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Evaluating the Preventive Alert Function for UAS Detect and Avoid Systems

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16. Abstract

The research effort was an examination of the alerting level for the Detect and Avoid (DAA) Preventive Alert function as defined by the RTCA Special Committee 228 Detect and Avoid Working Group in the DAA Phase I Minimum Operational Performance Standards (MOPS) (RTCA DO-365B). The term “alert” is used in this report generically to include Warnings, Cautions, and Advisories. RTCA DO-365B specifies that the DAA Preventive Alert is a Caution-level alert, but the DAA Preventive Alert does not require an action, so it matches the definition of an Advisory-level alert as defined in § 25.1322. Consequently, we were interested in understanding whether showing the DAA Preventive Alert as an Advisory (rather than a Caution) would influence the pilot’s behavior and potentially compromise safety of flight.

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Executive Summary

The research effort was an examination of the alerting level for the Detect and Avoid (DAA) Preventive Alert function as defined by the RTCA Special Committee 228 Detect and Avoid Working Group in the DAA Phase I Minimum Operational Performance Standards (MOPS) (RTCA DO-365B). The term “alert” is used in this report generically to include Warnings, Cautions, and Advisories. RTCA DO-365B specifies that the DAA Preventive Alert is a Caution-level alert, but the DAA Preventive Alert does not require an action, so it matches the definition of an Advisory-level alert as defined in § 25.1322. Consequently, we were interested in understanding whether showing the DAA Preventive Alert as an Advisory (rather than a Caution) would influence the pilot’s behavior and potentially compromise safety of flight.

We conducted a simulation study with 32 unmanned aircraft system pilots who were asked to perform a fire-fighting mission that required them to locate and photograph “hot spots” while piloting their aircraft. Most of the mission was flown following pre-programmed waypoints. During the mission, the presence of other traffic coming close to ownship would trigger traffic alerts. Of primary interest was pilots’ response to the DAA Preventive Alert, which would sometimes be followed by a higher-importance Corrective or Warning alert that required the pilot to maneuver their aircraft to avoid losing well clear from the other aircraft.

The results suggest that changing the Preventive Alert level from a Caution-level to an Advisory-level alert will not compromise safety of flight as it relates to traffic avoidance. The level of Preventive Alert did not affect the probability of losing well clear nor the pilot response time to maneuver to maintain well clear. Although pilots who received only an Advisory-level Preventive Alert were less likely to see traffic until a Corrective or Warning Alert occurred, this did not affect their ability to remain well clear.

The data collected here are only preliminary. Further research is needed to formally reduce the status level of the Preventive Alert. It is also important to understand whether pilots would consider a Caution-level Preventive Alert a nuisance or distraction to the pilot, since it implies that a corrective action is needed when no action may be required.

Acknowledgments

Research reported in this paper was conducted under the Flight Deck Program Directive of the FAA NextGen Human Factors Division (ANG-C1), Federal Aviation Administration (FAA) Headquarters, and the Aerospace Human Factors Division (AAM-500) of the Civil Aerospace Medical Institute, FAA. We thank Melanie Flavin (ANG-C35) for managing this research program. Michelle Yeh (AIR-600) was the sponsor of this research. 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 to Ashley Awwad (AAM-510) for assistance in coordination efforts with sponsors, managers, and subject matter experts. Thanks also to Cherokee Nation 3-S for assistance in the scheduling of participants and in the development of the online portion of the questionnaires and informed consent form and to Suzanne Thomas in particular for assistance in running participants and in the extraction and analysis of data. Finally, thanks to Robert “Buck” Joslin and Stephen Plishka (AUS-420) for recommendations regarding display formatting and positioning and input regarding the experimental design.

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List of Abbreviations

Abbreviation	Term
ADS-B	Automatic Dependent Surveillance-Broadcast
ATC	Air Traffic Control
CFR	Code of Federal Regulations
DAA	Detect and Avoid
DAIDALUS	Detect and Avoid Alerting Logic for Unmanned Systems
DTV	Daytime View
DWC	DAA-defined Well Clear
FAA	Federal Aviation Administration
GS	Ground Speed
HMD	Horizontal Miss Distance
IR	Infrared
MOPS	Minimum Operational Performance Standards
NASA	National Aeronautics and Space Administration
nmi	Nautical Mile
PIC	Pilot in command
RTCA	Radio Technical Commission for Aeronautics
SLoWC	Severity Loss of Well Clear
TCAS	Traffic Alert and Collision Avoidance System
TOST	Two One-Sided *t*-test
UAS	Unmanned Aircraft System
VS	Vertical Speed
ZTHR	Z-dimension (vertical) distance threshold

Introduction

This paper describes an examination of the alerting level for the Detect and Avoid (DAA) Preventive Alert function as defined within the DAA Phase I Minimum Operational Performance Standards (MOPS) developed by the Radio Technical Commission for Aeronautics (RTCA) Special Committee 228, RTCA DO-365B. The Federal Aviation Administration (FAA) Code of Federal Regulations (14 CFR) has established specific definitions for alerts on the flight deck and is expected that these definitions will be applied to the unmanned aircraft system control station environment. 14 CFR 25.1322, Flightcrew Alerting, defines three levels of alerting:

(1) Warning: For conditions that require immediate flightcrew awareness and immediate flightcrew response.
(2) Caution: For conditions that require immediate flightcrew awareness and subsequent flightcrew response.
(3) Advisory: For conditions that require flightcrew awareness and may require subsequent flightcrew response

Note that the term “alert” is used generically to include Warnings, Cautions, and Advisories. The DAA Preventive Alert is one of four alerts specified in the Phase I MOPS. Its purpose is to make the pilot aware of traffic within 700 feet vertically of ownship but whose trajectory would remain more than 450 feet vertically of ownship, thus making it unnecessary to maneuver ownship to remain well clear of the traffic. Because the DAA Preventive Alert does not require an action, it matches the definition of an Advisory-level alert as defined in § 25.1322. However, RTCA DO-365B specifies that the DAA Preventive Alert is a Caution-level alert.

Because the function of the DAA Preventive Alert matches that of an Advisory-level alert, the research question addressed was whether changing the DAA Preventive Alert indication from a Caution-level alert to an Advisory-level would influence the pilot’s behavior and compromise safety of flight. This study compared use of the Preventive Alert at both the Caution and Advisory levels to see if there were differences in the ability of pilots to recognize and respond to traffic encounters during a mission and whether there were detectable differences in how pilots responded to the Preventive Alert at each of these alert levels.

DAA Alerting System

The DAA alerting system is a means of alerting the pilot to the presence of other aircraft in the vicinity of ownship and displaying information about those aircraft to the pilot on the traffic display. This section provides a description of the DAA alerting system.

DAA Alerting System Description

The DAA alerting system is based on a set of alerting algorithms that compute if another aircraft is on a course that will result in a loss of DAA-defined well clear (DWC) from ownship. Well clear is defined from two different parameters; a time-based parameter (closure rate) as used in the Traffic Alert and Collision Avoidance System (TCAS) II and distance-separation minima (e.g., < 450 feet vertically). The alerting algorithms used for this study are collectively called DAIDALUS (Detect and Avoid Alerting Logic for Unmanned Systems) and were developed by National Aeronautics and Space Administration (NASA) Langley Research Center personnel (Muñoz et al., 2015). The selection of timing parameters for the alerts is 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, Fern & Shively, 2016; Santiago & Mueller, 2015).

The DAA alerting system defines four traffic alerts (Advisory Alert, Preventive Alert, Corrective Alert, Warning Alert) indicating the presence of conflicting, or potentially conflicting traffic. RTCA DO-365B, paragraph 2.2.4.3.5.1, describes the DAA Preventive Alert as follows:

> "The DAA Preventive Alert is intended to draw the remote pilot's attention to traffic that would trigger a Corrective or Warning Alert if the ownship and/or the intruder maneuvers in the vertical direction toward the other. It is intended to capture aircraft separated by 500' pressure altitude when both aircraft are in level flight, but is specified such that it could capture additional geometries as well. It is not meant to be a pre-alert prior to DAA corrective alerts for non-accelerating encounters. It is expected that the remote pilot, upon receiving a Preventive Alert, will maintain altitude unless a change is necessary and will monitor the intruder aircraft for a change in altitude. If an ownship maneuver is required, the remote pilot will take into account the position and path of the intruder beforehand."

RTCA DO-365B, paragraph 2.2.4.3.5.2, describes the DAA Corrective Alert as follows:

> “The DAA corrective alert is intended to get the [Pilot In Command] PIC’s attention, get the PIC to determine a needed maneuver, start PIC coordination with ATC, and is the earliest point at which the PIC is expected to begin maneuvering, per their judgment, to maintain DWC. The corrective alert necessitates immediate awareness of the PIC and subsequent PIC response.”

Table 1 provides information regarding each of the DAA alerts, including the icon used for the traffic display, the verbiage used for both the aural alert and the Alerting Textbox, information regarding separation criteria that triggers the alert, and the time to loss of DWC for the alerts. RTCA DO-365B categorizes both the Preventive and Corrective Alerts as Caution-level alerts, but the Preventive Alert does not indicate an impending loss of well clear and therefore does not require a subsequent pilot response.

Table 1.
DAA Alerting System

Alert Level	Separation Criteria	Time to Loss of DWC	Icon	Aural Alert Verbiage
DAA Warning Alert	HMD = 0.75 nmi ZTHR = 450 ft. modTau = 35 sec.	25 sec.		"Traffic, Maneuver Now, Traffic, Maneuver Now"
DAA Corrective Alert	HMD = 0.75 nmi ZTHR = 450 ft. modTau = 35 sec.	55 sec.		"Traffic, Avoid"
DAA Preventive Alert	HMD = 0.75-1.0 nmi ZTHR = 450-700 ft. modTau = 35 sec.	N/A		"Traffic, Monitor"
Advisory (Proximate) Traffic w/Maneuver Guidance	HMD = 0.75-1.0 nmi ZTHR > 700 ft. modTau = 35 sec.	N/A		N/A
Non-alerted Traffic w/o guidance	N/A	N/A		N/A

Horizontal Miss Distance (HMD) indicates aircraft on the same horizontal plane must be separated by a minimum distance of 4,557 feet (ft.; 0.75 nautical miles [nmi]). Z-dimension (vertical) distance threshold (ZTHR) indicates an aircraft on the same vertical plane must be separated by a minimum distance of 450 ft. ModTau is an extended direct line calculation of time to loss of DWC, accounting for vertical separation, horizontal separation and closure speed.

According to the information in Table 1, the only difference in the separation criteria between the current DAA Preventive Alert and Advisory Traffic alerting is that the Preventive Alert requires a vertical separation between 450 and 700 feet and the Advisory Traffic alert requires vertical separation of greater than 700 feet. The DAA Corrective Alert and the DAA Warning Alert both indicate that a loss of well clear will occur if both aircraft remain on their current courses. The DAA Corrective Alert is intended to provide more time for the pilot to make a maneuver (55 seconds to loss of DWC) than the DAA Warning Alert (25 seconds to loss of DWC). Pilots receiving a Corrective Alert are expected to contact air traffic control (ATC) and request permission to deviate from their flight plan before performing a maneuver, if they believe they have enough time to do so. However, if they receive a DAA Warning Alert, they should maneuver first before contacting ATC.

If we compare the symbology of the DAA alerting system to the symbology for other established traffic alerting systems, we find a mismatch. Table 2 shows a comparison between the DAA alerts, TCAS alerts, and Automatic Dependent Surveillance – Broadcast (ADS-B) alerts established in RTCA DO-317 (RTCA, 2014). In both the TCAS and ADS-B systems, proximate traffic is alerted with an Advisory-level alert only. However, the DAA system has two levels of proximate traffic alerting, one at the Advisory level () and one at the Caution level (), the latter of which is the DAA Preventive Alert.

