Developing an Unmanned Aircraft System Pilot Kit (UASP-kit) for Wildland Fire UAS Operators

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The use of unmanned aircraft systems (UAS) to support disaster management is becoming more widespread. Uninhibited by many of the operational constraints imposed on crewed aircraft, UAS have the potential to augment the aerial response in a number of ways, including supporting situation awareness, thereby accelerating disaster management efforts. The intent of the Scalable Traffic management for Emergency Response Operations (STEReO) activity is to build an ecosystem that will allow small UAS (sUAS) operations to fly safely in the airspace during disaster management events. The first step toward this goal is to develop a small, single-user tool (the UASP-kit) that will enhance an sUAS pilot's situation awareness of the airspace. User needs for the functions and features of this tool were collected during a walkthrough over multiple days with subject matter experts from the US Forest Service. A prototype of the UASP-kit was then taken on an extended demonstration to multiple users, who were able to interact with it. User feedback was largely positive, and users discussed the information they needed to support situation awareness in context. The demonstration also highlighted features that were unintuitive to use, and functions that need to be modified to make the kit more user-friendly and robust.

I. Introduction

Small Unmanned Aircraft Systems (sUAS) are establishing their usefulness as an effective technology in many domains. Among these is in support of disaster management, including the response to wildland fires and

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for prescribed burns. sUAS can be used for reconnaissance to give firefighters on the ground a 'birds eye' view of an area or a fire, can be used to set fires to provide a control line, or can infill outlined areas with fire for prescribed burns. sUAS are an agile and cost-effective addition to a fire-fighting toolkit, as a UAS Pilot (UASP) or crew and their equipment can be deployed in a single vehicle and can be in the air minutes after arriving on-scene.

During wildland fire disasters, especially, fighting a fire from the air is a key component to controlling it. However, safely managing air traffic over a disaster requires communication, coordination, situation awareness (SA) and years of training and experience among all those involved, all of which are currently achieved by a person keeping track of aircraft in the area and managing aerial operations with no greater technological support than a radio. Currently, only a manual system exists to manage sUAS operations in this challenging, low-altitude space above an active incident. The safety of today's sUAS operations falls completely to the sUAS remote pilots, who maintain awareness of one another and other aerial vehicles, and ensure safe separation at all times. With the addition of new types of aerial vehicle, e.g., both large and small UAS, the airspace is becoming ever-more complex. There is a need for support services and functions to be developed that can reinforce user awareness and, through this, assist with situation awareness, coordination, and airspace management.

The Scalable Traffic management for Emergency Response Operations (STEReO) activity is being undertaken to demonstrate the application of NASA technologies for the modernization of emergency aerial response operations, focusing first on wildland fires and prescribed burns. STEReO is evaluating new and emerging technologies that could connect stakeholders under adverse conditions, use onboard autonomy to support safe line of sight (LOS) or beyond line of sight (BVLOS) operations, and employ tools to enhance situation awareness and improve collaborative decision-making [1]. The intent of STEReO is to build an ecosystem that allows sUAS operations to integrate with crewed aircraft more effectively in the airspace. Many of the technologies under consideration are based on the UAS Traffic Management system (UTM) [2]. UTM defined a new paradigm of air traffic management using automation more extensively inside a service-oriented architecture, while providing the operators (people) enough information to make strategic decisions and retain control of operations [3]. STEReO is applying the same basic principles to explore new planning and situation awareness enhancement tools to assist emergency response. It also extends the UTM paradigm to address the issues first responders face that are not experienced in nominal urban flying, such as degraded communications networks and adverse environments.

Although sUAS bring new capabilities to wildland fire management, they also bring new challenges. Chief among these is that their small size makes them difficult to see in the airspace. Despite procedures that provide physical separation – both laterally and temporally – concern remains about sUAS flying in the vicinity of crewed aircraft due to their lack of visibility. As today's procedures set out that sUAS give way to crewed aircraft, it is important for UASP to maintain good SA of the airspace [4]. However, from their position on the ground, UASP often have an occluded view of this space and have to rely heavily on radio communication to maintain SA. While airspace awareness tools developed for crewed aircraft are available to UASP, e.g., Foreflight and Sentry [5], and provide much-needed awareness, these are not tailored for remote pilots, and so can give limited coverage in a cellular network-starved area. Thus, the UASP must check a number of sources to verify information and construct a mental picture of the airspace [6]. Endsley, Bolstad, Jones, and Riley [7] argued that, although the data a decision maker needs may be available, they can be overloaded by the process of developing SA if they have to integrate these data before they can use the information to take action. As complex situations are often dynamic and fast moving (and wildland fire is no exception), users may have to interpret the data they are provided repeatedly during a mission. Endsley, et al. [7] suggest new technologies should be designed with user needs in mind and, in the case of a task that requires the user to maintain SA in dynamic situations, should take on the burden of combining data to present necessary information in a timely manner.

To gain a better understanding of UASP needs and to scope the data available and information required, a walkthrough and demonstration was held in Arizona in 2021. The findings from this walkthrough redirected the research and development work, leading the STEReO team to develop a single-user prototype tool, which is now undergoing user testing in the field (during 2022). The remainder of this paper describes these preliminary research and development steps.

II. Defining User Needs

An initial walkthrough /demonstration was conducted to solicit feedback from US Forest Service (USFS) sUAS Subject Matter Experts (SME) about the functions and features they would need in a tool that might enhance their awareness of crewed aircraft. Participants were SME who were experienced in flying sUAS in emergency response operations. To add realism to the walkthrough, the STEReO team brought some example tools, and the USFS provided a live setting. The walkthrough was conducted in the Tonto National Forest (Arizona, USA) and was timed to coincide with USFS aerial firefighting training. The aerial training exercises involved an outdoor simulation of a wildland fire in the National Forest, and an aerial firefighting work environment was created by several crewed aircraft to allow trainees to exercise communication procedures. Each day underneath the aerial training exercises, the research team conducted a parallel, but completely separate, simulation of an aerial firefighting response, with researchers and SMEs acting the roles for flight crew, Air Tactical Group Supervisor, and Incident Command (IC).

