Incorporating UAS Traffic Management into Wildland Firefighting Operations: Initial Findings of Subject Matter Expert Interviews

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***Abstract*—Uncrewed Aircraft Systems (UASs) are being utilized throughout the disaster and emergency response domain, including in wildland firefighting operations. While UASs can offer safety benefits in comparison to crewed aircraft, such as removing the human pilot from the vehicle so that they are not exposed to the same risks and the ability to operate in low-visibility conditions, they are not without tradeoffs. For example, it can be challenging for UAS pilots (UASPs) to build situation awareness of the airspace in which their UAS is operating. In order to address some of the challenges associated with using UASs and provide greater assistance to the firefighters and incident personnel in the wildland firefighting environment, the National Aeronautics and Space Administration (NASA) launched the Advanced Capabilities for Emergency Response Operations (ACERO) project.**

Building on previous NASA research, ACERO will explore the implementation of a traffic management system in the wildland fire environment to enhance safety and support situation awareness. ACERO draws on the UAS Traffic Management (UTM) system previously demonstrated in an urban environment. However, a traffic management system implemented in the wildland fire environment is expected to look and function much differently in order to meet the unique needs of this domain.

At the outset of the ACERO project, interviews were conducted with five UASPs who operate UASs at wildland fire incidents. The interviews focused on exploring UASPs' initial insights about the application of a traffic management system in wildland firefighting and understanding the unique needs of this environment. The UASPs discussed a range of topics including, the shape, size, and organization of UAS operations in the wildland fire environment, information needs for a user interface, such as traffic and map information, an alerting function when other traffic nears their operation area, and the importance of conformance monitoring. The UASPs also discussed their willingness to share operational information to support safety.

In this paper, we describe the foundational work upon which ACERO will build and summarize the information and insights gathered during the UASP interviews, some of which have already informed the development of the ACERO work.

Keywords*—*Uncrewed Aircraft System (UAS), UAS Traffic Management (UTM), Wildland Firefighting

I. Introduction

A wildfire is an unplanned, unwanted fire burning in a natural area, such as a forest, grassland, or prairie [1]. In addition to the economic costs, wildfires cause a significant threat to human lives, communities, structures, and ecological systems. Their impact and trends are assessed through a number of statistics, including the number of fires, acres burned, as well as, length of fire season.

Over the past thirty years in the United States (U.S.), the number of acres affected by wildfires has increased [2]. Since 2000, there has been an average of 70,025 wildfires and 7.0 million acres impacted annually, with the average acreage being more than double the size of fires in the 1990s (i.e., 3.3 million acres) [2]. In the western U.S. and Alaska, the incidence of large forest fires has increased since the early 1980s [3]. Since the 1970s, in the western states, the wildfire season – that is, months between the first and last large fires – has extended from 5 months to over 7 months in length [4].

A. Wildland Firefighting

Wildland firefighting is made up of a complex organization of personnel and resources who utilize well-established procedures and practices while working in a challenging, high-workload environment [5].

In addition to firefighters and incident personnel on the ground, aerial resources play an important role in wildland firefighting. During an active fire, crewed aircraft serve a number of critical functions, including, the Air Tactical Group Supervisor (ATGS) to direct traffic from a higher altitude, air tankers that drop water and/or fire retardant, the Aerial Supervision Module (ASM) aircraft that identify the drop location for the air tanker, and helicopters that transport crew and equipment, sometimes to remote areas. Crewed aircraft can face constraints like low visibility due to smoke and their operations can be limited to daylight hours.

1) UAS in Wildland Firefighting

Uncrewed Aircraft Systems (UASs) are now utilized throughout the disaster and emergency response domain, including in wildland firefighting operations. They are used for a variety of purposes in wildland firefighting and prescribed burns, such as aerial ignition, real-time video monitoring, and data collection for thermal imaging. UASs offer the benefits of:

- Removing the human pilot from the vehicle so they are not exposed to the same risks as in crewed aircraft.
- Being able to operate in low-visibility conditions (e.g., smoke or nighttime) where crewed aircraft operations are limited.
- Being relatively quick and easy to maneuver.

UASs have shown to be a cost-effective technology application in wildland firefighting operations [5].

However, there are challenges and tradeoffs associated with utilizing UASs in the wildland fire environment. An active fire incident is surrounded by a Temporary Flight Restriction (TFR), that is, an airspace boundary designated by the Federal Aviation Administration's (FAA). Within a TFR, a UAS Pilot (UASP) can operate the UAS *beyond visual line of sight* (BVLOS), and above 400 ft, which can make it challenging to develop good situation awareness for where other UASs and crewed aircraft are relative to their own vehicle.

Additionally, although someone in incident command (e.g., the Air Operations Branch Director (AOBD) or a Division Supervisor) may communicate the assigned tasking for a UAS crew during a pre-operational briefing for shared awareness among all team members, once operating, very few UASP have a mechanism to share real-time telemetry (speed, location, altitude) with other UAS operators. Instead, UAS crews generally rely on radio communications to build and maintain their situation awareness of other operations in the airspace.

