

CHAPTER XX

Varying Levels of Automation on UAS Operator Responses to Traffic Resolution Advisories in Civil Airspace

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ABSTRACT

Continuing demand for the use of Unmanned Aircraft Systems (UAS) has put increasing pressure on operations in civil airspace. The need to fly UAS in the National Airspace System (NAS) in order to perform missions vital to national security and defense, emergency management, and science is increasing at a rapid pace. In order to ensure safe operations in the NAS, operators of unmanned aircraft, like those of manned aircraft, may be required to maintain separation assurance and avoid loss of separation with other aircraft while performing their mission tasks. This experiment investigated the effects of varying levels of automation on UAS operator performance and workload while responding to conflict resolution instructions provided by the Tactical Collision Avoidance System II (TCAS II) during a UAS mission in high-density airspace. The purpose of this study was not to investigate the safety of using TCAS II on UAS, but rather to examine the effect of automation on the ability of operators to respond to traffic collision alerts. Six licensed pilots were recruited to act as UAS operators for this study. Operators were instructed to follow a specified mission flight path, while maintaining radio contact with Air Traffic Control and responding to TCAS II resolution advisories. Operators flew four, 45 minute, experimental missions with four different levels of automation: Manual, Knobs, Management by Exception, and Fully Automated. All

missions included TCAS II Resolution Advisories (RAs) that required operator attention and rerouting. Operator compliance and reaction time to RAs was measured, and post-run NASA-TLX ratings were collected to measure workload. Results showed significantly higher compliance rates, faster responses to TCAS II alerts, as well as less preemptive operator actions when higher levels of automation are implemented. Physical and Temporal ratings of workload were significantly higher in the Manual condition than in the Management by Exception and Fully Automated conditions.

Keywords: unmanned systems, collision avoidance, automation

1 INTRODUCTION

Continuous demand for the use of Unmanned Aircraft Systems (UAS) has put increasing pressure on airspace operations in civil airspace. This demand is driven by two main advantages that UAS have over manned aircraft, perceived cost efficiency and the minimization of risk to pilots' lives (Gertler, 2012). The need to fly UAS in the National Airspace System (NAS) in order to perform missions vital to national security and defense, emergency management, and science is increasing at a rapid pace due to the foreseen advantages of their use. In addition to limiting UAS usage for civilian applications, current Federal Aviation Administration (FAA) restrictions on UAS access to the NAS constrain the U.S. military's ability to fulfill regular training requirements to prepare UAS operators for combat (DoD UAS ExCom NAS Access Working Group, 2010).

In order to ensure safe operations in the NAS, operators of unmanned aircraft, like those of manned aircraft, may be required to maintain separation assurance and avoid loss of separation and conflicts with other aircraft while performing their mission tasks. A commonly used conflict avoidance measure for manned aircraft is TCAS II, or the Tactical Collision Avoidance System. TCAS II is a transponder based system that provides Traffic Advisories (TAs) to alert the pilot of incoming traffic, and Resolution Advisories (RAs) to provide pilots with instructions for avoiding conflicts within a five second time limit (FAA, 2001). Resolution Advisories provided by TCAS II are limited to vertical maneuvers only; examples include "Climb, Climb" and "Descend, Descend". While the FAA has ruled TCAS II alone to be unacceptable for UAS flight due to latencies that are inherent to UAS operation and the differing flight characteristics from manned aircraft (FAA, 2011), it is reasonable to expect that a TCAS II – like system could be part of a layered solution involving an integrated traffic display and conflict alerting system.

Those latencies present in UAS operations may create the need for automation to assist operators in responding successfully to conflict alerts, regardless of the conflict avoidance system, or suite of systems, used to provide them. The wide variability of automation capabilities in current unmanned systems raises the question about the effect of human-automation interaction on the ability of operators to respond safely and timely to conflict alerts. Some present day UAS

(e.g. MQ-1 Predator) require manual control of the flight control systems, and operator tasks closely resemble those traditionally associated with manual flying. Other UAS (e.g. RQ-4 Global Hawk) are highly automated, with operators flying in pre-programmed waypoint-to-waypoint navigation mode under a supervisory capacity. Most current systems, however, fall somewhere in between fully manual and fully automated with a wide variety of partially-automated control and navigation interfaces. When latencies are present in the control loop, it becomes important to know whether operators can respond quickly enough to potential conflicts given the type of control input and automation capability present.

This experiment investigated the effects of varying levels of automation on UAS operator performance and workload while responding to conflict resolution instructions provided by a Tactical Collision Avoidance System II (TCAS II) during a UAS mission in high-density airspace. The purpose of this study was not to investigate the safety of using TCAS II on UAS, but rather to examine the effect of automation on the ability of operators to respond to traffic collision alerts provided by a commonly used system.

