AFRL-RH-WP-TR-2017-0018

DETECT AND AVOID (DAA)
AUTOMATION MANEUVER STUDY

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FEBRUARY 2017

Interim Report

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- **REPORT DOCUMENTATION PAGE**

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*	**2. REPORT TYPE**	**3. DATES COVERED *(From - To)***
20-04-17	Interim	1 August 2015– 1 March 2016

4. TITLE AND SUBTITLE

Detect and Avoid (DAA) Automation Maneuver Study

5a. CONTRACT NUMBER
In-House

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)

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5d. PROJECT NUMBER
5327

5e. TASK NUMBER
09

5f. WORK UNIT NUMBER
H0A7 (53270901)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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10. SPONSORING/MONITORING AGENCY ACRONYM(S)
711HPW/RHCI

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RH-WP-TR-2017-0018

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES
88ABW Cleared 05/16/2017; 88ABW-2017-2261.

14. ABSTRACT

The study described herein was an operator–in–the–loop assessment supporting the development of a Sense and Avoid (SAA) display that enables effective teaming of an Unmanned Aerial Systems (UAS) operator with an advanced SAA maneuver algorithm to safely avoid proximal air traffic. This study examined performance differences between candidate SAA display configurations and automation thresholds while UAS operators controlled a UAS through airspace including several proximal aircraft.

15. SUBJECT TERMS

Drones; Detect and Avoid; Remotely Piloted Aircraft; Graphical User Interface; Sense and Avoid; UAV; UAS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Guy French
Unclassified	Unclassified	Unclassified	SAR	23	**19b. TELEPHONE NUMBER** *(Include Area Code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

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ACKNOWLEDGEMENTS

The technical work reported herein is the result of a lot of effort by a lot of people. The authors would like to acknowledge the contributions of, and express their gratitude to, the many individuals responsible for this work. Thanks to the core Vigilant Spirit development team: Greg Feitshans, Jason Davis, Mark Squire, and Jimmy Whalen, who created the displays, functional control station and simulation environment. Also a big thanks the numerous pilots and subject matter experts who spent many hours with the authors and leaders intelligently, passionately, tirelessly, and sometimes patiently, testing and evaluating the display concepts put forth for this effort.

1.0 SUMMARY

A key challenge to integrating UAS into the National Airspace System (NAS) is providing a reliable means for UAS to safely avoid proximal aircraft through the development of a specialized system that would reside onboard the UAS. Although this system has to be capable of operating fully autonomously, in most cases it is expected that the operator will have the opportunity to engage with the system regarding situation assessment and response tasks via a SAA display. Given the increasing sophistication of algorithms underlying this new capability, experimental evaluation of display transparency and automation initiation is necessary in order to establish requirements for adequate human-automation system performance. The study described herein was an operator–in–the–loop assessment supporting the development of a Sense and Avoid (SAA) display that enables effective teaming of an Unmanned Aerial Systems (UAS) operator with an advanced SAA maneuver algorithm to safely avoid proximal air traffic. This study examined performance differences between candidate SAA display configurations while UAS operators controlled a UAS through airspace including several proximal aircraft. Twenty-two participants compared three stand-alone SAA displays (Banding, Probing & Dual Perspective) across two automation thresholds (Well Clear & Near Mid-Air Collision (NMAC)). The advanced SAA algorithm maneuvered significantly later than the pilots but it did so in a similar fashion. The Well Clear automation threshold resulted in significantly less time spent in violation of traffic when compared to the NMAC automation threshold. Although algorithm transparency features implemented on novel displays did not result in significant performance differences, participant feedback provided valuable insight into the potential utility and drawbacks of each. Further research will aim at increasing the complexity of engagements and operational scenarios where increased algorithm transparency may be of use and help tease apart any existing differences amongst SAA displays.

2.0 INTRODUCTION

Current DoD Unmanned Aerial Systems (UAS) have missions in every type of airspace, whether for training, transiting operations within the US, or for operational or humanitarian missions overseas. Thus, the need for UAS to access manned airspace already exists and the requirement will only grow as the number of UAS and their associated missions expand. A major technological barrier preventing UAS from freely operating in the US National Airspace (NAS) is the lack of a “Sense-and-Avoid” (SAA) capability, i.e., the ability to detect and safely avoid other aircraft in flight (Cook & Davis, 2013). In order to increase UAS flight safety and support UAS integration into the NAS and international airspace, several platform agnostic SAA capabilities consisting of sensors, specialized algorithms, and displays have been developed.

A bulk of the SAA display capabilities that have been established utilize simplistic SAA algorithms providing intruder threat level and single step, one dimensional suggestive maneuver guidance (i.e., turn to heading 095 or climb 1000 ft.). Several research efforts have attempted to identify the necessary display information needed to facilitate adequate avoidance and airspace separation with these single-dimensional systems. In one such study, Friedman-Berg, Rein & Racine (2014) compared four display categories differing in information level and concluded that the information present in the “prediction” display, consisting of intruder color coding and 30 second dead reckoning vector lines, was the minimum visual information required for a SAA pilot display. Intruder color coding and dead reckoning lines resulted in significantly less Near Mid-Air Collisions (NMACs) than the other lower level displays. Bell (2012) compared a basic SAA display to two “advanced” concepts depicting the relative Closest Point of Approach (CPA) and ownship avoidance areas via polygon shapes. Although the frequency of Well Clear violations did not significantly differ between the three display concepts, the basic display resulted in significantly longer violations than the two advanced displays. Similarly, the National Aeronautics and Space Administration (NASA) investigated the effect of information level and display location on UAS pilots’ performance on maintaining self-separation and collision avoidance from other aircraft while operating in civil airspace (Fern, Rorie, Pack, Shively & Draper, 2015). Response time analyses revealed significantly faster total response times with the advanced information displays, which included additional situational awareness information and maneuver guidance, than the basic information displays. These types of studies have allowed for a minimum information set to be established and implemented into several initial SAA capabilities. All these studies provide evidence that SAA algorithmic transparency, which is characterized by observability, directability, adaptability, and broadening (DePass et al., 2011; Truxler et al., 2012), is an important factor for successful employment of automation.

