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Airspace Deconfliction for UAS Operations

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Increased use of unmanned aerial systems (UAS) in combat zones has put mounting pressure on airspace operations. Interviews were conducted with military helicopter pilots, air traffic controllers, and UAS operators to better understand the current concept of operations for managing potential conflict between manned and unmanned aircraft during combat operations. Interviews with the UAS operators revealed limited situation awareness of the low altitude airspace picture. To address these issues, a graphical airspace display with basic conflict detection and alerting logic was developed. In simulation, this display was compared with a baseline textual display, derived from current operations as identified during the interviews. Operators controlled a single UAS in densely populated airspace and deconflicted with other aircraft while conducting a surveillance mission. Operators were evaluated on their ability to maintain separation assurance standards and deconflict with other aircraft. The graphical interface was found to improve operators' ability to maintain separation and perceived lower workload.

Due to ambiguities in the current low altitude airspace picture, airspace coordination procedures have evolved beyond published U.S. Army doctrine and field manuals. With the cooperation of the U.S. Army Unmanned Aerial Systems Training Center (TRADOC), Ft. Huachuca, AZ and Aviation Technical Test Center (ATTC), Ft. Rucker, AL, six UAS operators, five pilots, and six air traffic controllers with warfighter experience were interviewed on the planning and execution of a combat mission throughout all aviation mission phases. Structured interviews were recorded and summarized. Subjective ratings were collected from pilots and UAS operators to identify areas of perceived high workload during intense mission phases, when air-to-air conflict was most likely.

Interview findings were not intended to supersede any official concept of operations (CONOPs), but instead provide an understanding of the innovations and risks that the U.S. Army aviator faces when operating in the low level altitude airspace. Primarily, manned and unmanned aircraft are successfully deconflicted at HIDACZ airfields through horizontal separation, which channels vehicles down predictable flight paths. Predictability exposes low flying Army aviators to enemy targeting. As a matter of procedure, airfield throughput can be impacted when aviators are forcibly halted from arrivals and departures for UAS launches and recoveries.

Beyond the airfield, blanket altitudes, killboxes, and keypads are sufficient in separating manned and unmanned aircraft above the coordination altitude. mIRC chat is used effectively to communicate airspace clearances between controlling agencies and UAS operators. Discrete transponder squawk codes allow for identification, control, and deconfliction of aircraft by approach controllers. However, in aircraft without transponders (e.g., Raven UAV) or aircraft intentionally not transmitting position information below the coordination altitude, the risk of air-to-air collision increases. Below the coordination altitude, deconfliction is see-and-avoid using a Common Traffic Advisory Frequency (CTAF). Typically, small UAS operations and rotary wing aviators shared a common mission area and therefore were at risk for mid-air collision. Pilots are often unaware of small UAS daily operations because they are not listed in the Air Tasking Order (ATO) or Air Control Orders (ACOs).

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Recommendations from the aviators, UAS operators, and ATS personnel were collected and outlined to mitigate these low altitude airspace risks. The recommended technical solutions for aircraft deconfliction were: 1) an active traffic alert and collision avoidance system (TCAS) that emits position information and receives position information from transponder-equipped aircraft; 2) low altitude approach control radar; 3) look-down radar from an airborne platform; 4) fully integrated, near-real time Blue Force Tracker in all aircraft to include allied forces and civilian support aircraft; 5) UAS operator airspace displays to include manned and unmanned aircraft position with conflicting flight path trajectory and active ROZs affecting the planned mission; 6) an encrypted mode of communication for UAS and pilot communities to speak directly to deconflict flight paths.

As a direct result of these interviews, a graphical airspace display with basic conflict detection and alerting logic was developed to increase the amount and availability of airspace information to the pilot. It was hypothesized that the graphics display would decrease the total number and duration of conflict events (as detected by the detection and alerting logic) with other aircraft. Similarly, it was expected that since conflicts should be detected sooner, reaction time to initiate a flight path change to deconflict would also be faster in the graphics display condition. Lastly, the authors hypothesized that operators would be able to deconflict from other aircraft faster in the graphics display condition since they would be able to actually see the location of the conflicting aircraft when making flight path changes (rather than having to approximate it's actual location from the chat messages). In addition to the two display conditions, an audio condition was introduced in order to examine the possibility of interaction effects when a simple auditory tone was presented to the operator with a caution warning alert. It was expected that the auditory alert would likely improve performance, particularly in reaction time, in both display conditions, however it was not known if the performance benefits would be equivalent across the text and graphics-based displays.