2 METHOD

2.1 Participants

Six pilots were recruited to participate in this study. All were males (averaged 29.5 years) with an average of 2727 flight hours. Total flight hours ranged from 250 to 5300 hours. No pilots reported military or UAS flight experience. Eligibility was limited to participants who had normal or corrected to normal vision and were under 40 years old. Participants were required for approximately seven hours each and were compensated for their participation in the study.

2.2 Displays Setup

Participants were given two computer monitors to observe and manipulate: the Multiple-UAS Simulator (MUSIM) on the right, and the Ames 3D Cockpit Situation Display (CSD) on the left (Figure 1).

Multiple-UAS Simulator (MUSIM). This experiment used the Multiple-UAS Simulator (MUSIM), a full description can be found in Fern & Shively (2009). The current simulation configuration of MUSIM differed only slightly in that it utilized a 1:1 operator to vehicle interface with a generic fixed wing flight control model input with generic Mid-Altitude Long Endurance (MALE) UAS parameters. Ownship airspeed was fixed at 90 kts for the entire experiment. MUSIM was separated into four Graphical User Interfaces (GUIs): a map display indicated the position and flight path of the UAS in purple waypoints, a multi-function display (MFD) indicated UAS status and behavior, a TCAS II (Tactical Collision Avoidance System II) alert box provided textual and auditory Traffic Advisories (TAs) and Resolution Advisories (RAs), and a timer.

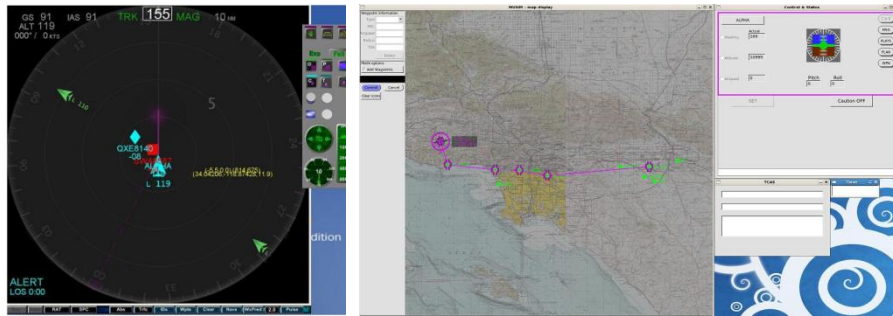


Figure 1 Displays set up with Multiple-UAS Simulator (MUSIM) (right) and Ames 3D Cockpit Situation Display with traffic information and TCAS II alerts (left). MUSIM interfaces include the map display (left), MFD (top right), TCAS alert box (lower right) and timer (far right).

Ames 3D Cockpit Situation Display (CSD). The Ames 3D Cockpit Situation Display was used to display TCAS II information in its basic 2D planar view (for a full description see Granada, Dao, Wong, Johnson & Battiste, 2005). The CSD had an ownship-centric view of surrounding airspace and utilized TCAS II symbology to alert operators of potential collisions. Participants were able to adjust the horizontal viewing distance from 10-640 nm, though no other manipulations were allowed on the CSD during this experiment.

2.3 Experimental Design and Mission Details

A within-subjects design was used to study operator performance and workload measures while flying a signal intelligence mission using a MALE UAS in high density Southern California TRACON airspace (LAX terminal area). Four different levels of automation for responding to TCAS II RAs were counterbalanced across four different mission flight paths.

Levels of Automation. Operators were given four different levels of automation to assist them in responding to TCAS II RAs: Manual, Knobs, Management by Exception and Fully Automated. In the Manual condition, operators flew the UAS in a waypoint-to-waypoint control mode. This was the baseline control mode for all conditions. Flight paths were edited by clicking each waypoint individually to activate the editing function. Once in editing mode, new altitudes were input manually and waypoints were clicked and dragged to new locations. In order to respond to an RA in the Manual condition, the operator would click on the next waypoint, manually input the new altitude, and commit the change. In Knobs, operators utilized the MFD Control and Status Page to quickly edit the altitude of the aircraft when an RA was received. Use of the Knobs input automatically applied the altitude change to the next waypoint on the aircraft's path, and was introduced as a "quick response" control option similar to dialing an analog knob in a cockpit. To change additional waypoints on the flight path, operators had to use the Manual control mode. In Management by Exception, participants either accepted or rejected

an automated altitude edit in the MUSIM TCAS II alert box when RAs were received. In the Fully Automated condition, altitude changes in response to RAs were automatically applied, with feedback provided to the operator of the altitude change in the MUSIM TCAS II alert box. All automated responses were in compliance with the RA instructions. In both the Management by Exception and Fully Automated conditions, all other route edits not in response to RAs were done through the Manual control mode.

