Initial Exploration of STEReO (Scalable Traffic management for Emergency Response Operations) System User Requirements for Safe Integration of Small UAS

Lynne Martin
Human Systems Integration Division
NASA Ames Research Center
Moffett Field, USA
lynne.martin@nasa.gov

Yasmin Arbab
Human Systems Integration Division
San Jose State University
(at NASA Ames Research Center)
Moffett Field, USA
yasmin.arbab@nasa.gov

Joey Mercer
Human Systems Integration Division
NASA Ames Research Center
Moffett Field, USA
joey.mercer@nasa.gov

***Abstract*— Environment-based disasters, such as wildfire, can cause substantial loss of life and loss of property and are costing billions of dollars annually. Existing disaster response operations are complex, with many challenges. The aim of the Scalable Traffic management for Emergency Response Operations (STEReO) system is to demonstrate the application of technologies that will enable small, low-altitude Unmanned Aerial System operations to safely take place in the airspace above a disaster event, increasing the effectiveness of the response. As a first step, the project aims to build a small prototype system with a display to demonstrate and test the core functions of this system, which are based on user needs and requirements that were gathered from experts in the field during discussions and walkthroughs.**

Keywords—UAS, emergency response, traffic awareness

I. INTRODUCTION

Wildfires are unplanned fires, originating in forests, grasslands or other natural areas [1]. Wildfires can spread quickly, rapidly consuming natural areas and moving into communities. The threat, at least on the U.S. West Coast, is increasing: the number of large fires doubled in the 30 years between 1984 and 2015 [2]. Fire seasons are becoming longer and the fires more costly and more destructive. For example, the California Department of Forestry and Fire Protection (CAL FIRE) [3] has charted that in 2018, over 7,500 fires in California burned an area of over 1.6 million acres, moving into urban areas and destroying nearly 20,000 structures, making it California's deadliest and most destructive wildfire season on record.

The current-day approach to fighting wildfires involves a complex organization of personnel and resources to attack the fire at multiple points. The Incident Command System is in place to organize and manage this response and expands to meet the needs to combat the fire – the more substantial disaster, the greater the number of resources mustered to manage the response. Firefighting from the air is an additional resource for the Incident Commander (IC) to draw on, if the circumstances warrant, and these teams of aerial specialists have their own sets of procedures through which they interact. The type and scale of aerial resources in disaster response are commensurate with the needs and complexity of the incident.

Aircraft are effective tactical and logistical tools that can provide the IC a multitude of capabilities in support of ground-based operations. Some aircraft capabilities include delivering equipment, transporting firefighters to remote areas, and dropping water and/or fire retardant. Aircraft can also provide information about the incident, report fire behavior, identify threats to people and/or property, locate access points, as well as track the progress of operations.

Many risks and complexities emerge when aerial resources are allocated to an incident. Aerial firefighting is routinely accomplished under adverse conditions, whereby aircrew contend with physical hazards (powerlines, towers, intruding aircraft), congested airspace, poor weather conditions (wind, turbulence, high temperatures), human factors challenges (fatigue, stress, low situation awareness, high workload), as well as visibility restrictions caused by smoke. And this all takes place close to terrain, as flying has to be at very low altitudes. This places a high demand on proactive mitigation of hazards, communication and coordination between air and ground personnel, and highly proceduralized actions, such as cross-checking information to verify its validity.

In recent years, firefighting organizations have been introducing unmanned aerial systems (UAS) into these challenging wildfire response events. UAS can be a beneficial and cost-effective technology to support disaster management and incident objectives – small UAS (sUAS) are relatively cheap, easy to use, quick to launch, and portable with the additional benefit that they are remotely piloted. Uninhibited by many of the operational constraints that apply to manned aircraft, sUAS have the potential to increase information gathering capabilities, thereby improving situation awareness (SA) and potentially accelerating response efforts. Moreover, sUAS could be used to complete tasks that are dangerous for firefighters – such as, prescribed burns or mapping a fire that is moving rapidly or prone to changing directions – while limiting pilot exposure.

