



Hazard Perception & Avoidance (HPA)

Part Task 1 - Results Outbrief

August 1, 2022



- Hazard Perception and Avoidance (HPA) is tasked with assessing tools for tactical conflict management for Advanced Air Mobility (AAM)
 - Using the FAA's Airborne Collision Avoidance System for Rotorcraft (ACAS Xr)
 - A traffic conflict detection and alerting tool, replacing TCAS II
 - RTCA SC-147 Minimum Operational Performance Standards (MOPS) for Xr development started Feb 2022
 - Research assumes an electric vertical take-off and landing (eVTOL) aircraft with an onboard pilot
- Study objectives
 - Characterize pilots' response to ACAS Xr alerting & guidance
 - Collect data on the effectiveness of the ACAS Xr guidance
 - Collect data on the utility of the automated maneuvers
 - Collect pilot feedback of overall simulation fidelity

- ACAS Xr provides Detect and Avoid (DAA) and Collision Avoidance (CA) functionality
 - DAA alerting/guidance is caution-level, suggestive, and triggers approximately 90 seconds from closest point of approach (CPA)
 - Originally designed for Unmanned Aircraft Systems (UAS)
 - Provides a means of compliance with “see and avoid” requirements
 - DAA Well Clear (DWC) defined as 4000ft horizontal & 450ft vertical separation & 35 sec modified Tau
 - CA alerting/guidance is warning-level, directive, and triggers approximately 30 seconds from CPA
 - TCAS/ACAS refer to collision avoidance commands as Resolution Advisories (RAs)
 - Designed to prevent Near Midair Collisions (NMACs)
 - 500ft horizontal & 100ft vertical separation
 - Can optionally be automated, DAA always assumes manual responses
- ACAS Xr issues a variety of novel Resolution Advisories (RAs) types
 - **Vertical** RAs command a *target vertical speed*
 - **Horizontal** RAs command a *target track*
 - **Blended** RAs command a target track & target vertical speed *simultaneously*

- Variables of interest were Encounter Type & Level of Automation
- Resolution Advisory Encounters
 - Manual Response
 - *Pilots trained not to respond to DAA alerting/guidance*
 - Pilots manually complied with RA guidance once it was triggered
 - Returning to course (RTC) was done manually
 - Automated Response
 - *Pilots trained not to respond to DAA alerting/guidance*
 - Pilots monitored system as it automatically responded to RA guidance
 - RTC was automated
 - *Pilots could override automation at any point by deflecting the side-stick controller*
- Detect and Avoid Encounters
 - Manual Response
 - Pilots were trained to respond as soon as a DAA Corrective alert (“Traffic, Avoid”) was generated
 - If an RA was issued at any point, pilots were trained to respond manually
 - RTC was also performed manually

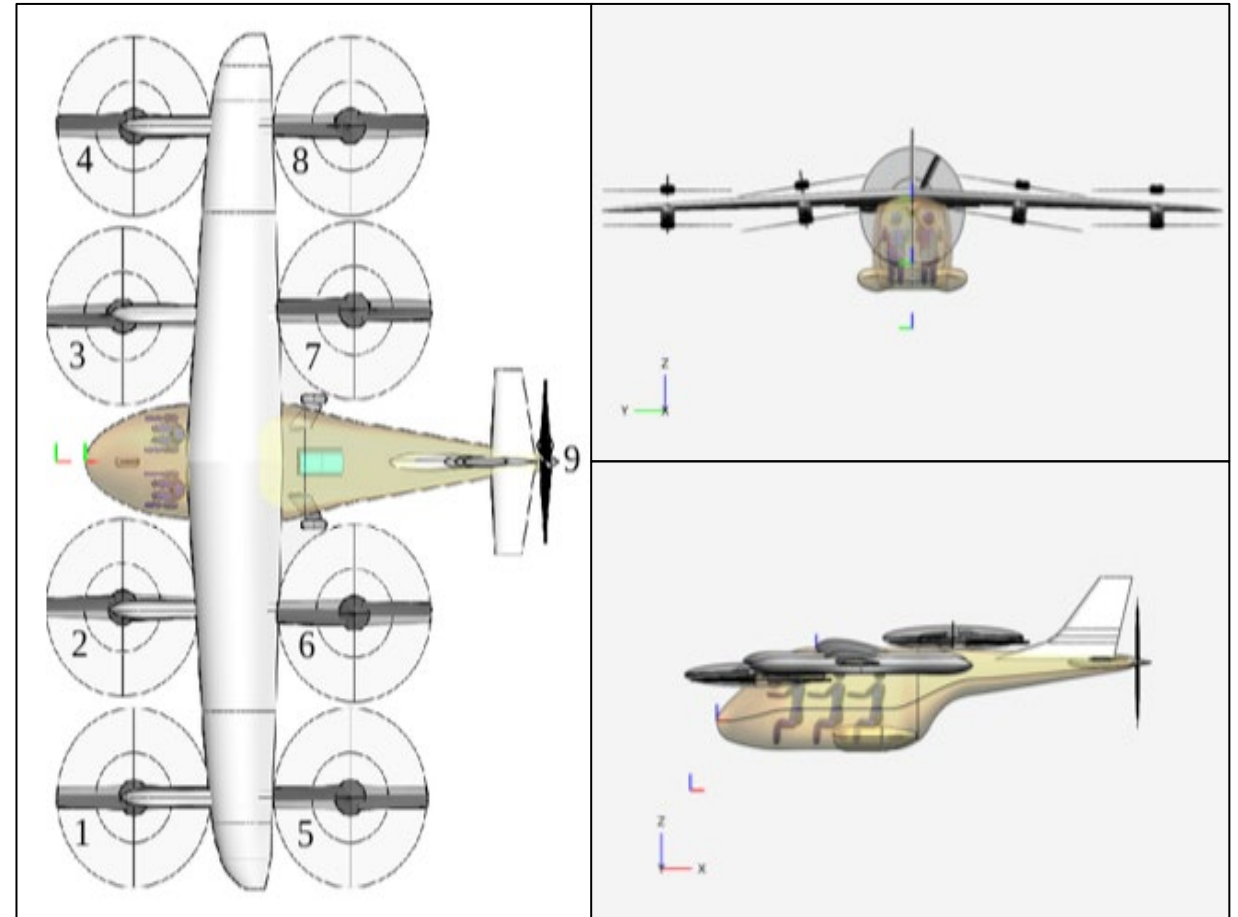
- Participants
 - 12 male participants with private helicopter licenses (average 1500 civilian hours with rotorcraft)
 - Average age = 56
- Simulator
 - Participants flew an eVTOL vehicle, under VFR, in our fixed-base simulator
 - Controls:
 - Right side-stick controller: longitudinal/latitudinal direction of motion
 - Left side-stick controller: acceleration/deceleration (not used for this study to preserve encounter timing)
 - Touch screen tablet: flight mode & navigational map interfaces
- Simplified airspace environment:
 - Vehicle started enroute (1500ft AGL) in auto-pilot mode (no takeoff/landing simulated)
 - Operations occurred in VMC
 - No background traffic
 - Traffic was not visible in out-the-window displays
 - No Provider of Services for UAM (PSU) or ATC interactions were included



Human Autonomy Teaming Lab: UAM Simulator

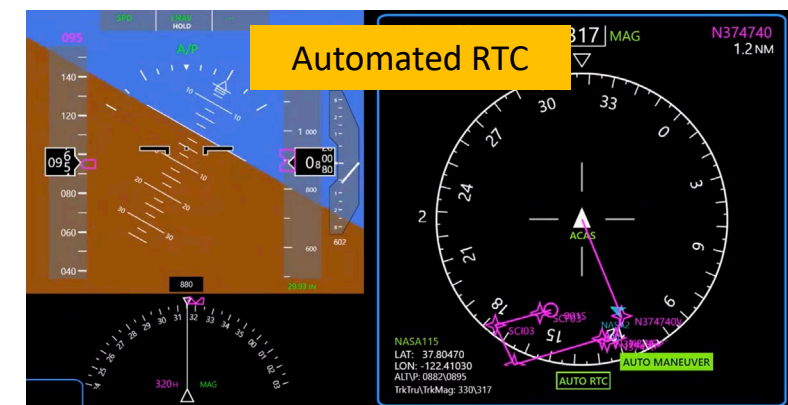
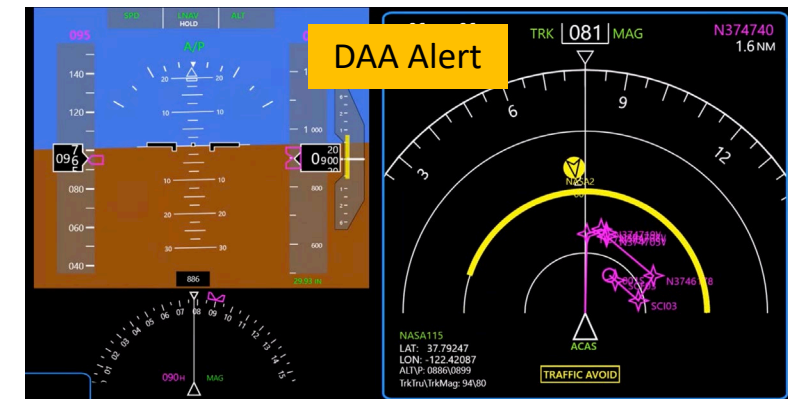
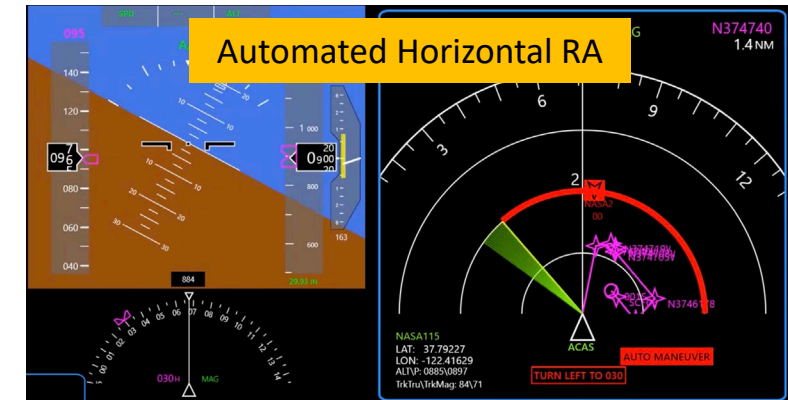


- Ownship
 - Using the Lift + Cruise eVTOL flight model via Flight Deck Z
 - Maintained a max cruise speed of 120KTAS
- Intruders
 - Fixed-wing intruder
 - Cruise speed at 160KTAS
- Surveillance
 - Utilized perfect data (no surveillance sensor models were emulated)



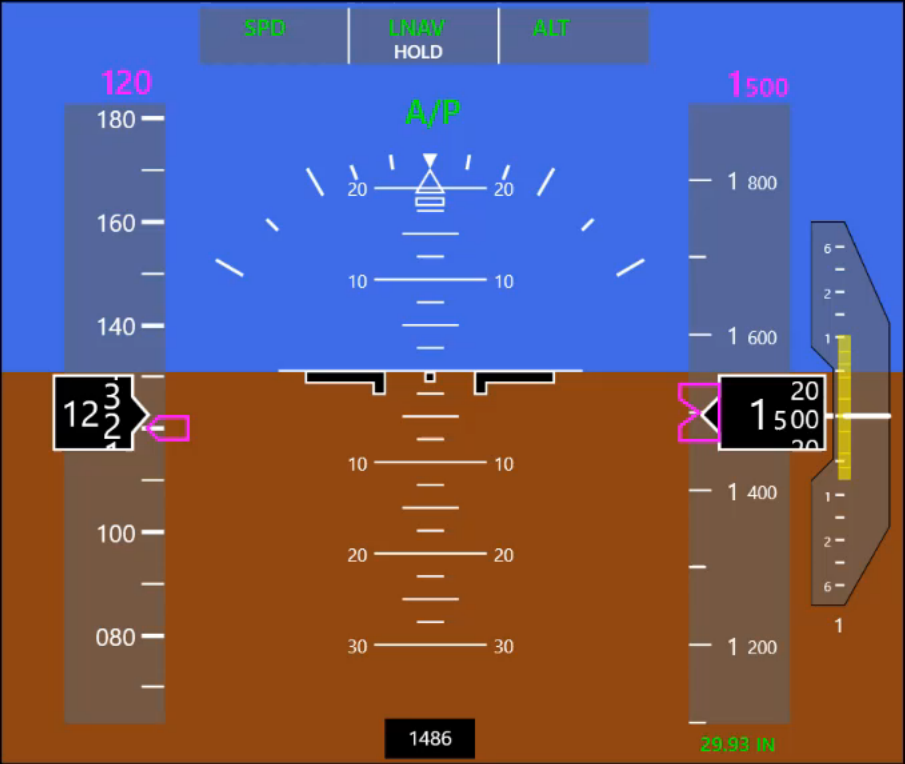
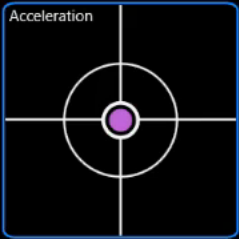
Conceptual drawings of NASA's LPC vehicle