Missions. Four training and four experimental missions were developed for this experiment. Training scenarios were 10 minutes long, and provided rerouting practice for the operators in the four different levels of automation. Experimental missions were 45 minutes long and differed only in the assigned waypoints and altitudes in the flight path that the operator was instructed to follow. All missions included TCAS II alerts that required operator attention and rerouting for RAs, though timing of conflicts and severity differed between missions to reduce predictability.

Mission Objectives. Participants were instructed to fly a signal intelligence mission with a MALE UAS in Southern California TRACON airspace with three mission objectives: 1) to fly the assigned mission flight path as closely as possible, 2) to respond to TCAS II alerts for collision avoidance by either climbing or descending in accordance with the Resolution Advisory, and 3) to communicate with Air Traffic Control (ATC). The first objective required operators to fly through predetermined mission flight paths while maintaining set altitudes at each waypoint and remaining as close to the original flight path as possible. The second objective required operators to monitor the TCAS II alerts on both the MUSIM and CSD displays and reroute the UAS's path to avoid conflicts while staying as close as possible to the original route. The third objective required operators to maintain radio contact with ATC while flying their route; tasks included calling in altitude requests, flight path edits, waypoint check-ins and responding to any received ATC communications.

2.4 Procedure

Participants were required to fill out an informed consent form and a demographic survey. Training was given to the operators before each experimental condition, with workload and situation awareness probes administered throughout.

Training Sessions. Operators were given a short briefing introducing MUSIM, the CSD and mission objectives after completing paperwork. Self-paced PowerPoint slides were provided before each experimental session detailing how to edit waypoints and altitudes appropriately for each condition. Training scenarios were then completed and lasted 10 minutes.

Experimental Sessions. The experimental sessions were blocked by level of automation and flight path using a Latin Square. Participants completed four experimental missions during the simulation. In each mission, operators received workload probes after each RA, administered verbally by the experimenter. Before each scenario, participants were given a practice mission to familiarize themselves

with the level of automation present. After each scenario, participants completed a NASA-TLX (Hart & Staveland, 1988) to measure workload and a 10-D SART (Situation Awareness Rating Technique; Selcon, Taylor, & Koritas, 1991) to measure situation awareness. At the end of the day, operators completed a Post-Simulation Questionnaire asking more in depth questions on workload and SA.

3 MEASURES

3.1 Objective Performance

Response Time. Response Time (RT) to RAs was measured in seconds from when the TCAS II alert was given until the operator committed a flight path change in the Manual and Knobs conditions. In the Management by Exception condition, RT was measured in seconds from when the operator was alerted of the RA to when they responded by clicking either “Accept,” or “Reject,” on the MUSIM TCAS alert box. If the operators did not respond within 5 seconds, the alert box timed out and automatically adjusted the altitude of the UAS. Reaction Time was not measured in the Fully Automated condition as operators did not need to respond to the RAs.

Operator Response Rate. Operator Response Rate measured the percentage of RAs that operators responded to (correctly or incorrectly) out of the total that occurred.

Compliance Rate. Compliance Rate was measured as the percentage of RAs that operators correctly complied with out of the total number that occurred.

Pre-Emptive Response Rate. Pre-Emptive Response Rate was measured as the percentage of times that the operator began a route edit in anticipation of an RA out of the total number of RAs that he responded to.

3.2 Subjective Ratings

NASA TLX. Workload was measured post-scenario with a 10-point NASA TLX. Participants rated their workload on six dimensions: Mental Demands, Physical Demands, Temporal Demands, Performance, Effort and Frustration.

Additional Measures. Additional Subjective Ratings were collected, though not discussed in this paper. Additional measures include the 10-D SART, workload probes administered during trials, a post-trial questionnaire and a post-simulation questionnaire that were given to further measure workload and situation awareness.

4 RESULTS

The data were analyzed using a one-way repeated measures analysis of variance (ANOVA) with Levels of Automation as the independent variable. Post hoc analyses utilized Bonferroni pair-wise comparisons. The results are organized by type of measure.

4.1 Objective Performance

Response Time. Response times to TCAS II alerts were found to be significantly faster in the Management by Exception condition ($M = 3.45$; $SE = .35$) compared to both Knobs ($M = 12.20$; $SE = 2.56$) and Manual ($M = 10.75$; $SE = 1.44$), $F(2, 12) = 8.408$, $p < .05$ (Figure 2).