While these SAA display capabilities have proven to be effective when utilizing relatively simplistic SAA algorithms, increasingly complex SAA algorithms are being created to provide pilots with additional maneuver information and autonomous control capabilities. Consequently, the previously established minimum information set needs to be reinvestigated for those displays that will utilize these more advanced algorithms to ensure adequate transparency and thus proper automation use (Parasuraman & Riley, 1997). Bihrle’s Jointly Optimal Conflict Avoidance (JOCA) algorithm is one such algorithm (Graham et al., 2011). Using a unique “2-stitch” probing mechanism, JOCA provides sophisticated suggestive maneuver guidance consisting of two step, multidimensional maneuvers (i.e., turn to heading 075 and then descend 500 ft.). If the engagement becomes imminent and the pilot does not take appropriate action, JOCA executes an autonomous avoidance maneuver to resolve the conflict. These additional capabilities offered by JOCA lend themselves to novel display concepts that convey additional transparency, therefore, in an effort to explore the utility of this additional transparency, the following study designed and evaluated two novel SAA suggestive displays against a proven SAA display design previously developed for more simplistic SAA algorithms (Pack, Draper, Darrah, Squire & Cooks, 2015).

While transparency is an imperative factor for human trust in automation other factors such as behavior familiarity are also important contributing factors (Chen et al., 2014; Lee & See, 2004). Autonomous flight systems that align with pilot training and behavior tend to support stronger trust perceptions from pilots (Lyons et al., 2016). With this in mind, this study compared the participants’ maneuver behavior to the SAA algorithm’s maneuver behavior. Lastly, recognizing that the utility of a SAA display might be effected by temporal implementation, two different thresholds were implemented for when automation took control for a response recovery.

The objective of the current study was to examine the display and performance implications associated with the use of advanced SAA algorithms such as JOCA. Several hypotheses were formulated based on past research: (1) those SAA displays designed to provide advanced algorithm transparency (Dual Perspective & Probing) would outperform the display designed with transparency associated with a more simplistic algorithm, (2) initiating automation support early (Well Clear Threshold) versus late (NMAC Threshold) will result in increased avoidance performance, and (3) given the SAA algorithm was designed for purely autonomous implementation (no human oversight), its solution recommendations will be dissimilar to that of a human operator's response to similar traffic engagements.

3.0 METHOD

3.1. Participants

Twenty-two male pilots (eight RQ-4, eight MQ-1/MQ-9, and six manned aircraft; mean age 38 ± 9 years) were recruited for this experiment. Participants had an average of 2,616 overall flight hours and 1,287 Unmanned Aircraft System (UAS) hours. Participation was limited to military rated pilots and civilian pilots with full Instrument Flight Rules (IFR) ratings. Recent experience (within the last two years) flying within controlled airspace was required as well. Each participant read and signed an informed consent form approved by the Wright Patterson Air Force Base Institutional Review Board (IRB).

3.2. Experimental Design

Participants were tasked with operating a simulated UAS, "HAWK21," along a flight path with a set mission altitude of 12,000 feet. Furthermore, participants were responsible for maintaining safe separation as if they were operating in the NAS and responding to a variety of scripted health and status tasks. A 3 x 2 within-subjects, repeated measures factorial design was used to compare the effect of display type and automation threshold on UAS pilots' performance on maintaining Well Clear from other aircraft while operating in the NAS. Three suggestive SAA Displays (Banding, Probing, & Dual Perspective) were compared across two Automation Thresholds (Well Clear, NMAC), thus participants completed a total of six trials. These display conditions are described below.

3.3 Simulation Environment

3.3.1. Ground Control Station. Participants were situated at the Air Force Research Laboratory's Vigilant Spirit Control Station (VSCS) (Figure 1). VSCS is a mature GCS operator interface designed to support the control of UAS and their associated payloads (Patzek et al., 2009). In this study, VSCS generated three separate pilot displays in the ground station: 1) Tactical Situation Display (TSD), 2) health and status panel, and 3) SAA traffic display. The TSD served as the pilot's primary control interface, providing ownship and route information, a moving map, and ownship control capabilities. The health and status panel contained telemetry data, a chat room, a backup radio communication panel, an electronic checklist, and a subsystem annunciator panel. The SAA display, which varied by trial, was populated with traffic information for those aircraft in relative proximity to the ownship.

