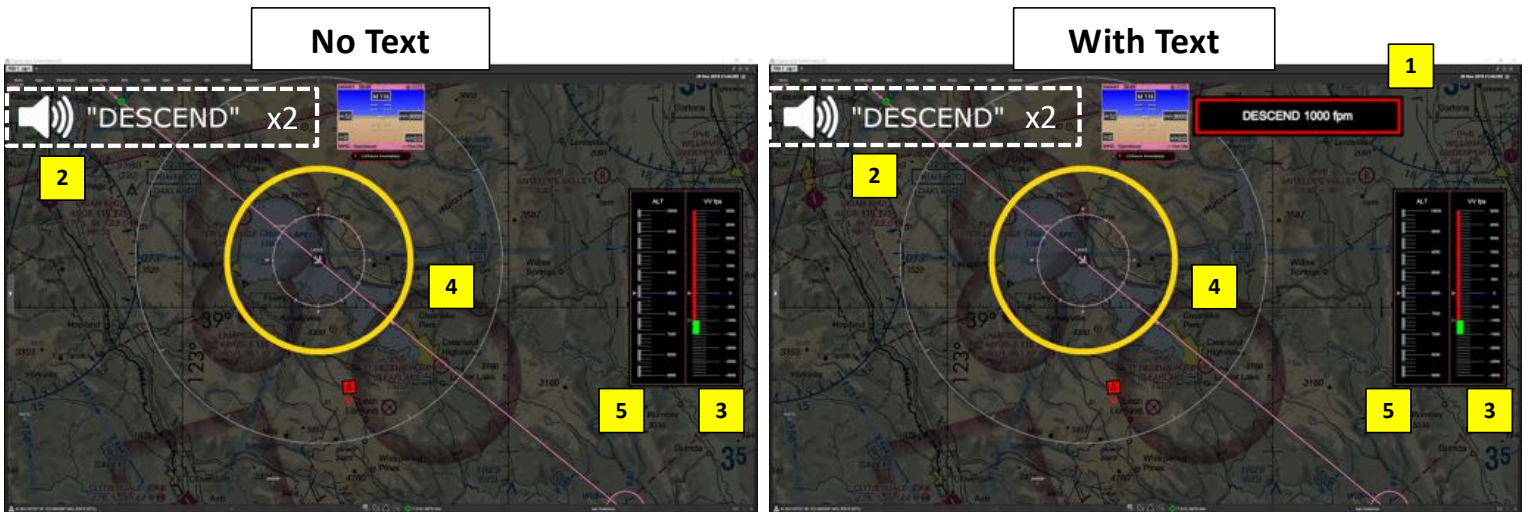
- Horizontal-only RA
 1. RA text box in upper right hand corner in the With Text condition
 2. Aural alert issued at onset of RA
 3. Target heading presented as 'wedge' (target heading *plus* 10°)
 4. DAA altitude bands saturated with Corrective-level bands
 5. Vertical speed guidance suppressed





RA Text Box Variable

- Vertical-only RA
 1. RA text box in upper right hand corner in the With Text condition
 2. Aural alert issued at onset of RA
 3. Target vertical speed presented within Vertical Speed Tape
 4. DAA heading bands saturated with Corrective-level bands
 5. DAA altitude bands suppressed





Blended-Offset Alert Variable

- Manipulated how to annunciate a transition from a single-dimension RA to a blended RA
 - Advanced condition changed the order of the 2nd RA & changed verbiage if pilot had already achieved initial RA target
- *Example: Right Turn RA followed 8 seconds later by a Climb RA*
 - **Basic** Aural Alert Condition:
 - 1st RA: “Turn Right” x2
 - 2nd RA: “Turn Right and Climb” x2
 - **Advanced** Aural Alert Condition:
 - 1st RA: “Turn Right” x2
 - 2nd RA: “Climb and Turn Right” x2 (if target heading *not yet* achieved)
or: “Climb and Maintain Heading” x2 (if target heading *has been* achieved)



Example Video – With Text, Blended-offset RA





Part 1 Test Setup

- 5 participants total
 - Manned pilots; all IFR rated with TCAS II experience
 - Avg. age = 51 years old
- 4 experimental trials per pilot (45 min. each)
 - Pilots saw 2 of each RA type per trial:
 - Horizontal-only
 - Vertical-only
 - Blended-simultaneous
 - Blended-offset
 - 2 non-threats per trial
- No secondary tasks, ATC, or background traffic