The demonstration tool combined communications and graphical user interface (GUI) ideas. The insight-UTM (iUTM) client [8] had provided situation awareness of operations to the research team during the UTM project and was repurposed as an interface for the walkthrough exercise. iUTM displays flight information in either a single-vehicle view, where detailed information about the operation is presented, or as a map of the airspace with all agents in the area presented in relation to each other (Figure 1). sUAS operations, ground personnel, ground vehicles, and some manned air traffic were simulated on this canvas. In addition to the simulated data, nearby live aircraft equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) transponders were detected and represented on the display. To do this, since the area had poor cell-network coverage, a local area communications network (LAN) was set up to allow data exchange. The communications network was created with a computer, a VHF radio, and a FirstNet router (with a public static internet protocol (IP) address).

To gather user feedback, SMEs were asked to walk through potential fire progression and firefighting scenarios, using the illustrations overlaid onto iUTM, giving examples of possible fire management decisions, sUAS mission types, and location tasking. The STEReO research team injected simulated sUAS operations within iUTM to demonstrate performing the missions in real time. Figure 1 shows the iUTM airspace map view with an sUAS operation drawn in magenta and crewed aircraft shown as white chevrons. The fire development (red hashed lines) and the incident's communications center (tower icon) are drawn onto the map along with other notes.

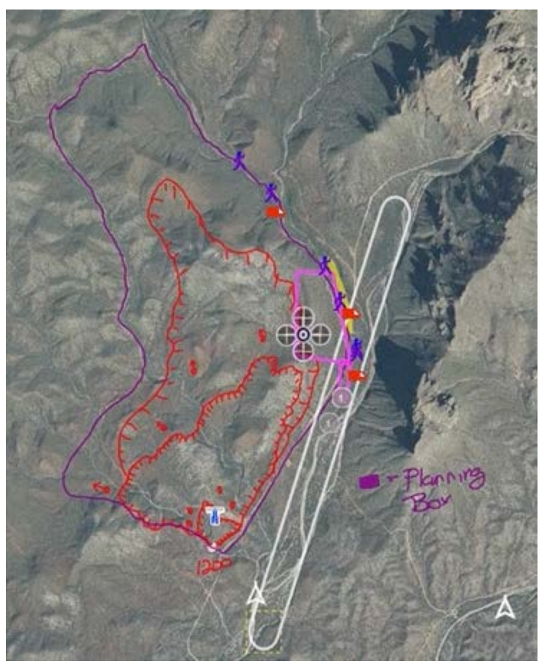

Fig. 1 Examples of the iUTM STEReO client airspace display, showing a large fire in a forest area with air response (including sUAS) and fire-related annotations.

SMEs used the agents provided in iUTM (personnel, vehicles, etc.) to create walkthrough scenarios where they described a growing fire and the potential actions of the ground and air response over time. SMEs used the surrounding area's terrain to describe how the fire might grow from a single ignition point (e.g., spreading up the canyon), and the missions that sUAS teams could be given, in coordination with other types of firefighting teams, to control and extinguish the fire. They outlined six possible tasks for the sUAS teams. During the initial phase of the fire, sUAS teams could be asked to perform information gathering to provide first-look details about the size of the fire and the surrounding environment to the IC. During subsequent phases, sUAS tasking could include surveying for structures, searching for people not associated with firefighting (e.g., hikers), checking for hotspots and spot fires, fire-edge mapping, and aerial ignition for controlled burns. Using iUTM, the group discussed how an improved interface might support SA and necessary features and functions. A number of the display's features were well liked; for example, the ability to modify an operational volume, the ability to use a drawing tool to annotate the map area, and the data tags on vehicles (not shown in Figure 1). Conversely, some features made the display challenging to use, such as non-intuitive procedures to set up an operation and the terminology and colors used on button labels. However, overall, SME liked the way the client effortlessly added to their situation awareness and how it displayed volume-based operations. Also, having an example to focus discussion was particularly useful for increasing understanding of the preferences, concerns, and needs of current and future users who need to safely operate sUAS in emergency response situations.

It is this last point – that although future users will need tools, current day users need tools *now* to enhance their airspace awareness just as much – that led to the opportunity to apply certain capabilities planned for STEReO to a very focused set of functions designed for a specific end user. The STEReO system is intended to ultimately encompass the entirety of a disaster area and provide information for all those involved in air operations. However, this describes a substantial system, that may require years to fully realize, and meanwhile, sUAS pilots have a pressing need for support for their air traffic awareness. The conclusion from the walkthrough was that an initial tool, the Unmanned Aircraft Systems Pilot kit (UASP-kit), should focus on enhancing airspace awareness for sUAS pilots. SME feedback from the walkthrough scenarios, as well as researcher observations were sorted and compiled to determine this small set of capabilities. The six primary functions the UASP-kit needed to provide are:

- a base map, for example a satellite view,
- the ability to import and display a fire operations map (GeoPDF) onto this base map display;
- a way to define an operational volume for an sUAS, which would include area, height and location, in a graphical representation shown on the base map display;
- detection of ADS-B traffic, which requires integration with a local ADS-B receiver;
- a graphical representation of the ADS-B messages or 'tracks', shown on the base map display; and
- notifications or alerting based on the proximity between ADS-B tracks and the operational volume of the sUAS.

A valuable finding from the walkthrough was that the UASP-kit should directly address the challenges from the sUAS pilots' perspective, which echoes the points made by Endsley, et al. [7]. Specifically, SMEs asked that all these functions be easy to use, straightforward to interpret, and clear; and the SME actively participated in discussions during the initial development phases to help ensure these design goals were being met. More detail on these parameters can be found in Martin, Arbab, and Mercer [9]. User feedback will be required to verify that the workflows and display design meet these criteria. Only components that will allow these limited functions will be included in the UASP-kit initially and will be augmented as the UASP-kit is further developed.