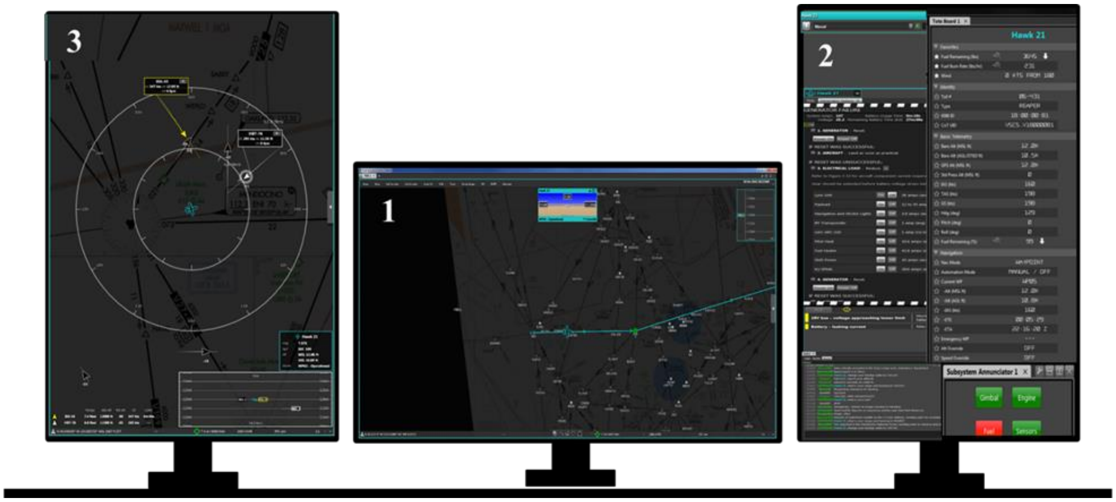


Figure 1. Vigilant Spirit Control Station

3.3.2 Traffic Simulation. The Air Force Research Laboratory's Vigilant Spirit (VS) simulation capability was used to generate the air traffic environment for this study. The VS simulation capability allowed for six unique traffic encounters to be generated and repeated from participant to participant. A mix of geometries including head-on, side, and overtake encounters were incorporated into the traffic encounters.

3.3.3 Sense and Avoid Algorithm. For this study, the Air Force utilized a SAA Maneuver Algorithm developed by Bihrle known as the Jointly Optimal Conflict Avoidance (JOCA) algorithm (Graham et al., 2011). In addition to evaluating and categorizing surrounding traffic according to their predicted threat level relative to ownship, the SAA maneuver algorithm is capable of providing suggestive maneuver guidance and executing autonomous avoidance maneuvers. The viability of potential avoidance maneuver resolutions are tested using a "2-stitch" probing mechanism in which an initial series of maneuver resolution probes spawn a secondary series of maneuver resolution probes (Figure 2).

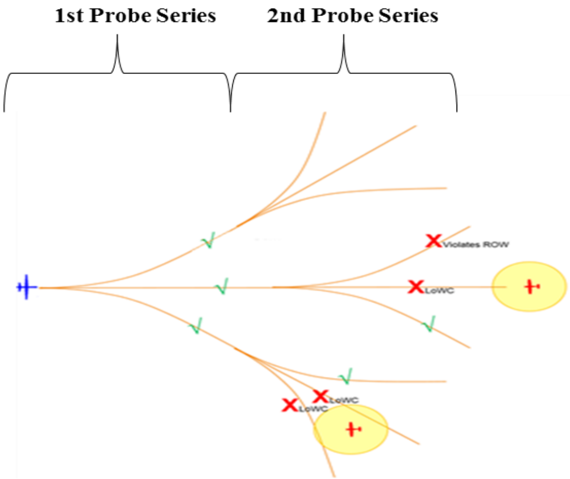


Figure 2. SAA Maneuver Algorithm "2-Stitch" Probing Mechanism

The resulting maneuver resolution probes are categorized according to a hierarchy of constraints to produce a “branch-like” network of potential maneuver options. Maneuver options include not only heading and altitude maneuvers but also two-step maneuvers (e.g. turn to heading 030 and then climb 500 ft.) and combination maneuvers (e.g. turn to heading 050 while descending 1,000 ft.). For this study, the SAA maneuver algorithm detected and color coded traffic based on a set alerting structure (Table 1). Maneuver probes were utilized to initially provide potential maneuver resolutions for the pilots to choose from. If the situation progressed to a certain threshold where the algorithm had to take over, maneuver probes were used to determine and execute an autonomous avoidance maneuver that maintained safety of flight while also minimizing deviation from mission path. The automation threshold, dictating when the SAA maneuver algorithm would take control of the aircraft, was systematically varied in the study (as described below). With an update rate of 1 HZ, the SAA displays were populated and then continually updated to reflect the latest data output from the SAA maneuver algorithm.

