DOT/FAA/AM-20/06
Office of Aerospace Medicine
Washington, DC 20591

Minimum Information Requirements for an Unmanned Aircraft System Detect-and-Avoid Traffic Display under Full-Mission Conditions

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August 2019

Final Report

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-20/06		

4. Title and Subtitle Minimum Information Requirements for an Unmanned Aircraft System Detect-and-Avoid Traffic Display under Full-Mission Conditions	5. Report Date August 2019 6. Performing Organization Code
7. Author(s) Williams, K.	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract

The purpose of this study was to evaluate the usability of the Detect-and-Avoid (DAA) alerts for Unmanned Aircraft Systems (UAS) in conditions where the occurrence of a traffic encounter would be relatively unexpected and to examine the impact of the location of the alerts within or outside of the primary field of view of the pilot. Thirty-two pilots, holding a current instrument rating, flew a simulated unmanned aircraft control station in the conduct of a fire-fighting mission in which their task was to locate and photograph hot spots. During the mission, five intruder aircraft triggered a traffic alert in the control station. Three of those aircraft triggered a low-level preventive alert that did not require the UAS pilot to maneuver, however, the other two intruder aircraft approached the ownship in such a way as to trigger a higher-level alert that required the UAS pilot to initiate an avoidance maneuver. For half of the pilots, the traffic display provided basic aircraft location information. The other half received basic information plus additional suggested maneuver information to avoid a loss of well clear with the intruder. In addition, half of the pilots were provided with a master alert textbox located within the pilot's primary field of view while the other half were not. Finally, one of the maneuvering encounters occurred with the aural alert turned off while the other encounter was accompanied by an aural alert. Results showed that the effectiveness of the traffic display containing suggestive maneuver information is not diminished under full-mission conditions and does not warrant adjustment of alerting timing requirements as specified in the Phase I MOPS (RTCA, 2016).

17. Key Words	18. Distribution Statement
Unmanned Aircraft Systems, Detect and Avoid, Traffic Display, Alerting Guidance	Document is available to the public through the Internet: http://www.faa.gov/go/oamtechreports/

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	62	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgments

Research reported in this paper was conducted under the Flight Deck Program Directive of the Human Factors Division (ANG-C1), FAA Headquarters, and the Aerospace Human Factors Division (AAM-500) of the Civil Aerospace Medical Institute, FAA. We thank Bill Kaliardos (ANG-C1) and Stephen Plishka (AUS-420) for managing and sponsoring this simulation. Thanks to Victor Shortt, Dennis Rester, and Eamon Perry for providing computer support in setting up the Vigilant Spirit simulation, creation of the traffic display, and creation of all of the supporting software related to simulating the traffic encounters and recording all of the relevant data related to the pilot interactions with the system. Thanks also to Cherokee CRC, LLC for assistance in the recruiting and scheduling of participants and in the development of the online portion of the questionnaires and informed consent form. Finally, thanks to Robert "Buck" Joslin and Michelle Yeh (AIR-600) for recommendations regarding display formatting and positioning.

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List of Acronyms

ANOVA	Analysis of Variance
ATC	Air Traffic Control
CAT	Collision Avoidance Threshold
CDTI	Cockpit Display of Traffic Information
CFR	Code of Federal Regulations
DAA	Detect and Avoid
DAIDALUS	Detect and Avoid Alerting Logic for Unmanned Systems
DWC	DAA Well Clear
FAA	Federal Aviation Administration
HMD	Horizontal Miss Distance
ICOMC2	Insitu’s Common Open Mission Management Command and Control
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NMAC	Near Mid-Air Collision
RTCA	Radio Technical Commission for Aeronautics
SLoWC	Severity Loss of Well Clear
SME	Subject Matter Expert
TCAS	Traffic Collision Avoidance System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UATD	Unmanned Aircraft Traffic Display
WJHTC	Williams J Hughes Technical Center
ZTHR	Z-dimension (vertical) distance threshold

Executive Summary

One of the requirements for successfully integrating Unmanned Aircraft Systems (UASs) into the National Airspace System (NAS) is that UAS pilots be able to conform to Title 14 Code of Federal Regulations (14 CFR) § 91.113 which requires pilots to "see and avoid" other aircraft. The purpose of this study was to evaluate the usability of the Detect-and-Avoid (DAA) alerts in conditions where the occurrence of a traffic encounter would be relatively unexpected and to examine the impact of the location of the alerts within or outside of the primary field of view of the pilot. This is unlike previous studies, in which participants are presented with encounter after encounter, and consequently become primed for the event. This study was conducted to support the development of Minimum Operational Performance Specifications for UAS DAA Systems being developed by RTCA Special Committee 228. It was a planned follow-on to previous research conducted at the William J. Hughes Technical Center in Atlantic City, NJ in 2016.

The experiment evaluated two configurations of the traffic display using a control station simulation. In the baseline condition for the study (baseline), the traffic display contained the following pieces of information related to each intruder aircraft in the vicinity of ownship (unmanned aircraft):

- Position (range and bearing) indicator
- Relative altitude (in hundreds of feet)
- Heading indicator (chevron)
- Climb/descend indicator (up/down arrow)
- Collision threat status alert (icon coloring)
- Visual projection of future position(s)

The second display configuration (suggestive) contained everything available in the baseline display plus suggestive (vs. directive) maneuver information in the form of:

- Avoidance area information indicating areas to avoid so as to remain well clear[1] from other aircraft

[1] RTCA Special Committee 228 has defined "well clear" algorithmically (RTCA, 2016). This definition is referred to as DAA Well Clear (DWC) or simply Well Clear in this paper. Roughly speaking, well clear is 4000 feet horizontally, and 450 feet vertically from another aircraft but the boundary is modified by how quickly the aircraft are converging.

- Banding information indicating horizontal and vertical vectors to avoid to prevent a loss of well clear.

In addition to testing these two traffic display configurations, the experiment also manipulated the presence or absence of a master alert box within the pilot's primary field-of-view (i.e., 15 degrees vertically and horizontally from the design eye point). To evaluate the detectability of the visual alert locations, the third manipulation was the presence or absence of an auditory alert accompanying the visual traffic alerts that were triggered during the flight.

Based on the current findings, and combined with findings from other supporting research, the following conclusions are warranted:

- Effectiveness of the traffic display containing suggestive maneuver information is not diminished under full-mission conditions and does not warrant adjustment of alerting timing requirements as specified in the Phase I MOPS (RTCA, 2016).

- Dedicated traffic displays should be positioned as close to the primary field of view of the pilot as possible and should be accompanied by a master alert located within the primary field of view of the pilot.

- Some portion of training on these systems should emphasize the importance of immediately initiating an avoidance maneuver when a warning alert is triggered, regardless of whether or not communication with ATC is ongoing.

Post-test questionnaire items of the individual alert icons showed that the preventive and corrective alert traffic icons are easily confused with each other.

Introduction

The FAA has tasked the standards development group, RTCA Special Committee 228, to develop Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft Systems (UAS) Detect and Avoid (DAA) Systems (RTCA, 2016). The committee is currently, as of this writing, working on the Phase 2 MOPS for these systems. Because of the rapid acceleration in the growth of the UAS industry, the pace of growth has challenged the ability of standards development groups like RTCA and government entities to complete the work required for full integration of UAS into the National Airspace System (NAS).

While there is abundant research related to the use of traffic displays in both manned aircraft (e.g., Rantanen, Wickens, Xu, & Thomas, 2004; Thomas & Rantanen, 2006; Thomas & Wickens, 2006; Wickens, Helleberg, & Xu, 2002; Xu & Rantanen, 2007) and unmanned aircraft (e.g., Bell, Drury, Estes & Reynolds, 2012; Fern, Rorie, Pack, Shively, & Draper, 2015; Rein, Friedman-Berg & Racine, 2013; Rorie & Fern, 2015; Rorie, Fern, & Shively, 2016; Santiago & Mueller, 2015), there are still issues that have not been studied, or studied in relation to other factors. In a recent experiment that was summarized in two reports (Williams, Caddigan, & Zingale, 2017; Williams, Caddigan, & Zingale, 2018), a set of UAS traffic display concepts was evaluated for their effect on avoiding loss of well clear separation, as defined by the RTCA committee, from other aircraft. That study also looked at whether different pilot populations (i.e., pilots of manned aircraft and of unmanned aircraft) and different control station interface designs influenced the ability to avoid losses of well clear.

Results from that study demonstrated that the addition of maneuvering information during a traffic alert greatly improved pilot performance in avoiding loss of well clear relative to not having such maneuvering information. Also, this performance improvement was found across different pilot populations and control station designs. In the current study, we wanted to focus on a few issues that were not included in that study and have not been focused on in prior research.

The main issue of interest was how pilots would perform during a traffic encounter under real-world conditions where the pilots would not be fixated on the DAA traffic display. Most, if not all, of the research conducted to date has placed pilots in traffic encounters that were anticipated. For example, in Williams et al. (2017), pilots were presented with 32 traffic encounters under various conditions. Every encounter required the pilot to maneuver the aircraft to avoid a loss of well clear from another aircraft.

This is in contrast to what will occur in the real world where traffic encounters are relatively rare and, therefore, unexpected. Research looking at unexpected events in the cockpit have categorized reactions to these events into three types; startle, surprise, and distraction (Rivera, Talone, Boesser, Jentsch, & Yeh, 2014; Talone, Rivera, Jimenez, & Jentsch, 2015). Startle has been defined as “a brief, fast, and highly physiological reaction to a sudden, intense, or threatening stimulus, such as the sound of a pistol shot” (Landman, Groen, van Paassen, Bronkhorst, & Mulder, 2017, p.1162). Surprise, on the other hand, is a cognitive-emotional response to mismatches between mental expectations and perceptual representations of the actual environment (Meyer, Niepel, Rudolph, & Schützwohl, 1991; Schützwohl & Borgstedt, 2005). Distraction, finally, has been defined as “the diversion of attention away from activities that are required for the accomplishment of a primary goal to other competing sensory (e.g., visual, auditory, biomechanical) and cognitive activities” (Talone et al., 2015, p. 279).

All three types of reactions have been shown to have negative consequences in terms of the slowing of response times (Thackray & Touchstone, 1983), task interruption (Horstmann, 2006), and failures to identify the development of dangerous situations (Talone et al., 2015). However, reproducing these reactions for traffic encounters in a simulation is difficult to accomplish. Participants have to be trained on how to interpret the information presented on the traffic display, what the various types of traffic alerts mean, and on how to maneuver the aircraft during a traffic encounter. While we did not think we could make the traffic encounters startling or even surprising, we thought we could achieve encounters that were somewhat unexpected, at least to the point of causing the pilot to be distracted from performing other tasks.

Within this distraction paradigm, several variables were of interest. The first was a comparison of different levels of information presented on the traffic display. In Williams et al. (2017), a traffic display containing baseline information was compared to three other display configurations that included some type of maneuver guidance, which was referred to as suggestive maneuver information because it provided a range of maneuver options from which the pilot could select. This additional information was either (1) an indication of the closest point of approach between ownship and an intruder aircraft, (2) avoidance area information indicating areas avoid so as to prevent a loss of well clear from another aircraft, or (3) banding information indicating horizontal and vertical vectors to avoid to prevent a loss of well clear. The results from Williams et al. (2017) found clear support for both the banding and avoidance area information relative to the baseline display but no support for the closest point of approach information. The first issue of interest, then, was whether pilot distraction away from the traffic display would affect whether the suggestive maneuver information was still as beneficial to the pilot as was found in Williams et al. (2017).

Besides the traffic display information content, a second issue involved the use of a separated traffic display. The RTCA MOPS (RTCA, 2016) allows the use of either a traffic display that is integrated with the display used to control the aircraft or as a separate display. It would be expected that this separated traffic display would be located as close to the primary field of view of the pilot as possible[2] for safety of flight requirements, but there is still a question as to whether that location would be effective under conditions where the pilot was distracted. If locating the traffic display outside the primary field of view is not effective for attracting the pilot's attention to a traffic encounter, it is likely that control stations will also have a master alert display that would be located within the primary field of view (i.e., within 15º of the design eye position) of the pilot. To test this issue, a second manipulation was to run traffic encounters with either the presence or absence of a master alert display within the pilot's primary field of view.