- Pilots tasked with using ACAS Xr alerting and guidance to resolve scripted traffic conflicts:
 - Manual RA encounters
 - Pilots disengaged the auto-pilot to manually respond to RAs
 - Pilots trained to ACAS performance assumptions:
 - 3°/sec turn rate
 - +/-1000ft per min climb/descend rates
 - 5 second response time
 - Automated RA encounters
 - RAs were executed automatically (within 1 sec) and pilots monitored system performance
 - Automated maneuvers conformed to the assumed rates
 - They had the ability to disengage the auto-maneuvering mode if so desired
 - DAA encounters
 - Pilots disengaged the auto-pilot to manually respond to DAA/Corrective alerts
- Returning to course
 - Automated in Auto condition
 - Performed manually in Manual & DAA conditions



UTC: 20:43:35
PST: 13:43:35

95 %
Flight Time Remaining: 57 mins



(WBL) ACSH-RCAH-TC



- Experimental Scenarios:
 - Pilots ran through 10, ~5-minute encounters per experimental condition (each trial lasted ~50 minutes)
 - 3 separate conditions: Manual RA, Auto RA, & DAA
 - The ownship was re-set at the start of every new encounter
- Created 10 unique RA encounters that were each presented twice, with order of presentation counter-balanced between the Manual & Auto RA conditions
 - 4 co-altitude encounters with different approach angles (head-on, crossing, overtake)
 - 2 vertical offset encounters (e.g., 250ft vertical separation from ownship)
 - 2 non-level intruder encounters (intruder climbing/descending into ownship)
 - 2 multi-intruder encounters (both intruders level, with different approach angles)
- Also created 10 unique DAA encounters
 - 4 co-altitude, 4 non-level, & 2 multi-intruder encounters

- Dependent Variables

- Objective Metrics:

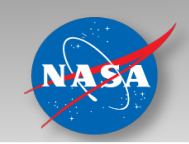
- RA Types: count of horizontal, vertical, & blended RAs
 - Response Times: time from onset of DAA Corrective and RA alerts to start of maneuver
 - Losses of DAA Well Clear (LoDWC): the number of LoDWC against DAA and RA conflict types
 - Near Midair Collisions (NMACs): instances of NMACs
 - Maneuver Types: types & sizes of DAA & RA maneuvers
 - RA Compliance: count of instances where the pilot did not comply with the RA guidance

- Subjective Metrics:

- Post Encounter Questionnaire: asked questions regarding ACAS performance
 - Post Trial Questionnaire: assessed workload & impressions of ACAS
 - Post Simulation Questionnaire: asked questions regarding all aspects of simulation experience
 - Debrief: open-ended discussion on a few key topics



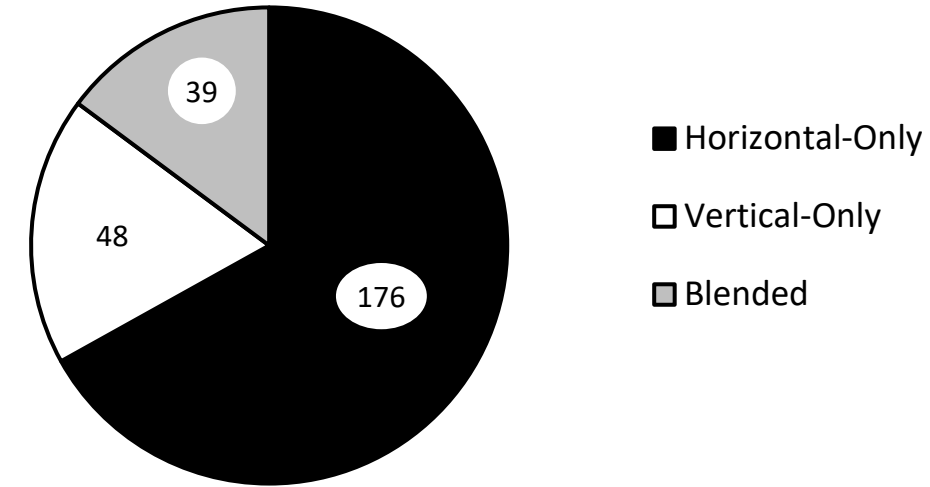
RESULTS



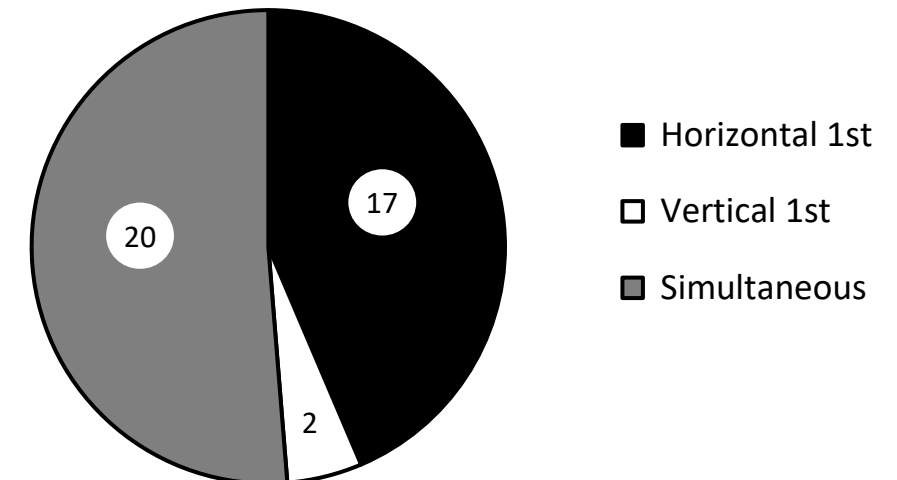
RESOLUTION ADVISORY ENCOUNTERS

- Horizontal-only RAs were the most common RA type (67%) seen in this study
- The second-most common RA type were Vertical-only RAs (18%) followed by Blended RAs (15%)
- The majority of Blended RAs (51%) had the Horizontal and Vertical RA components issued *within 2 seconds* of one another
 - Of the remainder, 44% of Blended RAs started as Horizontal RAs
 - The Vertical RA component added an average of 14 seconds after the Horizontal RA was issued

Total RAs (Man & Auto)



Total Blended RAs (Man & Auto)



- RA type was consistent within individual encounter types
 - The two encounters with non-level intruders were the most variable encounter type seen in the study

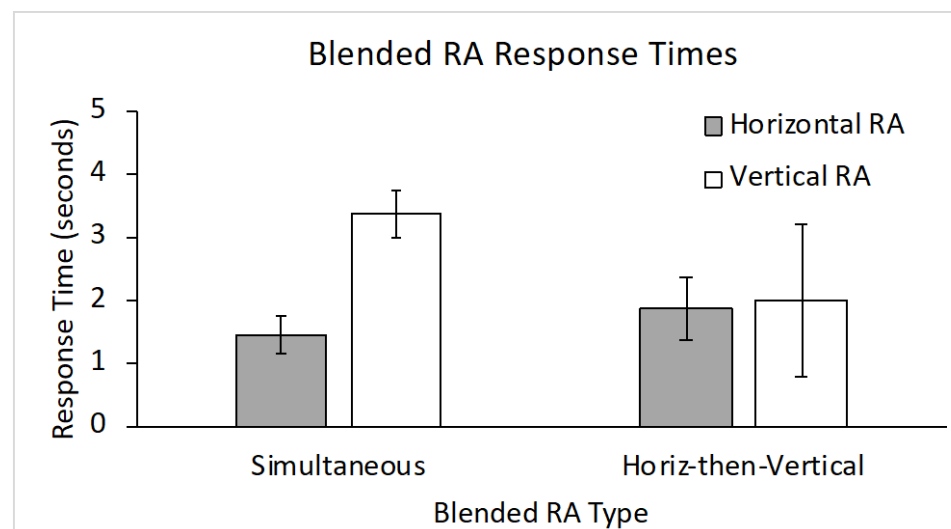
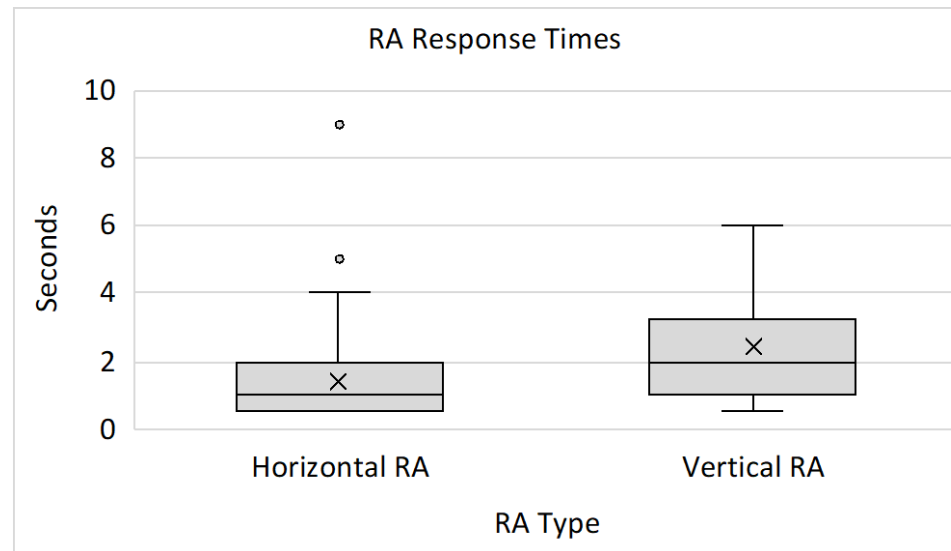
Encounter Type	Horizontal-Only RA Count	Vertical-Only RA Count	Blended RA Count
Co-Alt & Crossing	24	0	0
Co-Alt & Crossing	24	0	0
Co-Alt & Head-on	24	0	0
Co-Alt & Overtake	24	0	0
Multi-Intruder	2	0	22
Multi-Intruder	23	0	1
Vertical Offset	0	24	0
Vertical Offset	0	24	0
Non-Level	14	0	10
Non-Level	18	0	6

- 0 NMACs were recorded
- 4 of 360 total encounters (1%) resulted in a loss of DAA well clear
 - 1 each in the Automated and Manual RA conditions
 - 2 recorded in the DAA condition
 - All 4 instances happened *after* the initial conflict had been resolved and occurred while the pilot was returning to their previous routing
 - In 3 of the cases, RWC bands were clearly indicating a return to course would re-trigger a DAA Corrective alert
 - In the 4th instance, the alerting was only triggered after the auto-pilot descended and turned toward the intruder

LoDWC Instance	Condition	LoDWC Duration (sec)	HMD at 3D CPA (ft)	VMD at 3D CPA (ft)
1	Manual RA	9	3519	202
2	Auto RA	6	3958	66
3	DAA	6	2602	702
4	DAA	3	644	2105

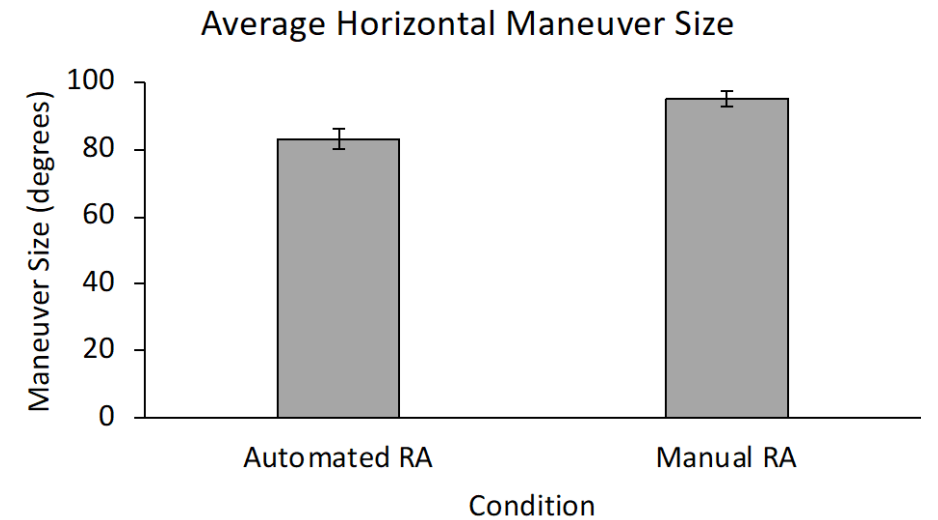
* LoDWC = 4000ft horizontal, 450ft vertical, & 35 sec Tau