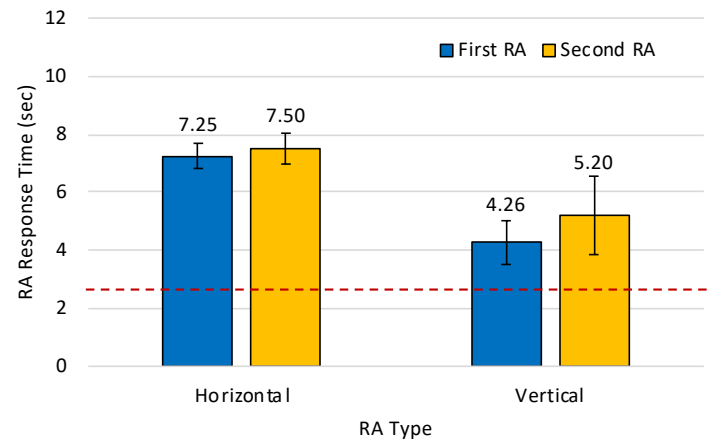
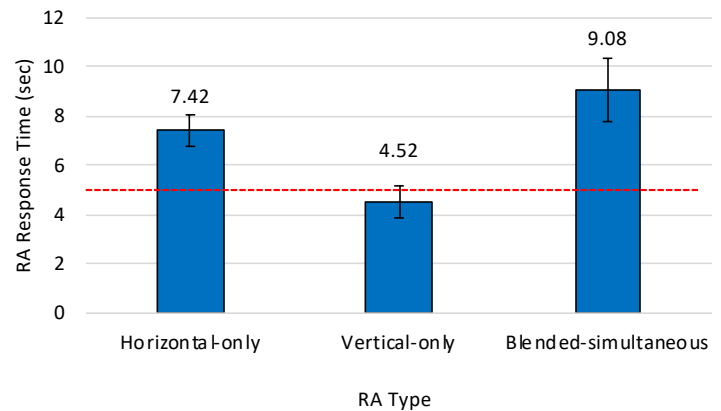
PART 1 RESULTS

OBJECTIVE DATA



Response Times

- Response time to *initial* RA
 - Time it took pilot to upload maneuver following initial RA
 - **Vertical-only** was the only RA type less than 5 seconds
 - Simplified input method
- Response time to *Blended-offset* RAs
 - Response times were the **same or slower** to 2nd RA
 - Unable to meet the 2.5sec response time requirement
 - RA type the major factor in response times

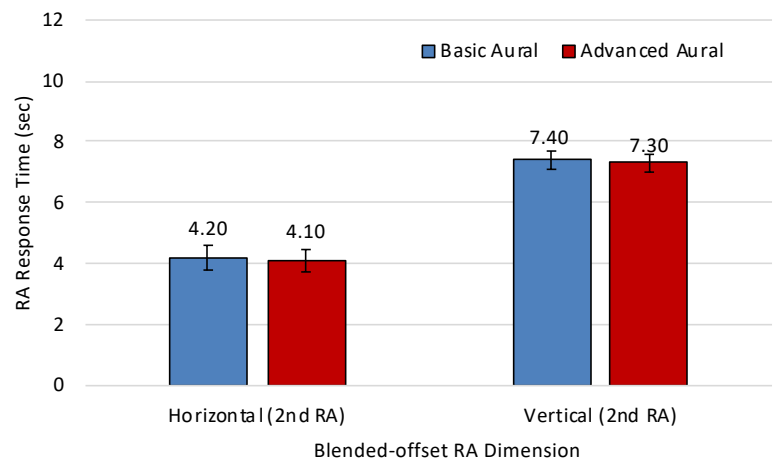
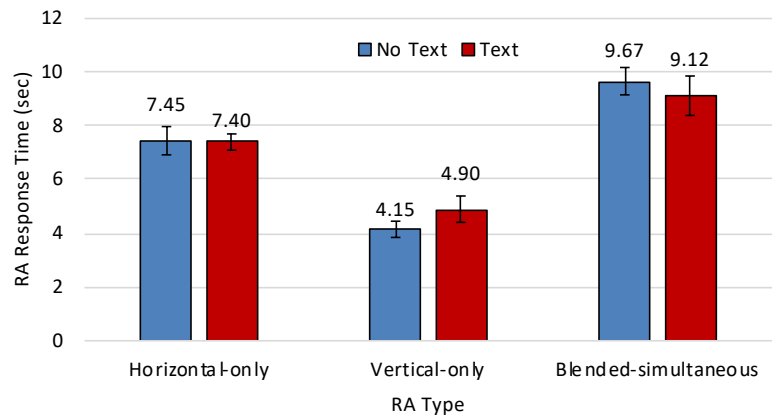