Nonetheless, sUAS bring some additional challenges to aerial response, chief among these is their extremely low visibility to pilots in manned firefighting aircraft, which raises concerns about the impact of sUAS on aerial safety. Currently, firefighters address this issue in two ways, firstly by ensuring lateral separation, i.e., sUAS are allocated operational tasks in areas (or at times) where manned aircraft are not operating, and secondly by adhering strictly to procedures. The National Wildfire Coordinating Group (NWCG) [4] sets out standardized processes and procedures for utilizing sUAS in a safe, effective, and efficient manner. While many of these standards overlap between manned and unmanned aircraft operations, there are additional responsibilities that sUAS operators follow in order to be granted authorization to fly in incident airspace. Never-the-less, to ensure safety, sUAS are often assigned flying locations and tasks on the periphery of an incident.

Given the many potential uses for sUAS within wildfire fighting, there is motivation to overcome the key drawback and threat to safety which is their lack of visibility. Enhancing the physical contrast of vehicles with lights and bright paint has limited effectiveness, as this can be cancelled by both dense smoky conditions and bright sunlight [5] [6]. An alternative way to address this problem could be to increase the awareness of pilots by providing information about sUAS operations at their Ground Control Station (GCS) or in the cockpit. A potential tool could be a system that draws on the features and functions of the UAS Traffic Management System (UTM) developed by Rios, et al. [7], which was designed to be used in urban settings. The Scalable Traffic management for Emergency Response Operations (STEReO) system could take these capabilities and repurpose them for disaster response. It could initially represent sUAS operations that would assist a wildland UAS operator (UASO) with building situation awareness, along with interactive flight planning capabilities that would assist with scheduling and coordination.

A. *Scalable Traffic management System for Emergency Response Operations (STEReO)*

As noted, STEReO is based on the UTM Project whose concept of operations defined a new paradigm of air traffic management [8]. Using automation more extensively inside a service-oriented architecture, STEReO will strive to apply the same basic principles of a federated network, while providing the operator with enough information to make strategic decisions and retain control of their operations. The STEReO concept works on the same premise as UTM, where four-dimensional volumes are created around sUAS operations. These are cross-referenced with all other operations and only approved if there is no overlap with any other events. When the sUAS takes off, the client displays real-time position updates from the vehicle, via its GCS. However, STEReO also needs to extend the UTM paradigm, as wildfire UASO face issues that are not experienced in nominal urban flying, such as degraded communications networks, and a mix of vehicles in a constrained airspace at a similar (low) altitude. These issues need to be addressed at the outset for STEReO to be useful in wildfire situations. The project needs to not only develop possible solutions but the solutions should also be understandable, reliable, and robust [9] [10] – qualities that are required to build trust in a STEReO tool.

Because any tool in wildfire response will be used in dangerous situations where there is a threat to human life, firefighters are wary about trusting any type of electronic tool that could fail in the field. It will be important for any tool to consistently be able to provide information to support UASOs' situation awareness under challenging circumstances. In the flight test demonstrations for the UTM system [11], one of the research objectives was to determine whether the system interfaces provided timely and reliable information, thereby supporting UASO situation awareness. A system that is perceived as highly usable and accurate translates into higher levels of operator trust in the information it presents [12].

B. *Elements of STEReO*

The STEReO group began by considering the elements that would need to be combined to build a prototype tool that could provide emergency responders with the timely information required for shared awareness and decision-support. Firstly, the *expertise* held by subject matter experts (SME) in the emergency response community and their emergency response goals form the basis for the information a tool has to represent to provide a service that is useful and usable. While folding SME experience into the system, its functionality needs to advance on four fronts (Fig. 1).

1) UTM Services. The STEReO system is based on developing a standardized platform for sharing operational information and data (Fig. 1, yellow segment). By ensuring the system takes inputs and creates outputs that are consistent and adhere to a standard, new users can easily access STEReO and begin to work within it. Sharing operational information will assist users to develop not only their own situation awareness but shared SA.

