Federal Aviation Administration

DOT/FAA/AM-17/14
Office of Aerospace Medicine
Washington, DC 20591

An Investigation of Minimum Information Requirements for an Unmanned Aircraft System Detect and Avoid Traffic Display

Kevin W. Williams [1]
Eamon Caddigan[2]
Carolina Zingale[3]

[1]Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

[2]T.G. O'Brien & Associates, Inc.
Westcliffe, CO 81252

[3]Williams J. Hughes Technical Center
Federal Aviation Administration
Atlantic City, NJ 08234

June 2017

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-17/14		

4. Title and Subtitle An Investigation of Minimum Information Requirements for an Unmanned Aircraft System Detect and Avoid Traffic Display	5. Report Date June 2017 6. Performing Organization Code
7. Author(s) Williams K,[1] Caddigan E,[2] Zingale C[3]	8. Performing Organization Report No.
9. Performing Organization Name and Address [1]FAA Civil Aerospace Medical Institute P.O. Box 25082, Oklahoma City, OK 73125 [2]T.G. O'Brien & Associates, Inc. Westcliffe, CO 81252 [3]Williams J. Hughes Technical Center Federal Aviation Administration, Atlantic City, NJ 08234	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

Work was accomplished under approved task AM-B-HRR-521

16. Abstract

A study was conducted to support the development of Minimum Operational Performance Specifications for UAS Detect and Avoid traffic displays being developed by RTCA Special Committee 228. The study involved over 1,000 traffic encounters across 32 participants. Data collection began January 20th, 2016, and was completed on April 1st, 2016. The experiment tested four different display configurations. A baseline display , an indication of the Closest Point of Approach (CPA) between ownship and an intruder aircraft, avoidance area information indicating areas to avoid preventing a loss of well clear from another aircraft, and a banding information display indicating horizontal and vertical vectors to avoid preventing a loss of well clear. In addition,the experiment also manipulated whether the pilots had UAS experience or were only instrument-rated manned aircraft pilots, and the type of control station interface that was used. The results replicated the findings of other studies showing the benefits of banding information in addition to baseline information for a UAS detect and avoid traffic display. In addition, these benefits were seen across a more varied population of pilots than were looked at in previous studies as well as different control station interface designs than were used in previous studies, thus giving strong support for the decision made by the RTCA SC-228 committee to require banding information as part of the minimum requirements. The study also found strong support for the avoidance area (blob) information. Ramifications of this support are discussed.

17. Key Words	18. Distribution Statement
DAA, Detect and Avoid, Sense and Avoid, UAS, Unmanned Aircraft Systems, Traffic Displays	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	72	

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

ACKNOWLEDGMENTS

We thank Sherry Chappelle (ANG-C1), Bill Kaliardos (ANG-C1) and Steve Plishka (AFS-086) for managing and sponsoring this simulation.

We thank the following groups and individuals from the William J. Hughes Technical Center for ensuring successful development, preparation, and execution of the simulation.

From the Unmanned Aircraft Systems Engineering Branch (ANG-C35), we thank

- Matt Mariani, Phil Maloney, and Jean-Christophe Geffard (ATAC), aerospace engineers, for preparing the UAS simulators, ensuring required functionality throughout the simulation, and training pilots on general simulator operation
- Marcello Mirabelli, UAS pilot SME, for training pilots on UAS simulator operations and test procedures used in the simulation
- Bina Pastakia, engineering research psychologist, for assisting with simulation execution and data collection
- Ngoc Nguyen, computer scientist, for developing the simulation website and ensuring all needed materials (briefings, questionnaires) were available and saved
- Lana Manovych (ATAC), senior engineer, for consolidating and analyzing simulation data
- Lacey Thompson (ANG-C35), operations research analyst, and Tyler Travis (ATAC), business management analyst, for setting up and modifying the questionnaires during simulation preparation
- Scott Sunder (ATAC), UAS Lab Systems Administrator, for ensuring network and virtual machine functionality throughout the simulation

From the Surveillance Branch (ANG-C33), we thank

- Tammy Willson, computer specialist, Phil Hoang, electronic engineer, Kevin Szagala, computer scientist, and William Mateer, computer scientist, for developing the Unmanned Aircraft Traffic Display (UATD), integrating and testing RTCA requirements on an iterative basis over many months, implementing and evaluating user interface requirements, and troubleshooting during the simulation.

From the Laboratory Services Division (ANG-E1), we thank

- Scott Doucett, Manager, Target Generation Facility Section (ANG-E161) and Kim Mortensen (Hi-Tec Systems) for recruiting and scheduling pilots
- Pilots Bruce Slack and Bob Engeles (ANG-E161) for supporting simulation development and shakedown
- Tim Swantek, Simulation Branch (ANG-E16) for providing TGF support during scenario development

- Chris Continisio (GDIT), software engineer, for preparing and troubleshooting DESIREE systems and recording equipment
- Robin Peterson Brown (ANG-E142) for scheduling NIEC laboratory resources
- Engineers from the Communications Maintenance Section (ANG-E153) for setting up, monitoring, and troubleshooting the pilot-controller communications system

Finally, we thank the 32 manned and unmanned pilots who participated in our simulation. Special thanks to Horsham, PA Air Force Base for providing experienced Predator pilots for the simulation.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
CPA	Closest Point of Approach
DAA	Detect and Avoid
DAIDALUS	Detect and Avoid Alerting Logic for Unmanned Systems
FAA	Federal Aviation Administration
HDI	Highest Density Interval
ICOMC2	Insitu's Common Open Mission Management Command and Control
MOPS	Minimum Operational Performance Specification
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NIEC	NextGen Integration and Evaluation Capability
NMAC	Near Mid-Air Collision
RTCA	Radio Technical Commission for Aeronautics
RTTS	Real Time Tracking Surveillance
SAA	Sense and Avoid
SLoWC	Severity of Loss of Well Clear
SME	Subject Matter Expert
SST	Self-Separation Threshold
TCAS	Traffic Collision Avoidance System
TGF	Target Generation Facility
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UATD	Unmanned Aircraft Traffic Display
WCV	Well Clear Violation
WJHTC	Williams J Hughes Technical Center

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 (14CFR) Part 91.113 which requires pilots to “see and avoid” other aircraft. This study was conducted to support the development of Minimum Operational Performance Specifications for UAS Detect and Avoid traffic displays being developed by RTCA Special Committee 228. The study involved over 1,000 traffic encounters across 32 participants. Data collection began January 20th, 2016, and was completed on April 1st, 2016.

The experiment tested four different display configurations. The baseline display 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)

The other three displays contained everything available in the baseline display plus an additional type of information. This additional information was (1) an indication of the Closest Point of Approach (CPA) between ownship and an intruder aircraft, (2) avoidance area information indicating areas to avoid preventing a loss of well clear from another aircraft, or (3) banding information indicating horizontal and vertical vectors to avoid preventing a loss of well clear.

In addition to testing four display types, the experiment also manipulated whether the pilots had UAS experience or were only instrument-rated manned aircraft pilots. The experiment also manipulated the type of control station interface that was used, with half of the participants flying a General Atomics, Predator control station interface and the other half using the Insitu company’s ICOMC2 interface.

Analysis of the well clear violations showed a significant effect due to display type. Individual comparisons revealed that both the avoidance area and banding displays significantly decreased the likelihood of violating well clear relative to the baseline display. The CPA display was not significantly different from the baseline display.

The pattern of well clear violations for both pilot types is nearly identical to the overall findings. However, while it appeared that UAS pilots performed somewhat better than the manned pilots, the result was not statistically significant. Likewise, no significant difference was found between the use of different control interfaces in regard to the violation of well clear boundaries.

Analysis of the Severity of Loss of Well Clear (SLoWC) revealed a significant effect of pilot type, with unmanned pilots performing better than the manned pilots. No other main effects or interactions were found.

As with measurements of well clear violations, subjective estimates of the displays also favored the avoidance area and banding displays over both the baseline and CPA displays.

This study replicated the findings of other studies showing the benefits of banding information in addition to baseline information for a UAS detect and avoid traffic display. In addition, these benefits were seen across a more varied population of pilots than were looked at in previous studies as well as different control station interface designs than were used in previous studies. This gives strong support for the decision made by the RTCA SC-228 committee to require banding information as part of the minimum requirements.

The study also found strong support for a different form of maneuver guidance implicitly provided in the avoidance area (blob) information. Objective measures of performance suggested that the blob display was even more effective than the banding information. One explanation might be that the avoidance areas provide the pilot with information regarding the urgency of a maneuver in addition to the maneuver guidance provided by banding. More research is required before recommending such "urgency information" be included in the minimum requirements for these displays.

An Investigation of Minimum Information Requirements for an Unmanned Aircraft System Detect and Avoid Traffic Display

INTRODUCTION

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 (14CFR) Part 91.113, which requires pilots to "see and avoid" other aircraft. Achieving this conformance requires research to assist in the development of technology that would allow UAS to detect other aircraft that the UAS pilot cannot see and to enable the UAS pilot and/or system to transmit maneuver commands to the unmanned aircraft (UA) so that it can avoid those other aircraft. As part of that effort, human factors research is required to determine what control station displays and controls are needed to support the UAS pilot in performing this traffic avoidance task.

Reports generated from the FAA-sponsored Sense and Avoid (SAA) workshops (FAA, 2009; 2013b) divide avoidance maneuvers into two types. The first type, called separation maneuvering (or self-separation), is intended to allow the UA to remain well clear of other aircraft beyond the collision avoidance threshold (CAT). The second type of avoidance maneuver is collision avoidance and includes maneuvers to prevent a threat aircraft from entering the near mid-air collision (NMAC) volume: the area surrounding the UA that is defined by a horizontal radius of 500 feet and a vertical height of 200 feet (100 feet above and below). Figure 1 presents a depiction of the self-separation threshold, the well clear violation threshold, the collision avoidance threshold, and the near mid-air collision volume.

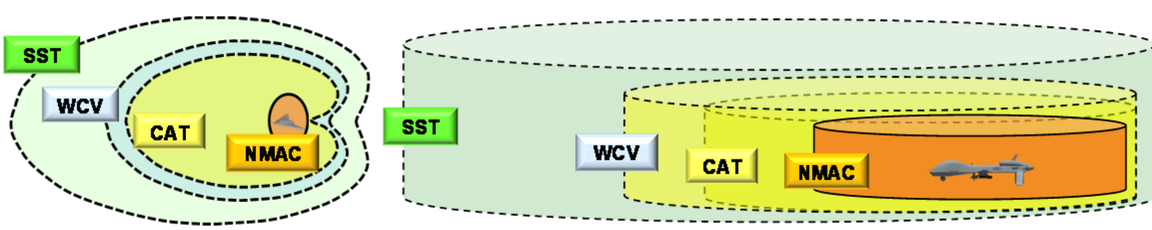


Figure 1. Graphical depiction of self-separation threshold (SST; "well clear"), well clear violation threshold (WCV), collision avoidance threshold (CAT) and near mid-air collision (NMAC) (FAA, 2013).

One primary difference between separation and collision avoidance maneuvering is that most separation maneuvering will involve interaction and coordination with air traffic control (ATC), while collision avoidance maneuvering will not. Because of this interaction and coordination with ATC, display information requirements are not the only contributing factor to the overall level of safety of these operations. However, it has to be assumed that there will be potential encounters where ATC coordination is minimal or absent and therefore where separation maneuvering is primarily the responsibility of the pilot. In such instances, the only information available to the pilot for selecting a maneuver is what is available on the traffic display. The current research effort is intended to assist with identifying that information.

Previous Research

Before research on traffic displays for UAS control stations was being performed, there had already been numerous studies on the use of cockpit displays of traffic information, commonly referred to as CDTIs (e.g., Rantanen, Wickens, Xu, & Thomas, 2004; Thomas & Rantanen, 2006; Thomas & Wickens, 2006; Wickens, Helleberg, & Xu, 2002; Xu & Rantanen, 2007). This research focused on a number of different aspects of the CDTI including the effects of display dimensionality, conflict geometry, and time pressure on conflict detection and resolution performance (Thomas & Wickens, 2006), as well as maneuver preference (Thomas & Wickens, 2008). Other aspects included the effect of false alerts (Thomas & Rantanen, 2006), workload (Wickens, Helleberg, & Xu, 2002), and unique display types (Knecht, 2008) on pilot performance.

One result of this research has been the development of a set of standards for CDTIs (RTCA, 2014). Among other things, the standards have established display symbology requirements for ownship and traffic symbols. These symbology standards have been adopted for UAS traffic display standards being developed by the standards group RTCA Special Committee 228, Detect and Avoid working group (SC-228 DAA). However, there are unique aspects to the use of a traffic display within a UAS control station that require new research efforts. This research has already begun. Some of this research has been performed independently of either the FAA or any standards organizations (e.g., Bell, Drury, Estes & Reynolds, 2012), while other efforts have come from research organizations within the FAA (e.g., Rein, Friedman-Berg & Racine, 2013). Yet other research, most notably from NASA, has been on behalf of the RTCA SC-228 DAA working group (Fern, Rorie, Pack, Shively, & Draper, 2015; Rorie & Fern, 2015; Rorie, Fern, & Shively, 2016; Santiago & Mueller, 2015).

While there are numerous questions that can, and perhaps should, be addressed with this research, of particular importance for the establishment of standards is the set of minimum information requirements for these displays. Both Rein et al. (2013) and the NASA studies were attempts at identifying the set of minimum information requirements. We will review these studies.

In Rein et al. (2013), 10 high-time (median = 1450 hrs.) active UAS Predator pilots flew a series of 120 traffic encounter scenarios across four different display conditions. The experimenters started with a basic information display and added information components successively in three other displays. They described the experimental approach as adding more information to the display until traffic avoidance performance leveled off. This performance level-off occurred with the third of the four displays, which was called the Prediction display.

The Prediction display contained the following information components:

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)

One issue with this approach was that the experimenters did not define the required minimum performance levels. If the performance plateaus, you can still ask whether the level of performance is acceptable. Because you added more information and found no performance increase, we cannot conclude that an increase in performance is unattainable. There might be other types of information that could be added to the display, or there might be different ways of displaying the same information that could be more effective in improving performance.

Therefore, a question raised by this study was whether, from a safety standpoint, the performance levels obtained were adequate using the Prediction display. We know that a lower level of information leads to worse performance, but is performance with the Prediction display good enough? It is a difficult question to answer because there are a number of related questions that need to be considered such as:

1. Does the pilot control interface have a bearing on performance and would a different interface yield different performance levels?
2. Was the pilot sample used in the study representative of the expected user population? Do we know whether less-experienced UAS pilots would perform similarly?
3. Were the encounter geometries representative of the population of potential encounters? Would the display information adequately support more complex encounters?
4. Was the display symbology representative of what will actually be used for these types of displays?

The set of NASA studies (Fern, Rorie, Pack, Shively, & Draper, 2015; Rorie & Fern, 2015; Rorie, Fern, & Shively, 2016; Santiago & Mueller, 2015), in addition to establishing minimum information requirements, were interested in looking at the effectiveness of guidance beyond the baseline information. In particular, this additional guidance focused on the inclusion of maneuver guidance for the pilot. Within the RTCA

SC-228 DAA working group, maneuver guidance is separated into either suggestive guidance or directive guidance (RTCA, 2015). Suggestive guidance in the context of a DAA traffic display is information that provides the pilot with maneuver options for maintaining separation from other aircraft. Usually, this information focuses on heading changes and/or altitude changes but can also include airspeed changes as well. Directive guidance, on the other hand, involves a single maneuver. The NASA research studies have presented suggestive guidance primarily in the form of colored bands at the perimeter of the traffic display that show which headings or altitudes, if flown, would result in a violation of well clear for a particular intruder aircraft. Results from these studies have shown support for the use of these displays to remain well clear from other traffic.

As with Rein et al., (2013), these studies evoked questions regarding the pilot control interface, the representativeness of the pilot sample, and the encounter geometries that were used. The control station pilot interface was optimized for using suggestive heading guidance bands by allowing the pilot to select heading changes using a mouse click-and-drag procedure. The participant population, as with Rein et al., consisted only of current UAS pilots. In addition, the traffic encounters were established by having confederate air traffic controllers maneuver aircraft toward the unmanned aircraft as it flew along a predetermined course. While effective, the reliance on human decision-making and reaction times limited the precision that could be achieved with the encounters.

Current Effort

The current research effort sought to answer many of the questions raised by these previous studies. In this section, we outline several aspects of the current effort, particular design decisions that were made, and the reasoning behind those decisions. Unfortunately, the number of potential variables in this type of research is always much larger than can be reasonably accommodated within a single research design. However, the results of this research should assist in directing future efforts.

Display configurations

The display configurations used in the study are a natural extension of earlier efforts. The baseline information display was essentially the same as the Prediction display that was established as “minimum” in Rein et al. (2013). The other three displays look at different types of suggestive maneuver guidance. Pictures of all of the displays, along with more detailed descriptions, can be found in Appendix A.

Suggestive maneuver guidance can be provided in a variety of ways to the pilot. While the NASA studies have supported the effectiveness of heading and altitude bands, other display concepts that have not been as thoroughly researched can be found in the literature. Two of these concepts, a depiction of the closest point of approach (CPA) between the aircraft and an intruder (Bell, Drury, Estes, Reynolds, & Jella, 2011), and a depiction of avoidance areas where a loss of well clear will obtain (Bell, Drury, Estes, & Reynolds, 2012; Tadema, 2011), were selected for comparison to the baseline and banding display concepts for this research effort. Because of the way it appears on the display, the avoidance area concept was usually referred to as the “blob” display during the course of this research.