Response Times

- **RA Text Box Variable:**
 - Text box had no effect on response times to initial RAs

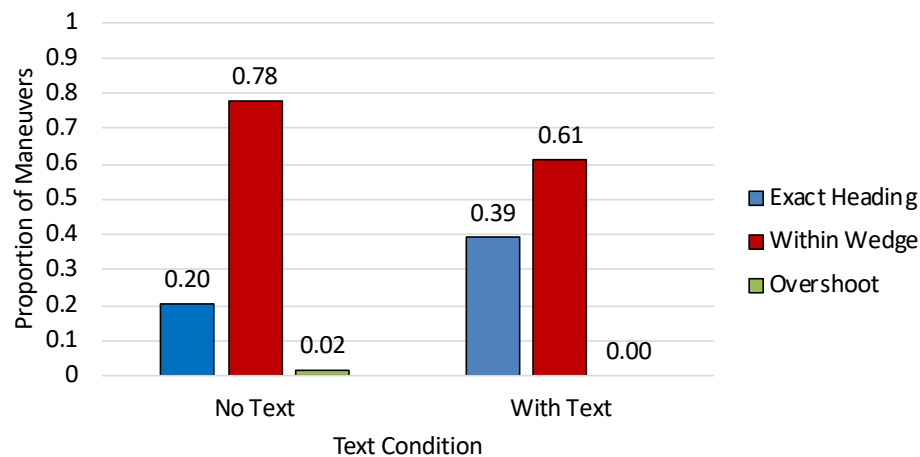
- **Aural Alert Variable:**
 - Advanced aural alert did not impact response times to Blended-offset RAs





Compliance Rates

- RA compliance essentially perfect
 - 1 instance where pilot delayed vertical RA compliance to make a heading change
- RA text box did impact how often pilots flew the *exact* RA target heading
 - Pilots uploaded exact RA target heading twice as often in With Text condition
 - Nonetheless, pilots nearly always remained within the ‘wedge’





**PART 1 RESULTS:
SUBJECTIVE DATA**



Questionnaire Responses

- Do you consider the RA Text Box necessary?
 - 1/5 Strongly Agreed
 - 4/5 either Neutral or Disagreed
 - Note: answers may have differed if we used a 'Standalone' display configuration
- Did you prefer the Basic or Advanced aural alert configuration?
 - 4/5 preferred *Basic* ordering – maintaining original RA sequence
 - 4/5 preferred *Advanced* verbiage – say 'Maintain...' if target had already been reached
 - E.g., "Climb, Climb" followed by "Turn Right and Maintain Vertical Speed"
- RA Guidance
 - Effectiveness of Horizontal RA guidance rated 5 out of 5 by all pilots
 - Effectiveness of Vertical RA guidance rated 4.6 (two pilots rated it '4')
 - Pilots noted the guidance could be moved closer to the center of the display



Part 1 Takeaways

- Pilots struggled to meet the response time requirements
 - Horizontal and Blended RAs fell short of 5sec initial response time requirement
 - All RA types fell well short of the 2.5sec subsequent RA requirement
- RA text box not considered a requirement by pilots in this study
- Mixed reception to Advanced aural condition – pilots did not like the re-ordering but did like the ‘Maintain’ logic
- Pilots highly accepting of horizontal and vertical RA guidance presentation



PART 2 OVERVIEW



Part 2 Experimental Design

- Independent Variable:
 - Automation Level (within-subjects, 4 levels):
 - 1. Manual**
 - Carries over preferred display (per pilot feedback) from Part 1
 - 2. Automated Collision Avoidance (CA)**
 - RA automatically executed *immediately* upon RA issuance
 - Pilot can disengage (override) automation at discretion
 - 3. Automated CA & Return-To-Course (RTC)**
 - RTC is also automatically executed *immediately* upon Clear of Conflict (CoC)
 - Pilot can disengage (override) automation at discretion
 - 4. Automated CA & RTC+**
 - Same as above but includes an aural alert (“Executing” and “Returning”) to indicate when automation engaged
- Embedded Variables (within-trial):
 - RA type: same as Part 1
 - Automation Failure
 - Auto-CA indicates it has ‘engaged’ but fails to do so – pilot forced to ‘disengage’ and manually upload the necessary maneuver
 - 1 instance per trial