Table 2.
Comparison of traffic alerting system logic

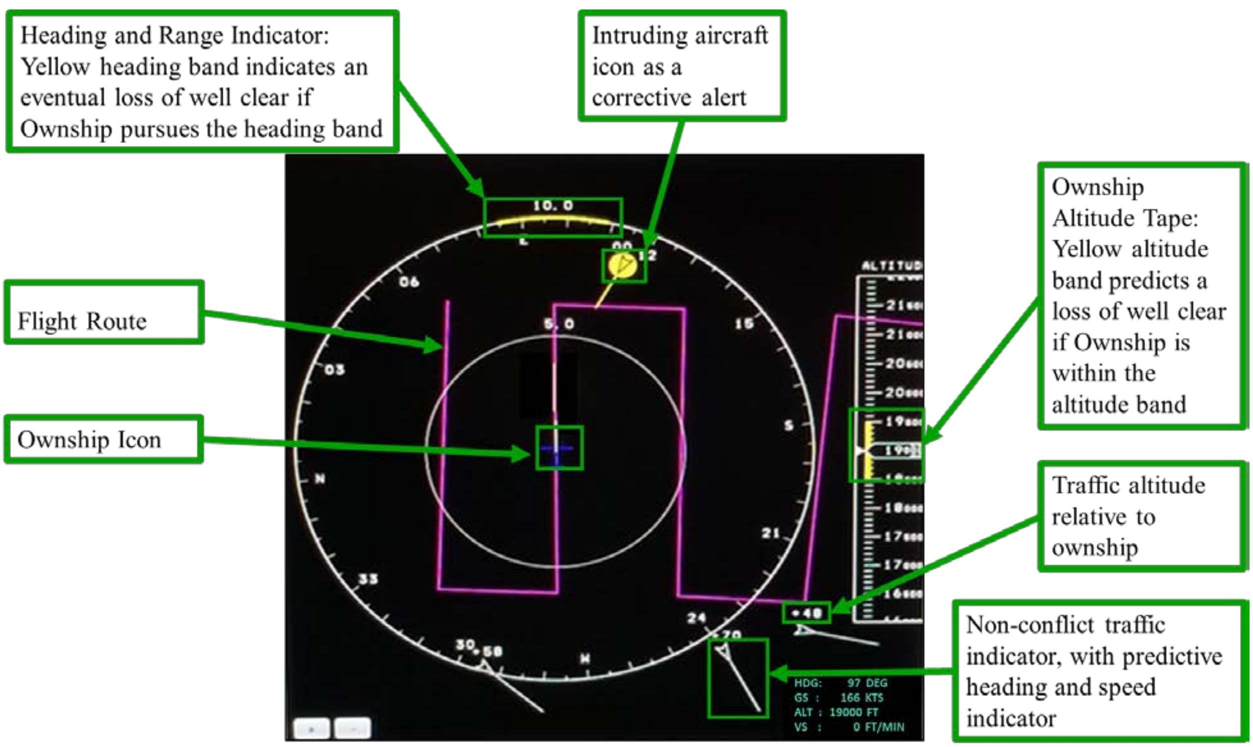
Alert Level	**TCAS**	**ADS-B (RTCA DO-317)**	**Detect and Avoid**
Traffic		 	 
Proximate Traffic (Advisory-level alert)		 	 
Traffic Caution		 	Preventive Alert  Corrective Alert 
Traffic Warning (Resolution Advisory)		 	

In addition, the icons defined in the DAA alerting system for the Preventive and Corrective Alerts assign different meanings to a symbology set that is **not** differentiated in TCAS II or ADS-B. The similarity between these icons can lead to confusion as to which alert it represents within the DAA system, as has been demonstrated in a previous human in-the-loop simulation (Williams, 2020).

DAA System Traffic Display

Figure 1 provides a close-up view of the DAA traffic display we used for this study. The display provided information regarding other aircraft in the vicinity of ownship as well as information regarding potential maneuvers required to avoid losing well clear.

Figure 1.
Unmanned Aircraft Traffic Display with suggestive maneuver information during Corrective Alert



As shown in Figure 1, ownship was presented in the center of the display. Ownship's current heading ground speed (GS), altitude, and vertical speed (VS) were in the lower right hand corner. The programmed flight path was shown in the background (magenta line). In addition, the display also contained suggestive maneuver information to assist the pilot in preventing loss of well clear from aircraft. This information was in the form of yellow or red colored bands on the heading ring and altitude tape, indicating heading and altitude values to avoid so as to avoid losing well clear. This banding information can be associated with both a currently alerted intruder or it can indicate that a maneuver in a specific direction will trigger an alert against an intruder. The bands were depicted in the same color as the level of alert with which they were associated. Figure 1 shows the banding information for a Caution-level (yellow) Corrective Alert.

Research Study Objectives

The primary research question was whether or not there might be a change and/or safety impact in the response to traffic encounters if the level of the Preventive Alert was changed from a caution- to an Advisory-level alert. We wanted to measure whether an Advisory-level Preventive Alert would have a negative effect on the pilot's awareness of the presence of traffic intruders or his/her ability to avoid the traffic.

Method

Experimental Design

We manipulated two independent variables. The first independent variable was whether the Preventive Alert was presented as a Caution-level alert or as an Advisory-level alert. When presented as a Caution-level alert, the traffic icon would change to yellow, an alert message would be displayed in the Alerting Textbox (see Figure 11 for a picture of the Alerting Textbox), and the pilot would hear the alert message in their headset. If the Preventive Alert was displayed as an Advisory-level alert, the traffic icon would change to a filled-white chevron, but there would not be an aural alert message and there would not be a message displayed in the Alerting Textbox. The differences between the Advisory-level and Caution-level Preventive Alerts are contrasted in Table 3.

Table 3.
Visual and auditory alert differences between Advisory-level and Caution-level Preventive Alert

Level of Preventive Alert	**Textbox Alert**	**Aural Alert**	**Intruder Icon**
Advisory-level	N/A	No Aural Alert	
Caution-level	Traffic, Monitor	"Traffic, Monitor; Traffic, Monitor"	

The second independent variable was the alert level requiring a maneuver: either Caution (Corrective alert) or Warning. During a traffic encounter, if the intruder maneuvered toward ownship, a maneuvering alert would be triggered. This maneuvering alert could be either a Corrective or a Warning Alert, depending on the proximity of the intruder to ownship and how much time there was to maneuver. We wanted to understand if changing the Preventive Alert from a Caution-level to an Advisory-level alert might introduce the possibility that the pilot is less prepared to react to a maneuvering alert (Corrective or Warning). In cases where the pilot has more time to react, such as with a Corrective Alert, this lack of preparedness would be less likely to manifest itself in any measurable way. A lack of preparedness would be more likely in cases where there is less time to maneuver the aircraft, such as when the Preventive Alert changes directly to a Warning Alert. Including both types of transitions to a maneuvering alert provided more information regarding the level of pilot preparedness after the Preventive Alert.

The first independent variable, level of Preventive Alert, was treated as a between subjects variable. The second independent variable, level of maneuver alert, was treated as a within subjects variable.

Participants

The participant group consisted of 32 pilots of large unmanned aircraft system (UAS > 55 pounds) with at least 100 hours of unmanned aircraft flight experience regardless of manned aircraft experience. All of our participants were male, and experience flying UAS ranged from 1 to 22 years (M = 8.26 years, SD = 4.78). Pilot UAS flight hours ranged from 170 to 10,318 hours

(M = 2283.38 hours, SD = 2080.49). Pilots had experience in different systems, including MQ-1/9 (Predator/Reaper), RQ-4 (Global Hawk), RQ-7B (Shadow), and Resolute Eagle. Thirteen participants indicated having previous experience with TCAS in a manned aircraft. TCAS experience ranged from 2 to 11 years.

The pilots were randomly separated into two experimental groups of 16 pilots each. One group received Preventive Alerts at the Advisory level and the other received Preventive Alerts at the Caution level. Table 4 compares the age, unmanned flight experience, manned aircraft experience, instrument flight rules certification, and TCAS experience between these two experimental groups.

Table 4.
Participant demographics by level of Preventive Alert

Preventive Alert Group	**Age in Years, Mean (Median)**	**Unmanned Flight Hours, Mean (Median)**	**Pilots with Manned Experience**	**Pilots with IFR Rating**	**Pilots with TCAS Experience**
Advisory-level	35.4 (37)	2346.6 (2150)	12	9	7
Caution-level	40.3 (40.5)	1926.8 (1502)	11	6	6

Encounters

The design of the experiment required that the pilot see a number of traffic encounters during the course of a flight. For half of the pilots, the alerting structure would include Caution-level Preventive Alerts while the other half of the pilots would be presented with Advisory-level Preventive Alerts. We created two scenarios, each lasting approximately 50 minutes. Each of the scenarios contained nine traffic encounters so each participant saw 18 traffic encounters total. In addition to these traffic encounters, there was also distractor traffic appearing on the traffic display that would not trigger an alert. To keep pilots from anticipating an intruder maneuver toward ownship during every encounter, a majority (10 of 18) of the encounters remained as a Preventive Alert where the intruder did not change trajectories and did not trigger a maneuvering alert (Corrective or Warning). These encounters were called Non-maneuvering Encounters. There were two types of Non-maneuvering Encounters, one for each of the two Preventive Alert levels (Caution vs. Advisory). Participants were presented with only one of the two types of Non-maneuvering Encounters depending on the experimental condition to which they were assigned. Figures 2 and 3 are representations of these Non-maneuvering Encounters.

Figure 2.
Caution-level Preventive Alert (Non-maneuvering Encounter) trial

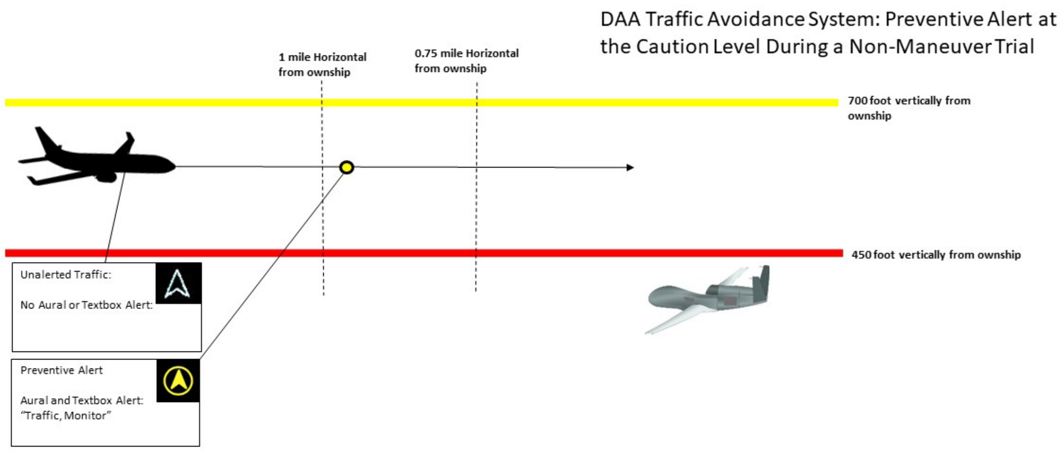
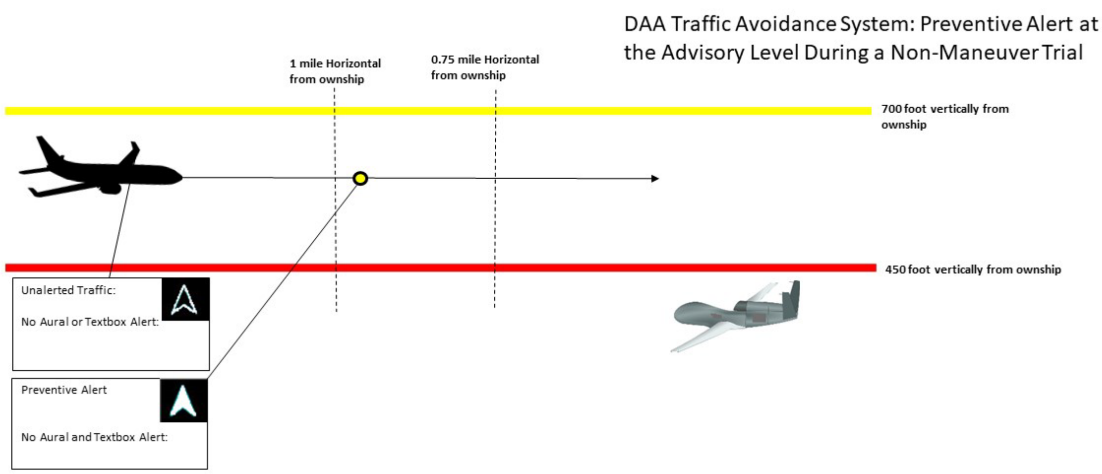