Method

Participants

Twelve pilots were recruited to participate in this study. All 12 participants were male, with an age range of 20 to 40 years of age (M = 29.08). Participants were required to hold, at minimum, an active Private Pilot License. Total flight hours ranged from 540 to 6038 hours (M = 2754.42). None of the pilots had any military flight or UAS control experience. Eligibility was limited to participants who were right-handed and had normal or corrected-to-normal vision.

Multiple UAS Simulator (MUSIM)

Ground Control Station Hardware. This simulation was generated with a quad-core CPU using an NVidia GeForce GTX 280 video card, and 2GB RAM. The monitor used was a 30" Apple Cinema Display, with a display resolution of 2560X1600 and 24-bit color.

Software. This experiment was run on the openSuse 11.1 Linux operating system. MUSIM has the following software dependencies: 1) OpenSceneGraph for graphics and 2) FLTK for graphical user interface.

Terrain Database. A visual database was created using Creator Terrain Studio 2.0.2 and Creator 2.5.1. Terrain imagery was obtained from U.S. Geological Survey satellite photography. The simulation utilized 30-meter elevation data with 45-meter texture data in the lower resolution areas and 0.7-meter texture data in the high resolution areas. Three designated areas within the database were utilized for this experiment. These areas can be characterized as dense, urban terrain, or medium density, industrial terrain.

UAS Flight Model. Four generic flight models were used to emulate the ownship and traffic in this simulation: 1) a Shadow 200 with an average cruise speed of 80-90 kts, and a speed range of 70-130 kts was used to simulate the ownship as well as tactical UAS traffic; 2) a Predator B model with an average cruise speed of 75 kts and max speed of 220 kts was used to simulate a general aviation fixed wing aircraft; 3) a C-130 model (modified to simulate a Boeing 747) with an average cruise speed of 200 kts was used to simulate commercial aircraft; and 4) a generic helicopter model with the same mass as an OH-6A and variable cruise speed capabilities was used to simulate VTOL aircraft.

Operator Interface. This simulation utilized a 1:1 operator/vehicle ratio user interface, consisting of one sensor view, a 2D top-down map (or tactical situation) display with gridded overlay and manual waypoint editing GUI, an Air Vehicle (AV) control panel, and a chat room window (see figure 1). An optical mouse was used for navigation of operator control panels in the operator interface.

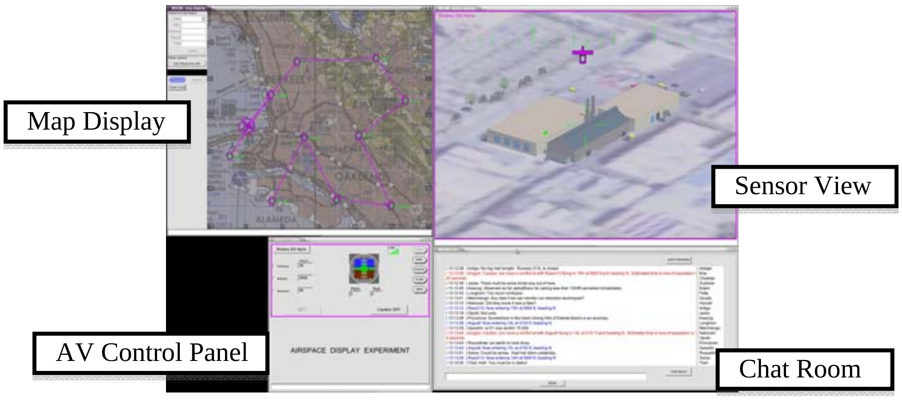

Figure 1. The MUSIM interface.