- Average RA response times < 3 seconds
 - Horizontal RAs = avg. **1.4 seconds**
 - Vertical RAs = avg. **2.7 seconds**
 - *In the Automated RA condition, the vehicle executed all RAs within 1 second*
- Response times had very little variability outside of a handful of slow responses
- Blended RA Response Times
 - Pilots prioritized horizontal maneuvers in 'simultaneous' Blended RAs
 - When Blended RAs were 'offset' in time, response times were < 2 seconds



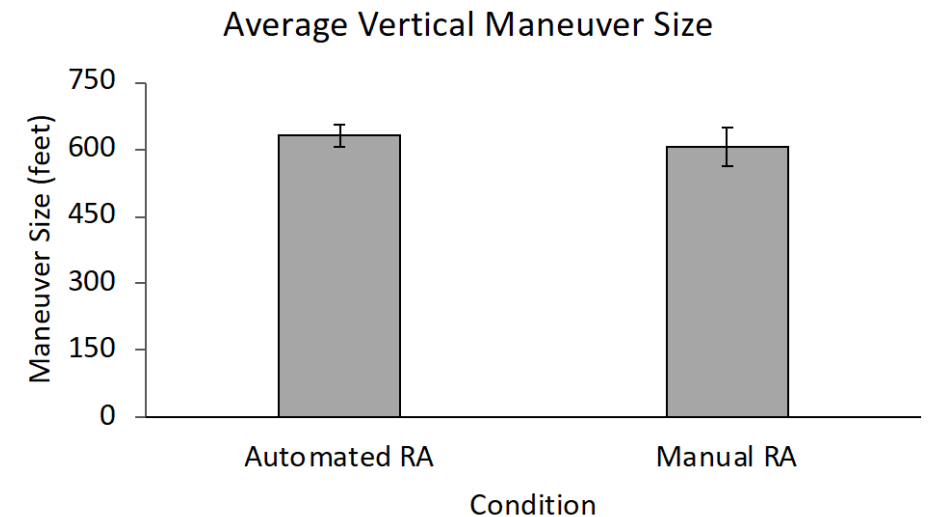
- Horizontal Maneuvers

- Responding to Horizontal RAs in the Manual condition increased average deviation size from 83° to 95°

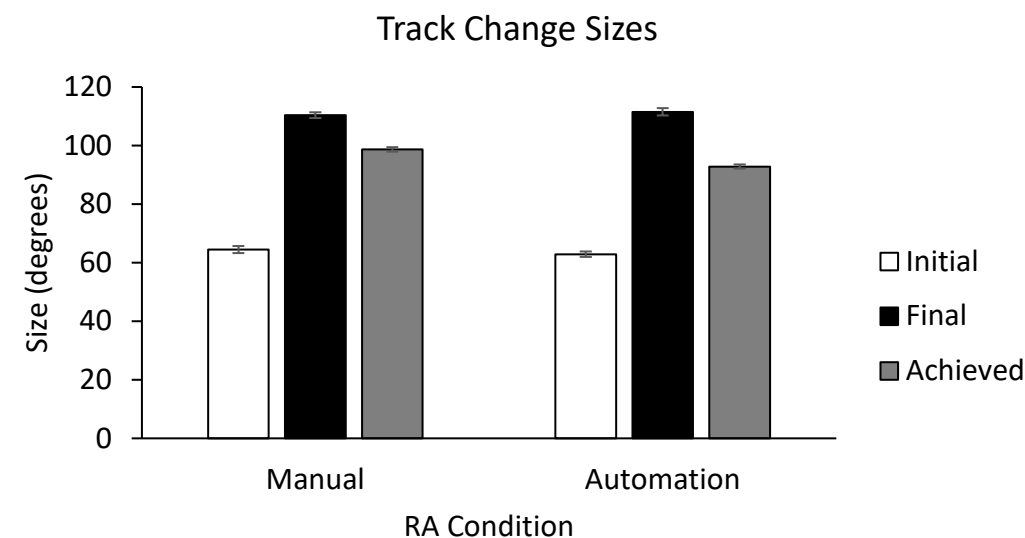
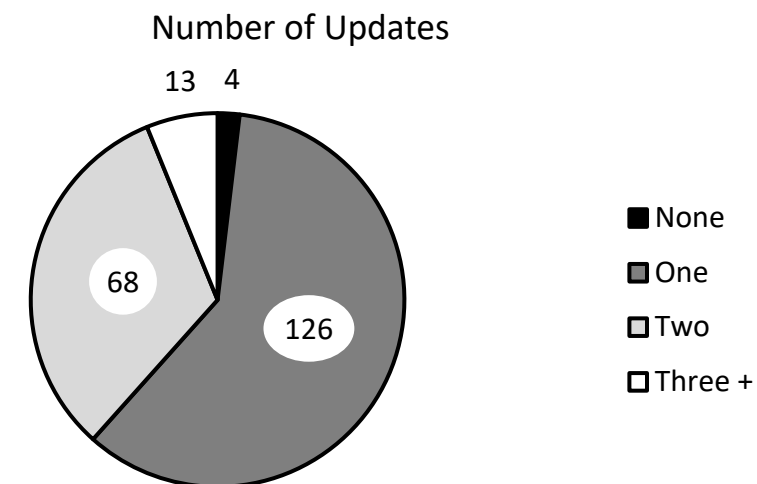


- Vertical Maneuvers

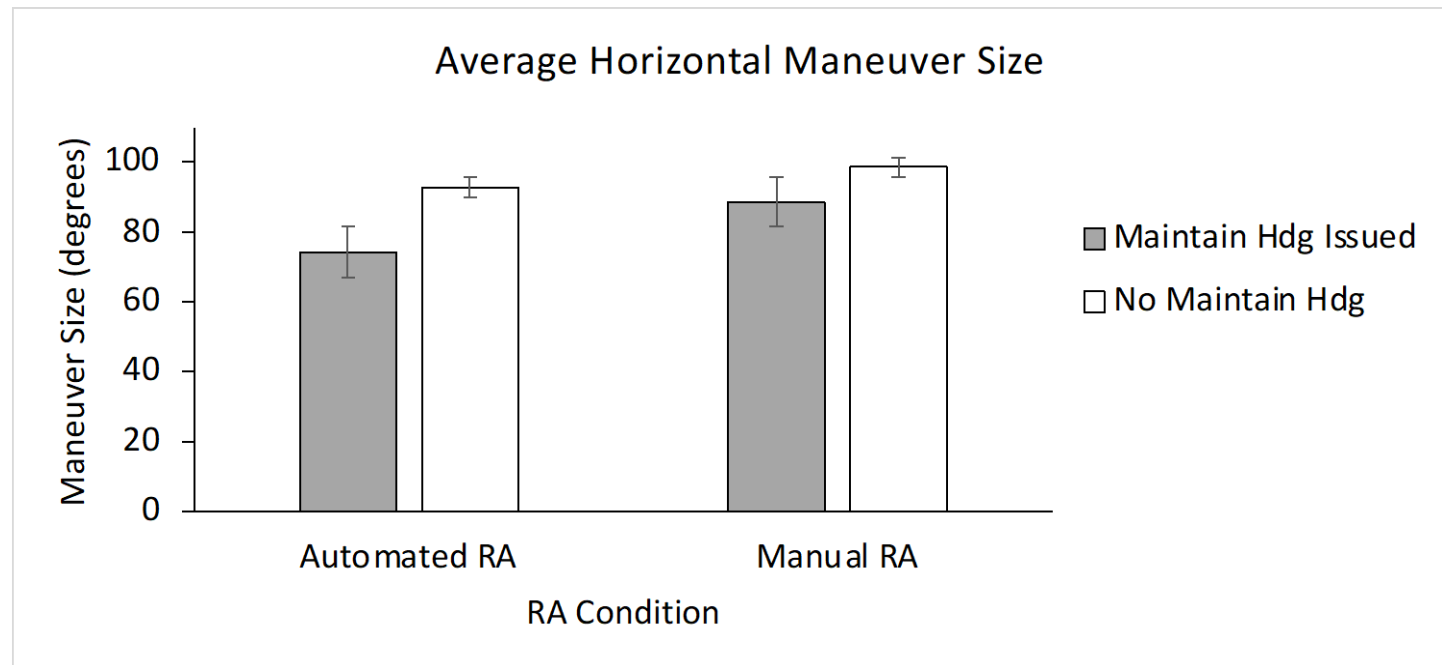
- Automated condition had smaller effect for vertical maneuvers
 - Manual: 630 ft
 - Automated: 600 ft



- More single-update RAs overall
 - One update occurred more often in the automated condition
 - Two updates occurred more often in the manual condition
- Relative to ownship's initial heading...
 - Trends were consistent between conditions
 - Average difference between initial RA target track and final target track was 45°
 - Average difference between final achieved track and final RA target track was 15°



- Horizontal maneuver sizes were smaller when 'maintain heading' RA was issued
 - 18° reduction in Automated condition, 10° reduction in Manual condition
 - 47% of horizontal RAs ended with a 'maintain heading' RA

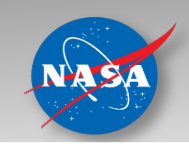




RA Non-Compliance

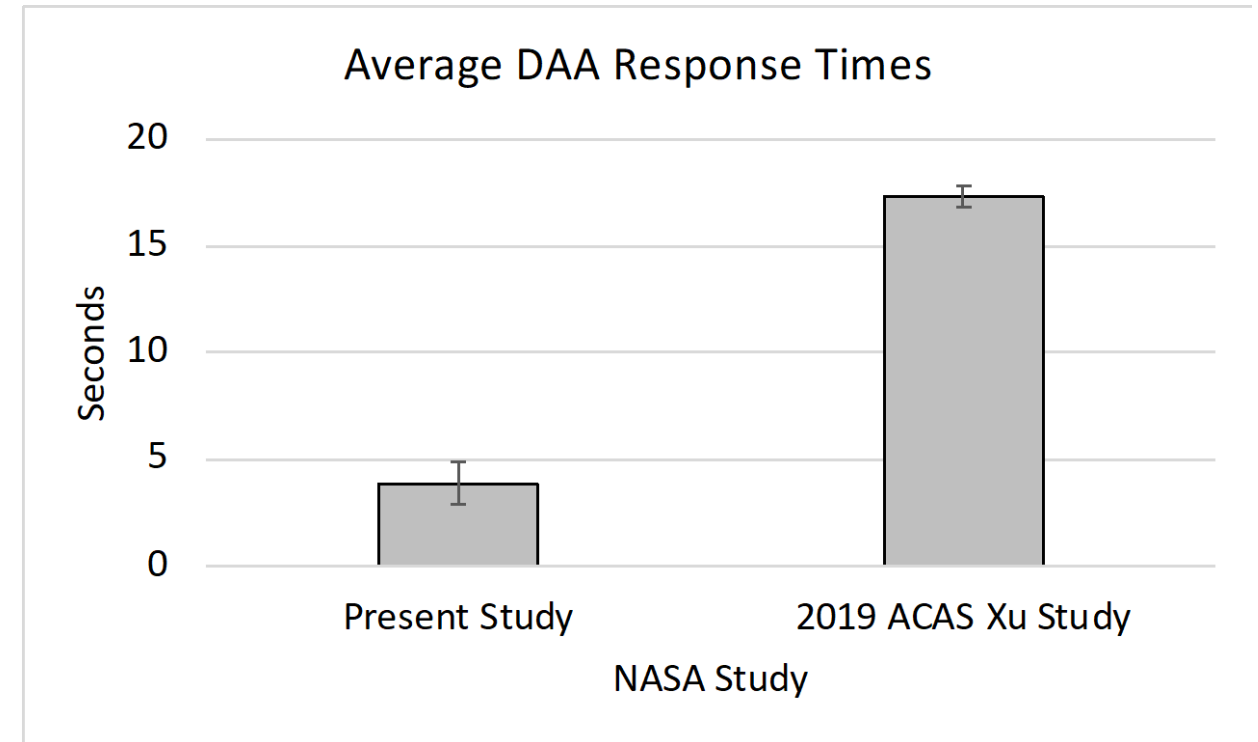


- 20 total cases of non-compliance (8% of encounters that had an RA)
 - Levelled out while Descend RA was still active due to nearby terrain - 9
 - Stopped short of target heading and/or did not attempt to keep up with target track updates - 3
 - Ignored Horizontal RA entirely in favor of a climb/descent - 3
 - Returned to course before RA cleared – 2
 - Ignored vertical RA when it was added to existing horizontal RA – 2
 - Levelled out of descent early (seemed to think 500ft vertical separation was sufficient) – 1
- Number of cases of non-compliance were near-identical between Manual RA & Auto RA conditions