We knew that testing the positioning of the traffic and master alert displays would be problematic for at least one reason. All DAA visual alerts, whether on the traffic display or a master alert box, are always accompanied by an aural alert as well. The presence of the aural alert is independent of the placement of the visual alerts and independent from distraction by a mission task. To test the effect of the different types and placement of visual alerts alone, it was decided that one of the traffic maneuvering encounters would be run without the aural alert and without informing the participant that the alert would be muted. While this is not consistent with the planned implementation of these systems, nor compliant with 14CFR §25.1322(c)(2) flight

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[2] The Primary Field of View (PFOV) of the pilot is normally defined as within 15º vertically and horizontally of the design eye point (Yeh, Swider, Jo, & Donovan, 2016).

crew alerting requirements, it is possible that the aural alert could malfunction or be masked by ambient noise in the control station and so is not unrealistic.

Independent of the distraction paradigm, another issue of interest for the current study centered around two of the traffic alert aircraft icons being used (see Figure 3 for information about the alerting icons and their alerting parameters).

RTCA Paper No. 261-15/PMC-1400 (RTCA, 2016) defines three priorities of traffic alerting that involves both an auditory and visual alert[3]. The selection of traffic alert symbols and auditory alerts was based on recommendations established by the RTCA SC-228 working group. The lowest priority alert is a caution-level indication called a preventive alert. It is used to inform the pilot that an intruder aircraft is going to pass less than 700 feet but more than 450 feet vertically of ownship. No immediate corrective action is required; rather, pilots are instructed to monitor the situation. If neither the intruder nor ownship changes course, the aircraft will remain well clear of each other. The RTCA's well clear definition is called DAA Well Clear (DWC). The distance parameters for DWC are nominally 4000 feet horizontally and 450 feet vertically from the intruder but this distance is modified by time, which is determined by the relative closing speed of the aircraft (see RTCA, 2016, for the full mathematical definition of DWC).

The second caution-level alert is the corrective alert. This alert is triggered when DWC is expected to be lost within 55 s but more than 25 s. This alert requires the pilot to maneuver but is supposed to provide enough time for the pilot to contact Air Traffic Control (ATC) and request a maneuver before the maneuver is initiated. The reason for providing time to contact ATC is that large UAS are required, as of now, to be on an instrument flight plan under careful guidance from ATC.

The highest priority alert is the warning alert. The warning alert is triggered when DWC is expected to be violated within 25 s or less. It requires the pilot to maneuver before contacting ATC.

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[3] While both the preventive and corrective alerts are technically caution-level alerts, they have been prioritized (in RTCA, 2016), in terms of how they are displayed within the DAA system.

The issue of interest in the current study involves the two lower priority alerts, the preventive and corrective alerts. Because both of these alerts are caution-level alerts, the icons used to depict the traffic, as well as the banding and master alert color for these alerts, are yellow while the coloring for the warning alert is red (see Methods Section, Figure 3).

Because of the similarity of the preventive and corrective alert icons, there is a potential for confusing the icons with each other. All of the studies using these icons (e.g. Fern, Rorie, Pack, Shively, & Draper, 2015; Williams et al., 2017) have paired the icons with their respective auditory alert so there has not been a direct measure of how likely the icons can be confused under conditions where the auditory alert is not available. In the current study we decided to test potential confusion of the caution-level alert icons.

One final issue of interest for this study involved pilot maneuver preferences. Several studies have looked at pilot maneuver preferences with respect to the traffic encounters. Some of those studies have found a strong preference for horizontal maneuvers (e.g., Rorie et al., 2015). In Williams et al. (2018) we found much more balanced preferences between horizontal and vertical maneuvers. One reason considered for this difference in maneuver preferences was the use of UAS pilots vs. a mixture of UAS and manned aircraft pilots. It was thought that UAS pilots had a stronger tendency toward horizontal maneuvers because that was how they were trained. Manned pilots on the other hand, especially those with experience with TCAS II (with resolution advisories), might favor vertical maneuvers over horizontal maneuvers.

However, a second suggestion that has been considered is that the control station interface might also have a strong influence on maneuver preferences. The NASA studies (Fern et al., 2015; Rorie & Fern, 2015; Rorie et al., 2016; Santiago & Mueller, 2015) primarily used the same pilot interface design based on the Vigilant Spirit control station interface developed by the U.S. Air Force whereas Williams et al. (2017) compared two other interfaces (Predator interface developed by General Atomics, Inc. and the Boeing/Insitu ICOMC2 interface). In the current study, we used a version of the Vigilant Spirit control station but used only manned-aircraft pilots. It was expected that the results would provide some information about whether pilot training or user-interface design played a stronger role in maneuver selection.

Hypotheses

Assuming that the participants would be sufficiently distracted by the secondary task, it was expected that muting the auditory alert would, at least, introduce a delay in a participant's ability to notice and respond to a traffic alert. This delay would manifest itself in the proportion of encounters that resulted in a DWC loss, in the severity of the loss, and in the response time to react to the encounter. In addition, if there was confusion with the two types of caution-level alerts, we would see a response delay between muted encounters where the master alert was not available and muted encounters with the master alert present.

For the effect of display configuration, we expected to see better performance in the avoidance of losses of well clear and response times with the suggestive display information configuration relative to the baseline display. This would support what was found with Williams et al. (2017). In addition, we believed that the effect of distracting the participant might result in slower overall reaction times across all of the conditions relative to the results from previous studies.

We expected that manipulating the presence or absence of the master alert would have a significant effect on traffic avoidance only if the secondary task distraction prevented the pilot from monitoring the traffic display, and primarily under the muted encounter condition. This would result in a significant interaction effect between the muting and master alerting conditions.

From the post-test questionnaire, we expected to find evidence of pilot confusion regarding the two caution alert icons. We thought we might also find support for superior usability scores related to the suggestive information traffic display relative to the baseline display.

Method

Participants

Thirty-two pilots were recruited for the study. All of the pilots were recruited from the Oklahoma City metro area and were compensated for their participation. Participants were required to hold an FAA pilot certificate (manned aircraft) with a current instrument rating and have at least 200 hours of flight experience. Table 1 presents the demographic summary statistics for the participants.

Table 1. Participant demographic summary statistics.

Mean Age (yrs.) (Median)	Age Range	Mean Total Flight Hours (Median)	Mean TCAS Experience (yrs)
48.8 (50)	27-73	4626.3 (2700)	7.1

None of the participants had experience flying large UAS but six indicated they flew small UAS (drones) as a hobby. Twenty-eight of the 32 participants (87.5%) stated that they had maneuvered to avoid traffic at some point in real life.

Vigilant Spirit Control Station

The simulated control station used in the study was the Vigilant Spirit Control Station (VSCS), which was developed by the U.S. Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base in Ohio (Feitshans, Rowe, Davis, Holland, & Berger, 2008). Figure 1 shows a picture of the control station as it was configured for the study. The screen on the left was a moving-map display showing current location of ownship (unmanned aircraft) and the programmed flight path. It also contained a box for entering commands to maneuver the aircraft and to return the aircraft to the pre-programmed flight path. The display in the lower center contained a screen showing the camera imagery as well as ownship primary flight information such as heading, altitude, and airspeed. This display also contained interface commands for selecting infra-red (IR)/day time view (DTV) camera settings. Because of the nature of the secondary task (see section on secondary task below for a detailed explanation), participants spent most of their time looking at this display, which we will call the mission task display.

The display on top in the middle presented the DAA traffic display. Traffic information appeared only on the DAA traffic display. The display on the right was not used in this study. For the purpose of determining the primary field-of-view, a design eye point was identified by measuring the point on the forward screen that was eye-level with someone seated in front of the screen and locating the position 15º below that point. This position is denoted in Figure 1 with a red circle. The green box in the figure indicates 15º horizontally and vertically from the design eye point, which is defined as the primary field-of-view.

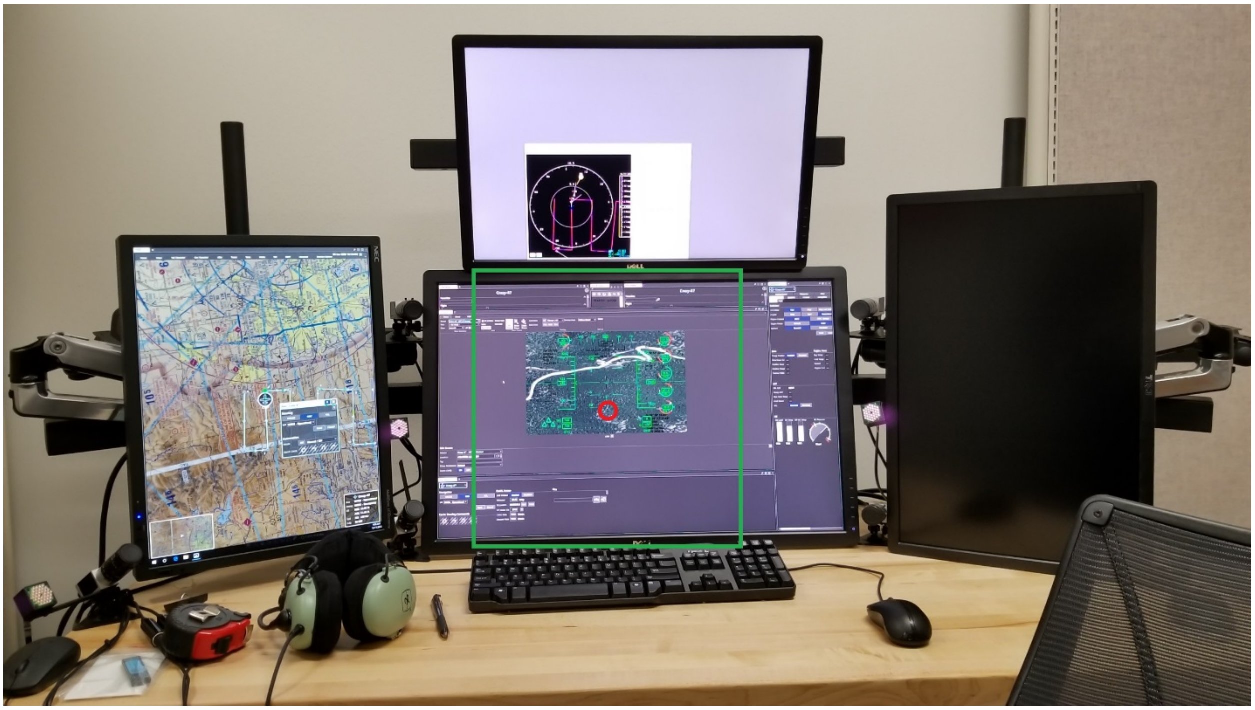


Figure 1. Vigilant Spirit control station with the traffic display on top. The design eye point is shown as a red circle. The green box depicts the primary field-of-view around the design eye point.

Traffic Display

A traffic display was created for inclusion with the VSCS platform (see Figure 2). This display provided information regarding other aircraft in the vicinity of ownship and, depending on the display condition being tested, information regarding potential maneuvers required to avoid losing DAA well clear. The baseline display that was used, based on results from Rein et al. (2013), contained the following pieces of information:

- Aircraft ID
- Position (range and bearing) indicator
- Relative altitude
- Heading indicator (e.g., chevron)
- Climb/descend indicator (e.g., up/down arrow)
- Collision threat status alert
- Visual projection of future position(s)

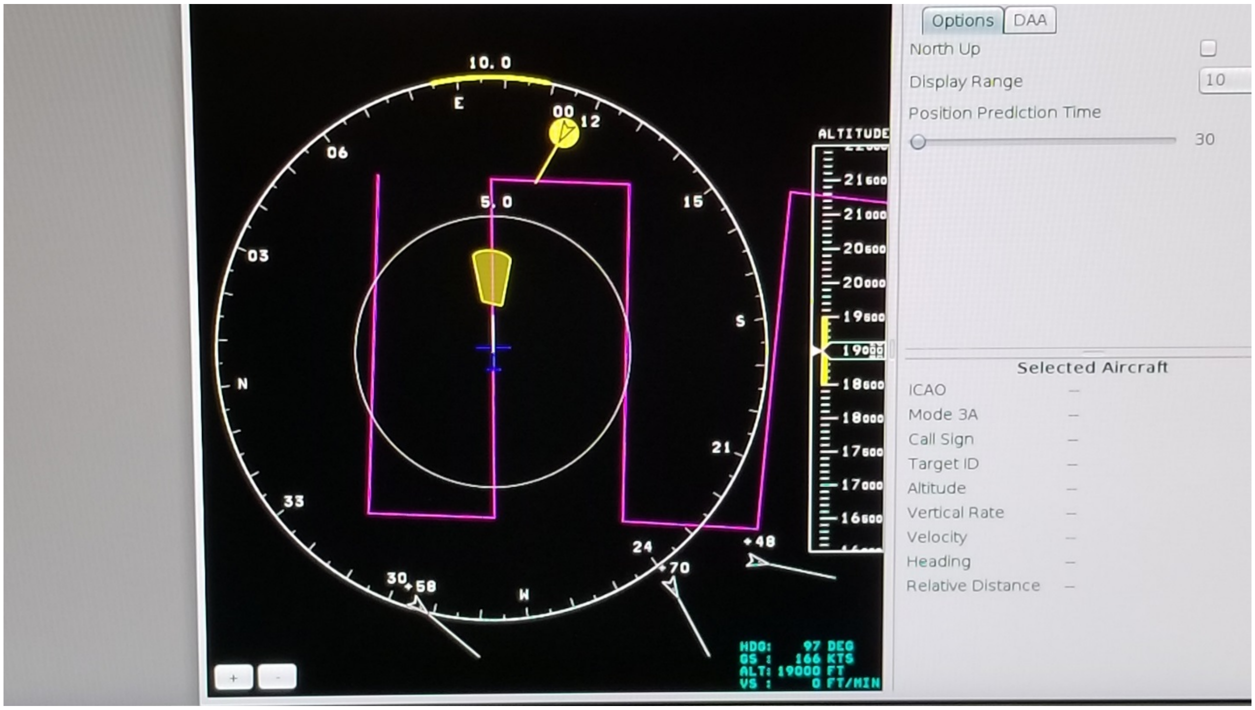


Figure 2. The Unmanned Aircraft Traffic Display used in the study with suggestive maneuver information.