2) Human factors. With safety as the priority, providing situation awareness during operations is the key purpose of the tool. There is an opportunity for technology to help incident responders maintain awareness of how their assets are being utilized, readily add new assets to the response, and share operational information with others. A common view of sUAS operations will assist operators to coordinate their actions, supporting the safety and efficiency of unmanned flights. Human factors investigation (Fig. 1, red segment) is essential to ensure that information are efficiently displayed.

3) Communications connectivity. To ensure that STEReO services are relevant and available, assuring data flow – the ability to both send and receive information – is of primary importance. There is an opportunity for technology to provide a resilient system that can detect non-participating UAS and broadcast relevant aircraft information (altitude, speed, direction, relative distance, etc.) to the UASO (Fig. 1, brown segment).

4) Autonomy. Additional workload-reducing functions are possible when mission-driven, on-board decision-making autonomy is added to the sUAS (for example, Safe2Ditch [13]), which will potentially support the operator in beyond visual line of sight operations (Fig. 1, green segment).

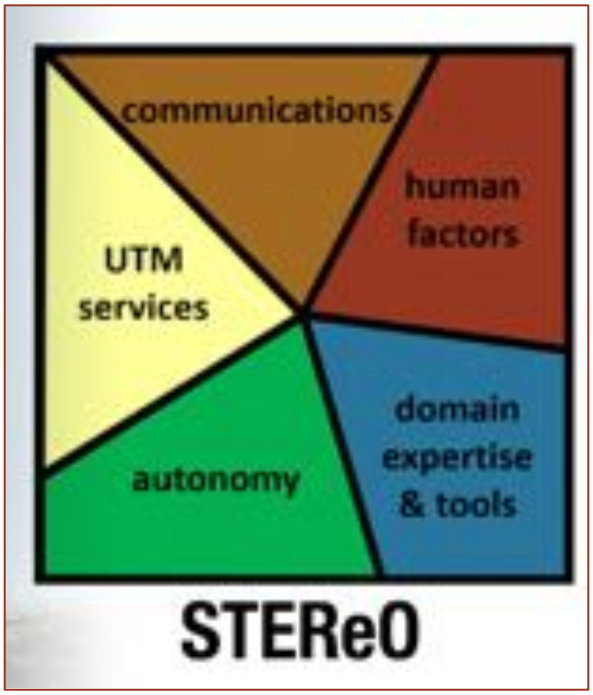

Fig. 1. The five elements considered in the STEReO Feasibility Assessment.

The first prototype built in STEReO will represent sUAS operations along with interactive planning capabilities that will assist the UASO with situation awareness and scheduling. Future phases of STEReO research will endeavor to facilitate greater numbers of operations in support of emergency response, expanding the visibility of sUAS to a larger number of users, accommodating a greater set of vehicle types, and utilizing new developments in vehicle autonomy to reduce user workload. However, this paper describes the initial work undertaken to define the afore-mentioned first prototype of the system, dubbed the UAS-Operator Kit (UAS-OK) using a tool previously developed for the UTM Project as a base. Through this platform, the STEReO approach aims to demonstrate core functionalities and to investigate the effectiveness and usefulness of SA tools to wildfire UASO in the field. The paper describes how user requirements for the UAS-OK were distilled and then refined through three sets of interactions with wildfire SMEs. These three events were a workshop, where members of the larger wildfire management community met to discuss challenges and solutions to using sUAS in wildfire response; a small walkthrough with an example display; and a larger simulation demonstration in the field.

II. WORKSHOP

The first aim of the project was to collect a broad view from the disaster management community on the challenges of using sUAS in fighting wildfires today, and the areas in which research and development of tools and methods could be useful. A three-day workshop was held at NASA Ames, CA, early in 2020 to discuss these topics with SMEs. Nearly 60 participants attended from government agencies, industry, and academia. Each day of the workshop had a focus topic: current day barriers and challenges to using UAS in disaster response, game changing advances that could transform emergency response operations, and strategies for integrating STEReO into emergency response. These topics were discussed in breakout sessions where the larger group split into six mixed-discipline groups of eight to ten people.