A. The Contents of the UASP-kit

UAS Pilot kit, as a small-scale prototype system, hones the core STEReO ideas and focuses them into a one-operator system that is smaller 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 initial components include a display and a communications infrastructure that collects 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 computer, a power source and a display. These are housed in a 21" by 32" ruggedized case (Figure 2). The view of the airspace is generated through receiving ADS-B messages from airborne traffic that are broadcasting their enhanced Global Positioning System (GPS) position out to other traffic and to the ground [10]. The ADS-B receiver [11] 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 interface (Figure 3), which is a touchscreen tablet. A Javascript browser-based GUI application was built, and the set of six functions described above have been designed into the initial prototype unit, including two map layers upon which an operational volume for the sUAS can be created and displayed along with, of course, the ADS-B traffic (Figure 3). There are a few features that assist with interpretation of the display including five types of aircraft icons to distinguish between helicopters and large and small fixed wings, and a filter that allows the user to reduce the range of the ADS-B traffic displayed.

Fig. 2 A view of the UASP-kit inside its case adjacent to an sUAS, on location at a prescribed fire in Mississippi, USA.

To obtain user feedback for this first prototype the research team visited a wildland fire in northern California, in September 2021, and then the UAS Aerial Ignition Academy (AiA) in Florida in March of 2022, where the UASP-kit was demonstrated to, and used by, UASPs.

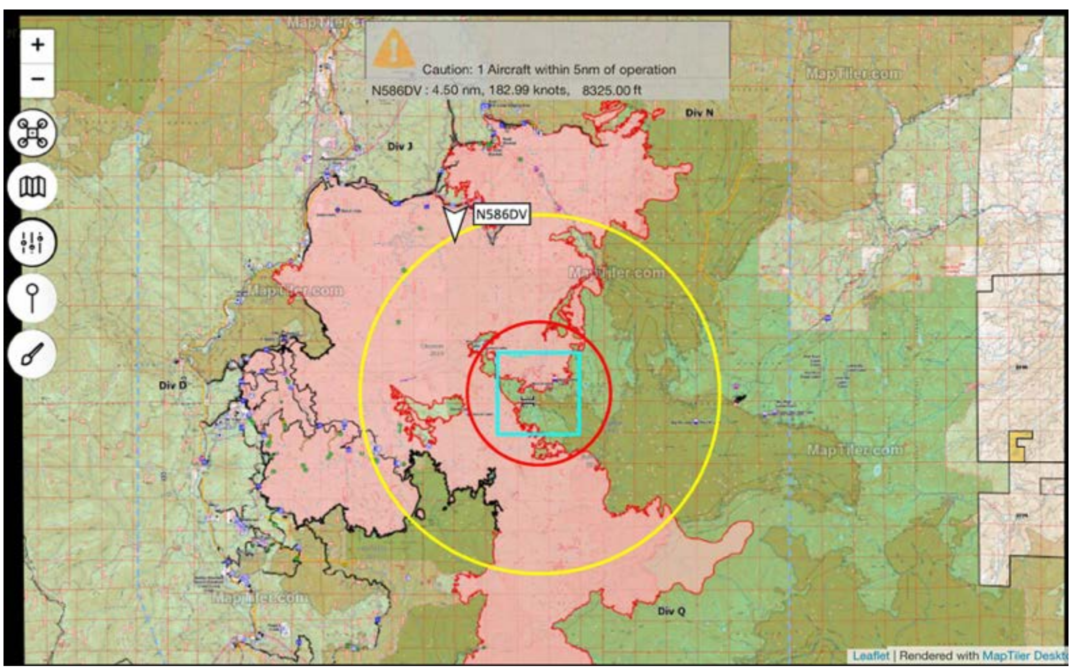

Fig. 3 An example of an interim version of the first prototype of the UASP-kit display, with a cube operational volume (cyan), alerting rings (yellow and red), and an aircraft flying across the 5 nmi yellow boundary which triggered an alert (grey banner).

III. Demonstrations and Reviews

A. First Demonstration of the Prototype UASP-kit

The research team visited the McCash fire in northern California's Klamath National Forest for three days. In an informal series of presentations, they demonstrated the UASP-kit on-scene to the US Forest Service SMEs. The location had steep, rough terrain and was difficult to access on foot. There were relatively few roads and limited communications infrastructure in the area. In one section of the fire, crews were working to put in a control line around the rim of a valley and burn out the underbrush to reduce the chances of new fires starting in this area. Crews were working to clear and burn the control line along the rim by hand. sUAS aerial-ignition modules were requested to assist with laying down control fires inside this line.

The STEReO team co-located with the sUAS team at four locations along the forest road that ran close to the rim of the valley, demonstrating the USAP-kit during each sUAS flight. The UASP-kit was shown to the UASPs and crew bosses who were working the area, and first-look feedback was obtained. Comments were gathered on interface usability and styling, and about how pilots would use information from the UASP-kit in their operational planning. In addition, the research team exercised every function and feature of the UASP-kit in all locations to begin to test its performance.

The demonstration was successful, showing the UASP-kit is portable, that it can be operated from the back of a vehicle, and can remain operational for the duration of one full day of sUAS missions. The UASP-kit's basic functionality was also successfully demonstrated, with aerial vehicles' ADS-B messages being received and displayed. All the initial functions –alerting, importing a fire-operations map, setting up operational volumes, and filtering ADS-B were all successfully demonstrated. UASPs suggested new features for to the UASP-kit, such as a drawing tool, and discussed the usefulness of being able to see ADS-B traffic over an even greater distance.

