AN INVESTIGATION OF MINIMUM INFORMATION REQUIREMENTS FOR AN UNMANNED AIRCRAFT SYSTEM DETECT AND AVOID TRAFFIC DISPLAY

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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 experiment tested four different display configurations. These were a baseline display, an indication of Closest Point of Approach (CPA), an avoidance area (blob) indication, and a banding display. Also manipulated in the study were two levels of pilot experience and two types of control 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. Performance with the CPA display was not significantly different from the baseline display.

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.

Building primarily off previous work from the FAA (Rein, Friedman-Berg & Racine, 2013) and NASA (Fern, Rorie, Pack, Shively, & Draper, 2015; Rorie & Fern, 2015; Rorie, Fern & Shively, 2016; Santiago & Mueller, 2015), four traffic display formats were compared with regard to their effectiveness in assisting the pilot in remaining well clear from other aircraft. The first display format, based on the work of Rein et al., 2013, was considered a baseline format. The other three formats used the baseline display and added additional information to the display to see if there was a significant increase in the ability to remain well clear from other traffic. In addition to manipulating display format, the experiment tested two different types of control station pilot interfaces and two levels of pilot experience levels. For a complete description of the experimental design and results, the reader is directed to the FAA Technical Report by Williams, Caddigan, and Zingale (2017).

Method

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. Two separate control stations were used for the study. 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. The ICOMC2 Station consists of a single screen. Interaction with the system is accomplished using a 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. For both stations, a separate 19" monitor was used for the traffic display. Figure 1 shows the baseline traffic display depiction and symbology used for the other display configurations.

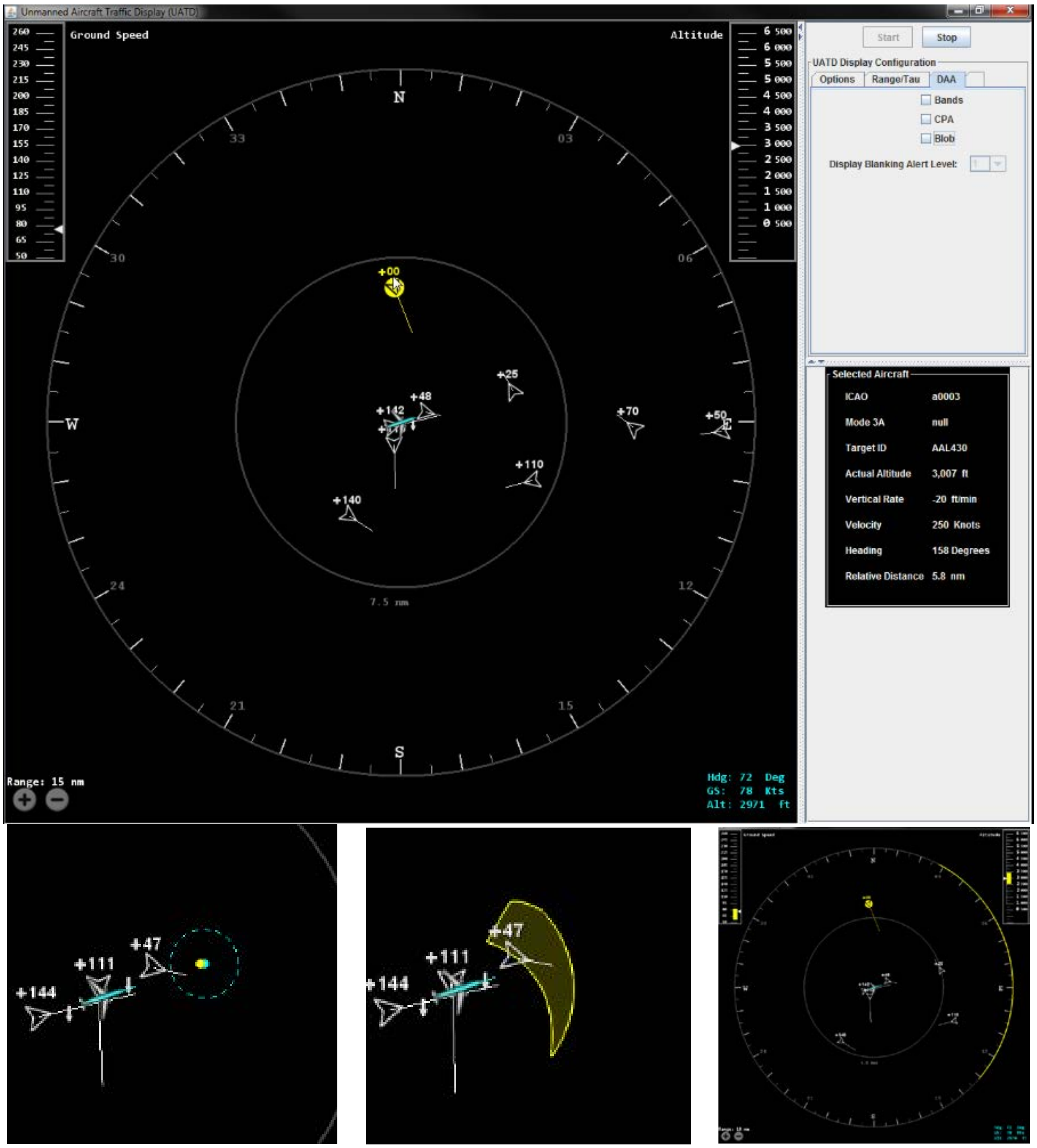

Figure 1. Display formats used in the the study. Clockwise from the top, baseline display, banding format, avoidance area (blob) format, and closest point of approach (CPA) format.

