INITIAL TESTING OF THE UNCREWED AERIAL SYSTEM PILOT KIT (UASP-kit) IN OPERATIONAL SETTINGS

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Pilots for small uncrewed aerial systems (sUAS) are at a disadvantage for building situation awareness of the remote airspace in which they are flying, simply because they are distant from their vehicles. A tool to provide increased air traffic situation awareness for an sUAS pilot is being developed. The UAS pilot kit, "UASP-kit," is small and self-contained, with its chief capability being to collect and display Automatic Dependent Surveillance-Broadcast reports of local aircraft. UASP-kits were taken into the field, introduced to users during a training course, and then left with them for the summer fire season. sUAS pilots used the prototypes when it was appropriate throughout the summer. The UASP-kits were operational for a total of 79 flight-days. Users reported that the UASP-kits supported their situation awareness but also identified several usability issues. The findings contribute to validation of the UASP-kit, and support continuing the work to improve the tool and develop additional functionality.

The use of uncrewed aerial systems (UAS) is proliferating throughout many domains as the capabilities of these aircraft and recognition of their versatility increases. One example is the use of UAS within disaster and emergency response, and one branch of this is combatting wildland fire. The increasing number and severity of wildland fires over the last two decades (Hoover & Hanson, 2023; NIFC, 2022) have emphasized that new methods need to be explored to provide greater assistance to the firefighters working in wildland areas. One way to achieve this is to take advantage of technological developments to provide firefighters with strategic tools in addition to improved physical tools. Strategic tools, designed to assist awareness and decision making, could provide more, and better-organized, information to assist operational personnel to identify and select the most effective strategies and methods for fighting a fire.

The use of UAS by disaster and emergency response services is growing rapidly because, as their name describes, they remove the operator from the vehicle and thereby do not expose the remote pilot to the same risks as the aircraft. The remote operator or UAS pilot (UASP) is still subjected to the environmental hazards around a wildland fire, e.g., smoke, and must be aware of additional ground hazards, such as ground equipment. One tradeoff for a remote UAS pilot, however, is that they no longer have a wider view of aerial operations since they are not in the airspace. UASPs have to build airspace situation awareness (SA) from the information shared over the radio (and through briefings). In addition, if the UASP is operating a small UAS (sUAS), e.g., for Infrared (IR) imaging or controlled burn missions, the other aviators in crewed vehicles are unlikely to be able to see their sUAS vehicle. The burden is therefore on the UASP to stay clear of crewed aircraft.

NASA's Scalable Traffic Management for Emergency Response Operations (STEReO) research activity investigated developing a prototype tool that would assist sUAS pilots to maintain an awareness of the airspace in which their vehicle is operating. The initial ideas for such a tool were formulated in collaboration with the U.S. Forest Service (USFS) and CAL FIRE, during 2020, through two demonstrations and a series of discussions; for more details see Martin, et al. (2022). The necessary properties for a tool that supports UASP situation awareness are both physical and informational. The tool needs to operate in a communications-denied environment (without Wi-Fi or cellular connections) and be small and light enough for a person to transport it. It needs to be easy to use, to provide information about the airspace around the sUAS, and draw the UASP's attention to potential hazards in the airspace. The UAS Pilot-kit (UASP-kit) was designed through these discussions and is intended to meet these prerequisites.