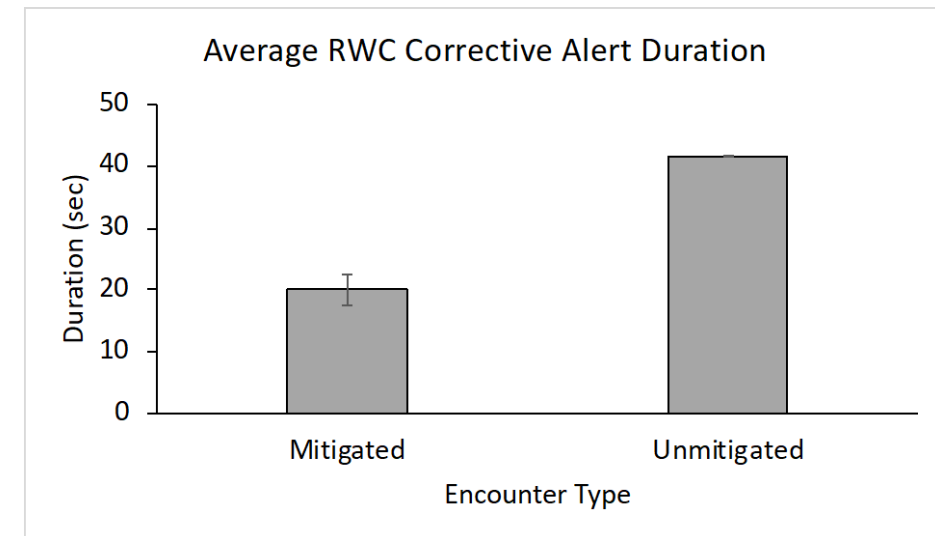
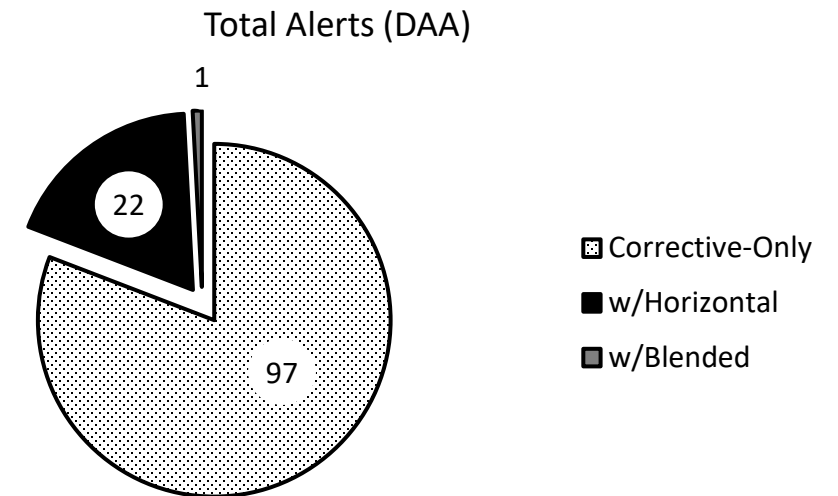


DETECT AND AVOID/REMAIN WELL CLEAR ENCOUNTERS

- Average DAA response times were comparable to the RA response times
 - < 5 seconds
- Response times were particularly quick compared to 2019 study looking at DAA & ACAS Xu
 - Previous study had pilots at a ground control station
 - Pilots were flying VFR, which meant pilots had to coordinate with ATC prior to maneuvering



- 19% of DAA encounters progressed to an RA *before the pilot could resolve it*
 - 2 encounter types were responsible for **all such cases** and they involved extremely high intruder descent rates
 - These encounters transitioned from DAA alerts to RAs in ~11 seconds
 - None of the other 8 encounter types ever reached an RA
 - *Note: there are other DAA trials where pilots triggered an RA while returning to course*
- Corrective alerts lasted an average of 20 seconds when pilots maneuvered against them
 - In RA conditions (i.e., trained not to respond), they lasted an average of 41 seconds



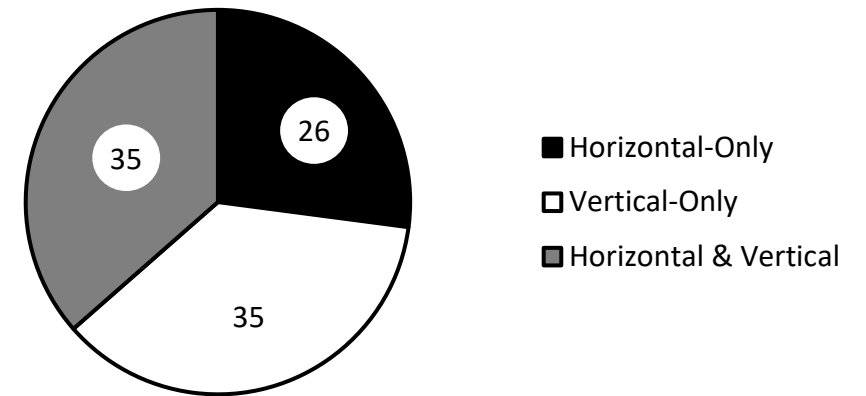
- Pilots' maneuvers against DAA Corrective alerts were balanced

- 27% of DAA maneuvers were horizontal-only
- 72% of maneuvers were vertical only or blended

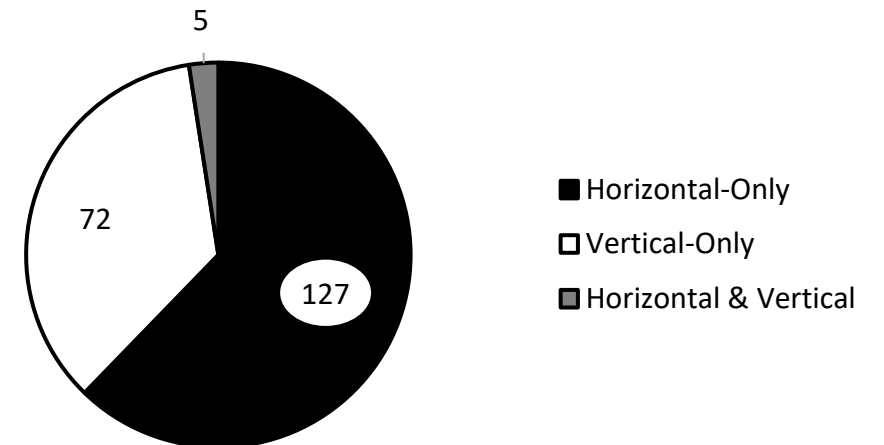
- This is a substantial difference compared to NASA's 2019 study with ACAS Xu

- 62% of DAA maneuvers were horizontal-only
- 35% were vertical only
- Blended maneuvers were especially uncommon

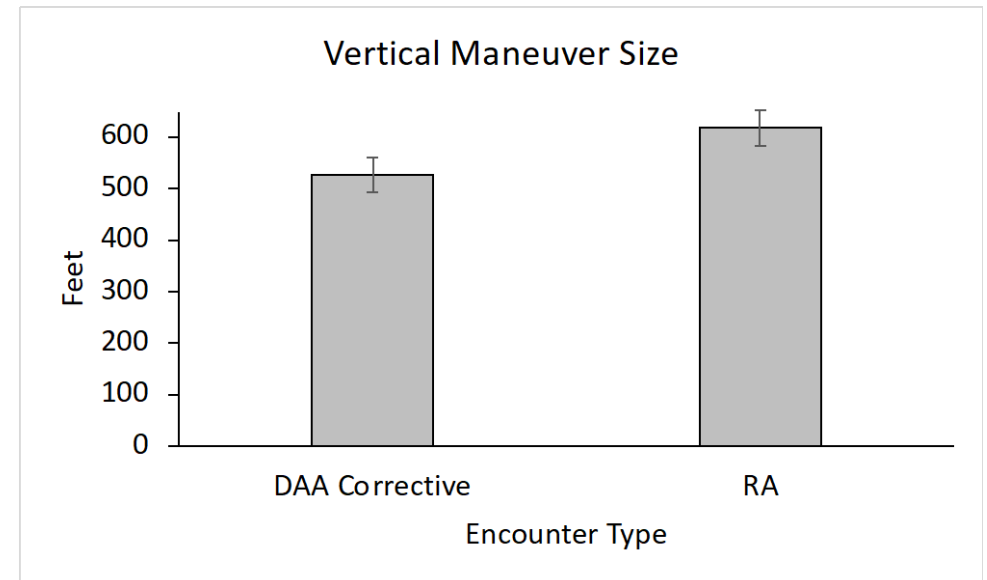
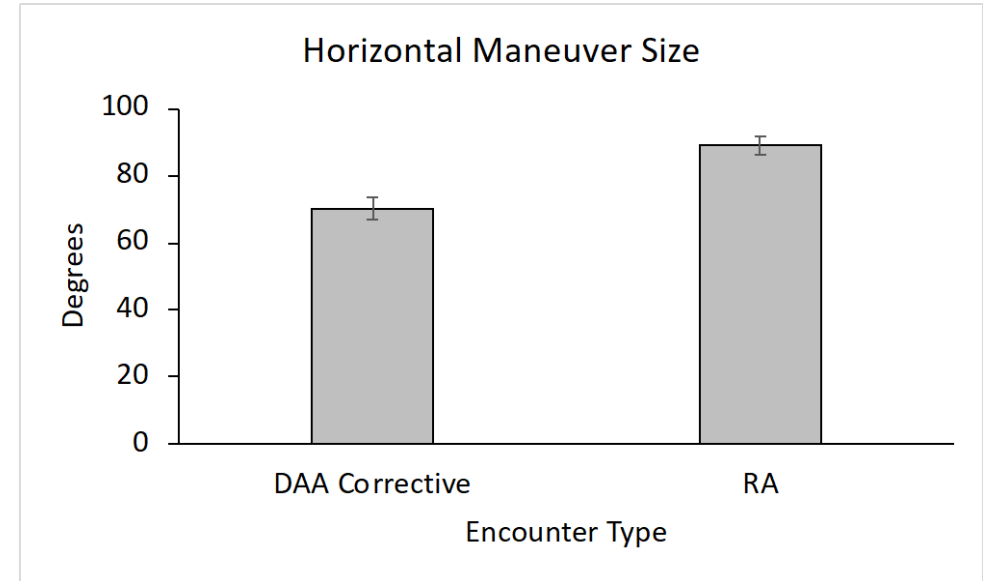
DAA Maneuvers - Current Study