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). The selection of timing parameters of the alerts, as well as the selection of traffic alert symbols and auditory alert messages was based on work accomplished by the RTCA SC-228 DAA working group. Figure 2 shows the visual and auditory alerts used in the study.

		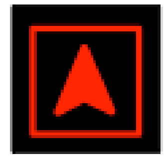
Preventive DAA Alert "Traffic, Monitor"	*Corrective DAA Alert "Traffic, Avoid"*	*DAA Warning Alert "Traffic, Manveuver Now Traffic, Maneuver Now"*

Figure 2. 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 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.

Eight different encounter geometries were used for the study (see Table 1). 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.

Table 1. *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

Procedure

After arriving at the facility, the participant viewed an introductory briefing. They then read and signed an Informed Consent Statement and completed a background questionnaire. Next, the participant was given familiarization training on the appropriate UAS simulator.

Participants completed eight encounter scenarios for each traffic display configuration. Order of the display configurations was counterbalanced across participants. Before flying the encounter scenarios for a particular display configuration, participants completed one or two practice scenarios to ensure complete understanding of the display configuration being flown.

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.

After the last scenario in each display configuration, the participant completed the Post-Display Questionnaire. After completing all four of the display configurations, the participant was given a post-study questionnaire. More complete details of the procedure and questionnaires can be found in Williams et al. (2017).

Results

Figure 3 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, $t(31) = .61$, $p = .27$.

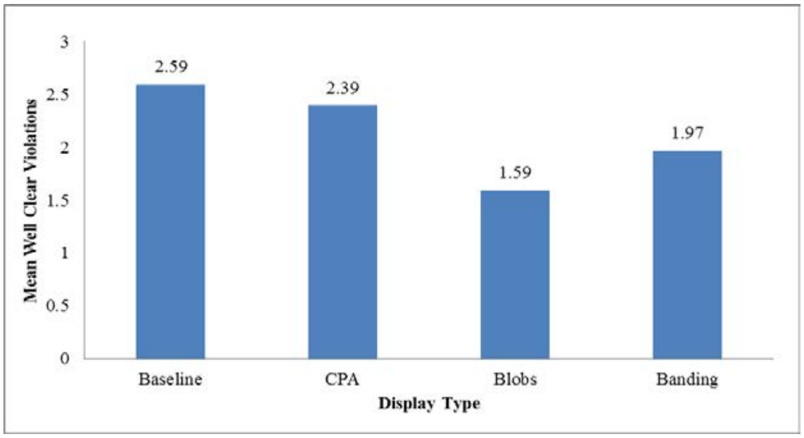

Figure 3. Mean well clear violations by display type.

Figure 4 presents the mean well clear violations across display types separated by pilot type.

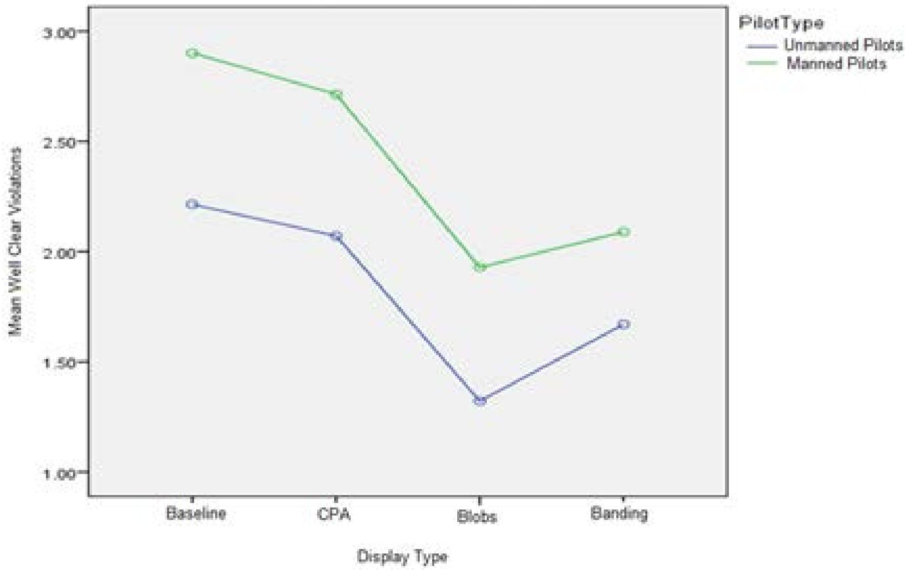

Figure 4. Mean well clear violations across display type by pilot type.

Looking Figure 4, 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 3 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.

Discussion

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.

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. The relative success of the blob display 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 effectiveas the banding display, suggests that the vertical banding information as a form of suggestive guidance is not as useful as horizontal guidance. Further research on this issue is warranted.

Acknowledgements

I would like to acknowledge my coauthors on the technical report, Dr. Carolina Zingale with the FAA William J. Hughes Technical Center in Atlantic City, NJ and Dr. Eamon Caddigan with T.G. O'Brien & Associates, Inc. I also wish to express my thanks to all the personnel at the FAA William J. Hughes Technical Center who assisted in the running of this study. Unfortunately, there is not enough room to name everyone involved.

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