Likewise, pilots of crewed aircraft or the ATGS, may also have limited awareness of exactly where each UAS is operating, due to UAS vehicle's lack of visibility, which creates a safety concern for crewed aircraft. Today, UASPs and crewed pilots manually coordinate and deconflict operations in wildland firefighting [6]. Furthermore, degraded communications can be an additional obstacle for UASPs, due to location-specific challenges, such as lack of communication infrastructure and terrain.

In order to address some of the challenges associated with using UASs and provide greater assistance to the firefighters and incident personnel in the wildland firefighting environment, the National Aeronautics and Space Administration (NASA) launched the **Advanced Capabilities for Emergency Response Operations (ACERO)** project in 2023 [7]. Through a series of demonstrations over the next six years, ACERO aims to **demonstrate technology that will improve the efficiency and enhance the safety of UAS operations in wildland fire management.**

From our Human Factors perspective, one of the first steps in this work was to conduct a series of interviews with UASPs who fly wildland fire missions. Theses interviews captured current-day practices, constraints, and information needs that will have implications for the design of a wildland firefighting airspace management system. In this paper, we first discuss previous NASA research which serves as the foundation for the ACERO work and then document information and insights from our interviews with UASPs.

B. *ACERO Draws on Previous NASA Work*

As a means of safely managing UAS operations and providing a common operating picture with improved situation awareness for UAS crews, crewed aircraft pilots, and incident personnel on the ground, ACERO is investigating the implementation of a traffic management system in the wildland fire environment. This effort draws on two previous areas of work at NASA: UAS Traffic Management (UTM) and Scalable Traffic Management for Emergency Response Operations (STEReO).

1) *UAS Traffic Management (UTM)*

The initial UTM concept [8] arose from the need to safely manage a high number of small UAS (sUAS) vehicles operating in low-altitude airspace (below 400 ft). This was driven by the predicted increase in sUAS operations for commercial applications, such as infrastructure surveillance, deliveries, videography, and agriculture, as well as, public safety applications. [9]. Because Air Traffic Control (ATC) radar cannot detect sUAS vehicles operating at such low altitudes (i.e., below 400 ft) and the manpower/cost required for the FAA to manage UAS operations at scale is not cost-effective [10], a new approach to traffic management was necessitated. NASA and the FAA worked in collaboration to develop, research, and evolve this new paradigm of Air Traffic Management (ATM).

The UTM concept recognized that sUAS operations are fundamentally different from conventional, crewed aviation in that they are operated remotely and do not have a pilot on board to detect and avoid other vehicles, have different, and varying, performance characteristics (e.g., ascent/descent rate, turn speed, sensitivity to wind), and require different separation standards from conventional aircraft [9].

In the UTM Concept of Operations (ConOps), the FAA established that – in contrast to conventional ATM where ATC is responsible for separation between aircraft via voice communication with the pilot(s) – UTM will operate as a community-based, cooperative system in which operators share their intent and operation information amongst themselves, rather than receiving separation services from ATC [11]. Using a federated network, operators will rely on third-party service suppliers and automation for connecting with other operators, sharing information, exchanging data, planning, deconflicting trajectories, and monitoring conformance [11].

NASA's five-year UTM project conducted a series of flight tests in which they demonstrated increasingly complex sUAS operational scenarios in low-altitude airspace (ground to 400 ft) [12]. The demonstrations began with a single UAS operating in a constraint-free, rural, unpopulated airspace *within* visual line of sight (VLOS) of the operator and increased in complexity to multiple UASs flying in an "urban canyon" setting with restrictions and alerts that required the operator to maneuver precisely to avoid obstacles [13].

In the UTM concept, operators "define" the area in which they plan to operate their sUAS in the form of four-dimensional (4D) volumes of airspace, which are delineated by latitude/longitude, altitude, and time. Depending on the setting and nature of the operation (e.g., package delivery in an urban environment), a full flight plan can be made up of a series of contiguous volumes, akin to “tunnels” running through the airspace, as shown in Fig. 1 [14]. Operators share where and when they plan to operate, that is, their *operational intent* defined by 4D volumes, with the UTM system for planning and trajectory deconfliction, and to support situation awareness with other operators.

During NASA’s UTM demonstrations, each sUAS operator utilized a software tool, referred to as a UTM Service Supplier (USS) to participate in the UTM system and visualize UAS operations (Fig. 1). As the flight tests progressed over the course of the project, more functionality was added to the USS tool [15]. By the final flight test, Technical Capability Level 4 (TCL4), that took place in urban environments, operators used the USS tool to plan their flight by defining 4D operational volumes of airspace through which their UAS would transit.

The UTM system used an automated process for approving (or rejecting) volumes to ensure that operations were deconflicted. Using the USS tool, operators manually input their operation plan, which was made up of 4D volumes. The UTM system compared the 4D volumes to operations submitted by other operators to ensure there were no overlaps, or “conflicts” with other operations. If no conflicts were detected, the operation plan was approved by the UTM software. Alternately, when a conflict was detected, different approaches were used to resolve the overlap, including ‘first come, first served,’ operator negotiation/replanning, or an agreement to share the same airspace, provided the vehicles are equipped for vehicle-to-vehicle data transfer [14].

In TCL4, the USS also had the capability to provide alerts when another sUAS was out of conformance with its 4D volumes [14]. As depicted in Fig. 1, color-coding was also incorporated into the USS display to represent operational state (magenta for an active volume, cyan for a future operation, and orange when a sUAS is out of conformance with its volume).