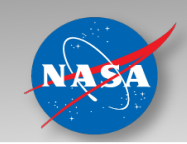


DAA Maneuvers - ACAS Xu 2019 Study



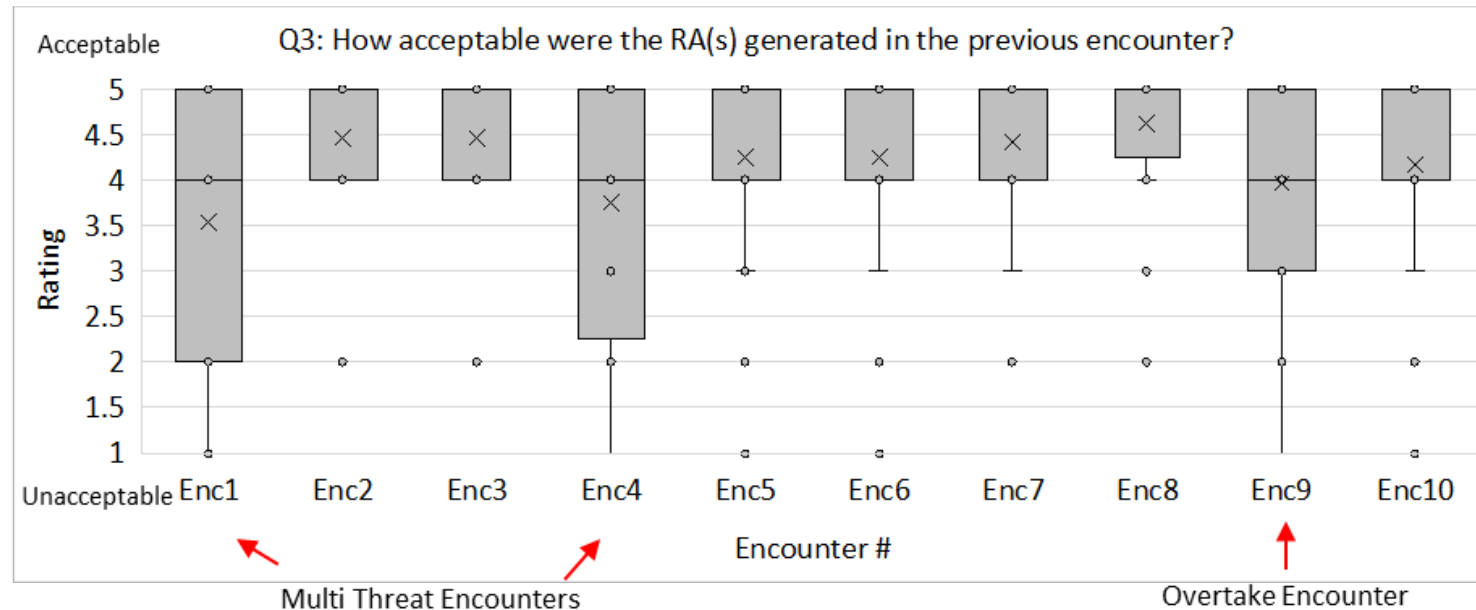
- Horizontal DAA maneuvers averaged 70°
 - An average of 20° less than horizontal RA maneuvers
- Vertical DAA maneuvers averaged 525ft
 - Approximately 100ft less than vertical RA maneuvers



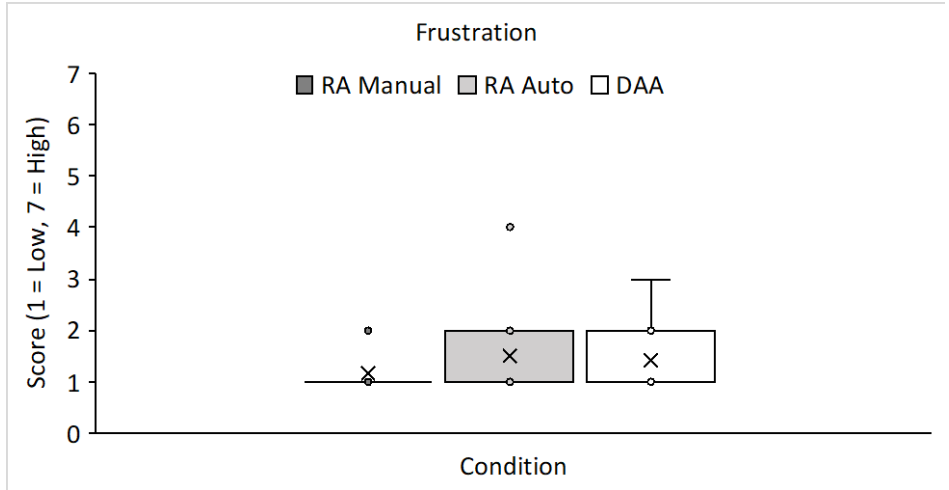
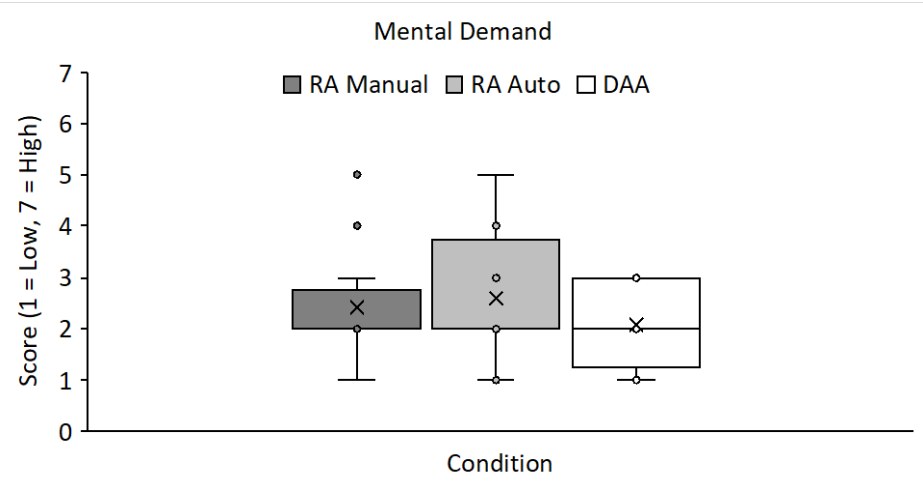
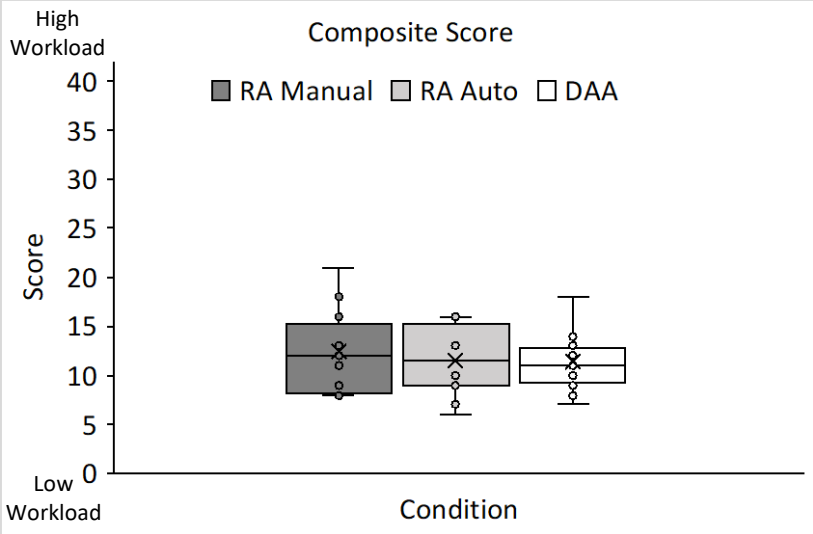


SUBJECTIVE DATA

- Pilots rated each encounter on:
 - Difficulty & acceptability of the guidance issued by ACAS, and the appropriateness of the timing, duration, and size of the commanded maneuvers
- Observed trends:
 - Pilots rated most encounters as easy to resolve and ACAS guidance as acceptable and appropriate
 - The two *Multi-Threat* RA encounters had the most variable ratings on difficulty and acceptability
 - The *Overtake* encounter received slightly lower ratings on acceptability of guidance



- Workload ratings were low overall (avg. **Composite** rating = 11.5)
 - Max. Composite Rating = 42; Min. Composite Rating = 6
 - No significant differences between conditions ($\chi^2 (2) = .439, p > .05$)
- No workload benefits, overall, seen for the Automated RA condition
 - Very low Physical Demand ratings were offset by (relatively) higher **Mental Demand** and **Frustration** ratings



- Broad agreement that the DAA alerting and guidance:
 - Was easy to understand and useful
 - Impacted how pilots decided to maneuver against Corrective alert-level intruders
 - Pilots consistently mentioned that the presence of the DAA/RWC banding made it easier to decide how and how far to maneuver; also helped confirm initial maneuver impressions
 - Would be beneficial in current-day, VFR helicopter operations
 - Areas for improvement are on less sensitive alerting and guidance – pilots noted current DAA/RWC thresholds would lead to nuisance alerts
- RA alerting and guidance:
 - Rated as easy to understand and useful
 - Pilots felt that ACAS over-relied on lateral maneuvers when climb/descends would have been simpler
 - 42% (5/12) responded that RAs tended to stay active slightly longer than necessary
 - 67% (8/12) said the 3°/sec and 1000fpm performance assumptions were appropriate
 - The most common suggested change was using 500fpm rather than 1000fpm



Post Simulation Questionnaire

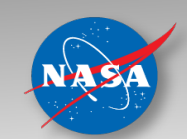


- Automated Maneuvering
 - Pilots generally agreed that they had sufficient information regarding onset of auto-RA and auto-RTC functions
 - Pilots split regarding whether they preferred manual vs automated conditions
 - 5 preferred manual and 7 preferred the auto-RA & auto-RTC capabilities
- Terrain and Obstacle Awareness
 - Most pilots considered it “highly necessary” that ACAS Xr take terrain and obstacle data into account when generating guidance
 - Particularly when the RA maneuvers are automated (11/12 ranked it as highly necessary)

- Trends

- All pilots found it essential for ACAS Xr to incorporate terrain & obstacle awareness into its guidance
 - 7/12 argued it was preferable to have the same system providing traffic & terrain/obstacle avoidance (rather than two separate systems)
 - 11/12 pilots thought there should be a fixed AGL altitude cut-off
 - 7/10 thought 500ft AGL would be the cutoff (100ft was lowest suggestion, 1000ft was highest)
- Pilots were split on the effect of frequent target heading updates
 - 9/12 found the target heading jumps frustrating and confusing but no clear fix
 - Some pilots said the initial target heading could be larger, since it (almost) always has you turn further anyway
 - 2 pilots recommended issuing horizontal RAs as a target bank angle rather than target track
- All pilots liked the idea of having the ability to toggle the DAA/RWC alerting and guidance ON/OFF but said they would default to flying with in ON and disable in congested airspace

- Overall
 - Losses of Well Clear & NMACs were extremely rare
- Resolution Advisories
 - Response times easily met the 5 second assumptions for all RA types
 - Pilots demonstrated an ability to perform blended maneuvers within 5 seconds
 - Participants noted an over-reliance on horizontal RAs
 - A drawback of horizontal RAs was the size of the deviation commanded (+100°)
 - Ending with a 'Maintain Heading' RA reduced horizontal maneuvers sizes by ~20°
 - Lack of terrain & obstacle awareness led to less trust & non-compliance
- Detect and Avoid
 - Pilots reported that they found DAA alerting & guidance helpful for situational awareness
 - Compared to remote operations
 - Far faster response times suggest that the alerting look-ahead time can be significantly reduced
 - Pilots were less reliant on horizontal-only maneuvers in this study (i.e., onboard)
- Automated Maneuvering
 - Was not found to significantly impact our objective metrics
 - Lack of traffic awareness by the return-to-course logic led to less trust during RTCs
 - Pilots consider terrain and obstacle integration as critical to the safety of the automation



Next Steps



- Initial brief of the results to ACAS Xr program office in late July
 - Will focus on specific observations from the sim to inform next version of ACAS Xr
- Larger brief to RTCA SC-147 (ACAS Xr MOPS) in November
 - May cover current and upcoming AVA-1h sims
- Write two paper(s) for AIAA Aviation and/or DASC 2023
 - Plan for objective data & subjective data papers
- VMS AVA-1h Simulation
 - Developing test plan
 - Experiment review July 5th @ 11:00am PDT
 - Shakedown week of August 8
 - Data collection August 15-September 2
- Questions?