The baseline display also showed the position of ownship, current heading and altitude of ownship, ownship ground speed (GS) and vertical speed (VS) in the lower right-hand corner, and the position of the programmed flight path. For the suggestive-information condition, the traffic display contained everything available in the baseline display plus additional information, called suggestive information, to assist the pilot in preventing loss of well clear from aircraft. This information was in the form of (1) avoidance-area information in the form of a colored polygon on the traffic display, and (2) banding information indicating heading and altitude values to avoid so as to avoid violating well clear. Both the avoidance area polygon and horizontal and vertical bands were depicted in the same color as the alerting traffic icon. Figure 2 shows both the avoidance area polygon and banding information for a caution level (yellow) corrective alert.

Visual and Auditory Alerts

The alerting algorithms used for this study are collectively called DAIDALUS (Detect and Avoid Alerting Logic for Unmanned Systems) and were developed by NASA Langley Research Center personnel (Muñoz et al., 2015). DAIDALUS provided the values used in the different display configurations.

The selection of timing parameters of the alerts was based on work accomplished primarily by NASA researchers working on behalf of the RTCA SC-228 DAA working group (Fern, et al., 2015; Rorie & Fern, 2015; Rorie et al., 2016; Santiago & Mueller, 2015).

The DAA system used three types of alerts for the presence of traffic. When an alert was triggered by the DAIDALUS algorithms, the traffic symbol corresponding to the intruder aircraft would change from a white unfilled chevron to one of the three shown in Figure 3. In addition to the traffic icons used in the study, Figure 3 also provides the separation criteria established for each alert level in terms of horizontal miss distance (HMD), vertical miss distance (ZTHR) and a time-based distance (modTau).

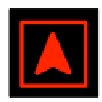
Alert Level	Separation Criteria	Time to Loss of DWC	Icon	Aural Alert Verbiage
Warning DAA Alert	HMD = 0.75 nmi ZTHR = 450 ft. modTau = 35 sec	25 sec		“Traffic, Maneuver Now, Traffic, Maneuver Now”
Corrective DAA Alert	HMD = 0.75 nmi ZTHR = 450 ft. modTau = 35 sec	55 sec		“Traffic, Avoid”
Preventive DAA Alert	HMD = 0.75-1.0 nmi ZTHR = 450-700 ft. modTau = 35 sec	N/A		“Traffic, Monitor”

Figure 3. Visual and auditory alerts with their respective alerting criteria.

In addition, Figure 3 shows the established time to loss of DAA well clear (DWC) for each type of alert and the aural alert verbiage for each type of alert. The lowest priority alert, the Preventive DAA Alert, did not require an action on the part of the pilot but was intended to draw attention to an aircraft that needed to be monitored. The explanation of this alert that was provided to participants was as follows:

> “The lowest priority alert is the Preventive DAA Alert, which is accompanied by the aural alert, ‘Traffic, Monitor’. This alert indicates that there is traffic on a course that will take it close to ownship but not close enough to cause the loss of well-clear. The pilot should monitor the movement of the traffic but does not need to perform any maneuvers to remain well clear.”

The other two alerts, the Corrective DAA Alert and the Warning DAA Alert, both indicated that a loss of well clear would occur if both aircraft remained on their current courses. The participants were told that the main difference between these two alerts was that the Corrective DAA Alert was intended to provide more time for the pilot to make a maneuver than the highest priority Warning DAA Alert. Participants were given instructions that, if they felt they had enough time to do so, they should contact air traffic control and request permission to deviate from their flight plan before performing the maneuver. However, if they received the Warning DAA Alert, they were instructed to maneuver first before contacting air traffic control.

Master Alert Box

In addition to the auditory alerts, changes in the traffic display icons, and suggestive maneuver information, participants could also receive a third type of visual alert presented on the master alert box. Figure 4 shows the positioning of the master alert box just above the mission task display and midway between the mission task display and the traffic display. The position of the master alert was positioned so as to be within the primary field-of-view of the participant.

When a traffic alert was triggered, a text message would appear in the master alert box matching the auditory alert provided to the participant. If the alert was a preventive alert, the text would say, “Traffic - Monitor” in black lettering on a yellow background. For a corrective alert, the text would say, “Traffic – Avoid” in black lettering on a yellow background. In addition, the yellow portion would flash on and off for the duration of the alert. Triggering a warning alert would cause the text to say, “Traffic – Maneuver Now” in black lettering on a red flashing background.

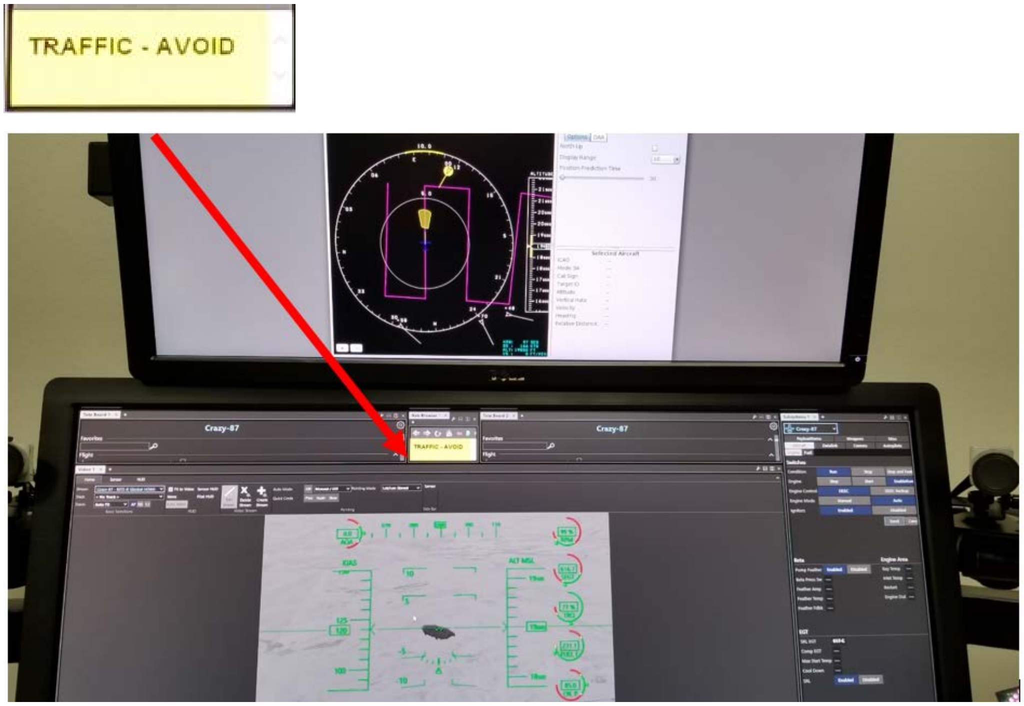


Figure 4. Position of the Master Alert Box (indicated by a red arrow).

Experimental Design

The experimental design was a three-factor, full factorial, mixed factors design with two between-subjects variables and one within-subject variable. The first between-subjects variable was the amount of information available on the traffic display. Two conditions were tested. Either the traffic display contained only the baseline information (baseline condition) or it contained the baseline information plus suggestive maneuver information in the form of both banding and avoidance area information (suggestive condition).The second between-subjects variable was the presence or absence of a Master Alert box. The within-subject variable was the presence or absence of an aural alert accompanying the visual alerting information.

Design of Traffic Encounters

In designing the traffic encounters, we were constrained by the need to keep the encounters relatively unexpected. To accomplish this, we decided to keep the number of encounters where a potential collision might occur to two. For one of these encounters, the aural alert would be muted and for the other it would not. The order of muting was counterbalanced across participants. In addition, we included three other traffic encounters that did not involve the need to maneuver. For these encounters, the participant would receive a preventive alert but the alert would remain at that level because the intruding aircraft would not change altitudes. A third manipulation we used to produce unexpected encounters was to distract the participant as much as possible through the use of a task that was both interesting and relevant to the flight mission. The task that was chosen was searching for hot spots as part of a firefighting operation and photographing the hot spots to assist other firefighters.

Two separate traffic encounter scenarios were created for the study. Both scenarios included five traffic encounters (two maneuvering encounters and three preventive-alert-only encounters) and used the same automated flight path but varied the timing and types of the encounters. The general shape of the flight path consisted of 12 waypoints configured in a parallel track pattern that could be completed in approximately 45 minutes. A large portion of the flight path can be seen in the traffic display in Figures 2 and 4.

Three of the encounters were preventive-alert-only encounters in which the two aircraft would come within 700 feet of each other vertically but not closer than 500 feet so that no maneuver was required to remain well clear of each other. The other two encounters were maneuver encounters that would begin as either a preventive or corrective alert and transition to a warning alert if the participant did not maneuver the aircraft in time. In scenario one, the order of the encounters between preventive only (P) and maneuvering (M) was MPPMP. For scenario two, the order of encounters was PPMPM.

For both scenarios, one of the maneuver encounters involved an intruder converging from in front of ownship and descending. For the other maneuver encounter, the intruder was co-altitude and crossing the path of ownship.

Maneuvering the Aircraft

At the beginning of the mission scenario, and most of the time during the scenario, the aircraft flew on a pre-programmed flight path. However, in response to a traffic alert, the participant was required to send a command to maneuver the aircraft, thus exiting the aircraft from the pre-programmed flight.

Figure 5. Steering box for sending maneuver commands to the aircraft.

To maneuver the aircraft, the participant used a mouse and keyboard to interact with the steering box located on the moving-map display. This box was usually present on the moving-map display, but could be made to appear by double-clicking on the ownship symbol located on the moving-map display. Figure 5 shows the steering box and the heading bug and compass rose surrounding the ownship. The participant had three options for changing aircraft heading. The first option was to use one of the quick-command buttons located at the bottom of the steering box. These were activated by left-clicking twice on the button, once to remove the button shield and the second click to activate the command.

A second way to change heading was to click and drag the heading bug triangle located on the heading circle to a specific heading, which was shown in the green box inside the heading circle and then clicking on the “Send” key located inside the Steering box. The third way to change heading was to click in the heading entry box in the Steering box, typing in a new heading, and then clicking the “Send” key.

Changing altitude was accomplished in one of two ways. The first method involved clicking in the altitude entry box in the Steering box, pressing the up or down arrows on the keyboard to change the altitude by 500 feet each time the arrow was pressed, and then clicking

“Send”. The second method was to click in the altitude entry box, typing in a new altitude, and then clicking “Send”.

After sending a maneuver to the aircraft, the aircraft was no longer using the programmed flight path information. To return the aircraft to the programmed flight path, the participant needed to select the “NAV” tab in the Steering box, click on a dropdown menu to select the appropriate waypoint, and then click “Send”. The aircraft would then return to the programmed flight path going to the selected waypoint by selecting the shortest turn to a 30-degree intercept of the flight path.