Part 2 Test Setup

- 5 participants total
 - Active-duty UAS pilots
 - Avg. age = 29
- 4 experimental trials per pilot (45 minutes each)
 - Pilots saw each of the following RA types twice (same as Part 1):
 - Horizontal-only
 - Vertical-only
 - Blended-simultaneous
 - Blended-offset
 - 2 non-threats per trial
- No secondary tasks or background traffic
 - Researcher in separate room served as ATC





ENCOUNTER EXAMPLE:

**AUTO-CA & RTC AUTOMATION CONDITION
(HORIZONTAL-ONLY RA)**



DAA Corrective Alert

- DAA Corrective guidance bands visible





Horizontal RA Issued

- Right turn is automatically executed (standard aural alert issued)





Clear of Conflict Issued

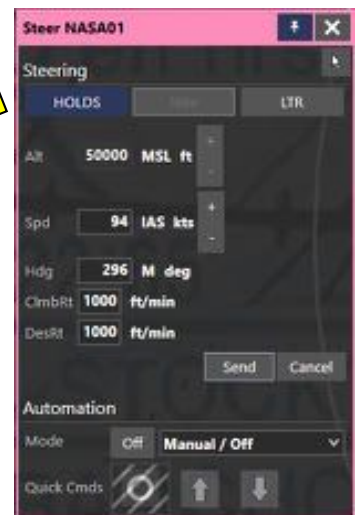
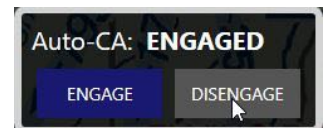
- Return to course executed automatically (no aural alert)





Disengaging Automation

- When Auto-CA was *Engaged* pilots were locked out from modifying or uploading a maneuver in the active dimension
 - E.g., pilots could not upload a climb or descent during a vertical RA without disengaging
 - Done to prevent going against an RA inadvertently
 - Orthogonal maneuvers were available
- Pilots had to click Disengage to modify the RA dimension
 - Disengaging did not disable the automation globally
 - Disengaging did not change the state of the aircraft
- Automation failure forced pilots to disengage the automation
 - Note: failure was **not** annunciated