Fig. 1. Example of live and simulated operational 4D volumes depicted in the USS tool from UTM flight tests in Corpus Christi, TX [14]. Operational volumes are color-coded to indicate their state; UAS icons with white dots represent active sUAS vehicles.

As described in [14] and [15], Human Factors analyses of the operator’s experience with the USS, using data collected through participant questionnaires, interviews, debriefs, and observations, showed that the USS was an effective tool for supporting the human operator’s interaction with the UTM system. The USS supported data exchange with the system and with other operators, and provided situation awareness of sUAS operations for the operator.

2) Scalable Traffic Management for Emergency Response Operations (STEReO)

Like the UTM project, STEReO continued to investigate UAS traffic management and technologies to support situation awareness among users; however, STEReO focused on UAS operations in the *wildland firefighting environment* [6]. To more effectively integrate sUAS operations with crewed aircraft at wildland fire incidents, STEReO’s aim was to create a tool to support the UASP’s situation awareness [6].

In comparison to the environments in which the UTM flight tests were conducted (e.g., rural or downtown, urban areas), the wildland fire environment presents unique challenges for UAS operations. First, there is the potential for a mix of both crewed aircraft and UAS vehicles to be operating at lower altitudes at the same time. While UASPs and incident personnel adhere strictly to procedures for UAS operations at wildfire incidents and take many safety precautions (e.g., importantly, lateral separation between crewed and uncrewed operations), they generally rely on radio communications to build and maintain their situation awareness of other operations in the airspace [5]. Further adding to the challenge is the extremely low visibility of UAS vehicles to pilots in crewed aircraft. The second challenge is the possibility of degraded communications (due to location, lack of communication infrastructure, and sometimes terrain), which has implications for the timeliness of sharing information and supporting situation awareness among UASPs and other incident personnel [5].

STEReO drew on the concept and technology demonstrated during the UTM project and engaged with experts in the disaster response and wildfire management communities, including the U.S. Forest Service and the California Department of Forestry and Fire Protection (CAL FIRE), for their insights about how a software tool could be designed to support UAS operations and meet their needs, given the unique challenges of the wildland firefighting environment. Findings from workshops [5] and knowledge-building activities in the field [6] with Subject Matter Experts (SMEs) pointed to the importance of supporting data exchange, improving situation awareness, and facilitating a shared experience through access to common information, *without increasing workload or causing distraction*.

To help address these needs in the near-term, the STEReO team created a prototype system to support the UASP’s situation awareness of crewed operations at a fire incident. The ground-based, portable, and self-contained “UASP-kit” (pictured in Fig. 2) is lightweight enough for one person to carry and can work “offline” as it is not dependent on a Wi-Fi network or cellular connection. The kit consists of several components, including an ADS-B (Automatic Dependent Surveillance-Broadcast) receiver, a server, and power source, and a touchscreen tablet contained in a ruggedized case [16].

Fig. 2. A UASP-kit, in a ruggedized case, being utilized in the field.

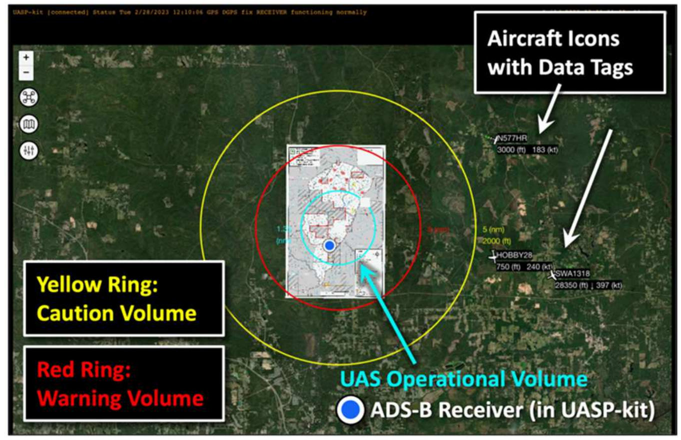

Fig. 3. The STEReO UASP-kit UI displaying crewed aircraft icons from ADS-B messages, the UAS Operational Volume (cyan circle), a yellow Caution ring (5 miles, in this example), a red Warning ring (3 miles, in this example), and the location of the ADS-B receiver contained within the UASP-kit (blue dot).

To provide UAS crews with increased situation awareness about the airspace in which they are operating, ADS-B messages from nearby crewed aircraft are processed and displayed on the user interface (UI) as aircraft icons with data tags, and then overlaid on a satellite map, and optionally, an incident map, as shown in Fig. 3 [16]. Drawing on the UTM concept, where operators define an area in which their UAS will operate, the user creates a 4D cylindrical or cube-shaped *operational volume* where they plan to carry out their mission (cyan circle in Fig. 3) [16].

The notion of airspace volumes is also applied to alert the UAS crew to nearby traffic. The user can create two alerting rings – essentially, two additional *volumes* of airspace – around their own operational volume. These volumes, the size of which are set by the user, are displayed as a yellow "caution" ring and a red "warning" ring around the UASP's cyan operational volume (5 miles and 3 miles wide, respectively, in the example shown in Fig. 3). If an ADS-B equipped crewed aircraft crosses into the caution or warning volume, then users are alerted with a visual and audio alert [16]. The auditory alerting feature affords the UASP and crew the opportunity to focus on the Ground Control Station (GCS) and other aspects of the operation, while maintaining a visual scan of the airspace. In the event that a crewed aircraft does come near their operating area, it is common operating practice for the UAS crew to move their ownship and possibly return it to its launch area, to deconflict with the other aircraft.