Alerts and alerting parameters

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 (see Table 1).

The selection of timing parameters of the alerts is based on work accomplished by the RTCA SC-228 DAA working group. Although these parameters have not been fully established at the time of this writing, research to date by NASA (Fern, Rorie, Pack, Shively, & Draper, 2015; Rorie & Fern, 2015; Rorie, Fern & Shively, 2016; Santiago & Mueller, 2015) has allowed selection of alert timing values that are believed to approximate those that will be adopted as the recommended values.

In addition to the alerting algorithm and timing parameters, the selection of traffic alert symbols and auditory alerts was also based on recommendations established by the RTCA SC-228 working group. A full description of these symbols and alerts and their timing parameters is given in the methods section.

Selecting encounter geometries

The selection of encounter geometries was driven by the belief that if the encounters were too simple, no differences between the various display configurations would be found. Even a poorly designed or otherwise inadequate traffic display could support traffic encounters where almost any maneuver would resolve the conflict. It is only when there is a certain level of complexity involved in the encounter that you are more likely to find differences between display configurations.

A review of CDTI research by Rantanen et al. (2004) on CDTI displays revealed factors within traffic encounters that added complexity to the encounters and therefore made the encounters more difficult to resolve. Three factors listed by Rantanen et al. (2004) were (1) traffic that is climbing or descending is more difficult to handle, (2) different relative speeds between ownship and intruding traffic make detection and understanding the encounter more difficult, and (3) non-orthogonal approach angles are more difficult to resolve. For the current study, an effort was made to incorporate these factors into the scenarios.

In addition, it was assumed that giving the pilot less time to respond to traffic would increase the difficulty of the encounter. To accomplish this, two manipulations were included in the scenarios. First, the traffic display did not display any traffic other than ownship until a traffic alert was triggered. This prevented the pilot from anticipating a potential avoidance maneuver before the alert occurred. This was also intended to simulate real-world events in which pilots would be engaged in many tasks and would not be continuously monitoring the traffic display. Second, for some of the encounters, an ownship maneuver was used to prevent the DAIDALUS algorithms from detecting a potential well clear violation until the aircraft were in close proximity to each other. This led to encounters in which the first alert received was the highest level warning alert based on the time to CPA.

Control station interfaces

Currently, there are no standards that have been established for UAS control station design. This presents a problem for the creation of standards for the use of a traffic display because the overall interaction with the traffic display can be influenced by the control interface that is used to input flight commands. Rorie & Fern (2014) looked at the influence of different control interfaces on time to maneuver the aircraft. That research demonstrated that different overall response times would result from the use of different control interfaces. We believe that the control interface might also affect traffic avoidance in other ways as well. For example, it is possible that a control interface design might bias the type of maneuver that is selected, especially if the procedure for commanding a particular type of maneuver (e.g., horizontal maneuver) in one control station is faster or easier than commanding that same maneuver in a different control station. To look at the effect of the pilot control interface on the effectiveness of the traffic display, we decided to include two radically different pilot control interface designs in the experiment. One of these control interfaces (Predator station) uses both a joystick and keyboard commands to enter flight commands. The other interface (ICOMC2 station) requires a mouse and keyboard to enter flight commands and does not use a joystick. The flight command interface for the Predator station is noticeably more complex than the ICOMC2 station command interface and was expected to require more training for the pilots.

Aircraft models

In addition to differences in control station interface design influencing traffic avoidance effectiveness and procedures, differences in aircraft performance could also have an influence. The two control station simulators selected for the study use aircraft models that differ from each other to a great extent. The aircraft model used in the Predator control station was the General Atomics Predator B UA while the model used in the ICOMC2 control station was the Insitu Integrator UA. Of particular relevance to this study, the turn and climb rates and cruise speeds of the two aircraft were markedly different. Table 1 provides the values of the aircraft models as they were established for the study.

Table 1. Configurable parameters used in the study, including the default values for the DAIDALUS algorithms.

Configurable Parameters	**Default Value set -DAIDALUS**	**Predator B**	**Integrator**
Turn Rate	3 deg/s	2.5 deg/sec	8.5 deg/sec
Bank angle	30 deg	30 deg	30 deg
Horizontal acceleration	2 m/s^2	2 m/s^2	2 m/s^2
Vertical acceleration	2 m/s^2	2 m/s^2	2 m/s^2
Minimum ground speed	50 kts	75 kts	58 kts
Maximum ground speed	250 kts	160 kts	90 kts
Minimum vertical speed	-5000 fpm	-1500 fpm	-750 fpm
Maximum vertical speed	5000 fpm	1500 fpm	450 fpm
Track step	1 deg	1 deg	1 deg
Ground speed step	1 kt	1 kt	1 kt
Vertical speed step	10 fpm	used default	used default
Minimum Altitude	500 ft	500 ft	1,000 ft
Maximum Altitude	50,000 ft	50,000 ft	19,000 ft

Note that even though the performance parameters of both aircraft models differed, both of the sets of aircraft performance specifications met the requirements for aircraft using a DAA system that have been established in Appendix D of the RTCA SC-228 DAA Minimum Operational Performance Standards (RTCA, under review).

Participants

Prior FAA and NASA studies have only used experienced UAS pilots as participants. While the use of UAS pilots adds to the validity of the research with regard to the training and operation of the UAS, many of these pilots do not have extensive experience with traffic displays or traffic avoidance procedures. In addition, most UAS operations are currently flown in segregated airspace and such operations are different from the majority of instrument flight rule (IFR) flights within the NAS. For these reasons, we decided to include a sample of instrument-rated manned aircraft pilots in addition to UAS pilots within the study.

Hypotheses

In regard to the effectiveness of the various display configurations in avoiding traffic, it was expected that the banding display would be more effective than the baseline display based on the findings from the NASA studies cited above. While there is some support for the effectiveness of the avoidance area (blob) display concept (Tadema, Theunissen, & Kirk, 2010a, 2010b), support for the CPA display concept is lacking. Bell et al. (2012) found potential support for the CPA symbology, but the display paired the CPA and blob symbology together so the two concepts were confounded. However, given that the CPA display concept, like the banding and blob concepts, provides suggestive information to the pilot, there was an expectation that it would be more effective than the baseline display as well.

It was thought that the use of pilots with only manned aircraft experience and the use of control stations with different pilot interface designs might have an effect on the ability to avoid traffic but that these differences would not interact with the display configurations. That is, the expectation was that overall performance across display conditions would be the same regardless of pilot aircraft experience or control station condition, but there might be some significant main effects for traffic avoidance measures.

In addition to traffic avoidance measures, there was an expectation that pilot and control station differences might lead to measurable differences in maneuver preferences. Training and operational protocols differ between the manned and unmanned systems, which could lead to different maneuver biases. In particular, manned pilots, especially those with Traffic Collision Avoidance System (TCAS) experience, might be biased toward vertical maneuvers more so than pilots with no TCAS experience because avoidance maneuvers for TCAS are only vertical. Also, as mentioned earlier, different methods for inputting maneuver commands might bias which maneuvers were selected as well.

METHOD

Participants

Thirty-two pilots were recruited for the study. Sixteen of the pilots had UAS experience and the other 16 were instrument-rated manned aircraft pilots with no UAS experience. The sample size was based on the need to have enough participants sufficient to yield robust data while meeting cost, personnel, and time constraints. We recruited manned pilots based only on having a current instrument rating, while UAS pilots were required to have mission experience, 200 hours flight experience, and be current within the last 3 years. Unmanned pilots recruited for the Predator simulator were experienced Predator pilots. Of these, five flew the MQ-9, one flew the MQ-1B, and two had both MQ-9 and MQ-1 experience. However, because of the relative newness of the ICOMC2 simulation, no pilots could be found with operational experience with the ICOMC2. For this reason, the unmanned pilots recruited for the ICOMC2 had a mix of operational experience. Five of these pilots were Global Hawk pilots. One pilot flew the RQ-7B Shadow UAS. One pilot flew the Scan Eagle, and one pilot flew both the Shadow and Scan Eagle UAS. Pilots were recruited from available sources including contract companies who have qualified participants on staff and the Department of Defense.

Equipment

Predator Station

The Predator Station pilot interface includes controls on the joystick but also accepts keyboard commands. For most flight commands, both the joystick and keyboard must be used. Figure 2 shows a picture of the Predator Control Station as it was configured for the study.

Figure 2. Predator control station with the traffic display on the right.

The moving map display at the top contained a depiction of the flight plan as well as a display used for changing aircraft heading. The center screen below the map display provided airspeed, altitude, heading, and vertical speed indications to the pilot. The bottom two screens provided information regarding the current control mode as well as other diagnostic information. The DAA traffic display can be seen on the right behind the joystick.

ICOMC2 Station

Unlike the Predator control station, the ICOMC2 Station consists of a single screen. Figure 3 shows a picture of the ICOMC2 Station as it was configured for this study. Interaction with the system is accomplished using the mouse and keyboard. Inputting flight commands can be accomplished either by typing values in certain locations on the screen or by clicking and dragging with the mouse. The traffic display is shown on the right.

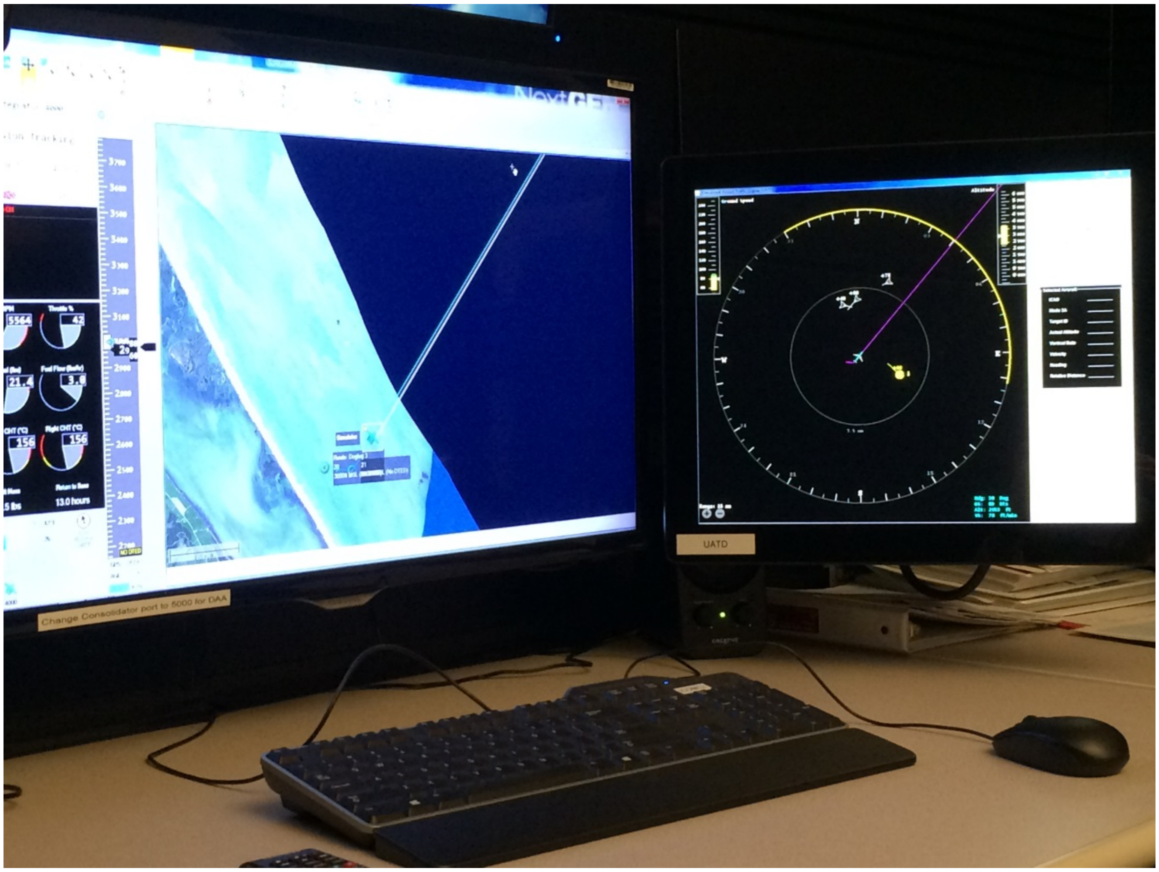


Figure 3. ICOMC2 control station with the traffic display on the right.

Target Generation Facility (TGF)

The Target Generation Facility (TGF) is a software tool developed by William J. Hughes Technical Center (WJHTC) engineers that simulates traffic surrounding the UA. TGF uses dynamic flight models, preset flight plans, and aircraft performance characteristics to dynamically display aircraft with realistic climb, descent, and turn rates.

Real-Time Tracking Surveillance Software (RTTS)

Real Time Tracking Surveillance (RTTS) software is capable of displaying real-time or recorded surveillance data. RTTS was used to display information from the TGF on the traffic display used in the study. This traffic display was referred to as the unmanned aircraft traffic display (UATD).

Unmanned Aircraft Traffic Display

We used a customized version of the UATD to provide information about the ownship and surrounding traffic on a 19” monitor adjacent to each control station’s flight displays. The display includes a minimum set of information as identified by Rein et al.

(2013) plus additional symbology (CPA, banding, or blobs) depending on the display condition. The UATD allowed pilots to toggle the traffic display range between 5, 10, and 15 nm.

Audio and Video Recording

Both audio and video recordings were produced using ceiling-mounted cameras that provided a view of the pilot and UA controls and displays and a microphone to capture any communications between the pilot and researchers.

We used the following equipment to record pilot audio/visuals:

- Sennheiser ME64 - Cardioid Condenser Microphone Capsule
- Canon VB-H43 Network Dome Camera
- Sierra Video Video/Audio Router

The NIEC laboratory engineers mounted the video cameras on the ceiling behind the participant to provide a view of the pilot workstation displays and controls. We recorded all of the scenarios so that we could review any events that we had questions about during data analysis as needed.

We used the following equipment to record control station displays:

- Techsource ReVue MG1
- Skysoft-ATM Recording Hardware

We used the following headsets to record the communications between the pilot and one of the researchers who acted as the air traffic controller:

- Plantronics SHS1890 Amplifier with Push-To-Talk Switch
- Plantronics MS260 Headset

Display Configurations

Four display configurations were tested in the study: (1) Baseline display, (2) CPA display, (3) Blob display, and (4) Banding display. Details of these display configurations, along with pictures of each configuration, are provided in Appendix A.

Visual and Auditory Alerts

The DAA system used three levels of alerting for the presence of traffic. When an alert was triggered by the DAIDALUS algorithms, the traffic symbol corresponding to the intruder aircraft would change to one of the three shown in Figure 4, depending on the level of alert that was triggered, and an auditory alert would sound as well using the language in quotation marks under the symbol shown in Figure 4.

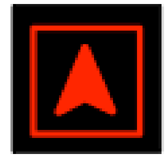
		
Preventive DAA Alert “Traffic, Monitor”	*Corrective DAA Alert “Traffic, Avoid”*	*DAA Warning Alert “Traffic, Manveuver Now Traffic, Maneuver Now”*

Figure 4. Visual and auditory alerts used in the study.

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 in the Participant Instructions (see Appendix A) 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 violate the well-clear area of ownship. 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 DAA Warning Alert both indicated that a loss of well clear would occur if both aircraft remained on their current courses. The main difference between the two was that the Corrective DAA Alert was intended to provide more time for the pilot to make a maneuver than the highest priority DAA Warning 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.

Encounter Geometries

Each simulation (ICOMC2 and Predator) used 32 scenarios that were roughly matched in encounter geometry and the timing of the encounter. Pilots flew four distinct routes, all of which required a 49° turn at an initial waypoint followed by straight flight; two routes had a final bearing northwest and the other two had final bearing northeast. The initial waypoint was reached approximately 40 s into the scenario after pilots had flown 2.0 nmi in the Predator or 0.8 nmi using the ICOMC2. One route included a descent of 2000 ft at the waypoint while the others were level flight. Participants flying the Predator flew at an altitude of 9000 ft on easterly routes (8000 ft on westerly routes), while participants flying the ICOMC2 system flew at 3000 ft on easterly routes (4000 ft on westerly routes).

Table 2. Encounter geometries used in the study.

Encounter	Horizontal Geometry	Vertical Geometry Ownship	Vertical Geometry Intruder
1	Head-on	Level	Level
2	Head-on	Descending	Level
3	Intruder Overtaking	Level	Level
4	Intruder Overtaking	Level	Climbing
5	Crossing	Level	Level
6	Crossing	Level	Level
7	Crossing	Descending	Level
8	Crossing	Level	Descending

There were a total of eight encounter geometries: two per route (see Table 2). Of the eight encounters, two involved a head-on intruder, one of which occurred while ownship was in level flight and the other occurred during ownship descent. The intruder overtook ownship in two encounters while ownship was in level flight; the intruder was also level in one encounter but was climbing in the second. The remaining four encounters featured a crossing intruder: one during ownship descent, one including a descending intruder; both ownship and intruder were in level flight otherwise.

Further variations in the scenarios were generated by altering the position of non-intruder "distractor" aircraft to create four versions of each encounter, thus resulting in 32 different scenarios. Each scenario contained 2-4 distractors, an intruder, and ownship. The mean number of aircraft across scenarios, including ownship, was 5.0.