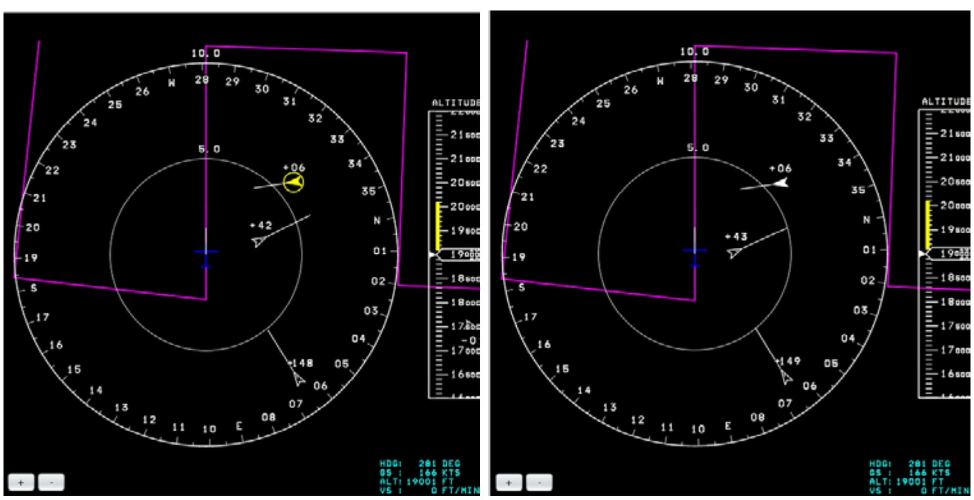
Figure 3.
Advisory-level Preventive Alert (Non-maneuvering Encounter) trial



Looking at the figures, in both conditions the intruder aircraft usually initially appeared as an unfilled traffic icon on the traffic display. When the intruder was less than 115 seconds from closest point of approach, a Preventive Alert was triggered. In the Caution-level Preventive Alert condition, the traffic icon (white chevron) changed to a yellow chevron, an aural alert of “Traffic, Monitor” was provided, a text alert of “Traffic, Monitor” appeared in the Alerting Textbox, and peripheral banding appeared on the altitude tape of the traffic display. As long as neither ownship nor the intruder maneuvered vertically, the intruder icon returned to an unfilled chevron once the intruder had passed by ownship. For the Advisory-level Preventive Alert condition for which no maneuver was required (Figure 3), the intruder icon changed from an unfilled to a filled white chevron. There was no aural alert and no text appeared in the Alerting Textbox. However, the vertical guidance bands still appeared on the altitude tape.

Figure 4 demonstrates how these two types of Preventive Alert conditions appeared on the traffic display. The left-hand picture shows a Caution-level Preventive Alert and the right-hand picture shows an Advisory-level Preventive Alert. Note that both types of alerts could contain red or yellow banding on the altitude tape, depending on time separation between the intruder and ownship.

Figure 4.
Unmanned Aircraft Traffic Display with a Caution-level Preventive Alert (left panel) and with an Advisory-level Preventive Alert (right panel)



The remaining 8 of the 18 encounters were Maneuvering Encounters. The intruder aircraft triggered a Preventive Alert (either Caution-level or Advisory-level depending on the condition being tested) which then changed to a maneuvering encounter when the intruder maneuvered vertically toward ownship. For four of these encounters, the intruder maneuver triggered a Caution-level Corrective Alert. For the other four encounters, the intruder maneuver triggered a Warning Alert, skipping the Caution-level Corrective Alert entirely. Figures 5 through 8 show these encounter types.

Figures 5 and 6 show the conditions when the Preventive Alert (Caution-level or Advisory level) transitioned to a Corrective Alert and then a Warning Alert. In the Advisory-level Preventive Alert condition, the intruder was shown as a white-filled chevron with no aural or visual alert; in the Caution-level Preventive Alert condition, the intruder was presented as a yellow filled chevron surrounded by an unfilled yellow circle and pilots heard an aural message, “Traffic, Monitor”. Approximately 10-15 seconds after triggering the Preventive Alert, the intruder began a vertical maneuver toward ownship that triggered a Corrective Alert. The intruder was presented as a yellow filled chevron surrounded by a filled yellow circle, and pilots heard the aural message, “Traffic, Avoid”. If no avoidance maneuver was initiated, the Corrective Alert changed to a Warning Alert that would remain until the encounter was resolved, at which time the intruder icon would change back to an unfilled chevron to complete the encounter.

Figure 5.
Caution-level Preventive Alert changing to a Corrective Alert (Maneuvering Encounter) trial

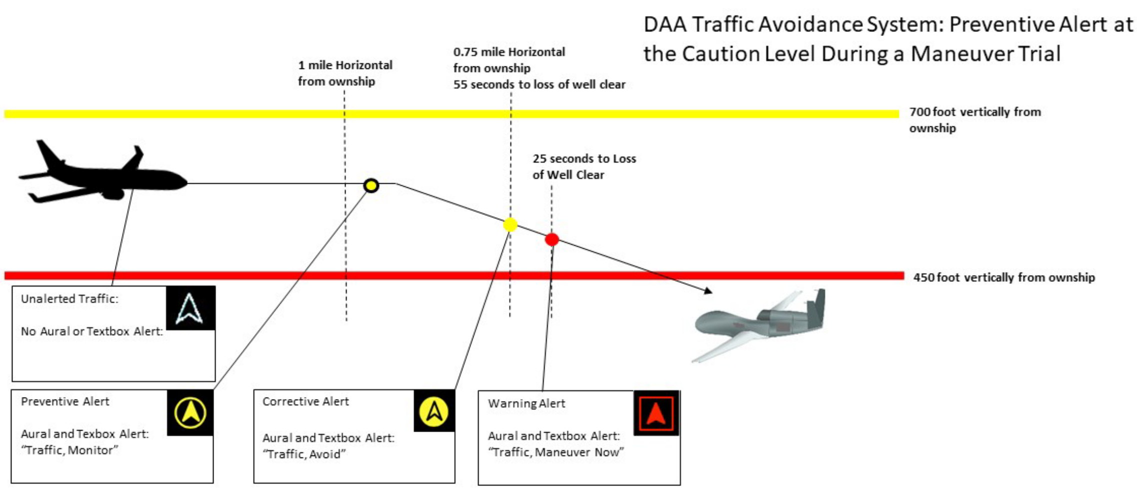
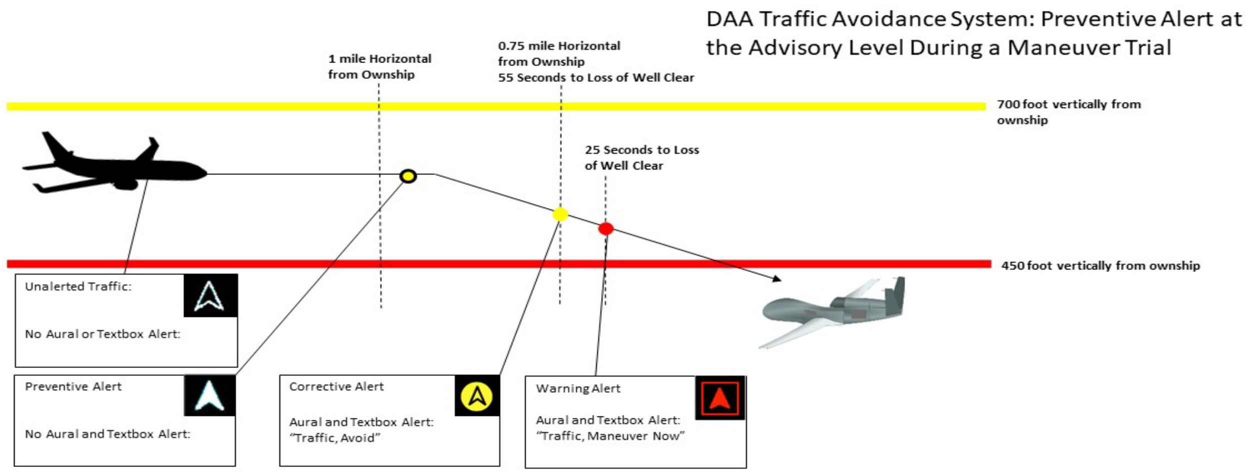


Figure 6.
Advisory-level Preventive Alert changing to a Corrective Alert (Maneuvering Encounter) trial



Figures 7 and 8 show the conditions when the Preventive Alert (Caution-level or Advisory level) transitioned directly to a Warning Alert. Approximately 20-25 seconds after triggering the Preventive Alert, the intruder began a vertical maneuver toward ownship that triggered a Warning Alert. The intruder was presented as a red filled chevron surrounded by a red square, and pilots heard the aural message, "Traffic, Maneuver Now, Traffic, Maneuver Now", which would remain until the encounter was resolved, at which time the intruder icon would change back to an unfilled chevron to complete the encounter.