A. Emerging Themes

The six groups summarized their discussions as a set of key points. These six sets of key points were combined and categorized for each breakout session. Discussions from the first breakout session, which identified barriers to using UAS in disaster response, were of particular interest. Challenges listed by participants were wide ranging – encompassing points about the environment, tools, technology, the organizations, and the personnel involved in disaster response (see Fig. 2). SMEs emphasized that wildfires tend to occur in areas of very little infrastructure and, looking more widely at other types of disasters, e.g., hurricanes, existing communications infrastructure is often damaged. Inability to exchange information (communicate data) and to communicate with others was raised most often as a concern. Timeliness of sharing data was also an issue. Although categorized in Fig. 2

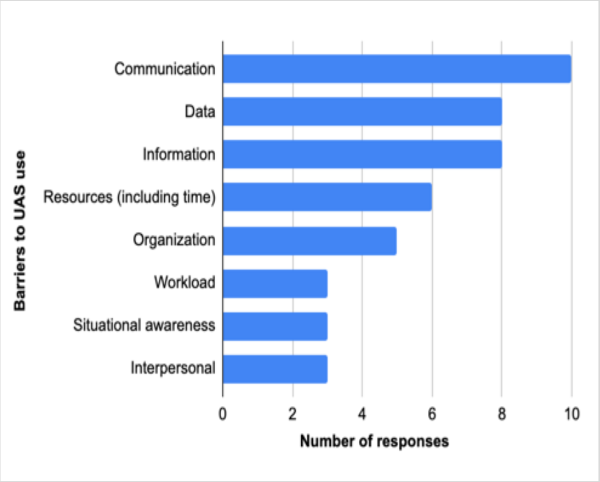

Fig. 2. Types of challenges to flying sUAS in emergency response and the frequency with which they were dicusssed.

as three different items, when combined personal stressors were also mentioned often, including: high workload, difficulty forming and maintaining situation awareness, and conveying information to others.

From the three breakout group sessions across the workshop, an initial set of themes that a tool must meet (high level objectives) were:

- *Improve communications* - Communications have to be robust/resilient and the means to exchange data will need to be part of any tool.
- *Safety first* - Using a tool should not increase demands on resources, for example UASO workload and distractions must not increase at critical times.
- *Provide situation awareness* - Data must be organized to provide information that will increase situation awareness (but not be a demand on resources).
- *Provide a shared experience* - Facilitate cross-organizational communication by providing common access to information.

These themes reflect and support four of the five elements of STEReO (Fig. 1) that comprise the Feasibility Assessment's approach. They underline the importance of a robust communication network, and the need for UTM services that are designed not only with the SME user in mind but also to promote safety. Taking these themes as goals, the second two interactions with SMEs – walkthroughs using simulated events as stimuli – were scoped to ask more detailed questions and to describe more detailed capabilities.

A first demonstration platform was also created to demonstrate the network elements that could be necessary. STEReO is intended to be deployed in the field and will limit network traffic to essential operational data. The demonstration platform created a local communications network using a single server, a single VHF radio, a single router (with a public static internet protocol (IP)), and had an external generator for power.

III. WALKTHROUGHS

Data was collected across two walkthrough demonstrations, both of which were co-located with aerial firefighting training events. The training exercises involved an outdoor simulation of a wildland fire and several piloted aircraft to recreate an aerial firefighting work environment for trainees to exercise communication procedures critical for effective fire suppression. Each day at the flight training site, researchers conducted a parallel, but completely separate, simulation of an aerial firefighting response, with researchers and participants acting the roles for flight crew, air attack, and IC. The simulations included multiple scenarios that captured a growing fire and the movement of the ground and air response over time. Data exchange at the walkthroughs was enabled by setting up a local communications network, as both took place in remote areas – one in an area of national forest and the other on ranchland – both of which had poor cell-network coverage.