Secondary Task

In an attempt to fully engage the participants during the course of the mission, a secondary task was created. This task consisted of searching for, and photographing hot spots located around the programmed flight path of the aircraft. A hot spot basically consisted of a group of trees on fire. To search for these hot spots, there were two camera settings available to the participant. The first camera setting provided a natural world view and was referred to as the daytime view (DTV). Figure 6 shows a hot spot as it appeared using the DTV mode. The second camera setting provided an infrared (IR) view. While using the IR setting, the participant could select between “White-Hot” or “Black-Hot” modes. The selection of a particular camera setting was made using a mouse by clicking one of two buttons (labeled “DTV” and “IR”) that were located just above and on the left side of the mission task display. When using the IR setting, two buttons appeared below the IR button to allow selection of the White-Hot or Black-Hot modes.

The camera system was set up so that when the participant left-clicked on an object in the camera field-of-view, the camera would reposition so that the object would be centered on the display. Centering an object in the display was somewhat challenging because of the uneven terrain where many of the hot spots were located. Once an object was centered, the camera would move automatically, independently of any aircraft movement, so that the object would remain centered on the display until some other location was clicked on or the camera was repositioned using the moving-map display. Repositioning using the moving-map display could be accomplished either by left-clicking and dragging a small gray dot that indicated the current stare point of the camera to a new location or by right-clicking a location on the moving-map display and selecting “Stare here with the MTS-gimbal” from a pop-up menu. Participants were shown all three ways to reposition the camera and were allowed to practice each of the methods during training.

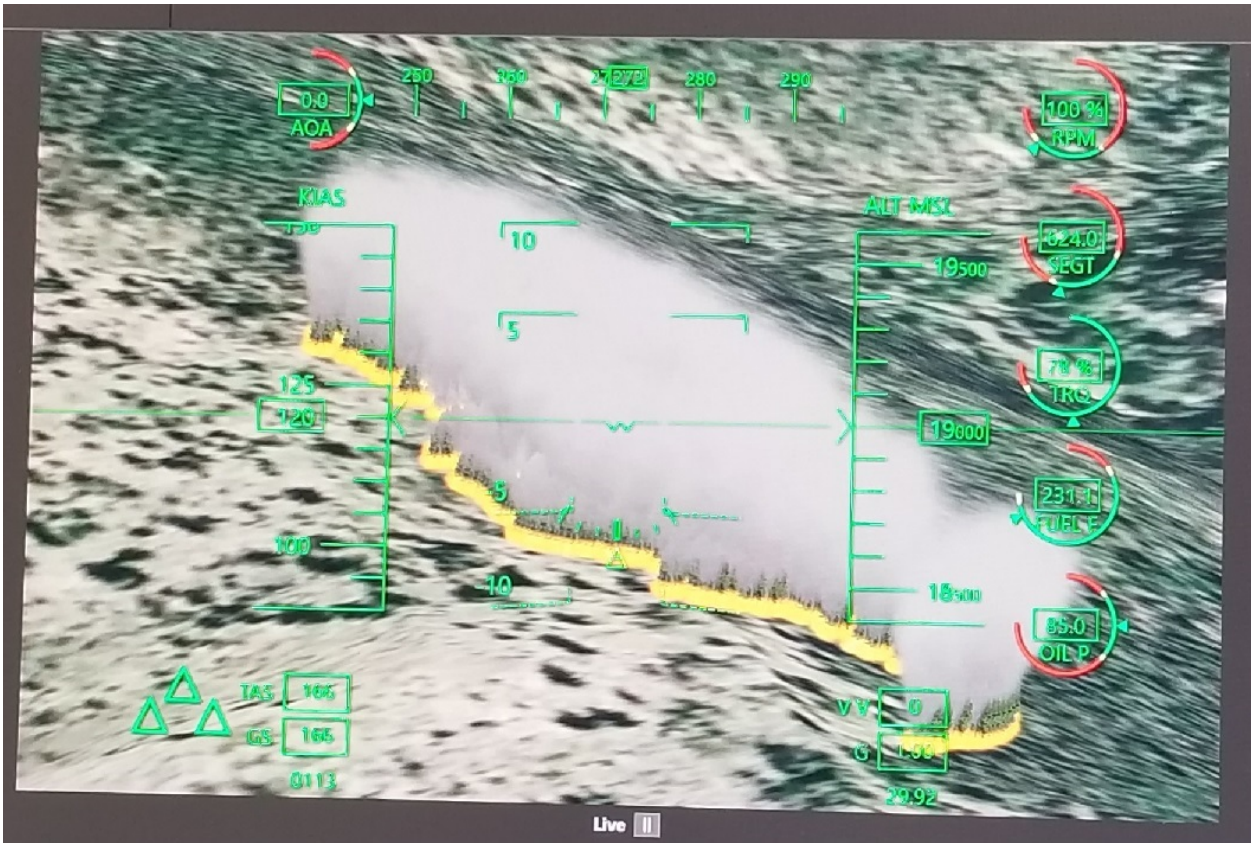


Figure 6. View of a hot spot using the daytime TV (DTV) setting.

Zooming the camera was accomplished by using the scroll-wheel on the mouse. Zoom levels were not continuous but jumped in increments. The degree to which the zoom would change for each increment was dependent on how far away the object was from the camera, making it somewhat of a challenge to find an appropriate zoom level. Participants were asked to zoom in enough so that the hot spot could be seen clearly, but not so close that the edges of the hot spot were not visible.

Participants were instructed to search for the hot spots using the IR mode but were asked to switch to the DTV mode to take a photograph of the hot spot. Figure 7 shows a view of the same hot spot shown in Figure 6 but at a different zoom level and using the IR setting with Black-Hot mode. After locating a hot spot, they would center the hot spot. They would then switch to DTV and zoom to an appropriate level before taking a photograph. Taking a photograph was accomplished by right-clicking anywhere on the mission task display and selecting “Take a snapshot” from the pop-up menu.

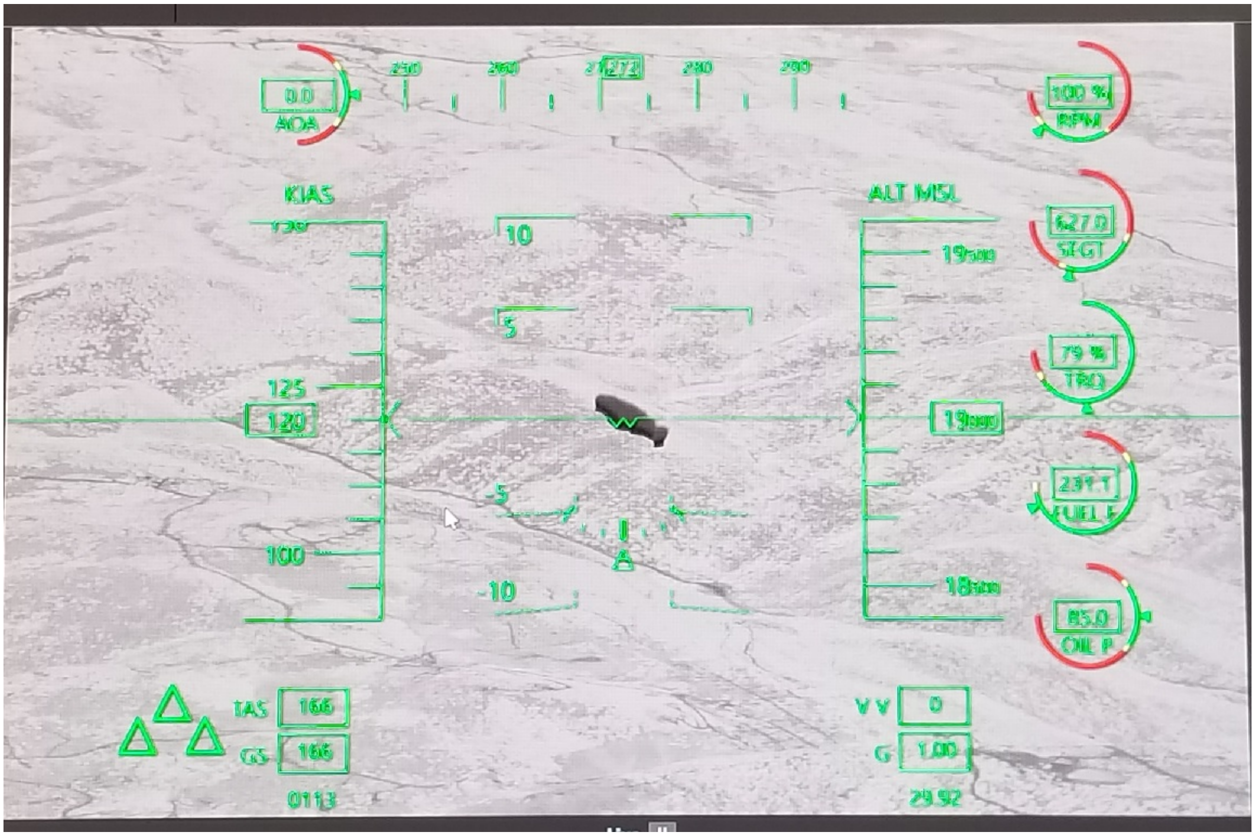


Figure 7. View of a hot spot using the Infrared (IR) setting with Black-Hot mode.

After taking a photograph of the hot spot, a small green square would appear at the location of the photograph on the moving-map display. Participants were told that they would most likely be finding the same hot spots several times during the flight from different angles and distances. They were instructed that it was permissible to take a photograph of the same hot spot several times but it was also a waste of time. To prevent this, they were told that they could reference the current position of the camera on the moving-map display (marked by a gray dot) and that the presence of a green square at that location would indicate they had already taken a photograph at that location.

Materials

Participant Instructions

Participants were presented with the purpose of the experiment. To prevent focusing on the traffic encounter, they were told that they would be asked about various aspects of the control station displays and controls and that their main task was to find and record hot spots. Participant instructions can be found in Appendix A. Additional information from the participant consent form concerning the goals of the experiment and the ability of the participant to leave at any time during the study was also provided. The consent form is shown in Appendix B.

Demographics Questionnaire

A demographics questionnaire (Appendix C) was administered to the participants to record their age, gender, and flight experience on both manned and unmanned platforms, their experience with other types of traffic displays, and their flight simulation experience.

Post-Study Questionnaire

After completion of all of the encounters, participants were administered a post-study questionnaire. This questionnaire gathered information regarding the visual and auditory alerts used in the study and asked the participants to identify each of the alerting icons. It asked about the difficulty of the secondary task and if they had ever had an encounter with traffic while they were flying. If they indicated they had experienced a traffic encounter, we asked them to describe the encounter. A copy of the questionnaire is provided in Appendix D.

Procedure

After arriving at the facility, the participant was asked to read and sign an Informed Consent Form (Appendix C) and to fill out the Demographics Questionnaire (Appendix B). Next, the researcher read a summary of the experiment (Appendix A). The experiment summary described their main task as the identification and photographing of hot spots in support of a firefighting operation in Colorado. After these instructions the researcher asked if there were any questions and then began training the participant on how to manipulate the camera and take photographs, how to maneuver the aircraft if necessary and return to the pre-programmed flight path, and were given details about the traffic display and potential alerts they might receive during the conduct of the mission. After this initial training, the participants flew a practice scenario where they performed finding and photographing hot spots, making maneuvers, and responding to traffic encounters. The participants completed one practice scenario sitting next to the researcher. The length of this initial practice scenario depended on how successfully the participant performed all of the tasks and whether they felt comfortable with those tasks. If necessary, the aircraft was redirected toward earlier waypoints so that certain actions could be repeated until the participant was successful and felt comfortable performing those actions.

Once the participant had completed the practice scenario while sitting next to the researcher at the experimenter station, the scenario was reset and the participant was moved into the control station so they could perform the practice scenario one more time by themselves. After completing the practice scenario a second time from the control station, the experimenter loaded the appropriate experimental scenario for the participant. The experimental scenario took approximately 45 minutes to complete. After completion of the experimental scenario, the participant filled out a post-experimental questionnaire (Appendix D) and was then released. The entire study was completed by each participant in about 2 hours, 15 minutes.

Results

Violating Well Clear

We conducted an analysis of the proportion of losses of well clear (out of two) using a mixed model analysis of variance (ANOVA). Table 2 shows the *F* and significance values for all of the main effects and all of the two-way interactions. The three-way interaction was not significant.

Table 2. Loss of Well Clear main effects and 2-way interactions.