Alert/Threat Level	**Horizontal Threshold (nm)**	**Vertical Threshold (feet)**	**Time Threshold**	**Color**
Proximate	2.0 nm	1,000 ft	N/A	White
Preventative	.66 nm	>450 to <700 ft	< 120 sec	White with circle
Well Clear	.66 nm	450 ft	< 110 sec	Yellow/Yellow w/red outline
NMAC	.08 nm	100 ft	< 40 sec	Red

Table 1. Multi-Level Alerting Structure

3.4 Stimuli

3.4.1 Automation Thresholds. Automation thresholds were systematically varied to either allow a larger degree of separation between aircraft to be maintained (Well Clear) or a smaller degree of separation (Near Mid-Air Collision (NMAC)). When the automation threshold was set to Well Clear, the SAA maneuver algorithm would take over to avoid a “Well Clear violation”, which was defined as having a predicted horizontal miss distance (HMD) less than or equal to 4000 feet (0.66 nautical miles), a current vertical separation less than or equal to 450 feet, and a modified tau (a metric of time to closest approach in the horizontal plane) less than or equal to 35 seconds. When the automation threshold was set to “NMAC”, the pilot was solely responsible for maintaining Well Clear separation but the SAA maneuver algorithm would take over to avoid a NMAC violation, which was defined as having a current HMD less than or equal to .08 nautical miles and a current vertical separation less than or equal to 100 feet.

3.4.2 SAA Displays. Three SAA displays were designed and tested in this study. The Banding Display proved to be an effective display in previous studies (Pack, Draper, Darrah, Squire &

Cooks, 2015) (Figure 3). In addition to intruder alerting, a color coded arc and altitude tape were included to continually show ranges of potential heading and altitude resolutions, respectively. The arc on the inner range ring represented a 180° range of potential heading maneuver resolutions and the altitude tape, consisting of five blocks, represented potential elevation resolutions in 500 foot increments +/- 1000 feet from the ownship's current flight level. Color indicated the predicted quality or safety of a heading or altitude maneuver resolution (green = no conflicts, yellow = predicted Well Clear violation, red = predicted NMAC violation). The arc and altitude tape reflected the SAA maneuver algorithm's 1st series of probes. Secondary probes were not factored into this display

Hawk 21
Hdg T 075
Spd IAS 160
Alt MSL 12.0K ft
AGL 8872 ft
Mode WP03 - Operational

	Range	Abs Alt	Rel Alt	GS	LoWC
ELD 117	6.9 Nmi	11999 ft	00	248 kts	0m:45s
GDF-05	3.9 Nmi	11498 ft	-05	394 kts	---

Figure 3. Banding Display

The Probing Display was a design concept that emphasized the SAA maneuver algorithm's "2-stitch" probing logic (Figure 4). In addition to intruder alerting (same as used in Banding Display), a color-coded series of dots and a vertical stack were included to show potential discrete heading and altitude maneuver resolutions, respectively. The nine dots on the inner range ring represented ownship potential headings, with four potential heading resolutions to the right and four potential heading resolutions to the left of a current heading resolution. The vertical stack, consisting of four arrows and the current heading resolution dot, represented potential elevation resolutions in 500 foot increments +/- 1000 feet from the ownship's current flight level. Color once again indicated the predicted quality or safety of a heading or altitude maneuver resolution. The dots and vertical stack on the inner range ring reflected the SAA maneuver algorithm's 1st series of probes. Insight into the SAA maneuver algorithm's 2nd series of probes was provided via a "pimento" display feature and an interactive probing capability. The "pimento" display feature distinguished a heading or altitude resolution with a yellow center if it was predicted to result in a Well Clear violation based on the 2nd series of probes. Triggered via a button click, the interactive probing capability expanded upon the "pimento" display feature by providing a second series of dots and vertical stack for a specific heading or altitude maneuver resolution. This second set of dots and arrows reflected one of the SAA maneuver algorithm's

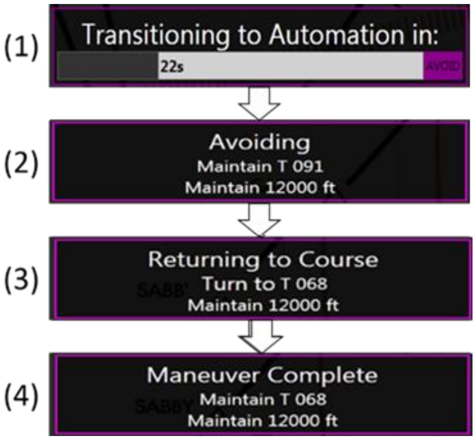
2nd probes, allowing operators to gain detailed insight into the entire series of probes for a particular heading or altitude resolution. By allowing the operator to observe and direct more of the algorithm functionality associated with the two probes, algorithm transparency was thought to be increased, thus we expected to see an increase in performance.

Figure 4. Probing Display

The Dual Perspective Display was a novel design concept that emphasized the SAA maneuver algorithm's capability to provide combination maneuver resolutions (Figure 5). In addition to intruder alerting, a color coded series of squares within a cockpit view was included to show potential heading, altitude, and combination maneuver resolutions. The nine squares on the x-axis represented the ownship's current heading (center), four potential heading resolutions to the right, and four potential heading resolutions to the left. The five squares on the y-axis represented potential elevation resolutions in 500 foot increments +/- 1000 feet from the ownship's current flight level. Combination maneuver resolutions were represented by those squares that didn't fall on a specific axis but rather within a quadrant. Color once again indicated the predicted quality or safety of a heading or altitude maneuver resolution. The squares reflected the SAA maneuver algorithm's 1st series of probes. Similar to the Probing Display, insight into the SAA maneuver algorithm's 2nd series of probes was provided via the "pimento" display feature. Once again, bringing out more features and functionalities of the algorithm, particularly combo maneuvers, for the pilot to work with was thought to bolster transparency.