An example scenario from the first walkthrough is: the fire begins from a single ignition point close to where the wash from a dry creek meets a larger (also dry) stream. The fire (fictional) spreads up a canyon and is contained as it begins to spill over the canyon ridgelines into adjoining areas. Six tasks are outlined for sUAS. During the initial phase of the fire, sUAS are asked to perform information gathering and photography tasks to provide first-look details about the size of the fire and the surrounding environment to the IC, which the IC could use in resource planning and decision making. During subsequent phases, sUAS tasking includes surveying for structures, searching for people not associated with firefighting (e.g., hikers), checking for hotspots and spot fires, fire-edge mapping, and controlled burns. A characteristic of all these tasks is that they are tactical, in that they are requested based on the IC assessment of the current fire response needs, and so would vary day by day and may or may not be requested on a fire.

These scenarios were represented on a mobile client, which is an application for iOS devices, originally built for the UTM Project, called insight-UTM (iUTM) [14]. During UTM, the iUTM client provided situational awareness of operations to the research team, and it was repurposed as a starting point display for STEReO. 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 based on the position reports they are sending (Fig. 3). This tool also includes a drawing function which allows the user to annotate and share details about the fire scenario, or to sketch their own notes.

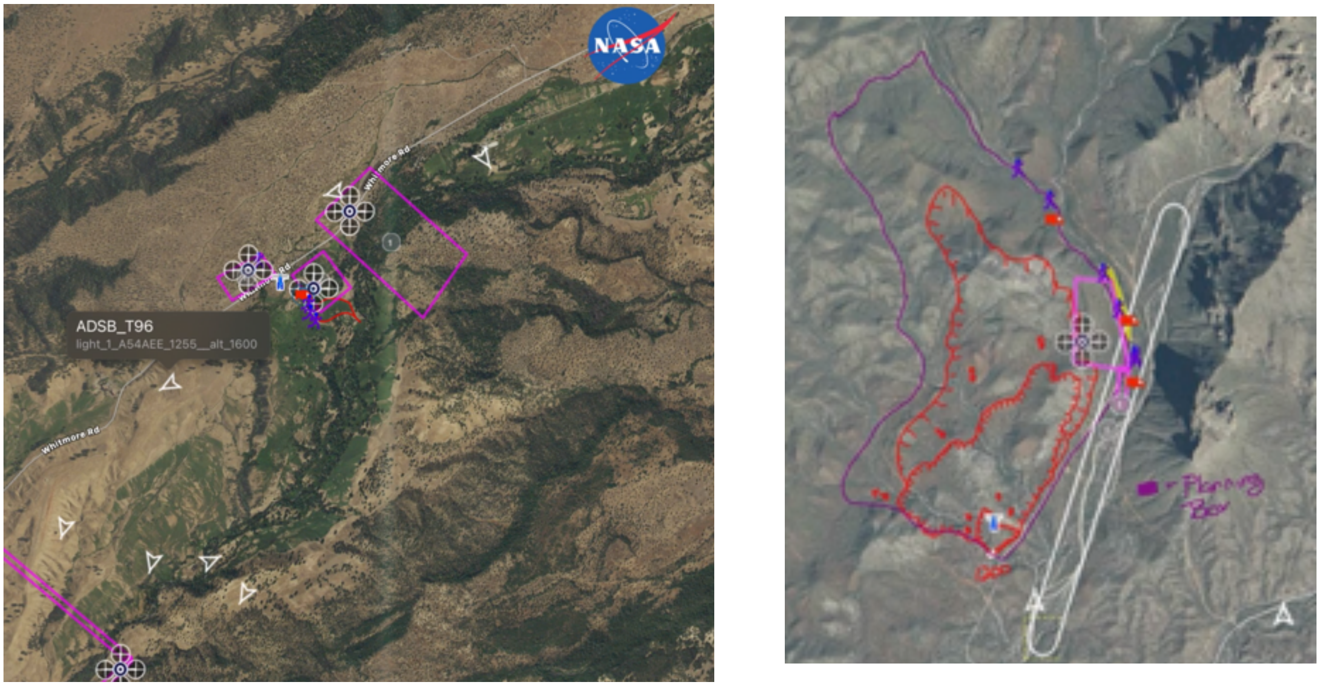

Fig. 3. Examples of the iUTM STEReO client airspace display, showing (left) a scenario with a small fire, ground response, and aircraft response; and (right) a larger fire with air response and fire-related annotations.