Description of the First Prototype UASP-kit

The UAS Pilot-kit is a one-operator system that is small both in physical size and in its capabilities. As the aim of the UASP-kit is to provide increased air traffic situation awareness for one sUAS pilot, it is designed to be self-contained and portable. The components include a display and a communications infrastructure that collects Automatic Dependent Surveillance-Broadcast (ADS-B) messages to give the user a view of crewed vehicles in the surrounding airspace, especially when they are in areas of low connectivity with poor cell service. The first prototype was designed and built during the summer of 2021. It consists of an ADS-B data link receiver with a power over ethernet (POE) switch, a server, a power source, and a display. These are housed in a 21" by 32" ruggedized case. The view of traffic in the airspace is generated by receiving ADS-B messages from airborne traffic that are broadcasting their enhanced Global Positioning System (GPS) position to other traffic and to the ground (FAA, 2022). The ADS-B receiver (uAvionix, 2020) listens for and receives messages reported on the 978MHz and 1090MHz frequency bands. The messages are interpreted and displayed as icons on the UASP-kit's graphical user interface (GUI) (Figure 1), which is a touchscreen tablet. The JavaScript browser-based GUI application uses a base map, e.g., a satellite image, as a canvas on which the aircraft traffic is displayed. This interface has features to assist with interpretation of the display including aircraft icons to distinguish between types of aircraft, and a filter that allows the user to reduce the range of the ADS-B traffic shown. In addition, the UASP-kit can import and display a fire operations map onto the base map display and allow users to define an operational volume for an sUAS, which includes area, height, and location. The user can configure the UASP-kit to notify them when a situation requires their attention based on the proximity between ADS-B tracks and the operational volume of the sUAS.

After the UASP-kit prototype was built, and reviewed by Subject Matter Experts, it underwent two phases of field assessments to evaluate its performance in real-world settings and collect user feedback to direct future development of the UASP-kit. These two phases are described below.

Method for Field Data Collection

The first user-testing data were collected during a two-week spring sUAS prescribed burn (PB) training session that was hosted by the U.S. Forest Service. The second set of data was collected during the summer fire season of 2022 when the USFS and CAL FIRE used sUAS to help with their efforts to combat wildland fires.

Prescribed Burn Data Collection

During the spring of 2022, researchers from the STEReO team shadowed three units of UAS prescribed burn trainees as they traveled throughout the south-eastern U.S., conducting prescribed burns with sUAS as part of their hands-on training for certification. Each unit was comprised of six trainees and two instructors (18 UASP-kit users in total). The units set up the UASP-kits as they prepared their equipment (sUAS and Ground Control Station) for the day's flights, setting the operational volume dimensions and alerting dimensions to the sizes that they determined would be most useful each day.

While active, each UASP-kit recorded logs of the ADS-B messages received and the users' interactions with the display, i.e., those to set up the operational volume and the alerting. Feedback from users was gathered in an intentionally ad-hoc manner. Each research team had a list of prepared questions and topics of interest, e.g., questions asking about constructing situation awareness, usability of the UASP-kit and communications between team members. Researchers solicited feedback from the users when there was an opportunity and asked a selection of these questions to prompt conversation. User responses were hand-written by the research team and transcribed into a common spreadsheet.

Summer Fire Season Data Collection

Five UASP-kits were supplied to sUAS crews for their use during the summer fire season of 2022. sUAS crews (usually two to three people) set up the UASP-kits when they considered it appropriate, as they were on missions to fly sUAS to assist with control of wildland fires, mainly in the western U.S. While active, each UASP-kit recorded logs of the ADS-B messages received from crewed aircraft and the users' interactions with the display to set up the operational volume and the alerting. Twice during the summer fire season, feedback about the UASP-kit's usability was solicited from the UASPs – once via phone conversations and again at a second point in person as the logs were retrieved from the UASP-kits. During these conversations, the usability of the UASP-kit was the focus of the questions.

Comparison and Discussion of UASP-kit Settings and Usability

Three UASP-kits generated logs during the spring prescribed burn training event, with UASP-kit-1 being active for the most flight-days (14) and UASP-kit-2 showing the most alerts (76 total or approximately 60% of the alerts). Five UASP-kits were in the field and operational for the summer fire season, UASP-kit-5 was active for the most flight-days (26) with UASP-kit-4 showing the most alerts (72 or approximately 45% of the alerts).