Figure 7.
Caution-level Preventive Alert changing to a Warning Alert (Maneuvering Encounter) trial

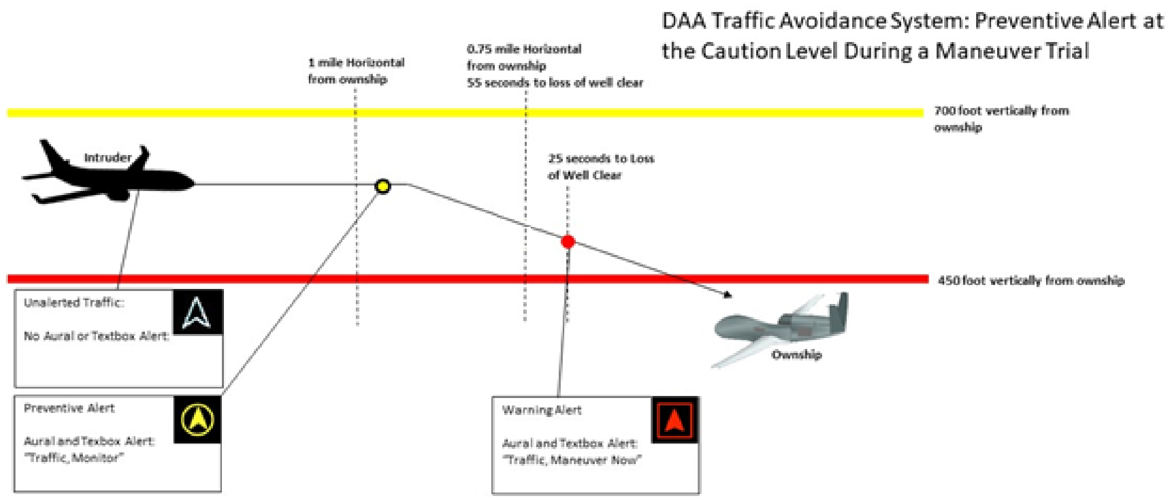
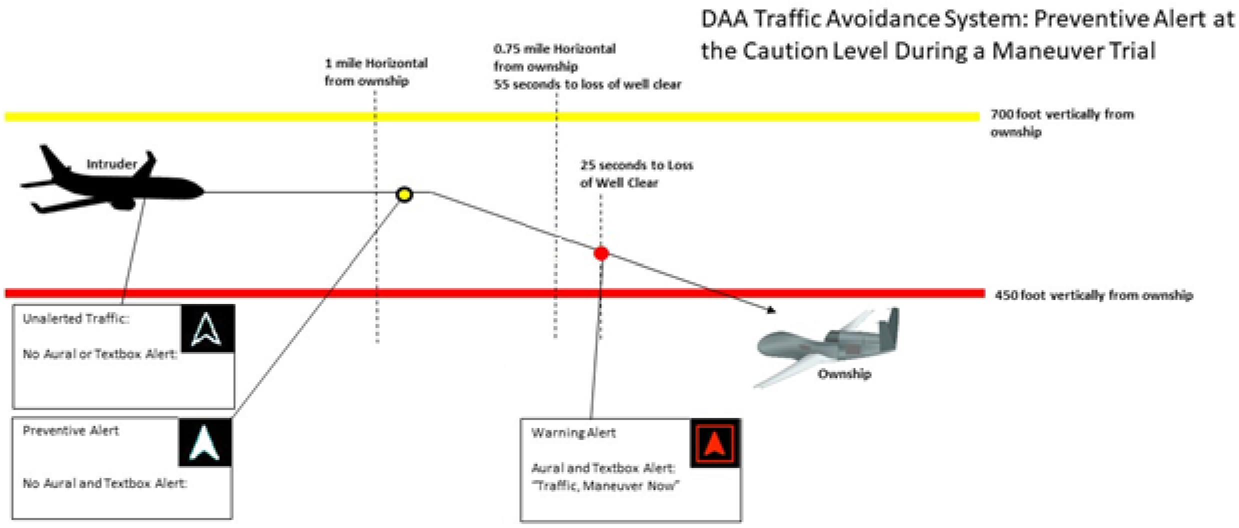


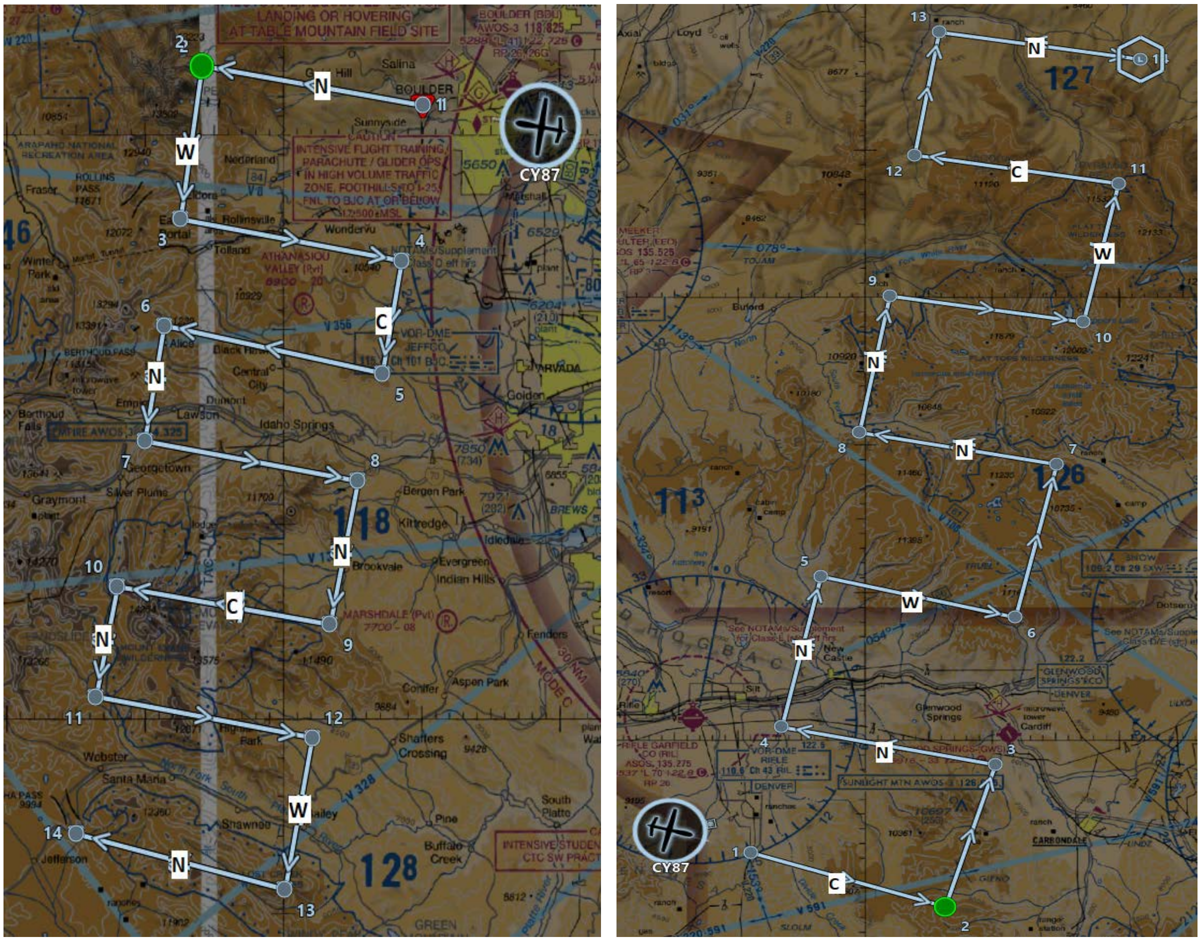
Figure 8.
Advisory-level Preventive Alert changing to a Warning Alert (Maneuvering Encounter) trial



Flight Scenarios

Every participant flew two experimental scenarios lasting approximately 50 minutes each. The scenarios were characterized as a fire-fighting task involving looking for and photographing hot spots along a pre-programmed mission route. Figure 9 shows the flight paths constructed for the scenarios and legs where the traffic encounters occurred. An “N” indicates a Non-maneuvering Encounter, a “C” indicates a Maneuvering Encounter that transitions to a Corrective Alert, and a “W” indicates a Maneuvering Encounter that transitions to a Warning Alert.

Figure 9.
Experimental scenario flight paths with indications of Non-maneuvering Encounters (N), Maneuvering Encounters transitioning to Corrective (C) and Maneuvering Encounters transitioning to Warning (W)



Although the paths appear identical for both flight paths, the first scenario had an initial heading of west, with the course proceeding in a southerly direction, while the second scenario had an initial easterly heading, proceeding in a northerly direction throughout the flight. The presentation order of the experimental scenarios were counterbalanced across participants.

Control Station Simulation

The control station simulation used was the Vigilant Spirit, developed by the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio.

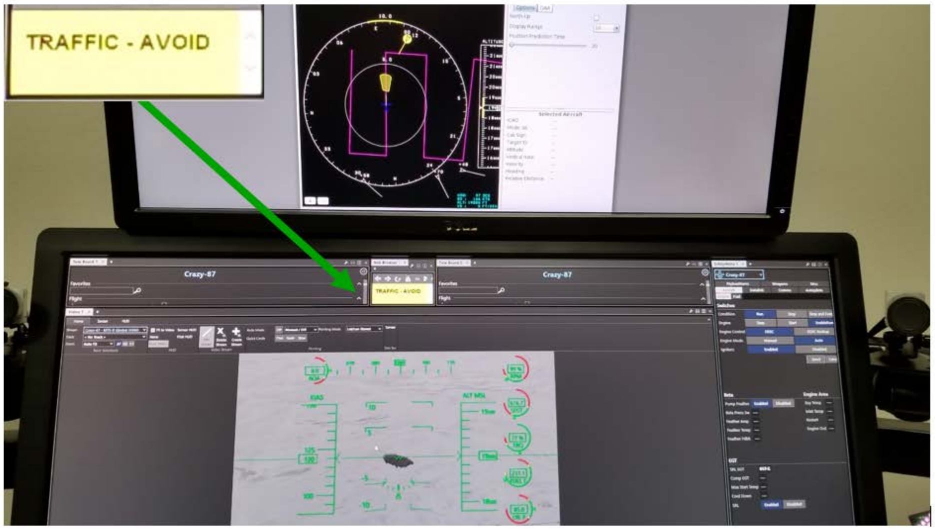
Location of the Displays

Figure 10 shows a picture of the control station as configured for the study. The display in the lower center was the mission-task display, showing camera imagery as well as ownship primary flight information such as heading, altitude, and airspeed. The screen on the left was a moving-map display showing current location of ownship (unmanned aircraft). It also contained a box (Steering Box) for entering commands to maneuver the aircraft. At the top of the mission-task display was the DAA Alerting Textbox.

Figure 10.
Vigilant Spirit control station with the traffic display on top. The design eye point is shown as a red circle. The center green box depicts the primary field-of-view around the design eye point.

When a Caution or Warning-level traffic DAA alert was triggered, pilots were presented with a visual text message on the DAA Alerting Textbox and an auditory alert. If the alert was a Caution-level Preventive Alert, the text would be, “Traffic – Monitor” in black lettering on a yellow background. For a Corrective Alert, the text would be, “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 textbox to display, “Traffic – Maneuver Now” in black lettering on a red flashing background. This is shown in Figure 11.

Figure 11.
Position of the DAA Alerting Textbox (indicated by blue arrow)



Maneuvering the Aircraft

To maneuver the aircraft, the pilot 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. However, if the pilot clicked on a waypoint, which would sometimes happen accidentally, the steering box would be replaced by a waypoint box. When that occurred, the pilot could make the steering box reappear by double-clicking on the ownship symbol located on the moving-map display. Figure 12 shows the steering box, the heading bug, and compass rose surrounding the ownship.

Figure 12.
Steering box for sending maneuver commands to the aircraft

The pilot had three options for changing aircraft heading: 1) clicking on one of the quick-command buttons, 2) typing a heading and clicking “Send”, or 3) Dragging and dropping the heading bug (white triangle) located on the heading ring surrounding the ownship symbol. The quick-command buttons were located at the bottom of the steering box. When the aircraft was being flown in waypoint mode, left-clicking twice on a quick-command button activated a turn command, which resulted in an immediate turn. After initiating a turn with a quick-command button, the turn could be modified to a new heading by typing in a heading and clicking on the “Send” button or by, dragging the heading bug to a new heading. The “Send” button could also be activated by pressing “Enter” twice on the keyboard.

Changing altitude could be accomplished in one of two ways. The first method was by double-clicking on the altitude numbers in the “Alt” box, typing in a new altitude, and sending the command using either the “Send” button or the keyboard. The second method was to click in the “Alt” entry box and then pressing the up or down arrows on the keyboard to change the altitude by 500 feet each time the arrow key was pressed, and then sending the command.