However, the demonstration revealed two or three features that were not working as intended (or at all) – one was the auditory component of the alerting, another was the coupling of the alerting rings to the operational volume. UASP asked for more features to be user-configurable so that they could tailor their own views, such as the ability to select the radius of the alerting rings. They also suggested many adjustments to the display that would improve their user experience, such as, changing the color scheme of the callsigns. One of the more significant changes necessary was to move to either a Bluetooth or a hard-wired connection between the computer and the touchscreen, as the WiFi connection was on the same frequency (5.8 GHz) as the video-feed from the sUAS. These fixes and changes were made, and a more formal evaluation of the UASP-kit was undertaken.

B. Second Demonstration and Usability Review of the UASP-kit

The UAS Aerial Ignition Academy is a three-week course, held in partnership between the National Interagency UAS Training Program and the National Prescribed Fire Training Center. The course combines classroom instruction and on-the-job training in the form of two weeks of field work. For the field exercise portion of the course, students and instructors travel all over the southern US conducting prescribed burns (that have been requested by local foresters and land managers), using sUAS platforms fitted with a specifically configured plastic sphere dispensers for aerial ignition. During this course students also gain experience coordinating, deconflicting, and monitoring the airspace in order to safely conduct their prescribed burns using sUAS.

Method: The UASP-kit usability evaluations followed the ethnographic model of field usability testing described by Rosenbaum and Kantner [12]. Their method was designed to take prototype products out to the user to be tested live in end-users' work environments. Users work with their own data (i.e., information that they work on daily) to complete a set of tasks laid out by the research team. The research team records user interactions, difficulties, and opinions to evaluate new tools and task flows. For the UASP-kit usability evaluation, a set of four tasks were chosen and observation was the primary method of data collection. However, because the evaluations took place during AiA training, and due to the dynamic nature of the environment in which students were training, Rosenbaum and Kantners' method was not followed exactly. Participants were not scheduled to spend a set amount of time testing the kit and they were not asked to complete surveys, that is, an effort was made to make data collection as flexible as possible.

Participants: There were 24 trainees and nine instructors who formed four field training groups or "modules" within the AiA course. Each module was comprised of six trainees and two instructors. Trainees had sUAS piloting experience and had attended UASP courses previously. Instructors were fully qualified sUAS aerial ignition instructors. The research team shadowed three of the modules (18 trainees and seven instructors) as they completed the two weeks of fieldwork that followed a week of classroom training. Two researchers shadowed Modules 3 and 4 while three researchers shadowed Module 1.

Procedure: Four UASP-kit tasks were identified: setting up a (sUAS) operational volume, setting a placemark, setting up the UASP-kit's alerting function, and loading an annotated map to overlay the satellite map that is the base display. Tasks varied in the number and complexity of steps to completion, from setting a placemark – with only four steps using a single pop-up panel, to loading a new map – which has 14 steps across two devices and five panels.

During the final classroom training day for the AiA, the UASP-kit was briefly demonstrated to the entire group of trainees and instructor cadre. Once at their respective on-site locations, each research team conducted a hands-on training session, where they walked through use of the UASP-kit, explaining the tasks in more detail.

Over the two weeks of practical training, researchers traveled with the modules to their burn locations in eight different national forests and one national wildlife refuge across Georgia, Alabama, Florida, and Mississippi. A trainee or instructor would set up the UASP-kit and all members of the module were invited to monitor the display and change the settings if they desired. During these times, and when trainees were not busy with aerial ignition tasks, the research team solicited the module's feedback on the usability of the GUI and drew from a set of approximately 80 questions to gain responses on a wider set of themes. The questions were focused on four themes: how the UASP-kit affected situation awareness, trust, usability and future capabilities desired for the UASP-kit. Answers to these questions were recorded by the research team along with observations about the use of the UASP-kit and the sUAS mission activities. In addition, the UASP-kits themselves logged user interactions and aerial traffic detected by the ADS-B receiver.

Analyses of the UASP-kit logs, user opinions, question responses and observation notes are descriptive. Although Rosenbaum and Kantner [12] do not describe their analyses, in their findings they report counts and cite observations the research team made of users working through the set tasks. Our analysis follows this format with counts of logged events, reports of user interactions with the UASP-kits, and researcher observations.

C. Task Descriptions, Findings and Discussion

1. The alerting function and tasks

The purpose of the alerting function is to draw the user's attention to aircraft that are potentially going to fly close to the user's sUAS operation. Beyond this, the alerting serves two purposes: firstly, it allows the user to make an assessment, with time to act, whether an incoming aircraft will fly directly into their operation; and, secondly, allows the user to discount aircraft as "no factor" based on their heading and altitude.

Two concentric cylindrical volumes set from the center of the operation denote alerting areas. On the display these volumes are depicted as rings (Figure 3). The outer caution ring is yellow, and the inner warning ring is red. When an aircraft crosses either boundary, the kit gives an alert with a visual and auditory component. An audio alert sounds – a horn for the caution alert and a claxon for the warning – along with a callout of either "caution" or "warning." A banner is shown on the display that provides details about the aircraft including its distance from the center point of the operation and the aircraft can be seen crossing the boundary on the display. To configure the alerting, the user is able to select the radius of both volumes and a common ceiling value, using either sliders or direct text entry. A button switches the alerting function on and off.

Crews used the alerting function every time they used the UASP-kits. Figure 4 shows the range of settings with which users experimented. However, by far the most popular setting was the default, with the caution ring set to 5 nautical miles (nmi), the warning to 2 nmi and the ceiling to 12,000 feet (ft). Users cited different strategies for setting the alerting rings, with some choosing larger rings because they liked the traffic to alert when it was further out, and others choosing tighter rings because they only wanted to be alerted when traffic was more likely to be a factor. They did not have any difficulties with the task steps, only commenting that the slider bars were sometimes difficult to grab.