In 2022, the UASP-kit was tested by crews operating UASs in two different types of real-world, wildland fire settings [16].

- First, during the spring, throughout the southeastern U.S., UASP instructors and trainees, accompanied by NASA researchers, utilized three UASP-kits while they conducted *prescribed burns*. During planned and controlled fires like these, sUASs can be utilized in place of crewed helicopters for aerial ignition.
- Second, during the summer fire season in the western U.S., five UASP-kits were used by UAS crews during *active wildland fires*.

The ADS-B alerting functionality for traffic was enabled on each kit. When the UASP-kit produced an audio alert, a member of the UAS crew looked at the display to assess whether they needed to take action to deconflict with the crewed aircraft, by moving or returning the UAS to its launch area.

As described in [16], the Human Factors analyses focused on usability ratings and feedback from users. UAS crews reported that the UASP-kit supported their situation awareness of traffic in the airspace, and that they especially liked the auditory alerting feature. For a complete description of results from STEReO's UASP-kit field research, see [16].

Although the STEReO activity was completed in 2022, UASP-kits are still being used by UAS crews at wildland fire incidents during the current 2024 fire season to continue to collect data to further improve the UASP-kit tool.

II. Advanced Capabilities for Emergency Response Operations (ACERO)

While STEReO successfully demonstrated a much needed *near-term* technology for improved airspace awareness in wildland fire environments, there is a need to explore a longer-term, more far-reaching vision for UAS airspace management in wildland firefighting. NASA launched the ACERO project in 2023 with the overall goal to: Develop, demonstrate, and transition-to-operations emerging NASA and industry aviation technologies that can 1) identify, 2) monitor, and 3) mitigate wildland fires, as a means to enhance safety and improve the efficiency of operations. ACERO is planning a series of increasingly complex demonstrations (TCLs) over the next five years.

Some of ACERO's stated objectives include:

- Provide a systematic vision for the future by leading the development of a ConOps for a wildland fire airspace management system.
- Demonstrate emerging airspace management technology to improve the emergency responder's effectiveness and safety during a wildland fire.

- Develop and demonstrate new mission capabilities using emerging aviation technologies that support 24-hour operations.
- Utilize UAS to support aerial connectivity, logistics, and suppression.
- Leverage public, private, and philanthropic partnerships and cross-mission directorate technologies to develop and demonstrate prototype capabilities.

In short, ACERO aims to **demonstrate technology that will improve the efficiency and enhance the safety of UAS operations in wildland fire management**. The field demonstrations (TCLs) are expected to encompass the development of 1) an airspace management system to support multiple UAS operations, 2) a UI to visualize and input information, and 3) communication technology to support information sharing between UAS operators, crewed aircraft, and ground crews.

From a Human Factors perspective, one of our first steps in this work was to conduct a series of group interviews with UASPs who fly wildland fire missions for federal and state agencies. These group interviews captured feedback regarding current-day practices, constraints, and information needs that will have implications for the design of an airspace management system in the wildland firefighting environment. A total of five SMEs participated in the interviews. In addition to their experience as UASPs, they all have a background in other wildland firefighting roles, such as hotshot firefighters, engine crew, helitack firefighters, and ATGS.

In the next two sections, we present: A) An overview of UAS vehicles and the nature of their missions in current-day wildland firefighting, as described by the UASPs, and B) The UASPs' initial insights into the application of a traffic management system in wildland firefighting.

A. *UASP Interviews: UAS Vehicles and Operations*

UAS vehicles used in wildland firefighting are generally categorized into two groups based on similar attributes (Fig. 4). Type 1/Type 2 UASs are larger, fly longer missions, and can carry more equipage, but are more cumbersome to transport and require assembly at their destination. In contrast, Type 3/Type 4 UASs are smaller, more maneuverable, and easier to transport (e.g., some can be carried in a backpack), but because of limited battery power, they can only operate for around 30 minutes before the battery needs to be changed.

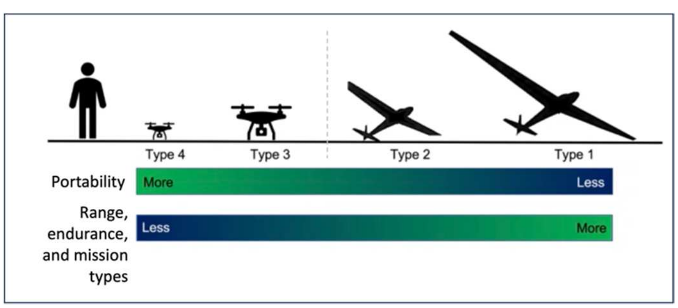

Fig. 4. Types of UAS vehicles used in wildland firefighting and their associated attributes.

Characteristics of Type 1/Type 2 and Type 3/Type 4 UAS operations are described in Table I.