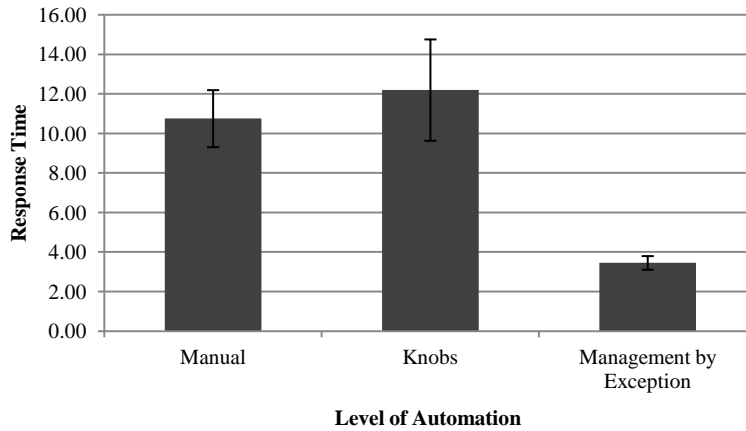


Figure 2 Response Time to TCAS II alerts by Level of Automation

Operator Response Rate. There was not a significant difference in operator response rates across the different conditions, $F(2, 12) = 2.602$, $p = .115$. However, there appeared to be a trend toward higher response rates in Management by Exception ($M = 95.92$; $SE = 2.64$) than in both Manual ($M = 85.86$; $SE = 4.09$) and Knobs ($M = 74.40$; $SE = 10.25$) (Figure 3).

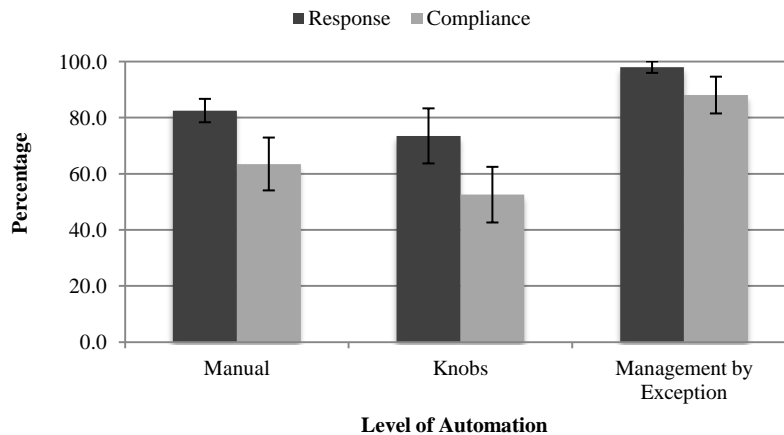


Figure 3 Response and compliance rates by level of automation.

Compliance Rate. Compliance rates for Management by Exception ($M = 89.71$; $SE = 6.04$) were significantly higher than both Manual ($M = 74.40$; $SE = 10.58$) and Knobs ($M = 63.78$; $SE = 12.27$), $F(2, 12) = 7.233$, $p < .01$ (Figure 3). Several reasons were noted for noncompliance; operators did not feel a collision would occur, horizontal route edits were performed instead of vertical, and accidental inputs of wrong altitudes were made.

Pre-Emptive Response Rate. Operators made significantly more pre-emptive responses in the Manual condition ($M = 6.21$; $SE = 2.96$) and the Knobs condition ($M = 42.09$; $SE = 8.20$) than in Management by Exception ($M = 6.20$; $SE = 2.96$), $F(2, 12) = 8.705$, $p < .01$.

4.2 Subjective Ratings

NASA TLX. Significant differences between the levels of automation were found in the physical and temporal dimensions of workload, $F(3, 18) = 3.358$, $p < .05$, and $F(3, 18) = 4.078$, $p < .05$, respectively (Figure 4). Ratings of physical workload were significantly higher for Manual ($M = 3.43$; $SE = 1.02$) compared to Knobs ($M = 2.57$; $SE = 1.04$), Management by Exception ($M = 2.21$; $SE = .69$), and Fully Automated ($M = 2.29$; $SE = .68$). Ratings on temporal workload were significantly higher for Manual ($M = 6.00$; $SE = .59$), compared to Knobs ($M = 3.50$; $SE = .29$) and Fully Automated ($M = 3.93$; $SE = .93$). Ratings of temporal workload in Management by Exception ($M = 4.43$; $SE = 1.09$) were not found to be significantly different than any of the other levels of automation.