Users were enthusiastic about the alerting function, citing numerous occasions when the UASP-kit correctly alerted them to traffic that crossed one of the boundaries, e.g., "Two unknown aircraft entered our warning alert area and they both went off. The [UASP-] kit is 2-0." The presence of two rings (providing progressive levels of alert) was well-received and the auditory element was noted as a particularly useful feature. Users described how the audio alerts drew their attention if they were "eyes-out" watching the airspace.

The four UASP-kits alerted 127 aircraft that crossed the caution (yellow) boundary over the 16 flight-days observed. Of these, the majority (67.7%) only crossed the caution boundary (Figure 5). Of the remainder, 25.9% of the aircraft came within 2 nmi of the center point of the defined operational volume and four (3.1%) came within 0.5 nmi of this center point. It is hearing the alerting for these aircraft that prompted the positive comments from users, e.g., "[we] listen for the audible alerts, then 'let's investigate!'" However, there was one occasion when a helicopter took off from a site within a caution ring and this only triggered the on-screen banner and not

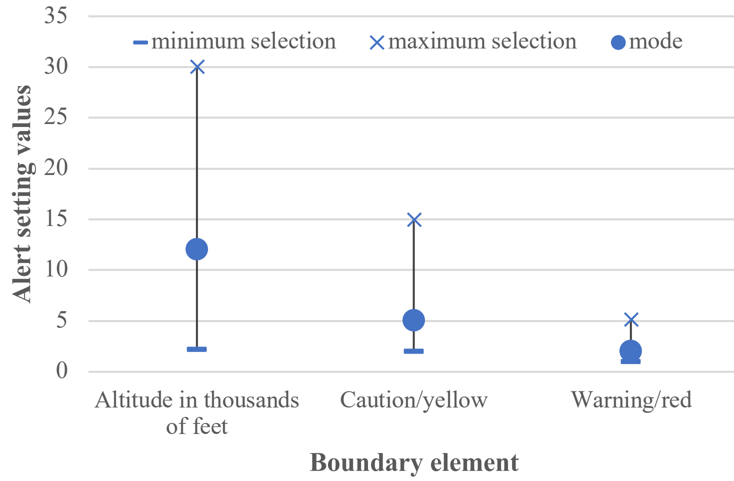

Fig. 4 Minimum, mode and maximum values selected for the alert rings settings, one of the tasks users completed using the UASP-kit.

the auditory alert. Users were clear that they want the audio signal on every occasion that an aircraft crosses an alert boundary.

Of all the UASP-kit functions, users had the most suggestions for improvements and additional features to the alerting. These included showing the alert settings on the main display and adding a verbal readout of the alert banner information to the audio alert. With seven items of information in the banner, there are concerns that this would result in a constant readout. When prompted, users most often selected altitude as the most important of these items. Crews discussed that the cylindrical alerting volumes are a good shape for prescribed burns but an additional feature, that would be more useful for other mission types, would be the ability to define their shape as a polygon.

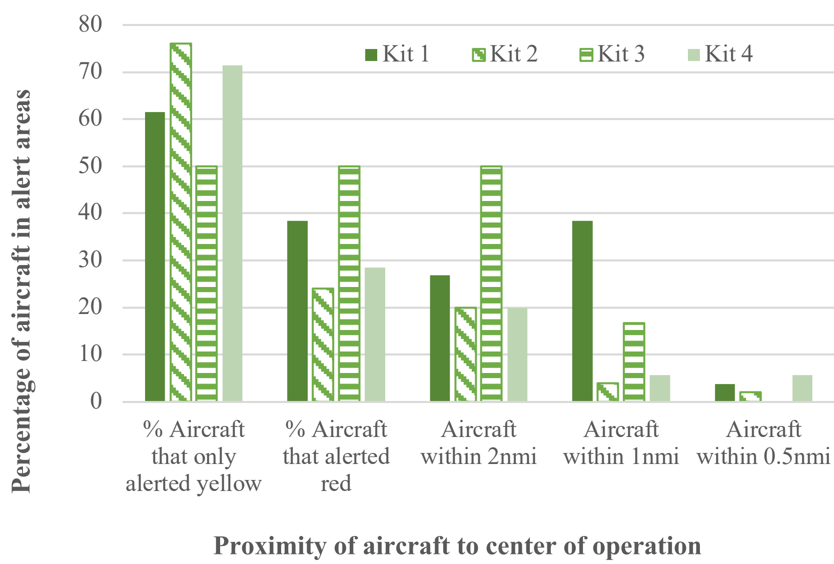

Fig. 5 Of the aircraft that caused an alert, the percentage that flew through the caution and warning rings on the display and the closest approaches.

2. The placemark function and tasks

The placemark allows the user to mark a location on the map, for example the center-point of their operation. The placemark remains as an identifiable icon even as the display is zoomed out, allowing users to return to a location easily. It has a dropped pin shape (see Figure 6). To set up the placemark, the user selects its icon from the main menu, and is then able to drag the pin to the desired location (or enter the latitude/longitude coordinates by hand).

The placemark was set 28 times on average for each kit over the two weeks. Although recognizing the steps to set the placemark proved to be no issue, users found setting it accurately was laborious. Typing in the coordinates was unintuitive as it required pressing the return key, while other text fields in the GUI did not; and dragging the placemark to the desired location was a multi-step process if the user wanted to mark a precise point, because they had to set the placemark and then use the zoom function alternately until they zoomed in to the location as accurately as they required. It can be the case that users tend to avoid interface interactions that cause confusion or that are difficult to use, and the researcher team was interested in identifying the "pain points" when using the UASP-kit's interface. There was some evidence of this avoidance seen in the frequency of placemark use between crew members who had no trouble with setting a placemark and those who found it to be unintuitive and difficult. Despite these difficulties, users saw value in the function – in one instance they used the placemark to identify an active airport that was within their caution alerting ring and discussed using it as a way to identify other sUAS operations.