For the first walkthrough, sUAS operations, ground personnel, ground vehicles, and some manned air traffic were simulated. In addition to the simulated data, nearby live aircraft equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) transponders were detected and fed into the field deployable system to be visualized on the iUTM display.

Fig. 3 shows the airspace map view with (on the left) live manned aircraft (chevrons), ground personnel (people icons), fire engines (red truck icons) and two sUAS vehicles (sUAS icons), along with their operational volumes (magenta) working on the fire. On the right of Fig. 3, a previous, now closed, operation is shown in white. The fire development (red hashed lines) and center of the local communications network (tower icon) are drawn onto the map along with other notes.

Participants were SMEs who are experienced in flying sUAS in emergency response operations. To gather user requirements, the researchers facilitated daily informal, semi-structured discussions and group debriefs with participants. Researchers would re-order the questions based on participants' responses to maintain a natural flow of discussion. This was particularly useful for increasing understanding of the attitudes, preferences, concerns, practices, and needs of current and future users for safely operating sUAS in emergency response situations.

The SMEs used the iUTM client to step through the fire scenario phases, giving examples of possible IC decisions, sUAS mission types, and location tasking. The STEReO research team created sUAS operations on iUTM to demonstrate performing the tasks in real time. Using these views, the group discussed how an improved display might support SA and necessary features and functions.

The second walkthrough also involved a mix of live and simulated vehicles. The simulated sUAS operations and live ADS-B data of the aircraft participating in the aerial firefighter training activity were fed into the field deployable system and visualized on the iUTM client. In addition to the iUTM client, a wider network of components were included in this walkthrough. Operations were represented through Q-Ground Control [15] and the NASA-Reflection [16] tools to demonstrate the ability to exchange data between different components.

A. *Themes and Defining User Requirements*

Both walkthrough field demonstrations were successful tests of a potential STEReO system. In both cases, a local communications network was set up and several different components exchanged data over the established protocols, e.g., through iUTM and the digital VHF gateway. This exchange was validated through the interactive scenarios.

Statements collected during the walkthroughs were sorted into categories of important features and functions that the SMEs described a tool needs to have. The walkthroughs confirmed the importance of the four objectives derived from the workshop discussions: improve communications, safety first, provide SA, and provide a shared experience. It was emphasized that a UASO Kit needs to contribute to sUAS being integrated more safely into wildfire operations. Any increase in workload to set up operational plans that can be shared over the local network has to be offset by a benefit (in terms of safety) for using the kit. An additional theme that became clear was the need to engender trust in STEReO. This is particularly important to consider during interface design – a goal has to be to create a tool that will support users during stressful tasks when they are operating in distracting environments.

A number of the features and functions presented in the iUTM client were well liked, including the ability to modify an operational volume, the ability to use the drawing tool to annotate the map area, the data tags on vehicles (not shown in Fig. 3), and the volume contingency box or "home" location. On the other hand, the SMEs commented that the operation setup functionality, terminology used on button labels, and button colors made the display challenging to use. More general comments were that the client functions were non-intuitive and the processes to set up the client were too long and involved. However, overall, SMEs liked the way the client effortlessly added to their situation awareness and how it displayed volume-based operations. These points were all discussed in the around-the-table sessions.

The walkthrough statements and researcher observations were used to draft an initial set of goal-level user requirements for the prototype UAS-OK client. Setting out these needs provides guidance not only about the requisite usability of the tool but also the way the system should provide operators with information to build SA, or understanding, of their aircraft and surroundings. The categories include user requirements at a system- and an interface-level regarding: 1) operation planning, 2) display elements, 3) display information management, and 4) device configuration and set up. Each has one or more accompanying features that describe the user requirement in more detail.