Effect	***F****	**p**
Muting	10.286	0.005
Display	16.667	0.001
Master Alert	2.667	0.122
Muting*Display	1.143	0.301
Master Alert*Muting	7.143	0.017
Master Alert*Display	<0.001	>0.999

*Note: All degrees of freedom were (1,16) using a pooled error term

Looking at the table, we see that there were significant main effects of the muting condition and the display type on the proportion of losses of well clear. The proportion of losses of well clear for traffic encounters when the auditory alert was muted was approximately 66%. The proportion of losses of well clear when the auditory alert was available was 28%. Table 3 below shows the mean proportion of losses of well clear across conditions.

Table 3. Mean proportion of losses of well clear across conditions.

Independent Variable		**Master Alert**	**Alert Muted**	**Audible Alert**
Display	Baseline	No Master	1.00	0.38
		Master	0.75	0.38
	Suggestive	No Master	0.75	0.00
		Master	0.13	0.38

For display type, we found a significantly higher proportion of losses of well clear for participants using the baseline display (62.5%) than those using the display containing both baseline and suggestive maneuver information (31.3%). The main effect of having a master alert box was not significant but favored the presence of the master alert (master alert absent: 53.3% loss of well clear, master alert present: 41% loss of well clear.

In addition to two of the main effects, there was one significant interaction effect between the master alert and muting conditions. Figure 8 shows this interaction effect with error bars representing the 95% confidence intervals.

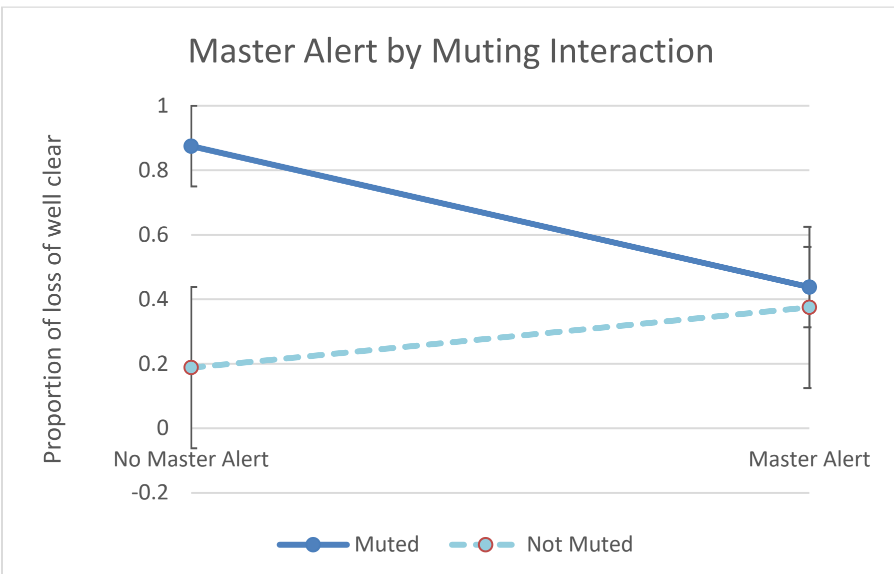


Figure 8. Master Alert by Muting interaction for proportion of loss of well-clear.

Looking at the figure, we see a definite advantage of the auditory alert over the muted condition. However, the presence of the master alert had a more positive effect on losses of well clear only when the auditory alert was muted.

Severity of Loss of Well Clear (SLoWC)

In addition to the number of losses of well clear, we also analyzed the severity of loss of well clear (SLoWC, pronounced "slow C"). The objective SLoWC metric was developed by the RTCA SC-228 Detect and Avoid working group as a way to compare results across different studies and within studies when comparing different avoidance maneuvers (Lester, Kay, Kunzi, Pratt, & Smearcheck, 2016). The SLoWC metric is a number ranging from 0 to 100, indicating the percentage of intrusion into the well clear area around ownship. The metric is assessed based on the severity of the local penetration into all three of the Well Clear components: Horizontal Proximity, Horizontal Miss Distance Projection and Vertical Separation. A value of 0 indicates that well clear was not violated and a value of 100 indicates that both aircraft (ownship and the intruder) were at the same point in time and space (i.e., mid-air collision). Table 4 shows the main effects and two-way interactions for the SLoWC ANOVA.

Table 4. SLoWC main effects and 2-way interactions.

Effect	***F****	**p**
Muting	24.41	<0.001
Display	2.368	0.143
Master Alert	14.945	0.001
Muting*Display	0.27	0.872
Master Alert*Muting	11.128	0.004
Master Alert*Display	0.728	0.406

*Note: All degrees of freedom were (1,16) using a pooled error term

We found a significant main effect of muting of the auditory alert and for the presence/absence of the master alert box on the SLoWC values. In addition, there was a significant interaction between these two main effects as well. No other interactions were significant and the main effect for display type was not significant. Table 5 below shows the mean SLoWC across conditions.

Table 5. Mean Severity of Loss of Well Clear (SLoWC) across conditions.

Independent Variable		Master Alert	Alert Muted	Audible Alert
Display	Baseline	No Master	46.55	11.79
		Master	15.79	4.90
	Suggestive	No Master	39.26	0.00
		Master	9.34	5.88

Figure 9 shows the interaction of the main effects of presence/absence of the master alert by muting/not muting the auditory alert. As can be seen in the figure, the results are similar to the interaction seen with the proportion of loss of well clear discussed previously.

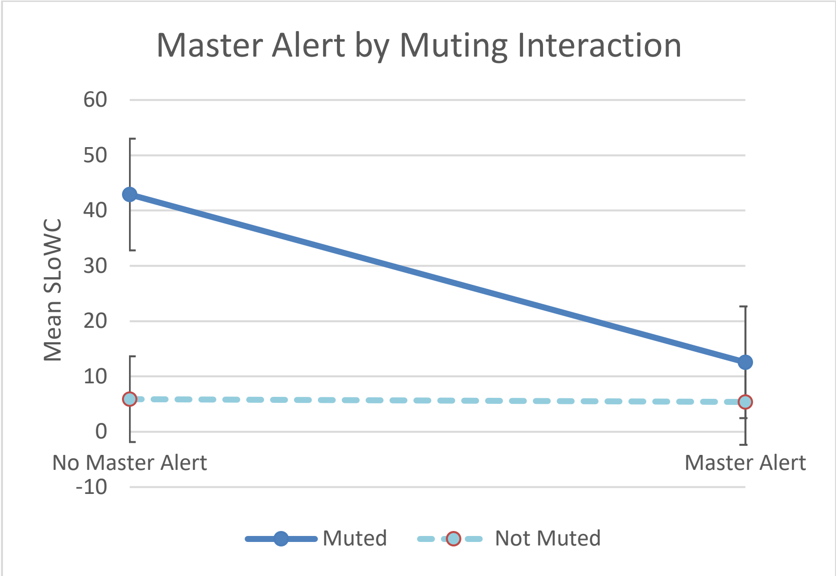


Figure 9. Master Alert by Muting interaction for SLoWC scores.

As with the losses of well clear, the SLoWC were influenced by the presence/absence of the master alert primarily when the auditory alert was muted. When the auditory alert was not muted the master alert status appeared to have no influence.

Pilot Response Time

Pilot response time was measured from the moment a corrective alert was triggered until the aircraft began an avoidance maneuver. It included the time required for the participant to recognize the alert, decide whether a maneuver was required, input the maneuver into the control station, and have the aircraft begin the maneuver. It also usually included the time required for the participant to contact ATC, request a maneuver, and receive clearance to perform the maneuver. If the alert elevated from a corrective alert to a warning alert, the time from the onset of the corrective alert was still used to calculate the response time.

Out of the 64 total traffic encounters where a maneuver was required, participants contacted ATC to request a maneuver 50 times (78%). For nine of the encounters, participants maneuvered first and then contacted ATC (14%). For the remaining five encounters (8%), participants did not attempt to make a maneuver because they never noticed the alert and so never contacted ATC. In cases where no maneuver was attempted, we assigned a response time of 67 s, which was slightly larger than the longest recorded response time of 66.64 s. Incidentally, of the five encounters where no maneuver was attempted, all five occurred with no auditory alert and the master alert box not present. Four of the five occurred when the traffic display showed only baseline information and the fifth with the traffic display showing both baseline and suggestive maneuver information.

Table 6 shows the *F* and probability values of an ANOVA of the response times for all of the main effects and two-way interactions. The three-way interaction was not significant.

Table 6. Mean pilot response time main effects and 2-way interactions.

Effect	***F****	**p**
Muting	56.981	<0.001
Display	8.407	0.01
Master Alert	24.246	<0.001
Muting*Display	3.36	0.085
Master Alert*Muting	28.664	<0.001
Master Alert*Display	0.224	0.643

*Note: All degrees of freedom were (1,16) using a pooled error term

All three of the main effects were significant. In addition, as with the losses of well clear and SLoWC values, there was a significant interaction between the master alert and muting manipulations. Table 7 presents the mean pilot response times for each condition.

Table 7. Mean pilot response times across conditions.

Independent Variable		**Master Alert**	**Alert Muted**	**Audible Alert**
Display	Baseline	No Master	57.63 s	21.48 s
		Master	33.21 s	22.20 s
	Suggestive	No Master	46.51 s	17.79 s
		Master	22.39 s	22.37 s

For the muting manipulation, the mean response time for encounters occurring with no auditory alert was 39.93 s while the mean response time for encounters with the auditory alert was 20.96 s. Manipulating the traffic display information resulted in a mean response time of 33.63 s for encounters with the baseline display information only but a mean response time of 27.26 s for encounters that included the suggestive maneuver information on the traffic display. For the main effect of master alert box present/absent, the mean response time for encounters without the master alert box was 35.85 s while encounters with master alert box present was 25.04 s.

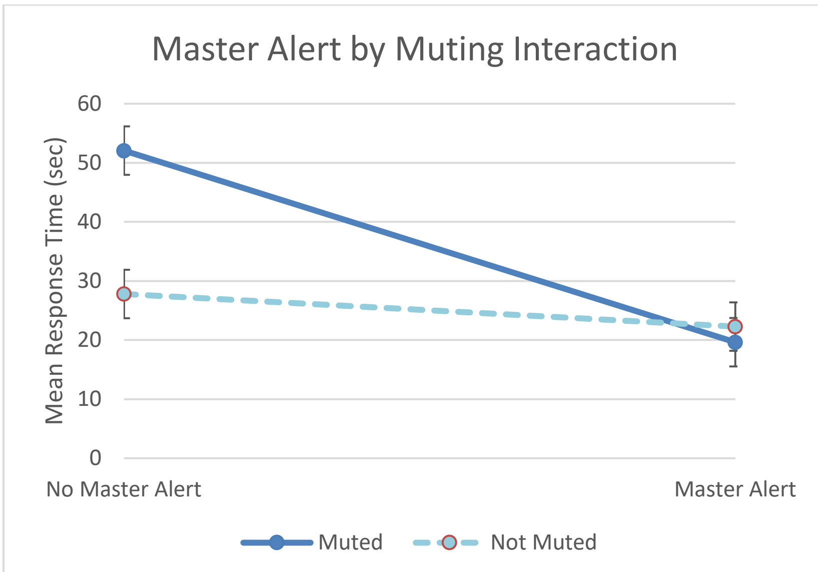


Figure 10. Master Alert by Muting interaction for mean response time.

Again, as with this same interaction for losses of well clear and SLoWC calculations, the presence/absence of the master alert box had a more pronounced effect when the alert was muted than when it was not (see Figure 10).

In addition to an overall analysis of response-time data, we conducted a two-way ANOVA for just those response times under the muted condition. The purpose of this analysis was to isolate the ability of only visual cues to alert the participant to the presence of a traffic conflict. The two between factors of display condition and presence/absence of the alerting box were analyzed for their effect on response time. Significance was found for both factors (display type: $F(1, 28) = 6.827$, $p = 0.014$; alerting box: $F(1, 28) = 33.389$, $p < 0.001$) with faster response times for participants using the suggestive-maneuver information (28.36 s) than those using only the baseline information (39.34 s) and faster response times for participants who had the master alert box (27.8 s) than those who do not (52.07 s).

Post-Test Questionnaire

After completing the flight task, participants were given a questionnaire via an electronic tablet. The questionnaire covered a variety of topics including the difficulty of performing the secondary task, experience with traffic alert displays, usability of the traffic displays, and their opinions regarding the traffic alerts. Complete questions and response options are provided in Appendix D.

Secondary Task Difficulty

The first question in the post-test questionnaire asked participants to rate the difficulty of performing the task of locating and photographing the hot spots on a five-point scale from "very easy" to "very hard". Twenty-two (69%) of the participants rated the task as "very easy" or "somewhat easy". Only one participant rated the task as "very hard".