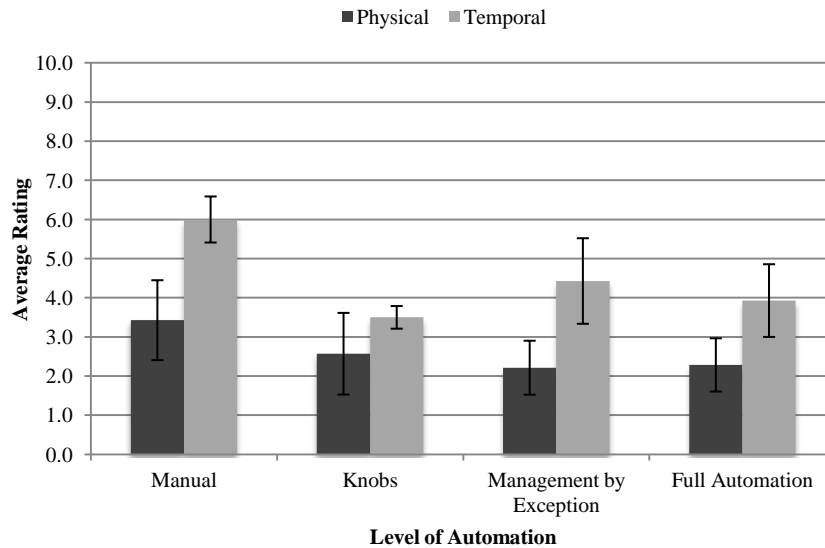


Figure 4 NASA-TLX ratings on the Physical and Temporal dimensions of workload by level of automation.

5 DISCUSSION

In order for UAS to safely operate in the NAS, they must be able to successfully avoid conflicts and respond appropriately when collisions are imminent. This study examined the effects of varying levels of automation on the ability of UAS operators to respond to traffic collision alerts in high-density airspace. The results indicate that response times and compliance rates for unmanned aircraft operating with lower levels of automation could be unacceptable in the NAS environment. The required five-second or less response time was exceeded in both the Manual and Knobs levels of automation by more than five seconds on average. In the event that a UAS is relying on satellite communication and data links, it will have additional operational delays of up to two seconds. This could create an aircraft response time to resolution advisories of 12 seconds or more; over twice the current five-second standard for manned aircraft.

Current regulations allow for noncompliance with TCAS II alerts only when pilots have the conflicting aircraft in visual sight and can ensure separation (FAA, 2001). Although difficult to find accurate reports for actual TCAS II compliance rates for manned aircraft, compliance with RAs has been estimated between 50 – 60%. This is supported by Olson & Olszta (2010), who found a compliance range of 41 – 59%, and Pritchett & Hansman (1997) who reported approximately 61% of pilots complying within the five second limit, and a compliance range of 33 – 71% when including pilots who began to edit for RAs preemptively or late.

Compliance rates across levels of automation in this experiment often exceeded these previously reported rates, with averages for Manual, Knobs and Management by Exception being 74%, 64% and 90%, respectively. Possible reasons for this difference include among others: a lack of an out-the-window view to be used in visual separation (in which application of the FAA regulation to UAS operation should result in 100% compliance); unfamiliarity with the flight characteristics of a MALE UAS causing a reliance on automated, opposed to personal, collision avoidance judgments; taking longer than five seconds to decide on a course of action in the Management by Exception condition (forcing the automation to comply with the resolution advisory); trust in automation; and ease of use for conflict avoidance in the higher automated conditions. Further research is required to better understand the benefits of automation for increased safety and collision avoidance while operating in the NAS.

Interestingly, the Manual condition was found to perform better than the Knobs condition overall with a lower average response time, and a higher average response and compliance rate, despite Knobs being introduced as a “quick response” control input. The lower performance for Knobs goes with a trend of more preemptive, or anticipatory, responses made in that condition. Operators remarked on how the Manual and Knobs conditions took “too long,” to perform the edits required for collision avoidance, and would begin to preemptively edit before an RA was given in order to avoid the impending collision.

Overall, slow response times for Manual and Knobs, combined with 1.5 times greater compliance rates for Management by Exception illustrate the need for some

level of automation to assist UAS operators in responding quickly and appropriately to collision avoidance alerting while operating in the NAS. However, the lower workload scores for Management by Exception compared to the Fully Automated condition indicate a need for the operator to remain on the loop and capable of overriding the automation when necessary. Continued research on the effects of human-automation interaction on the safe operation of UAS in the NAS is needed if the demands for civil and public UAS operations are to be met.

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