1) *Type 1/Type 2 UAS Operations*

The UASPs explained that Type 1/Type 2 operations are generally more *strategic* in nature, as they require more pre-planning prior to the mission and the data they collect often requires processing before it can be disseminated. Generally, their data product (e.g., a thermal map or a fireline map) is not available until the beginning of the next shift, although some maps may be available within an hour of data being collected. Type 1/Type 2 crews focus on the *data objective* of the mission and take care to ensure that the vehicle is equipped with the proper sensors and equipage.

Upon arriving at the incident, Type 1/Type 2 crews conduct a site survey to determine an optimal location for the Launch and Recovery Zone (LRZ), which is set up farther away from the fire than the Type 3/Type 4's Takeoff and Landing Area. To decide where the LRZ should be located, the UAS crew considers a number of factors, including terrain and vegetation. The crew conducts a viewshed analysis in an effort to verify that the UAS will be able to maintain its Command and Control (C2) link with the GCS for the entirety of the mission.

Because the Type 1/Type 2 UAS climbs to approximately 5,000 ft above ground level (AGL) using a spiral climb pattern in a 2-mile wide "cylinder," the crew is responsible for making sure the airspace is clear and that everyone is aware of the UAS operation. Prior to launch, the UAS Manager (UASM) is required to make numerous notifications via the phone and over shared radio frequencies (e.g., air-to-ground FM frequency, air-to-air AM frequency) to communicate when the UAS will launch and *in what area* it will be climbing – the same is also true at the end of this mission when the UAS prepares to descend. As the UAS is climbing/descending, the "cylinder" of airspace is considered "hot," which means that the airspace from the LRZ on the ground to the ceiling of the TFR is deemed a no-fly zone. Today, awareness about aerial operations is communicated verbally, primarily via radio communications.

2) *Type 3/Type 4 UAS Operations*

The UASPs described Type 3/Type 4 operations as more *tactical* in nature. They fly at lower altitudes and for shorter durations, generally 20–30 minutes because of battery limitations. The UASPs described them as a "ground-based aviation resource/asset" driven by the needs on the ground (e.g., a request for a Type 3/Type 4 UAS could originate from an Engine Captain or a Hotshot Superintendent).

The Type 3/Type 4 UAS can stream real-time video that is displayed on a monitor for incident personnel on the ground. These smaller UASs can also be used for spot fire detection, where the UAS crew guides firefighters to a spot fire in real-time using radio communication and the lights on the UAS vehicle. Type 3/Type 4 UASs are considered more dynamic because they may transition between multiple Takeoff and Landing Areas, depending on the needs of the mission. Type 3/Type 4 typically provide information in real-time, but the UAS crew may also debrief information following the mission.

TABLE I. UAS OPERATIONS IN WILDLAND FIREFIGHTING

Attribute	**Type 1/Type 2 UAS**	**Type 3/Type 4 UAS**
Vehicle examples	Scan Eagle, FVR-90	Alta-X, M-600, Mavic, Anafi
Mission types	**Strategic** – During an active fire, thermal imaging, map entire fireline.	**Tactical –** Real-time video, photos, Aerial Ignition during active fires and prescribed burns, Spot fire detection
Data products	Requires post-processing, data product takes longer to disseminate	Real-time data (e.g., video)
Acquiring UAS at an incident	Once requested, may take 24–48 hours to get onsite	Once requested, faster to bring onsite, a crew member may have already transported the UAS with them; UASs are agency owned and operated
Required approval to operate at a fire incident	***At an active fire incident within a TFR:*** Certificate of Waiver or Authorization (COA) that specifies operating BVLOS above 400 ft in the TFR	***At an active fire incident, within a TFR:*** COA that specifies operating BVLOS above 400 ft in the TFR ***At a prescribed burn (without a TFR):*** UAS have to stay below 400 ft to fly BVLOS; or EVLOS *with* observers
Setup location	The LRZ generally farther away from the fire	Takeoff and Landing Area is generally closer to the fire
Remote operation	BVLOS is permitted *within* the TFR	BVLOS is permitted *within* the TFR
Altitude	Expected to fly at or around 5,000 ft	Operate at lower altitudes, generally, ground to 700 ft
Mission duration	Long-duration platform: Depending on needs of mission, up to 12 hours	Generally limited to 20–30 minutes, before the battery needs to be changed
Crew	UASP, UASM, and UAS Data Specialist (UASD)	UASP and Visual Observer (VO)
Equipage	e.g., Infrared (IR) camera for thermal imaging of the fireline	e.g., Video, camera, Electro-Optical (EO) and IR Sensors, aerial ignition hopper and spheres
Climb	Spiral climb pattern in a 2-mile wide "cylinder"; no-fly area during climb	No specified pattern
Remote piloting	Typically pre-programmed and flown on autopilot	Typically flown manually
Lost link procedure	Return to base (LRZ) or contingency location	Return to base (Takeoff and Landing Area) or contingency location

B. *UASP Interviews: Insights on the Implementation of a Traffic Management System in the Wildland Fire Environment*

The current ACERO work explores the implementation of a traffic management system to support safe and integrated UAS operations at wildfire fire incidents. A system for managing UAS traffic would draw on the fundamental principles of the UTM concept, that is, defining areas of operation in the form of volumes, sharing operational intents cooperatively with other users, comparing the location/time of volumes to deconflict operations, monitoring conformance, and providing users with a common operating picture for situation awareness. However, in order to meet the unique needs and constraints of the wildland firefighting environment, a UTM system in this context is expected to look and function much differently than it did in the original UTM demonstrations [14].