Materials

Participant Instructions

Participants were presented with an explanation of the purpose of the experiment, descriptions for each of the display types, and details regarding the alerts that would be given. These instructions were originally in the form of a Word document (Appendix A) but were converted to a series of PowerPoint slides for viewing by the participants. 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 included in the PowerPoint presentation. The consent form is shown in Appendix B

Demographics Questionnaire

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

Post-Display Questionnaire

Following the completion of a set of encounters using a particular display type, participants were given a questionnaire. The questionnaire asked about their ability to avoid traffic using that display and collected subjective feedback regarding the display. A copy of the questionnaire is provided in Appendix D.

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 about the maneuver decisions made by the pilots. It also asked the pilots to rank order the display types based on their usefulness in avoiding traffic. A copy of the questionnaire is provided in Appendix E.

Control Station Training Material

Training for the control stations was performed by a subject matter expert (SME) familiar with the operation of the control station being trained. A training briefing was developed for each of the control stations by the SME. Appendix F contains copies of the training briefings for both the Predator and ICOMC2 stations. The training briefings provide insight regarding the relative complexity of the two control station interfaces.

Control Station Procedure Checklists

Prior to running the simulations, the experimenters prepared the simulator for data collection and ensured that it was working properly. In addition, prior to each of the scenario runs, the aircraft needed to be positioned at the appropriate location and altitude dictated by the particular scenario and certain aircraft parameters needed to be adjusted because the ownship started in the air in every scenario. This repositioning and adjustment was accomplished by both the SME and/or the participant under the supervision of the SME. The checklists used for initial setup and scenario setup for both the Predator and ICOMC2 stations are provided in Appendix G.

Experimental Design

The experimental design was a three-factor, full, mixed factorial design with two between-subjects variables and one within-subjects variable. The between-subjects variables were type of flight experience (UAS or manned) and control station interface (Predator or ICOMC2). The within-subjects variable is the traffic display type (baseline, CPA, blob, banding). The order in which the display types were presented to the pilots was partially counterbalanced to control for learning and exposure effects. The counterbalancing that was used ensured that each of the display types occurred twice in each order position (i.e., first second, third, or fourth) within each level of flight experience and control station interface.

Procedure

We collected data from Tuesday to Friday each week from 8 AM to 4:30 PM. Each pilot completed the simulation in one day except for the manned pilots assigned to the Predator B simulator. We allocated more familiarization and training time to the schedule for those participants so that they could learn enough about the more complicated control functions on this simulator to effectively complete the tasks required. The manned pilots assigned to the Predator B simulator completed the simulation in one and one-half days. We collected data from one participant at a time.

After arriving at the facility, the researchers presented the Introductory Briefing (Appendix A) and answered any initial questions that the participants had. Next, the participants read and signed the Informed Consent Statement (Appendix B) and completed the Background Questionnaire (Appendix C). The UAS laboratory engineer then provided familiarization training on the appropriate UAS simulator, and the UAS SME provided specific training on the procedures that would be used during the simulation. The pilot training focused on how to give flight commands to the aircraft, how to deviate from the flight plan to avoid traffic, and how to return the aircraft to the flight plan. Flight command training focused on how to change altitude, heading, and airspeed. The length of familiarization and training depended on whether the participants were manned or unmanned pilots and the simulator to which they were assigned.

The participants completed one or two practice scenarios before beginning the eight test scenarios in each traffic display configuration. These practice scenarios involved only one other aircraft (threat) so that the participant could focus on the aircraft and display information that would be presented in that traffic display configuration. The UAS SME provided control instructions to the participants during those scenarios so that participants could practice executing climb/descend, heading, and speed maneuvers.

After familiarization and training, the participants took a break and then began the first of the four (eight-scenario) test sessions. All traffic scenarios began with the UA already in the air. Each scenario assumed that the aircraft was following an instrument flight plan. Each scenario contained one traffic encounter, maneuver(s) to avoid the traffic, and command(s) to return to course. To increase the difficulty of the encounter, the traffic display did not display any traffic other than ownship until the occurrence of a traffic alert. This prevented the pilot from anticipating a potential avoidance maneuver before the alert. The scenario ended once the aircraft had started its return to course. Depending on the encounter and pilot responses, each scenario lasted from three to six minutes.

The participants completed eight test scenarios for each traffic display configuration. After the last scenario in each display configuration, the participant completed the Post-Display Questionnaire (Appendix D). We provided the questionnaires on a laptop computer adjacent to the UAS control station. One of the researchers ensured that the questionnaires were properly coded with the participant number and appropriate display configuration condition prior to administering it. When the participant completed the questionnaire, a short (10-15 min) break was permitted before beginning the next display configuration condition.

When the participant completed all four of the display configurations, we administered the Post-Study Questionnaire (Appendix E) to obtain feedback about the overall simulation and the participant's rank ordering of the different display configurations. The researchers spent additional time at the completion of the simulation listening to the participant's comments and reactions.

Some of the participants also completed a set of four Exploratory Scenarios after they had completed the formal simulation. We implemented the Exploratory Scenarios only if time allowed. These exploratory scenarios allowed the participants to select any one or more of the UATD options they had experienced during the simulation. They could change the selections during or between scenarios as desired. We included these scenarios to provide some additional insight into which display configuration the participants found most useful. There were no experimental conditions associated with these scenarios, therefore no statistical analyses were performed on these data. Table 3 provides a summary of the simulation schedule.

Table 3. Simulation schedule.

Length	Event
45 min.	Introductory Briefing, Demographics Questionnaire, Informed Consent Statement
1-3 hrs.	Familiarization & Training
15 min. (30 min.)	Questions & Break or (Lunch Break)
1 hr.	Test Session1 & Questionnaire
1 hr.	Test Session 2 & Questionnaire
1 hr.	Test Session 3 & Questionnaire
1 hr.	Test Session 4 & Questionnaire
30 min.	Final Questionnaire
30 min.	Exploratory Scenarios *

*Exploratory scenarios were only completed if time allowed.

RESULTS

Demographics

Recruiting of the participants was performed by an independent contractor based on requirements established by the researchers. When we began analyzing the demographic data from this study, one unexpected finding that became immediately clear was that our group of manned aircraft pilots was much older than the group of unmanned aircraft pilots. Table 4 presents the demographic summary statistics for the participants.

Table 4. Participant demographic summary statistics.

Group	Mean Age (yrs.) (Median)	Age Ranges	Mean Total Flight Hours (Median)	Mean TCAS Experience (yrs)
Unmanned	35 (35)	29-46	2037.7 (1595)	5.8
Manned	51.2 (55)	34-77	12344.6 (9450)	17.6

As can be seen in the table, the mean age for the manned pilots was approximately 16 years older than the unmanned pilots. In addition, and most likely because of this, the number of total flight hours for these groups was drastically different as well. All but two of the unmanned pilots had an IFR rating and all of them had training in manned aircraft. In regard to experience with TCAS, 13 of the 16 (81%) unmanned pilots claimed they had experience with TCAS, while 14 of 16 (87.5%) manned pilots had TCAS experience. When asked about their level of familiarity with TCAS, 15 of the 16 (94%) manned pilots claimed they were "very familiar" or "expert" with TCAS, but only 7 of 16 (44%) of the unmanned pilots made the same claim. Seven of the manned pilots had experience with an ADS-B traffic display, but none of the unmanned pilots did. When asked if they had actually had to maneuver to avoid traffic (in real life), 12 of the 16 (75%) unmanned pilots responded "yes," and 15 of the 16 (94%) manned pilots responded "yes."

Violating Well Clear

Analysis of Well Clear Violations

Figure 5 presents the mean number of well clear violations as a factor of display type. Analysis of the well clear violations showed a significant effect due to display type, $F(3, 78) = 3.465$, $p = .02$. No other main effects or interactions were found in the analysis of well clear violations. Individual comparisons revealed that both the blob display, $t(31) = 3.66$, $p = .0005$, and banding display, $t(31) = 1.80$, $p = .04$, significantly decreased the likelihood of violating well clear relative to the baseline display. The CPA display was not significantly different from the baseline display, $t(31) = .61$, $p = .27$.

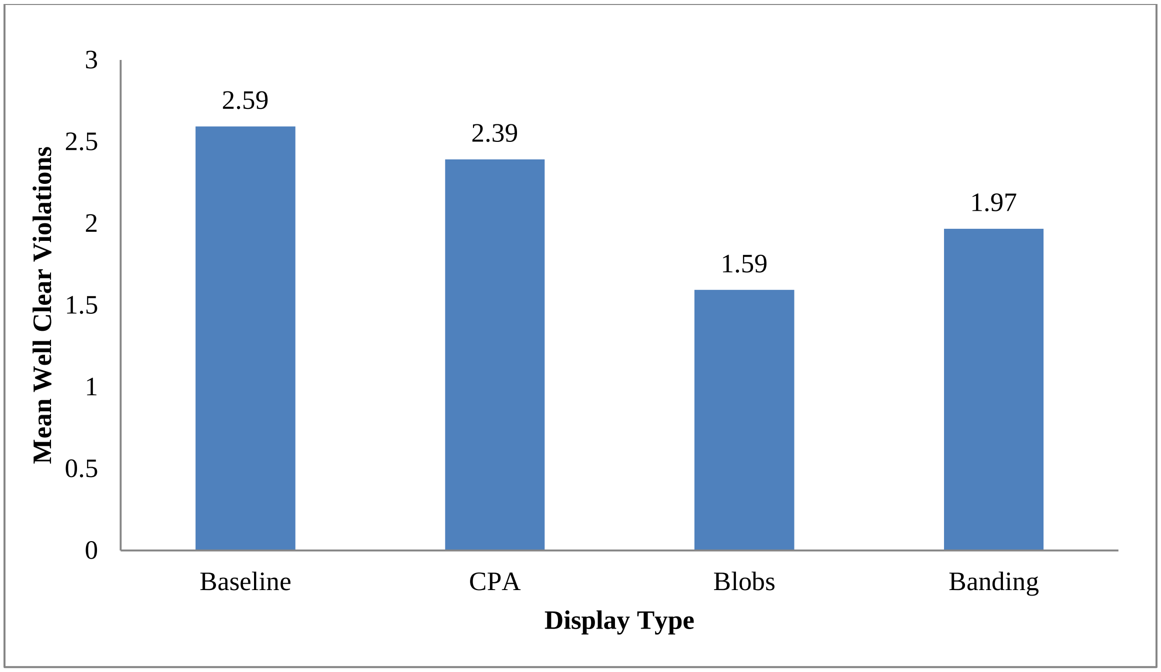


Figure 5. Mean well clear violations by display type.

Figure 6 presents the mean well clear violations across display types separated by pilot type.

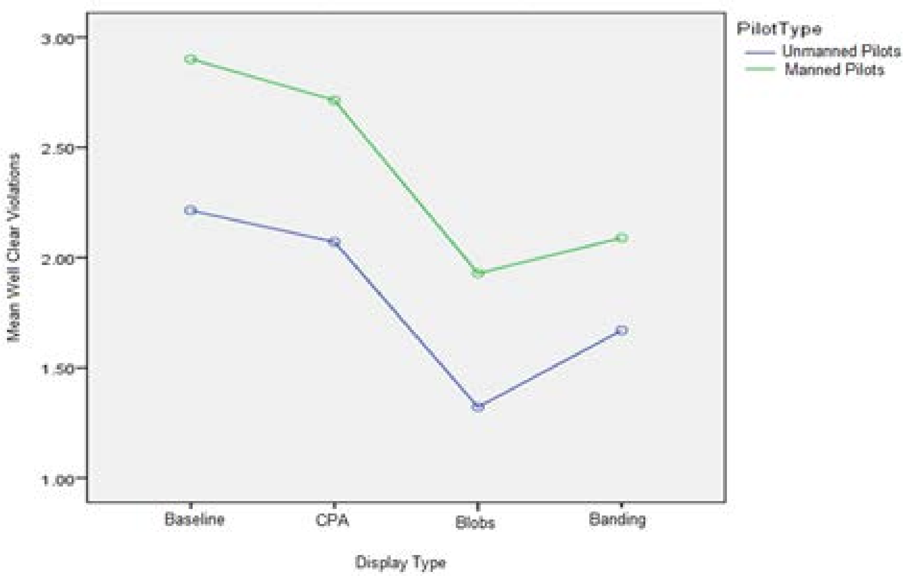


Figure 6. Mean well clear violations across display type by pilot type.

Looking at the figure, the green (top) line is the mean well clear violations for manned aircraft pilots across display type and the blue line (bottom) is the mean well clear violations for the unmanned pilots across display type. Overall, the pattern of well clear violations for both pilot types is nearly identical to the overall findings shown in Figure 5 with the baseline display having the most well clear violations, followed by the CPA display, banding display, and the blob display having the fewest number of well clear violations. While performance between UAS and manned pilots was not significantly different, $F(1,26) = 3.616$, $p = .068$, both pilot groups responded similarly across display configurations in regard to avoiding well clear violations.

To look at the effect of encounter complexity on well clear violations, we compared the percentage of well clear violations for each level of alert that was first provided to the pilot. As discussed in the introduction, specific encounter geometries, along with ownship or intruder maneuvers, could result in the pilot receiving an alert later than what was intended with the timing parameters employed by the algorithms. Thus, some traffic encounters began with the lowest-level preventive alert, some with the mid-level corrective alert, and some with the highest level warning alert. Results showed that the probability of a well clear violation was highest if the first alert was a warning alert (*"Traffic, Manveuver Now Traffic, Maneuver Now")*. Out of 224 encounters where the first alert was a warning alert, 148 (66%) resulted in a well clear violation. Encounters that began with a corrective level alert had a probability of only 13.67% (79 of 578) of a well clear violation and encounters that began with a preventive level alert had a probability of 20.39% (42 of 206) of a well clear violation.

The connection between the probability of a well clear violation and the amount of time available to maneuver can be seen even more clearly by looking at the time to closest point of approach of the intruder aircraft to ownship when an alert is first provided to the pilot. The encounters were separated into bins based on the time to closest point of approach at first alert. For comparison purposes, the bin time parameters were based on the previous work of Santiago and Meuller (2015). Figure 7 shows the proportion of encounters where well clear violations occurred by time to closest point of approach when the first traffic alert was provided. Figure 8 provides comparison data from Santiago and Meuller (2015).

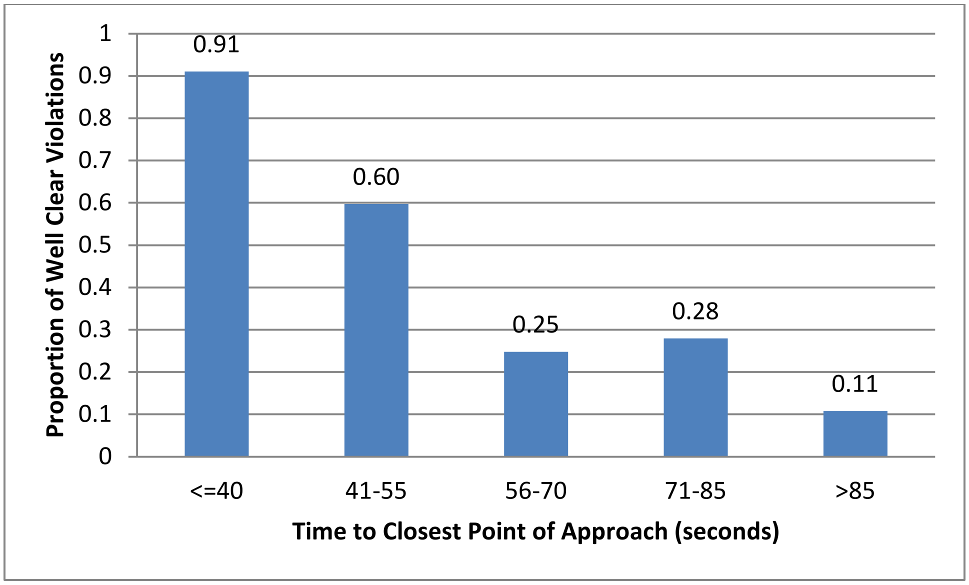


Figure 7. Proportion of encounters where well clear violations occured by time to closest point of approach when the first traffic alert was provided.

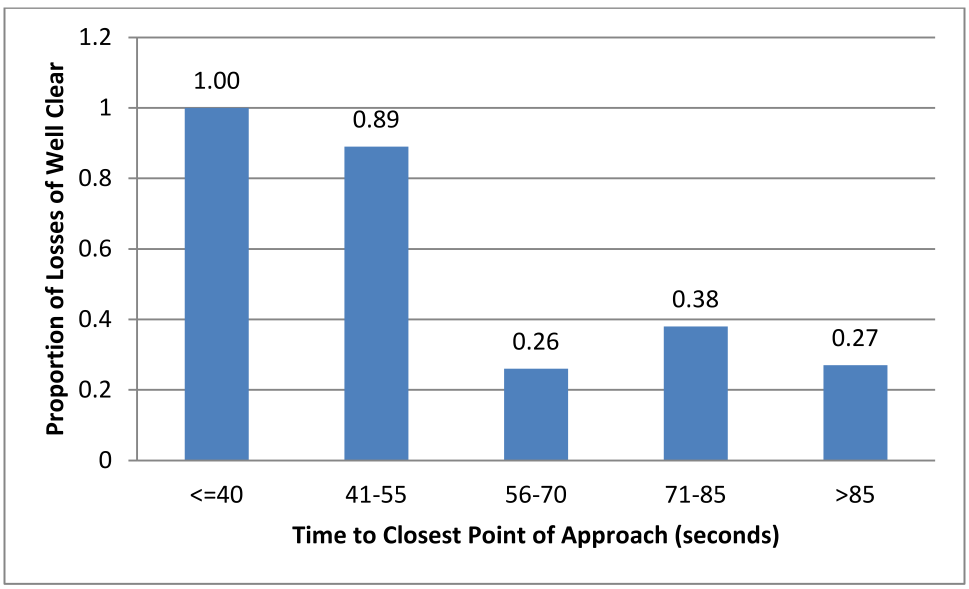


Figure 8. Data from Santiago and Meuller (2015) reprinted with permission.