However, the placemark prompted users to talk about alternatives that would make a function like this more useful. Many users, from all three modules, suggested that the location of the UASP-kit should be automatically marked with a "blue dot" on the map. This geolocation ("you are here") function is available in other map applications that fire-crews use, as a blue dot. As a familiar feature, and one that crews know how to make best use of already, not only would a geolocation function provide common reference points across applications but would reduce the need to set the placemark in the interface. If a geolocation marker was supplied, the placemark could then be reserved for other locations that the user wishes to highlight.

Fig. 6 An example of the display on the first prototype of the UASP-kit, with a cylindrical operational volume (cyan) the center of which is marked with a placemark on a fire-operations map, alerting rings (yellow and red), and an aircraft flying above the 5nmi yellow boundary.

3.   Map upload function and tasks

The UASP-kit has a base map layer that shows ground features. The user can choose from a satellite map, a topographical map, or a street-plan view (see examples of a satellite map in Figure 6 and a street-plan view in Figure 7). Wildland fire fighters, however, use specially constructed maps that take a topographical layout, add information about a fire and the firefighting plan, and highlight hazards using lines, icons and text (small inset map in Figure 6). These maps are created as a geospatial PDF file (GeoPDF) that can be printed or shared electronically. These fire operations maps are updated daily, provided to all personnel, and then become the common reference point for firefighting planning and work that day. Due to this, the fire operations map is a critical element of the firefighter's tool kit and the crux of developing and maintaining shared awareness within and between teams. The UASP-kit is able to ingest these maps and turn them into a layer of map tiles that the user can toggle on and off (Figure 6). The UASP-kit is able to hold five maps within its software, that the user can switch between with one button click.

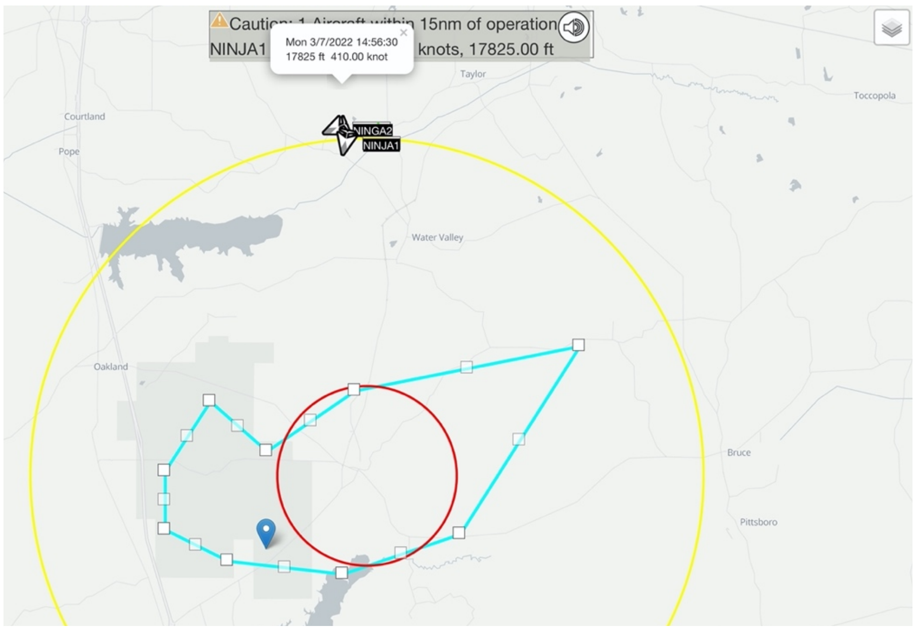

Fig. 7 An example of a plan view map base layer, with a polyhedral operational volume (cyan), alerting rings (yellow and red), a placemark, and an aircraft crossing the 5 nmi yellow boundary triggering an alerting banner (grey).

The module teams uploaded new fire operations maps for each site where there was a burn planned. There were up to 11 maps available for each forest, depending on how complex the burn areas were. Overall, the modules loaded 25 different maps onto the UASP-kits, around eight per module. As the UASP-kit only allowed storage of up to five maps, by the end of the two weeks users had to delete previous burn sites before they could upload new maps for that day.

As a tool they use at every deployment, module crews expected to be able to see the fire operations maps and to be able to switch them out, so commented very little on the presence of this function, other than to request that the UASP-kit be able to save and hold 12-15 maps at a time. Bringing up an already-saved map caused no problems and downloading the map initially is a task they already complete every day. Even though the set of steps to complete the map download/upload process was by far the longest for all the tasks, everyone was willing to work through them for the benefit of seeing the burn-area map. However, although the UASP-kit provided feedback as a sequence of short tones to signal the start and end of the upload, this did not give users enough information to troubleshoot the process if it failed. Sometimes maps could not be integrated onto the display because the originally downloaded map did not have the format or structural features the UASP-kit needed to turn it into tiles. Users were not given a reason by the UASP-kit for the failed upload and so, on occasion, tried more than once to have the UASP-kit ingest a map that was not compatible. However, the most common reason for a failed upload was a failed interaction between the folder/ application that the map had been uploaded into on the touchscreen tablet and the UASP-kit's computer.

Users commented that an ability to draw additional notations onto the display (primarily on the fire operations map) would be useful for planning purposes and suggested this feature would become more useful if they were able to share an image of their work site that showed both their proposed operation and their notations: "If I had the ability to get a quick photo or kml … to share back and forth – would be nice."

4. UAS operational volume function and tasks

The notion of an sUAS flying in a four-dimensional (4D) operational volume was used in UTM exploratory research [3]. The operational volume is used to define the area and the time window in which the operator intends to fly. When an operator defines their area of operation, this allows other operators to define their own areas outside of and around this space, which facilitates multiple operators working in the same area. This idea of working within a defined 4D operational volume was extended to the UASP-kit. While currently the UASP-kit only represents one operation at a time, the ability to display multiple operations is a mid-term goal.