During the prescribed burn data collection, three UASP-kits were used for 27 flight-days. Over the summer fire season, the UASP-kits were not active for all sUAS missions but were used on 52 flight-days. Because the number of flight-days differed a good amount between the prescribed burn and

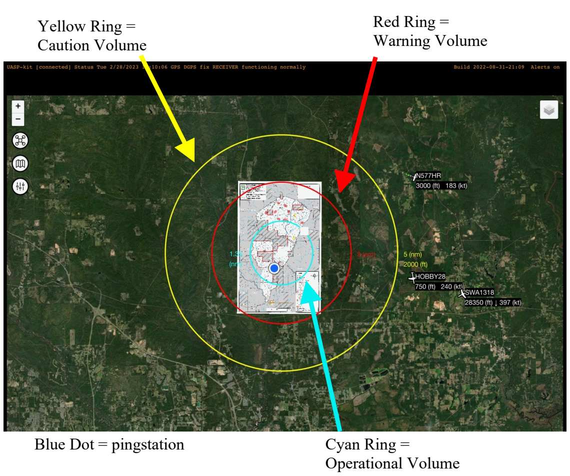

Figure 1. Image of the UASP-kit display showing caution and warning rings.

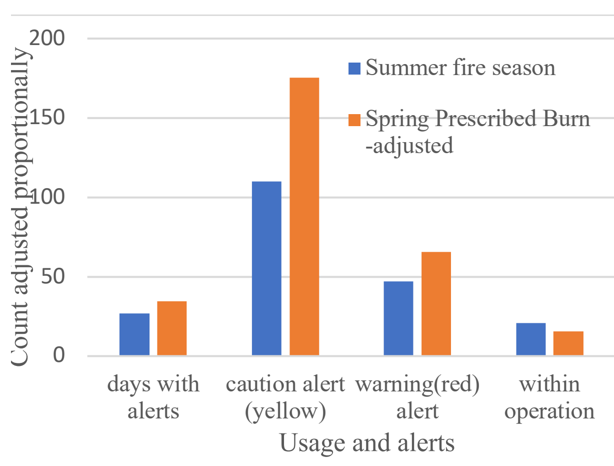

Figure 2. Proportionally adjusted UASP-kit usage by flight-day, and alerts generated to nearby aircraft.

summer season, the data from the prescribed burn were adjusted, in proportion with the difference, to allow for a comparison between the two data collection periods (see Figure 2). The UASP-kit traffic alerting was triggered on 66% of the flight-days during prescribed burns, alerting 91 times. During summer fire season, the UASP-kit alerting was triggered on 52% of the flight-days and alerted 110 times. All these alerts announced a crewed aircraft flying into the caution (yellow) alert volume defined by the user. During prescribed burns, 37% of the crewed aircraft continued to move closer to the UAS, flying into the warning (red) volume and a similar percentage of the aircraft (43%) continued into the warning volume during summer fire season. Further, 9% of the aircraft tracked by the UASP-kits during prescribed burn flight-days remained on their approaching trajectories to fly into the operational volume defined by the sUAS pilot, the nearest of these coming as close as 0.11 nautical miles (nmi) to the center of the operation. Of those aircraft tracked during the summer, 19% flew through the operational volume of the sUAS, and the closest approach was within 0.05nmi (304ft) of the operation's center.

Users created cylinder-shaped operational volumes 91.5% of the time during the spring prescribed burn operations, while over the summer fire season they selected cylindrical operational volumes only 58.2% of the time (the alternative was a cube). Most often users selected operational volumes that had 1nmi radii and a 700ft ceiling (Figure 3a and b). Both the width and the height of operations varied more widely during the summer data collection (from 0.17nmi to 6.73nmi laterally (radius) and 100ft to 8500ft vertically) than during prescribed burns (0.86nmi to 3nmi laterally (radius) and 700ft to 2107ft vertically).