Looking at the figures, we see both sets of data reveal similar responses to the effect of time to CPA on the proportion of well clear violations. It is interesting to note that, although there might be an expectation that more time to react would lead to smaller proportions of well clear violations, this was not what was found. For both data sets, there was an increase in well clear violations at the 71-85 second time frame. Discussions with NASA scientists (Lisa Fern, personal communication) suggested that post-test analysis of well clear violation causal factors showed that there was a tendency for their pilots to turn back toward the flight path prematurely and that this might account for the spike in violations during that time frame. Unfortunately, an analysis of causal factors was not completed with our data so we were unable to verify if this occurred in our study as well.

Analysis of Post-Display Questionnaire Data

Two items from the post-display questionnaire (Appendix D) that were relevant to the analysis of the well clear violations were subjective ratings of the complexity of the encounters (Question 3) and subjective estimates of the number of losses of separation (well clear violations) that occurred using each display type (Question 4). The response scale for the complexity question was a five-point scale with the responses as follows: (1) Very easy to detect and resolve, (2) Somewhat easy to detect and resolve, (3) Neither easy nor difficult to detect and resolve, (4) Somewhat difficult to detect and resolve, and (5) Very difficult to detect and resolve. Figures 9a-d shows the number of responses for each point in the scale for each display condition.

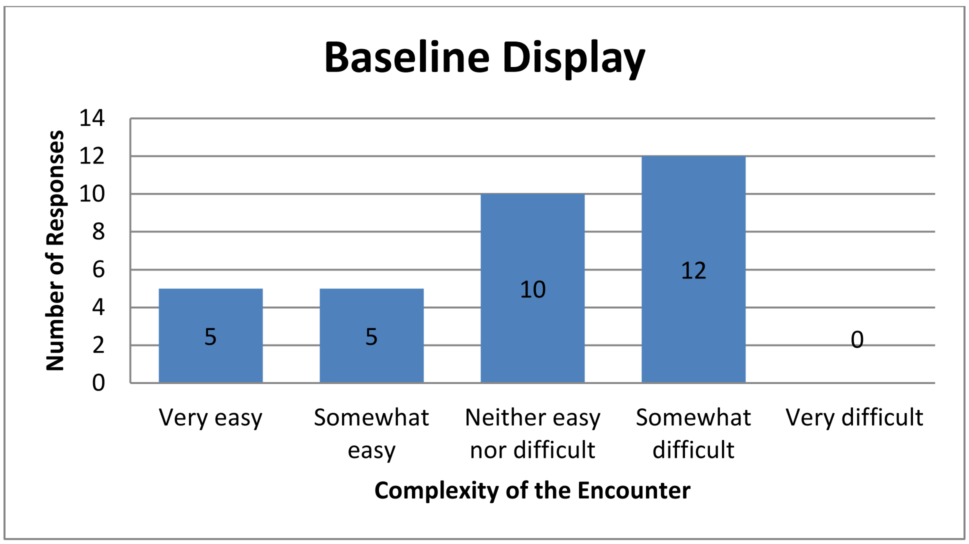


Figure 9a

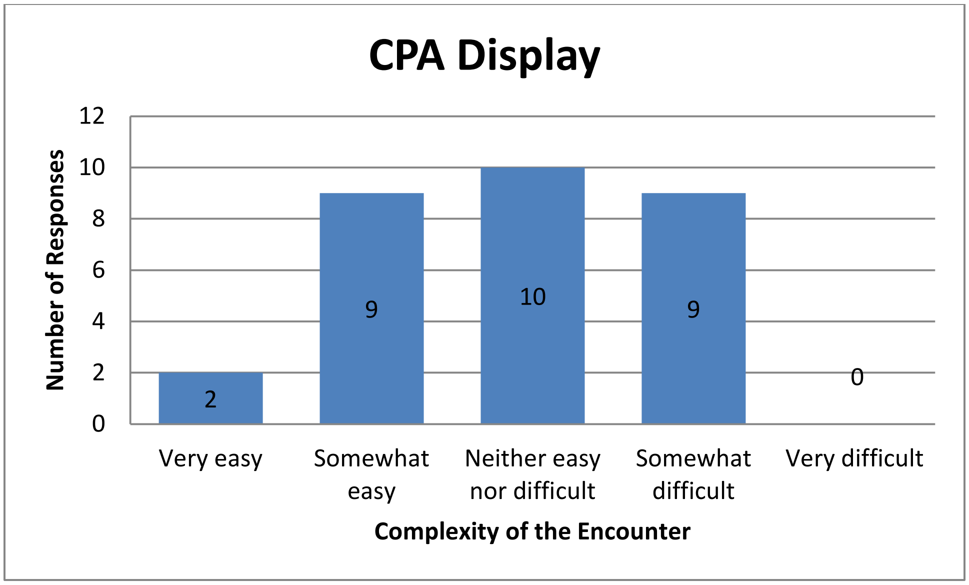


Figure 9b

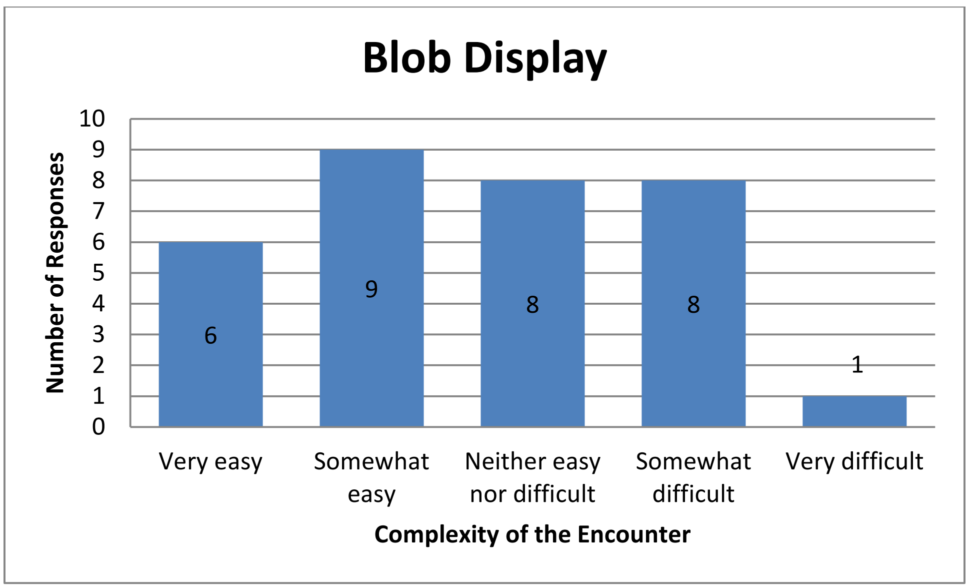


Figure 9c

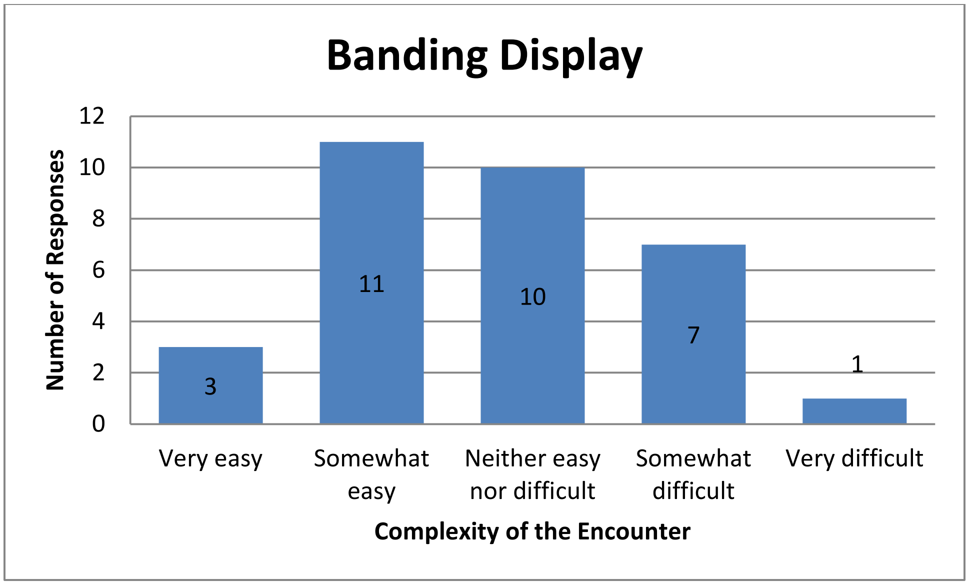


Figure 9a-d. Number of responses for each scale item for the request, “Rate the complexity of the encounters in this session.”

Looking at Figures 9a-d, we see that, for all of the display conditions, the majority of participants did not rate the encounters as either very easy or very difficult but somewhere in the middle of those two responses. Converting the responses to their corresponding numbers, the mean response across all display conditions was 2.79. Separating out the responses by display type, we found that the encounters using the baseline display were scored as the most complex on average (2.91), followed by the CPA display (2.87), banding display (2.75), and then the blob display (2.66). Given that the encounters were constructed to be equivalent across display conditions, we can attribute the differences in these subjective estimates primarily to differences in the information content provided by the displays.

For the subjective estimates of the number of well clear violations, we found that the participant’s estimates of the number of violations were very conservative relative to the actual number of well clear violations. The number of estimated violations across all participants was 169, while the actual number of well clear violations was 269 across all of the encounters (1008). Figure 10 shows the mean number of estimated violations for each display type alongside the mean number of actual violations.

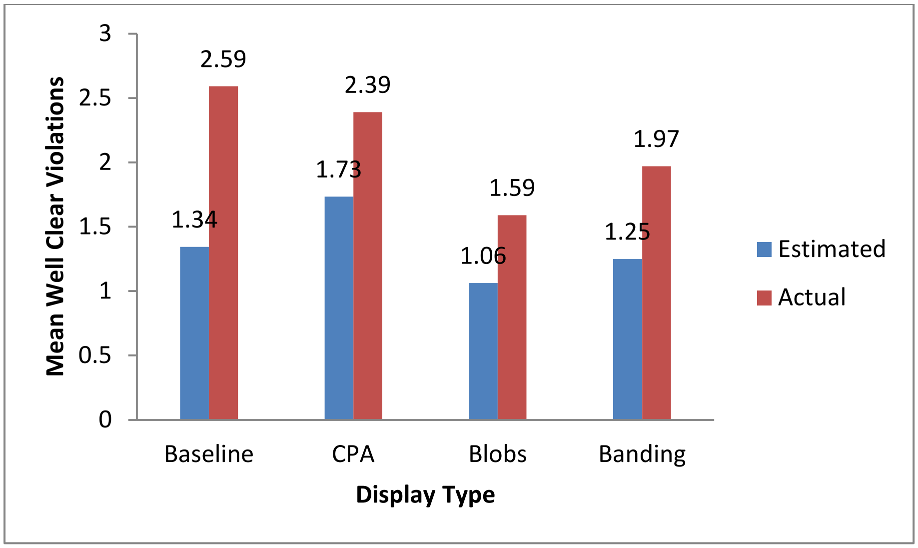


Figure 10. Mean number of estimated vs. actual well clear violations for all participants by display type.

Despite underestimating the number of violations, we find a rough correspondence between the estimated and actual violations across display types. The one exception is the baseline display condition where the number of estimated violations (43) was close to half of the number of actual well clear violations (83). This is probably due to the fact that, unlike the other three display configurations, the baseline display provides no information to the pilot regarding whether a well clear violation has occurred. While pilots were given an approximate description of what constituted a well clear violation (closer than 4000 feet horizontally, or 450 feet vertically), the actual definition is much more complicated as it is based on current airspeed and altitude, as well as distance. Even with the approximate description, the baseline display would not indicate precisely when the closest point of approach to another aircraft was less than 4000 feet, nor would it show vertical distances at less than 100 foot units.

Severity of Loss of Well Clear (SLoWC)

In addition to the number of well clear violations, we also analyzed the severity of loss of well clear (SLoWC, pronounced "slow C"). The 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. 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). Analysis of the SLoWC data did not reveal a significant result due to display type. However, there was a main effect of pilot type on the SLoWC metric, $F(1, 26) = 7.681$, $p = .01$. That is, unmanned aircraft pilots had lower

SLoWC scores than the manned aircraft pilots. Table 5 presents the mean SLoWC values across display type by pilot type.

Table 5. Mean Severity of Loss of Well Clear (SLoWC) across display type by pilot type.

Pilot Type	Baseline	CPA	Blobs	Banding
Overall	6.49	7.17	4.60	5.92
Manned	7.85	8.58	5.58	6.47
Unmanned	4.63	5.70	3.77	4.79

As can be seen in the table, the effect appeared across all display types. The relatively low numbers indicated in the table are primarily due to the fact that only about 27% of the encounters resulted in a well clear violation. 73% of the encounters were scored as 0 (zero) by the metric. No other main effects or interactions were found.

Lester et al. (2016) identify a SLoWC score of 71.9 or higher as the theoretical lowest value indicative of a near mid-air collision (NMAC). Based on this value, four of the 1008 (0.4%) encounters resulted in a NMAC. Three of these encounters were produced by manned aircraft pilots and one by an unmanned aircraft pilot.

As with well clear violations, the severity of loss of well clear was strongly influenced by the time provided to the pilot to perform a maneuver, which was evidenced by the level of first alert that was provided. To look at this effect, we performed an analysis of variance on the SLoWC mean scores across each level of alert (preventive, corrective, warning). The analysis of variance (ANOVA) was a (3 x 2 x 2) mixed model ANOVA with level of alert (3) as a within factor and control station type (2) and pilot type (2) as between factors. Unlike the first analysis of SLoWC scores across display types, the mean SLoWC scores for this analysis were computed only using scores when well clear was violated, except when there were no violations for a particular alert level for that participant, in which case a score of zero was assigned. Figure 11 shows the mean SLoWC scores across alert levels, separated by type of control station and pilot type.

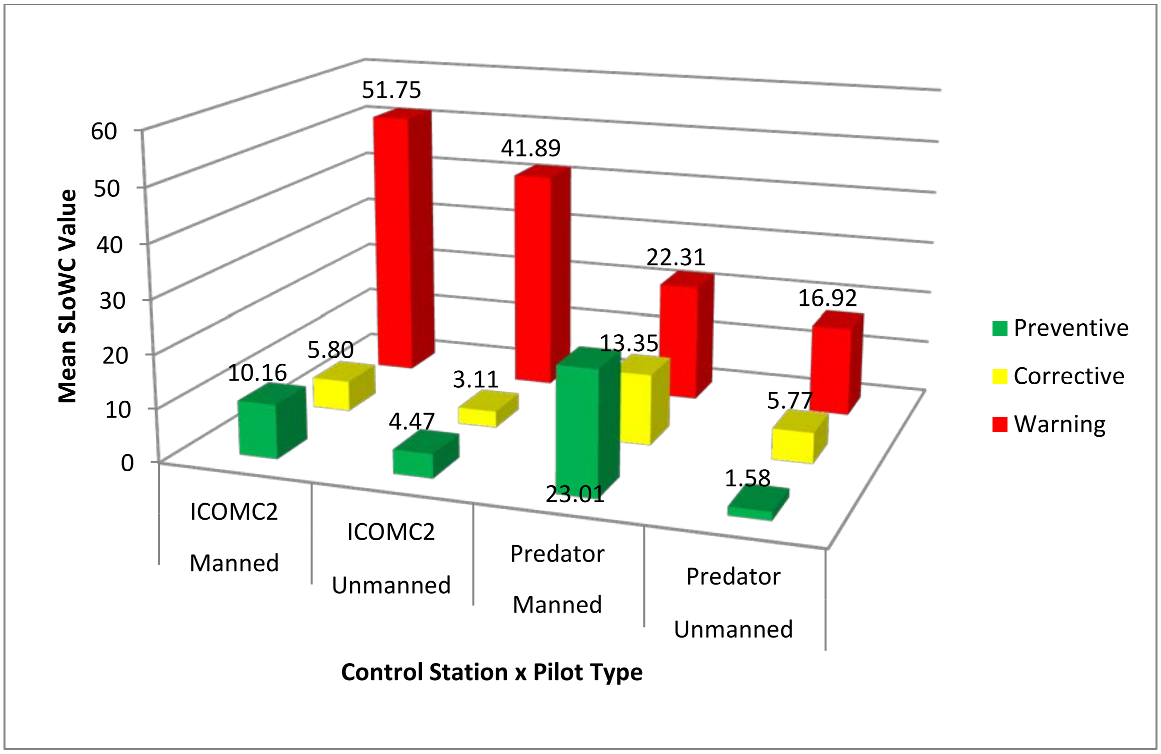


Figure 11. Mean SLoWC scores across level of first alert, separated by type of control station and pilot type.