Traffic Display Familiarity

Questions 2-4 asked about the participant's familiarity with TCAS or other traffic displays and whether they had ever needed to take evasive action to avoid another aircraft. 24 (75%) participants had experience using TCAS and 16 of those 24 said they were "very familiar" or "expert" with TCAS. 23 of the participants claimed they had some level of familiarity with other types of traffic displays, of which the majority were some type of ADS-B display.

Usability of the Traffic Display

Figure 11 shows the mean response to nine questions (questions 5-13) from the post-test questionnaire separated by display type (baseline or baseline + suggestive maneuver information). The first three of these questions pertained to the traffic encounters concerning ability to maintain separation (Question 5), minimize path deviations (Question 6), and complexity of the encounters (Question 7). The next five questions dealt with the perceived utility of the traffic display along several dimensions. These dimensions were subjective measures of: ease of use (Question 8), ease of understanding (Question 9), the ability to predict a loss of separation from an intruder (Question 10), the ability to select an avoidance maneuver

(Question 11), and the amount of trust in the accuracy of the information (Question 12). That last question asked if participants felt they had received enough training on the use of the display. On all dimensions, higher values represent a more favorable response.

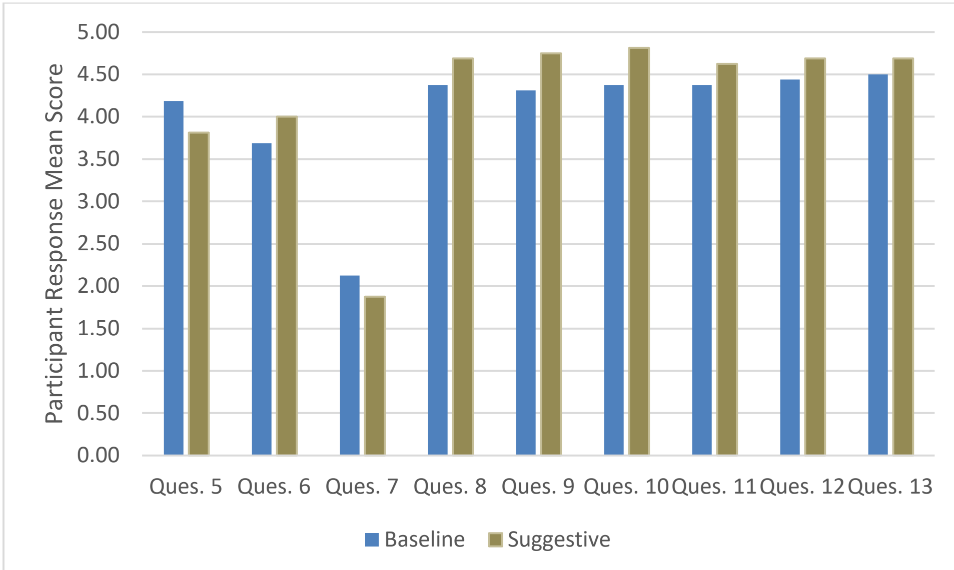


Figure 11. Mean responses to questions 5-13 of the post-test questionnaire.

For Question 7, which asked participants to rate the complexity of the traffic encounters, 9 said they were "very easy", 16 said "somewhat easy", 5 said "neither easy nor difficult", and 2 said "somewhat difficult". No one rated the encounters as "very difficult". While all of the usability questions (Questions 8-12) slightly favored the suggestive information traffic display over the baseline display, none of the differences were significant. Regarding training on the display (Question 13), 24 (75%) of the participants responded "strongly agree" that they had received sufficient training. 6 (19%) participants responded "agree", one responded "disagree" and one responded "strongly disagree". N.B. that these responses were gathered post hoc; none of the participants had stated before the mission flight that they required more training and all of them had successfully completed maneuver requests and traffic avoidance tasks.

Display Elements

Questions 14-17 asked about individual elements in the traffic display: which ones were the most helpful, which ones were not necessary, and whether more information should be added. Responses were sparse except for the question about which display element was the most useful. Interestingly, the element mentioned most often was the relative altitude information and accompanying climb/descend arrow, which was mentioned by 15 participants. Second most-mentioned were the traffic icons that provided an indication of the direction the traffic was moving as well as an indication of the level of the alert, mentioned 12 times. Third most mentioned was presence of the auditory alert, mentioned 10 times. As far as the suggestive maneuver information, banding was mentioned 3 times and the avoidance area polygon only once. Because of the experimental design, only half of the participants saw the suggestive maneuver information, whereas everyone was exposed to the other elements mentioned.

Understanding Alerts

To gauge how well the participants understood both the auditory and visual alerts that were provided, eight items were included in the Post-Test Questionnaire. The first of these was an item that was added to the questionnaire after data collection had begun. It was added for the purpose of measuring how easily participants could identify each of the alerting icons used in the traffic display. Results showed that, of the 23 participants that were asked, 21 (91%) of the participants correctly identified the red warning alert icon, with the other two participants identifying it as a corrective alert. Thirteen (57%) of the participants correctly identified the corrective alert icon and 18 (78%) participants correctly identified the preventive alert. In addition, 9 (39%) of the participants identified both of the yellow icon symbols as the same alert. Only one participant identified the warning alert icon and another icon as belonging to the same alert.

For Question 2, the majority of participants agreed to some extent that the aircraft icons used for the alert levels were easy to understand, but we're more certain about the warning alert than the other two: Preventive Alert (26 of 32, 81%); Corrective Alert (24 of 30, 80%); Warning Alert (31 of 32, 97%). Questions 3 and 4 were concerned with whether the participant would be likely to contact ATC before the maneuver (Question 3), or after the maneuver (Question 4). Figures 12 and 13 show how participants responded to these two items.

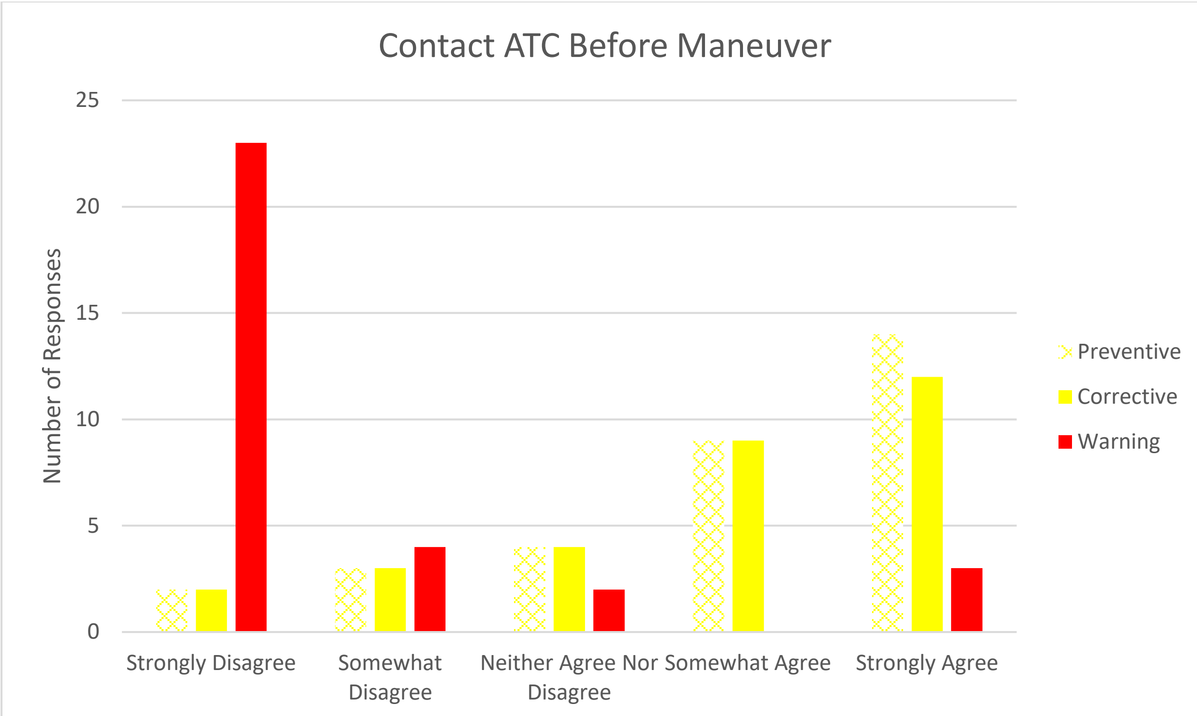


Figure 12. Response patterns for how alert type should determine whether to contact ATC before maneuvering.

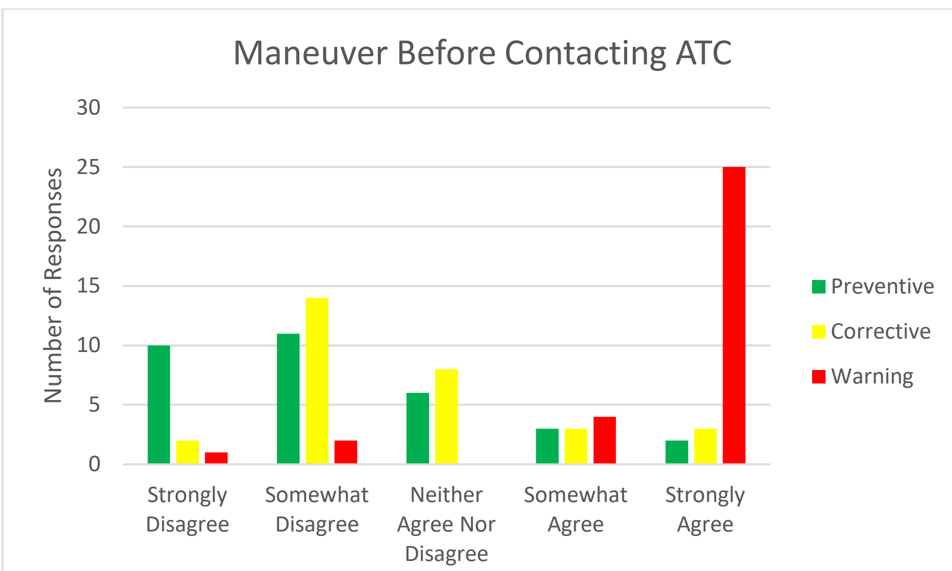


Figure 13. Response patterns for how alert type should determine whether to maneuver before contacting ATC.

Given the fact that a preventive alert does not require a maneuver at all, these items could be confusing for this alert level. Of most interest, then, are the responses for the corrective and warning alerts. As can be seen in the figures, while there seems to be some indecision regarding the corrective alert whether to contact ATC or maneuver first, the large majority of participants indicated that the warning alert would require maneuvering first before contacting ATC. What is most interesting about this finding is that, with the actual encounters, for 41 of those encounters a warning alert level was triggered. Of those 41 warning alert encounters, the participants contacted ATC before the maneuver 37 times (90%). Potential reasons for this mismatch between the post-test questionnaire responses and the actual encounters are discussed later.

Question 5 asked participants to agree or disagree with the statement that a particular alert level indicated an eventual loss of separation (loss of well clear) if both the ownship and intruder trajectories remained the same. This statement would be true for the corrective and warning alert levels but not for the preventive alert. Results showed that 30 of 32 (94%) of the participants agreed that a warning alert would lead to a loss of separation, but only 22 of 30 (73%) participants agreed that a corrective alert indicated an eventual loss of separation. For the preventive alert, 18 of 32 participants (56%) believed that the preventive alert indicated an eventual loss of separation, which was surprising given the fact that everyone received three preventive alerts during the mission that did not result in a loss of separation.

Questions 6 and 7 dealt with the auditory alerts that were issued. Question 6 asked how much they agreed with the statement that the alerts were distinguishable from each other. A large majority of respondents agreed that the auditory alerts were distinguishable (preventive 30 of 32, 94%; corrective 30 of 32, 94%; warning 30 of 31, 97%). Question 7 asked for the level of agreement that the alerts were useful for maintaining separation. Again, there was a high level of agreement for all three alert types (preventive 31 of 32, 97%; corrective 30 of 31, 97%; warning 29 of 31, 94%).

Question 8 was the last to deal with alerting and asked participants to judge whether the timing of the alerts was too early, somewhat early, appropriate, somewhat late, or too late. The majority of participants believed the timing to be appropriate (preventive 28 of 32, 88%; corrective 28 of 31, 90%; warning 21 of 30, 70%). For the warning alert, 30% of the participants felt that the timing was “somewhat late” or “too late”.