At the start of the UASP interviews, we briefed the UTM concept and its implementation in an urban environment (i.e., contiguous 4D volumes that create narrow "tunnels" for transiting through the airspace). We then posed a wide range of discussion questions about how a concept like UTM might be applied to UAS operations in the wildland fire environment. The UASPs discussed various aspects of a UTM system, including volume shape/size, the display of UTM information in a UI, and how operations would be prioritized and deconflicted. The following is a summary of the interview discussions.

Operational Volumes: In contrast to the way 4D volumes, sometimes called "trajectory volumes," were designed in the urban UTM environment, operational volumes at a wildland fire would be larger, and fewer volumes would be needed by each operation. In wildland fire operations, UASs generally work in their own well-defined areas. The UASPs agreed that Type 1/Type 2 operations could use two volumes, a cylindrical "LRZ" volume for climb/descent and a wider operating volume that would encompass the entirety of their mission at altitude (e.g., flying around the perimeter of the fire). The UASPs thought that the Type 3/Type 4 operation could be contained in a single, cubical volume. During one of the interview sessions, a rough, "back of the napkin," sketch was made to capture these ideas (Fig. 5).

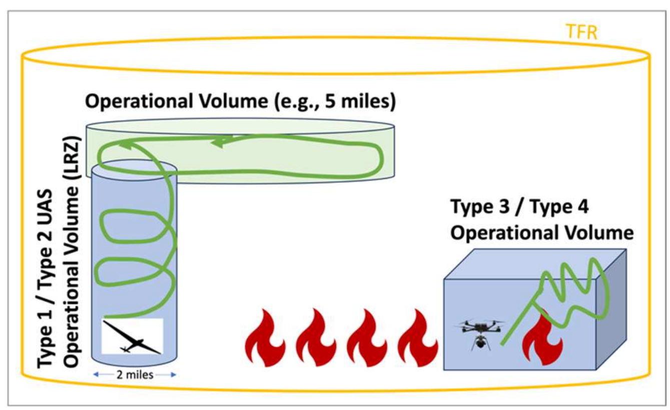

Fig. 5. Sketch of operational volumes for Type 1/Type 2 and Type 3/Type 4 operations at a wildland fire incident.

Size of Operational Volumes: The UASPs favored making volumes large enough to accommodate the mission, but small enough to leave room for other airspace users. One UASP said that, "*The whole idea is to keep as much airspace open for other people to use as possible.*"

Organization of Airspace Volumes: Another important difference, as compared to the UTM system in the urban environment, is the arrangement of multiple operations in the airspace. When asked about ensuring safe separation between UAS operations, the UASPs indicated that multiple UAS operations should not be vertically "stacked" on top of each other. Rather, a UTM system could ensure safe separation by continuing to organize UAS operations *laterally*, as they do in current-day wildland fire operations. When arranged laterally, if one UAS vehicle has a mechanical or communications issue and makes an emergency descent, it is less likely to impact other UAS vehicles. UASPs also felt that spacing *between* volumes of different operations (e.g., a buffer) is critical for safety.

Information Sharing: In the UTM ConOps [11], the FAA states that, "*UTM is predicated on layers of information sharing and data exchange ... to achieve safe operations. Operators share their flight intent with each other and coordinate to de-conflict and safely separate trajectories.*" When the UASPs were asked about information sharing in a wildland fire environment, they agreed that they would be willing to share all operation information (e.g., location, speed, altitude, heading, mission intent). The UASPs were supportive of information sharing because they felt strongly that knowing where other vehicles are is a safety issue and crucial for situation awareness.

UI Information Needs (Traffic): In current-day wildland fire operations, UAS crews generally rely on radio communications to build and maintain their situation awareness of other operations in the airspace. (Note that some crews are using tools that provide added situation awareness: NASA's UASP-kit provides an ADS-B alerting functionality and a visual display for traffic [6] [16] and, in addition, DroneSense software provides a visual display of drones made by DJI.) As part of a future traffic management system, users will also have a UI through which they can submit operational volumes and view airspace/aircraft information for enhanced situation awareness. The UASPs described information they would like to see on the display.

- **All Traffic:** The UASPs said that the most important information to display on a UI map is the location of *all* traffic – that is, both crewed and uncrewed aerial vehicles. They said that the display of traffic is a safety issue and crucial for situation awareness. One UASP, who is a former ATGS, said, *"One of the most disconcerting things as an Aerial Supervisor is knowing every aircraft that's out there, but not being able to see every aircraft that's out there."* (The implication for surveillance equipage is that every aircraft, both UASs and crewed aircraft, would need to have ADS-B or some kind of identifying signal.)
- **Prioritize Nearby Airspace:** The UASPs further clarified the importance of traffic information by explaining that seeing traffic in the area of their operation is the highest priority. One UASP said, "*... knowing what's happening [with respect to other traffic] in this geographical area that we have, that's the number one priority.*"
- The next most important priority would be seeing traffic in the area *just beyond their operation*, which might be defined by a distance around their operational volumes, like the caution and warning rings in the UASP-kit, for example, or the boundary of the division in which they are operating (a large fire may be divided into several divisions). One UASP said that during a very large fire, seeing information about traffic on the other side of the fire is not useful to them.