The ANOVA revealed a significant effect of level of alert on the severity of loss of well clear, $F(2,56) = 66.157$, $p < 0.001$, which can be easily seen in Figure 10, showing that the SLoWC values were significantly higher when the first alert was a warning (m = 33.22) than when the first alert was a corrective (m = 7.01) or a preventive (m = 9.81). In addition to this main effect, there was also a significant interaction with alert level and the type of control station, $F(2, 56) = 27.673$, $p < 0.001$. This can also be seen in the figure by noting the dramatically lower values for the warning alert using the Predator station than when using the ICOMC2 station as well as the relatively higher SLoWC values for both the corrective and preventive alerts using the Predator station compared to the ICOMC2 station. A reason for this interaction is unclear, but rather than being differences between the two user interfaces, it is possible that differences between encounter timing parameters are responsible. The Integrator model used for the ICOMC2 station was much slower than the Predator model. This affected when alerts occurred and how much time pilots had to react to the alerts.

In addition to these effects, there was also a main effect for both the control station type, $F(1, 28) = 7.955$, $p = 0.009$, and the pilot type, $F(1, 28) = 18.813$, $p < 0.001$. The effect of control station type is attributable to the much larger SLoWC values for warning level alerts using the ICOMC2 station, while the main effect for pilot type matches the first SLoWC analysis, showing higher SLoWC values for the manned pilots relative to the unmanned pilots across all levels of alert.

Display Preferences

Figure 12 summarizes the responses to seven questions from the post-display questionnaire. All of the questions dealt with the perceived utility of the display along several dimensions. These dimensions were subjective measures of: (1) the ability to maintain separation from an intruder, (2) the ability to minimize deviations from the flight path, (3) ease of use, (4) ease of understanding, (5) the ability to predict a loss of separation from an intruder, (6) the ability to select an avoidance maneuver, and (7) the amount of trust in the accuracy of the information. On all dimensions, higher numbers represent a more favorable response. Complete questions and response options can be found in Appendix D. Looking at the figure, the gray bars represent the proportion of responses (1-5) for that particular question for each display type. The black triangle indicates the median response value, and the dots indicate model predictions and predicted certainty for each response.

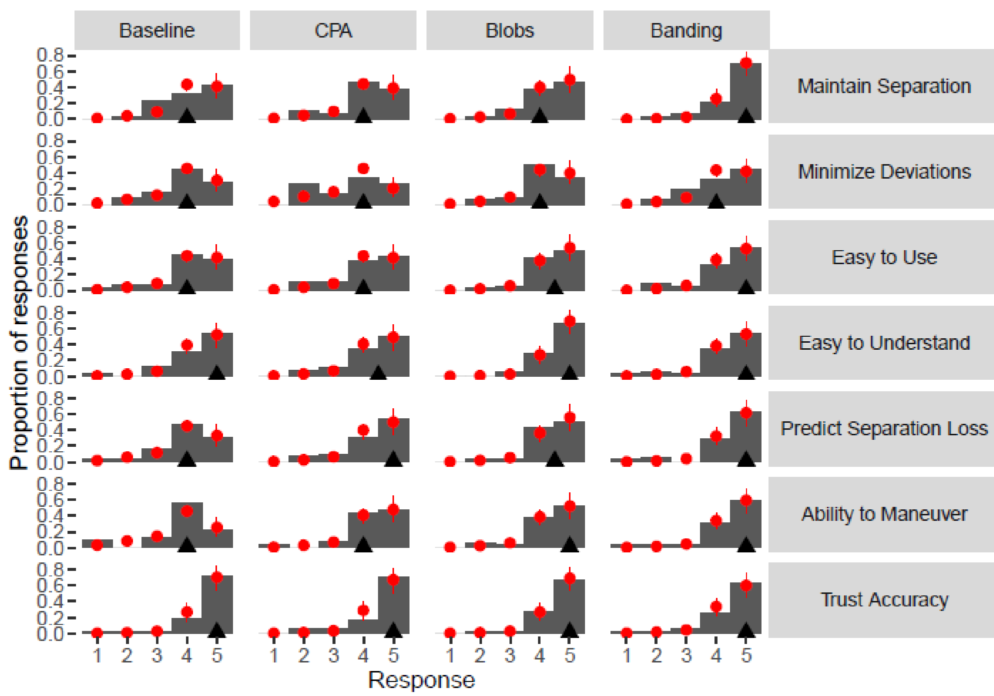


Figure 12. Summary of questions 1-2 and 5-9 from the post-display questionnaire.

To measure the effect of display type on these responses, we looked at the β_{uatd} values for each display type. The Bayesian modeling approach used here doesn't simply provide a point estimate of these coefficients but, instead, produces a distribution of credible values. Figure 13 presents these distributions with the 95% highest density interval (HDI) highlighted in red. Results show that responses to the questions were reliably higher (more favorable) for the blob and banding displays relative to the baseline and CPA displays.

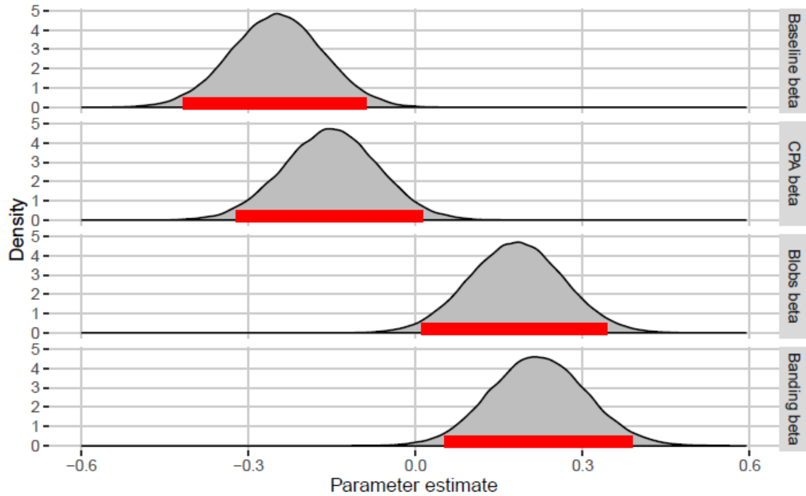


Figure 13. Probability distribution of the combination of questions 1-2, 5-9 from the post-display questionnaire for each display type.

One of the end-of-study questions asked the participants to rank order the displays from best to worst. Figure 14 shows the mean ranking of each display type. A lower number indicates a better ranking. Looking at the figure, we see that the Blob display was ranked best on average, followed by banding, CPA, then baseline. This pattern matches the actual (as opposed to the estimated) well clear violation data results (Figure 10).

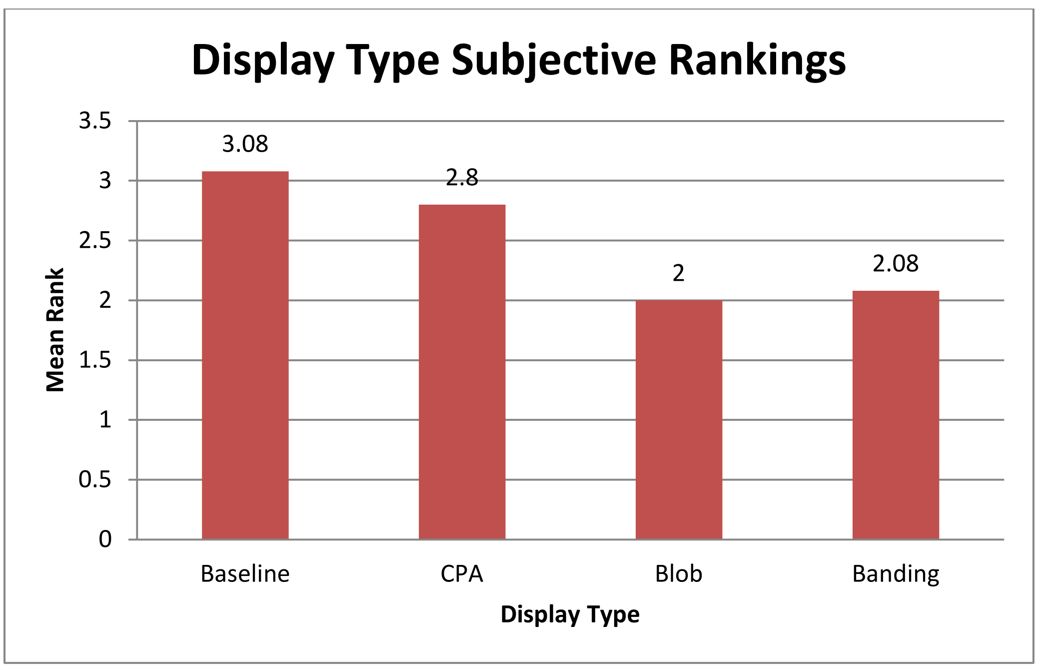


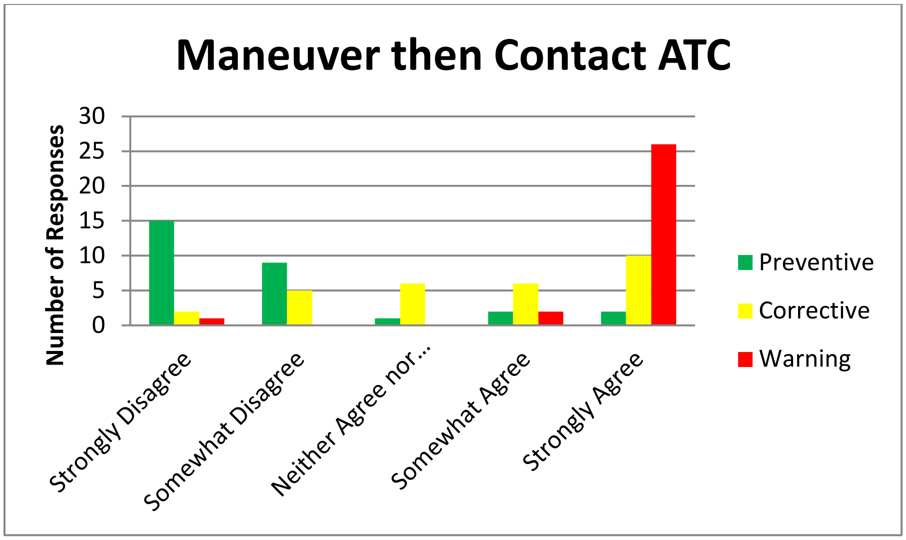
Figure 14. Mean subjective ranking for each display type.

After each of the display configurations, participants were asked if they felt they had received enough training with that particular display configuration to operate safely during that set of encounters. For 94% of the responses (116 of 123), participants either agreed or strongly agreed they had received sufficient training, with the large majority (102 out of 116, 88%) strongly agreeing.

Understanding Alerts

To gauge how well the participants understood both the auditory and visual alerts that were provided, seven items were included in the Post-Study Questionnaire (Appendix E). For item 1, the majority of participants agreed to some extent that the aircraft icons used for the alert levels were easy to understand: Preventive Alert (24 of 30, 80%); Corrective Alert (24 of 29, 82.8%); Warning Alert (29 of 29, 100%).

Items 2 and 3 were concerned with whether the pilot would be likely to contact ATC before the maneuver (item 2), or after the maneuver (item 3). Figure 15 shows how participants responded to these two items.



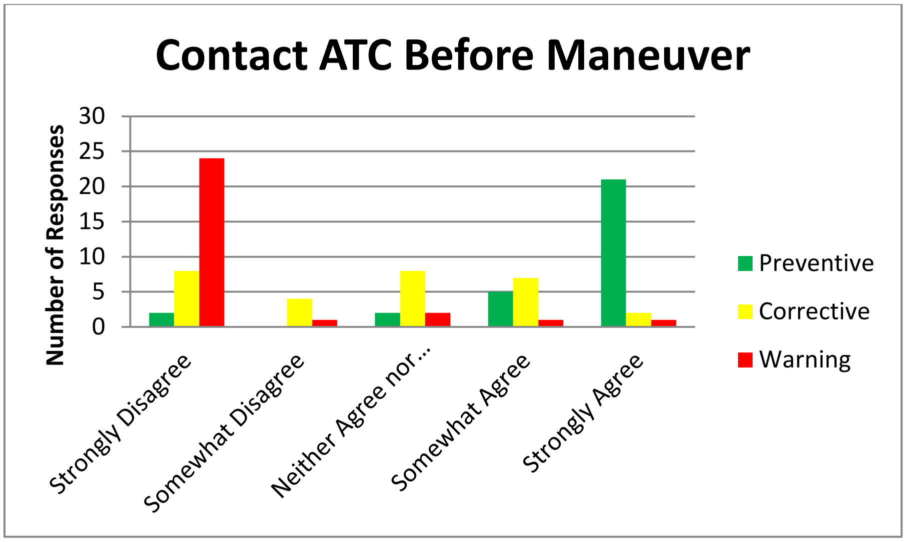


Figure 15. Response patterns for how alert type should determine when to contact ATC.

Given the fact that a preventive alert does not require a maneuver at all, these could be considered trick questions for this alert level. However, because all of the encounters required a maneuver, it was decided to review the pilot post-test responses to see how they were influenced by the encounters. As can be seen in the figure, the majority of respondents thought that ATC should be contacted prior to a maneuver given a preventive alert but after the maneuver for a warning alert. For the corrective alert, the results are not as clear, with 16 of 29 (55%) agreeing that one should maneuver first and 12 of 29 (41%) disagreeing they should contact ATC before a maneuver. One would expect that these percentages would be the same. These results suggest that there may be some indecision for pilots when receiving a corrective alert about whether to contact ATC before or after maneuvering.

Item 4 asked participants to agree or disagree with the statement that a particular alert level indicated an eventual loss of separation (well clear violation) 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 all of the participants agreed that a warning alert would lead to a loss of separation, and 29 of 30 (97%) respondents agreed that a corrective alert indicated an eventual loss of separation, but there was confusion regarding the preventive alert. Eighteen of 30 respondents (60%) believed that the preventive alert indicated an eventual loss of separation, which was technically incorrect. However, again, all traffic encounters included in the study would have resulted in a potential loss of separation had pilots not maneuvered appropriately.

Items 5 and 6 dealt with the auditory alerts that were issued. Item 5 asked how much they agreed with the statement that the alerts were distinguishable from each other. A large majority of respondents (26 of 30, 87%) agreed that the warning alert was distinguishable, but there was less agreement with the preventive (17 of 29, 59%) and corrective (18 of 30, 60%) alerts. Item 6 asked for the level of agreement that the alerts were useful for maintaining separation. Again, the warning alert garnered the largest percentage of agreement (28 of 30, 93%), but less agreement for the preventive (22 of 29, 76%) and corrective (22 of 29, 76%) alerts.

Item 7 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 respondents believed the timing to be appropriate: Preventive (20 of 29, 69%); Corrective (21 of 30, 70%); and Warning (19 of 30, 63%). Most of the responses that indicated something other than "appropriate" showed that the timing was "somewhat late" or "too late" for all of the alerts.

Avoidance Maneuvers

The post-study questionnaire contained three questions about the pilot's maneuver preferences (items 10-12, Appendix E). For each of the three maneuver possibilities, horizontal, vertical, or airspeed change, pilots were asked which factors had an influence on the decision to select that particular maneuver. The factors listed were (a) flight plan profile (b) whether or not ownship was turning, (c) whether or not ownship was climbing or descending, (d) whether or not the intruder was turning, (e) whether or not the intruder was climbing or descending, (f) encounter geometry, (g) uncertainty, or (h) other. In addition, participants could indicate that there were no factors that influenced their maneuver selection or they could indicate that the particular maneuver type (horizontal, maneuver, or airspeed change) was never selected.

Results showed that all of the participants who responded (30) used both horizontal and vertical maneuvers to avoid traffic, but only 19 of the 30 (63%) used an airspeed change. Of the 11 respondents that indicated they did not use an airspeed change, 9 were manned pilots and only 2 were unmanned pilots. In addition, of these 9 manned pilots, 6 of them were using the Predator control station and 3 were using the ICOMC2 control station. Of the 2 unmanned pilots that did not use an airspeed change maneuver, 1 was a Predator pilot using the Predator control station and the other was a Global Hawk pilot using the ICOMC2 control station. All of the respondents indicated that at least one of the listed factors influenced their maneuver decisions.

The largest influencing factor for airspeed changes was encounter geometry (15 of 30, 50%). Whether the intruder was climbing or descending was second (8 of 30, 27%) and the remaining listed factors were cited by 2 to 6 of the respondents. The only “Other” factor mentioned was that, for the ICOMC2, changing airspeed had a significant effect on vertical speed of the aircraft (1 citation).

For horizontal maneuvers, the two influencing factors cited most often were whether or not the intruder was climbing or descending (22 of 30, 73%) and the encounter geometry (22 of 30, 73%). Half of the respondents indicated that whether or not the intruder was turning was an influencing factor (15 of 30, 50%). All of the remaining listed factors were indicated as being influential for 6 to 11 of the respondents. “Other” factors that were cited were the presence of other traffic in the area (3 citations), ownship aircraft performance (ICOMC2, 1 citation), the ease of performing a horizontal maneuver despite taking longer to execute (ICOMC2, 1 citation), and the recommendations of the traffic display (in particular, the blob display provided only horizontal maneuver information, 1 citation).