1. *Operation planning*

- The procedure to create and submit an operation should be intuitive with only a few steps
    - User can quickly and easily set up a tactical operational volume
    - Execution sequence on the interface is simple and only has a few steps
    - User has different options for the shape of operational volumes (polygons)
    - User can modify their operations

2. *Display elements*

- The main interface should be simple – with only a handful of action options
    - Has few buttons
    - Has good/logical workflow
    - Buttons can be seen easily outdoors

- Alerting preferences should be available
    - User has option to be alerted to incoming sUAS
    - User has option to receive alerts for own ship leaving its volume

- Incident-related resources should be available to view in the display
    - Displays manned aircraft (using ADS-B)
    - Displays other UAS
    - Displays firefighter locations and equipment (using an Automatic Packet Reporting System (APRS))
    - Displays daily fire map

- Objects/terminology on the display should be familiar to users
    - Incorporates symbology/icons that are already used in emergency response, such as the NWCG symbols [17]
    - Icons and buttons in the display are labeled with words that are used by SMEs
    - Uses "layers" that refer to different maps

3. *Display information management*

- The interface should allow the user to add information to the map
    - Includes a drawing tool for users to annotate the map
    - Provides ability to place icons/markers on the map

- The interface should allow the user to manipulate/interact with certain items of displayed information
    - Provides ability to turn icons on and off, one by one, or all (e.g., option to have Fire Traffic Area shown or not, to have airbases shown or not)
    - Provides ability to turn ADS-B and/or APRS data off
    - Allows user to set the buffers for alerting functions
    - Gives the option to share operation volumes with other UAS operators/others

4. *Device configuration/setup*

- The equipment for the communications network should be portable
    - Whole system fits in a pickup truck

- The procedure to set up the UAS-OK in the field should be straightforward without the need to connect every element of the network individually
    - Communications are included in the system
    - Communications start up with very little preparation (flick of a switch)
    - Device connects automatically on start up

B. *Next Steps*

The next steps for the STEReO Feasibility Assessment are to build a UAS-OK prototype, with a communications module that fits into a smaller space, and to redesign the client user interface so that it is more tailored to SMEs' needs. Specifically, the interface will support a more intuitive task flow and require fewer user actions. Furthermore, the first build of this prototype will be a field deployed network that is intended to limit network activity to the essential UTM traffic. It will use a single server, a single VHF radio, two cellular routers (with public static IPs), SATCOM (also with a public static IP), and have an external generator for power. Each UAS-OK will be able to join a multi-node Mesh WiFi network with directional links from the main base to remote GCS locations, enabling more than one UASO to be in the system in the local area. It is planned that the UAS-OK prototype will be tested in simulations and field studies, similar to those described above, to advance STEReO on three fronts: firstly, to verify and test the technologies; secondly, to support UASOs by providing information for situation awareness and decision support; and thirdly, to gather user experience data to improve the usability and functioning of the tool.

IV. SUMMARY

Safety is the principal consideration for all incident responders. Within a wildland aerial fire response environment, a large number of low-altitude aerial assets operating in a relatively small area create a high level of airspace complexity. Introducing sUAS into this environment is difficult, as these vehicles add to the challenges. As a counterpoint to this, sUAS have much to offer, being relatively quick and easy to use and able to maneuver close to the fire edge while the operator is further from harm's way. While the long-term aim for STEReO is to provide technology that supports large-scale efficient use of aircraft in emergency response, the initial focus for STEReO is to demonstrate a smaller system of technologies, the UASO Kit, that will enhance UASO airspace awareness.

The discussion above describes how SME user requirements and needs were gathered from the emergency response community through three events where the research team was able to interact with wildland fire experts. Technical elements of STEReO need to interact and demonstrate that they can improve the safety and effectiveness of sUAS assets in order to support their increased utilization. A valuable finding from the above work was that the tools should also directly address the challenges from the users' perspective. Specifically, participants asked that the system respond to user needs as they pertain to operation planning, display elements, display information management, and device configuration/setup. Understanding and considering the user as the keystone of the system is an essential step in ensuring the success of STEReO. The value of a UAS-OK will be in its ability to confirm user situation awareness, provide SMEs with decision support, and foster trust.

ACKNOWLEDGMENT

The authors would like to thank the members of the USFS UAS Program (Justin Baxter, Gary Baumgartner, Dirk Giles, and Zachary Holder) and CAL FIRE's Tactical Air Operations Program Division Chief, Jake Sjolund, for all of their help and guidance during the STEReO Feasibility Assessment.