UI Map: In addition to the display of traffic, UASPs described other information needs on the UI map display.

- **Operational Volumes in the Planning Stage:** UASPs will utilize the UI to input their operational volume(s) (defined by location, altitude, and time) and then submit them to the UTM system for approval. We asked the UASPs if volumes that are still in the "planning stages" (i.e., prior to approval) should be displayed on the UI map for other UAS crews and incident personnel to see. They indicated that it would be useful to see other operators' volumes depicted on the map during all three stages, that is:

  1) the planning stage, *prior to approval*,

  2) after the volumes have been *approved*, but before the UAS is flying, and

  3) while the UAS is operating and the volume is *active*.
- **Data Tags:** UASPs said that the most important pieces of information to display on UAS data tags are: Callsign, heading, airspeed, altitude, UAS mission type (e.g., aerial ignition, mapping, search and rescue), who is operating the vehicle (pilot name), battery percentage, aircraft type, and UAS status (on ground, in the air, non-conforming, or lost link).
- **Maps:** UASPs said the following types of maps should be available on a UI display: AirOPS map that typically covers the entire TFR area and includes dip sites (a body of water that can be accessed to collect water for fire suppression), an OPS map that covers the entire fire, an Incident/Fire map, a topographic map, and a Visual Flight Rules (VFR) sectional.
- **Map Clutter:** UASPs cautioned against the maps becoming visually cluttered with too many features. They also explained that information needs may change in different phases of the operation. For example, the information that they refer to while planning their mission may not be the same information they want to see while the UAS is flying. Therefore, map features should be user-selectable so they can be toggled on and off as needed.
- **Up-to-Date Information:** UASPs also stressed the importance of displaying the most up-to-date version of map information. Displaying old, inaccurate information can cause a user to lose trust in the system.

Alerting: As described earlier, the UASP-kit provides users with visual and auditory alerting when an aircraft crosses the caution ring or warning ring. UASPs were asked what kind of alerting a future traffic management system should provide.

- The UASPs unanimously agreed that users should be alerted if another UAS or crewed aircraft comes within proximity of their operational volume. One UASP said they would want to receive the first alert when another aircraft is within 1–0.5 miles of their own operational volume, and a second alert if that aircraft crosses the boundary of their own volume. Depending on the proximity of the “approaching” aircraft, the UAS crew may deconflict by moving their ownship, and possibly returning it to its launch area.

- Likewise, the UASPs also indicated that it would be useful to receive an alert if their own vehicle drifts outside of their operational volume.

Process for Approving Operational Volumes: In the UTM demonstrations, UAS operators used the USS tool’s UI to input and submit their operational intent information to the UTM system. If their volumes did not conflict, or overlap, with other operations, then the system approved their operation. In the wildland fire environment, however, a different process for approving operations could be used. UASPs would use the UI to define, submit, and validate their operational intents, but they would be sent directly to the ATGS, who manages traffic at a wildfire incident, for “manual” approval. The ATGS would ensure that UAS are safely separated from crewed operations before approving the operation.

Overlapping Volumes: The UTM demonstrations also included a method for allowing two operators to share an airspace, provided that the vehicles were equipped for vehicle-to-vehicle data transfer [14]. The UASPs felt strongly that overlapping intents are not feasible in the wildland fire environment.

Conformance Monitoring: In the UTM demonstrations, the system monitored the UAS’s conformance to its 4D volumes, based on location, altitude, and time, and declared the UAS operation as “non-conforming” when it was outside of those parameters. When a UAS operation was declared “non-conforming,” the NASA-developed USS displayed an alert and used color-coding to indicate which vehicle was out of conformance with its 4D operation plan to support situation awareness among all operators. When asked about conformance monitoring to 4D operational volumes in the wildland fire environment, the UASPs agreed that, because it is critical for UAS operations to adhere to their planned altitude and operating area, especially when crewed aircraft are also operating at an incident, that conformance monitoring would be an important part of the traffic management system. With that being said, the parameters used to declare non-conformance need to be implemented in accordance with the nature of operations in the wildfire environment. As an example, if the UAS crew sets a start time for their climb volume, but actual takeoff time differs by several minutes because a priority mission (e.g., an Emergency Medical Services (EMS) helicopter) needs to transit through the airspace, causing the UAS to delay takeoff, should the system declare that UAS “out-of-conformance” and alert the UAS crew? In that scenario, the crew would find an “out-of-conformance” alert to be an annoyance. It will be important to consider scenarios like these in order to optimize conformance parameters in a traffic management system.

Timing and Scheduling of UAS Operations: Related to the previous bullet point is the scheduling of UAS operations in the wildland fire environment. The UASPs explained that, although the UAS crew is responsible for the operation itself and safety-of-flight, it is someone in the Operations chain of command (e.g., the Division Supervisor) who guides the overall “tempo” of operations. The scheduling of UAS operations may be impacted by the overall tempo of aerial operations at an incident.