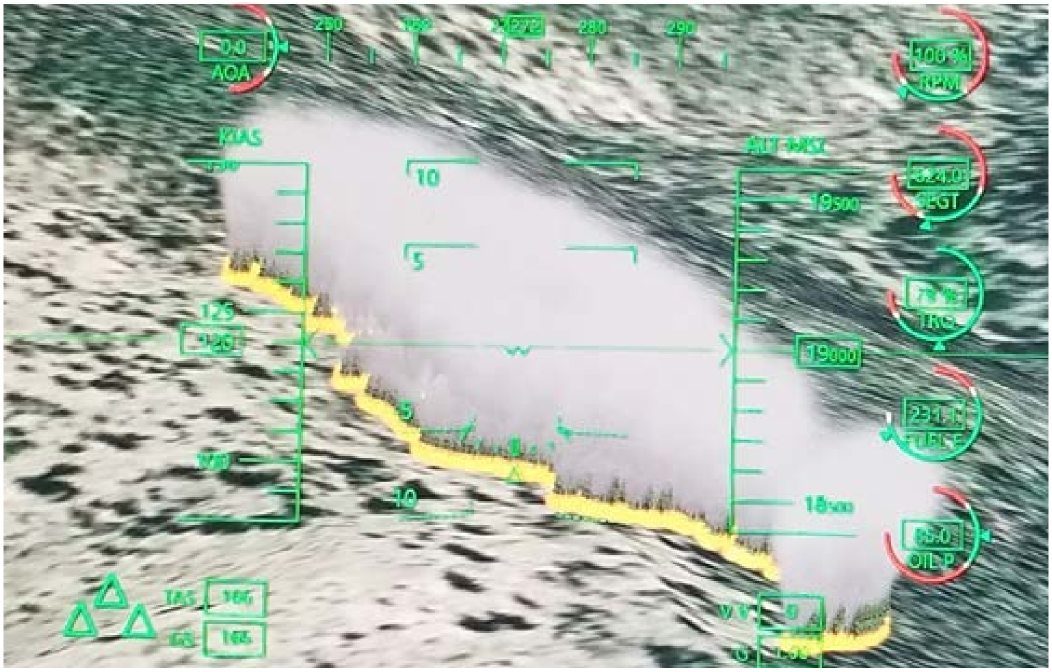
After sending a maneuver to the aircraft, the aircraft was no longer using the programmed flight path information. To return the aircraft to the programmed flight path, the pilot needed to select the "NAV" tab in the Steering box, click on a dropdown menu to select the appropriate waypoint, and then click "Send". The aircraft would then return to the programmed flight path, going to the selected waypoint by activating 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 13 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 pilot could select between "White-Hot" or "Black-Hot" modes. Selection of a particular camera setting was made using a mouse by clicking one of two buttons (labelled "DTV" and "IR") located just above and on the left side of the mission task display.

The camera system was set up so that when the pilot left-clicked on an object in the camera field-of-view, the camera would reposition so that the object was 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.

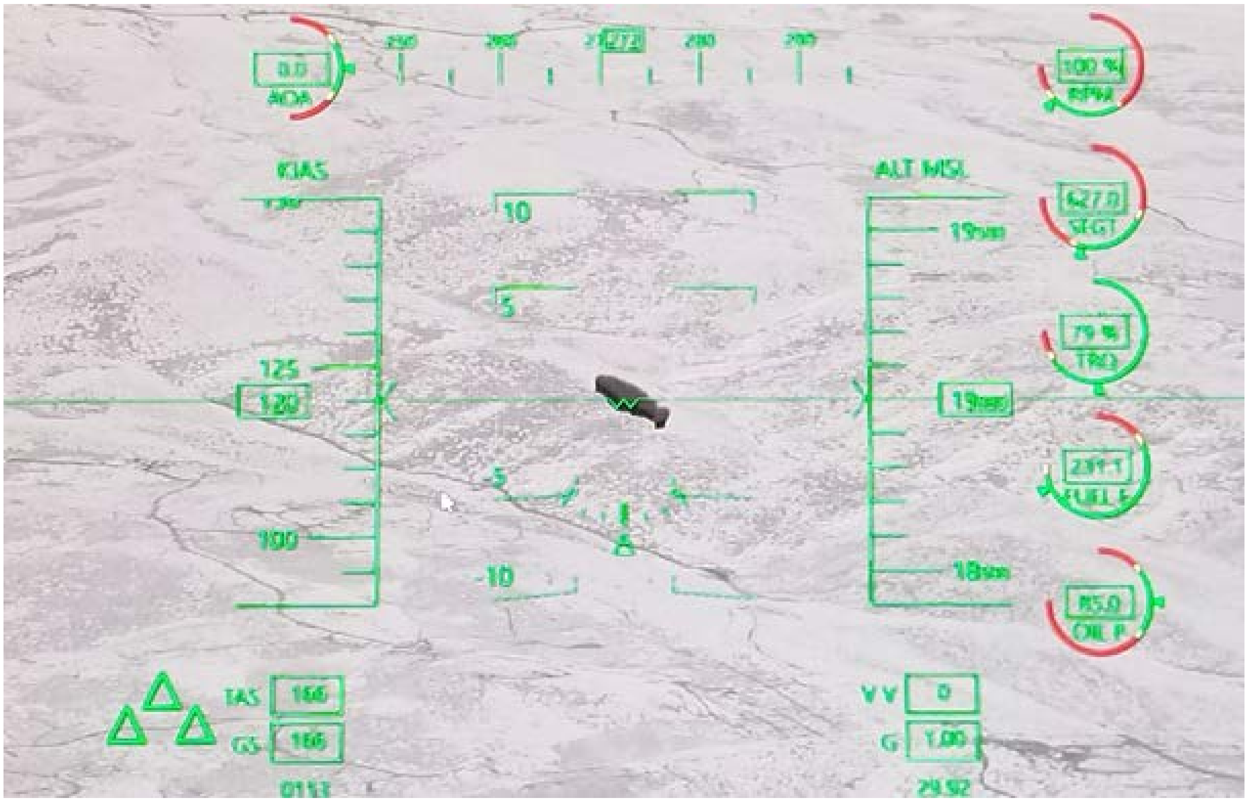
Figure 13.
View of a hot spot using the Daytime TV (DTV) setting



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 changed for each increment was dependent on how far away the object was from the camera, making it 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 14 shows a view of the same hot spot shown in Figure 13 but at a different zoom level and using the IR setting with Black-Hot mode. After locating a hot spot, participants 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 14.
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 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.

Procedure

Upon arrival at the laboratory, participants were asked to read and sign a consent form describing the experimental procedure and the purpose of the study. Pilots then filled out a demographics questionnaire; including information about their manned-flight experience and experience with unmanned aircraft (see Appendix A). After completing the demographics questionnaire, pilots were given a briefing regarding the purpose of the experiment, but with a focus on the performance of the secondary task (firefighting operation). After this briefing, the participant was shown the control station setup and training was begun regarding how to maneuver the aircraft and how to perform the secondary task (see Appendix B). A portion of this training included an explanation of the types of traffic alerts they would be given that was tailored to the level of Preventive Alert they would be receiving (see Appendix C). Average training for this portion was approximately 20 minutes.

After this training, pilots flew a training scenario where they were allowed to practice the secondary task as well as respond to traffic encounters. Each type of traffic encounter (Maneuvering and Non-maneuvering) they would experience were shown to the participants during the training scenario. The training scenario was flown at least two times, once sitting next to the instructor at the experimenter station and once at the pilot station, communicating with the instructor over a headset. This training continued until the participant demonstrated proficiency with all aspects of the task and stated that they felt comfortable with performing the task. Proficiency was defined as the ability to respond to all of the traffic alerts quickly enough to avoid a loss of well clear with an intruder. Only two pilots required a third repeat of the training scenario to achieve proficiency.

Once training was complete, the participant was given a break and then flew one of the two experimental scenarios, depending on the counterbalancing order. On completion of the scenario, they were offered a second break before flying the other experimental scenario. After completion of both experimental scenarios, they were asked to complete a post-test questionnaire (see Appendix D) before being dismissed. As with the traffic alert instructions, the questionnaire they received was dependent on the level of Preventive Alert the pilot was exposed to during the scenarios.

Results

Participant Exclusion Criteria

Five participants maneuvered in response to the Preventive Alert: two maneuvered in response to the Advisory-level Preventive Alert and three maneuvered in response to the

Caution-level Preventive Alert. Although this information was valuable to understanding how the pilots reacted to the Preventive Alert, these participants were not reacting to alerts designed to initiate a maneuver. Consequently, the response time and loss of well clear data from these participants were excluded from the analyses. The data set for our analysis consisted of 27 participants ($N_{\text{Advisory-level Preventive Alert}} = 14$, $N_{\text{Caution-level Preventive Alert}} = 13$). Demographics for each participant group are shown in Table 5. The number of encounters for each level of Preventive Alert included in the analyses is shown in Table 6.

Table 5.
Participant demographics by level of Preventive Alert

Preventive Alert Group	**Age in Years, Mean (Median)**	**Unmanned Flight Hours, Mean (Median)**	**Pilots with Manned Experience**	**Pilots with IFR Rating**	**Pilots with TCAS Experience**
Advisory-level	35.4 (37)	2177.1 (2050)	11	8	7
Caution-level	38.9 (40)	1926.8 (1502)	10	5	5

Table 6.
Number of encounters used for analysis by level of Preventive Alert

Preventive Alert Group	**Maneuvering Encounters**	**Non-Maneuvering Encounters**	**Total Encounters**
Advisory-level	112	140	252
Caution-level	104	130	234

Loss of Well Clear

The first metric used to judge the ability of pilots to avoid other traffic was how often they came too close to other aircraft during a traffic encounter. RTCA Special Committee 228 has developed a definition for “too close” called loss of well clear (technically Detect and Avoid well clear, or DWC). As described earlier, DWC is defined (approximately) as greater than 450 feet vertically and 0.75 nmi horizontally.

First, a frequency analysis for loss of well clear was performed to investigate if the frequency of loss of well clear differed between Caution-level and Advisory-level Preventive Alert conditions during the Maneuver Encounters. One encounter from the Caution-level Preventive Alert conditions and four from the Advisory-level Preventive Alert condition did not trigger properly because of pilots maneuvering against the Preventive Alert or because of maneuvers from a prior encounter. Results indicated 7% (7 out of 100 encounters) in the Caution-level Preventive Alert condition experienced a Loss of Well Clear compared to 5.41% of encounters (6 out of 111 encounters) in the Advisory-level Preventive Alert condition (see Table 7*)*. A Pearson's Chi-Square test showed no significant difference at the 0.05 level, $X^2(1, 211) = 0.231$, $p = 0.631$.