Vertical maneuvers were influenced most strongly by the encounter geometry (21 of 30, 70%) and, secondly, by whether or not either the intruder or ownship was climbing or descending (both 20 of 30, 67%). Again, half of the respondents indicated that whether or not the intruder was turning was an influencing factor (15 of 30, 50%). The rest of the listed factors were indicated as influential for 7 to 11 of the respondents. “Other” factors cited were the presence of other traffic (2 citations), the decreased likelihood of colliding with another aircraft when making a vertical as opposed to horizontal maneuver (1 citation), and the fact that vertical maneuvers could be executed faster (ICOMC2, 1 citation).

DISCUSSION

When developing a minimum operational performance specification (MOPS) for any new system, the goal is to identify a minimum set of requirements that meets a specified level of safety for that system. When these requirements can be stated in terms of mean-time-between-failures for components of the system or required tensile strength of material, the task is easier than when specifying minimum information requirements. This is because the effect of information on performance is not easy to characterize or measure. Not all information is the same and there can be interactive effects between different kinds of information. For these and other reasons, characterizing how changes in information in a system will affect the performance of that system is unpredictable. Thus, while it might not be possible to identify the absolute minimum level of information required for the DAA traffic display, it has been shown that the addition of particular types of information can significantly improve the performance of the pilot in terms of avoiding well clear violations.

This study replicated the findings of other studies showing the benefits of suggestive maneuver guidance in the form of banding information, in addition to baseline information, for a UAS detect and avoid traffic display. Evidence for these benefits came from both objective and subjective measures. Objectively, use of the banding display resulted in significantly fewer well clear violations compared to the baseline information display. This effect was seen across a more varied population of pilots than have been looked at in previous studies as well as different control station interface designs than were used in previous studies. The pilot sample included both manned and unmanned pilots across a wide range of ages and flight experience levels. This gives strong support for the decision made by the RTCA SC-228 committee to require banding information as part of the minimum requirements.

Subjective measures supporting the banding display included both display preference rankings and usability measures. The usability measures included measures pertinent to a traffic display such as the ability to recognize a potential loss of separation from other aircraft and the ability to minimize a deviation from the flight path, as well as more general display usability measures such as ease of use of the display. Measures of the complexity of the encounters showed that pilots considered the encounters easier to handle when using the banding display as well.

In addition to the banding display, the study also found strong support for a different form of suggestive maneuver guidance implicitly provided in the avoidance area (blob) information. Objective measures of performance suggested that the blob display was as effective as the banding information. Although not a significant difference, the proportion of well clear violations was lower with the blob display than with the banding display. This finding was consistent across pilot types as well. In addition, the severity of loss of well clear was lower on average with the blob display compared to the banding display, although again, this difference was not statistically significant. Subjective measures did not reveal an advantage between the blob and banding displays, although both usability and complexity measures favored the blob display. Further, on all of the subjective measures, there was a statistically significant advantage of both the blob and banding displays relative to the baseline and CPA displays.

The consistency of the advantage of the blob display over the banding display across a range of objective and subjective measures is compelling enough to warrant an explanation. One explanation might be that the avoidance areas provide the pilot with information regarding the urgency of a maneuver in addition to the maneuver guidance provided by banding. Such urgency information might provoke pilots into reacting more quickly under conditions where they might be trying to decide whether to contact ATC before maneuvering. Evidence for this decision-making conflict was provided from the Post-Study Questionnaire questions, which suggested that the pilots were unsure whether to first contact ATC when given a corrective alert. More research is required before recommending urgency information be included in the minimum requirements for these displays.

The relative success of the blob display to the banding display also raises a separate issue regarding traffic display information requirements. While the banding display contained an altitude band on the altitude tape instrument, the blob display only had suggestive guidance for a horizontal maneuver. The only information available for making a vertical avoidance maneuver was the same as was available on the baseline display, which consisted of relative altitude and vertical speed information located next to each traffic symbol.

That the blob display was as effective, if not more so, than the banding display, suggests that the vertical banding information as a form of suggestive guidance is not as useful as horizontal guidance. One likely reason for this is that a vertical maneuver is less complex than a horizontal maneuver (Thomas & Wickens, 2008). Whereas horizontal maneuvers require deciding on a particular heading to use, vertical maneuvers use a commonly utilized change in altitude. For example, in our experiment, most pilots used a 1000 foot altitude change (climb or descent) and rarely anything else. This eliminated a portion of the decision-making task as well as the need for presenting specific altitude choices on the traffic display.

FUTURE RESEARCH

Future efforts should look at whether urgency information has a significant impact on the effectiveness of a traffic display and the need for suggestive guidance for vertical maneuvering. Vertical suggestive guidance, in particular, is relevant for these systems when looking at the integration of TCAS vertical guidance with DAA system guidance. If the vertical suggestive guidance provided by the DAA system has no measurable benefit, there is no need to struggle with the task of integrating that guidance with TCAS directives to climb or descend. This would greatly simplify the specification of minimum information requirements for these systems.

A follow-on experiment is being planned to look at the performance of these displays in full-mission scenarios instead of the 3-6 minute encounters used in the current study. Ideas for manipulations for the study are still being developed. In addition to those mentioned in the previous paragraph, potential manipulations include the following:

- Using Preventive Alerts in both situations where the pilot needs to maneuver to avoid a well clear violation and when no maneuver is necessary if neither aircraft changes course. In the current study, pilots knew that every scenario would lead to a well clear violation once an alert was given and often started maneuvering when the Preventive Alert occurred.
- Whether in full-mission scenarios, pilots contact ATC before, after, or during a maneuver similarly to the manner that occurred during partial mission scenarios.
- Validate how many of the well clear violations are caused by the pilot turning back on course too quickly.

REFERENCES

Bell, S., Drury, J., Estes, S., Reynolds, C. and Jella, C. (2011). *Refining the GBSAA concept and display*. The MITRE Corporation. www.mitre.org

Bell, S., Drury, J., Estes, S., and Reynolds, C. (2012). *GDTI: A ground station display of traffic information for use in sense and avoid operations*. Paper presented at the 31st Digital Avionics Systems Conference, October 14-18, 2012.

Federal Aviation Administration. (2009). *Sense and avoid (SAA) for Unmanned Aircraft Systems (UAS)*. SAA Workshop Final Report.

FAA Sponsored “Sense and Avoid” Workshop (2013). *Sense and Avoid (SAA) for Unmanned Aircraft Systems (UAS)*. Second Caucus Workshop Report.

Fern, L., Rorie, R. C., Pack, J., Shively, R. J., & Draper, M. (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.

Knecht, W.R. (2008). Testing a multidimensional nonveridical aircraft collision avoidance system. *Human Factors, 50*(4), 565-575.

Lester, T., Kay, J., Kunzi, F., Pratt, E., & Smearcheck, S. (2016). *SC-228 closed-loop metrics white paper*. RTCA Special Committee 228 white paper (11 May 2016).

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.

Rantanen, E.M., Wickens, C.D., Xu, X. and Thomas, L.C. (2004). *Developing and validating human factors certification criteria for cockpit displays of traffic information avionics*. Institute of Aviation, Aviation Human Factors Division, University of Illinois at Urbana-Champaign, final report for Federal Aviation Administration Research Grant 02-G-32.

Rein, J.R., Friedman-Berg, F. & Racine, N. (2013*). Information requirements for sense and avoid: High-fidelity human-in-the-loop simulation.* U.S. Department of Transportation, Federal Aviation Administration summary report for UAS Task 12-01a.

Rorie, R.C. & Fern, L. (2014). *UAS measured response: The effect of GCS control mode interfaces on pilot ability to comply with ATC clearances*. Proceedings of the 58th Human Factors and Ergonomics Society Annual Meeting, pp. 64-68.

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, Oct 26-30, 2015.

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, Jan 4–8, 2016.

RTCA (2014). *DO-317B: Minimum operational performance standards (MOPS) for aircraft surveillance applications (ASA) system*. RTCA document #DO-317B.

RTCA (2015). *SC-228 WG#1 Whitepaper: Recommended DAA Display Terminology.* Document posted 3-04-2015 on RTCA SC-228 WG1 website.

RTCA (under review). *DRAFT detect and avoid (DAA) minimum operational performance standards (MOPS) for verification and validation*. RTCA Paper No. 261-15/PMC-1400.

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

Tadema, J., (2011). *Unmanned Aircraft Systems HMI & Automation: Tackling Control, Integrity and Integration Issues*. Maastricht: Shaker Publishing BV, ISBN 978-90-423-0405-5.

Tadema, J., Theunissen, E., and Kirk, K.M. (2010a). Beyond traffic depiction: Conformally integrating the conflict space to support level 3 situation awareness. In *Proceedings of the SPIE Enhanced and Synthetic Vision 2010*, Vol. 7689, 1.1-1.16 Orlando, Florida.

Tadema, J., Theunissen, E. and Kirk, K.M. (2010b). Self separation support for UAS. In *Proceedings of the AIAA Infotech@Aerospace Conference*, Atlanta, GA.

Thomas, L. C., & Rantanen, E.M. (2006). Human factors issues in implementation of advanced aviation technologies: A case of false alerts and cockpit displays of traffic information. *Theoretical Issues of Ergonomics Science*, *76*, 1-25

Thomas, L.C. & Wickens, C.D. (2006). Display dimensionality, conflict geometry, and time pressure effects on conflict detection and resolution performance using cockpit displays of traffic information. *International Journal of Aviation Psychology*, *16*(3), 321-342.

Thomas, L.C. & Wickens, C.D. (2008). Display dimensionality and conflict geometry effects on maneuver preferences for resolving in-flight conflicts. *Human Factors*, *50*(4), 576-588.

Wickens, C.D., Helleberg, J. & Xu, X. (2002). Pilot maneuver choice and workload in free flight. *Human Factors*, *44*(2), 171-188.

Xu, X. & Rantanen, E.M. (2007). Effects of air traffic geometry on pilots' conflict detection with cockpit display of traffic information. *Human Factors*, *49*(3), 358-375.

APPENDIX A

Participant Instructions

Introduction

Welcome, thank you for coming. The purpose of the research study you are participating in today is to assist the FAA in determining display requirements for what is called a Detect and Avoid (DAA) traffic display that will be used in Unmanned Aircraft Systems (UAS) control stations for use by the pilot in remaining separated from other aircraft. It is the responsibility of the FAA to specify a minimum set of information requirements for these displays. These requirements will be used by control station manufacturers when they include these displays as part of their suite of pilot displays within the control station. Your participation today is a vital part of that effort.

During this study, you will be the pilot of an unmanned aircraft which is following a predefined instrument flight plan. You will be receiving training on how to give flight commands to the aircraft, how to deviate from the flight plan path if necessary to avoid traffic, and how to return the aircraft to the flight plan. Each traffic encounter scenario will begin with the aircraft already in the air and will end that way as well, so you will not need to be trained on how to launch and recover the aircraft. In addition, most of the flight will be fairly automated and flight path deviations will be accomplished through an autopilot-like interface so that training requirements for controlling the aircraft are minimized as much as possible.

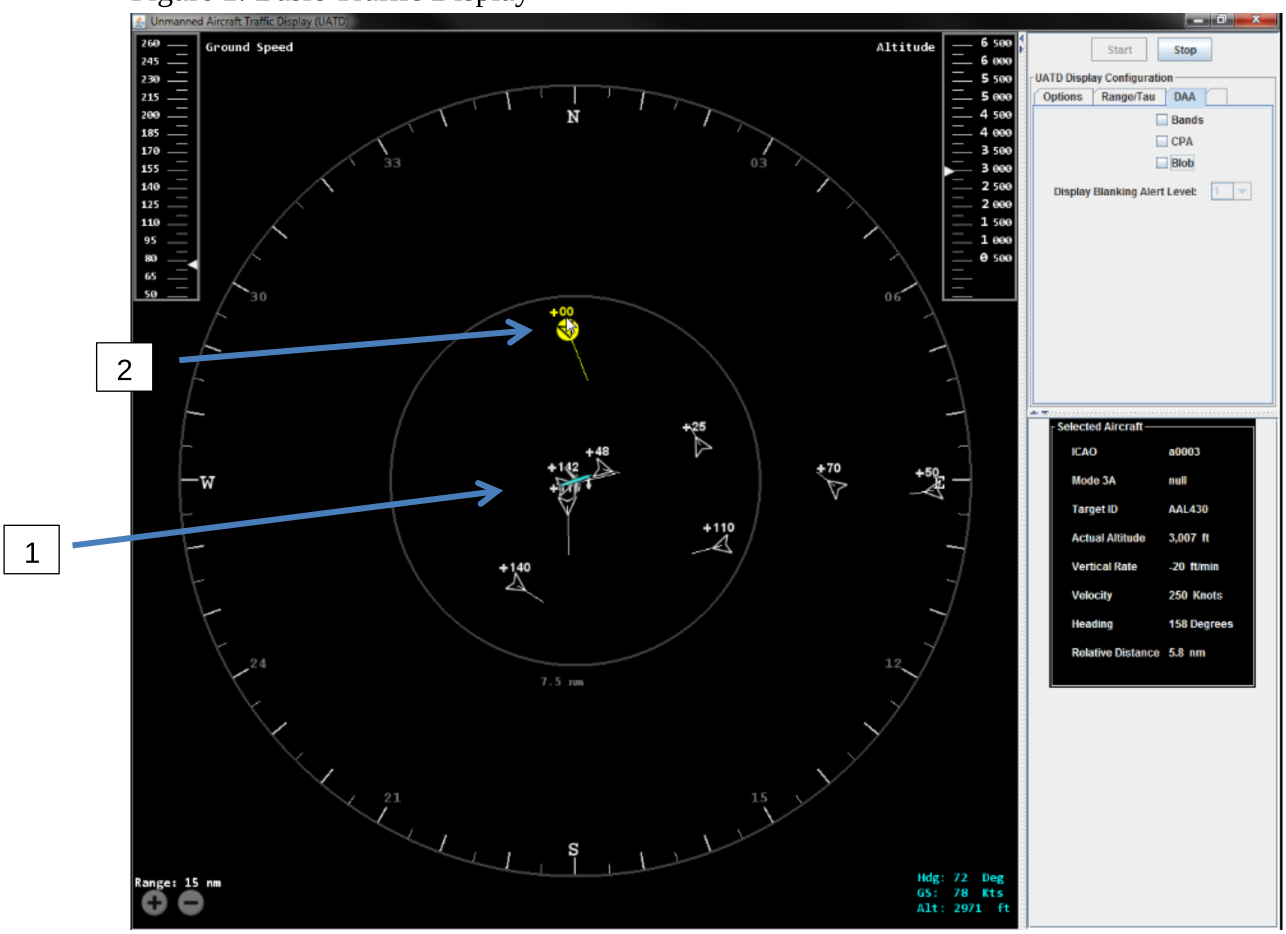
After you have been trained on how to operate your aircraft, we will introduce you to the functioning and symbology of the traffic display and the traffic alerting system. During the study, you will be exposed to four different versions of the traffic display and will fly eight flight scenarios with each version of the display. Each of the scenarios assumes that you are following an instrument flight plan. Deviating from the flight plan requires that you contact air traffic control and request a change in the flight plan. Contacting air traffic control should be accomplished before you maneuver if you have the time to do so, but can be done after you maneuver away from traffic if necessary. Your call sign during the flight will be displayed on the control station and you will be contacting Jacksonville Center for your requests. It is our intent that the traffic encounter scenarios will be challenging to you. One way we are purposely making it more challenging is that the traffic display will be blank until the system provides a traffic alert. The traffic alert includes an aural alert and the lighting up of the traffic display.

After each set of scenarios for a particular display, we will ask you to fill out a questionnaire about that particular display version. After you have flown with all four versions of the display, we will ask you to fill out a separate questionnaire to collect your thoughts about the overall study. We will provide breaks during the day to prevent you from becoming overly fatigued and, of course, for lunch as well. If you have any questions, feel free to ask, otherwise, let us begin your training.

Basic Traffic Display

Figure 1 shows a picture of the basic traffic display used in this study. In the center of the display, the symbol pointed to by box 1 is the ownship symbol. The magenta line running through ownship is the predefined flight plan path. The symbol pointed to by box 2 is a traffic symbol that has triggered a detect and avoid (DAA) alert. The empty white chevron symbols represent other traffic in the area. Next to each traffic symbol is a number that represents the relative altitude of that aircraft to ownship. If the relative altitude number is above the symbol it means that the aircraft is above ownship (unless the number is 00, which means co-altitude). If the relative altitude number is below the symbol it means that the aircraft is below ownship. An up or down arrow next to the symbol indicates the aircraft is climbing or descending at a rate equal to or greater than 500 fpm. The lines extending from the front of the traffic symbols indicate the predicted position of the aircraft in 30 seconds based on its current heading and speed.

Figure 1: Basic Traffic Display



Down at the bottom right of the display are three values showing ownship heading, altitude and speed. The heading is also indicated by the ownship symbol itself. The range of the traffic display is indicated on the bottom left. The display range can be changed by touching the '+' or '-' symbols on the screen. The display range (radius) varies from 5 to

15 nautical miles. The inner circle represents half of the display range. On the outer circle of the display you can see bearing numbers. The numbers are shown every 30 degrees. Larger tick marks appear every 10 degrees and smaller tick marks indicate at 5 degree offset from the larger marks. At the top left and right side of the display are tapes that show the current airspeed and altitude of ownship, respectively. This, of course, is a duplication of the information shown at the bottom right side of the display.