When setting up an operational volume, the user had the choice of three shapes – cylinder, cube or polyhedron. The cube and the cylinder have default settings, i.e., default radius of 1 nmi, a 700ft height, and a duration of 60 minutes (min). The polyhedron shape has to be user-defined, but its duration and height are the same default values. Once the desired volume dimensions are drawn/ set, the volume can be activated, and changing the operational status to "active" also activates the alerting rings.

Users did not have any difficulty with the operation set-up task steps. Even an additional step, that is a hold-over from the UTM approach, where a different panel is used to manage operational status from volume set up, was hardly commented on and was not a stumbling point for users.

Overall, across the four UASP-kits 56 operational volumes were set at burn sites and 15 modifications were made. Of these, crews overwhelmingly preferred cylinder-shaped volumes, choosing them 91% of the time. Due to some issues with setting up the polyhedron volume, users were encouraged to use one of the symmetric shapes. Although crews experimented with the ceiling altitude of the volume (the base being set at ground level), with some preferring a higher ceiling to give a larger buffer, they fairly quickly tended towards a 1 nmi radius (the default) for the width of the volumes (Figure 8). Crews usually either left the duration at its default value of 60 minutes or made it much larger, e.g., 240 mins. They expressed that they did not see the point of adding a duration to the volume as they just wanted to leave the operation open until their burn mission was completed.

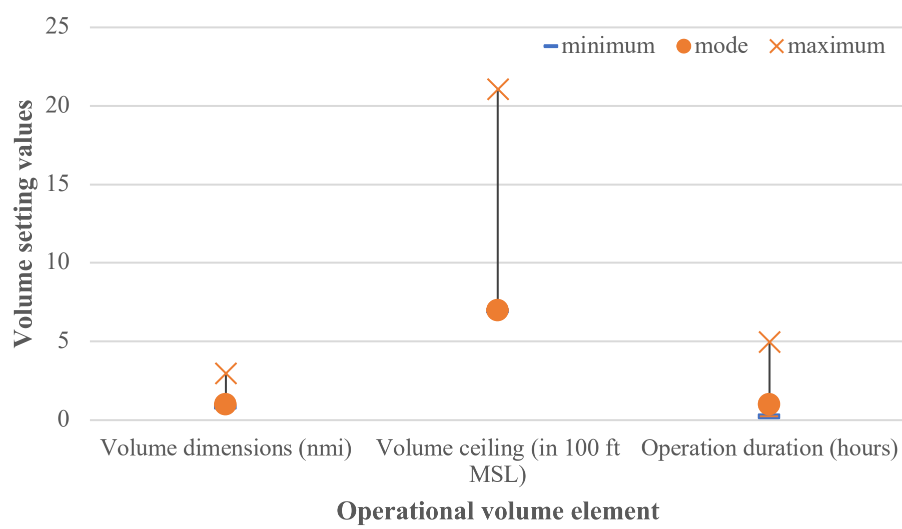

Fig. 8 Minimum, mode and maximum values selected for the operational volume, one of the tasks users completed using the UASP-kit.

Operation duration is the fourth dimension of the volume that is created by users in UTM. In urban settings, there is high demand for airspace and so a time window allotted to each volume allows different users access [3]. For prescribed burns, the module stays in the field until the mission is complete, hence operation duration is not only less important but also difficult to define ahead of time. However, as UTM functionality that could be incorporated in the future that will likely need a temporal dimension, it may be preferable currently to merely extend the duration range so that the operation can be set to remain active for the extent of the day's mission and the time window is not a factor. In addition, there needs to be a clear notification as the volume expires, since the alerting function is connected to the volume and will also expire.

Users stressed that, whereas for prescribed burns the shape of the operational volume was not too important and could be a cylinder or cube, for wildfire missions the shape of the operational volume is often critical to ensure areas where other operations are working are avoided. Hence, the need for a free-form or polyhedral volume option. In addition, users suggested that the alerting "rings" should conform to the volume polygon they define.

D. Themes Discussed and Observations

1. Situation Awareness

Across the modules, each crew monitored the airspace with all the tools available to them. They positioned a visual observer, used Foreflight [4] or another live air traffic application, and everyone at the launch and recovery zone (LRZ) collectively exercised see-and-avoid duties, all contributing to a shared airspace awareness in the team. Crews included the UASP-kit into this portfolio of tools and, as part of participating in our usability evaluations, for the duration of the AiA's two-weeks of field work, used the UASP-kit as much as they could, while verifying its information through their other sources.

Researchers observed that crews would often set tight parameters for alerting on the UASP-kit but configure the display to maximize the amount and availability of airspace information. When alerted, a crew member would use the UASP-kit to track aircraft in case there was a need for immediate deconfliction. Crew members commented on this, saying "When we heard that aircraft, we were comfortable carrying on with a mission because we were tracking constantly" and "We had two that flew through, one was no factor and one we waited to see if it would turn in." In the absence of alerts, researchers found that crew members would track aircraft over time for general awareness as well as to anticipate potential interactions with other airspace users. Crews commented on how the UASP-kit could provide increased airspace awareness, e.g., "If you're looking at it [the USAP-kit], or even with the [auditory] alerts, you're picking up stuff that is way further than you could have done yourself. It … validates what you're hearing." It was also observed that crews readily referred to the UASP-kit for maintaining shared awareness when distributed across multiple LRZs; crew members without access to the kit expected all caution and/or warning alerts to be communicated over radio. One researcher counted seven instances in which a crew member proactively radioed about no-factor aircraft that the other crew should anticipate hearing and/or seeing.