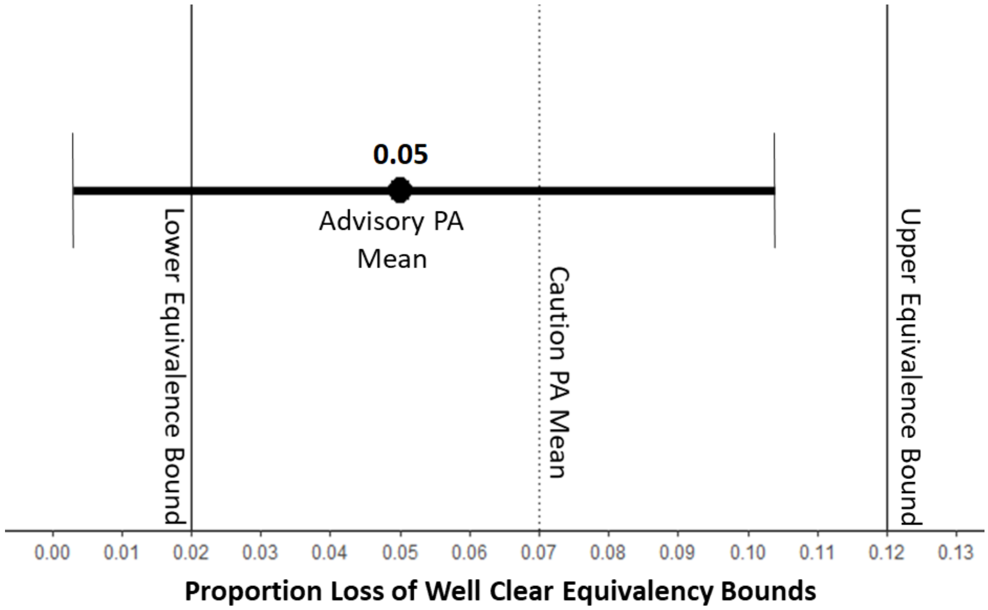
Table 7.
Loss of Well Clear by level of Preventive Alert

Preventive Alert Group	**Number of Trials**	**Number of Loss of Well Clear**	**Loss of Well Clear**
Caution-level	100	7	7.00%
Advisory-level	111	6	5.41%
All	211	13	6.16%

Due to the expectation there would be no difference between the Advisory-level and Caution-level Preventive Alert conditions, we conducted a statistical test of equivalence (Schuirmann, 1987; Seaman & Serlin, 1998; Lakens, 2017). The two one-sided *t*-test (TOST) is a procedure where the null and alternative hypotheses are reversed to provide evidence as to whether two groups are statistically equivalent. Standard hypothesis testing provides analytical evidence to support a statistical difference between two groups. Conversely, a null result indicates the two groups are not statistically different but a conclusion cannot be made that the groups are statistically equal. Thus, the TOST procedure provides a method to find statistical equivalence. Central to the TOST procedure is the establishment of what are called equivalence bounds. According to Lakens (2017), "in equivalence tests, such as the two one-sided tests (TOST) procedure, an upper and lower equivalence bound is specified based on the smallest effect size of interest" (p. 355). This effect size estimate is the same as the one used to perform power analyses when deciding how many participants should be included in a study and is usually measured in terms of an estimate of the standard deviation of the population. In the TOST procedure, an upper (DU) and lower (DL) equivalence bound is specified based on the smallest effect size of interest (e.g., a positive or negative difference of 0.3 standard deviations). Two composite null hypotheses are tested: When both these one-sided tests can be statistically rejected, we can conclude that the observed effect size falls within the equivalence bounds and is close enough to zero to be practically equivalent (Seaman & Serlin, 1998).

A TOST procedure based on Welch's *t*-test indicated that the 90% confidence interval for the observed proportion of losses of well clear during Advisory-level Preventive Alert encounters /exceeded the lower equivalency bound for Caution-level Preventive Alert encounters, $t(24.82) = -0.84$, $p = 0.204$, but was within the upper equivalency bound, $t(24.82) = 1.785$, $p = 0.043$. In other words, the proportion of pilots in the Advisory-level Preventive Alert condition who experienced a Loss of Well Clear was found to be equivalent or better than for the Caution-level Preventive Alert condition, as the Advisory-level confidence interval is within the upper equivalence bound but outside the lower equivalence bound as seen in Figure 15.

Figure 15.
Equivalency graph for proportion loss of well clear data



Note. PA indicates Preventive Alert.

Looking at the figure, the dotted vertical line represents the Caution-level Preventive Alert proportion of loss of well clear mean and the solid lines represent the equivalence bounds based on a 0.05 standard deviation proportional difference. The horizontal bar represents the 90% confidence interval for the Advisory-level Preventive Alert proportion loss of well clear with the mean indicated by the filled circle.

Severity Loss of Well Clear

To evaluate the level of safety provided by either the Caution-level or Advisory-level Preventive Alert, the Severity Loss of Well Clear (SLoWC) measure was calculated for both Corrective and Warning Alert encounters. The SLoWC metric is a number ranging from 0 to 100, indicating the percentage of intrusion into the well clear area around ownship (Lester et al., 2016). The metric is calculated 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., midair collision). To evaluate the SLoWC values from each of the Preventive Alert conditions, a one-way ANOVA was performed including the sample of 27 participants ($N_{Caution\ Preventive\ Alert}$ = 13, $N_{Advisory\ Preventive\ Alert}$ =14) combined for a total of 211 encounters ($N_{Caution\ Preventive\ Alert}$ = 100, $N_{Advisory\ Preventive\ Alert}$ = 111). The mean SLoWC value for the Caution-level Preventive Alert condition was 0.20 (SD = 1.35) with a maximum value of 11.19, and the mean SLoWC value for the Advisory-level Preventive Alert condition was 0.36 (SD = 2.98) with a maximum value of 30.87 (*see* Table 8). The ANOVA for SLoWC means was not significant at the 0.05 level ($F(1, 209) = 0.254$, $p = 0.615$).

An equivalence test was performed on the SLoWC values from each condition. The TOST procedure based on Welch's t-test indicated that the observed effect size ($d = -0.07$) was significantly within the equivalency bounds, $t(156.81) = 2.62$, $p = 0.005$[1]. In other words, SLoWC values for the two Preventive Alert conditions were found to be statistically equivalent.

Table 8.
SLoWC values by level of Preventive Alert

Preventive Alert Group	Number of Trials	Mean SLoWC Value	Maximum SLoWC Value
Caution-level	100	0.20	11.19
Advisory-level	111	0.36	30.87
All	211	0.29	30.87

Avoidance Maneuver Response Time

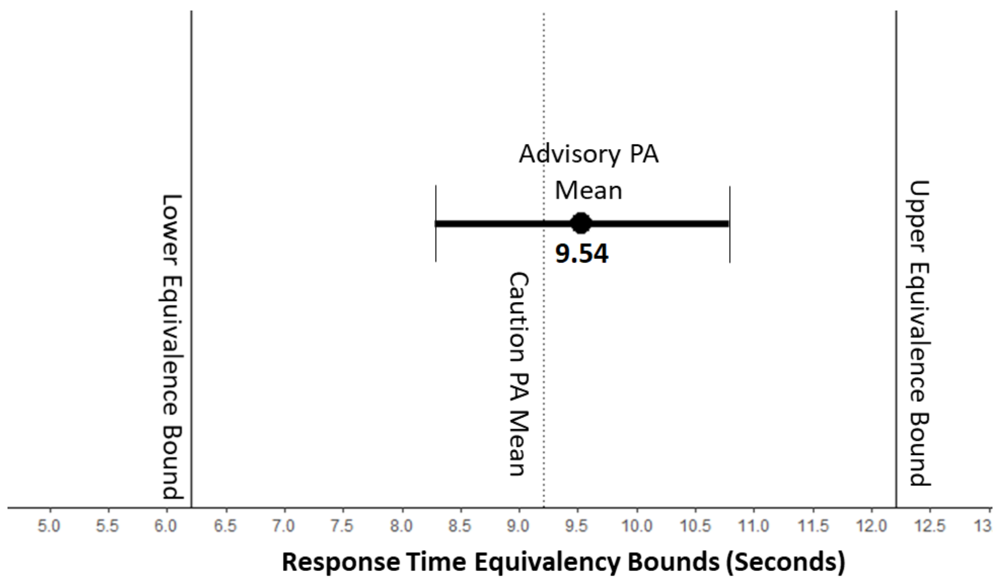
For Corrective Alert encounters, participants were instructed to contact ATC before maneuvering their aircraft. This resulted in a response time measure that was confounded with ATC interaction time. During trials when the Warning Alert was issued immediately following the Preventive Alert, the pilots were instructed to maneuver first before contacting ATC. Thus, Warning Alert trials solely were used in subsequent response time analyses as they captured only the time between alert and maneuver while excluding the confound of ATC communication time.

[1] The t-test value reported represents the test with the highest p-value (the lower bound in this analysis)

Three trials were excluded from analysis due to simulator issues or pilots not adhering to the preprogrammed flight path (one trial from the Advisory-level Preventive Alert condition and two trials from the Caution-level Preventive Alert condition). This results in a total of 105 trial encounters ($N_{\text{Caution Preventive Alert}} = 50$, $N_{\text{Advisory Preventive Alert}} = 55$) available for analysis.

A TOST was performed to evaluate if the response times between levels of the Preventive Alert were statistically equivalent. The parameters for the TOST equivalence bounds were based on a power analysis performed before the beginning of the study. An agreed-upon effect size of 0.6 was used to set as *Cohen's d* = 0.6, representing a 3 second difference in raw scores. The TOST procedure based on Welch's *t*-test indicated that the observed effect size (d = -0.07) was significantly within the equivalence bounds of d = -0.6 and d = 0.6, (or in raw scores: -3.01 and 3.01 seconds), $t(101.22) = 2.74$, p = 0.004)[2]. In other words, response times for the two Preventive Alert conditions were found to be significantly statistically equivalent (See Figure 16).

Figure 16.
Equivalency graph for avoidance maneuver response time data



[2] The *t*-test value reported represents the test with the highest *p*-value (the upper bound in this analysis)

Looking at the figure, the dotted vertical line represents the Caution-level Preventive Alert response time mean and the solid lines represent the equivalence bounds based on a 3-second difference from that mean. The horizontal bar shows the 90% confidence interval from the Advisory-level Preventive Alert response time mean, which is displayed as the black circle on the bar.

Detecting Traffic

One potential problem with simulation studies like this one is that participants might be sensitive to the presence of traffic, given they had just received instructions regarding the traffic display and how to perform avoidance maneuvers. This might lead to the claim that the findings of equivalency might be due to the fact that participants in both conditions expected to see the traffic aircraft and could have spotted the traffic before the alerts were triggered. To test whether this actually happened, we asked pilots to verbally call out all traffic when they saw it on the traffic display. These callouts were classified as late if they occurred more than 2 seconds after the appearance of the Preventive Alert. They were classified as missed if the participant did not call out the traffic or called the traffic out after the intruder passed ownship.

During Maneuver Encounters, participants called out traffic late during 4% of the traffic encounters (4 out of 100 encounters) for the Caution-level Preventive Alert condition, but called out late 24.3% of encounters (27 out of 111 encounters) for the Advisory-level Preventive Alert condition. A *t*-test showed this difference to be significant at the 0.05 level ($t(25) = -3.054$, $p = 0.0005$). In addition, a review of a subset of 23 of these 31 late callout encounters (3 Caution-level, 20 Advisory-level) revealed that a large portion of the late callouts exceeded the 2-second criteria by a significant amount, especially for the Advisory-level condition. The median delay for the Caution-level subset was 3.83 seconds, but the median delay for the Advisory-level subset was 11.73 seconds.

Similarly, during Non-maneuver Encounters, pilots called out traffic late in 5.51% of encounters (7 out of 127 encounters) after the Caution-level Preventive Alert, but called late for 34.56% of encounters (47 out of 136 encounters) with the Advisory-level Preventive Alert. A *t*-test conducted to evaluate for a statistical difference between the conditions was significant at the 0.05 level ($t(25) = 2.921$, $p < 0.0001$). A review of 37 of these 54 late callouts (3 Caution-level, 34 Advisory-level) found a median delay for the Caution-level subset of 6.46 seconds, and the median delay for the Advisory-level subset was 12.1 seconds.

Looking at missed callouts, under the Advisory-level Preventive Alert, four of the participants missed one traffic encounter each, which is a miss rate of 2.94%. No traffic was missed under the Caution-level Preventive Alert condition. Taken together, it is clear that participants were less expectant and aware of the presence of traffic in the Advisory-level Preventive Alert condition.