Payload and Cursor Controllers. The simulated sensor payload on each UAS was electro-optical only with three degrees of freedom (DOF) sensing capability, including 360deg pan capability and +45/-135 pitch limits. Zoom (y-axis) capabilities supported a progressive change in FOV from 2 to 16deg (x – 8x). Sensor slew rate was set at 60deg/second. The gimbaled sensor was operator-controlled via a 6-DOF 3Dconnexion SpaceExplorer input device. The SpaceExplorer utilizes 6-DOF sensing technology (x-, y-, z-axes, pitch, heading, and roll) in a pressure-sensitive device that requires right/left and up/down twisting motions to control the stare point of the payload.

Experimental Design

The present study utilized a within-subjects, repeated measures design to examine task performance and workload measures while conducting a reconnaissance mission and deconflicting with traffic in high density airspace. Two different airspace displays were compared across two audio alert conditions.

Airspace Displays. Two different airspace displays were developed for experimental comparison: textual and graphical. The textual was an Internet Relay Chat (mIRC) display that was designed based on current military UAS airspace operations as identified in the operational interviews. The graphical display was an integrated airspace display developed by overlaying graphical traffic information on the tactical map display.

In the text condition, operators were required to monitor the airspace mIRC chat room window located below the payload window (see Figure 1). All aircraft within the mission area of the UAS reported their location, via the chat room, as they transited grid locations. If the caution warning algorithm detected either a caution or warning level conflict, a message was sent to the operator from the air traffic controller, and repeated at 30 second intervals for as long as the conflict lasted.

In the graphical display condition, traffic and conflict information was presented to the operator on the tactical map display (see Figure 1). Non-conflicting aircraft were represented by white icons with rollover data tag information displaying aircraft identification (i.e., call sign), altitude and speed. Conflicting aircraft with 2 minute trajectory lines were displayed with color-coding according to alert level (e.g. yellow for caution, red for warning).

Audio alert. Two audio conditions were used for comparison: and off. In the audio alert condition, a simple tone was presented to the operator with the initial detection of all caution and warning level conflicts, regardless of display type

Caution Warning Algorithm. For this experiment, a predictive conflict detection caution/warning algorithm was developed based W.E. Kelly's work (1999), where conflict is defined as a "predicted violation of a separation assurance standard." The conflict algorithm uses instantaneous state vectors to calculate the closest point of approach and time remaining until separation standards are violated. If the closest point of approach is less than a stated minimum and time remaining to loss of separation is within a specified look-ahead window, then a conflict is declared.

Based on the Shadow Air Crew Training Manual separation standards, a cylindrical protection zone measuring 1000ft above and below with a 1000ft radius was defined around the ownship UAV. If another aircraft was within two minutes of entering the protection zone, based on instantaneous state vectors, a caution, predictive-level conflict was declared. If an aircraft breached the protection zone of the ownship, separation standards were lost and a warning, loss of separation-level conflict was declared. The algorithm was intended only to give conflict alerts, and not suggest conflict resolutions. Figure 2 illustrates the protection zone around the ownship UAS.

Figure 2. Shadow UAS separation assurance standards used to develop the caution warning algorithm.

Missions. Operators were tasked with flying a reconnaissance mission in an urban terrain scenario with 10 Named Areas of Interest (NAIs) and dense air traffic. The reconnaissance mission required the operator to set a flight path around the urban area in order to acquire imagery on each NAI. The ownship (Shadow 200) maintained a mission altitude of 6000ft and encountered aircraft of various types. One 10-minute practice session and eight 20-minute experimental missions were flown. Various target configurations at the NAIs and timing of conflict events were established. Fifteen conflict events with different aircraft types were programmed for each experimental mission. Operators' primary mission objective was to plan and fly a flight path around the 10 NAIs while maintaining safe separation from other aircraft. Deconfliction with other air traffic was managed by changing the ownship's waypoint headings. Operators were instructed that they were solely responsible for deconflicting with other aircraft (i.e. the aircraft would not change their own trajectories to move out of the way of the UAS). Their secondary mission objective was to collect intelligence, by identifying the number of targets at each of the NAIs.

Procedure

All participants were required to fill out an informed consent for minimal risk form and demographic survey intended to elicit information regarding participants flying experience and computing/gaming experience. Participant were then given a pilot briefing describing the MUSIM environment and the mission requirements. After the training material was presented, pilots were given the opportunity to fly MUSIM with no traffic in order to familiarize themselves with the simulation. Once participants indicated feeling comfortable with the simulation, they started the experimental sessions.