Avoidance Maneuvers

We analyzed the avoidance maneuvers that were used by the participants to see if there were any recognizable tendencies. Overall 69% of the avoidance maneuvers were horizontal and the other 31% were vertical. We conducted an ANOVA on the proportion of vertical first maneuvers to see if the selection of avoidance maneuver was influenced by any of the manipulated variables. None of the main effects were significant. However, there was one significant interaction between display type and presence/absence of the master alert box, $F(1, 23) = 6.927$, $p = 0.015$. Figure 14 shows this interaction.

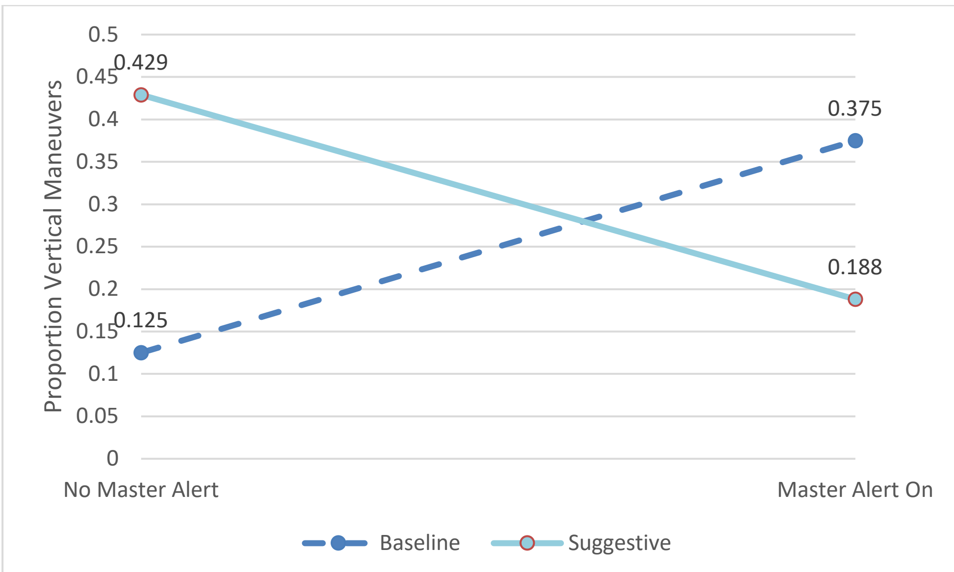


Figure 14. Interaction of display type and master alert on proportion of vertical maneuvers.

For participants using the baseline traffic display, the presence of the master alert box led to an increase in vertical avoidance maneuvers. For participants using the suggestive information traffic display it was the exact opposite with the presence of the master alert box leading to a decrease in vertical maneuvers (increase in horizontal maneuvers).

In addition to maneuvers selected for the corrective and warning alerts, we were also interested in whether participants would elect to maneuver when presented with the preventive alerts as well. Out of 96 preventive-alert encounters, participants chose to maneuver 6 times (6.25%). Only three of the participants maneuvered for a preventive alert. All of the maneuvers were vertical maneuvers with the intent to increase vertical separation during the preventive alert.

Discussion

One purpose for this research was to see if occupying the pilot in a task that required most of their attention would interfere with their ability to react to and resolve traffic encounters, and if that ability would be differentially affected by differences in the traffic display information content. While it is unlikely that we were able to produce encounters that were totally unexpected, we believe that we were able to distract pilot participants sufficiently enough to render the traffic encounters, if not surprising, at least unanticipated. Evidence for this was found primarily in the effect of muting the traffic alert. The participants were absorbed to the point that response times were significantly longer for the muted encounters, losses of well clear were more frequent, and the severity of the losses of well clear were significantly higher relative to when the aural alert was present.

While we believe the participants were distracted by the hot spot search task, our findings indicate that participants did notice the presence of visual traffic alert indications. There is not enough evidence available to conclude that the participants' handling of the encounters, once they were recognized, were negatively affected. Across all encounters where the auditory alert was available, the mean response time was 20.96 s. This response time is respectably close to values reported in other research. For example, in Williams et al. (2017), overall response time for pilots flying the ICOMC2 station was 20.88 s across over 500 traffic encounters.

No other studies looking at the currently established DAA traffic display information requirements have looked at the effectiveness of the visual alerting information by itself to attract the attention of the pilot. One critical finding from this study is that the positioning of the traffic display just outside of the primary field of view of the pilot was sufficient to attract the attention of the pilot to a traffic encounter as long as the display included the suggestive maneuver information. However, the presence of a master alert within the pilot's primary field of view was even more effective.

This study replicated the findings of other studies showing the benefits of suggestive maneuver guidance in the form of bands and area-avoidance polygons, in addition to baseline information, for a UAS DAA display (e.g., Williams et al., 2017). The use of the suggestive-maneuver information resulted in significantly fewer losses of well clear compared to the baseline information display. It also resulted in significantly faster response times. In addition, even though other studies have used the Vigilant Spirit control station interface (Fern et al., 2015; Rorie & Fern, 2015; Rorie, Fern, & Shively, 2016; Santiago & Mueller, 2015), there were differences in certain details of the current interface from those used in these other studies. In particular, the methods for commanding both heading and altitude changes were different from these other studies. This adds further support for the utility of the suggestive maneuver information across a wider variety of pilot interface designs as was demonstrated in Williams et al. (2017).

One of the more interesting findings in the current study was a mismatch between participants' understanding of how to respond to the warning alert and their actual responses to the warning alerts during the mission. In responding to the question of whether the pilot should maneuver before contacting ATC under the warning alert, 29 of 32 (91%) of the participants indicated they agreed to some level that they should maneuver first. Twenty-five of the participants (78% strongly agreed they should maneuver first. However, during the mission, of the 41 encounters where a warning alert was generated, the participants contacted ATC before the maneuver 37 times (90%). Of those 37, there was a DWC loss 25 times (68%). Why is there such a disparity between understanding and action for these encounters? All of the maneuvering traffic encounters began as a caution-level alert that was elevated to a warning alert at some point during the encounter. One speculation for the behavior is that the participants might have begun interacting with ATC before the warning alert was triggered and felt compelled to complete a conversational transaction they had already begun before making the maneuver. There is a large body of literature regarding conversation analysis and conditions for interrupting or being interrupted (e.g., Sacks, Schlegloff, & Jefferson, 1974). While participants had an understanding of making the maneuver before contacting ATC for a warning alert, they did not receive specific instructions regarding halting a conversation with ATC in the event that conversation is interrupted by the presence of a warning alert.

Unlike what was found in Williams et al. (2017), there was a stronger bias for horizontal avoidance maneuvers during a traffic encounter. In Williams et al. the overall percentage of horizontal avoidance maneuvers was 49.7%[4] while in the current study a horizontal avoidance maneuver occurred 69% of the time. This percentage is less than what was found in NASA's Part Task 5 HITL (Rorie et al., 2015, 85% for their baseline display to 92% for their banding display) but is more than NASA's Part Task 6 HITL (Rorie, Fern, Shively, & Santiago, 2016, 61% of the time). One difference between the current study and the NASA HITL studies is that the current study used only manned aircraft, instrument-rated pilots while the NASA HITL studies used UAS pilots, although the Part Task 5 HITL used only Predator pilots while the Part Task 6 HITL used a mixture of Predator and Global Hawk pilots.

There was speculation by the NASA researchers (Fern, personal communication) that the very high percentage of horizontal maneuvering in the Part Task 5 HITL was because that was the way Predator pilots were instructed to avoid traffic. However, in Williams et al. (2017), half of the pilots were manned instrument-rated and half were UAS pilots, with half of the UAS pilots being Predator pilots and the others a variety of systems. It is difficult to say what influenced maneuver choices the most, whether it was training, the pilot interface, the types of encounters, or other factors, but it is likely that each of these played some role, as has been demonstrated in previous research (Thomas & Wickens, 2008; Williams et al., 2018).

During traffic encounters that involved only a preventive alert, the majority of participants did not maneuver their aircraft. This was expected given that the aural alert was to monitor the traffic and the description of the preventive alert contained an explanation that the presence of the alert did not mean that well clear would be violated, only that the two aircraft would be passing relatively close in the vertical dimension.

One final finding of interest was in regard to the two caution-level alert icons. Both the preventive and corrective alert icons are yellow and white (see Fig. 3) and it had been speculated that they could be easily confused with each other. Multiple lines of evidence from the current study lend support to this speculation. Participants had much less difficulty identifying the

[4] In Williams et al. (2017), pilots had the option for a speed change in addition to horizontal or vertical maneuvers. The percentage of vertical maneuvers was 47.6%. Speed change maneuvers occurred 2.3% of the time.

warning alert icon than they did the other two during the post-test questionnaire. In addition, nine of the participants guessed that the preventive and corrective alert icons were the same when they were shown one at a time during the questionnaire. The other line of evidence is provided by the results from the encounters where the auditory alert was muted, the master alert box was not presented, and no suggestive information was present. For those encounters, the pilot has no other way besides the traffic icons to distinguish between a preventive alert and a corrective alert. During some of those encounters, it appeared from looking at video replay of the pilot station camera, that the participants noticed the traffic but not take immediate action. Post-test interviews revealed that the participants were watching the relative altitude information available on the traffic display to determine whether a maneuver should be initiated. If they were able to distinguish between the two alerting icons, it is likely they would have initiated a maneuver more quickly.

Conclusions and Future Research

Based on the current findings, and combined with findings from other supporting research, the following conclusions are warranted:

- Effectiveness of the traffic display containing suggestive maneuver information is not diminished under full-mission conditions and does not warrant adjustment of alerting timing requirements as specified within the Phase I MOPS (RTCA, 2016).
- A separated traffic display should be positioned as close to the primary field of view of the pilot as possible and should be accompanied by a master alert box located within the primary field of view of the pilot.
- Some portion of training on these systems should emphasize the importance of immediately initiating an avoidance maneuver when a warning alert is triggered, regardless of whether or not communication with ATC is ongoing.
- The preventive and corrective alert traffic icons are easily confused with each other and do not add redundancy to the alerting information. Redesign of at least

one of the icons is recommended, especially if both are considered caution-level alerts within the DAA system.

Because the post-test questionnaire showed that participants were not entirely sure of the purpose of the preventive alert, future efforts might look at the need for the preventive alert. If the preventive alert is deemed necessary, the research should determine whether the alert should be presented as an advisory- or caution-level alert, consistent with the definition of those alerts in Advisory Circular 25.1322-1, Flightcrew Alerting. Whether being aware of an intruder aircraft coming within 700 feet vertically of ownship is useful in preventing a loss of well clear or worse should be the focus of a future study.

Other efforts that are planned will look at the integration of the DAA system with a TCAS II-like system that provides directive information to the pilot instead of just the suggestive information used in the current DAA requirements. Results from these efforts will provide needed information for RTCA SC-228 Phase II MOPS, and towards the goal of allowing UAS to become fully integrated into the NAS.

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Appendix A

Participant Instructions

Welcome to the study. Thanks for coming. In this study you are going to be piloting an unmanned aircraft system in support of a firefighting operation in Colorado. Your main task is going to be the discovery and documentation of hot spots that will provide operations on the ground and in the air a better idea of where to focus their efforts. You will be flying an approximately 45-minute mission of a particular area where there are reports of hot spots. Assistance is needed in finding the exact locations of these areas and photographing each of the areas that you find. The photographs will contain lat/lon coordinates that will help other firefighters reach the areas and know what to expect when they get there.

Before you fly, you will be receiving training on how to pilot the aircraft and how to control the onboard camera. To make flying easier, and to allow you to focus more easily on the primary task, most of the flight will be flown using pre-programmed waypoints that the aircraft will be following automatically. However, because there will be other aircraft operating in the area, it is possible that you will need to maneuver your aircraft to avoid coming too close to another aircraft. So we will provide training on how to interrupt the programmed flight, maneuver the aircraft, and then resume the programmed flight.

At the conclusion of the mission, we will ask for your feedback regarding the control station pilot interface design, its usefulness for performing the mission task, and about the various displays you used during the flight. If you don’t have any questions, let’s get started with your training.

Appendix B

Full Mission Evaluation of an Unmanned Aircraft System Control Station

Kevin Williams, Ph. D

Human Factors Research Laboratory

CAMI Aerospace Human Factors Research Division

Individual's Consent to Voluntary Participation in a Research Project

I ____, understand that this study is: (a) titled "Full Mission Evaluation of an Unmanned Aircraft System Control Station"; (b) sponsored by the Federal Aviation Administration's (FAA) Civil Aerospace Medical Institute (CAMI) in Oklahoma City; (c) under the direct supervision of Kevin W. Williams, Ph. D., of the Aerospace Human Factors Research Laboratory of the Aerospace Human Factors Research Division of CAMI; I understand that I am being compensated by a private contractor and am not considered to be under the employment of the FAA.