Right-of-Way Guidelines: To gain an understanding of how a future traffic management system should implement rules for handling two aircraft in proximity of each other (e.g., because one aircraft is out-of-conformance with their 4D volume), the UASPs were asked to discuss “right-of-way” procedures.

- **UAS and UAS:** If one UAS drifts out of its volume, the onus should be on the UASP of the *non-conforming* UAS to move their vehicle back into their volume. This might also involve radio communication between the operators.
- **UAS and Crewed Aircraft:** If a crewed aircraft drifts out of its volume (out of conformance), the onus is on the UASP to “see and avoid” the crewed aircraft.
- **Priority Aircraft:** The UASPs explained that some aircraft with *priority missions*, such as EMS, could possibly be routed through a UAS operation. Although this does not occur frequently, if it did occur, then the UASP would respond by creating distance between the priority aircraft and their UAS (e.g., by descending and moving toward the GCS or by delaying their launch).
- **An Aircraft in Distress:** A crewed aircraft in distress (e.g., with an engine problem) gets “priority.” Every other aircraft will move out of its way and the ATGS will help to coordinate the air traffic.

Network Bandwidth: We discussed how limited bandwidth might impact the display of information on the UI. UASPs said that if it becomes necessary, the UI should prioritize updating displayed information in the vicinity of their own operation – that is, the information most crucial for safety – and dismiss the information on the map that is farther away from their operation. If the UAS has to move to a different location, the UI should be responsive and display updated information for the new location. UASPs also emphasized the need to toggle map features on and off. For example, if location tracking for ground troops is available on the map display at a large fire, it could mean that location data for *hundreds* of people is being sent to the UI display.

UAS Vehicles: In our discussions with the UASPs, it was noted that because UAS vehicles are still relatively new, as compared to conventional, crewed aircraft, their reliability has not been fully tested. A traffic management system may take considerations like these into account when implementing standards for spacing (e.g., a buffer) between volumes.

A comparison summary of some of the key differences between the nature of UAS operations during previous UTM demonstrations in urban environments [14] and a future implementation in a wildland firefighting environment, based on preliminary discussions with UASPs, is shown in Table II.

TABLE II. PRELIMINARY FINDINGS ABOUT A HOW A UTM SYSTEM IN A WILDLAND FIRE ENVIRONMENT MIGHT DIFFER FROM PREVIOUS UTM IMPLEMENTATIONS IN URBAN ENVIRONMENTS

Characteristic	**UTM Demonstrations in an Urban Setting**	**Wildland Firefighting Environment**
Volume shape, number	Depending on the operation, multiple, contiguous volumes; akin to "tunnels" for transiting through the airspace.	**Type 1/Type 2:** One cylindrical climb/descent volume and one operational volume at altitude. **Type 3/Type 4:** A single cubical volume, closer to the fireline.
Operating altitude	Generally, below 400 ft	*At an active fire incident, within a TFR:* **Type 1/Type 2:** 5,000 ft, for example. **Type 3/Type 4:** Generally, ground to 700 ft
Airspace organization	Multiple volumes could be "stacked" vertically (with appropriate spacing)	Multiple volumes should be arranged *laterally;* UAS operations should not be above/below each other
Interaction with crewed aircraft	In the UTM demonstrations, crewed aircraft did not operate in proximity of the UAS	Crewed aircraft may be operating at the fire incident and occasionally passing through
Priortization rules	UAS operations were not impacted by higher priority crewed operations	Crewed aircraft take priority over UAS vehicles
Conformance monitoring	Non-conforming declared when UAS is outside of its 4D volume	UAS operations may need more flexibility with respect to time, as the "tempo" of operations is outside of the UASP's control

III. CONCLUSION

As an alternative to crewed aircraft, UASs offer reduced risk and cost benefits, but they need to be safely integrated with aerial operations at wildfire incidents. Drawing from the UTM project, in which sUAS operations were demonstrated in an urban environment, ACERO will explore the implementation of a traffic management system in the wildland fire environment to enhance safety and support situation awareness. This includes developing a UI that allows UASPs to interact with the traffic management system, share information, and visualize airspace/traffic information.

At the outset of the ACERO project, members of the Human Factors group conducted interviews with five UASPs who operate UASs at wildland fire incidents. In this paper, we described the foundational work upon which ACERO will build (i.e., UTM and STEReO) and summarized the information and insights gathered during a series of group interviews with five UASPs. Insights from the UASPs have already started to inform development for ACERO's first demonstration (TCL1).

A. ACERO's First Technical Demonstration (TCL1)

Since these interviews were conducted, the ACERO team has progressed plans for the first of six technology demonstrations expected to take place in early 2025. In TCL1, it is anticipated that UASPs will operate three uncrewed vehicles in a real-world flight demonstration:

- One large, **Type 1 UAS** carrying technology to support a communications network and enable information exchange.
- Two smaller, **Type 3 UASs**.

All three aircraft will feed information about their flight profiles and missions down to the ground-based system at their landing zones. This information will be used by the UASP, but also shared to the other two UASs in the communications network.

Each of the three UAS crews will utilize a UI to create their own operational volumes and to view the status/location of the other UTM operations. The UTM system will deconflict UAS operations and monitor vehicle conformance. From a Human Factors perspective, we plan to collect usability assessments of the UI through observations, questionnaires, and debriefs.

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