Figure 5. Dual Perspective Display

3.4.3 Transition to Automation Display Features. Display features accompanying the transition from traditional flight control to autonomous control were developed and remained constant across each display type as a means of informing the pilot about algorithm intentions and operations (Figure 6). Throughout the transition pilots were provided with (1) a countdown to automation timer, (2) an avoidance notification accompanied by an auditory alert, (3) a returning to course notification, and (4) an indication of maneuver completion. In addition, a vector was provided off the nose of the ownship to indicate the SAA algorithm's intent.



(1) Transitioning to Automation in:
22s
AVOID

(2) Avoiding
Maintain T 091
Maintain 12000 ft

(3) Returning to Course
Turn to T 068
Maintain 12000 ft

(4) Maneuver Complete
Maintain T 068
Maintain 12000 ft

Figure 6. Transition to Automation Display Features

3.5 Procedure

Upon entry into the lab, participants read and signed an informed consent form and completed a demographics survey, which elicited information regarding their flight experience. Participants were provided an introduction to the study and their operator responsibilities. Responsibilities included flying “HAWK21” along a flight plan, responding to traffic alerts when necessary, and performing health and status tasks as they appeared. Initially, training was provided on the basic functionality of VSCS, including how to use the TSD to perform heading and altitude holds. Participants were not required to gain simulated Air Traffic Control (ATC) clearance prior to maneuvering during this study but were encouraged to return to the flight plan as soon as practical after maneuvering for traffic. After being taught the definitions of Well Clear and NMAC, the participants received training on the multi-level alerting structure. The next portion of training focused on the SAA maneuver algorithm. Lastly, participants were trained on each suggestive display and automation threshold. To account for training and fatigue effects, automation threshold and suggestive SAA display order were assigned based on a counterbalance.

Participants saw the three suggestive SAA displays across both automation thresholds for a total of six 6-minute trials. Six unique traffic engagements involving either one or two intruders were randomized in such a way that each suggestive SAA display was paired with each traffic engagement an equal number of times. Following the completion of each trial, participants completed a subjective questionnaire, which garnered feedback on the usefulness of each display and the autonomous avoidance maneuver as well as display ranking data. After completing all six trials, participants completed a final questionnaire allowing participants to score individual aspects of each display.

3.6 Data Analysis

Data was analyzed utilizing multiple repeated-measures Analyses of Variance (ANOVAs), t-tests, and chi-square goodness-of-fit tests. The dependent variables included Well Clear violation rate, time from maneuver input to predicted loss of Well Clear (LoWC), and subjective display rankings. An alpha level of .05 was used for all analyses to establish statistical significance.

4.0 RESULTS

4.1 Objective Results

4.1.1 Well Clear Violations. Well Clear violation rate was used as the primary measure of performance in this study. A 3 (display type: Banding, Probing & Dual Perspective) X 2 (automation threshold: Well Clear & NMAC) repeated-measures ANOVA revealed that neither display type, $F(2, 42) = .42$, $p > .05$, nor automation threshold, $F(1, 21) = .19$, $p > .05$, had a significant effect on performance (Figure 7). Overall, Well Clear violations were rare with only 13.6% of trials resulting in a violation of Well Clear.

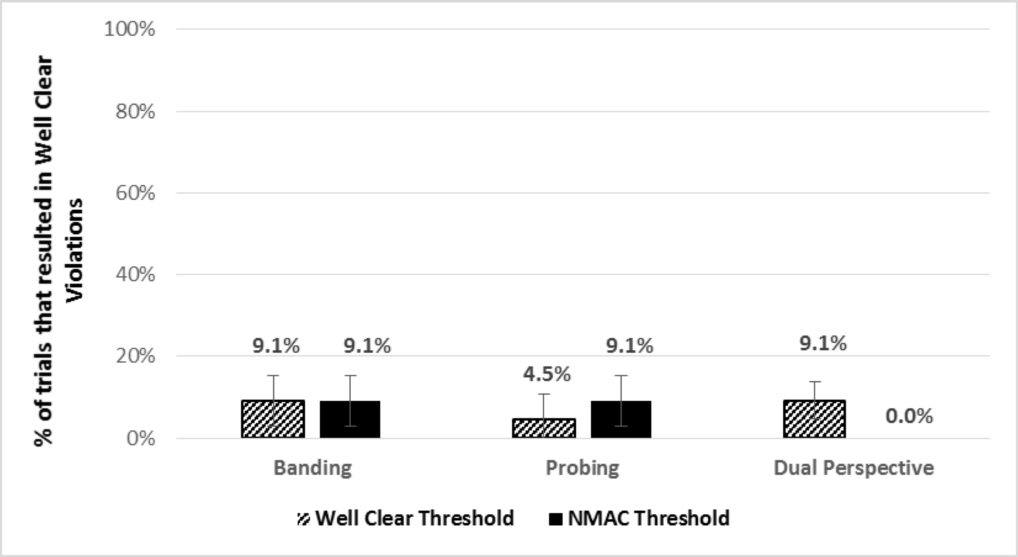


Figure 7. Prevalence of Well Clear Violations

That being said, a 2 sample t-test revealed that of those Well Clear violations that occurred more time was spent in violation of Well Clear when the automation threshold was set at NMAC rather than Well Clear, $t = 4.73$ $df = 7$, $p < .05$ (Figure 8). Thus, earlier onset of automation support enabled less time in violation of Well Clear space.