When a traffic alert occurs the traffic symbol changes to one of the three shown in Figure 2. There are three different traffic alerts. 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 violate the well-clear area of ownship. The pilot should monitor the movement of the traffic but does not need to perform any maneuvers to remain well clear. The second level of alert is the Corrective DAA Alert, which is accompanied by the aural alert, “Traffic, Avoid”. A corrective DAA alert indicates that the DAA algorithm has computed a loss of well clear between ownship and the intruder will occur within the next 55 to 75 seconds.

Figure 2: DAA Traffic Alerts

		
Preventive DAA Alert “Traffic, Monitor”	*Corrective DAA Alert “Traffic, Avoid”*	*DAA Warning Alert “Traffic, Manveuver Now Traffic, Maneuver Now”*

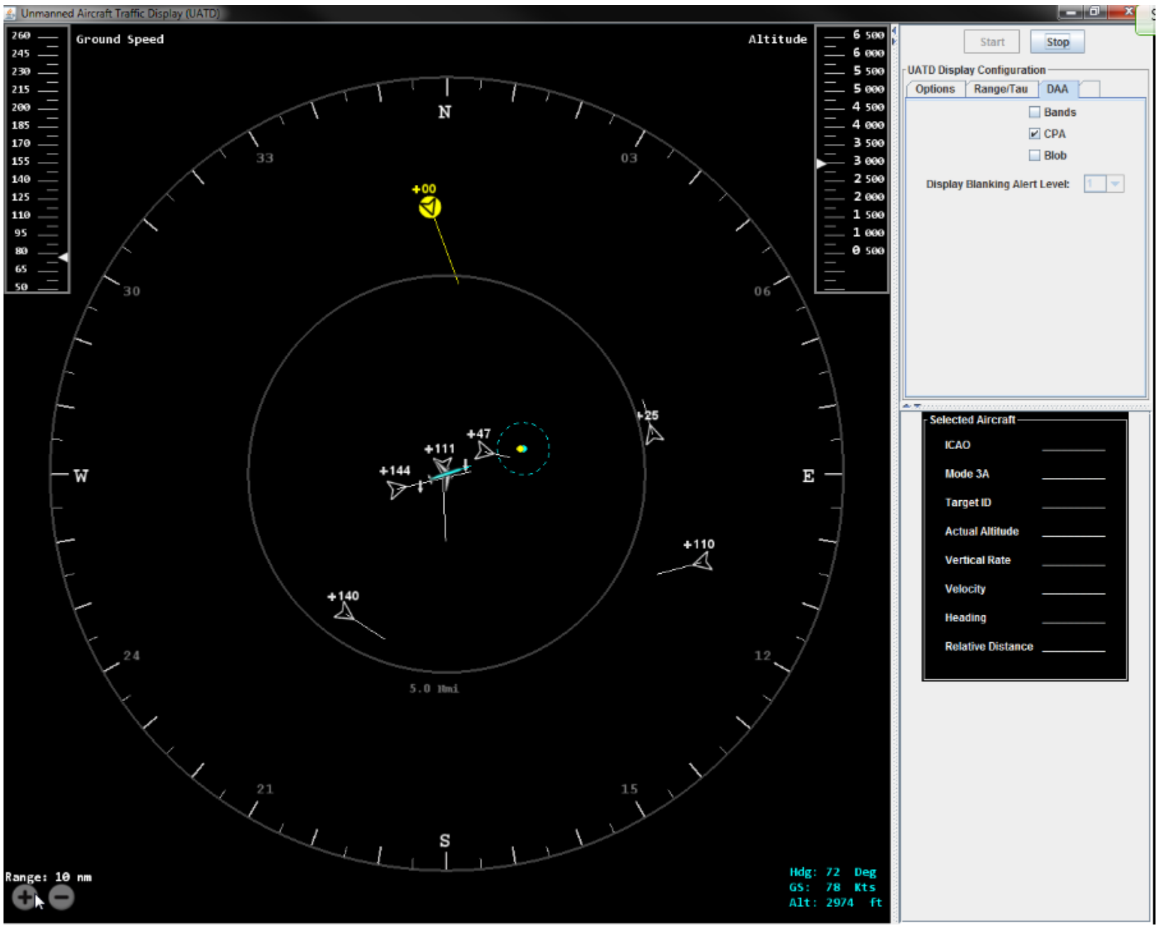
The third alert is the DAA Warning Alert, which is accompanied by the aural alert, “Traffic, Maneuver Now, Traffic, Maneuver Now”. The warning alert indicates that the DAA algorithm has computed that a loss of well clear will occur within the next 25 to 35 seconds. In general, the corrective DAA alert should provide enough time for the pilot to contact ATC before maneuvering away from the flight plan route. However, it is still up to the pilot to make the decision whether to maneuver before or after contacting ATC.

Once an alert is given, the alert will remain for at least 8 seconds, unless it is replaced by a higher level alert. After 8 seconds, the alert will remain until the DAA algorithm determines that a loss of well clear will not occur. If a loss of well clear does occur, the alert symbol will remain until the aircraft attains well clear again. Do you have any questions?

Closest Point of Approach (CPA) Display

Figure 3 shows an example of the CPA display. The CPA display provides all of the same information as the Basic Traffic Display, but in addition provides an indication of where the closest point of approach will be when an aircraft is expected to violate the ownship well clear area.

Figure 3. Closest Point of Approach Display

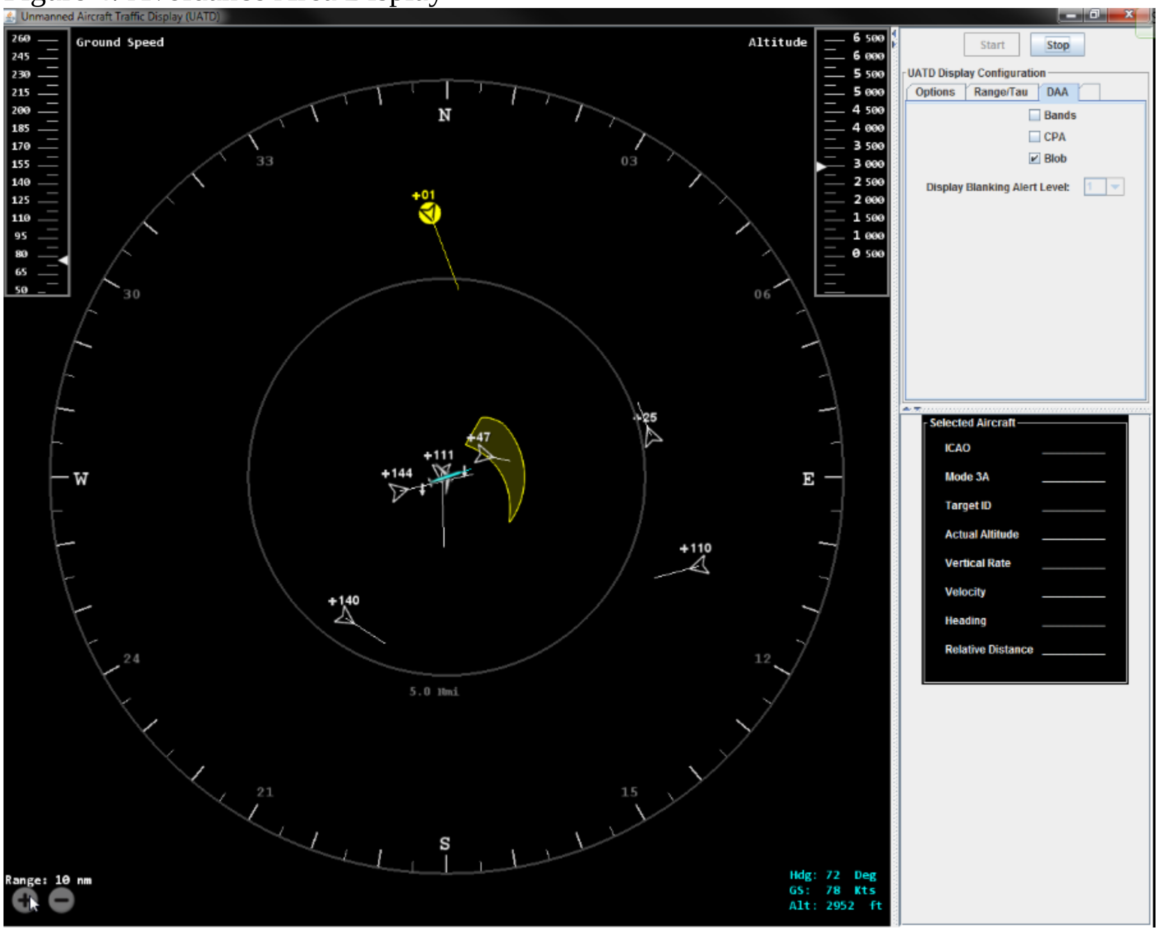


Looking at the figure, you will see a circle drawn with a dotted line. The dot at the center of this circle represents the future position of ownship at the time of closest point of approach by the intruder. The circle itself represents the well clear area around ownship at this future position, and the other dot within the circle represents the CPA of the intruder. The color of the intruder dot will match the symbol of the intruder and will be either yellow or red depending on the level of the alert. The relative position of the intruder dot will change if ownship maneuvers horizontally or initiates a change in airspeed, but not necessarily when changing altitude (unless that also causes a change in airspeed). The relative position of the CPA position to the future ownship position should provide an indication of which way to maneuver ownship to avoid violating well-clear.

Avoidance Area Display

Figure 4 shows an example of the Avoidance Area Display. The information on this display is the same as the Basic Traffic Display with the addition of a polygonal area that indicates a predicted loss of well clear anywhere inside the polygon.

Figure 4: Avoidance Area Display

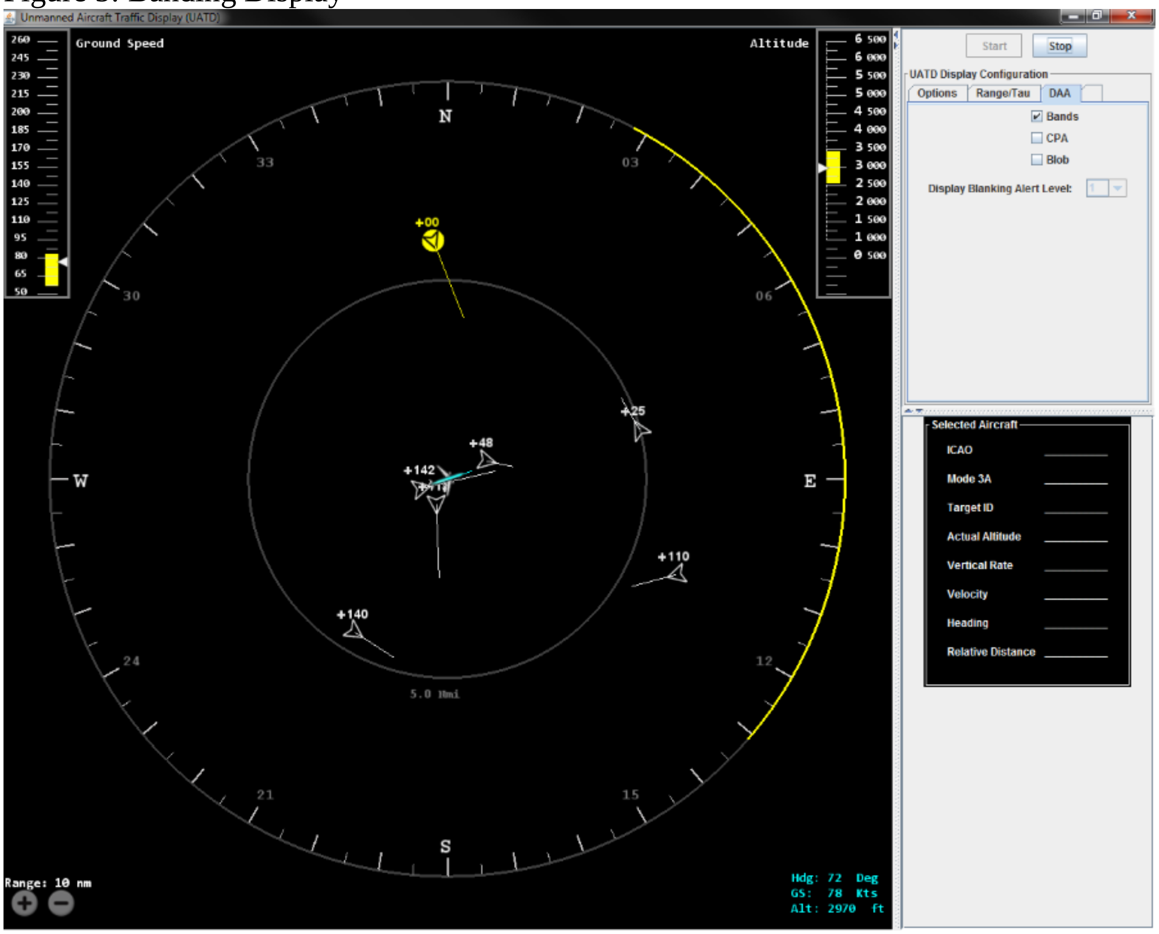


The basic task of the pilot using this display is to maneuver ownship in such a way as to avoid entering the polygon. The shape of the polygon will change as either ownship or the intruder maneuvers. In addition, the outline color and shading of the polygon will match the intruder symbol color.

Banding Display

Figure 5 shows an example of the Banding Display. There are three types of bands represented on the display. The heading band appears at the edge of the range circle and provides information about which headings will lead to a well clear violation. The altitude band appears on the altitude tape in the upper right corner of the display and shows which altitudes will lead to a well clear violation. The speed band appears on the speed tape in the upper left corner of the display and indicates which speeds will lead to a well clear violation.

Figure 5: Banding Display



The task of the pilot is to select a heading, altitude, or airspeed value that is not covered with a yellow band to avoid violating well clear. If a well clear violation occurs, the banding will change to green. The green banding indicates which headings, altitudes, or airspeeds will lead to the fastest recovery from a loss of well clear.

APPENDIX B

Human-in-the-Loop (HITL) Simulation to Investigate Minimum Information Requirements for an Unmanned Aircraft System (UAS) Detect and Avoid System Traffic Display: Task UAS DAA1

I, ___________________________________, understand that this study, entitled "Human-in-the-Loop (HITL) Simulation to Investigate Minimum Information Requirements for an Unmanned Aircraft System Detect and Avoid System Traffic Display:" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Kevin Williams, Ph.D., Carolina Zingale, Ph.D., and Eamon Caddigan, Ph.D.

Nature and Purpose:

I have been recruited to volunteer as a participant in the study named above. The purpose of the study is to provide baseline data on the effects of various types of information displayed on a traffic display on the ability of a pilot to remain well clear of traffic while flying an unmanned aircraft (UA). I will be asked to fly a UAS simulator in a series of short (4-5 min) scenarios that will involve other aircraft that could pose a potential threat to the aircraft I am controlling. I will be required to assess these situations and to take evasive action as needed. I will use a supplementary traffic display that depicts the UA and other aircraft in the scenario to identify these aircraft. The scenarios will include 10 kt crosswinds. Separation assurance by Air Traffic Control is assumed and I will be required to contact ATC regarding deviating from my flight plan. However, I will decide whether I need to contact ATC before making the maneuver or need to first make the maneuver and then contact ATC. I will complete a short questionnaire after each set of scenarios using a particular display type, giving ratings about the scenarios and my perceptions of the particular traffic display used. I will also complete a final questionnaire at the end of the simulation to provide my overall impressions. The FAA will use the results of this study as input to the development of requirements for the integration of UAS into the National Airspace System (NAS).

Experimental Procedures:

This study is a Human-in-the-Loop (HITL) simulation that involves participation from each pilot for 1 to 1 1/2 full days depending on the pilot's familiarity with the UA simulator being used. The researchers will present an introductory briefing to explain the purpose of the simulation, the experimental procedures, and participant rights and responsibilities. The participants will complete a background questionnaire to provide basic demographic information and information about their piloting experience. The researchers will provide training on the simulator and the participants will complete practice scenarios to become familiar with the simulator, the airspace, and the procedures. The participants will then complete a series of test scenarios using a particular display type and complete a questionnaire after completing all of the scenarios in that series. The participant will be evaluating four different displays, which will involve four series of scenarios. The researchers will provide training and practice for each display type before the participants complete the test scenarios. At the end of the full simulation, the participant will complete a final questionnaire and the researchers will provide a debriefing. The data from the simulator will automatically record pilot input at the control station and aircraft data during each scenario. The scenarios will also be video and audio recorded to allow the researchers to review specific components of the simulation for further analysis at a later time. These recordings are for internal use only.

Anonymity and Confidentiality:

The information that I provide as a participant is strictly confidential. Any information I provide will remain anonymous and will not be shared with anyone or included in any reports. I understand that no Personally Identifiable Information [PII] will be disclosed or released, except as may be required by statute. I understand that situations when PII may be disclosed are discussed in detail in FAA Order 1280.1B "Protecting Personally Identifiable Information [PII]."

Benefits:

I understand that the only benefit to me is that I will provide the researchers with insight regarding the minimum information requirements for UAS detect and avoid traffic displays for use in traffic separation maneuvers. My data will help the FAA determine minimum acceptable traffic display information for UAS.