Post-Test Questionnaire Responses

All participants completed an electronically-presented post-test questionnaire at the conclusion of the study. One set of questions asked the participants to identify the icons for the Preventive, Corrective, and Warning Alerts. Only the icons were shown. No aural alert or text message was presented. The icons were shown to the participants in a random order determined at the time the questionnaire was administered. Table 9 shows the percentage of icons that were correctly identified by level of Preventive Alert.

Table 9

Correct identification of traffic icons by Level of Preventive Alert

Preventive Alert Group	Correct identification of Preventive Alert (N)	Correct identification of Corrective Alert (N)	Correct identification of Warning Alert (N)
Advisory-level	87.5% (14)	56.3% (9)	68.8% (11)
Caution-level	75% (12)	50% (8)	56.3% (9)

As can be seen in Table 9, participants in the Advisory-level Preventive Alert condition were more successful at identifying the alerting icons than participants in the Caution-level Preventive Alert condition. However, a Chi-Square analysis of the data using Fisher's Exact Test did not find a significant difference between the two conditions for any of the alerting icons (Preventive Alert $p = 0.654$, Corrective Alert $p = 1.0$, Warning Alert $p = 0.716$).

A separate question asked the participants to rate their effectiveness in maintaining separation from other aircraft during the mission. Table 10 presents the percentage within each of the response items by level of Preventive Alert.

Table 10.
Maintaining separation by Level of Preventive Alert

	Rate your effectiveness for maintaining separation from other aircraft during the mission today.				
Preventive Alert Group	**Extremely Effective**	**Very Effective**	**Effective**	**Somewhat effective**	**Not at all Effective**
Advisory-level	25 %	56.3 %	12.5 %	6.3 %	0 %
Caution-level	18.8 %	43.8 %	31.3 %	6.3 %	0 %

Looking at Table 10, participants within the Advisory-level Preventive Alert condition rated their effectiveness generally higher than participants within the Caution-level Preventive Alert condition. But as was discussed earlier, in terms of losses of well clear or response time measures, there were no measurable differences between the ability of participants to maintain separation from other aircraft.

Discussion and Conclusions

This study looked at whether changing the DAA Preventive Alert from a Caution-level alert to an Advisory-level alert would compromise the level of safety of flight in regard to traffic avoidance.

The results of this study found no difference in the ability of pilots to remain well clear of other traffic based on the level of the Preventive Alert to which they were exposed. In addition, an equivalency test showed that the Advisory-level Preventive Alert was equivalent to *or better* than the Caution-level Preventive Alert in terms of the number of losses of well clear that occurred during the study. Equivalency between the two alerting levels was also demonstrated based on the severity, SLoWC, and the avoidance maneuver response time measure. Taken as a whole, these results provide strong evidence of there being no difference between the effectiveness of a Caution-level or Advisory-level Preventive Alert.

One disadvantage of the Advisory-level Preventive Alert was that participants were slower at detecting traffic than in the Caution-level Preventive Alert condition, likely because participants in the Caution-level Preventive Alert condition received an aural and visual message calling their attention to the traffic aircraft. However, this lack of traffic awareness did not lead to a difference in maintaining well clear of traffic or in avoidance maneuver response times in this study.

Given the results of this preliminary research, the following conclusions are warranted:

- Level of Preventive Alert did not affect the probability of losing well clear nor the pilot response time to maneuver to maintain well clear
- Pilots in the Advisory-level Preventive Alert condition were more likely detect traffic later than pilots in the Caution-level Preventive Alert condition. However, not being aware of the traffic before the maneuvering alert did not affect the ability of the pilot to remain well clear
- Results support the conclusion that changing the Preventive Alert level from a Caution-level to an Advisory-level alert will not compromise safety of flight as it relates to traffic avoidance.

The results of this study are preliminary and are not sufficient by itself to reduce the status level of the Caution-level Preventive Alert. Further research is needed to understand whether the Caution-level Preventive Alert could be considered a nuisance alert since no action is needed, or whether its presentation would distract pilots.

References

Fern, L., Rorie, R. C., Pack, J. S., Shively, R. J., & Draper, M. H. (2015). *An evaluation of detect and avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance.* Proceedings of the 15th Annual American Institute of Aeronautics and Astronautics (AIAA) Aviation, Technology, Integration and Operations Conference, Dallas, Texas, June 22 - 26, 2015. http://doi.org/10.2514/6.2015-3327

Lakens, D. (2017). Equivalence tests: A practical primer for t-tests, correlations, and meta-analyses. *Social Psychological and Personality Science*, *8*(4) 355-362. https://doi.org/10.1177/1948550617697177

Lester, T., Kay, J., Kunzi, F., Pratt, E., & Smearcheck, S. (2016, May). *SC-228 closed-loop metrics white paper* (RTCA Special Committee 228 white paper).

Muñoz, C., Narkawicz, A., Hagen, G., Upchurch, J., Dutle, A., Consiglio, M., & Chamberlain, J. (2015). *DAIDALUS: Detect and avoid alerting logic for unmanned systems.* Proceedings of the 34th Digital Avionics Systems Conference (DASC 2015), Prague, Czech Republic, September 13-17, 2015. https://doi.org/10.1109/DASC.2015.7311421

Rorie, R. C. & Fern, L. (2015). *The impact of integrated maneuver guidance information on UAS pilots performing the detect and avoid task.* Proceedings of the 59th Human Factors and Ergonomics Society Annual Meeting, Los Angeles, California, October 26-30, 2015. https://doi.org/10.1177%2F1541931215591012

Rorie, R. C., Fern, L., & Shively, R. J. (2016). *The impact of suggestive maneuver guidance on UAS pilots performing the detect and avoid function.* Manuscript in preparation. Proceedings of the 2016 AIAA SciTech Conference, San Diego, California, January 4–8, 2016. http://doi.org/10.2514/6.2016-1002

RTCA (2014). *Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System* (No. DO-317). Washington, DC: RTCA, Inc.

RTCA (2020). *Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems* (No. DO-365B). Washington, DC: RTCA, Inc.

Santiago, C., & Mueller, E. R. (2015). *Pilot evaluation of a UAS detect-and-avoid system's effectiveness in remaining well clear*. Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), Lisbon, Portugal.

Schuirmann, D. J. (1987). A comparison of the two one-sided tests procedure and the power approach for assessing the equivalence of average bioavailability. *Journal of Pharmacokinetics and Biopharmaceutics*, *15*(6), 657-680. https://doi.org/10.1007/BF01068419

Seaman, M. A., & Serlin, R. C. (1998). Equivalence confidence intervals for two-group comparisons of means. *Psychological Methods*, *3*(4), 403–411. http://doi.org/10.1037/1082-989X.3.4.403

Williams, K. W. (2020). *Minimum information requirements for an unmanned aircraft system detect-and-avoid traffic display under full-mission conditions* (Technical Report No. DOT/FAA/AM-20/06). U.S. Department of Transportation, Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2020s/media/202006.pdf

Appendix A: Demographic Questionnaire

ID Participant Code:

____

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

PART I - Pilot Experience

Age (years):

____ Years

2) Gender:

- ○ Male
- ○ Female

3) Do you have <u>manned</u> pilot flying experience?

- ○ Yes
- ○ No

3a) Number of years as a pilot:

____ Years

3b) Flight Hours (estimated):

_______ Civilian

_______ Military

_______ Approximate Hours in U.S. Civil Airspace (i.e. not restricted or special use)

3c) IFR rated:

- ○ Yes
- ○ No

3d) Number of Hours? (estimated)

____ Hours

3e) Other Ratings:

____

3e) Aircraft Types:

____

4) Do you have large UAS (> 55 lbs.) flying experience?

- ○ Yes
- ○ No

4a) Number of years as an unmanned aircraft pilot:

____

4b) Total UAS Flight Hours (estimated):

_______ Civilian

_______ Military

_______ Approximate Hours in U.S. Civil Airspace (i.e. not restricted or special use)

4c) UAS Aircraft Types:

____

PART II - Traffic Collision Avoidance System

5) Do you have any experience using the Traffic Alert and Collision Avoidance System (TCAS)?

- ○ Yes
- ○ No

5a) How would you rate your familiarity of the Traffic Collision Avoidance System (TCAS)?

- ○ Not Familiar
- ○ Somewhat Familiar
- ○ Familiar
- ○ Very Familiar
- ○ Expert

5b) How many years experience have you had with TCAS?

______ Years

5c) Specify the percentage of time with each of the following:

TCAS I: ______________________

TCAS II: ______________________

6) How would you rate your familiarity with flying using other traffic displays?

- ○ Not Familiar
- ○ Somewhat Familiar
- ○ Familiar
- ○ Very Familiar
- ○ Expert

7) How many years experience have you had with other traffic displays?

_____ Years

8) Which other traffic displays have you used?

9) Have you experienced any situations in which you needed to take an evasive action to avoid another airborne aircraft regardless of whether TCAS was involved?

- ○ Yes
- ○ No

9a) Please explain:

PART III - Flight Simulation

10) Do you have any desktop flight simulation experience on programs such as MS Flight Sim?

- ○ Yes
- ○ No

10a) Please Specify:

a) Number of hours: ______________________________________

b) Type: ____

11) Do you have any flight simulation experience on FAA-approved flight training simulators/devices?

- ○ Yes
- ○ No

11a) Please Specify:

a) Number of hours: _______

b) Type: ________________

Appendix B: Participant Training Checklist

<u>Controlling the Camera</u>

- ☐ The gray square on the moving map indicates where the center of the camera is located
- ☐ The white shaded polygon is the field of view for the camera on the moving map (as the camera is zoomed in the polygon will get smaller) [**If an x is shown in the middle of the polygon the camera will function as normal but the computer just does not recognize ownship altitude and cannot calculate the FOV on the moving map**]
- ☐ Zoom the camera by using the mouse wheel (moves in increments and not smooth) (increments are larger the further ownship is from the camera location)
- ☐ Panning the camera:
    - For small incremental shifts in the camera's FOV:
        - Left click to either the left or right side of camera view to shift to camera.
    - For large incremental shifts in the camera's FOV:
        - right-click on map on drop down-menu left-click "Stare Here"
        - Another option, grab the grey box on the map and drag to the point of interest (not recommended because if the pilot misses the square the moving map will got to North up mode and must be set back to track-up).
- ☐ To center the camera on an object:
    - Left clicking on the object in the camera's view will center the camera on the object
    - If the terrain is highly variable, centering the camera on the object may be difficult (**clicking in the middle of the object's location and the center of the camera will sometimes help center the camera on the object**)
- ☐ Switching between IR and DTV
    - IR will assist in finding hotspots (show how to get the camera to IR mode)
        - IR camera can be set to white hot or black hot and is adjustable by the controls at top of the screen
    - Switch to DTV to take a photograph of the fire (show how to get the camera to DTV mode)
- ☐ Taking a picture of the object
    - Right click and select "Take Photo"
    - A green dot will appear on the moving map indicating a picture was taken
        - Click on the green dot to show the photograph that was taken

Maneuvering the Aircraft

- Holds tab is used to input commands to the aircraft when not in waypoint mode
- Horizontal Maneuvering (3 methods)
  - Quick command (while in waypoint mode a “shield” will be over the quick command button and will require double clicking the quick command for the aircraft to respond)
  - Click twice in the heading box (this will highlight the numbers in the box) and type in a new heading (press send or enter twice)
  - Use the Navigational bug. (If the pilot misses the bug, moving map will go to North up mode and must be placed back to **track-up mode**).
- Vertical Maneuvering (2 methods)
  - Click inside the altitude box and use keyboard arrows to change by 500 ft increments
  - Double click in altitude box to highlight the whole number and type in new altitude (If pilot does not double click in the box will need to delete the pervious altitude before entering the new altitude).
- NAV Mode is used to return to waypoint mode
  - Click on the NAV mode go to dropdown menu and click the next waypoint.