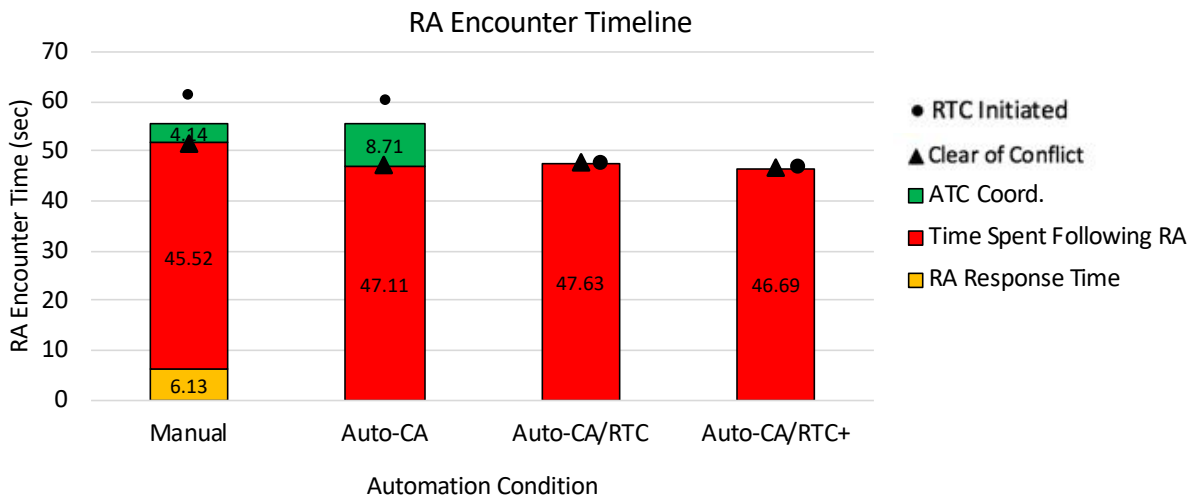
PART 2

RESULTS



Automation Utility

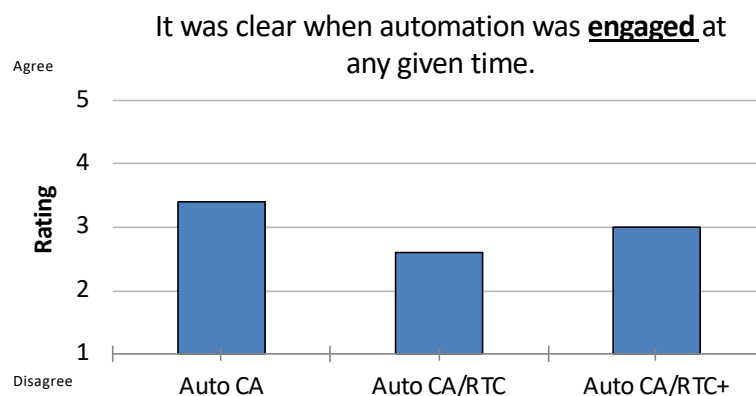
- Pilots reported both Auto-CA and Auto-RTC functionality to be useful despite presence of automation failures
 - 5 out of 5 positive responses regarding *automation usefulness*
 - Auto-CA and Auto-RTC viewed as about equally useful
- Utility of automation reflected in reduced time spent in a given encounter
 - Automating CA reduces total encounter time by ~6sec
 - Automating RTC reduces it by ~10sec
 - Pilots slightly slower to coordinate RTC in Auto-CA than Manual





Overall Reception

- Pilots found automation useful but mixed reception regarding its presentation
- Main areas for improvement:
 1. Visual/aural indications of automation state
 2. Auto-RTC predictability
 3. Annunciations for clear of conflict, disengaging automation, and failures of automation





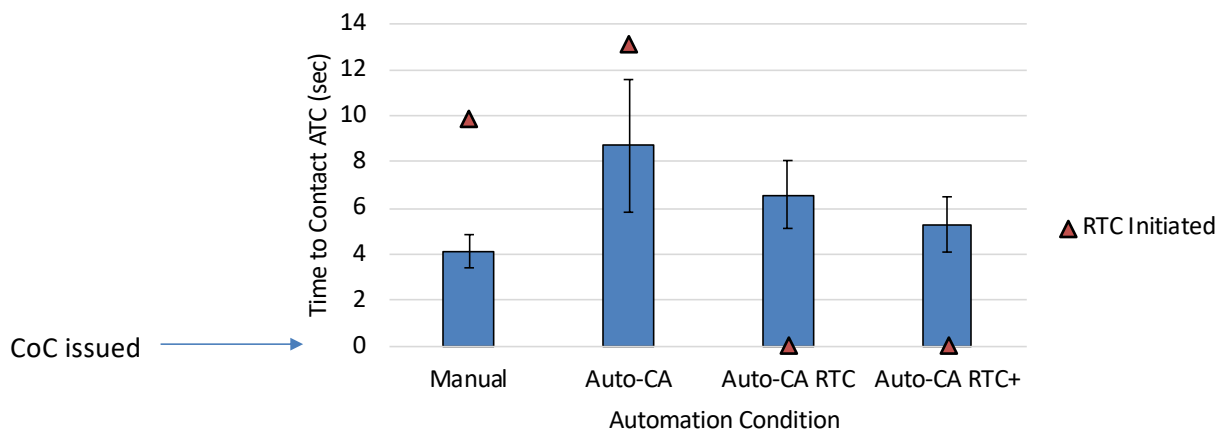
Visual and Aural Alerting

- **Visual** Indications of Automation Engagement:
 - 5/5 pilots felt the visual indicators for **Auto-CA** could be improved
 - Requested greater salience of indicators
 - E.g., flashing the status box, change color of ownship icon/instruments (go to grey scale), more conspicuous location of indicator
 - 5/5 pilots also felt that the visual indicators for **Auto-RTC** could be improved
 - Similar recommendations as those for Auto-CA
 - E.g., more conspicuous placement of indicator, flashing the status box
- **Aural** Indications of Automation Engagement:
 - 4/5 pilots rated the “Executing” / “Returning” verbiage used in the Auto-CA/RTC+ condition as *necessary*
 - Auto-CA/RTC+ rated as top of the 3 automation conditions
 - Pilots recommended some other options for the aural annunciations:
 - “Maneuvering” instead of “Executing”
 - “Resuming” instead of “Returning”