The experimental sessions were blocked and counter-balanced by display type so that participants received both the audio and non-audio conditions for one display type before being exposed to the second display type; the audio condition was also blocked within the display type. At the beginning of a testing block, the participant was trained for that particular display block (either mIRC or graphics), followed by a 10-minute practice mission. The practice mission was then followed by three 20-minute missions each for the audio and non-audio conditions for a total of six experimental missions per display and 12 for the entire session. Following each auditory alert block, the participants were asked to fill out a NASA-TLX workload rating form (Hart & Staveland, 1988).

Data Collection

Primary task performance. The primary task for this experiment was maintaining separation and managing deconfliction with other aircraft. The average number and duration (in seconds) of both caution and warning level conflicts were recorded. Reaction time and time to deconflict were also collected. Reaction time was measured from the time that the conflict alert was presented to the operator until he initiated a flight path change in

MUSIM. Time to deconflict was defined as the time from this initial change input until the alerting logic stopped, indicating that there was no longer a conflict.

Secondary task performance. The secondary task for this experiment was to identify the number of targets at each of the 10 NAIs in a mission. The percentage (%) of NAIs visited and the accuracy (%) of target identification were collected for this task.

Workload. A NASA-TLX was administered to the participants after each experimental block. Participants rated six dimensions of workload (mental, physical, temporal, performance, effort, and frustration) on a five-point scale. A composite score of was also calculated.

Results

The data was analyzed using a 2 (display: text, graphics) X 2 (audio alert: on, off) repeated measures analysis of variance (ANOVA). Post hoc analyses utilized Bonferonni pairwise comparisons. There were no significant effects of display or audio the secondary task measures, and significant interactions between display type and audio condition were found across any measures.

Primary Task

Number of conflicts. There was not a main effect of display type on the number of predictive conflicts. The average number of predictive conflicts encountered in the mIRC display condition did not differ significantly from the number encountered in the graphics display condition. However there was a main effect of display type on the number of loss of separation conflicts, $F(1, 11) = 30.415$, $p < .001$. There were significantly more loss of separation events in the mIRC condition ($M = 2.3$; $SD = 2.1$) than in the graphics condition ($M = .6$; $SD = .9$) (see Figure 3). There was no main effect of audio alert on the number of predictive or loss of separation conflicts.

Conflict Duration. There was no significant difference in the duration of predictive conflicts between the mIRC and graphics display conditions. However, as shown in Figure 4, the duration of loss of separation conflicts was significantly longer in the mIRC condition ($M = 18.19$; $SD = 11.09$) than in the graphics condition ($M = 11.31$; $SD = 5.27$), $F(1, 11) = 43.504$, $p < .001$. There was not a main effect of audio on duration of predictive or loss of separation conflicts.

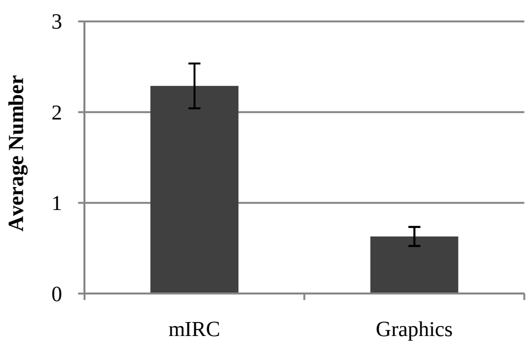

Figure 3. Number of loss of separation conflicts by display type.

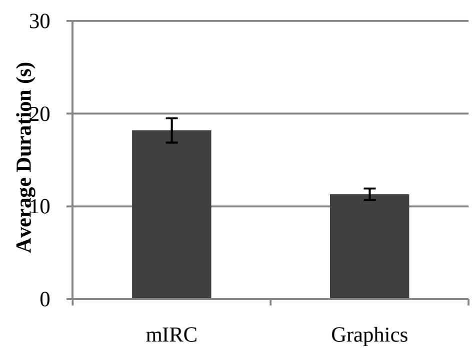

Figure 4. Average duration of loss of separation conflicts by display type.