Traffic Display

- Alert instructions (Books on IPad)
- Distinguish between preventive and corrective alerts
- Emphasize the directives given by the bands on the altitude meter and traffic display heading (bands and master alert)
- The number above the intruding aircraft in the traffic display is the altitude difference between ownship and the intruder next to the number is a (+) or (-) sign to indicate if the other aircraft is above or below ownship.
  - If an arrow appears next to the altitude number of the other aircraft this indicates the aircraft is climbing or descending.

Miscellaneous Control information

- The pilot may move the navigation box by a left click and hold the top-bar of the box, and move to desired location.
- Putting the map back into track up mode:
  - Right click on the moving map -> go to the airplane icon -> click on track up mode
- While maneuvering ownship to avoid traffic try to stay as close to the preplanned flight path as possible

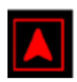
Additional Information

- Experimenter note: make sure to have the participant practice setting the map back to track-up mode.
- For purpose of the study we would like for the participant to call-out when they notice an aircraft that might present a situational conflict
- When maneuvering to avoid traffic try to stay as close to preprogrammed flight path as possible.

Appendix C: Alerting Type Instructions

Instruction set 1 (Caution-level) for participants – Preventive Alerting Study.

In this system there are three types of alerts regarding other aircraft in the area. For each of the alerts, the normal traffic icon  will be replaced by an alert icon. The first alert is called a preventive alert and is shown by this icon  which is a yellow, unfilled circle with a yellow chevron in the center. The purpose of the preventive alert is to inform the pilot that another aircraft will be flying between 700 and 450 feet vertically from ownship. If neither you nor the other aircraft changes altitudes, there will be more than 450 feet vertical separation from each other so no maneuver should be required. In addition to the change in icon, you should also hear an aural alert in your headset that says, “Traffic, Monitor”, and see “Traffic, Monitor” on the Master Alert Box on a steady yellow background.

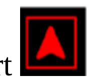
The other two alerts are the corrective alert , which is a yellow, filled circle with a yellow chevron in the center, and the warning alert , which is red box with a red chevron in the center. Both of these alerts indicate that the intruder aircraft will be getting too close to ownship on their current trajectories and that you should maneuver your aircraft to avoid getting too close. The only difference between these two alerts is that the corrective alert is intended to provide enough time for you to contact ATC and request a maneuver before you do so, while the warning alert indicates that you should make a maneuver immediately and then contact ATC afterwards. In addition to the icon change, for the corrective alert you will hear an aural alert of “Traffic, Avoid”, and will see “Traffic, Avoid” in the Master Alert Box on a flashing yellow background. For the warning alert, you will hear an aural alert of “Traffic, Maneuver Now. Traffic, Maneuver Now” and will see “Traffic, Maneuver Now” in the Master Alert Box on flashing red background.

In addition to the alerting icons and aural alerts, the traffic display also displays maneuver suggestions to the pilot during a traffic alert in the form of colored bands on the traffic display.

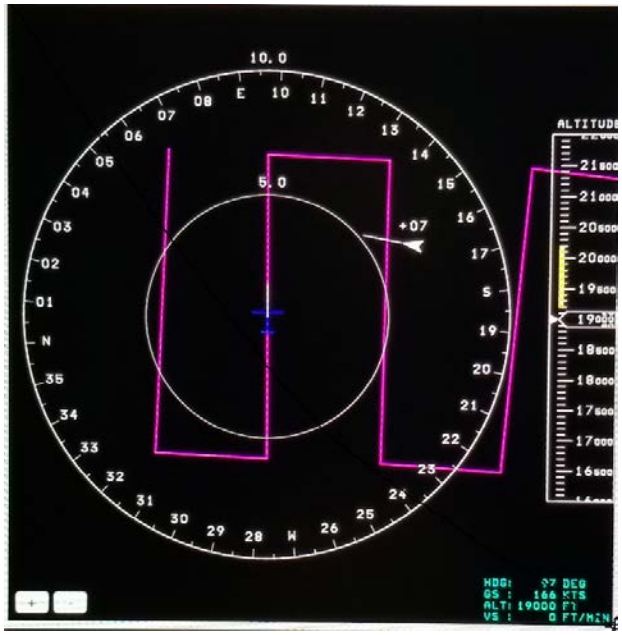
These bands appear on the heading compass (outer ring) of the traffic display and the altitude bar of the traffic display.

The purpose of these bands is to indicate headings and altitudes to avoid so as to remain well clear of an intruder aircraft. The color of the bands will be either yellow or red, depending on if the band is associated with a caution or warning level alert. If the band appears at the ownship current heading and altitude, it indicates that a maneuver is required to avoid losing well clear from another aircraft. During a preventive or advisory alert, there will be a band on the altitude bar that potentially extends to the ownship altitude but there will not be a band on the heading circle. If the alert changes to a corrective or warning alert, a band will appear on the heading circle that will cover the current heading of ownship.

In this system there are three types of alerts regarding other aircraft in the area. For each of the alerts, the normal traffic icon  will be replaced by an alert icon. The first alert is called a preventive alert and is shown by this icon  which is a white, filled chevron The purpose of the preventive alert is to inform the pilot that another aircraft will be flying between 700 and 450 feet vertically from ownship. If neither you nor the other aircraft changes altitudes, there will be more than 450 feet vertical separation from each other so no maneuver should be required. There are no other indications provided besides the change in the icon.

The other two alerts are the corrective alert , which is a yellow, filled circle with a yellow chevron in the center, and the warning alert , which is red box with a red chevron in the center. Both of these alerts indicate that the intruder aircraft will be getting too close to ownship on their current trajectories and that you should maneuver your aircraft to avoid getting too close. The only difference between these two alerts is that the corrective alert is intended to provide enough time for you to contact ATC and request a maneuver before you do so, while the warning alert indicates that you should make a maneuver immediately and then contact ATC afterwards. In addition to the icon change, for the corrective alert you will hear an aural alert of “Traffic, Avoid”, and will see “Traffic, Avoid” in the Master Alert Box on a flashing yellow background. For the warning alert, you will hear an aural alert of “Traffic, Maneuver Now. Traffic, Maneuver Now” and will see “Traffic, Maneuver Now” in the Master Alert Box on flashing red background.

In addition to the alerting icons and aural alerts, the traffic display also displays maneuver suggestions to the pilot during a traffic alert in the form of colored bands on the traffic display. These bands appear on the heading compass (outer ring) of the traffic display and the altitude bar of the traffic display.



The purpose of these bands is to indicate headings and altitudes to avoid so as to remain well clear of an intruder aircraft. The color of the bands will be either yellow or red, depending on if the band is associated with a caution or warning level alert. If the band appears at the ownship current heading and altitude, it indicates that a maneuver is required to avoid losing well clear from another aircraft. During a preventive or advisory alert, there will be a band on the altitude bar that potentially extends to the ownship altitude but there will not be a band on the heading circle. If the alert changes to a corrective or warning alert, a band will appear on the heading circle that will cover the current heading of ownship.

Appendix D: Post-Test Questionnaires

DAA3 Preventive Alert – Post Study Questionnaire - Advisory-Level

ID Participant Code:

____

Date:

____

1a) 

O Preventive Alert

O Corrective Alert

O Warning Alert

O Not Sure

1b) 

O Preventive Alert

O Corrective Alert

O Warning Alert

O Not Sure

1c) 

O Preventive Alert

O Corrective Alert

O Warning Alert

O Not Sure

2) How would you rate the difficulty of performing the task of locating the hot spots?

O Very Easy

O Somewhat Easy

O Neither Easy Nor Hard

O Somewhat Hard

O Very Hard

3) How would you rate the difficulty of performing the task of photographing the hot spots?

O Very Easy

O Somewhat Easy

O Neither Easy Nor Hard

O Somewhat Hard

O Very Hard

4) Rate your effectiveness for the following:

	Not at all Effective	Somewhat Effective	Effective	Very Effective	Extremely Effective
Maintaining separation from other aircraft during the mission today	O	O	O	O	O
Traffic Icon for helping perform the mission today	O	O	O	O	O
Alert Box for helping perform the mission today	O	O	O	O	O
Aural Alerts for helping perform the mission today	O	O	O	O	O
Preventive Alert at indicating the presence of traffic passing between 450 and 700 feet vertically of ownship	O	O	O	O	O

5) Was there a visual and/or aural alert used in the study that made you more aware traffic was in the area?

____

6) Was there a visual and/or aural alert used during the study that made it clearer a maneuver was required to remain separation from other traffic?

____

7) Was there a visual and/or aural alert used during that study that made it easier to determine if you should contact ATC prior to maneuvering?

____

8) Was there a visual and/or aural alert used during the study that made it easier to determine if you should contact ATC after maneuvering

____

9) Overall what were the most effective information elements (i.e. traffic icon, alert box message, aural message, etc.) in this display? Please Explain.

____

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

____

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

____

12) Please discuss any suggestions for improving this display, such as changing the location of the traffic display, size of the symbols, volume of the aural alerts, aural alert content, visual alert content or any other comments, issues or concerns.

____

<u>DAA3 Preventive Alert – Post Study Questionnaire - Caution-Level</u>

ID Participant Code:

____

Date:

____

Please identify the following traffic icon (Traffic icons were presented in random order).

1a) 

O Preventive Alert

O Corrective Alert

O Warning Alert

O Not Sure

1b) 

O Preventive Alert

O Corrective Alert

O Warning Alert

O Not Sure

1c) 

O Preventive Alert

O Corrective Alert

O Warning Alert

O Not Sure

2) How would you rate the difficulty of performing the task of <u>locating</u> the hot spots?

O Very Easy

O Somewhat Easy

O Neither Easy Nor Hard

O Somewhat Hard

O Very Hard

3) How would you rate the difficulty of performing the task of <u>photographing</u> the hot spots?

O Very Easy

O Somewhat Easy

O Neither Easy Nor Hard

O Somewhat Hard

O Very Hard

4) Rate your effectiveness for the following:

	Not at all Effective	Somewhat Effective	Effective	Very Effective	Extremely Effective
Maintaining separation from other aircraft during the mission today	O	O	O	O	O
Traffic Icon for helping perform the mission today	O	O	O	O	O
Alert Box for helping perform the mission today	O	O	O	O	O
Aural Alerts for helping perform the mission today	O	O	O	O	O
Preventive Alert at indicating the presence of traffic passing between 450 and 700 feet vertically of ownship	O	O	O	O	O

5) Was there a visual and/or aural alert used in the study that made you more aware traffic was in the area?

____

6) Was there a visual and/or aural alert used during the study that made it clearer a maneuver was required to remain separation from other traffic?

____

7) Was there a visual and/or aural alert used during that study that made it easier to determine if you should contact ATC prior to maneuvering?

____

8) Was there a visual and/or aural alert used during the study that made it easier to determine if you should contact ATC after maneuvering

____

9) Overall what were the most effective information elements (i.e. traffic icon, alert box message, aural message, etc.) in this display? Please Explain.

____

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

____

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

____

12) Please discuss any suggestions for improving this display, such as changing the location of the traffic display, size of the symbols, volume of the aural alerts, aural alert content, visual alert content or any other comments, issues or concerns.

____

13) Based on this alert, I would

	Contact ATC and then maneuver	Maneuver prior to contacting ATC	Neither maneuver nor contact ATC
Preventive Alert 	O	O	O
Corrective Alert 	O	O	O
Warning Alert 	O	O	O

14) If ownship and intruder trajectories remained unchanged, this alert indicates an eventual loss of separation.

	Agree	Disagree
Preventive Alert 	O	O
Corrective Alert 	O	O
Warning Alert 	O	O