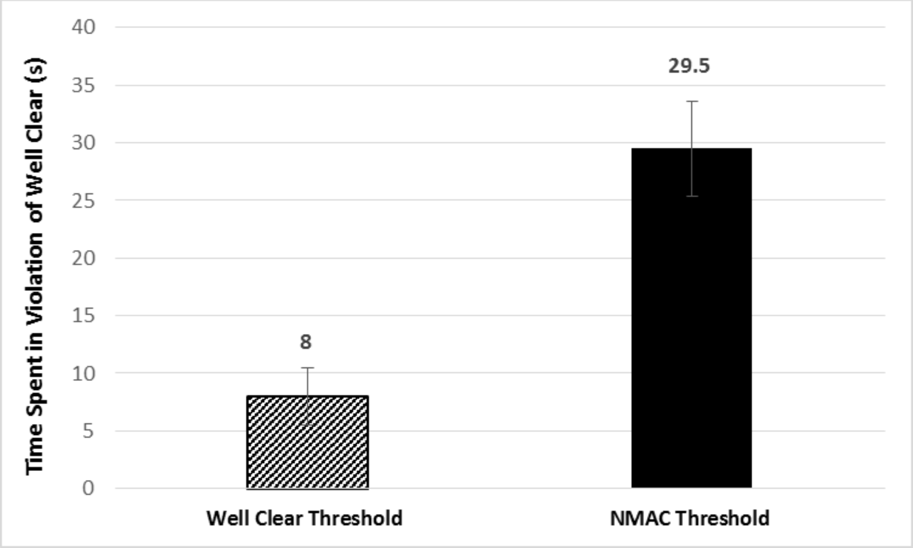


Figure 8. Time Spent in Violation of Well Clear

4.1.2 Pilots vs. SAA Algorithm Maneuver Behavior. Although the participants tended to maneuver earlier than the automation, the type of maneuvers being executed by the participants and the automation were similar. When further investigated the automation was found to maneuver in the same direction as the participants in five out of the six traffic engagements. Figure 9 shows the participants maneuver choices in comparison to JOCA's maneuver choice for Engagement 2, which involved two intruders approaching from the same side of ownship. The participant's maneuver choices are represented by dots and JOCA's maneuver choice is represented by a triangle. Of the 20 participants who responded to this engagement, ten chose to climb 500 feet to avoid the traffic. JOCA very similarly chose to slightly turn to the right and climb 500 feet.

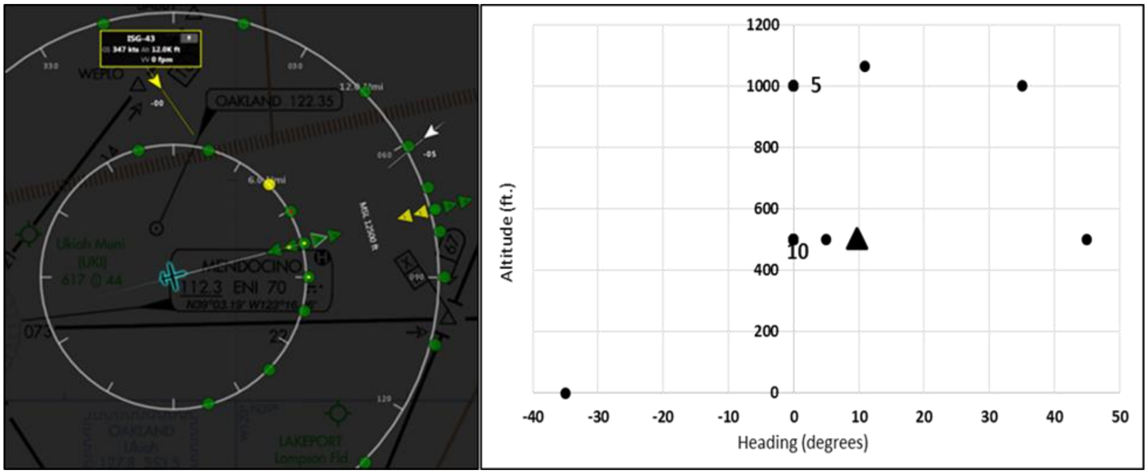


Figure 9. Pilot and SAA Maneuver Algorithm Maneuver Choice Breakdown for Engagement 2

4.2 Subjective Results

4.2.1 Suggestive Display Rankings. After completing the study participants ranked the suggestive displays from 1-3 in terms of preference with 1 being their least favorite and 3 being their favorite. A one-way ANOVA revealed display type did not have a significant effect on display ranking, F(2, 63) = 2.24, p > .05 (Figure 10).