Reaction time. There was a main effect of audio on reaction time to deconflict, $F(1, 11) = 12.213$, $p < .01$. Operators were significantly faster to react to conflict alerts when audio was present ($M = 17.53$; $SD = 8.19$) than when it was not ($M = 22.40$; $SD = 10.75$). There was not a significant main effect of display time on reaction time to deconflict from a conflict.

Time to deconflict. There was no main effect of display on the amount of time operators took to deconflict from other aircraft. Although operators appeared slightly slower with mIRC ($M = 20.13$; $SD = 15.77$) compared to graphics ($M = 15.26$; $SD = 6.74$), this difference was not significant. There was no significant main effect of audio on the amount of time it took operators to deconflict.

Workload

On the six dimensions of workload, there were significant main effects of display type on temporal, $F(1, 11) = 4.569$, $p < .05$, effort, $F(1, 11) = 10.160$, $p < .01$, and frustration ratings, $F(1, 11) = 12.294$, $p < .01$ (see Figure 4). Mean workload ratings on these dimensions were consistently higher in the mIRC condition (3.6, 4.1, and 3.1, respectively) than in the graphics conditions (2.9, 3.2, and 1.9). In addition, the overall composite score for workload was higher for mIRC ($M = 3.4$; $SD = .7$) than for graphics ($M = 2.6$; $SD = .6$), $F(1, 11) = 11.097$, $p < .01$. There were no significant main effects of audio on any of the six dimension or the composite score.

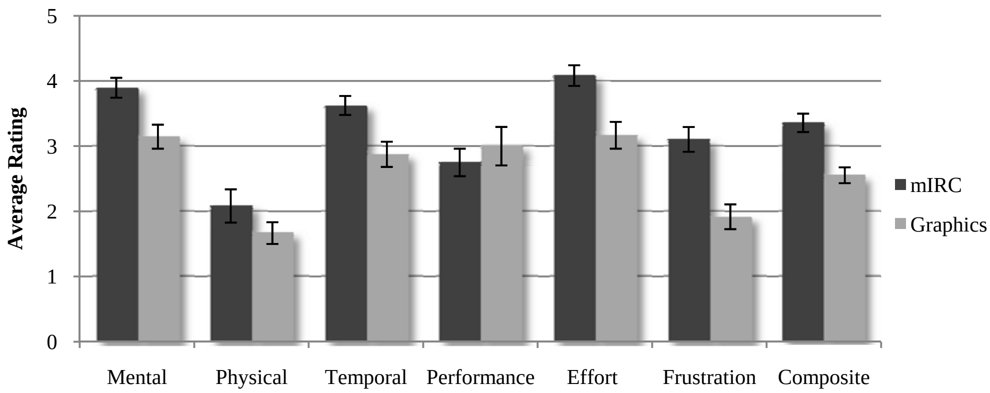

Figure 4. NASA-TLX ratings on the six workload dimensions and the overall composite score.

Discussion

The results of this experiment demonstrate the utility of a graphical airspace display to improve UAS operators' ability to maintain separation assurance standards and deconflict with other aircraft, while at the same time decreasing operator workload. This finding was evidenced by a reduced number of loss of separation events as well as a reduction in the duration of loss of separation conflicts. In addition, there were significant reductions in operator effort, time pressure and frustration when using the graphical display compared to the text display. Although there were no significant effects of display on reaction time to deconflict, time to deconflict or any of the secondary task measures, closer examination of the secondary task data reveals very high performance levels in both display groups. On average, operators visited 98% of the NAIs and reached 86% target identification accuracy across all missions. This data suggests that the secondary task was not difficult enough, and the lack of significant differences in performance measures may be a result of ceiling effects. Further evidence of this possibility is seen in the relatively low workload results; although there were significant differences in workload ratings, in general, workload scores were not very high.

Despite these challenges with the experimental design, the primary task and workload results give strong evidence to the need for a graphical user interface that presents airspace information to UAS operators, and serves as a basis for improving UAS operator airspace awareness both for military theater and civil operations. Follow on efforts will be needed to examine the effects of more challenging tasks, identify critical components of airspace SA, as well as explore different layouts and configurations that support optimal performance. Although mission profiles and requirements will differ, the results of this work will also inform new research on the design of user interfaces for civil airspace operations.

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