Participant Responsibilities:

I am aware that, to participate in this study, I must be a current instrument-rated pilot or a UAS pilot with mission experience, 200 hours experience, and who is current within the last 3 years. I will not discuss the content of the experiment with anyone until the study is completed.

Participant Assurances:

I understand that my participation in this study is completely voluntary, and I have the freedom to withdraw at any time without penalty. I understand that the researchers in this study may terminate my participation if they believe this to be in my best interest. I understand that the researchers will inform me if new findings develop during the course of this research that may relate to my decision to continue participation. I have not given up any of my legal rights, nor have I released any individual or institution from liability for negligence.

The research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Kevin Williams, Ph.D., Carolina Zingale, Ph.D., or Eamon Caddigan, Ph.D., will answer questions I have during this study.

If I have questions about this study, I will contact Kevin Williams, Ph.D., (405) 954-6843.

Discomfort and Risks:

I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques. However, I will be required to sit for up to 40 minutes at a time in the control station simulator over the course of the day (with regular breaks, including lunch). I agree to immediately report any injury or suspected adverse effects to Carolina Zingale, Ph.D., (609) 485-8629.

Signature Lines:

I have read this informed consent form. I understand its contents and I freely consent to participate in this study under the conditions described. I understand I may request a copy of this form.

Research Participant: ____ .... Date: ________________

Investigator: ____ ... Date: ________________

Witness: ____ .... 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. **Do you have manned pilot flying experience? Yes No**

If Yes, please complete the following:

a) Military**: Yes No**

b) Flight Hours:

Civilian ________ Military Non-Combat _________ Military Combat _________

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

c) IFR rated**: Yes No**

c) Other Ratings:

____

____

____

d) Aircraft Types:

____

____

____

____

3. Do you have UAS flying experience? Yes No

If Yes, please complete the following:

a) Training: **18X Undergraduate Pilot Training Other:** ____________

b) Military: **Yes No**

c) Total UAS Flight Hours:

Civilian ________ Military Non-Combat _________ Military Combat _________

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

d) UAS Flight Hours by phase of flight:

Launch and recovery: _____

Mission:___

e) 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:

____

PART III – Traffic Displays

1. 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?

____

2. 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 describe:

____

____

____

APPENDIX D

DAA1 – Post Display Session Questionnaire

1. Rate your ability to **maintain separation** from other aircraft:

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

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

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

3. Rate the **complexity of the 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
☐	☐	☐	☐	☐

4. Estimate the number of **losses of separation** (i.e., intruder came within 0.75nm, 450ft and 35sec of you) that you had in this session:

0	1	2	3	4+
☐	☐	☐	☐	☐

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

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

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

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

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

7. 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
☐	☐	☐	☐	☐

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

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

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

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

10. 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
☐	☐	☐	☐	☐

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

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

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

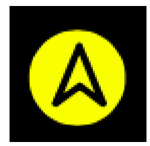
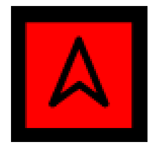
13. Please discuss any suggestions for improving this display or any other comments, issues, or concerns.

APPENDIX E

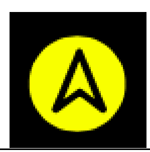
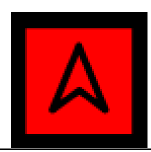
DAA1 – Post Study Questionnaire

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*
1. 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
2. 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
3. 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*
4. If ownship and intruder trajectories remained unchanged, this alert indicated an eventual loss of separation	Disagree Agree	Disagree Agree	Disagree Agree

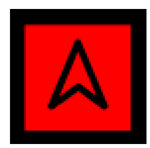
Rate the extent to which you agree with the following statements about each of the **AUDITORY ALERT LEVELS**.

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	 *"Traffic Monitor"*	 *"Traffic Separate"*	 *"Traffic, Maneuver Now*
5. 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
6. 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 **TIMING** of each ALERT LEVEL 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*
7. The onset of the alert was _____	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

8. Please rank all of the following display configurations (refer to display figures below) in order of their **effect on your ability to maintain separation**(1 = Best Supported Ability, 4 = Least Supported Ability).
__________ Basic Information Display
__________ Closest Point of Approach Circle Display
__________ Avoidance Contour Display
__________ Suggestive Guidance Banding Display

9. Do you think non-cooperative traffic need different visual or auditory alerting than cooperative traffic?
No Yes
Why? ____

10. Did any of the following factors influence whether you decided to make a **horizontal** maneuver? *Please circle **all** relevant factors.*

a. Flight Plan Profile

b. Whether or not ownship was turning

c. Whether or not ownship was climbing or descending

d. Whether or not the intruder was turning

e. Whether or not the intruder was climbing or descending

f. Encounter Geometry

g. Uncertainty

h. Other ______________________________

i. None

j. I did not make a horizontal maneuver to avoid traffic

11. Did any of the following factors influence whether you decided to make a **vertical** maneuver? *Please circle **all** relevant factors*.

a. Flight Plan Profile

b. Whether or not ownship was turning

c. Whether or not ownship was climbing or descending

d. Whether or not the intruder was turning

e. Whether or not the intruder was climbing or descending

f. Encounter Geometry

g. Uncertainty

h. Other ______________________________

i. None

j. I did not make a vertical maneuver to avoid traffic

12. Did any of the following factors influence whether you decided to make an **airspeed change** maneuver? *Please circle **all** relevant factors*.

a. Flight Plan Profile

b. Whether or not ownship was turning

c. Whether or not ownship was climbing or descending

d. Whether or not the intruder was turning

e. Whether or not the intruder was climbing or descending

f. Encounter Geometry

g. Uncertainty

h. Other ______________________________

i. None

j. I did not make an airspeed change maneuver to avoid traffic

APPENDIX F

PREDATOR MQ-9 SYSTEM BRIEF

System Overview:

Throttle

- Landing Gear Switch

Stick

- Landing Configuration (aka Autopilot Disconnect)
- Trim Button
- Trigger (Enables Landing Gear and A/P Disconnect)

Head Down Display (HDD):

Autopilot

- Autopilot Menu (M0), Hold Modes Sub-Menu (M0)
  - Heading Hold (M0)
    - Can be set independent
    - Annunciator WHITE when enabled; Dialog Box (M1) ORANGE when enabled
    - Defaults to current heading when enabled
    - Can set via numeric entry (M0) or Using Azimuth Indicator and Trim Button
  - Airspeed Hold (M1)
    - Can be set independent
    - Annunciator WHITE when enabled; Dialog Box (M1) ORANGE when enabled
    - Defaults to current speed when enabled
    - Can only be set via Stick and Trim Button
    - Required to be enabled to engage Altitude Hold (Speed Priority)
  - Altitude Hold (M2)
    - Cannot be set independent, MUST have Airspeed Hold engaged
    - Annunciator WHITE when enabled; Dialog Box (M1) ORANGE when enabled
    - Defaults to current altitude when enabled; No Altitude Pre-Select

- Can only be set via Altitude Command (M0)

Zero Trims

- Configuration (M6)
  - Zero Roll & Pitch Trims (M2)
    - Clear Autopilot Trims prior to each run

MANEUVER TRAINING

Setup:

- Landing Gear Switch - DOWN
- Landing Configuration - ENABLED
- Zero Trims
- WAIT for AP SELECT and NAV SELECT ENABLED (WHITE)
- Landing Gear Switch - UP
- Proceed with Autopilot setup

Autopilot:

- Autopilot Menu (M0), Hold Modes Sub-Menu (M0)
  - Heading Hold (M0) - SET, ENABLED (M1)
  - Airspeed Hold (M1) - SET, ENABLED (M1), Trim speed as required
  - Altitude Hold (M2) - SET, ENABLED (M1)
  - Altitude Command (M0) - SET

Scenarios:

- All HOLD Modes ENGAGED prior to run

- **Lateral Maneuvers**:
  - Maneuver Left / Right using Numeric Entry via HDD
  - Maneuver Left / Right using Azimuth Indicator and Stick Trim
    (Note: shortest distance to heading bug)
    (Note: Fast way to initiate a turn, then fine tune with numeric entry)

- **Vertical Maneuvers**:
  - Climb/Descend using Numeric Entry via HDD

- **Speed Changes**:
  - Slow-Down/Speed-Up using Stick Trim

- **Composite Maneuvers**:
  - Execute BOTH Lateral and Vertical Maneuvers
    (ie, "OMAHA-7, Turn Left 270, Descend and Maintain 8000")
  - Vector off course, then provide an initial heading to re-intercept course
    (ie, "OMAHA-7, Turn Right 180 for traffic…"
    "OMAHA-7, Turn Left 110 to intercept course, advise when established")

ICOMC2 Integrator SYSTEM BRIEF

System Overview:

General Interface

- Tabs along the top
  - Most important is Training and Map Tools
    - Switches to Map Tools with click on map
- Speed and altitude tapes and vertical speed indicator
- Heading indicator
- Control mode indicator
- Compass rose in heading mode
- Map does not move with aircraft
  - Auto Follow mode – keep off, but useful for finding aircraft.
- Panning and zooming
  - Zooms in on cursor
- Right click brings up menu
  - Menu depends on where the pilot clicks
- Very easy to accidentally click and move something around
  - If aircraft is grabbed, click "esc" before letting go of button

Two ways to input changes

- Bugs
- Typing a number
  - Orange means waiting to upload (pending)
  - Hitting return uploads (turns purple), then changes to blue

Three flight control modes

- Loiter mode
  - Can drag aircraft to a point, or right click at the target loiter point
  - "Direct to" the loiter
  - Speed controlled by bugs
  - Can adjust loiter radius
  - Menu to adjust loiter altitude
- Waypoint mode
  - Waypoint number
  - Altitude normally controlled by route settings
    - Can be changed by typing new altitude in box (override)
    - Bug next to box sets override to current altitude – useful to stop a descent
    - Circle is default route altitude
    - Active is highlighted blue
  - Speed controlled by tapes
    - Circle next to bug can put aircraft into default route altitude mode

- Be careful about moving waypoints around
  - Don't upload to aircraft – routes can be recovered, though
  - Discard All if waypoints are moved
  - Probably best to wait until between runs to discard
- Aircraft flies directly to target point
  - Even if next to the middle of a leg
- Track to
  - Drag aircraft to a leg instead of a point. Aircraft will go to nearest perpendicular point on leg, even if before the waypoint
- Start in this mode

- Heading mode
  - Drag or type
    - System accepts 0-359, not 360, in box.
    - Dragging is in 5 degree increments
  - Speed and altitude controlled by bugs

Autopilot is speed priority

- Will descend when speed increases, and climb when speed decreases
- Above 90kts, cannot maintain altitude at speed, even though it will allow speeds up to 113kts.
  - Will go into a descent and NOT slow down to recover
    - Will fly into the ground if pilot doesn't intervene
    - Pilot is responsible for monitoring this condition
- Autopilot will not allow a speed that will cause the aircraft to stall.

Simulation specific

- Pausing and restarting
- Don't hit Stop or Restart
- Warping
  - Get on heading and correct altitude first.
  - Remember that target point moves as its warping
  - Once in target area, drag onto first leg and select "track to".
  - Pause once over point.
- Starting and stopping logging
- Again - don't hit Stop or Restart

MANEUVER TRAINING

Scenarios:

- **Fly Training Route 1 in heading mode**:
  - Heading changes :
    - Turn using both the slider and typing
      (Note: shortest distance to heading bug)

- Vertical Maneuvers:
  - Climb/Descend using both slider and typing
- Speed Changes:
  - Slow-Down/Speed-Up using both slider and typing
- Divert and rejoin

- **Composite Maneuvers**:
  - Execute BOTH Lateral and Vertical Maneuvers
    (ie, "OMAHA-9, Turn Left 270, Descend and Maintain 3000")
  - Vector off course, then provide an initial heading to re-intercept course
    (ie, "OMAHA-9, Turn Right 180 for traffic…"
    "OMAHA-9, Turn Left 110 to intercept course, advise when established")

Logging file naming convention

<pilot number>_<display type>_<run number>.txt

Use T1 for training and 01 for live runs
Append a letter for reruns. i.e. 01a

Display types: Banding
Baseline
Blobs
CPA
Explore

Example:
P01_Baseline_T1.txt

Route recovery

Go to route window (Mission Planning tab)
Delete changed route
Upload changes to aircraft
Select Import Route, and select route that needs to be added.
Upload changes to aircraft

APPENDIX G

Predator GCS Preparation Checklist (01.21.2016)

Scenario Start

Checklist 1

1. Load operational mission if not already loaded (on map display Mission->Open->Operational Mission->*Mission name*)
2. WAIT for AP Select to become white In the lower left heads down display
3. Cycle landing gear UP (Dog fight slider + trigger)
4. Set heading hold ON (esc – esc - M0 – M0 – M0 -> M1)
5. Set airspeed hold to 140 KIAS (esc - M0 – M0 - M1 -> M1)
6. Set altitude hold ON (esc – M2 -> M1)
7. Enter altitude hold (M0) and enter value 8000 for missions 1 & 2, 9000 for 3 & 4 then enter
8. Place cursor somewhere on heads-up display (lower monitor)
9. Verify gear is up
10. Verify UATD range is at 15nm
11. Tell Operator all is ready

Scenario End

Checklist 2

1. Command Landing configuration (Slide on the joystick + trigger)
2. Command Gear DOWN (Dog fight slider on the throttle + trigger)
3. Zero the trims (esc-esc-M6 -> M2)
4. Announce Checklist 2 complete, wait for AvSim operator before proceeding to Checklist 2
5. Set the UATD range to 15 nm if it had been changed.
6. Go back to checklist 1

ICOMC2 GCS Preparation Checklist

Login:

****

Start of the day:

1) Launch ICOMC2 (Integrator 7.5.3 – Standalone Sim)
2) Launch the consolidator
3) In the consolidator window, click open file and open the file named ConsolidoatorIcomC2_with89RTI.cfg
4) Click Start

Launch:

1) Click the Training tab
2) Click the white aircraft icon in the lower left hand corner of the screen, below the "Aircraft Mass"
3) Click "quick Launch"
4) Once airborne, the airplane will climb to 4000 feet at 58 kts. Increase the airspeed to 75 kts.

If the routes aren't already loaded:

1) Open the Route Editor in the Mission Planning tab.
2) Select Import Routes and pick the correct routes for the scenario.
3) Click the Upload All Changes button.

For each scenario:

1) Go to Heading mode and set the aircraft onto the initial heading of the route.
2) Set the altitude to the initial route altitude.
3) Warp the aircraft about 2 miles from the start point of the route, heading toward the start point.
4) The aircraft will take a few seconds to warp and once it does, drag the aircraft onto the first waypoint, putting the aircraft into Waypoint mode.
5) Once the aircraft is on top of the first point, click the pause button in the Training tab.
6) Set the logging file name

Scenario Start:

1) Hit start on the logging tab
2) In the training tab, hit Start.

Scenario End:

1) Hit stop on the logging tab
2) Go to "For each scenario"

Predator GCS Preparation Checklist (01.21.2016)

Scenario Start

Checklist 1

12. Load operational mission if not already loaded (on map display Mission->Open->Operational Mission->*Mission name*)
13. WAIT for AP Select to become white In the lower left heads down display
14. Cycle landing gear UP (Dog fight slider + trigger)
15. Set heading hold ON (esc – esc - M0 – M0 – M0 -> M1)
16. Set airspeed hold to 140 KIAS (esc - M0 – M0 - M1 -> M1)
17. Set altitude hold ON (esc – M2 -> M1)
18. Enter altitude hold (M0) and enter value 8000 for missions 1 & 2, 9000 for 3 & 4 then enter
19. Place cursor somewhere on heads-up display (lower monitor)
20. Verify gear is up
21. Verify UATD range is at 15nm
22. Tell Operator all is ready

Scenario End

Checklist 2

7. Command Landing configuration (Slide on the joystick + trigger)
8. Command Gear DOWN (Dog fight slider on the throttle + trigger)
9. Zero the trims (esc-esc-M6 -> M2)
10. Announce Checklist 2 complete, wait for AvSim operator before proceeding to Checklist 2
11. Set the UATD range to 15 nm if it had been changed.
12. Go back to checklist 1

ICOMC2 GCS Preparation Checklist

Login:

****

Start of the day:

5) Launch ICOMC2 (Integrator 7.5.3 – Standalone Sim)
6) Launch the consolidator
7) In the consolidator window, click open file and open the file named ConsolidoatorIcomC2_with89RTI.cfg
8) Click Start

Launch:

5) Click the Training tab
6) Click the white aircraft icon in the lower left hand corner of the screen, below the "Aircraft Mass"
7) Click "quick Launch"
8) Once airborne, the airplane will climb to 4000 feet at 58 kts. Increase the airspeed to 75 kts.

If the routes aren’t already loaded:

4) Open the Route Editor in the Mission Planning tab.
5) Select Import Routes and pick the correct routes for the scenario.
6) Click the Upload All Changes button.

For each scenario:

7) Go to Heading mode and set the aircraft onto the initial heading of the route.
8) Set the altitude to the initial route altitude.
9) Warp the aircraft about 2 miles from the start point of the route, heading toward the start point.
10) The aircraft will take a few seconds to warp and once it does, drag the aircraft onto the first waypoint, putting the aircraft into Waypoint mode.
11) Once the aircraft is on top of the first point, click the pause button in the Training tab.
12) Set the logging file name

Scenario Start:

3) Hit start on the logging tab
4) In the training tab, hit Start.

Scenario End:

3) Hit stop on the logging tab
4) Go to “For each scenario”