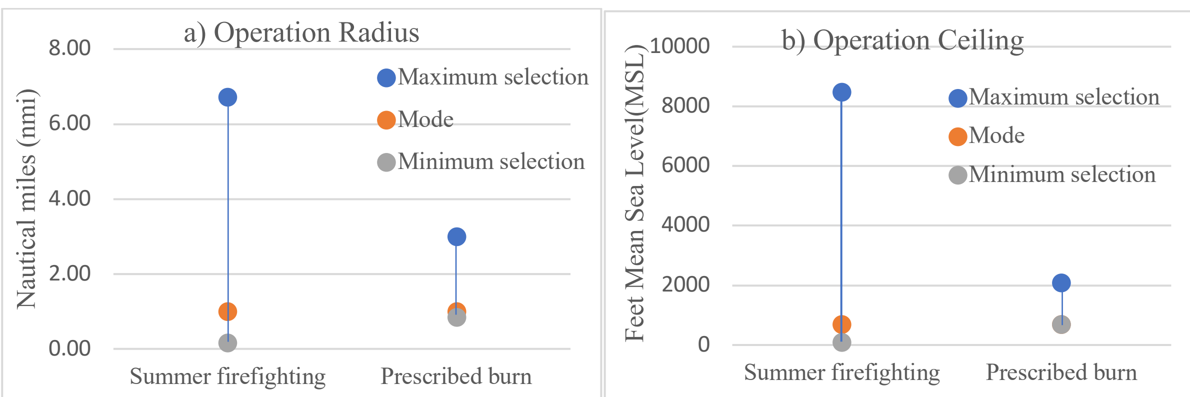

Figure 3. User-selected operational volume dimensions with a) showing the range of radius selections, and b) showing the range of height selections.

Although there was no significant difference in the most commonly chosen operation sizes between types of mission (both having a mode of 1nmi lateral radius and 700ft vertical), the range for both dimensions during the summer firefighting season was larger. During prescribed burns, the largest operation volumes had a 3nmi lateral radius and were 2100ft high, during the summer the largest operation volumes were more than twice that, with a 6.7nmi radius and an 8500ft profile although, when compared using a Mann-Whitney U-test, these differences were non-significant.

Dimensions of the alerting volumes around the operation were also user-selected. Most often users chose caution alerts that had 5nmi radii and warning alerts that had 2nmi radii with a 12,000ft ceiling (Figure 4a and b). While the width of alerting volumes was almost the same across both data collection periods, the height of the volumes varied more widely during the prescribed burn data collection (from 2,100ft to 30,000ft) than during the summer season (2,000ft to 12,000ft vertically), see Figure 3b. While it could be argued that the prescribed burn alerting volumes were substantially taller than the summer volumes, these higher values were only selected 6% of the time and both the mode and median alerting ceiling height was 12,000ft.

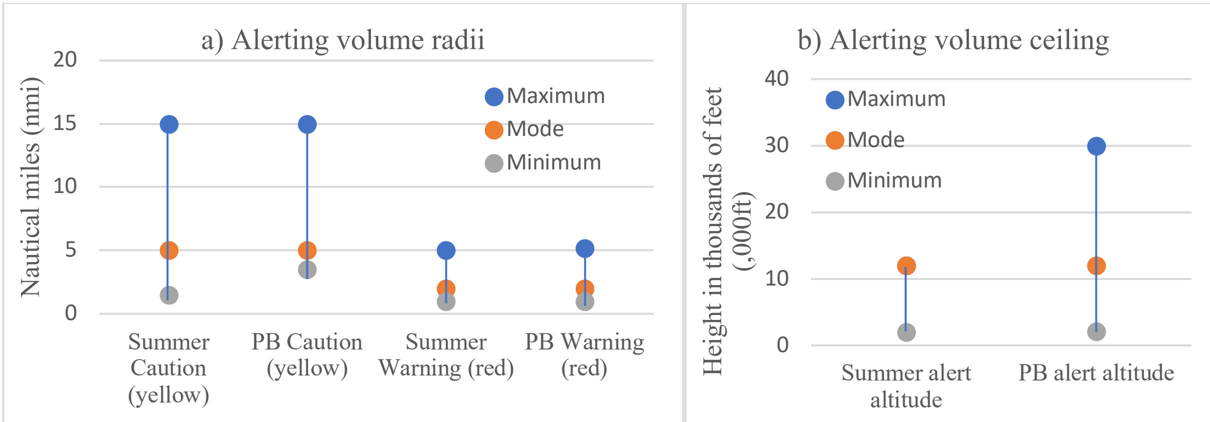

Figure 4. User-selected alerting volume dimensions with a) showing the range of radius selections for both the caution and warning alerting and b) showing the range of height selections.