Auto-RTC Predictability

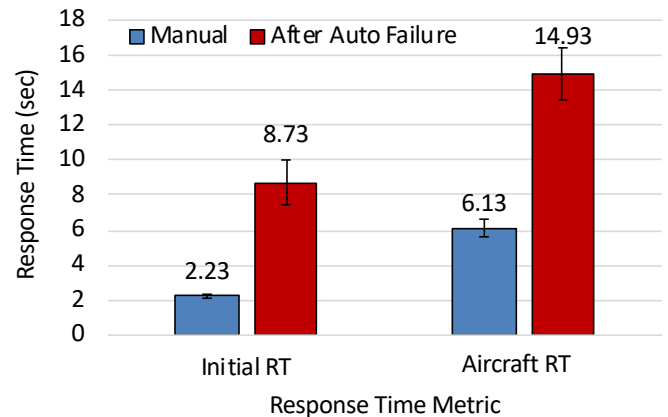
- During debrief, pilots noted that engagement of Auto-RTC needs to be made more predictable to support coordination with ATC
 - Pilots took 4-8sec to notice end of RA and initiate contact with ATC following CoC
 - Pilots in Manual and Auto-CA conditions took *an additional* 6sec to upload RTC maneuver





Additional Indications

- Clear of Conflict Annunciation
 - 5/5 pilots considered a CoC aural alert necessary
- Automation Failure
 - 5/5 pilots said indication of automation failure need to be improved
 - E.g., flash failure indicator; aural alert
 - Took pilots 6.5sec to notice failure 
- Disengaging Automation
 - 3/5 pilots rated dedicated aural alert as necessary
 - Strong agreement (4/5 pilots) that the two-step disengage process was too cumbersome
 - “Too many clicks”
 - “I don’t like being locked out.”
 - Want any new pilot command to vehicle to act as override





Part 2 Takeaways

- Pilots understood the value of automation but noted areas for improvement
- General consensus was that they needed more information regarding the state of the system
 - Need greater salience to indicate Auto-CA & Auto-RTC engagement
 - Greater conspicuity could be achieved by flashing (or changing color of) visual indicators and/or using aural alerts
 - The “Executing/Returning” aural alerts were considered valuable
 - Auto-RTC needs to be predictable to support ATC coordination
 - One option is to delay execution of RTC until pilot approves it
 - Pilots requested dedicated aural alerts for CoC and automation failure
 - CoC aural alert should not be issued if there is a follow-on Corrective DAA alert
- Pilots found the disengagement process cumbersome
 - One option is to not lock pilots out but to notify pilots if/when they upload a maneuver contra to the RA and require them to accept



ACAS Xu Full Mission HITL Update

- ACAS Xu HITL currently in data collection (June 10 – 19)
 - Running ACAS Xu Run 5 in full mission setting
 - ATC in the loop, background traffic, secondary tasks
 - Honeywell Sensor Model (HSM) in the loop
 - Leveraging findings from Part 1 of the engineering analysis
 - No automation in the HITL
- Display for the full HITL similar to Part 1 of the engineering analysis, *except*:
 - Incorporated an ‘auto-fill’ feature in Vigilant Spirit that removes the need for pilots to manually enter a heading or altitude for RAs
 - Should allow us to better meet the 5 and 2.5-second RA response time requirements
 - Did not include the RA text box
 - Was not deemed in the engineering analysis
 - Auto-fill behavior makes text box less necessary
 - Using a combination of the ‘Basic’ and ‘Advanced’ aural alerting
 - Carried forward the “Maintain Heading/Vertical Rate” aural alert logic



ACAS Xu HITL Experimental Design

- Independent Variable:
 - Display Integration Level (2 levels, **within-subjects**):
 - Integrated – DAA information presented within TSD
 - Standalone – DAA information shown in separate, dedicated display
- Embedded Variable:
 - Encounter Type – 6 scripted encounters per trial (4 trials per participant)

Threat Level at First Alert	Non-Cooperative (RADAR Only)	Cooperative (ADS-B & RADAR)
Corrective DAA Alert	1	3
Resolution Advisory (RA)	1	1

- 16 total participants (2 per day)
 - All are active UAS pilots
 - 4 experimental trials per pilot (~45min per trial)



ACAS Xu HITL Outbrief Plan

- Expected metrics:
 - DAA and RA response times
 - Loss of DAA well clear/NMAC rate
 - RA compliance rate
 - Alerting behavior:
 - Corrective alert duration
 - Instances of RA strengthening/reversals
 - Subjective data:
 - Acceptability of DAA and RA alerting and guidance
 - ATC acceptability/interoperability ratings

- Targeting early August for outbrief to SC-147 to meet help inform the RAC
 - SC-228 outbrief tentatively at September F2F