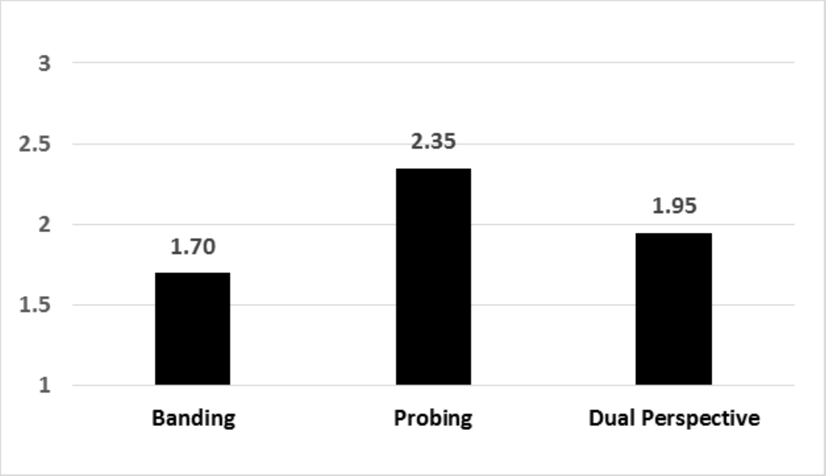


Figure 10. Average Display Rankings

4.2.2 Automation Threshold Preference. Upon completion of the study participants were also asked whether they preferred the Well Clear or NMAC automation threshold. Although the preference was not significant, of the 20 participants who responded eight preferred the Well Clear threshold and 12 preferred the NMAC threshold, t = .89 df = 19, p > .05.

4.2.3 Transition to Automation Display Features. Participants scored the transition to automation display features from 1-4 in terms of usefulness with 1 being "Not Useful" and 4 being "Extremely Useful". A chi-square goodness-of-fit was performed to determine that scores were not equally distributed in the population, X2(3, N = 20) = 10.8, p < .05 with the majority of participants scoring the transition to automation display elements as "Extremely Useful" (Figure 11).

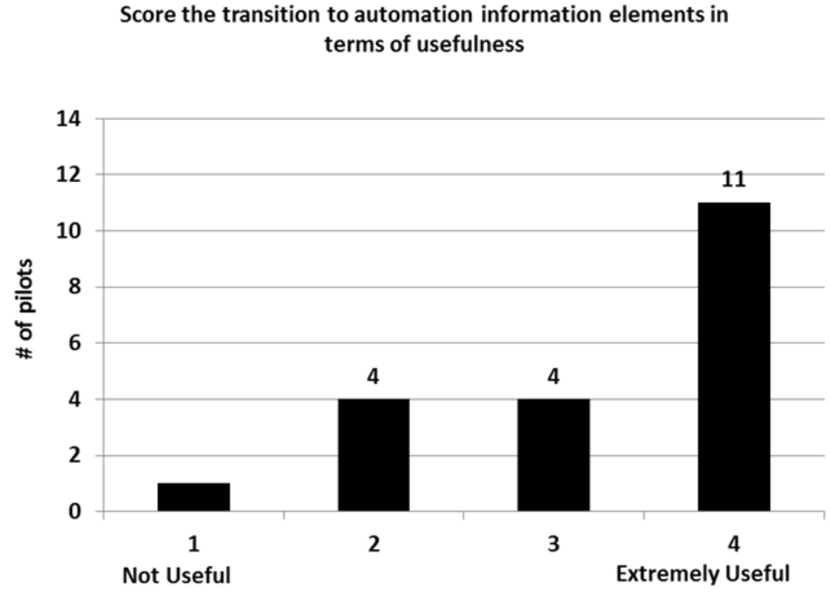


Figure 11. Transition to Automation Display Feature Scores

When asked if any additional information should be provided on the DAA display to facilitate a successful transfer of control, participants said they would like to know not only when the SAA maneuver algorithm is going to take over but also what maneuver it plans to execute. With that additional piece of information, the participants requested the ability to execute the planned maneuver prior to the countdown reaching zero via a button click. Lastly, they said they would like the aural cues to complement the textbox and vectors by indicating the SAA maneuver algorithm's commanded maneuver such as "climbing, climbing".

4.2.4 Automated Response Ratings. Participants were additionally tasked with providing subjective feedback on the effectiveness of the automated maneuver. Figure 12 shows the participants' responses when asked to score their agreeableness with the statement "The automated maneuver was able to maintain adequate separation". A chi-square goodness-of-fit was performed to determine that scores were not equally distributed in the population, $X^2(4, N = 22) = 14.36, p < .05$ (Figure 14) with the majority of participants indicating that they "Somewhat Agreed" with the statement. Written explanations such as "The auto maneuver made good decisions about how to maneuver, just not timely" indicate that participants could agree with the SAA algorithm's chosen maneuver but felt the maneuver wasn't executed early enough.