Given that the alerting volumes were usually similar sizes across the two data collection periods, the number of caution and warning alerts were informally compared. Although proportionally more aircraft flew through the caution (yellow) airspace during prescribed burns than the summer fire season data collection flight-days, that difference was far smaller for the aircraft that flew through the warning area (Figure 2). Operational volumes were constructed to be a good amount larger during the summer fire season (Figure 3a & b), making a comparison uneven. Nevertheless, the closest point of approach of a crewed aircraft to the center of the operation was during the summer fire season (0.05nmi).

From these descriptions a hypothesis could be presented that users' choices when setting up the UASP-kit are consistent with the different environments in which they were conducting their missions. During a prescribed burn, because they are flying in class G airspace, UASP only sometimes have advanced knowledge of the aircraft that could fly close to them, often the first time they become aware of an aircraft is when they hear a radio transmission or physically see/hear the aircraft. There could be many of these aircraft transiting the airspace or none. In this environment, it may help to set alerting distances farther from your operation to give earlier warnings and a longer time to react. During daytime aerial operations over a wildland fire, the number of aircraft and their flight paths will have been discussed in the morning briefing and so, although UASP still have to watch and listen to radio transmissions, when they are notified by the UASP-kit of an aircraft, they know approximately in which direction to expect to look and what type of vehicle to expect. In this environment, it may help to set alerting distances closer to the operation to reduce repeated alerts as other aircraft fly many passes over the fire. Specific user feedback on their reasons for the way they set up the UASP-kit should be solicited from UASPs to support or refute this hypothesis.

For both data collection periods, the research team asked users about the usability of the UASP-kit. Questions were asked face-to-face during the prescribed burn about which functions UASPs found useful and which new functions users felt would increase the tool's usefulness. Users liked the UASP-kit alerting function, especially the audio alert, saying alerting was "what [they] cared most about." They found configuring the alerting rings straightforward, and tried different combinations of ADS-B filters and alerting dimensions to explore how they could change their view of the airspace. If a UASP-kit alert sounded, a crew member viewed the display to track the aircraft in case there was a need for deconfliction. Crew members also used the map to track crewed aircraft over time for general awareness, as well as to anticipate potential interactions with other airspace users. Suggestions for improvements included having more information announced in the aural alert, e.g., the aircraft callsign, altitude and speed. Yet, other users commented that the UASP-kit adds complexity to operations and will take time to integrate into the workflow. Overall, the UASP-kit "took too long to get going" and would be improved if it could be activated with fewer steps.

One discussion concerned the need to build strategies for how best to use the alerting rings. There is a tradeoff between too many alerts and alerting volumes that are too small. The UASP-kit was noted to have useful functions for the prescribed burn setting but some users debated whether the airspace complexities associated with a busy wildland fire bring unique challenges that these early versions of the UASP-kit (like the version used in this data collection and described above) cannot support.

During telephone interviews conducted over the summer, questions focused on usability issues reported about the UASP-kits and new functions or features to mitigate these issues. Users described difficulties setting up the UASP-kits, commenting that the user guide was difficult to follow unaided, and that the logic of the initial location showed by the UASP-kit as the GUI was brought up was confusing, with some crews not ever moving past this initial set up step. Users reported frustration with the length of the start up process. A key suggestion was to streamline this, including having the UASP-kit automatically display a graphical indication of its current location. Users also faced challenges with the physical UASP-kit itself. Many users removed the power supply from the box. This made the UASP-kit much lighter but also allowed the components to shift. Some users found, on opening the UASP-kit at their work sites, the contents were jumbled and they were not sure whether set up issues they experienced were because not all the components were firmly connected.

Conclusions

The UASP-kit showed promise as a tool to support sUAS pilots' situation awareness. Having tried the UASP-kit in the field, pilots reported that the tool was useful, and they offered many ideas for expanding the functionality of the prototype. There were no significant differences in the way users set up the UASP-kits, but it also became apparent that without ongoing support from the research team, users found the UASP-kit more difficult to use than expected. These findings indicate there is more work needed to improve training and the usability of the UASP-kits, including reworking the user guide and simplifying the start-up procedures.

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