1. **Purpose:** The ultimate objective of this study is to evaluate the effectiveness of flight and flight-related displays for use in an unmanned aircraft system (UAS) control station under realistic mission conditions. Information gained from the study will be used to provide information to standards groups both within and outside of the FAA that bears upon the establishment of standards for UAS control stations.

2. **Status of Procedures Used in this Study:** The testing protocol used in this study involves the use of a simulated UAS control station, requiring the participants to remain seated at a desk for as long as 50 minutes. I will be interacting with the UAS using a mouse and keyboard and will be required to make notes using a pen and paper during the study.

3. **Description of Study Requirements:** I understand the following study requirements: There will be one session that will last no more than 3 hours. I will be asked to (a) complete a demographic questionnaire related to flight experience; (b) fly a training scenario that will familiarize me with requirements for controlling the aircraft, understanding the displays, familiarizing me with potential alerts that might occur, and performing the

mission task; (c) complete a subjective evaluation of the displays used in my flight, (d) participate in a posttest interview to provide further insight into the beneficial and the detrimental aspects of the experimental display formats. As a person, who is in reasonably good health, I know of no problems that would be caused by my participating in this study. Given the nature of this study and current Federal Air Regulations, I am aware that I have been asked to refrain from drinking any alcoholic beverage or taking any over-the-counter medication, prescribed medication, or illicit drugs that may affect my performance for a twenty-four hour period before the study begins and during the course of the study.

I will be briefed about the study, complete an informed consent form, and fill out demographic and flight history questionnaires. I will then be given training on the control of the unmanned aircraft simulator and all of the flight and other relevant displays. After a brief break, I will perform an approximately 45-minute flight simulating the performance of a firefighting operation. I understand I will also be debriefed following the mission, during which time I will complete a subjective evaluation of my experience with the control station.

A. Preliminary Information. I will first be asked questions about my age and flight experience to allow my simulator performance to be correlated with those variables. Second, I will fly a series of training flights in the simulator, and then take a short break. Third, I will complete a full-mission scenario in the simulator. Fourth, I will be asked to provide subjective feedback on the displays and controls.

B. Understanding of Subject Responsibilities. I understand that:

i. To properly evaluate my performance, I must perform to the best of my ability. If I do not meet certain performance criteria, I may be withdrawn from the study by the study monitor.

ii. It is essential that I follow several instructions during the course of this experiment. Failure to follow instructions may result in my withdrawal from the study by the study monitor.

iii. I am NOT to consume any alcoholic beverages (including beer and wine), nor any drugs (over-the-counter, prescribed, or illicit) until after completing the session. I have assured the experimenter that this is the case.

(participant initials) _________

iv. I agree to allow still photographs and/or videotapes to be made of me as required during the research, with the understanding that these records are the property of the U.S. Government, and that I am not entitled to monetary or other benefits, now or in the future, for the use of this material. I understand that these tapes are for research purposes only, will be identified by my subject number only, and will be erased following data analysis. **(participant initials) ___________**

v. I understand that I am being compensated for my time by a contractor, and am not considered to be under the employ of the FAA for this study. **(participant initials) _____________**

vi. If I have any questions, I may ask the Study Monitors.

4. **Benefits**. The major benefit from this study for the FAA will be a scientific basis for establishing minimum information requirements for different types of UAS control station displays and minimum performance functionality for UAS control station controls.

The major benefit for me will be my pay, unless I am a Department of Transportation employee. In addition, I have been informed by the contractor concerning my pay for participation in the study. I will receive reimbursement per the arrangements made with the contractor. An additional benefit will be an understanding of the extent to which unmanned aircraft flight performance/safety can be improved through use of the proposed advanced displays used during my flights.

If I am a DOT employee, I understand that my pay is part of my regular duty assignment and I will receive no further compensation unless I am on leave or off-duty status.

(participant initials) ___________

5. **Possible Risks.** The principal risks involved in this study relate to sitting at a UAS simulation for up to 50 minutes in one sitting. I acknowledge that I have been informed of the possible discomforts and benefits of the study and have had the opportunity to ask questions.

(participant initials) _____________.

6. **Assurances**. Furthermore, I understand that:

a. The CAMI Project Director, Dr. Kevin W. Williams, and his colleagues and consultants will take every precaution with the best research procedures. If I have questions or concerns after the study, I may call Dr. Williams, (405-954-6843). I may also call the branch manager, Dr. Katrina Avers (405-954-6299) to report any concerns I may have about this study.

b. By signing this consent form, I have not waived any legal rights or released CAMI or the simulation facility from liability for negligence. I may revoke my consent and withdraw from the study at any time.

c. The results of any tests administered to me will be treated as confidential and will receive a code number so that they will be anonymous when filed with the Laboratory Manager. In no case will any use be made of these tests other than application to experimental analysis unless I provide explicit written permission.

By signing, I understand that I am free to withdraw this consent and discontinue participation at any time, and my total pay will be based on the actual time I have been present at the time of my withdrawal (according to the arrangement made with the contractor).

Signatures.

I have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described here, I will receive a copy of this form upon request.

__________________________ ___________________

Participant's signature **Experimenter's Initials**

____

Today's Date

Appendix C

Pilot Demographics Form

*Please fill in the blanks or circle your response to **each question** below*

PART I - Pilot Experience

1. **Age: ________________** **2. Gender: M F**
3. **Do you have manned pilot flying experience? Yes No**

If Yes, please complete the following:

a) Flight Hours:

Civilian ________ Military Non-Combat _________ Military Combat _________

Approximate Hours in Civil Airspace (i.e. not restricted or special use) _____________

b) IFR rated**: Yes No**

c) Other Ratings:

____

____

d) Aircraft Types:

____

____

____

4. Do you have UAS flying experience? Yes No

If Yes, please complete the following:

a) Military: **Yes No**

b) Total UAS Flight Hours:

Civilian ________ Military Non-Combat _________ Military Combat _________

Approximate Hours in Civil Airspace (i.e. not restricted or special use) _____________

c) UAS Aircraft Types:

____

____

____

____

PART II - Flight Simulation

1. **Do you have any desktop flight simulation experience on programs such as MS Flight Sim? Yes No**

If Yes, Please Specify:

a) Number of hours: __________

b) Type:

____

____

2. **Do you have any flight simulation experience on rated flight training simulators?**

Yes No

If Yes, Please Specify:

a) Number of hours: __________

b) Type:

Appendix D

DAA2 – Post Study Questionnaire

1. How would you rate the difficulty of performing the task of locating the hot spots?

Very Easy	Somewhat Easy	Neither Easy Nor Hard	Somewhat Hard	Very Hard

2. Do you have any experience using the Traffic Alert and Collision Avoidance System (TCAS)? ___Yes ___No

a. **If yes, how would you rate your knowledge of the Traffic Collision Avoidance System (TCAS)?**

Not Familiar	Somewhat Familiar	Familiar	Very Familiar	Expert

b. **If yes, how many years experience have you had with TCAS?**

____

3. How would you rate your familiarity with flying using other traffic displays?

Not Familiar	Somewhat Familiar	Familiar	Very Familiar	Expert

3.a. How many years experience have you had with other traffic displays?

____

3.b. Which other traffic displays have you used?

____

____

4. Have you experienced any situations in which you needed to take an evasive action to avoid another aircraft regardless of whether TCAS was involved? ____Yes ____No

Please explain:

____

5. Rate your ability to **maintain separation** from other aircraft during the mission today:

Not at all effective	Somewhat ineffective	Satisfactory	Somewhat effective	Extremely effective
☐	☐	☐	☐	☐

6. Rate your ability to **minimize deviations from the planned path**:

Not at all effective	Somewhat ineffective	Satisfactory	Somewhat effective	Extremely effective
☐	☐	☐	☐	☐

7. Rate the **complexity of the traffic encounters** in this session:

Very easy to detect and resolve	Somewhat easy to detect and resolve	Neither easy nor difficult to detect and resolve	Somewhat difficult to detect and resolve	Very difficult to detect and resolve
☐	☐	☐	☐	☐

Rate the extent to which you agree with the following statements about the TRAFFIC DISPLAY

8. The display was easy to **use**:

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
☐	☐	☐	☐	☐

9. The display was easy to **understand**:

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
☐	☐	☐	☐	☐

10. The display provided the necessary information to predict a potential loss of separation:

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
☐	☐	☐	☐	☐

11. The display provided the necessary information to perform a maneuver for separation:

Strongly Disagree ☐	**Somewhat Disagree** ☐	**Neither Agree nor Disagree** ☐	**Somewhat Agree** ☐	**Strongly Agree** ☐

12. I trusted the accuracy of the information provided by the display:

Strongly Disagree ☐	**Somewhat Disagree** ☐	**Neither Agree nor Disagree** ☐	**Somewhat Agree** ☐	**Strongly Agree** ☐

13. I felt I had enough training with this display to operate it safely during this session:

Strongly Disagree ☐	**Somewhat Disagree** ☐	**Neither Agree nor Disagree** ☐	**Somewhat Agree** ☐	**Strongly Agree** ☐

---

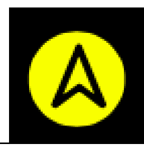
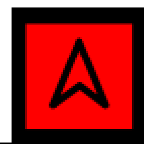
14. What were the most effective information elements in this display? Please explain.

15. Were any of the information elements unnecessary or confusing? Please explain.

16. Were there any information elements missing that you might need? Please explain.

17. Please discuss any suggestions for improving this display or any other comments, issues, or concerns.

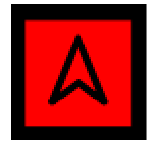
Please identify these alerting symbols.

		
Preventive alert___ Corrective alert___ Warning alert ___ Don’t know__	Preventive alert___ Corrective alert___ Warning alert ___ Don’t know	Preventive alert___ Corrective alert___ Warning alert ___ Don’t know

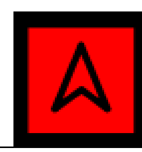
Note to reader – These symbols were presented electronically on a tablet, one at a time, and the participants were not allowed to go back to the questions after responding.

Rate the extent to which you agree with the following statements about each of the VISUAL ALERT LEVELS.

Refer to the scale provided in the top left of the table.
Please circle the appropriate number for each cell:

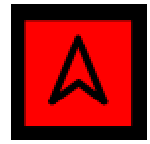
Scale 1 = Strongly Disagree 2 = Somewhat Disagree 3 = Neither Agree nor Disagree 4 = Somewhat Agree 5 = Strongly Agree	 *DAA Preventive Alert*	 *DAA Corrective Alert*	 *DAA Warning Alert*
18. The visual display of this alert (i.e., icon color, shape, etc.) was easy to understand.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
19. Based on this alert, I would likely contact ATC and *then* maneuver.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
20. Based on this alert, I would likely maneuver *prior* to contacting ATC	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Please circle 'Disagree' or 'Agree' for each of the ALERT LEVELS shown below:

	 *DAA Preventive Alert*	 *DAA Corrective Alert*	 *DAA Warning Alert*
21. If ownship and intruder trajectories remained unchanged, this alert indicated an eventual loss of separation	Disagree Agree	Disagree Agree	Disagree Agree

Rate the extent to which you agree with the following statements about each of the **<u>AUDITORY ALERT LEVELS</u>**.

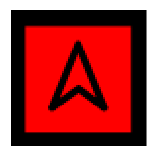
Please circle the appropriate number for each cell:

Scale 1 = Strongly Disagree 2 = Somewhat Disagree 3 = Neither Agree nor Disagree 4 = Somewhat Agree 5 = Strongly Agree	 *"Traffic Monitor"*	 *"Traffic Separate"*	 *"Traffic, Maneuver Now*
22. This auditory alert was clearly distinguishable from the other auditory alerts.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
23. This auditory alert was useful for maintaining separation.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Rate the **<u>TIMING</u>** of each <u>ALERT LEVEL</u> by completing the statement below.

Refer to the scale provided in the top left of the table.

Please circle the appropriate number for each cell:

Scale 1 = Too Early 2 = Somewhat Early 3 = Appropriate 4 = Somewhat Late 5 = Too Late	 *DAA Preventive Alert*	 *DAA Corrective Alert*	 *DAA Warning Alert*
24. The onset of the alert was ____	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5