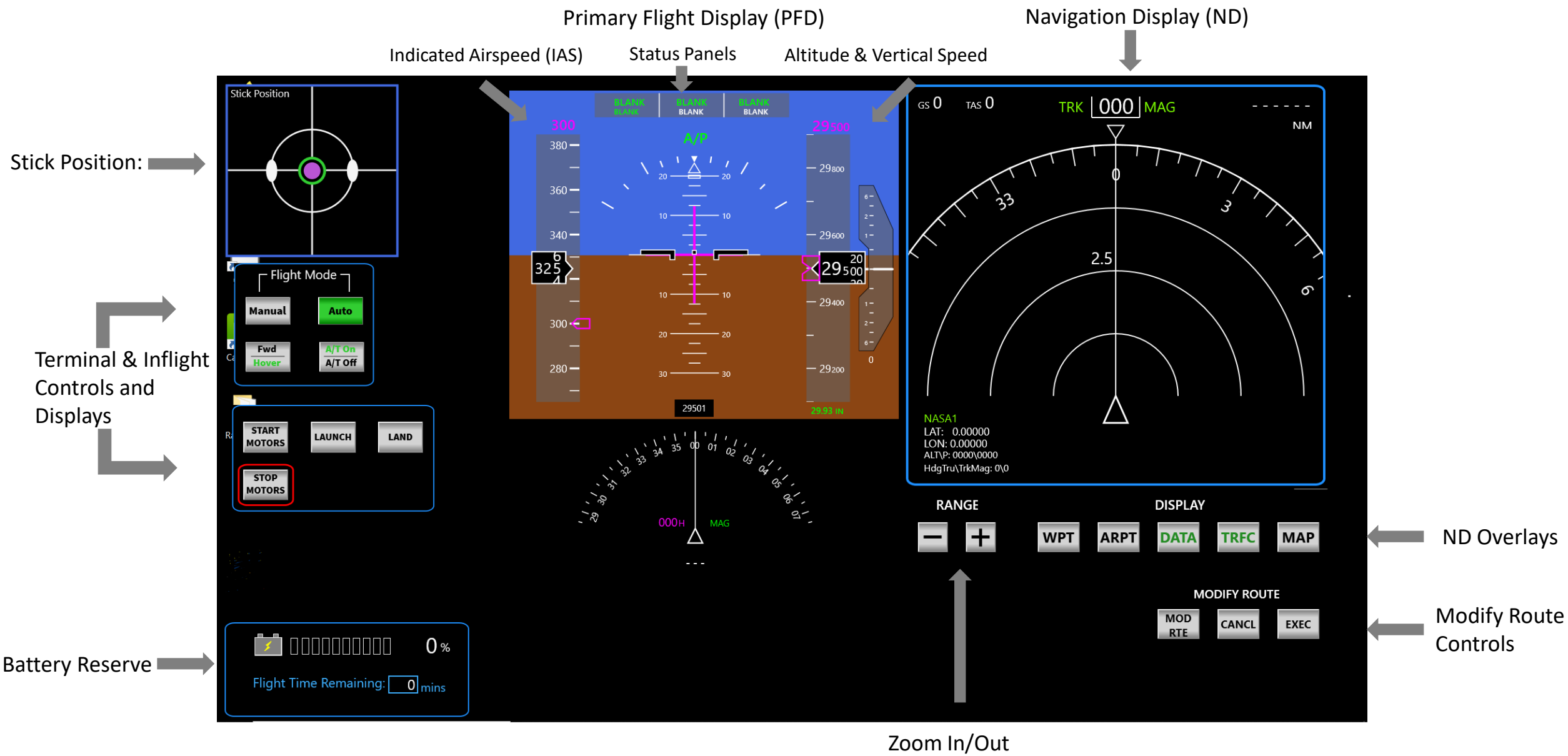
BACKUP SLIDES

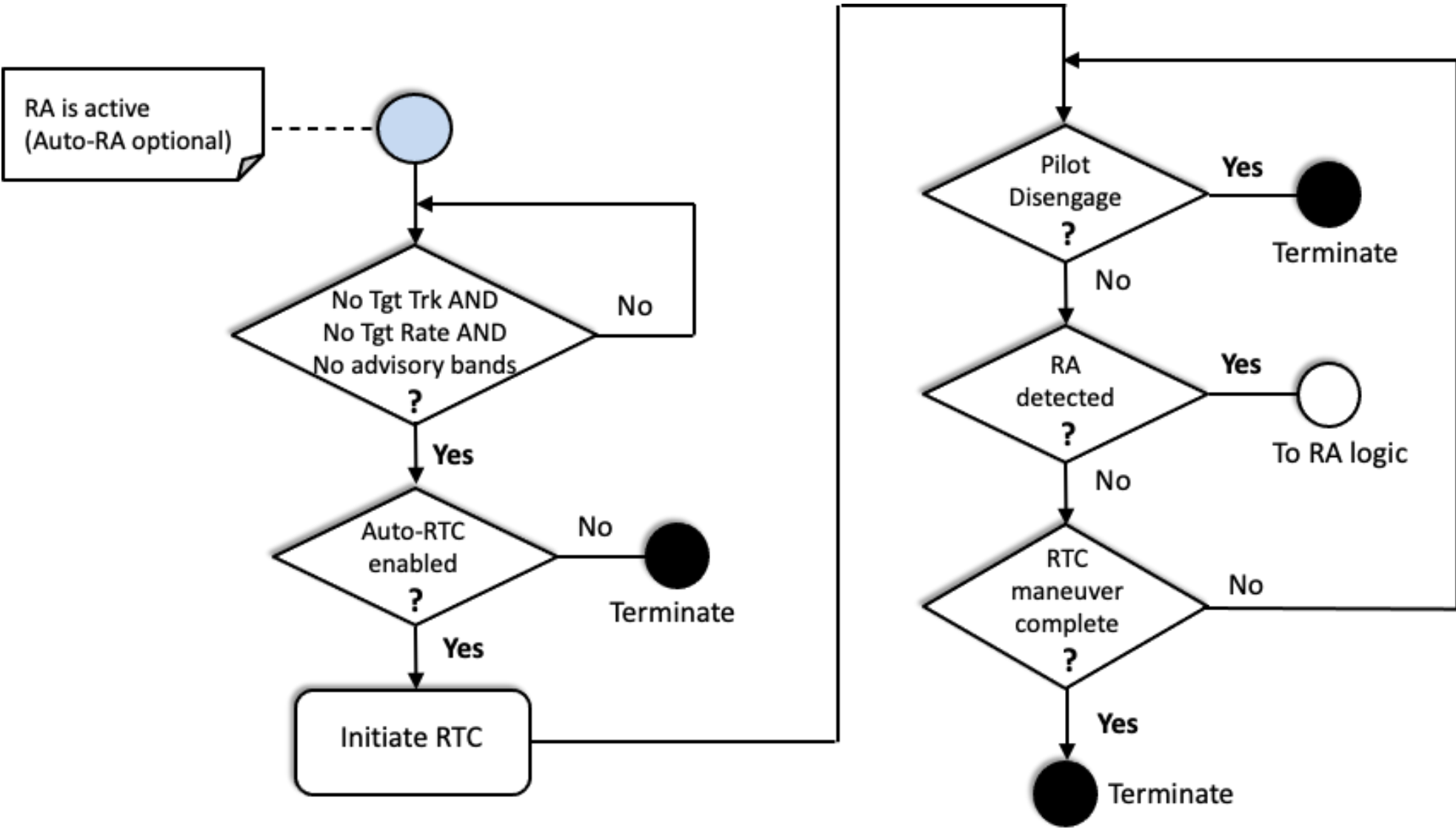


- Horizontal RA Reversals
 - 2 total; both occurred when pilot ignored horizontal RA in favor of a climb or descent
- Vertical RA Variants:
 - Limit
 - 20 climb (occurs after a descent RA)
 - 10 descent (was not accompanied by a vertical RA)
 - Reduce
 - 10 climb (occurs after a descent RA)
 - 10 descent (occurs after a climb RA)
 - Preventive RA
 - 3 w/ no clear RA type/text
 - Crossing
 - 1 climb, 2 descent



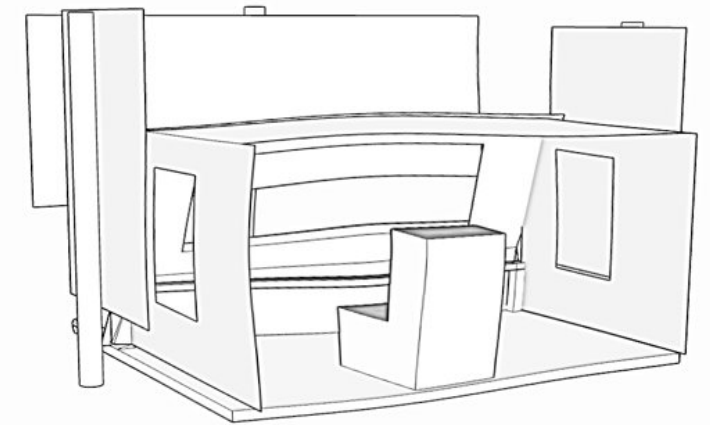
Simulator Displays (Example Designs)





- Hazard Perception and Avoidance (HPA) is using the FAA's Airborne Collision Avoidance System for Rotorcraft (ACAS Xr) as our tactical conflict detection and resolution technology
 - ACAS Xr is in pre-development – RTCA SC-147 Minimum Operational Performance Standards (MOPS) for Xr development does not start until Feb 2022
 - The logic will be expanded and tuned for UAM/rotorcraft as the MOPS development process gets underway
 - We will be using “version 1” of ACAS Xr, which was released in February 2021, and has limited functionality (e.g., is best suited for forward flight)
- ACAS Xr provides Detect and Avoid (DAA) and Collision Avoidance (CA) functionality
 - DAA alerting/guidance is caution-level, suggestive, and triggers approximately 90 seconds from closest point of approach (CPA)
 - CA alerting/guidance is warning-level, directive, and triggers approximately 30 seconds from CPA
 - TCAS/ACAS refer to collision avoidance commands as Resolution Advisories (RAs)
- ACAS Xr issues a variety of Resolution Advisories (RAs) types
 - **Horizontal** RAs command a *target track angle*
 - **Vertical** RAs command a *target vertical speed*
 - **Blended** RAs command a target track angle & target vertical speed *simultaneously*

- The current study proposes to collect data on the effectiveness of the ACAS Xr guidance and the utility of the automated RA maneuvers in the context of eVTOL with an onboard pilot
 - Previous research with ACAS focused on small and large Unmanned Aircraft Systems (UAS)
 - DAA conflicts will be resolved manually but RA maneuvers will be commanded automatically (in select conditions), as will the maneuver to return-to-course (RTC) following the conflict
- Pilots will fly short en-route/cruise scenarios in our lab's eVTOL fixed-base simulator and encounter scripted conflicts
 - Varying level of automation and intruder encounter geometry
 - Collecting pilot feedback on the display of ACAS Xr information and on how the automated maneuvers are implemented
- Study also provides the opportunity to integrate Flight Deck Z into our lab environment for the first time



- Experimental Conditions:
 - Manual RA Encounters
 - *Pilots trained not to respond to DAA alerting/guidance*
 - Pilots manually complied with RA guidance once it was triggered
 - Returning to course (RTC) was done manually
 - Automated RA Encounters
 - *Pilots trained not to respond to DAA alerting/guidance*
 - Pilots monitored system as it automatically responded to RA guidance
 - Returning to course (RTC) was automated
 - *Pilots could override automation at any point by deflecting the side-stick controller*
 - Detect and Avoid Encounters
 - Pilots were trained to respond as soon as a DAA Corrective alert (“Traffic, Avoid”) was generated
 - If an RA was issued at any point, pilots were trained to respond manually
 - RTC was also performed manually

- **Dependent Variables**

- **Objective Metrics:**

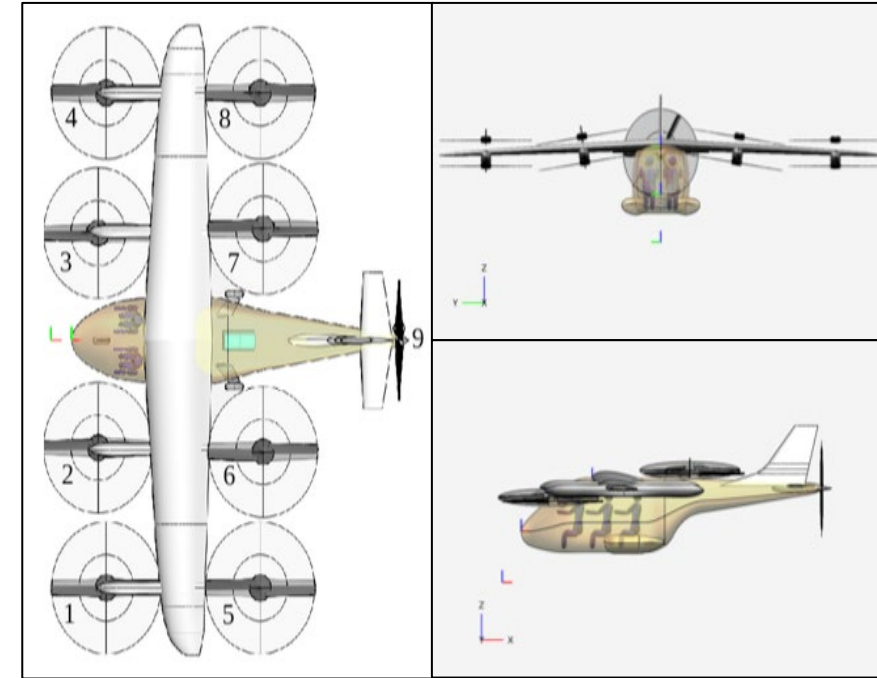
- Response Times: pilot response times to DAA Corrective alerts and RAs (in the manual condition) will be recorded
 - Losses of DAA Well Clear (LoDWC): the number and severity of LoDWC against DAA and RA conflict types will be recorded
 - Near Midair Collisions (NMACs): record instances of NMACs
 - Maneuver Size: the size of the maneuver/path deviation will be recorded for each encounter
 - Maneuver Duration: the time from the onset of the conflict and the start of the RTC maneuver will be captured
 - Maneuver Compliance: whether or not the pilot successfully complied with the DAA/RA guidance