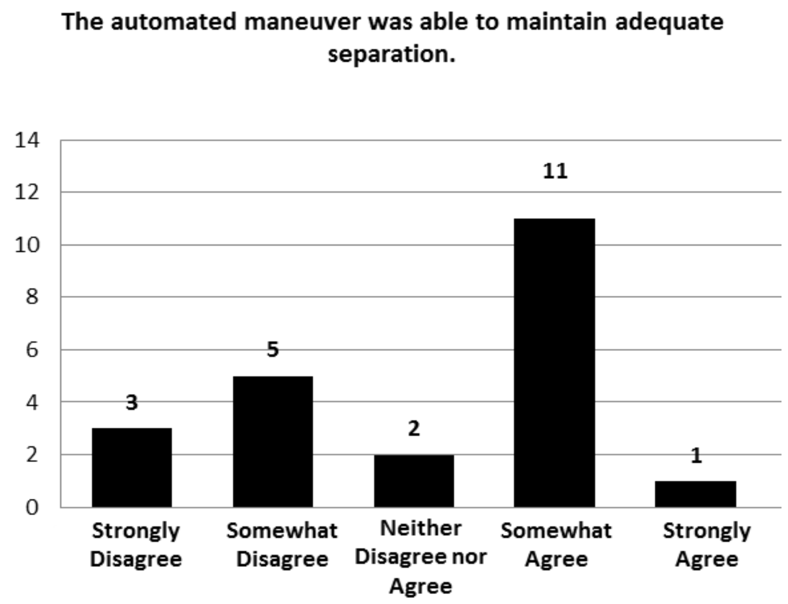


Figure 12. Automated Response Ratings

5.0 DISCUSSION

5.1 Hypothesis 1: Display Transparency

Our first hypothesis suggesting that those displays with enhanced algorithm transparency would outperform the display with less insight into the advanced SAA algorithm was not supported. Objectively, all three suggestive displays performed the same despite varying look ahead times and combo maneuver depiction capabilities. The probing and dual perspective displays tended to be ranked higher by participants than the banding display but this preference was not significant. The overall low level of well clear violations implies that each display, even the more basic banding display, afforded the participants with a proper level of understanding in regards to the maneuver algorithm's intent, performance, future plans, and reasoning process. The banding display might have been more basic and one-dimensional in terms of maneuver guidance presentation but the transparency "threshold" needed to result in appropriate automation usage, which is defined as both high rates of proper use when automation is accurate and high rates of proper disuse when it's not, was met (Chen et al., 2014). This in turn mitigated the decrease in performance we expected to see. The data suggests that those displays designed and successfully tested with less advanced SAA algorithms in mind still have merit even with more advanced SAA algorithms. That being said, it's also possible that the transition to automation features, which were included in each display, provided adequate transparency information and display effects were washed out as a result. Future studies plan to examine these displays under more stressful conditions that could reveal display shortcomings. Such conditions might include a greater number of intruders per encounter with dynamically varying routes, military airspace environments, uncertainty variables, and increased operator workload.

5.2 Hypothesis 2: Automation Thresholds

In regard to when the SAA algorithm would step in and autonomously maneuver the aircraft, we hypothesized that automation support at the farther out Well Clear threshold would lead to better avoidance performance than if this were to occur at the closer in NMAC threshold. Though well clear violation prevalence was the same across both automation thresholds, this hypothesis was supported by the time spent in violation of Well Clear data. When those Well Clear violations that occurred were further investigated, time spent in violation of Well Clear was found to be significantly less when the SAA algorithm was available to assist participants at the Well Clear automation threshold instead of the NMAC threshold. This finding suggests that while Well Clear violations might be rare, when they occur having automation available at the Well Clear threshold to assist the pilot mitigates the severity of the violation. Future research may examine adjustable thresholds of automation that would allow operators to adjust when automation would take over based on mission constraints.

5.3 Hypothesis 3: Pilot vs. SAA Algorithm Behavior

Lastly, we hypothesized that because the SAA algorithm used in this study was originally designed for machine to machine interaction, the participants and the SAA algorithm would react dissimilarly to traffic engagements in terms of maneuver time and maneuver type. The participants did indeed maneuver significantly earlier than the SAA algorithm in relation to the predicted loss of Well Clear. That being said, when the type of maneuvers being performed by the SAA algorithm were compared to the participants' maneuvers across each engagement they were found to be quite similar. This piece of data does not support our hypothesis. Instead, it suggests that although the SAA algorithm might maneuver later for enhanced efficiency, when it does actually choose to maneuver the type of maneuvers being executed are similar in direction and magnitude to operators' maneuvers. Feedback on the transition to automation features revealed a desire for a display function that would allow the operator to execute the algorithm suggested maneuver prior to the end of the countdown, implying once again that pilots tended to agree with the maneuver type but not the timing of it. Continued support and research of the SAA algorithm will focus on defining the operational role and optimizing for human-machine interaction.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The current study demonstrated the display and performance implications of integrating an advanced SAA algorithm. Despite the use of an SAA algorithm with advanced features, the baseline display, Banding, performed just as well as the two new novel display concepts. Based on these results, the additional algorithm transparency features included in the Dual Perspective and Probing displays such as the pimento logic, combo maneuvers and 2nd stitch probe observability, while useful, cannot be constituted as being a requirement for adequate performance. In regards to performance implications, though violations were consistent throughout both automation thresholds, a deeper analysis revealed that the Well Clear threshold paired with the algorithm resulted in less time spent in violation of Well Clear. Lastly, despite the algorithm maneuvering far later than when the operators preferred, it maneuvered in a similar fashion. Further research will aim at creating more complex engagements and operational scenarios where the increased transparency may be of use and help tease apart any existing differences amongst SAA displays. Furthermore, incorporation of adjustable automation thresholds rather than one or the other may prove to be the best solution in these more complex environments.

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8.0 LIST OF ACRONYMS

UAS = Unmanned Aerial Systems

NAS = National Airspace System

SAA= Sense and Avoid Display

NMAC = Near Mid-Air Collision

DoD = Department of Defense

CPA = Closest Point of Approach

NASA = National Aeronautics and Space Administration

JOCA = Jointly Optimal Conflict Avoidance

IFR = Instrument Flight Rules

IRB = Institutional Review Board

VSCS = Vigilant Spirit Control Station

TSD = Tactical Situation Display

HMD = Horizontal Miss Distance

LoWC = Loss of Well Clear

ANOVA = Analysis of Variance

ATC = Air Traffic Control