There were many inquiries about whether future capabilities of the UASP-kit could support multiple sUAS operators at one site to share operational information with each other from their respective LRZs. Crews emphasized such a capability would assist sUAS crews' shared awareness when operating in the same airspace. They anticipated that the ability to visualize nearby operations on a map would reduce ambiguities inherent in coordination efforts, thereby reducing radio congestion.

2. Trust

Feedback and observations regarding crews' trust in the UASP-kit was two-fold: trust in the accuracy of information displayed and trust in the alerting functionality. Researchers observed that crews routinely used familiar flight monitoring applications to maintain situation awareness before and during flights. As crews were getting acquainted with the UASP-kit, they would cross-check information taken from other sources or overheard on the radio with the GUI, mainly to verify that it confirmed what they already knew/saw. The observations suggest that cross-checking trusted sources of information with the UASP-kit was critical to build user trust in the information it provided.

Crews unanimously found the auditory alerts to be the most valuable feature of the UASP-kit. They conveyed this in comments such as, "The alerting is key. The [UASP-] kit helps you by alerting you when you need to focus your attention on it" and noted that the auditory alerts were highly effective for directing attention to potentially conflicting aircraft. They mentioned that the audio alerts had the potential to improve their deconfliction strategies, particularly in reaction time, since they could see an aircraft's location, and track its altitude, heading, and speed. It is worth noting that while all crew members shared an understanding that multiple factors could make the UASP-kit's ADS-B receiver susceptible to interference, thereby causing a degradation or interruption of ADS-B coverage, they found it concerning when there were sporadic alerting malfunctions for aircraft displayed within their alerting rings. One researcher reported two instances in which the UASP-kit displayed caution and warning banners but failed to trigger the auditory alerts. The absence of the audio alerts made the crew feel uneasy, one crew member voiced that "this is the whole point." Many crew member comments reflected that the perceived reliability of auditory alerting directly affected their trust in the UASP-kit as well as the extent to which they would monitor the display.

E. General Discussion

Feedback from the UASP-kit field usability evaluation suggests that the tool's development is having a positive impact on the on-going goal to support UASP airspace awareness. Trainees and instructors were invited to use the UASP-kit to find information and complete four tasks that had been identified as central: setting up an sUAS operational volume, configuring ADS-B alerting rings, setting a placemark, and loading a new fire operations map, and were able to complete these tasks unassisted after a couple of sessions. Crew members found the UASP-kit generally easy to operate when provided training and exposure, noting that powering the UASP-kit on/off, configuring ADS-B alerting rings, and setting up an operational volume were straightforward. It was observed that those who had more hands-on time with the kit were able to navigate the interface and troubleshoot with little to no assistance. However, there is still much work to be done to increase the functionality of the UASP-kit to meet its goals and to improve its reliability, along with limitations of the study method that need to be addressed.

While our adapted ethnographic model of field usability testing [12] worked well for gathering feedback, there are some limitations that arise from the adaptation that was made. Each module had different experiences with the UASP-kits as each burn site was unique and researchers had different opportunities to gather feedback about the STEReO work. While the ethnographic method encourages user-driven feedback, future work needs to design and implement a more thorough data collection and observation process, including stress-testing of the UASP-kit.

Users had many suggestions for new functions and capabilities that might add to the usefulness of the UASP-kit. Among these were proposals to incorporate other tools, such as visualizing the UASP-kit's ADS-B coverage with a geodesic viewshed tool (e.g., the ArcGIS 3D Analyst, [13]), and to make the interface available on different devices, such as a cell phone. However, there were some nearer-term suggestions that should be explored before expanding the UASP-kit across platforms and tools. A means to achieve wider ADS-B coverage of the local airspace should be explored. This may be achieved by integrating additional ADS-B receivers, set up in multiple locations within a site, which could create a network of coverage via sensor fusion for the UASP-kit but also for other users, such as at a temporary helibase as a "poor-man's" radar. But this solution requires exploration, because real-time management of the data collected by multiple ADS-B receivers could become an issue due to the quantity of information and likelihood of duplicate records. Secondly, adding functions or methods that allow the user to refine the UASP-kit display. Users wanted to be able to "tune" the display for different missions, and the workflow to easily and quickly achieve this capability needs to be carefully designed to avoid adding potential confusion.

One theme that was not explored in enough depth during the field usability evaluations was the UASP's concerns with risk. One user responded when asked to identify hazards with "everything is risky," and continued to list the ground environment, weather, distributed teams and the workload required to actively maintain team shared situation awareness in addition to airspace awareness. As the UASP user has to be concerned with all these elements of their situation and will be busy with sUAS flight tasks, care needs to be taken that the actions required to use the UASP-kit do not interfere with or interrupt current sUAS procedures and workflow. It is important to understand which functions and features of the UASP-kit interface will enhance situation awareness without causing any interruptions to current workflows and procedures. To work towards this, the STEReO team needs to establish the reliability of the UASP-kit, ensure that it continues to have a simple and clear interface, and continue to solicit feedback from SMEs.

IV. Conclusion

The prototype STEReO UASP-kit was developed on a short timeline that was achieved with input from SMEs at the USFS & CAL FIRE. Exercising the UASP-kit at the USFS AiA was a unique opportunity for an initial review of the tool. The usability review was successful, with all four kits operating as designed to show air traffic in the vicinity. However, an additional success was the favorable reception the UASP-kits received from the instructor cadre and trainees at the AiA. Notwithstanding a couple of software "bugs" and some areas of usability improvements, members of the modules exercised the UASP-kit during all flying days over the two-week field work period and self-reported using the information they gleaned from it. This encouraging feedback suggests that the UASP-kit has the promise to become one of the tools UASPs use to support their airspace SA. However, further work to make improvements and to expand the functionality of the UASP-kit, without losing the simplicity that users require, is necessary. The additional next steps of more rigorous testing are also requisite to determine whether the UASP-kit can achieve its potential to help enhance the UASPs' airspace awareness.

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