- **Subjective Ratings:**

- Acceptability of Automated RA & RTC Maneuvers
 - Workload - NASA TLX (Post Encounter)
 - Acceptability of Presentation of ACAS Xr Information – e.g., display of DAA/RA alerts and guidance, display of automation information

- Ownship

- Using the Lift + Cruise eVTOL flight model via Flight Deck Z
- Performance:
 - Cruise speed: 120KTAS
 - Minimum turn rate: $3^{\circ}/\text{sec}$
 - Climb/descent rate: 1000 ft/min
- Equipage: ADS-B In/Out
 - Perfect data assumed (no sensor models)



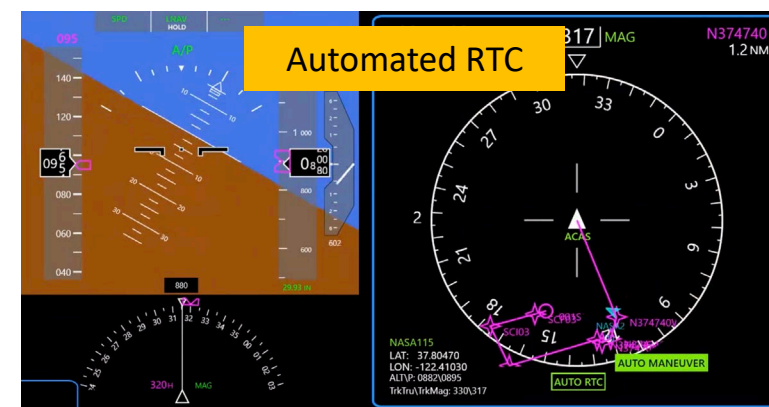
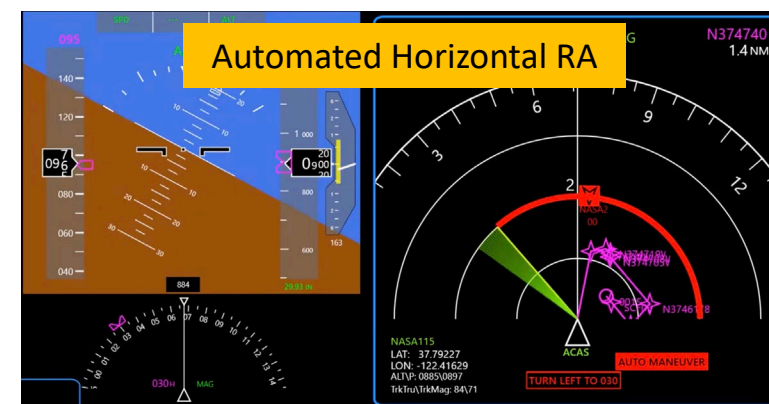
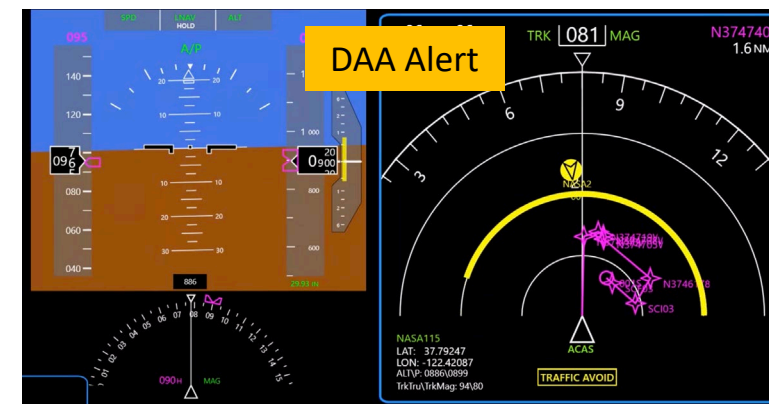
- Intruders

- General Aviation (e.g., Cessna-like)
- Performance:
 - Cruise speed: 100-160KTAS
 - Minimum turn rate: $3^{\circ}/\text{sec}$
 - Climb/descent rate: 1000 ft/min
- Equipage: ADS-B In/Out

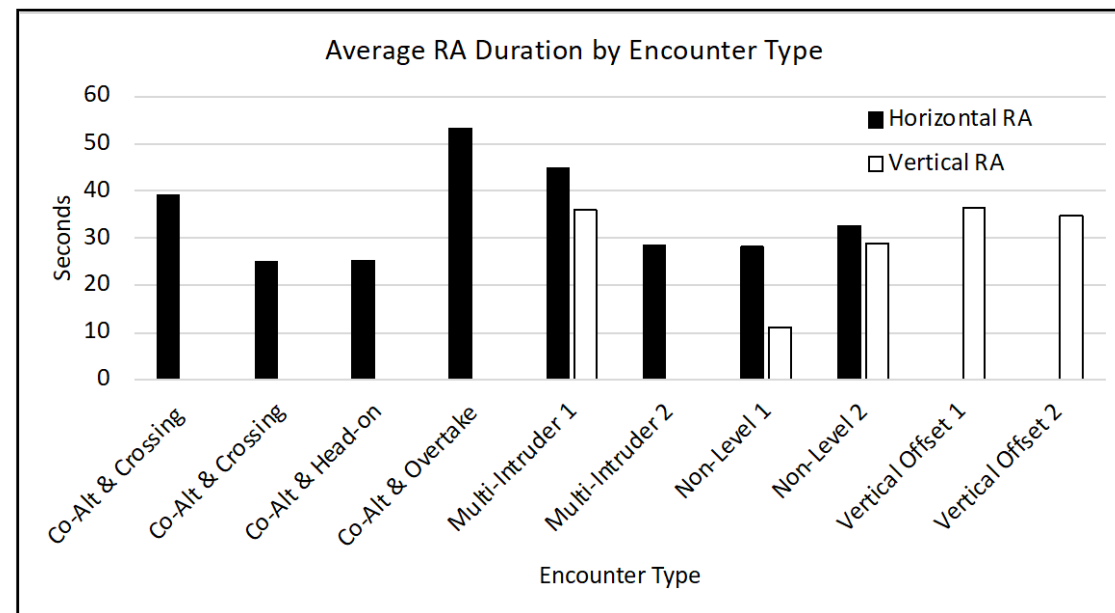
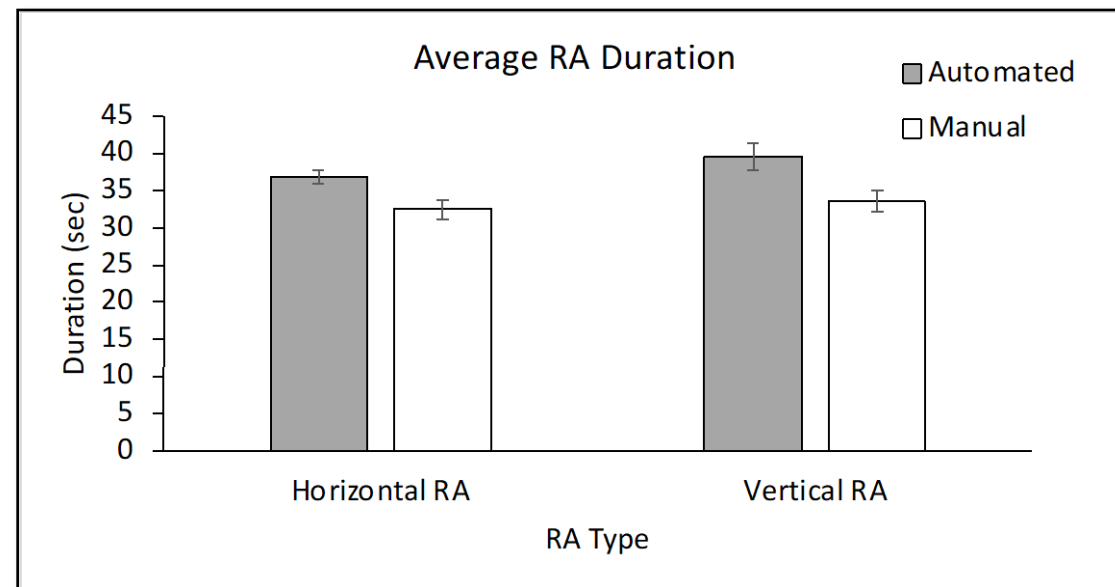


- Participants
 - Up to 12 current rotorcraft participants will be recruited for this study
- Simulator
 - Participants will be flying an eVTOL flight model in our fixed-base simulator
 - Vehicle will start at mission altitude (1500ft AGL) in level flight and in auto-pilot mode (no takeoff/landing will be simulated)
 - Controls:
 - 1 side-stick controller: longitudinal/latitudinal direction of motion with twist to control rudders (yaw)
 - 1 side-stick controller: acceleration/deceleration (not used)
 - Tablet & touch screen monitor: flight mode & navigational map interfaces
- Simplified airspace environment for the first study:
 - Vehicle will be in transit between two vertiports in San Francisco during VFR/VMC
 - **No** Take off & Landing (although checklists to anticipate landing may be included as a secondary workload)
 - **No** Provider of Services for UAM (PSU) interactions will be included in this study
 - **No** background traffic
 - Traffic will **not** be included in out-the-window displays
 - ATC interactions **may** be included

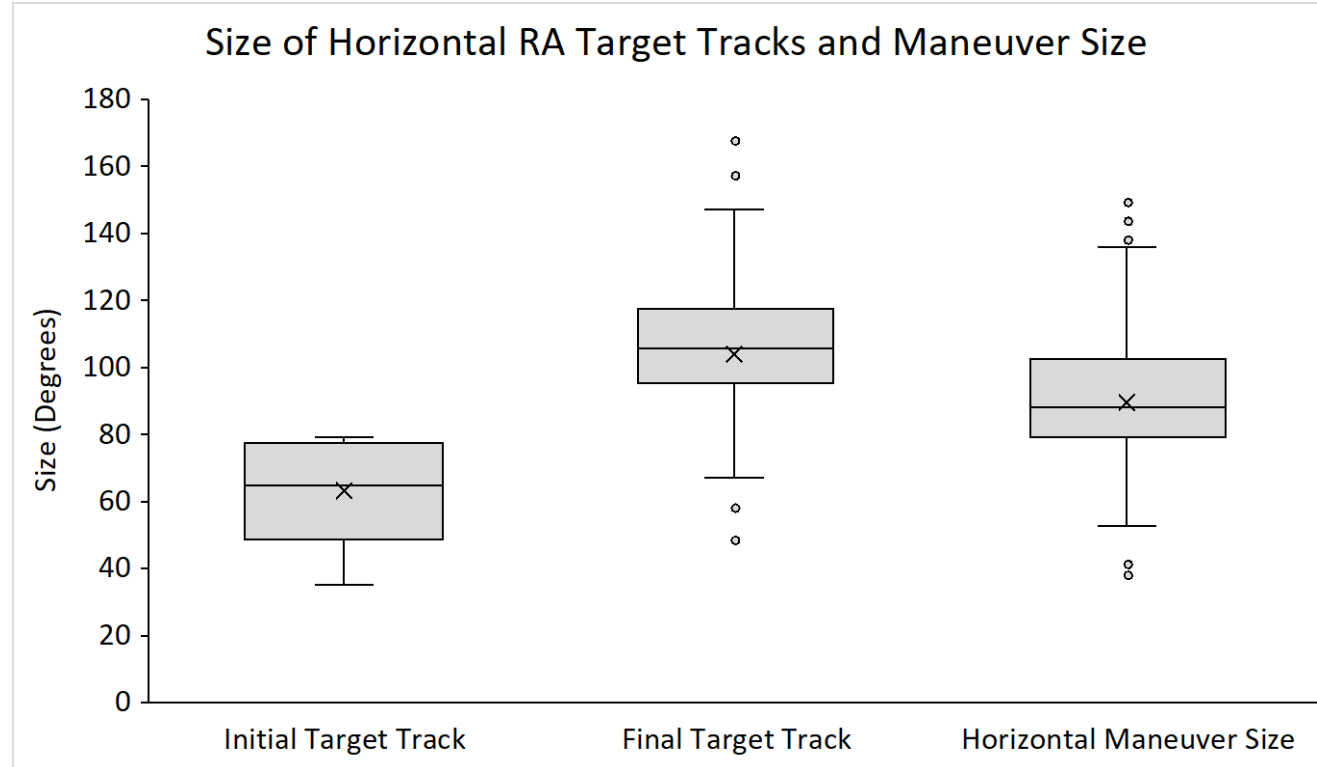
- Pilot Task:
 - Use ACAS Xr alerting and guidance to resolve scripted conflicts
 - Pilots will disengage the auto-pilot to manually respond to RWC/Corrective alerts and to RAs in the manual condition
 - The RAs will be flown automatically in the automated condition and pilots must monitor
 - They have the ability to disengage the auto-maneuvering mode if so desired
 - Pilots will be asked to return to course (in the manual condition) as soon as practical
- Experimental Scenarios:
 - Pilots will run through 10, ~5 minute encounters per experimental condition
 - Manual Maneuvers vs Automated Maneuvers
 - The ownship will be re-set at the start of every new encounter to simplify scenario development