This work was funded by NASA's Convergent Aeronautics Solutions (CAS) Project under the Transformative Aeronautics Concepts Program (TACP).

REFERENCES

[1] Ready, "Wildfires," Ready.gov, 2016, https://www.ready.gov/wildfires.

[2] Center for Climate and Energy Solutions (C2ES), "Wildfires and climate change," C2ES, 2021, https://www.c2es.org/content/wildfires-and-climate-change/.

[3] California Department of Forestry and Fire Protection, "2018 Incident Archive," CAL FIRE, 2021, https://www.fire.ca.gov/incidents/2018/.

[4] National Wildfire Coordinating Group, "NWCG standards for fire Unmanned Aircraft Systems operations," PMS-515, NWCG, 2019, https://www.nwcg.gov/publications/515.

[5] J. Stevenson, S. O'Young and L. Rolland, "Enhancing the visibility of small unmanned aerial vehicles," 6th International Conference on Applied Human Factors and Ergonomics (AHFE2015), Elsevier, 2015, doi:10.1016/j.promfg.2015.07.143.

[6] J. Loffi, R., Wallace, J.Jacob and J. Dunlap, "Seeing the threat: Pilot visual detection of small unmanned aircraft systems in Visual Meteorological Conditions." International Journal of Aviation, Aeronautics and Aerospace, 3, iii, Art. 13, 2016.

[7] J. Rios, D. Mulfinger, J. Homola and P. Venkatesan, "NASA UAS Traffic Management National Campaign," 35th Digital Avionics Systems Conference (DASC), IEEE/AIAA September, Sacramento, CA, 2016.

[8] J. Robinson III, M. Johnson, J. Jung, P. Kopardekar, T. Prevot and J. Rios, "Unmanned Aerial System Traffic Management concept of operations (v0.5) (UTM CONOPS), NASA/TM-2015-000000," NASA Ames, Moffett Field, CA, 2015.

[9] J. Lee and K. See, "Trust in Automation: Designing for Appropriate Reliance," Human Factors, 46, i, 2004, pp50-80, https://doi.org/10.1518/hfes.46.1.50_30392.

[10] T. Sheridan, "Telerobotics, automation, and human supervisory control," Cambridge, MA: MIT Press, 1992.

[11] L. Martin, et al., "TCL4 UTM (UAS Traffic Management) Texas 2019 flight tests, Airspace Operations Laboratory (AOL) report, NASA/TM-

2020-220516," NASA Ames Research Center, Moffett Field, CA, 2020.

[12] C. Jimenez, C. Faerevaag and F. Jentsch, "User interface design recommendations for small Unmanned Aircraft Systems (sUAS)," International Journal of Aviation, Aeronautics, and Aerospace (IJAAA), 3, ii, article 5, 2016.

[13] P. Lusk, P. Glaab, L. Glaab and R. Beard, "Safe2Ditch: Emergency Landing for Small Unmanned Aircraft Systems," Journal of Aerospace Information Systems, 16, viii, pp327-339, AIAA, August 2019, https://arc.aiaa.org/doi/pdf/10.2514/1.I010706.

[14] J. Homola, T. Prevot, J. Mercer, N. Bienert and C. Gabriel, "UAS Traffic Management (UTM) simulation capabilities and laboratory environment*,"* 35th Digital Avionics Systems Conference (DASC), IEEE/AIAA September, Sacramento, CA, 2016.

[15] Dronecode, "QGroundControl," Dronecode Project, Linux Foundation Collaborative Project, Linus Torvalds, 2019, http://qgroundcontrol.com.

[16] A. Chakrabarty and C. Ippolito, "Autonomous flight for multi-copters flying in UTM-TCL4+ sharing common airspace," AIAA2020-0881, AIAA SciTech 2020 Forum, Orlando, FL, January 2020, https://doi.org/10.2514/6.2020-0881.

[17] National Wildfire Coordinating Group (NWCG), "New ICS Symbology, PMS-936," NWCG, 2021, https://www.nwcg.gov/publications/pms936/symbology.