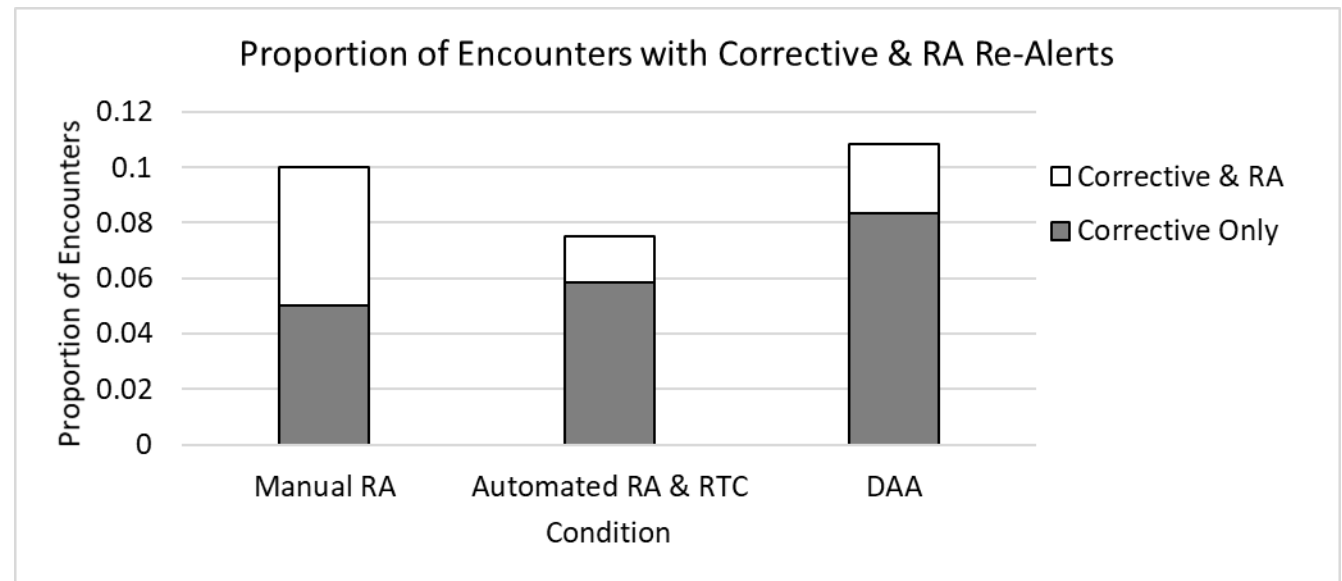
- Avg. Horizontal RA duration = 34.6 sec
- Avg. Vertical RA duration = 36.5 sec
- The manual response condition reduced RA duration times by 4-6 seconds
- The encounter that resulted in the longest average RA duration was an overtake scenario
 - Ownship often ended up in a horizontal chase scenario



- Plot of initial & final target track sizes and horizontal maneuver size
 - Pilots typically ended their maneuver $\sim 15^\circ$ short of the final target track commanded by the RA
 - 22% of horizontal RAs commanded a relative track greater than 117°
 - 24% of maneuvers were greater than 103°



- There were multiple instances where the pilot disengaged the auto-response
 - 7% (8/120) of encounters resulted in the pilot disengaging the RA response (primarily due to proximity to terrain)
 - 12% (14/120) of encounters resulted in the pilot disengaging the RTC maneuver (primarily to avoid re-engaging a traffic conflict)
- Re-Triggering Traffic Conflicts During RTC
 - All conditions were found to result in re-alerts
 - Most common in DAA (11%) and Manual RA conditions (10%)



- Horizontal RA resulting in a lateral 'chase' scenario, where ownship is in front of the intruder and the RA stays on for 1-2 minutes
 - Pilots eventually had to break away from the RA while it was still active – either start turning back to course and/or maneuver vertically to gain separation
- Multi threat encounters frequently led to a horizontal RA that commanded a track that was toward secondary intruder; later added vertical RA to account for second aircraft
 - Led to feedback from participants that the maneuver was perceived as unsafe and not effectively taking the secondary intruder into account with the first RA command
- Cases where vertical RA appeared to stay active for far too long (after > 1000ft separation had been achieved)
 - Example: p2_tr2_enc1; descend RA lasted 1.5 minutes; pilot climbed before RA was cleared



- DAA Non-compliance – 14 total
 - Turned into banding – 6
 - RWC horizontal bands tended to saturate very quickly, particularly when intruder was non-level
 - In these cases, pilots figured it was still safe to turn left/right and the bands eventually receded/the Corrective alert cleared
 - Returned to course early and into RWC bands – 2
 - Stopped turn short, keeping heading within RWC band region - 2



- Rapid horizontal banding saturation in cases where intruder was in climb/descent
- Not receiving a Corrective alert ahead of vertical RA when intruder was 250ft vertically separated
 - E.g., p1_tr1_enc6
- Rarely saw DAA Preventive alerts, even when level-level with 500ft vertical separation

- Resolution Advisories

- Pilots were able to avoid losses of well clear and NMACs at a very high rate *even when* they were told not to respond to the DAA Corrective alerting and guidance
 - No effect of the Automated vs Manual variable
 - Losses of well clear that did occur always occurred when returning to course
- Manual response times were consistently below 5 seconds
 - During simultaneous Blended RAs, pilots started with the horizontal maneuver, then quickly added the vertical maneuver
- Manual RA condition resulted in slightly shorter RA durations (~5 seconds) but larger horizontal deviations (~12°)
 - Turned at faster rates
- Half of all horizontal RAs ended with a final target heading of 100°+
 - 92% of horizontal RAs had 1 or 2 target track updates
 - Ending with a 'Maintain Heading' RA reduced horizontal maneuvers sizes by ~20°
- Non-compliance with an RA was most often due to proximity to terrain
 - Several others were due to neglecting the target track updates and preferring a climb/descent over a turn RA
- Pilots found the RA alerting and guidance intuitive and useful, found some areas for improvement:
 - Horizontal RAs seemed to update too often and required larger maneuvers than seemed necessary or reasonable
 - Lack of terrain/obstacle awareness led to occasional unsafe Descend RAs

- Detect and Avoid/Remain Well Clear
 - Pilots found DAA alerting and guidance intuitive and would find it useful in current VFR helicopter operations
 - Response times were extremely fast compared to what was seen in earlier ACAS Xu HITL
 - 4 seconds vs 17 seconds (due to hands-on control and lack of ATC coordination in current sim)
 - Pilots were found to perform vertical and blended maneuvers in response to DAA alerts more often than the ACAS Xu HITL
 - Horizontal-only maneuvers accounted for 27% of maneuvers in current study vs 62% of maneuvers in Xu sim
 - DAA banding appeared to saturate quickly, forcing pilots to often ‘turn into banding’
 - DAA alerts were inconsistent against intruders that were vertically separated
 - Preventive alerts uncommon; did not receive Corrective alert prior to RA with ~250ft vert. separation
- Automation
 - Slight majority of pilots preferred the automated RA and RTC conditions
 - Pilots rated Mental workload as slightly higher in Automation condition, demonstrating automation’s ability to add workload rather than reduce it
- Terrain and Obstacle Awareness
 - Pilots consider terrain and obstacle integration as critical to the safety of the system, particularly if RAs are automated

- Experimental Scenarios:
 - Pilots ran through 10, ~5 minute encounters per experimental condition (each trial lasted ~50 minutes)
 - Manual RA, Auto RA, & DAA
 - The ownship was re-set at the start of every new encounter
- Created 10 unique RA encounters that were each presented twice
 - 4 co-altitude encounters with different approach angles (head, crossing, overtake)
 - 2 vertical offset encounters (e.g., 250ft vertical separation from ownship)
 - 2 non-level intruder encounters (intruder climbing/descending into ownship)
 - 2 multi-intruder encounters

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Encounter Type	Enc #	Int 1 Non/Level	Int1 Alt	Int1 Ang	Int2 Alt	Int2 Ang
RA	1	Level	1750	-90	1500	45
RA	2	Level	1400	-45		
RA	3	Non-Level	2500	-90		
RA	4	Level	1250	-45	1500	90
RA	5	Non-Level	500	45		
RA	6	Level	1750	90		
RA	7	Level	1500	0		
RA	8	Level	1250	-45		
RA	9	Level	1500	-135		
RA	10	Level	1600	90		
DAA	11	Non-Level	2500	-45		
DAA	12	Level	1500	-90		
DAA	13	Level	1400	115		
DAA	14	Non-Level	500	-115		
DAA	15	Level	1500	45		
DAA	16	Non-Level	500	0		
DAA	17	Level	1600	0		
DAA	18	Non-Level	2500	90		
DAA	19	Level	1500	-90	1500	45
DAA	20	Level	1500	0	1500	135



- Other trends:
 - Auto RA condition rated as slightly less 'valid' (i.e., useful and reasonable) than Manual RA and DAA conditions (DAA guidance had highest average rating on this question)
 - Significant differences between conditions on whether ACAS Xr alerting & guidance was perceived as being valid, $\chi^2 (2) = 11.66, p = .003$
 - Auto RA slightly split on how risky it is to automate RAs – 6 slightly disagreed that it's risky, 4 strongly agreed that it's risky
 - Still, most agreed that they would utilize that auto RA function
 - Auto RTC rated as risky (6 agree, 3 neutral, 3 disagree) but would utilize the function (10 agree/slightly agree)

- Out-the-Window Traffic

- No general agreement on whether lack of OTW traffic negatively impacted their ability to use the ACAS Xr alerting and guidance (4 agreed it had negative impact, 3 neutral, 5 strongly/slightly disagreed)
 - However, 10/12 said future studies would benefit from having OTW traffic visible

- DAA Alerting and Guidance

- Broad agreement that the DAA alert icons & aural alerts were useful and easy to understand
- All 12 pilots strongly agreed that the DAA guidance affected their decision making on how to maneuver
 - Somebody needs to look into the open-ended responses under this question (how did the banding impact their maneuvering?)
 - Also look at open-ended responses in the following question (q6)
- 11/12 agreed that they would find DAA guidance useful in current day, VFR helicopter operations
 - Any trends on open-ended follow-on question?



- RA Alerting and Guidance

- Strong agreement that RA icon, RA aural alerting and vertical & horizontal RA guidance was easy to understand
- Majority of pilots felt that the RAs were issued at appropriate time (4 pilots thought they were issued, in general, slightly late)
- 7/12 said they intentionally disregarded/contradicted RA guidance; some reasoning:
 - Does not want to turn in front of traffic
 - Did not feel the need to keep up with large target track updates after they felt they had turned far enough already
 - Didn't like how system failed to account for secondary traffic when responding to the closer intruder
 - Descending too low
- 7/12 said clear of conflict was issued appropriately; 4 thought the RAs lasted too long
- 8/12 said the 3°/sec and 1000fpm were appropriate performance assumptions
 - Most common suggested change was using 500fpm vertical rates rather than 1000fpm



Post Simulation Questionnaire



- RA
 - Any general trends/important points made in q9? (changes to RA alerting/guidance?)
 - General agreement that they had the info they needed to indicate auto RA and auto RTC engagement
 - Wanted radar altimeter reading and indication of how vehicle would return to course
 - 7/12 preferred auto RA and auto RTC; 5 preferred manual in both cases
 - Any trends in the open ended questions below this? (what improvements could be made to auto RA/ RTC)
- Terrain and obstacles
 - Very strong agreement that incorporating terrain and obstacle information into ACAS Xr when generating DAA & RA alerts/guidance is highly necessary



- Alerting against wrong intruder
 - P1_tr1_enc4
 - NASA42 seems to have re-triggered the RA (17:56:10) when the video/ASIM makes it clear it should have been the other intruder (NASA43)
- Weakening RAs
 - Should we be annunciating “Weakening of Positive RA (after Climb/Descent)” as “Level-Off”, rather than limit/reduce climb/descent?
 - “Weakening of Descend RA (Low Altitude Inhibit)” should have no annunciation?